

Estimating Soil Moisture in Semi-Arid Sagebrush Steppe using NASA Earth Observations



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Overview

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- ▶ Community Concerns
- ▶ Study Area
- ▶ Partners & Collaborators
- ▶ SMAP Overview
- ▶ Satellites & Sensors
- ▶ Objectives
- ▶ Work Flow
- ▶ Data Access
- ▶ Results
- ▶ Conclusions



Image Credit: Critical Zone Observatory/USDA ARS

Background

- ▶ Over 60% of Idaho is public land
- ▶ Semi-arid sagebrush steppe at lower elevations covers much of the southern half of the state
- ▶ Higher elevations transition to mixed forest
- ▶ Averages 12 inches of precipitation per year ~1/3 national average
- ▶ These factors create specialized management challenges in the region



Image Credit: Bureau of Land Management

Community Concerns

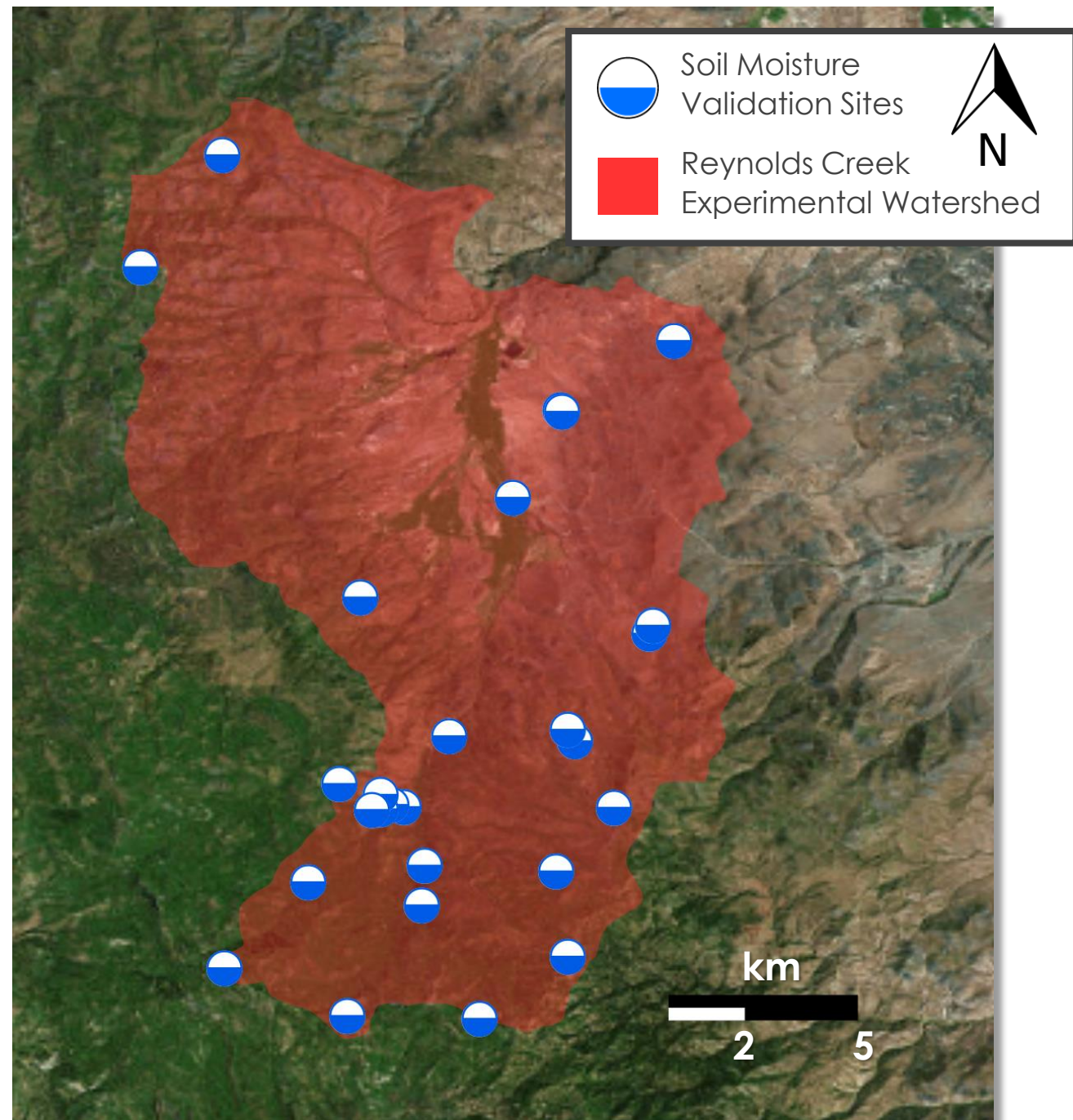
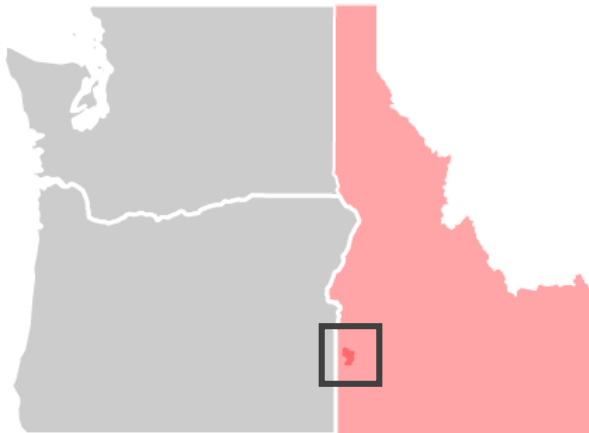
- ▶ Soil moisture and water storage research is critical to understanding ecosystem function:
 - ▶ Grazing impacts
 - ▶ Fire susceptibility
 - ▶ Native plant management
- ▶ Land managers currently rely on field-based measurements to collect soil moisture data
 - ▶ Costly and time intensive
 - ▶ Limited distribution for regional scales



