NASA Soil Moisture Perspectives and Advances

John Bolten
NASA Applied Sciences Program
Water Resources

john.bolten@nasa.gov

MOISST, Lincoln, NE
June 5, 2018

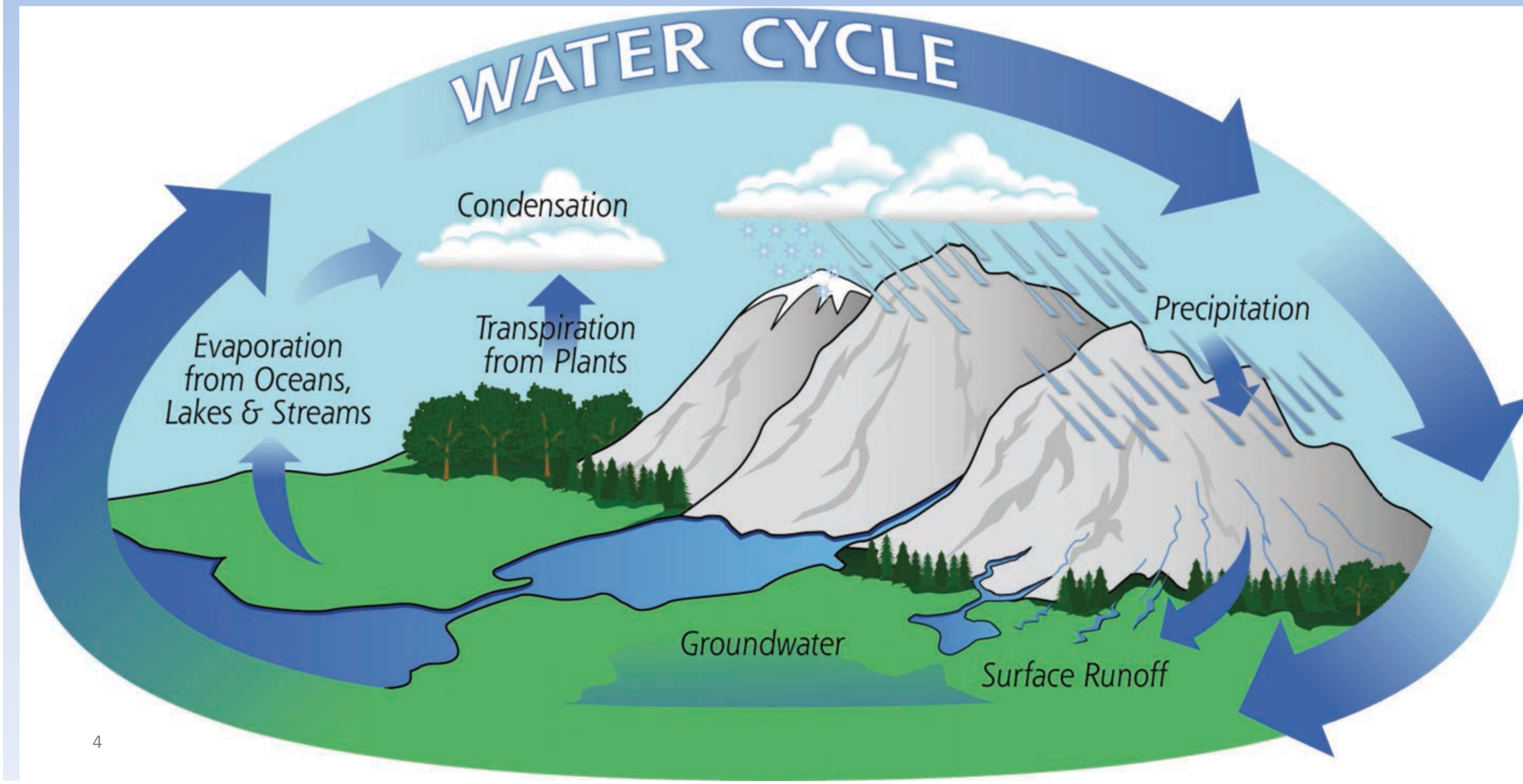
NASA Applied Sciences Program

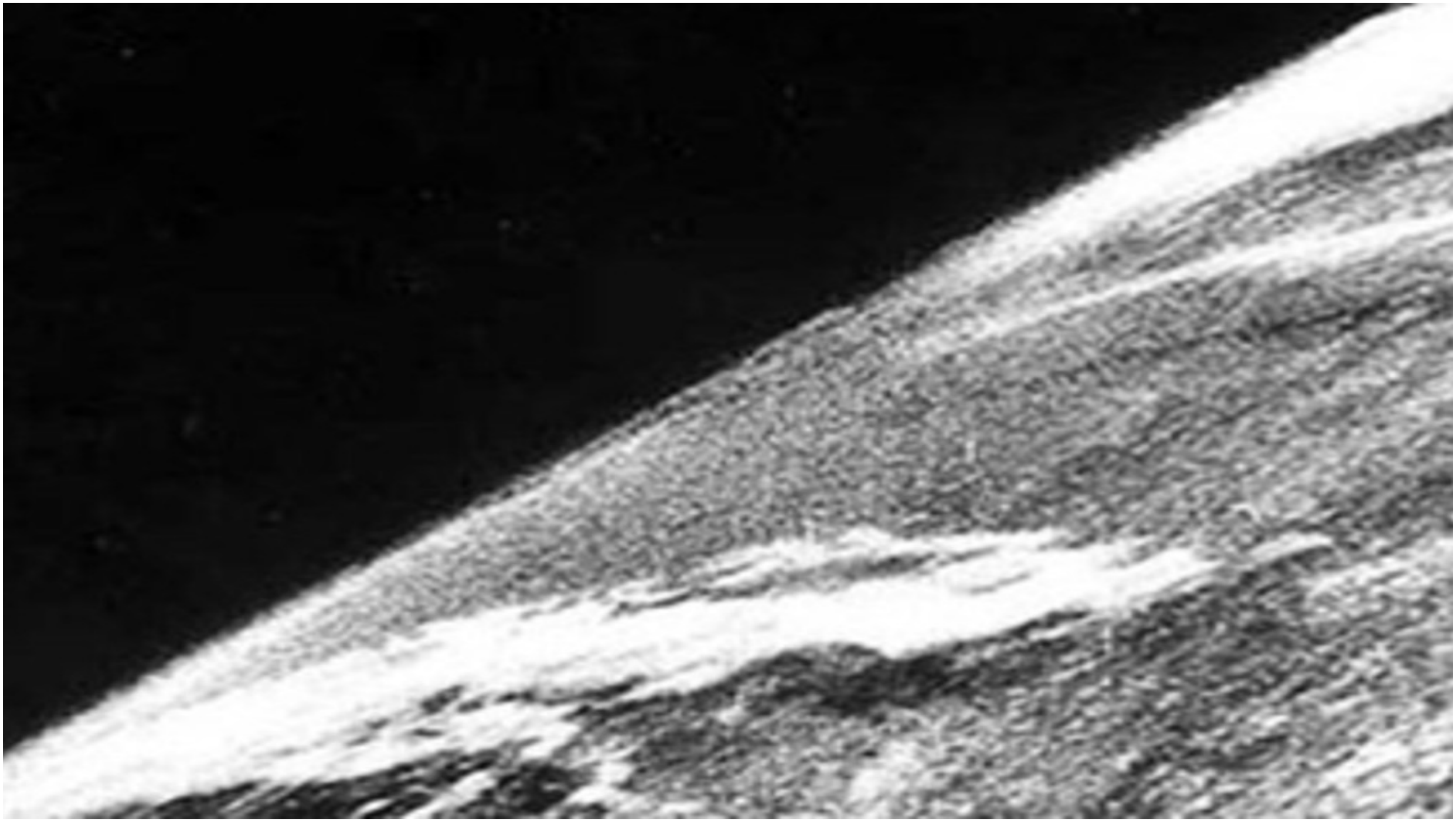
- Explain the basic underlying science and interactions
- Discuss outstanding issues and challenges
- Illustrate the state of art in earth observing technologies and strategies for environmental monitoring, assessment, and prediction

