

GSFC Hydrological Sciences Lab Research Capabilities Overview

John Bolten, Sujay Kumar, Carrie Vuyovich, Fritz Policelli, Rajat Bindlish, Mike Jasinski, Tim Lahmers, Ed Kim and Thomas Holmes... and many others!

Roadmap



- Who are we?
- Current research
- Connection to NASA science spheres
- Opportunities for collaboration



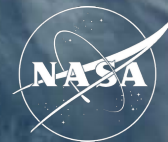
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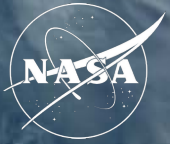


Hello!

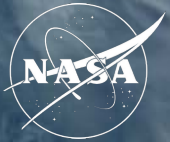


NASA's Goddard Space Flight Center
Earth Sciences Division
Hydrological Sciences Laboratory (617)
November 18, 2024

Hello!



Hello!



EARTH SCIENCES



What Do We Do in the Hydrological Sciences Laboratory?



Community Enabling

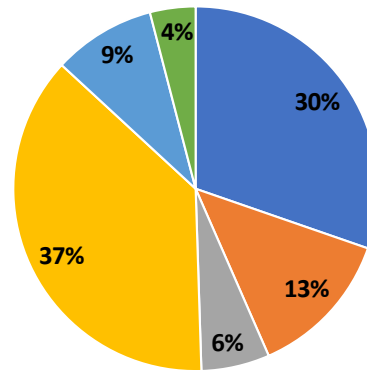
Remote Sensing data products,
Land Information System software,
LDAS datasets, drought maps,
landslide tools & data

Forward Looking

SnowEx, PBL, AI/ML, IMVI, and
other working group involvement

Participation on DO Studies

FALCON, MC, EAGLE



- LDAS
- Applications
- Machine Learning
- Scientific Research
- Instrument Science
- Other

Leadership in Science and Applications

Product development, publishing,
enhancing operational capabilities,
disaster management

Including 11 leadership positions as
mission / ESD / HQ support and DART
teams

93 peer reviewed pubs in last 12 months

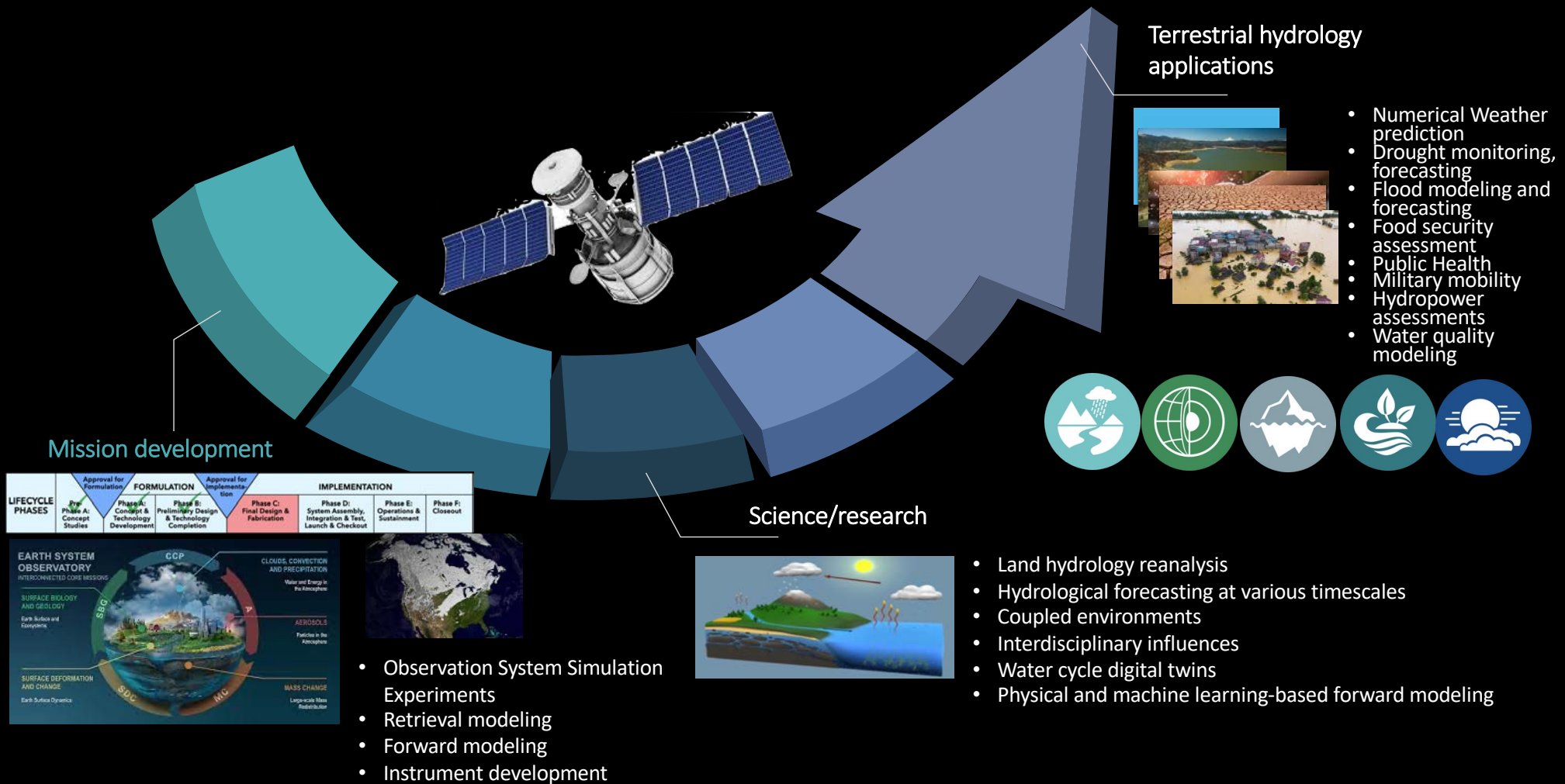
Mission Involvement

SMAP, Landsat 10, GPM, ICESat-2,
GRACE-FO, JPSS, NISAR, NOAA
JPSS, Quikscander, NOAA