Image Credit: Pat Clark

Study Area

- ▶ **Reynolds Creek Experimental Watershed**
- ▶ Founded in 1959 by act of Congress, outdoor laboratory for study of critical zone processes
- ▶ 29 stations – Weather and Soil Parameters





Partners and Collaborators



**Agricultural
Research
Service**



Image Credit: Leah Kucera

SMAP Overview

- ▶ National Research Council's **Decadal Survey** identified key targets for future research in 2008
- ▶ **Soil Moisture Active Passive (SMAP)** was first launched in January of 2015
- ▶ Measures land surface soil moisture and freeze thaw every **2-3 days**
- ▶ Uses L- Band RADAR (**microwave**) to measure water in the top 5 cm through vegetation

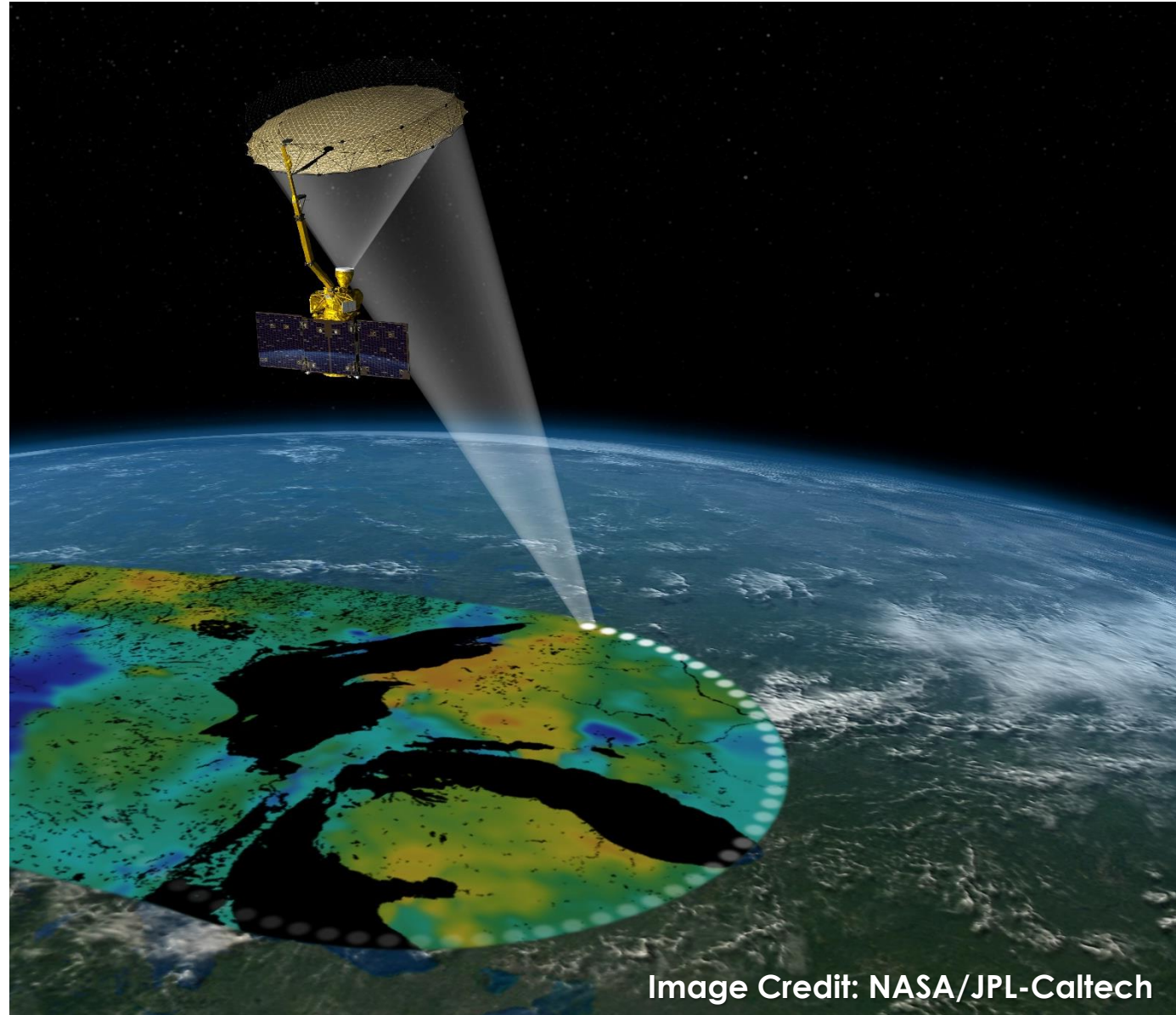
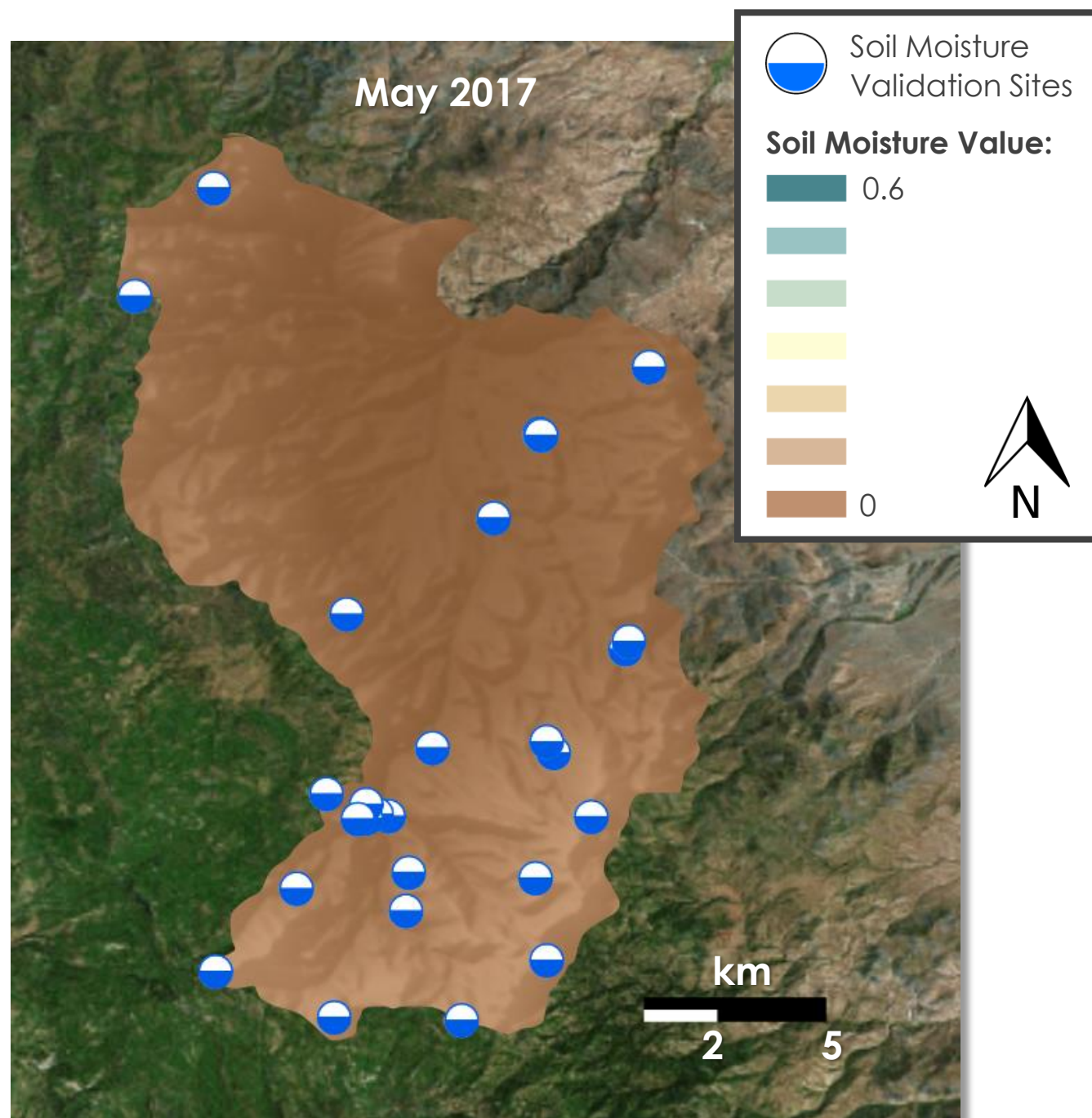