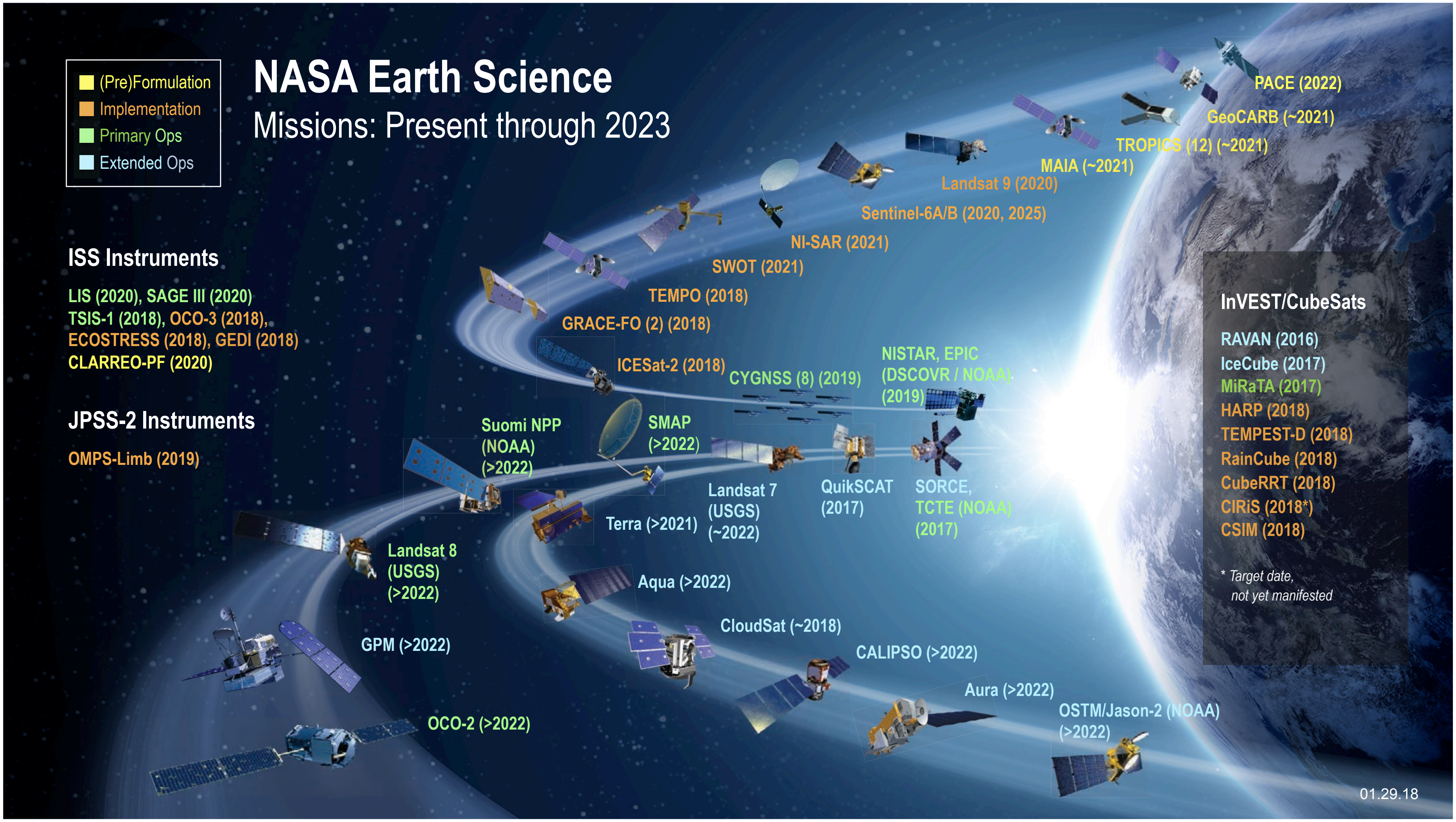
SMAP Applications Early Adopter Program

52 EA teams proceeding with SMAP applications spanning Agriculture, Weather, Floods, Droughts, Wildfires, Emergency Response, Human Health, and National Security

