Soil moisture estimation over agricultural fields using Synthetic Aperture Radar

SUMMARY

Key Points

- Satellite observations will be integrated with ground sensor data to generate field-scale soil moisture maps over alfalfa fields.
- The surface soil moisture information will be integrated into the CropX's hydrological model to generate root-zone soil moisture maps.
- Once the data from NISAR are available, the soil moisture estimation models will be expanded to the crops with the higher biomass.

Service

- Agriculture
- Food Security
- Mitigation

End users

- Industry
- Researchers
- Local communities

Intermediate User(s)

Intermediate users are the CropX clientele, typically farmers and farm managers. Improved agricultural monitoring and soil moisture metrics help farmers plan according to science-backed data, ultimately save on the cost of fertilizers, water usage, and nutrients and maximize crop yields.

Application(s)

We will integrate satellite data and Synthetic Aperture Radar (SAR) metrics into the existing CropX platform, improving the application's current features and providing new yield forecasting capabilities. With better modeling comes better-informed decision making (i.e., when to apply which resources and at what time in the growing season) to ultimately save on water, fertilizer, and energy costs—this has the downstream effect of increasing the uptake of sustainable farming methods. If farmers are able to reduce their costs without sacrificing yields while simultaneously saving on resource usage, it will demonstrate that sustainable farming is a viable solution not only for CropX clients but for agricultural producers around the world.

Furthermore, with access to ground data provided by CropX, NASA Harvest will have much-needed validation data to train SAR-based yield forecasting models. SAR models have shown promise in overcoming the major obstacle of cloud cover interference with optical satellite data. Although the ground data will remain private, the algorithms developed by NASA Harvest will be publicly available in service of public good.

Essential Climate Variables

—Atmosphere

- Precipitation
- Temperature

—Land

- Above-ground biomass
- Soil moisture
- Land cover
- Land Surface Temperature
- Leaf area index

Models

- Water Cloud Model (WCM)
- Machine learning algorithms
  Hosseini M., McNairn H., 2017, Using multi-polarization C- and L-band synthetic aperture radar to estimate wheat fields biomass and soil moisture, International Journal of Earth Observation and Geoinformation, vol. 58, 50–64.

Climate Data Records

- Crop data layer
- SMAP soil moisture products
- Precipitation

Agencies

- USDA
- NASA
- NOAA

Satellite Observations

- Sentinel-1
- RADARSAT Constellation Mission (RCM)
- Landsat-8
- Sentinel-2

Sustainability

This use case will be operational at the completion of the initial 12-month pilot with CropX. We will be able to scale the SAR-based yield model developed in this use case to other crops and other regions around the world.

DESCRIPTION

Soil moisture is an important parameter for many agricultural applications including crop irrigation, crop health monitoring, and crop yield prediction. However, this parameter is usually not available at spatial and temporal scales suitable for these applications. Because of the expensive cost of ground measurements of soil moisture, it is not a financially feasible measurement for small farm holders, in addition to the fact that satellite-based soil moisture products are at low spatial resolutions (e.g., NASA SMAP soil moisture products are at 3 km–36 km resolutions). In light of these challenges, NASA Harvest has recently partnered with CropX Inc. to develop a new soil moisture product based on the integration of satellite and ground sensors that will meet the needs of farmers—both economically and technically.

CropX has implemented strategies across a group of alfalfa fields in Arizona controlled by to test and fine tune the algorithms that will become the foundation of nationwide, and eventually global, agricultural insights. The company has currently installed in-house-built soil sensors to measure soil moisture and by integrating these measurements with hydrological models and soil information, they provide continuous soil moisture maps at different soil depths. This detailed data enables a greatly improved understanding of overall soil health and nutrient availability, which directly affect crop growth and plant health.

In parallel, Dr. Mehdi Hosseini of NASA Harvest—NASA's Food Security and Agriculture Program—has developed a soil moisture mapping tool that is used to generate soil moisture metrics from Synthetic Aperture Radar (SAR) data. In contrast to some of the low-resolution satellite-based products, the SAR signals are highly sensitive to the soil dielectric constant and therefore they are extremely useful for generating soil moisture maps. We are using the backscatter coefficients from different polarization bands from Sentinel-1 and RCM and reflectance values from Landsat-8 and Sentinel-2. Data from NISAR will be added once they are available. Land Surface Temperature derived from Landsat-8 will be tested as additional input data for training the Machine Learning Algorithms. Crop Leaf Area Index (LAI) or biomass or vegetation indices derived from the optical or SAR data will be used to correct the impacts of the crop canopy on the SAR signals. Our derived soil moisture data will be scaled to the SMAP 3km soil moisture resolution for the comparison. Crop data layer from USDA will be used to detect between different crops and develop models for each crop type separately for the next phases of the project. Also, precipitation data from NOAA will be used and tested as additional data for training the Machine Learning algorithms. For example, Figure 1 shows a soil moisture map generated for wheat fields over Carman, Manitoba, Canada using a RADARSAT-2 image.