Image Credit: NASA/JPL-Caltech

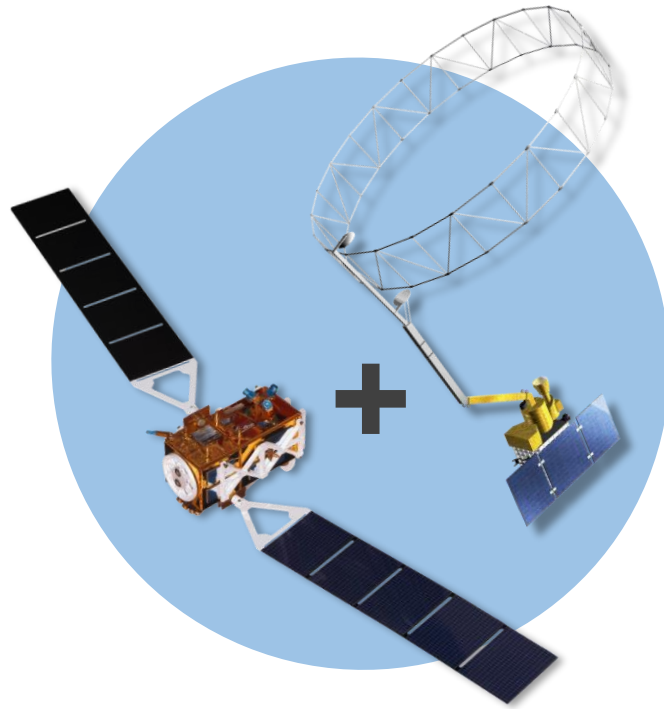
- ▶ **Passive** radiometer and **Active** Radar
- ▶ **Applications:** Water energy balance, carbon cycling vegetation growth, weather and climate forecasting, flood prediction and drought monitoring
- ▶ July 7 2015 SMAP's **active sensor** stopped transmitting
- ▶ “Anomaly” in High-Power Amplifier (HPA) connected to the radar power supply



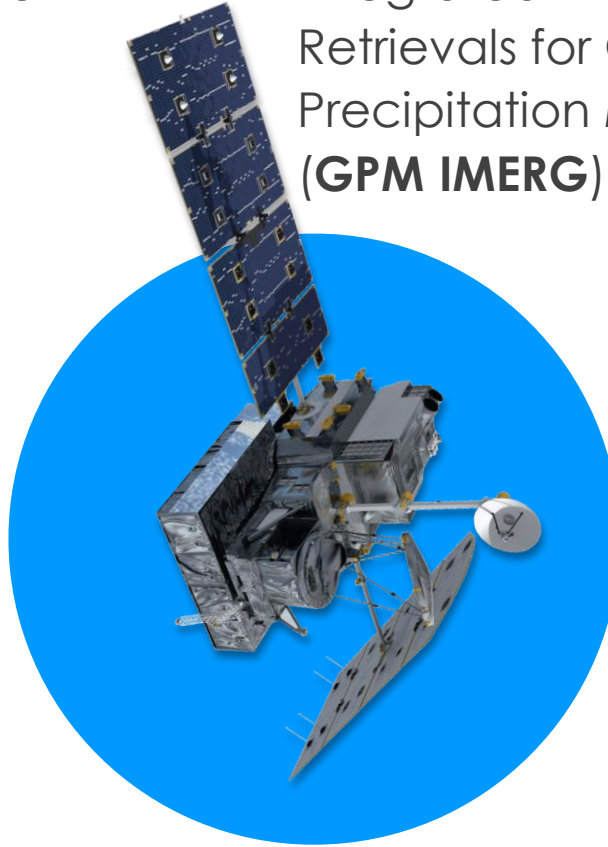
Satellites and Sensors

Sentinel-1 C-Band
Synthetic Aperture
Radar (**C-SAR**)