AGU Fall Meeting, San Francisco, CA, December 12-16, 2016

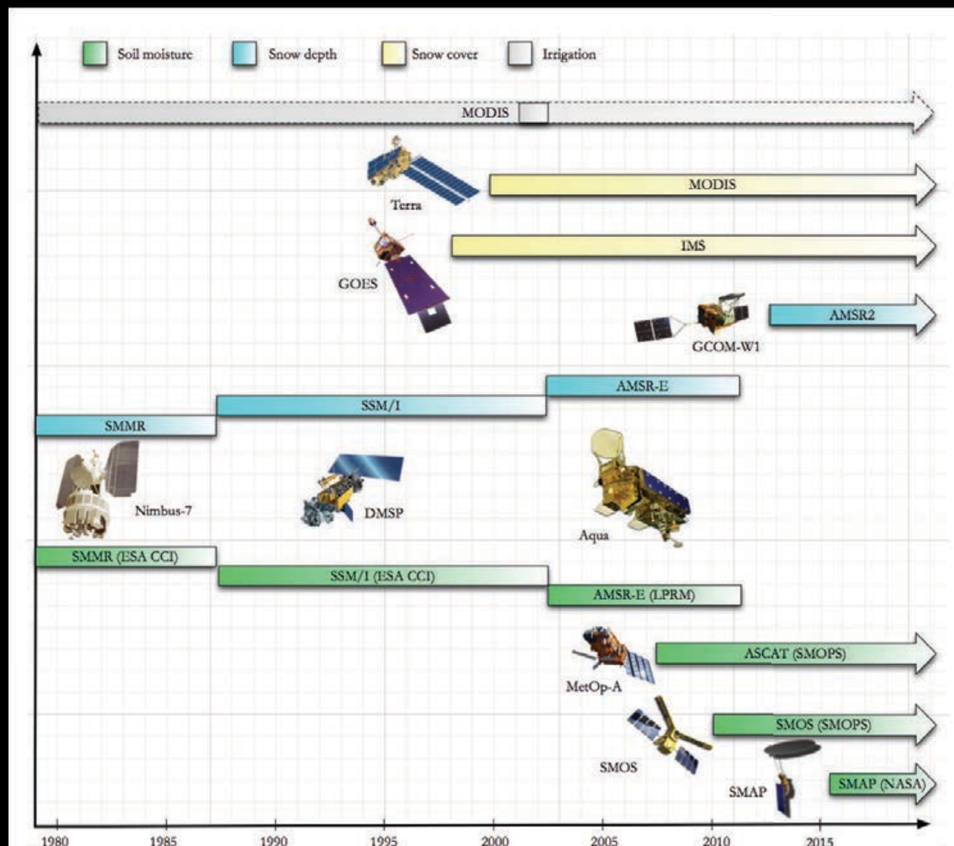

WATER CYCLE
Condensation
Transpiration
from Plants
Evaporation
from Oceans,
Lakes & Streams
Precipitation
Groundwater
Surface Runoff