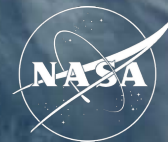
Instrument Development

SLAP, AESMIR, GREX, multiple IRADs,
thermal instruments

HSL research spans the full lifecycle of hydrology missions



Roadmap

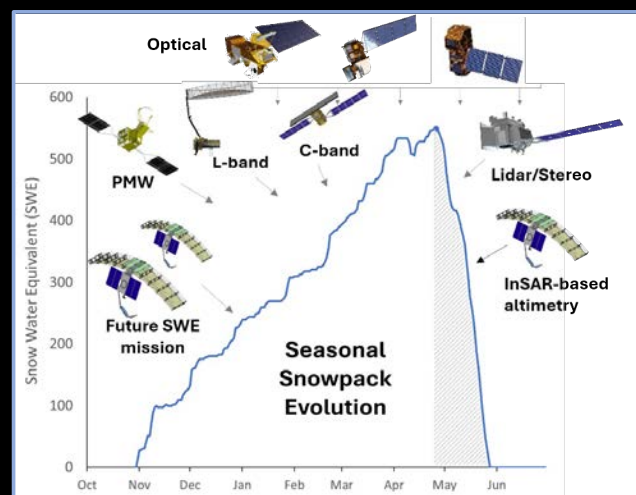


- Who are we?
- Current Research
- Connection to NASA Science Spheres
- How can we work together?

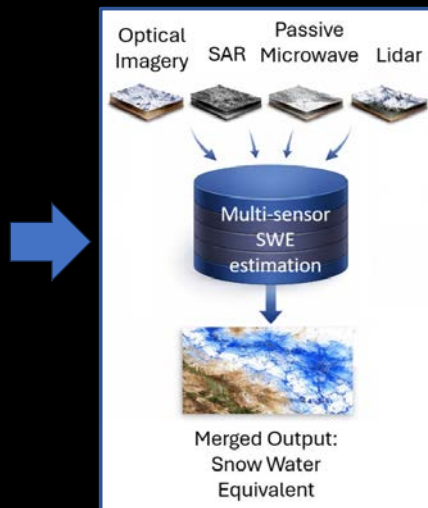


Research – Seasonal snowpack mapping and dynamics

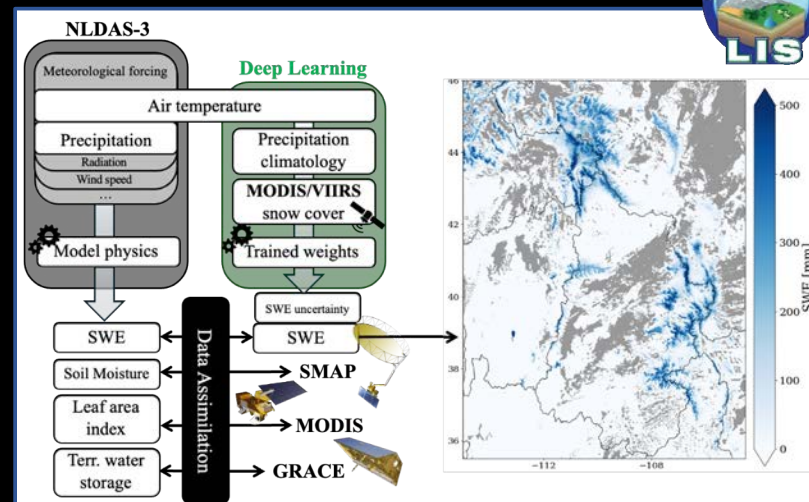
Collaboration Opportunity – Develop effective methods for merging snow data from multiple sensors



Multiple satellite sensors can be leveraged for seasonal snow mapping, but we need to understand each of their limitations and strengths¹



Combining observations from multiple, diverse sensors is a complex undertaking that may increase uncertainty in unpredictable ways²



Scaling globally and including land surface models is critical to developing a spatially and temporally consistent SWE product to address science and application needs.

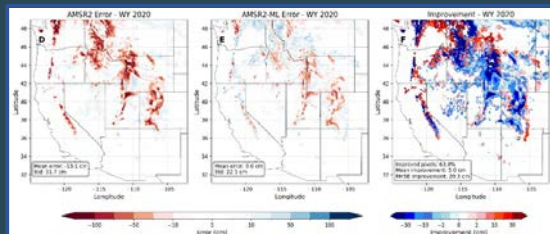
¹Vuyovich, C., Hall, D., Cho, E., Fair, Z., DiGirolamo, N., Wrzesien, M., Tarricone J., Pflug, J., Grogan P., Breen, C. and Kumar, S., A global snow observing strategy, in review, Remote Sensing of Environment, May 2026.

²Breen C, Yang K, Pflug J, Kumar S, Cristea N, Alabi I, Vuyovich C (in prep). A review of machine learning for snow remote sensing: trends and future directions for global snow measurements.

Research – Multi-sensor approach for estimating snow water equivalent

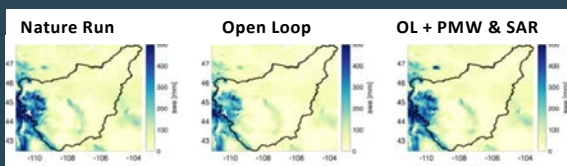
Collaboration Opportunity – Evaluate and improve current sensor performance, test gap-filling strategies, and develop multi-sensor observing and assimilation methods for snow

Passive Microwave



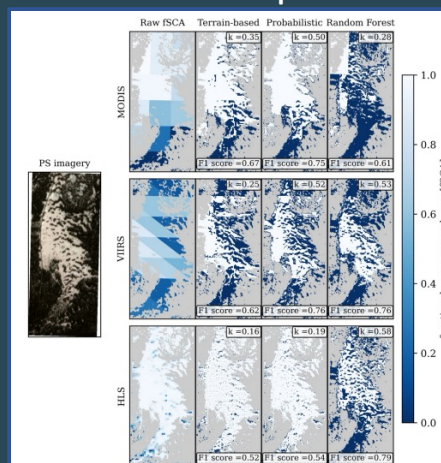
Passive microwave snow depth estimates are improved using machine learning and explainable AI²

Multi-variate data assimilation



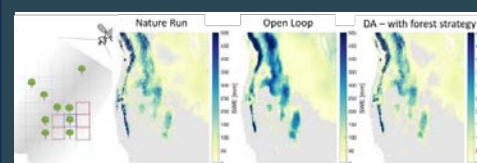
Merging passive microwave and a hypothetical SAR mission improved SWE estimates over the Missouri River Basin⁴

High-resolution commercial optical



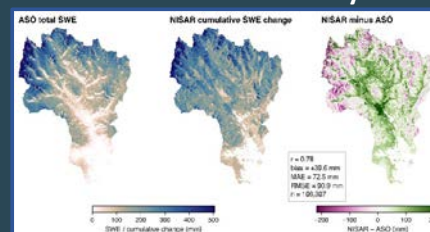
High-resolution commercial imagery from PlanetScope can be used to downscale fractional snow covered area data from coarser resolution satellites³