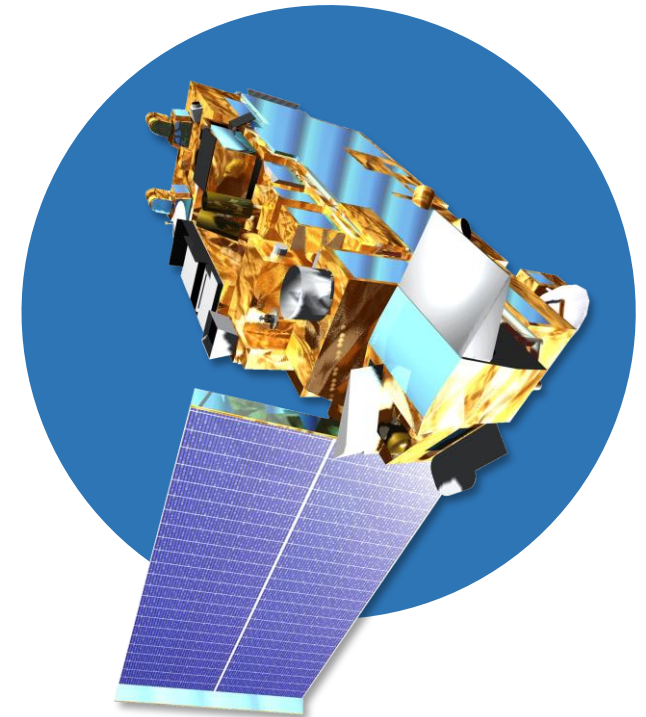
Soil Moisture Active
Passive (**SMAP**)



Integrated Multi-satellite
Retrievals for Global
Precipitation Measurement
(**GPM IMERG**)



Terra Moderate
Resolution Imaging
Spectroradiometer
(**MODIS**)



SMAP Launch:
Jan 2015

SMAP Dataset:
Aug 2015

SMAP + Sentinel-1 Dataset:
Dec 2016

Project Timeframe:
Feb 2017 – Jul 2018



Objectives

- ▶ **ASSESS** the ability of Sentinel-1 enhanced SMAP to accurately measure soil moisture in semi-arid environments
- ▶ **VALIDATE** these soil moisture values by correlating them against *in situ* measurements
- ▶ **CREATE** a workflow that land managers can use to rapidly reproduce data measurements of soil moisture
- ▶ **PRODUCE** maps and graphs of soil moisture observations and related data



Image Credit: Jenny Parks Illustration/SSCZO



Work Flow

DATA INPUTS

EOS Soil Moisture:
SMAP / Sentinel-1

***In Situ* Soil Moisture:**
RCEW Data

Precipitation:
GPM Microwave
Imager

Vegetation Health:
Terra MODIS

PROCESSING

Google Earth Engine
Confined data to
specified spatial and
temporal scales

ESRI ArcGIS Pro
Extract values at
RCEW Soil Moisture
points

ANALYSIS

Regression Analysis
SMAP + Sentinel-1
versus *in situ* soil
moisture,
precipitation, & NDVI

**Temporal Cross-
Correlation Analysis**
January 2017 –
December 2017
precipitation and soil
moisture values



Data Access

<https://earthdata.nasa.gov>

- ▶ **SMAP/Sentinel-1 L2 Radiometer/Radar 30-Second Scene 3 km EASE-Grid Soil Moisture V002**
 - ▶ Contains 3 km and 1 km “bands”
- ▶ **Data** was accessed using NASA's **EARTHDATA** website
 - ▶ Similar to USGS Earth Explorer, Access Idaho etc.
- ▶ Use map to identify area of interest
 - ▶ Point
 - ▶ Polygon
- ▶ Download granules letting website process and project images
 - ▶ GEOTIFF for ease of use in ArcGIS
 - ▶ UTM 11N for Reynolds Area

Reformat Output (Optional)

Output File Format

Spatial Subsetting (Optional)

☐ Enter bounding box

Projection Options

Re-projection Options

Set Parameters for UTM Northern Hemisphere (Optional)

CAUTION: Re-projection parameters may alter results.

UTM Zone
1..60

Minimum supported longitude -180

Maximum supported longitude -72

Band Subsetting (Optional)