(Pre)Formulation
Implementation
Primary Ops
Extended Ops
NASA Earth Science
Missions: Present through 2023
ISS Instruments
LIS (2020), SAGE III (2020)
TSIS-1 (2018), OCO-3 (2018),
ECOSTRESS (2018), GEDI (2018)
CLARREO-PF (2020)
JPSS-2 Instruments
OMPS-Limb (2019)
PACE (2022)
GeoCARB (~2021)
TROPICS (12) (~2021)
MAIA (~2021)
Landsat 9 (2020)
Sentinel-6A/B (2020, 2025)
NI-SAR (2021)
SWOT (2021)
TEMPO (2018)
GRACE-FO (2) (2018)
ICESat-2 (2018)
CYGNSS (8) (2019)
NISTAR, EPIC (DSCOVR / NOAA) (2019)
Suomi NPP (NOAA) (>2022)
SMAP (>2022)
Landsat 7 (USGS) (~2022)
QuikSCAT (2017)
SORCE, TCTE (NOAA) (2017)
Terra (>2021)
Landsat 8 (USGS) (>2022)
Aqua (>2022)
CloudSat (~2018)
CALIPSO (>2022)
Aura (>2022)
OSTM/Jason-2 (NOAA) (>2022)
GPM (>2022)
OCO-2 (>2022)
InVEST/CubeSats
RAVAN (2016)
IceCube (2017)
MiRaTA (2017)
HARP (2018)
TEMPEST-D (2018)
RainCube (2018)
CubeRRT (2018)
CIRiS (2018*)
CSIM (2018)
* Target date, not yet manifested
01.29.18

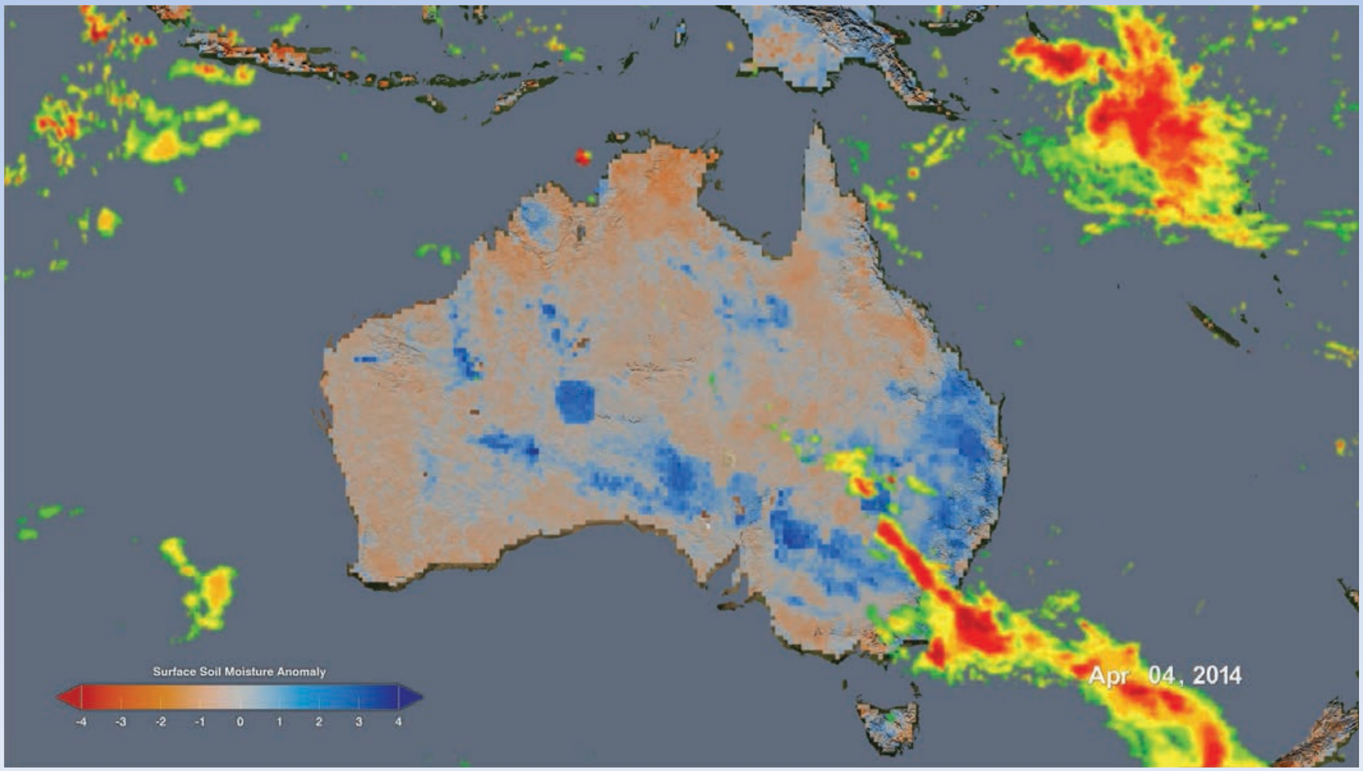
Evolution of Satellite-Based Soil Moisture Remote Sensing