Gap-filling in Forests



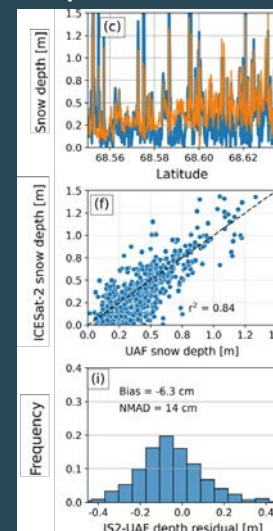
A forest search strategy to expand snow observations from forest clearings into the surrounding forests improved SWE and streamflow⁵

L-band Interferometry



NISAR total SWE retrievals results from the East River, CO show strong preliminary correlations

Spaceborne Lidar



ICESat-2 snow depth over Alaska shows strong correlation compared to airborne lidar¹

C. Vuyovich

¹Fair, Z., Vuyovich, C., Neumann, T., Larsen, C.F., Stuefer, S., Mason, M.L. May, L., 2025. Characterizing ICESat-2 snow depths over the boreal forests and tundra of Alaska in support of the SnowEx 2023 campaign. WRR. 61, e2024WR039076. <https://doi.org/10.1029/2024WR039076>.

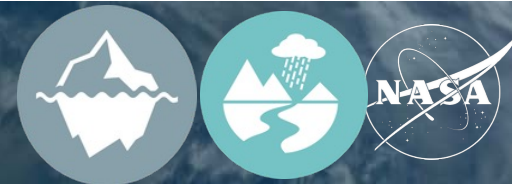
²Yang, K., S. Kumar, G. Konapala, J. Pflug, C. Vuyovich, E. Jalilvand, Y. Yoon, J. Wegiel, Improving near-real-time global snow depth retrieval from AMSR2 data using Machine Learning and Explainable AI, in review, Remote Sensing of Environment, Jan 2026.

³Pflug, J. M., Yang, K., Cristea, N., Boudreau, E. T., Vuyovich, C. M., and Kumar, S. V.: Comparing 3 m resolution snow cover downscaled from MODIS, VIIRS, and HLS using commercial satellite imagery and terrain information, EGUSphere

⁴Wrzesien, M., C. Vuyovich, H. Banefsheh, D. Ramachandran, E. Gonzalez, P. Grogan, Evaluating Dynamic Multi-Sensor Snow Observing Strategies in the Missouri River Basin (in prep)

⁵Pflug, J. M., Wrzesien, M. L., Kumar, S. V., Cho, E., Arsenault, K. R., Houser, P. R., and Vuyovich, C. M.: Extending the utility of space-borne snow water equivalent observations over vegetated areas with data assimilation, EGUSphere, <https://doi.org/10.5194/egusphere-2023-1603>, 2023.

Snow Mission Concept



Research –Mission concept development to produce global SWE data needed to address hydrologic applications

Collaboration Opportunity – Research to mature snow remote sensing technology and algorithms

A dedicated snow mission should include:

- Global coverage
- High spatial resolution (100-1000m)
- Frequent observations (3-5 days)
- Mature algorithms with demonstrated performance in multiple snow regimes
- Quantified uncertainty

The SnowGlobe mission concept consists of a constellation spacecraft pairs of X- and Ku-band SAR sensors to measure global SWE and melt.

- **Frequency** 1-5-day revisit
- **Resolution** 250 m
- **Global coverage** >95% seasonal snow extent
- **SWE Uncertainty** <20% for SWE > 50mm and < 800mm

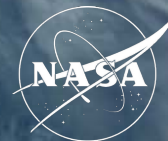


SnowGlobe

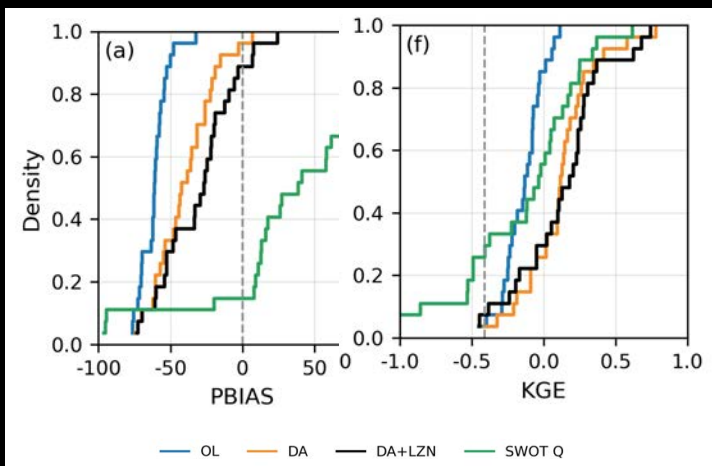
SNOW provides a vital source of freshwater and helps cool the planet



What are some other ways are we leading hydrologic scientific research?



SWOT DA



Yoon et al., "Assimilation of SWOT water surface elevation enhances simulations of river dynamics in the Ohio River Basin, JRL, 2026, Accepted.

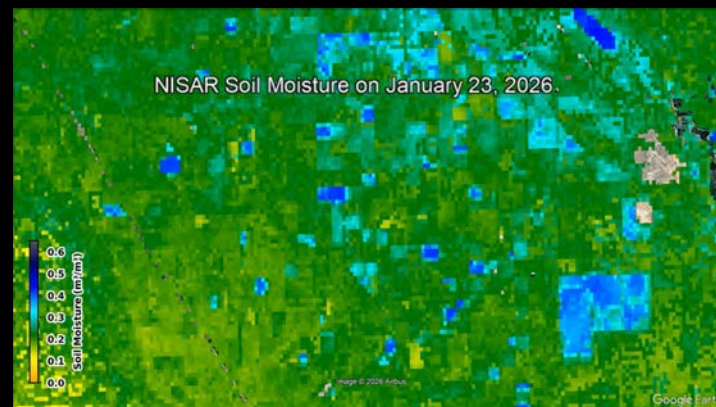
Collaboration Opportunities

Connecting with DART teams

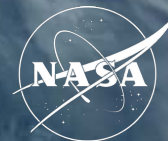
Testing and coordinating methodologies and solutions leveraging new EOs

- NISAR soil moisture at 200 m resolution over Central California (Jan 23, 2026; Feb 4, 2026)
- Irrigated agricultural fields can be seen in the image