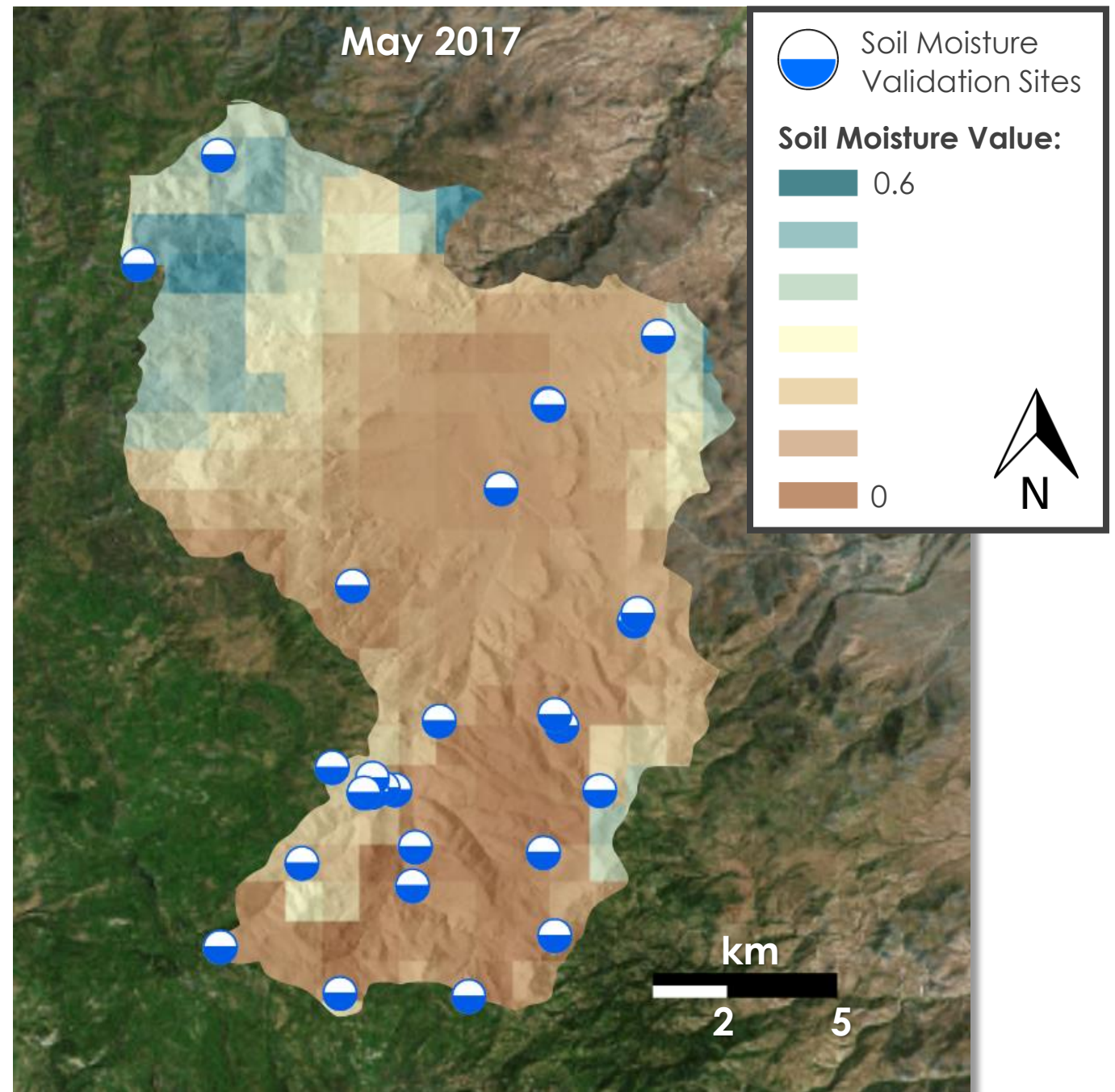
Choose Bands

104 of 104 bands selected

- ☒  SPL2SMAP_S
 - ☒  Soil_Moisture_Retrieval_Data_1km
 - ☒  Soil_Moisture_Retrieval_Data_3km

Results

- ▶ SMAP + Sentinel-1 Enhanced Map
 - ▶ 1 km² pixels
 - ▶ SMAP/Sentinel-1 produced unique values for each soil site location
- ▶ **Moderate positive correlation** between these values and *in situ* soil moisture for **82%** of stations
 - ▶ **83.4%** of data points show statistical overlap taking into account **Standard Deviations**
 - ▶ **Correlation** $r^2 = 0.12 - 0.51$
 - ▶ **Mean** $r^2 = 0.30$, p-value = 0.005
 - ▶ 9 of 29 stations **excluded** for $p > 0.05$



Conclusions

- ▶ SMAP/Sentinel-1 1 km² soil moisture estimates correlate well with *in situ* soil moisture
- ▶ **Low variability** in soil moisture estimates **based on topographic or vegetative controls**
- ▶ Low shrub and vegetation sites produced highest correlation values (**Not statistically differentiable** from other vegetation types)
- ▶ Sites with low-confidence (high p-values) from either low sample sizes or anomalously low *in situ* soil moisture values



Image Credit: Critical Zone Observatory/USDA ARS



Acknowledgements

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Trent Armstrong, Research Scientist

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Brandon Crawford, Research Scientist



Questions?