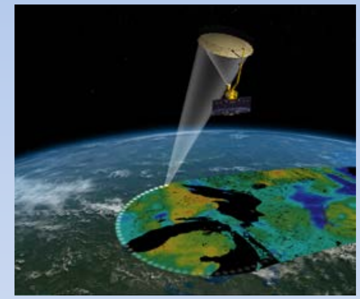


Sujay Kumar (NASA GSFC)

Explain the Basic Underlying Science and Interactions

Soil Moisture Captures Precipitation Memory



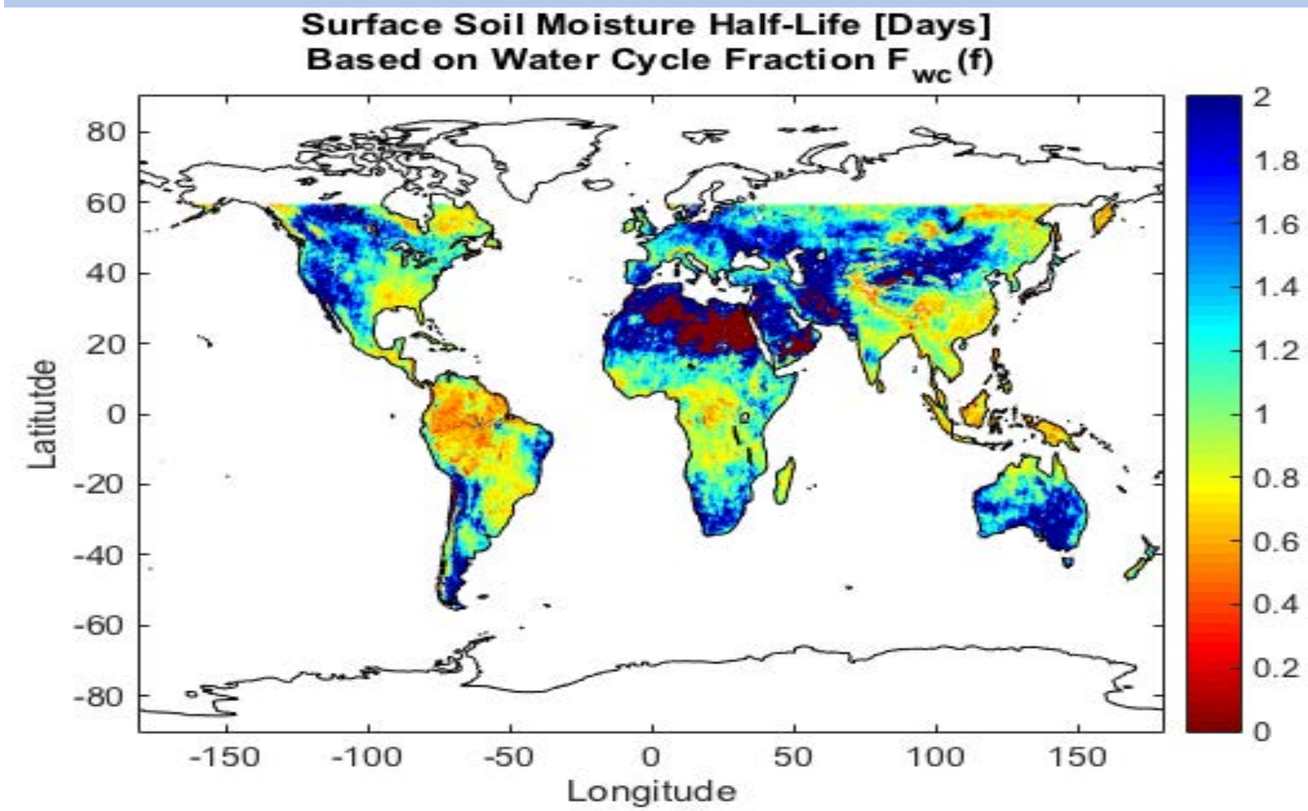


Soil Moisture Active Passive Mission

Global Precipitation Measurement Mission, Core Observatory

John Bolten (NASA GSFC)

Memory and Land-Atmosphere Interactions