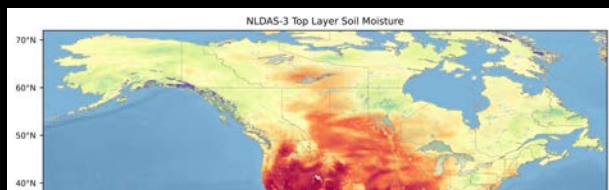
NISAR Soil Moisture



R. Bindlish



North American Land Data Assimilation System (NLDAS) Version 3 – S. Kumar



<https://ldas.gsfc.nasa.gov/nldas/v3>

NLDAS-3 State-Level Engagement Progress to enable regional preparedness

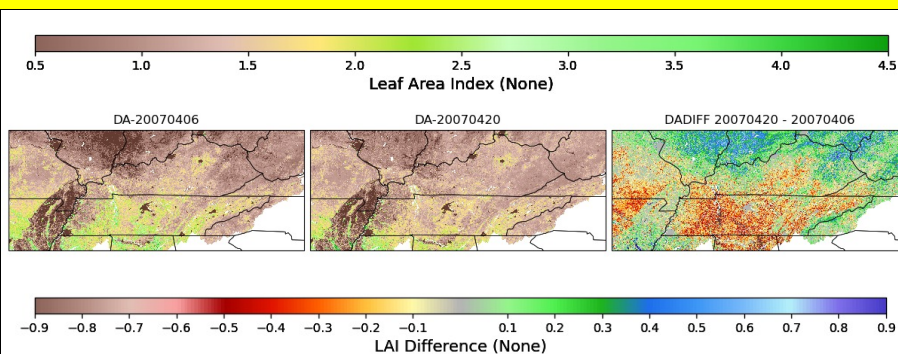
Water Insight State-Level Stakeholder Engagement/Co-Development



Collaboration Opportunities

Connecting with regional stakeholders

Testing and applying NLDAS3 data for new research and operational decision support



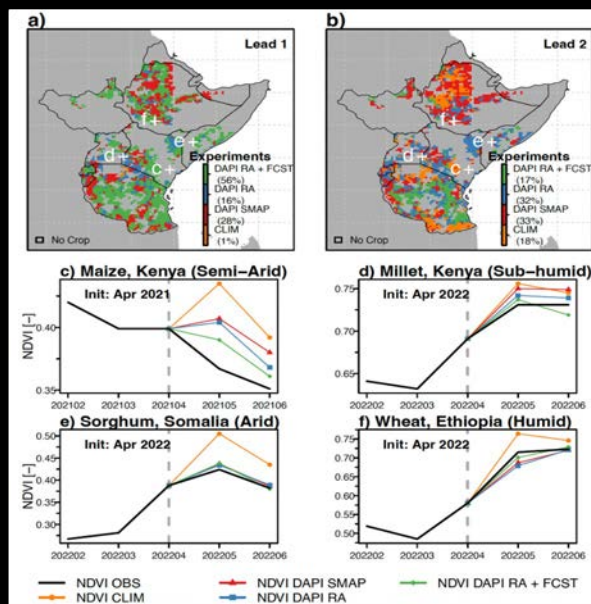
Maina et al., 2026, Retrospective and Near-Real-Time Surface Meteorology in the North American Land Data Assimilation System Phase 3 (NLDAS-3), JHM, accepted



“ NLDAS-3 has the potential to improve the consistency and resolution of drought monitoring analyses for map authors and state monitoring efforts, plus finally having data for Alaska, Hawaii, Puerto Rico, and the USVI is a major plus. ”

- Mark Svoboda, Director, National Drought Mitigation Center

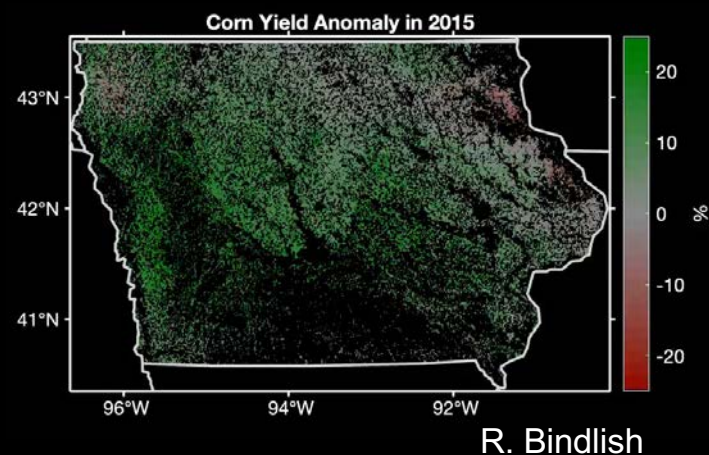
FEWSNET SMAP-BASED NDVI Forecasts



H. Le

Le, H. et al., "First Assessment of FLDAS Soil Moisture Forecast Value for NDVI Prediction Across Diverse Crop Types and Climate Zones in Sub-Saharan Africa", ERL, in review

Agriculture Land Information System (AgLIS)