Image Credit: Leah Kucera



Appendix

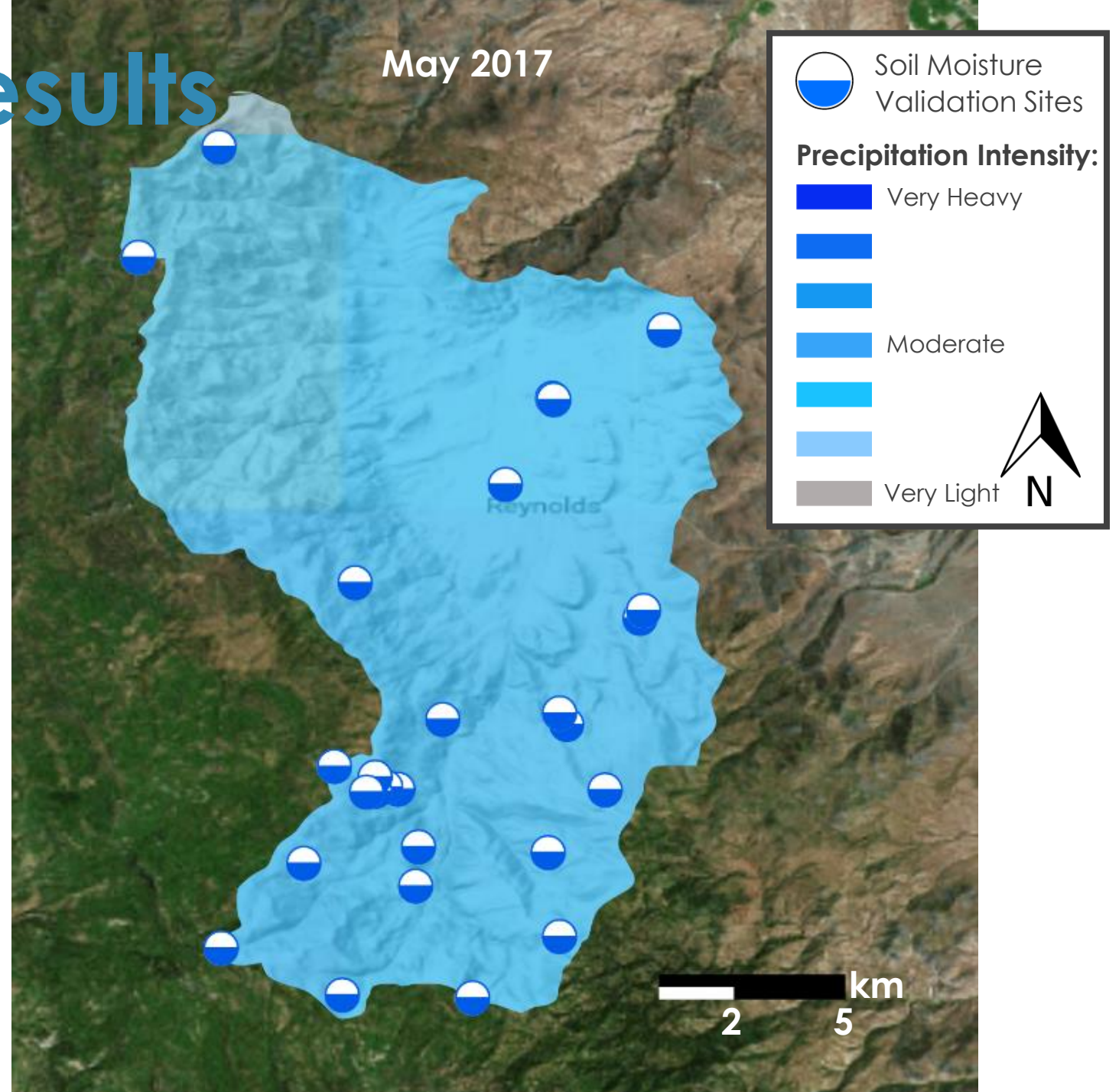
Dataset	Date	Use	Acquired From	Level	DOI
SMAP/Sentinel-1 L2 Radiometer/Radar 30-Second Scene 3 km EASE-Grid Soil Moisture V002 (SPL2SMAP_S)	2016-2018	Soil Moisture	NASA EARTHDATA	Level 2	10.5067/KE1CS VXMI95Y
GPM IMERG Final Precipitation L3 Half Hourly 0.1 degree x 0.1 degree V05 (GPM_3IMERGHH_05)	2015-2018	Precipitation	Google Earth Engine	Level 3	10.5067/GPM/IMERG/3B-HH/05
MOD13Q1.006 Terra Vegetation Indices 16-Day Global 250m (MOD13Q1.006)	2015-2018	Vegetation Indices NDVI	Google Earth Engine	Level 2	10.5067/MODIS/MOD13Q1.006
SMAP L3 Radiometer Global Daily 36 km EASE-Grid Soil Moisture, Version 5, NASA_USDA SMAP Global Soil Moisture Data (SPL3SMP)	2015-2018	Soil Moisture	NASA EARTHDATA	Level 3	10.5067/ZX7YX2 Y2LHEB

Dataset	Date	Use	Acquired From	Level	DOI
RCEW Soil Moisture	2015-2018	Soil Moisture	USDA-ARS	NA	NA
RCEW Precipitation	2017	Precipitation	USDA-ARS	NA	NA
Reynolds Creek - Soils, Vegetation, and Geology	1960-1970	Vegetation	Critical Zone Observatory - Reynolds Creek Experimental Watershed	NA	http://criticalzone.org/reynolds/data/dataset/3722/#policy
Reynolds Creek - Instrumentation, Regions, and Boundaries	2014	Boundaries and Instrument Locations	Critical Zone Observatory - Reynolds Creek Experimental Watershed	NA	http://criticalzone.org/reynolds/data/dataset/3934/#citation
USGS NED n44w117 1/3 arc-second 2013 1 x 1 degree ArcGrid	2013	Elevation	U.S. Geological Survey	NA	https://catalog.data.gov/dataset/national-elevation-dataset-ned-1-3-arc-second-downloadable-data-collection-national-geospatial



Appendix: Results

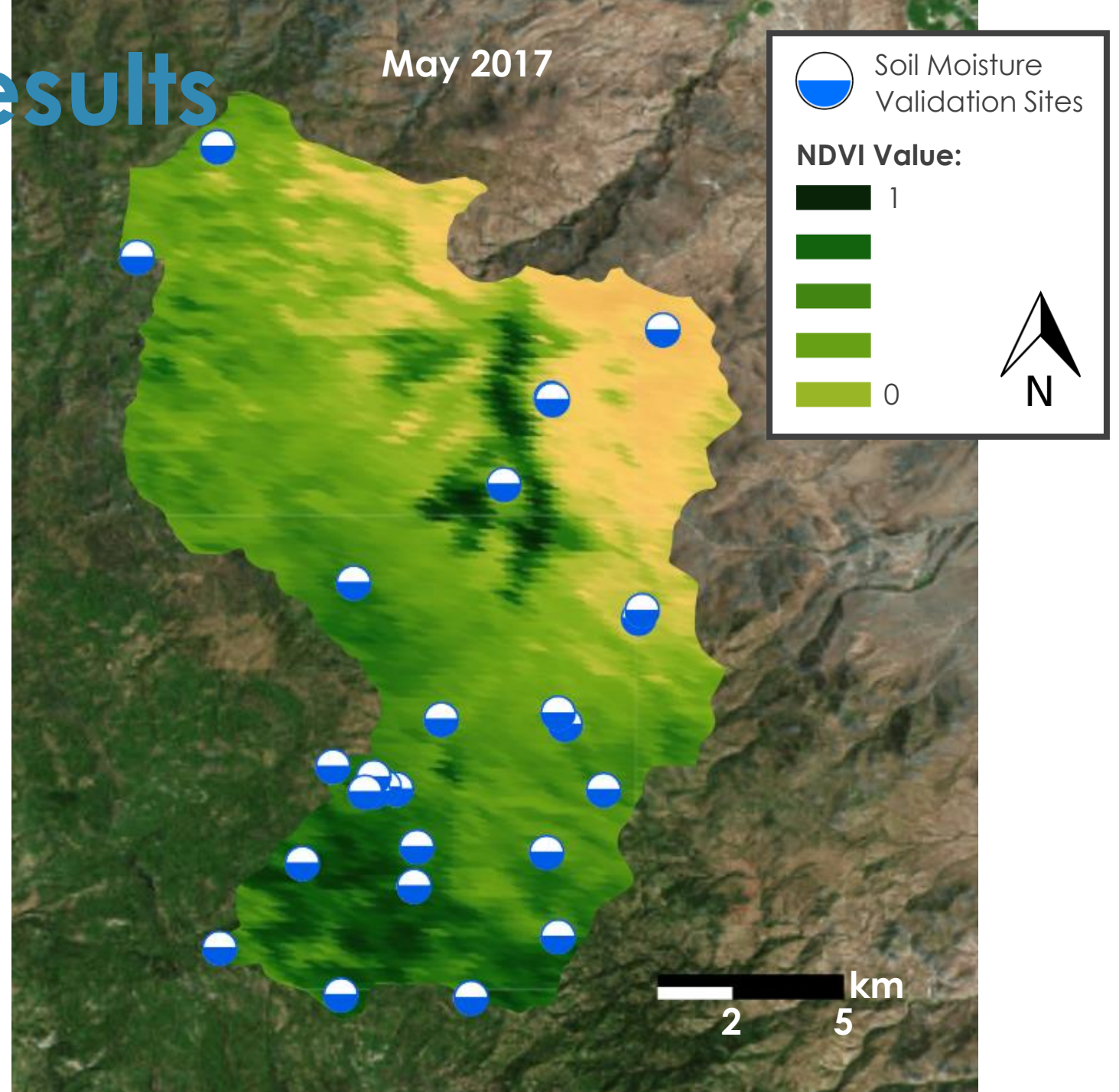
- ▶ Precipitation measured both with GPM and *in situ*
 - ▶ GPM (image for May 2017)
 - ▶ 11 km² Pixel
 - ▶ *In situ* rain gauges at all 29 sites
- ▶ Low direct temporal correlation between GPM and soil moistures (both SMAP and *in situ*)
 - ▶ Mean $r^2 = \sim 0.01$ for both
- ▶ **Moderate, positive correlation** of *in situ* precipitation to soil moisture when **time lag** taken into account
 - ▶ Mean $r^2 = 0.44$, lag = 2.5 days





