

# US GEWEX Soil Moisture Mini-Workshop #2 Summary

July 23rd, 2021 12-3:00 pm EDT

## Background

The US GEWEX, under the US Global Change Research Program, hosts discussions and coordinates interagency activities with the goal of an enhanced predictive understanding of the water cycle and energy fluxes of the changing Earth and global climate system, using satellite and surface-based observations, global and regional process-resolving models, and the resulting diagnostics and data. Current US GEWEX foci include precipitation predictability and hydroclimate studies.

Under the theme of hydroclimate studies, US GEWEX focuses on enhancing interagency coordination and collaboration around soil moisture data, products, and modeling. The US GEWEX agencies recognize that multiple soil moisture observations, modeled products, and metrics/indices exist and are supported across agencies. Better awareness of what they are, how they should be used, and how they might work together will support accelerated science progress toward GEWEX science goals.

On April 16, 2021, the US GEWEX held an initial mini-workshop in which seven groups reported on their soil moisture activities, a majority dealing with in situ observing systems for soil moisture ([link to the summary](#)). A finding from the workshop was that the collected audience wanted to know more about and seek connections with other ongoing activities, in particular those with **modeling and remote observations**. Following these recommendations from the soil moisture community, the 2<sup>nd</sup> workshop was organized with the primary goal to hear from groups creating soil moisture data sets that cover a significant period of time and spatial domain.

## Introduction.

The second US GEWEX Soil Moisture mini-workshop convened a group of agency program managers, representatives from a variety of soil moisture groups, and other interested participants. The main focus of this workshop was **modeling and remote observations for soil moisture efforts**. After brief introductions from Drew Story and Geoff Plumlee, US GEWEX members Jared Entin (NASA) and Jennifer Arrigo (DOE) shared their vision and objectives of the mini-workshop series before transitioning to the invited presentations. Presentations from the soil moisture group representatives were followed by a full group roundtable discussion on ideas for collaboration and coordination opportunities.

## **Soil Moisture Activities: Modeling and Satellite Data**

(Moderated by Renu Joseph – DOE) *10-minute presentations followed by 2 minutes for clarifying questions*

### **Xiwu "Jerry" Zhan: NOAA NESDIS Soil Moisture Operational Product System (SMOPS)**

Xiwu Zha introduced the time periods, satellite sensors, algorithms, and validation results of the soil moisture and soil moisture proxy data products from NOAA NESDIS SMOPS. SMOPS combines soil moisture retrievals from multiple satellites/sensors (e.g., GPM, SMAP, GCOM-W1, SMOS, Metop-A, and Metop-B) to provide a global soil moisture coverage. The SMOPS data are generated in 6-hourly and daily intervals and mapped with a cylindrical projection on 0.25 x 0.25-degree grids. The output includes soil moisture values (%vol/vol) of the surface (top 1-5 cm) soil layer with associated quality information and metadata. The SMOPS archived record begins in March 2017. SMOPS 6-Hourly product is for operational use while SMOPS daily product is for research and operational use. Xiwu Zha also showed results of assimilating SMOPS blended product into Noah-MP model and compared them with the assimilation of other GLDAS and ESA CCI soil moisture products. Some of the SMOPS product applications are drought monitoring and the soil moisture data assimilation into operational weather forecast model runs. SMOPS data products can be accessed at [NESDIS Operational Soil Moisture Products - Office of Satellite and Product Operations \(noaa.gov\)](https://noaa.gov).

### **Fred Ogden: Soil Moisture Predictions in the Current Operational and Next Generation National Water Model**

Fred Ogden introduced the National Water Model (NWM) and its applications. The current operational NWM uses the Noah-MP LSM to calculate the evolution of soil moisture on a 1 km grid, assuming a 2 m thick homogeneous (non-layered) soil over the modeled domain, which includes CONUS and contributing areas of Canada and Mexico, Hawaii, Puerto Rico, and portions of Alaska. Noah-MP, as employed in the current operational NWM, solves the water-content form of the Richardson/Richards equation, which is strictly valid only for homogeneous soils under non-saturated conditions, using four discretizations of 10, 30, 60, and 100 cm from the land surface down to the bottom of the soil, respectively. Coarse discretizations are commonly applied in land surface models (LSMs) to make the soil moisture code fast and reliable, and to avoid the occurrence of saturation from above. The homogeneity assumption prevents accurate simulation of the influence of ubiquitous soil layering. For these reasons, authors urge careful interpretation of soil moisture outputs from the current operational NWM, while they work to improve the representation of soil physics in the Next Generation NWM. The team performed the NWM soil moisture evolution. The model was forced using NLDAS2 re-gridded and downscaled to the 1km NWM land surface model grid. The outputs from this model (e.g., volumetric soil moisture on the 1km NWM grid at four depths) are available on the Amazon web services ([NOAA National Water Model Reanalysis Model Data on AWS](https://aws.amazon.com/)) from 1993 to 2018 (25-years record).