Water Cycle Fraction naturally yields a non-parametric estimate of soil moisture memory.

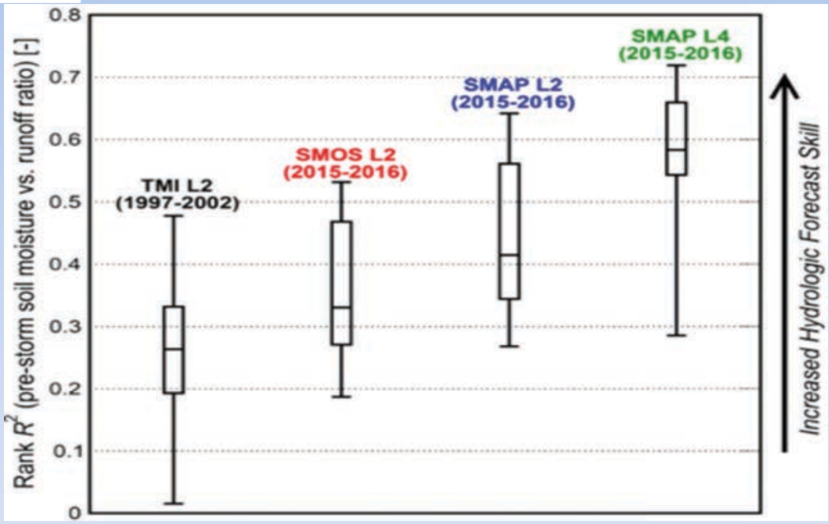
- Not based on fitting of autocovariance
- Not based on fitting of seasonal mean (required for autocovariance)

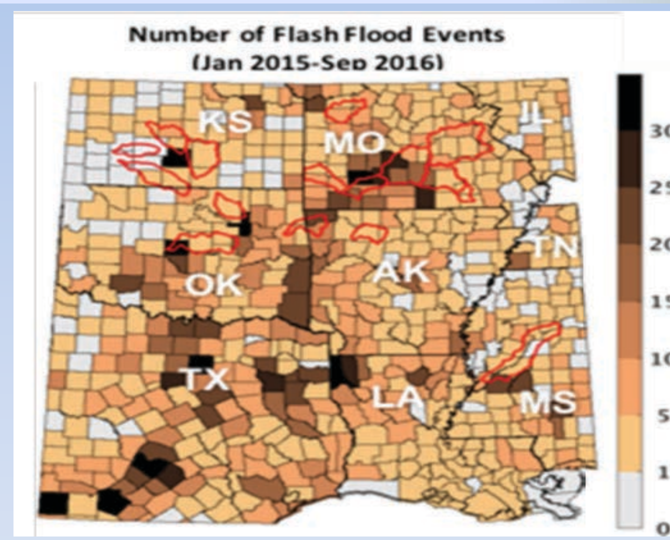
Soil moisture memory is co-factor in establishing land-atmosphere feedbacks