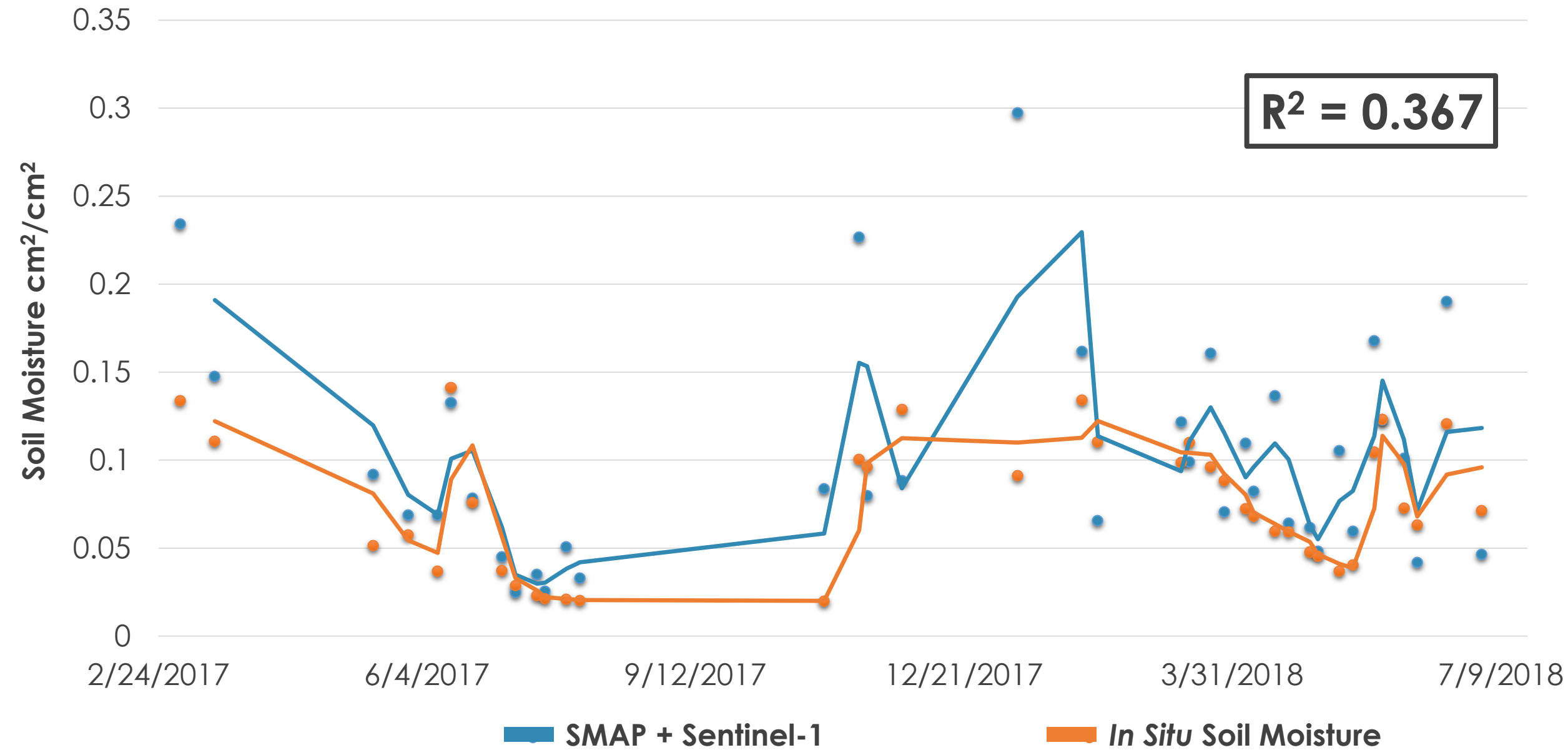
Appendix: Results

- ▶ Normalized Difference Vegetation Index Map from MODIS
 - ▶ 250 m²
 - ▶ 16 day aggregate means
- ▶ **Low association** with NDVI and SMAP values.
 - ▶ 16-day aggregates of NDVI are unlikely to capture the temporal variation of these values.
 - ▶ Future study taking advantage of higher temporal resolution datasets recommended to find time lag relationship, if any