### **Randy Koster: The SMAP Level-4 Soil Moisture Product**

In this presentation, Randy Koster describes the SMAP Level 4 data product and its extensive evaluation against surface measurements. The NASA satellite-based Soil Moisture Active Passive (SMAP) mission, launched in 2015, produces global estimates of soil moisture based

on passive L-band radiometer measurements. Although the SMAP instrument “sees” soil moisture in only (nominally) the top 5 cm of soil, the SMAP project includes a Level 4 product that combines the radiometer measurements with meteorological data in a data assimilation setting, thereby providing soil moisture estimates (globally, at 9-km spatial resolution) down to a depth of 1 meter. 3-hourly data starts on March 31, 2015 (latency ~2.5 days). Other documented variables include surface (0-5 cm) and root zone (0-1 m) soil moisture, full suit of model-generated water balance (e.g., latent and sensible heat flux), and thermodynamic variables (e.g., temperature) variables. Assessments of product accuracy and evaluations of the model’s overall skill are well documented (e.g., peer-reviewed publications, Product Specification Document, Algorithm Document, and Data Assessment Reports). The algorithm/product is updated every ~1-2 years and each update is fully documented and includes a full reprocessing of the SMAP record. SMAP doesn’t use regional or local inputs (e.g., US radar precipitation) and because of the limited coverage (2015- present), it is not applicable for climate trend detection. The primary motivation for producing SMAP soil moisture products are scientific research, model improvement, weather forecasting, climate projections, drought monitoring, floods predictions, among many others. SMAP data is very valuable in places where soil moisture data types are otherwise limited. The data, metadata, and/or additional information can be found on NSIDC website (<http://nsidc.org/data/smap>)

### **David Mocko: Soil moisture products within Land Data Assimilation Systems at the Hydrological Sciences Laboratory at NASA/GSFC**

David Mocko presented the details, evaluations, applications, and future directions of soil moisture products within Land Data Assimilation Systems (LDAS). LDAS aims to produce high-quality fields of land-surface states (including soil moisture) and fluxes by integrating satellite- and ground-based observational data products, using advanced land-surface modeling and data assimilation techniques. The Hydrological Sciences Laboratory at NASA’s Goddard Space Flight Center has been developing multiple LDASs and distributing LDAS output for more than two decades. Products include the Global (GLDAS), North American (NLDAS, in collaboration with and run operationally at NOAA), National Climate Assessment (NCA-LDAS), Famine Early Warning Systems Network (FEWS NET) (FLDAS), and Western (WLDAS) system frameworks. NASA’s Land Information System software framework is used to drive new and updated LSMs with advanced physics and perform data assimilation. As an example, the timespan of North American LDAS is January 1979 to present with hourly/monthly frequency and ~4 days latency. Grid spacing for this dataset is 1/8th-degree and covers the CONUS (25- 53N). NLDAS-2 soil moisture datasets have been extensively evaluated against many in situ soil moisture networks. Technical specifications and other details about GLDAS, FLDAS, and NCA-LDAS can be found online ([GLDAS: Project Goals | LDAS](#), [FLDAS: Project Goals | LDAS](#), and [LDAS | nca-lda](#)). GLDAS continues to add new LSMs, forcings, and assimilated products. NLDAS is currently developing the next phase and will build on the WLDAS efforts, as well as generate higher-resolution forcing data together with new LSMs and assimilation. Future directions of LDAS systems include but are not limited to continued evaluation of soil moisture, development of drought monitoring projects from all LDAS systems, and using machine learning in place of LSMs to predict soil moisture.

### **Clara Draper: Land Data Assimilation at NOAA**

This presentation reviews the current and planned use of land data assimilation at NOAA, focussing on applications relevant to constraining the soil moisture in NOAA’s global Numerical Weather Prediction (NWP) models. Currently, NOAA does not use data assimilation to constrain

the soil moisture in their global NWP models, although the model soil moisture is retrospectively corrected for errors in recent precipitation forecasts. A land data assimilation system is currently under development, and will initially assimilate 2m temperature and specific humidity to update the model soil moisture and soil temperature, using an Ensemble Kalman Filter. It is hoped that this will quickly be expanded to also assimilate satellite soil moisture observations. NOAA is working towards adding soil moisture to routine evaluation of their global NWP systems. Soil moisture observations can also be useful for ad-hoc evaluation. Representativity/systematic differences between different soil moisture estimates make an evaluation of soil moisture very difficult and uncertain. NWP models have compensating errors and a cause and effect of model biases can be difficult to identify.