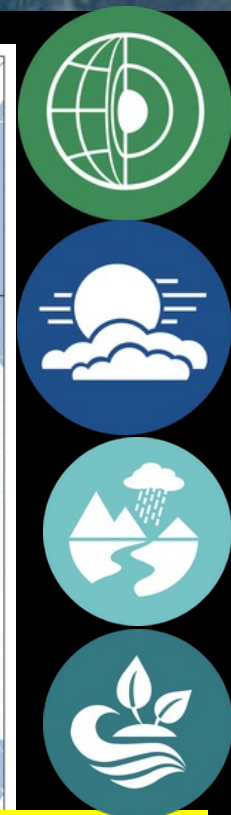
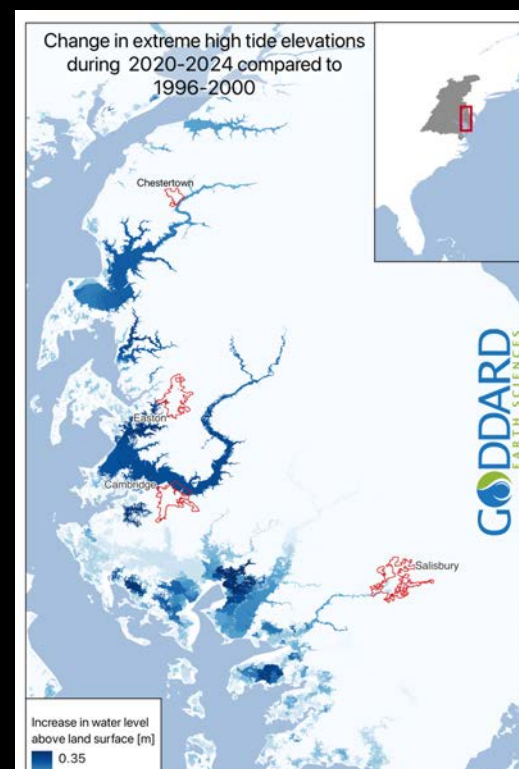
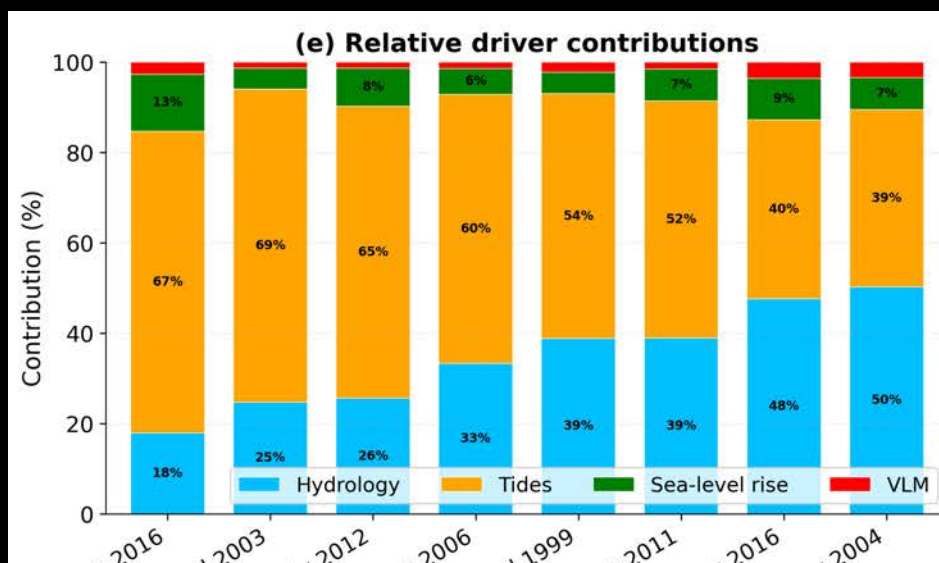


Collaboration Opportunities

- Calibration of crop management parameters
- Validation studies and transferability
- Hydrosphere-Biosphere relationship in agricultural domains
- Water demand and usage studies
- Detecting anthropogenic water use (irrigation)
- Food security monitoring and assessment
- Coupling with socioeconomic models for integrated impact assessment

Coastal Zone Digital Twin

We are currently expanding the analysis to all US coasts...

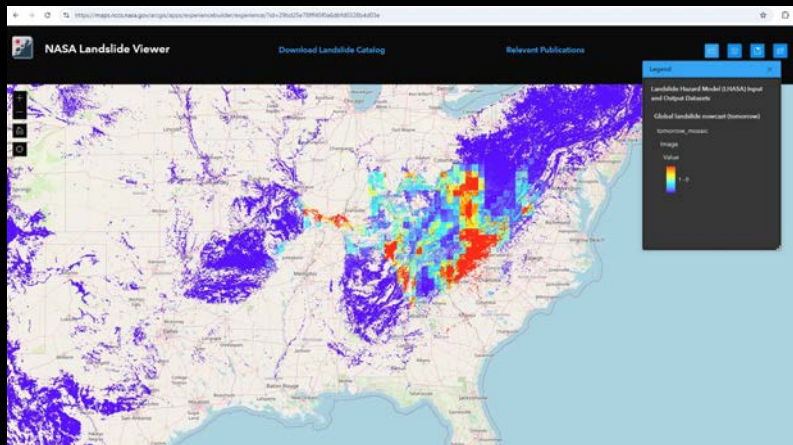


Collaboration Opportunities

Connection with other NASA spheres

Integrating these findings into water resource management solutions

Disasters Response Coordination System (DRCS) Landslide Hazard Model

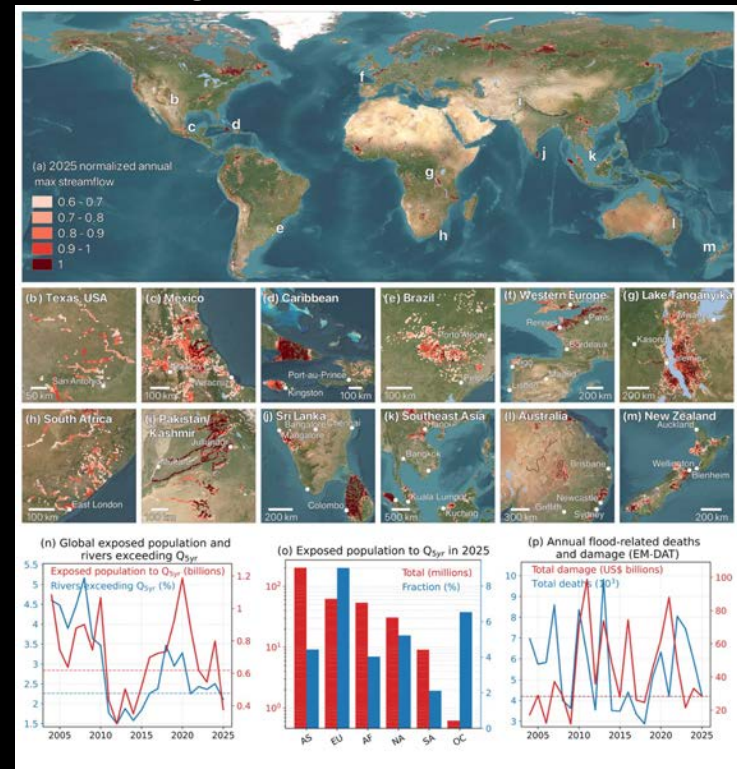


T. Stanley

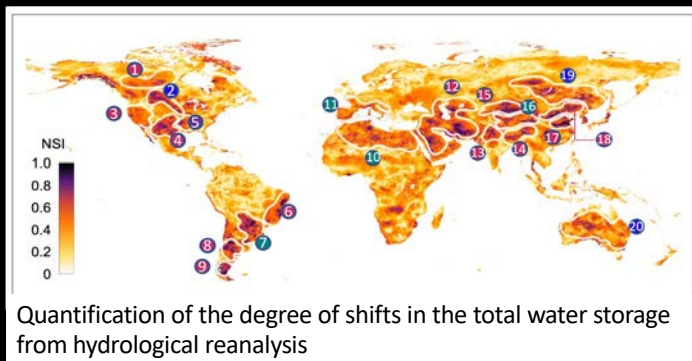
Collaboration Opportunities

- Explore use of NISAR and OpenET to improve LSM parameters
- Groundwater and streamflow coupling
- Application for land-atmosphere Interactions
- Connecting with new State and Local emergency management agencies