However, estimation of soil moisture over agricultural fields, especially during the growing season, has unique challenges because of the attenuation and scattering of the SAR signals by the crop canopy. Operational use of SAR for soil moisture mapping requires further research and experimentation to overcome these obstacles. The NASA Harvest and CropX partnership provides an innovative opportunity to develop a new approach for soil moisture mapping by better integrating satellite and ground sensors.

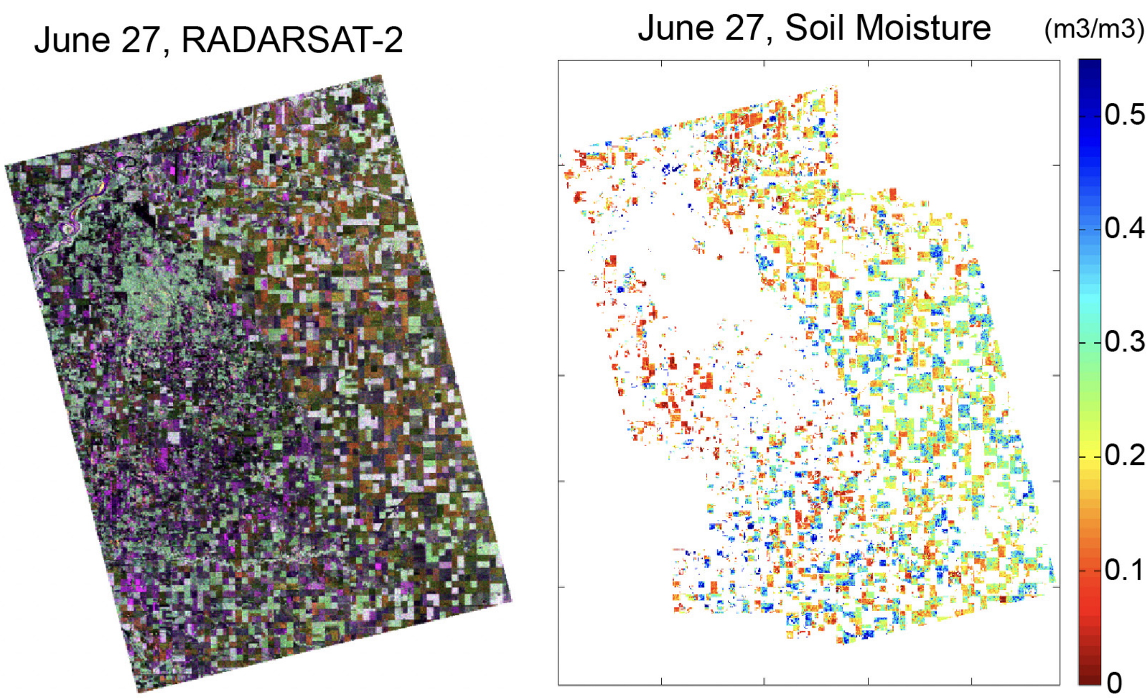
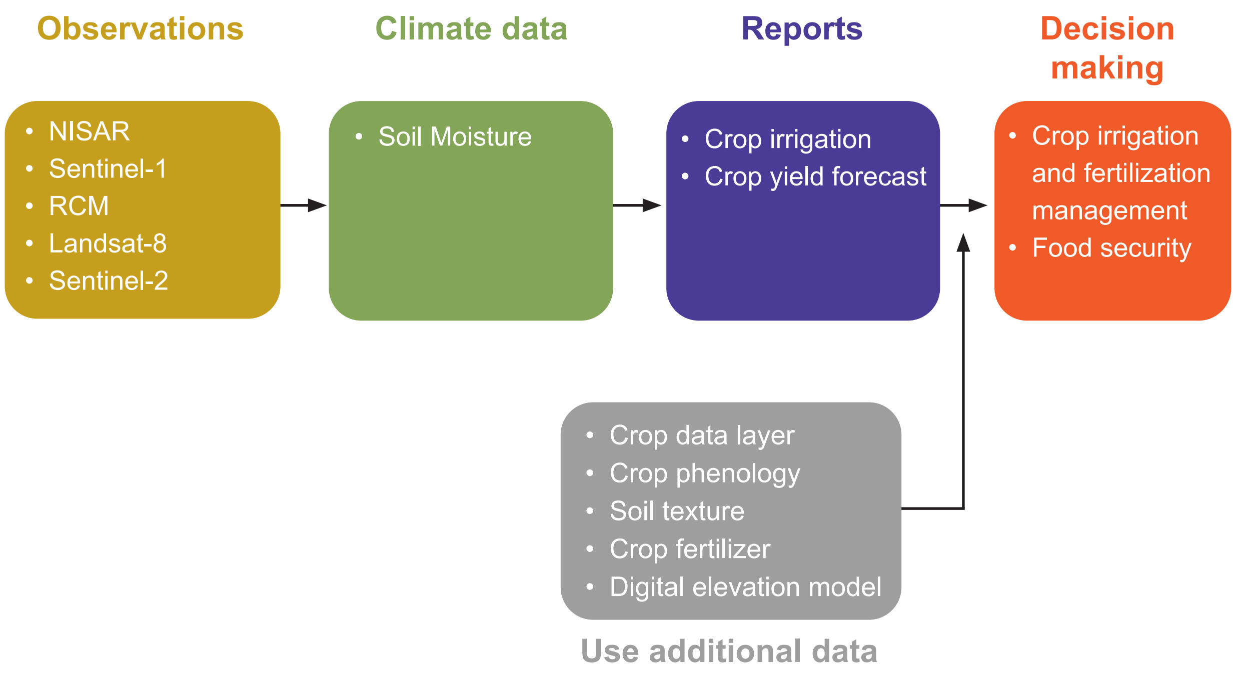