Appendix: Site 31





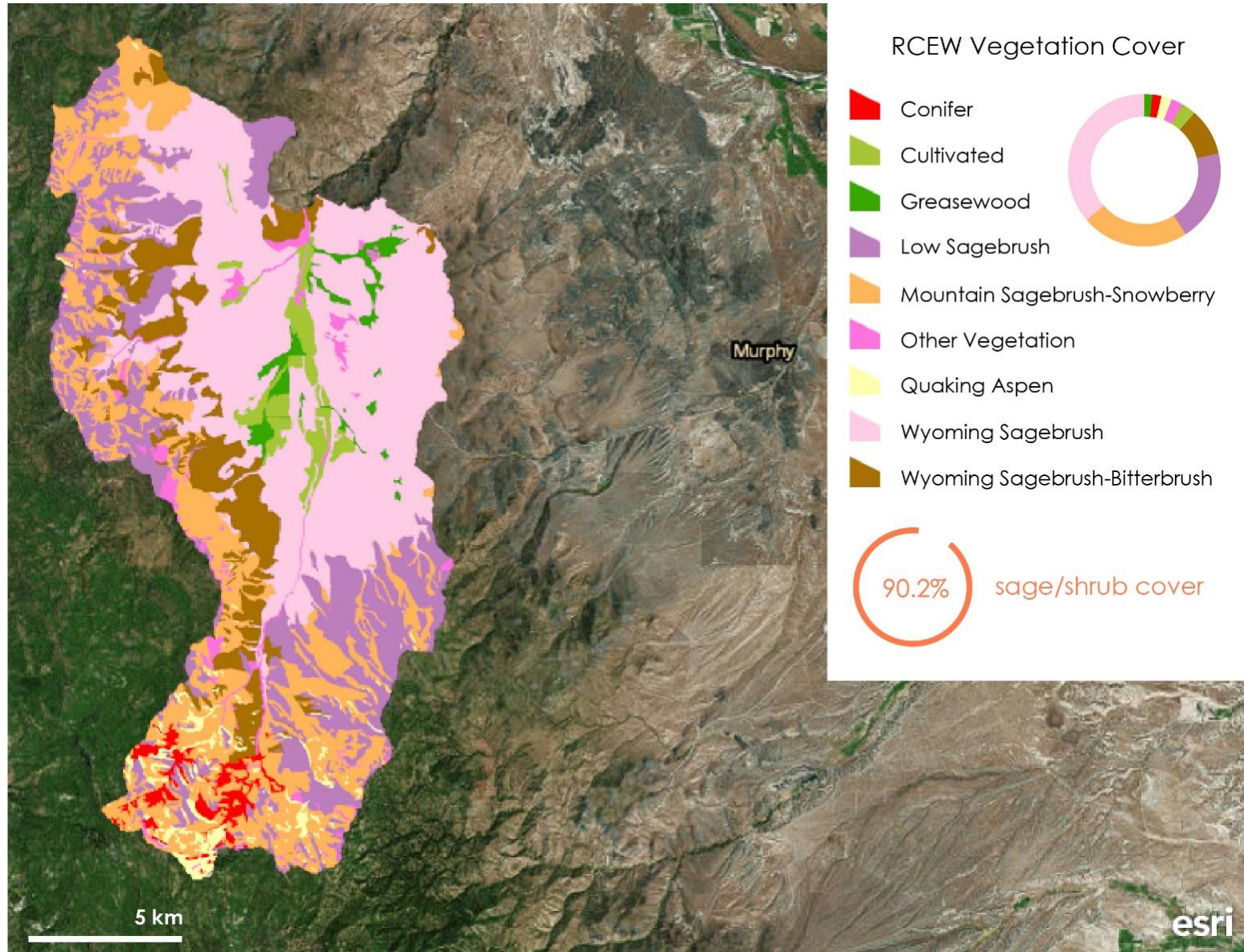
Appendix

83.4% of data points overlap taking into account Standard Deviations

06/08/17	0.068973444	0.0370625	1.5	0.196	31.822		R Square	0.412055	
06/13/17	0.132578731	0.141041667	27.9	0.196	50.609		Adjusted R	0.395723	
06/21/17	0.078217402	0.075760417	0	0.1883	35.403		Standard Error	0.048377	
07/02/17	0.045197897	0.037104167	0	0.1883	19.908		Observations	38	
07/07/17	0.024682751	0.02884375	0	0.1874	15.379				
07/15/17	0.035014492	0.023041667	0	0.1874	10.319		ANOVA		

098d-g	098d-n	116c	124b-a	124b-s	127	127d-g	127d-n	144	145	147	155	
0.23	0.22	0.45952	0.74	0.42579	0.22	0.25	0.12	0.34668	0.07	0.1	0.09	
0.48	0.47	0.67788	0.86	0.65252	0.47	0.5	0.34	0.5888	0.27	0.32	0.3	
0	0	2.9E-06	0.06	9.3E-05	0	0	0.05	0.00016	0.21	0.09	0.12	
37	37	38	5	30	35	34	34	36	24	29	27	
0.69	0.88	0.9375	0.97	0.4375	1	0.75	0.97	0.125	0.88	0.75	0.47	
	163	167	174	176	13803	jdt1	jdt2	jdt2b	jdt3	jdt3b	jbt4	jdt4b
	0.09	0.03	0.21	0.23	0.3267	0.3	0.14	0.47	0.27	0.26	0.19	0.38
	0.3	0.16	0.46	0.48	0.5716	0.55	0.37	0.68	0.52	0.51	0.44	0.62
	0.06	0.37	0.01	0.01	0.001	0	0.03	0.01	0	0.05	0.01	0.06
	38	33	29	32	30	34	34	13	32	15	32	10
	0.32	0.75	0.75	0.72	0.875	0.84	0.94	1	0.81	1	0.88	1

Appendix





Appendix