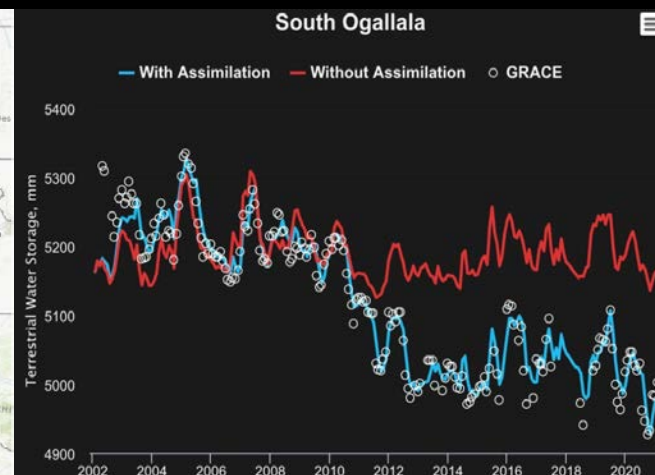
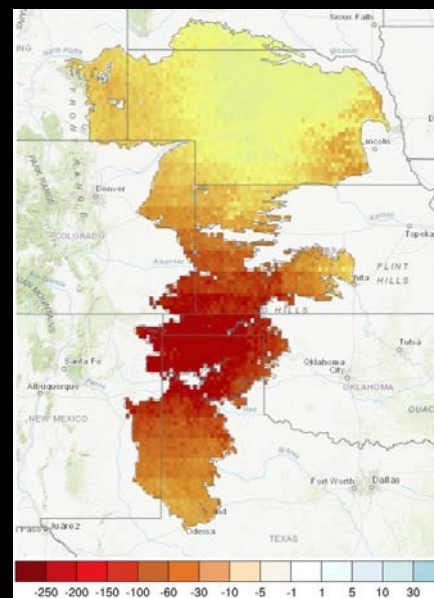
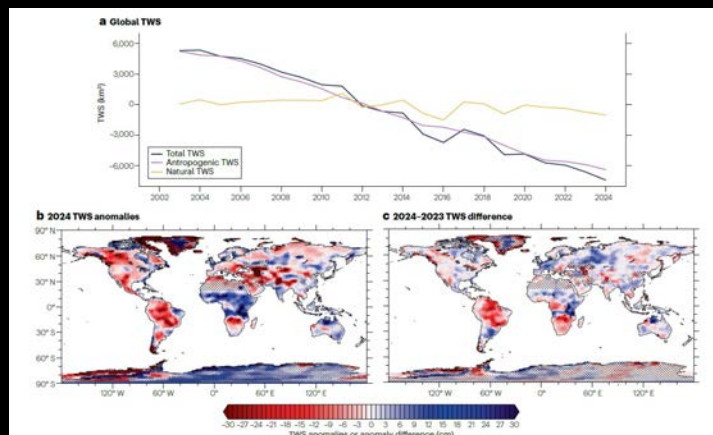
2025 global floods characterized



Getirana et al. (2026, Nature Reviews Earth & Environment)



S. Kumar



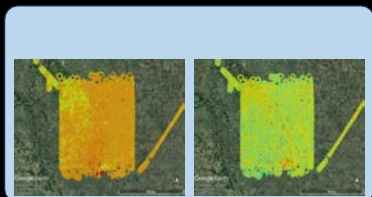
S. Kumar

Collaboration Opportunity – Supporting research challenges from other NASA spheres

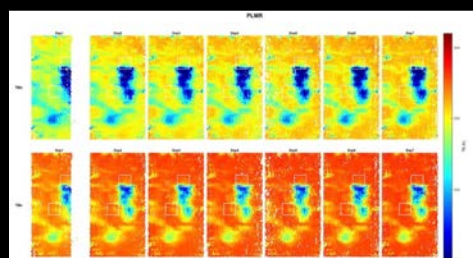


Snow Ex- C. Vuyovich

NASA Goddard's Scanning L-band Active Passive (SLAP) - E.Kim



2026 AU SM cal/val campaign – R. Bindlish



SM cal/val- J. Bolten



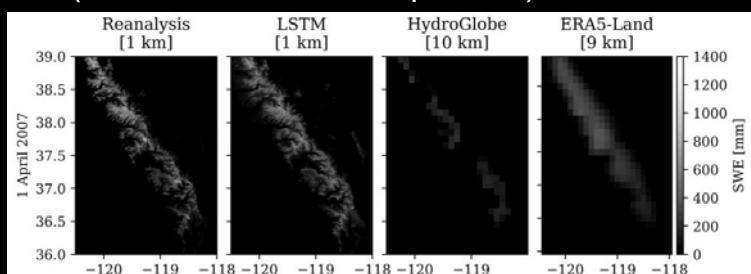
Vietnam SM cal/val- H. Le



Collaboration Opportunity – Always looking for volunteers and new locations!

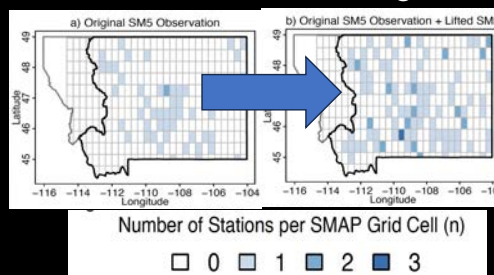


ML-based global MODIS-based SWE (1km resolution, 2000-present)



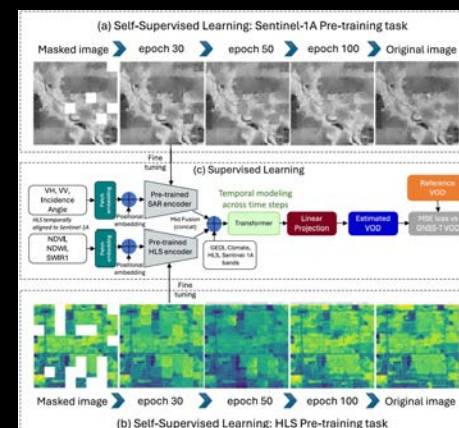
Pflug, J. et al, 2025: Efficient and regionally transferable snow water equivalent estimation using a long short-term memory network, *JGR Machine Learning and Computation*, 2, e2025JH000593,