### **Dave Lawrence: Soil moisture data in CMIP6 and a Representation of subgrid-scale soil moisture in the Community Land Model (CLM)**

The CMIP6 archive hosts a large number of soil moisture and related variables datasets from more than 12 Earth System Models. Available simulations include coupled and land-only historical simulations as well as coupled projection period simulations for multiple SSPs. Additionally, single forcing experiments (e.g., land use and land cover change including separation of various aspects of land management, aerosols, volcanic emissions, etc) enable researchers to isolate what aspects of forced and unforced variability affect soil moisture variations and trends. For land-only simulations, forcing uncertainty can be evaluated via simulations with four different historical climate/weather reconstructions. The Community Land Model (CLM5) is one of the models available in CMIP6. The next-generation version of CLM will include the capacity to computationally efficiently represent sub-grid soil moisture heterogeneity through a representative hillslope formulation. Within this formulation, the impacts of lateral subsurface flow, slope, aspect, and meteorological forcing downscaling drive more realistic variations in soil moisture across a large-scale grid cell without the computational cost of ultra-high-resolution simulations. CMIP6 archive can be accessed via ESGF at [cmip6 - Home | ESGF-CoG](#). Relevant variables are volumetric soil moisture, total water storage, soil liquid and ice content on soil levels, and several hundred other land-related variables. Horizontal resolution varies from 1 to 2 degrees for most models and 0.25 degrees for High-Res MIP.

### **Elena Shevliakova: Global soil moisture in the GFDL climate and Earth system models**

All GFDL climate and Earth system models include a land component. GFDL land components (e.g. LM3 and LM4) represent ecological, biogeochemical, and hydrological processes, including dynamics of liquid and frozen water in vertical soil columns. GFDL land models capture sub-grid heterogeneity in soil moisture due to land use and natural disturbances (e.g. fire and forest gap formation). GFDL has contributed dozens of experimental simulations to the Coupled Model Intercomparison Project (CMIP6) with a new coupled climate model CM4 and the new Earth system model ESM4.1. These experiments include multidecadal simulations of the preindustrial (constant 1850 radiative forcing), historical (1850-2014), and future (2015-2100) simulations as well as dozens of specialized climate experiments to explore effects of land use, specific radiative forcings, and land-climate coupling. Soil moisture data from these experiments are available from the public archives (e.g. [cmip6 - Home | ESGF-CoG](#)).

## **Panel Discussion and Q&A (Moderated by Jennifer Arrigo & Jared Entin)**

### **Key takeaways:**

- It would be helpful for someone to coordinate a directory of observations for researchers to access.
- From the modeler's perspective, more comprehensive observations at fewer sites would be better than a surplus of sites with fewer observations.
- Organizing around a common activity (workshop, project, etc.) to enhance interactions and collaborations between soil moisture modeling and observation soil moisture groups would be beneficial.

### Discussion:

During the Discussion, the in-situ soil moisture observation and the modeling communities talked about possible ways for collaborations to complement and enhance each other's activities. Key points are summarized below:

- The workshop participants on the modeling side discussed the needs for and benefits of comparing outputs from climate models with remote sensing and with real-time measurements. They expressed concerns that most of the time it is highly uncertain where to find those datasets. An opportunity exists to create **a network facilitating communication between modeling and observation (remote sensing and in situ) communities**.
- There is a strong interest in high-resolution data as the soil moisture field moves towards high-resolution modeling. Currently, **hosting and maintaining high-resolution institute data** is a challenge.
- The workshop participants also discussed a software challenge to organize data for use by the modeling community. The modeling community concluded that an effort towards **getting a complete set of measurements** (more than one measurement of soil moisture and other related variables) at a single site is highly desirable. The observation community pointed out that NEON measures soil moisture and a wide range of other variables, so NEON could be a good candidate for this task. Many AmeriFlux sites measure soil moisture but issues arise when some sites do not submit all measurements or do not make some measurements. Significant efforts are put into gathering the needed information, especially considering it is largely unfunded. There are many **opportunities for machine learning to fill the gap in the missing data**. One of the identified possible tasks is to make sure that compound datasets are more accessible to researchers and to coordinate research efforts to bring all datasets together.
- The GEWEX project comparison sites, called PLUMBER, were suggested as an example of how to **share and communicate the requirements** from the modeling community. PLUMBER provides a framework for which forcing variables and data one might need.
- A need for **connecting models with data as well as building communities** was also discussed. Some participants noted that there are a lot of existing groups dealing with soil moisture, and sometimes with a proliferation of workgroups, there are diminishing returns. **Focused activities around a scientific project** could also help to connect modelers with needed observation and encourage collaborations among groups

A conversation about different types of designs of observations and different ways to get more details on soil characteristics led to the following conclusions:

- The participants indicated it as a challenge to characterize soil for global models on a global scale.
- Machine Learning provides a great opportunity for filling in gaps in observations, creative designs for data collection campaigns, and data assimilation. POLARIS is a great example.
- Identifying areas where soil moisture is critical information will allow us to direct investments into soil moisture networks.

In terms of future engagements, the USGCRP/US GEWEX could facilitate:

- 1) Communication:
  - Among the US climate modeling centers
  - Between the US climate modeling centers and observational scientists,
  - Between the scientists and users/stakeholders.
- 2) Identification of missing or poorly resolved processes or interactions in climate models (e.g. water vapor diffusion in soils, effects of surface litter on soil moisture)
- 3) Collection of soil moisture data sources and putting them in one place/website.
- 4) Preparation of a review paper on next-generation needs in terms of soil moisture modeling and observations that would most likely require additional research and funding. For example, focus on a publication that would help modeling and observation groups work on one particular problem.
- 5) A synthesis paper that discusses different sources of soil moisture datasets/information and provides links to where to find them.