Figure 1. Soil moisture map over wheat fields using RADARSAT-2 images. The area is located at Carman, Manitoba, Canada (Hosseini and McNairn, 2017). The white color is the non-wheat pixels and so they were masked.

Over a 12-month time period with the integration of NASA data, Synthetic Aperture Radar (SAR) information, and international partner agency satellite data, the pilot program will quickly establish the parameters for water usage estimates, yield prediction, soil quality and land usage assessments based on multiple crop growing cycles. Particularly in light of a renewed focus on soil moisture metrics spurred by the NASA and ISRO NISAR mission, the team hopes to build upon the pilot study in the coming years by using the best available technology to analyze and support more cost-effective and environmentally efficient farming methods.

This public-private-partnership also serves NASA Harvest's mission to improve food security and advance sustainable agriculture, supporting farmer productivity while preserving natural resources in the United States and worldwide through the use of satellite data. Combining the power of CropX soil data monitoring, comprehensive insights provided by the CropX agriculture analytics platform, and NASA's network of Earth-observing satellites, NASA Harvest aims to deliver critical insights to governments and farmers around the globe in support of informed and science-driven decision making.

INFORMATION FLOW



The data from NISAR (once they are available) will be used to expand the soil moisture estimation models to the L-band SAR. Given the higher wavelength of L-band compared to C-band, they are less impacted by the crop canopy and will be more appropriate for soil-moisture monitoring during the crop-growing season, especially for the higher biomass crops.

Additional ground data is always needed because it is critical to validating machine-learning-based yield-forecasting models but is very costly to obtain. While we will have access to a vast amount of ground data through the fields that CropX currently has access to, expanding into other regions of the world and acquiring more ground data will enable scalability. We are also conducting this pilot study with a focus on alfalfa due to the multiple crop cuts that it undergoes in a year, so we could further improve this case study by analyzing different types of crops going forward.

Given the impacts of vegetation on SAR signals specifically at lower wavelengths, having data from NISAR with L-band and S-band wavelengths will help to mitigate this issue. Other crop parameters including the crop phenology, biomass, or LAI will help to improve the accuracies of the soil moisture product.

References

Hosseini M., McNairn H., 2017. Using multi-polarization C- and L-band synthetic aperture radar to estimate wheat fields biomass and soil moisture, *International Journal of Earth Observation and Geoinformation*, vol. 58, 50–64.