Soil Moisture Network Harmonization and Integration



Le, H., et al., 2026. "Statistical and machine learning for improving the utility of soil moisture networks for satellite-based soil moisture product assessment in the Upper Missouri River Basin.", *Vadose Zone Journal*, 25 (2)

VOD Retrieval



Hashemi, M. et al, "High-resolution L-band VOD retrieval using GNSS-T-calibrated multi-sensor fusion and self-supervised learning.", *Remote Sensing of Environment*, 344 115554

Collaboration Opportunity – Explore new methods for fusing EO data and LSM to map, monitor, and predict global water resources

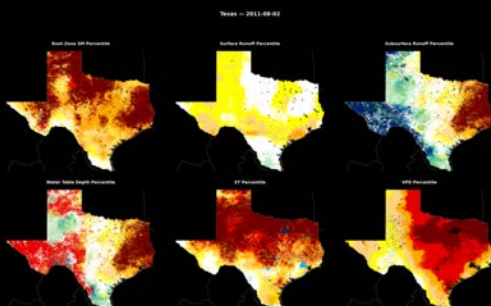


Hydrology Copilot - M. Hashemi

Show me the comparison of the daily percentile for root-zone soil moisture, surface runoff, subsurface runoff, water table depth, ET, and vapor pressure deficit for Texas, 2 August 2011.*

Multi-variable percentile comparison for Texas on 2011-08-02:

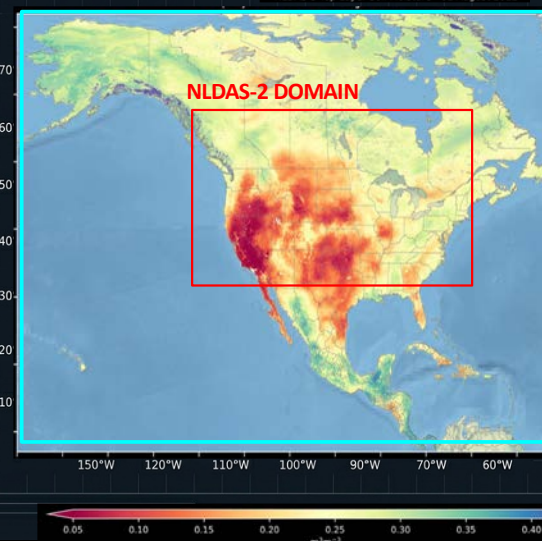
- SoilM_root_zone: Mean 15.5% → D1 (Moderate Drought), Drought area (below 20th): 73.6%, Wet area (above 80th): 0.5%
- Qs: Mean 32.5% → NULL (Near-Normal), Drought area (below 20th): 21.2%, Wet area (above 80th): 0.9%
- Qsb: Mean 57.9% → NULL (Near-Normal), Drought area (below 20th): 21.3%, Wet area (above 80th): 37.1%
- WaterTableD: Mean 27.5% → D0 (Abnormally Dry), Drought area (below 20th): 50.8%, Wet area (above 80th): 3.9%
- Evap: Mean 16.9% → D1 (Moderate Drought), Drought area (below 20th): 66.0%, Wet area (above 80th): 1.2%
- VPD: Mean 9.4% → D2 (Severe Drought), Drought area (below 20th): 83.5%, Wet area (above 80th): 0.0%



Demonstrating at operational scale with the NLDAS-3 archive

NLDAS-3 DOMAIN

NLDAS-3 Top Layer Soil Moisture - 01 August 2012



NLDAS-3 Operational Specs

Coverage	North America (25–60°N)
Resolution	1 km spatial
Timeframe	23 years (Jan 2001 – Dec 2023)
Volume	>8 TB uncompressed
Scale	>200,000 hourly NetCDF4 files
Not a sample – the actual operational archive.	

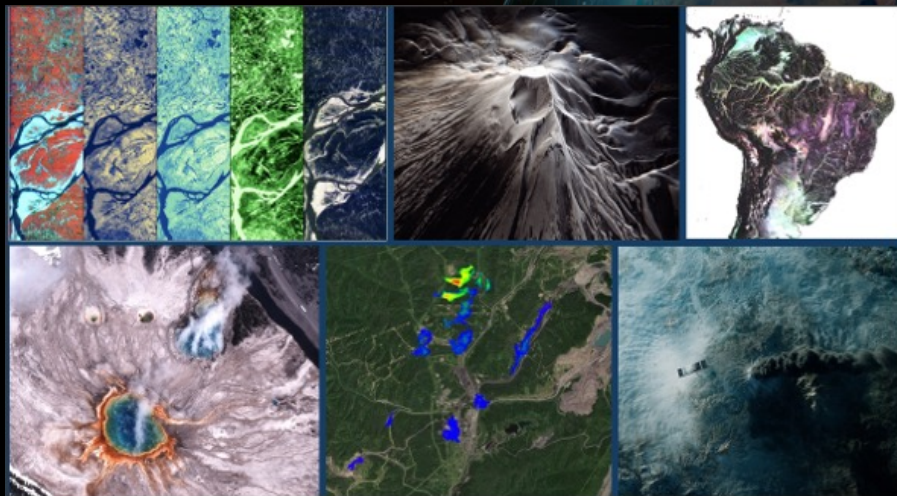
Hashemi et al., Hydrology Copilot: A Cloud-Native AI System for Hydrological Data Analysis, 2026, accepted

Collaboration Opportunity – Testing, stakeholder needs, education, outreach



NASA CSDA Commercial Data Portfolio

Broadening access to diverse, complimentary Earth observation capabilities



F. Policelli- CSDA Project Scientist

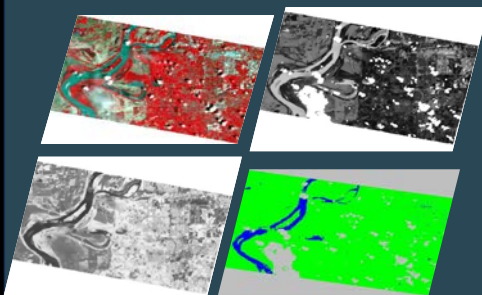
OPTICAL/ MULTISPECTRAL	HYPERSPPECTRAL (VNIR-SWIR)	SAR	GNSS (RO/R)
AIRBUS BLACK SKY SATELLOGIC SATLANTIS 	 pixel KUUG SPACE OSK	AIRBUS ICEYE UMBRA MDA	PLANETIQ
THERMAL INFRARED	Precipitation/ Microwave	ATMOSPHERIC/ GHG	DEM/ ELEVATION
 		 SATLANTIS	AIRBUS
DIVERSE Broad set of commercial partners and capabilities	COMPLEMENTARY Complements NASA's Earth observations	RESPONSIVE Rapid access to data for timely decision making	ACCESSIBLE Structured delivery framework broadens U.S. government access.

Collaboration opportunity – Testing strategic integration of CSDA data into EO-based solutions, LDAS, etc.

Collaboration opportunity - Data evaluation, exploring new approaches for synergistic multi-sensor adaptations



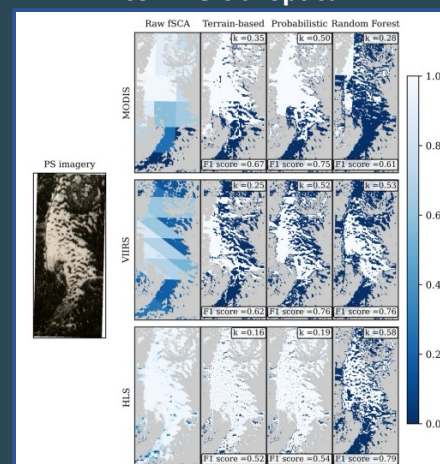
F. Policelli - Planetscope /
Machine learning-based
water mapping



<https://floodmapping.gsfc.nasa.gov/>

Policelli et al., 2026 A web-based high-resolution global water and flood mapping platform

High-resolution commercial optical



High-resolution commercial imagery from PlanetScope can be used to downscale fractional snow covered area data from coarser resolution satellites³

Pflug, J. M., Yang, K., Cristea, N., Boudreau, E. T., Vuyovich, C. M., and Kumar, S. V.: Comparing 3 m resolution snow cover downscaled from MODIS, VIIRS,

Collaboration Opportunity – blending of commercial data with land surface models, AI, and ML, data acquisition, and data harmonization

Roadmap



- Who are we?
- Recent efforts
- Connection to NASA science spheres
- Opportunities for collaboration



- GPM cal/val
- Snow validation

- GRACE DA
- GRACE applications
- Foundational TWS studies



- Snow mission design
- SWE estimation
- Snow applications

- WMO Global State of Water Resources Report
- Hydrology Copilot
- NLDAS 3
- NISAR DA
- SMAP applications
- NISAR SM algorithm development
- Disaster Response Coordination

- Ag LIS
- NDVI forecasting
- Crop CASMA
- Global Riparian Mapping

Roadmap



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Recap - Collaboration Opportunities





• Hydrosphere

- Water Quality research
- Analysis of model outputs
- Integration of physical processes into LSM solutions
- Blending of ML, AI, and physical process models
- Refined model parameters, forcing data
- Integration of human impacts
- Integration of socio-economic, human impacts into data
- Transition to operations for water mapping
- Accurate S-1 water mapping to enable accurate river width measurement
- Global interbasin groundwater flow estimates for closing the water budget for global basins
- Model output analysis and integration of new capabilities
- Consideration of S2S scales



• Cryosphere

- SWE validation efforts
- Develop effective methods for merging snow data from multiple sensors
- Evaluate and improve current sensor performance, test gap-filling strategies, and develop multi-sensor observing and assimilation methods for snow
- Research to mature snow remote sensing technology and algorithms
- Calibration / Validation Campaigns



• Biosphere

- Calibration of crop management parameters
- Validation studies and transferability
- Hydrosphere-Biosphere relationship in agricultural domains
- Water demand and usage studies
- Detecting anthropogenic water use (irrigation)
- Food security monitoring and assessment
- Coupling with socioeconomic models for integrated impact assessment
- Need to validate high resolution soil moisture retrievals
- Joint cal/val effort for high resolution soil moisture (NISAR, SMAP-NISAR)
- Water Quality impacts



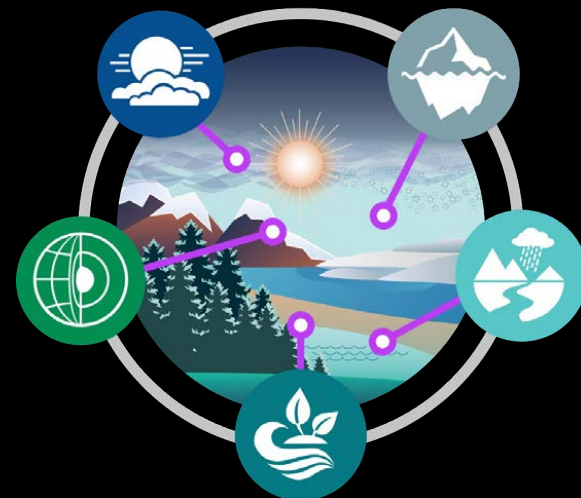
• Geosphere

- Evaluation of GRACE products / requirements
- Novel multi-sensor approaches leveraging GRACE
- Vertical land motion, informing surface water research



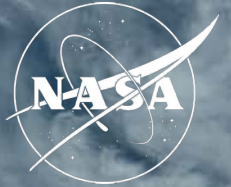
• Atmosphere

- Testing of multi-sensor snow retrievals
- Evaluate utility of producing our LDAS tools
- Estimated solid precip from SWE



Enabling Capabilities

- Testing strategic integration of CSDA data into EO-based solutions, LDAS, etc.
- Data evaluation, exploring new approaches for synergistic multi-sensor adaptations
- Physical Process Representation in Models for Improved Remote Sensing Data Integration
- Leveraging IMVI and MIO initiatives for increasing impact and reach of our science
- NLDAS 3 stakeholder engagement and applications
- Explore new methods for fusing EO data and LSM to map, monitor, and predict global water resources
- Coordination with emergency management end-users to support data needs during disasters
- New collaborations with State and Local emergency management agencies
- Connection with other NASA spheres
- Integrating these findings into water resource management solutions
- Blending of commercial data with land surface models, AI, and ML, data acquisition, and data harmonization



Thank You
john.bolten@nasa.gov

John Bolten, Sujay Kumar, Carrie Vuyovich, Fritz Policelli, Rajat Bindlish, Mike Jasinski, Tim Lahmers, Ed Kim and Thomas Holmes