Strong regional differences

D. Entekhabi (MIT)

Land Surface Response to Storm Events





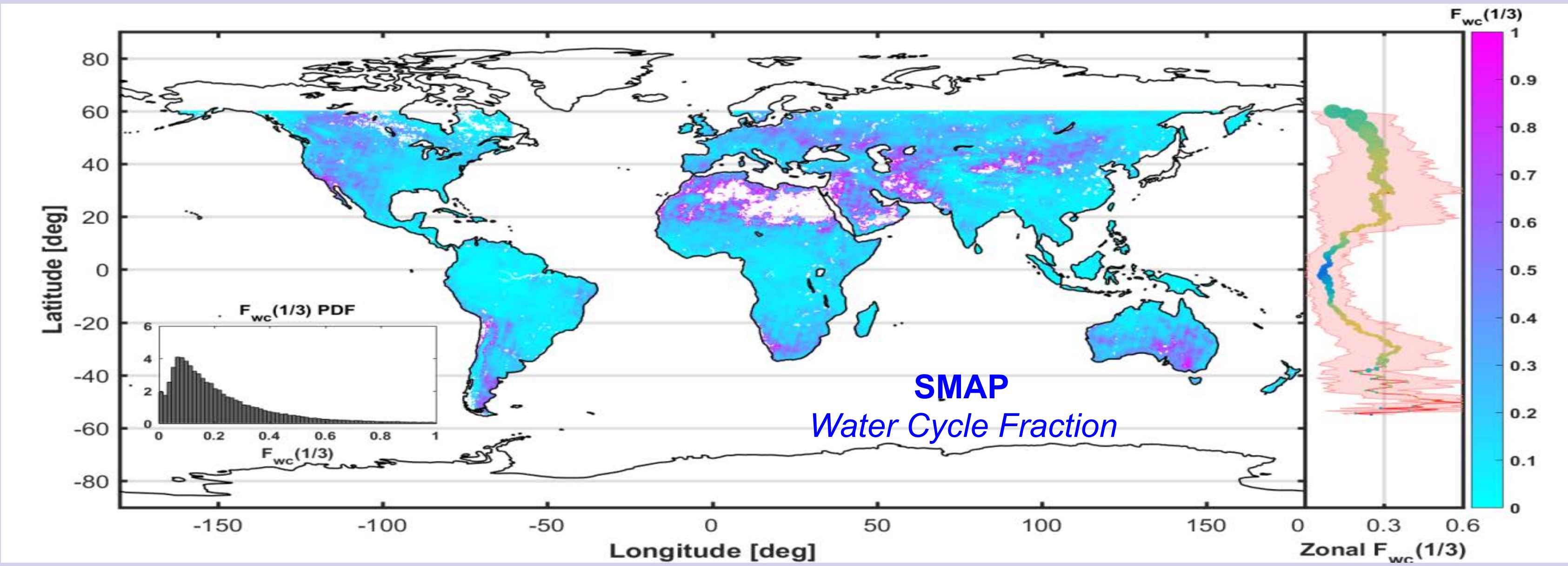
(**Left**) Skill of forecasting the land surface response to rainfall for satellite-based soil moisture products. Skill is measured as the rank coefficient of determination (R^2) between pre-storm soil moisture and subsequent storm-scale runoff ratio (i.e., total runoff divided by total rainfall) sampled across 16 basins. The SMAP Level 2 and Level 4 soil moisture products have the highest skill. Relatively lower values for the Tropical Rainfall Measurement Mission Microwave Imager (TMI) and Soil Moisture Ocean Salinity (SMOS) missions reflect skill obtained from earlier sensors. (**Right**) Boundaries (in red) of the 16 medium-scale (10^3–10^4 km^2) basins and total number of flash-flood events during January 2015–September 2016 in the south-central U.S.

Wade Crow (USDA ARS)

Exchanges Between Land and Atmosphere

Even Though Soil Moisture is 10 ppm of the Global *Water Budget*, it Captures About 20% of the *Water Cycle*

$$Water\ Cycle\ Fraction = \frac{storage_{t+1} - storage_t}{precipitation}$$



Surface Soil Moisture is the '*Gate*' Through Which All Exchanges of Water Between the Atmosphere and Subsurface Must Pass

McColl et al. (*Nature-Geoscience*, 2016)

Entekhabi (MIT)

Four LDAS systems are available from NASA/GSFC/HSL

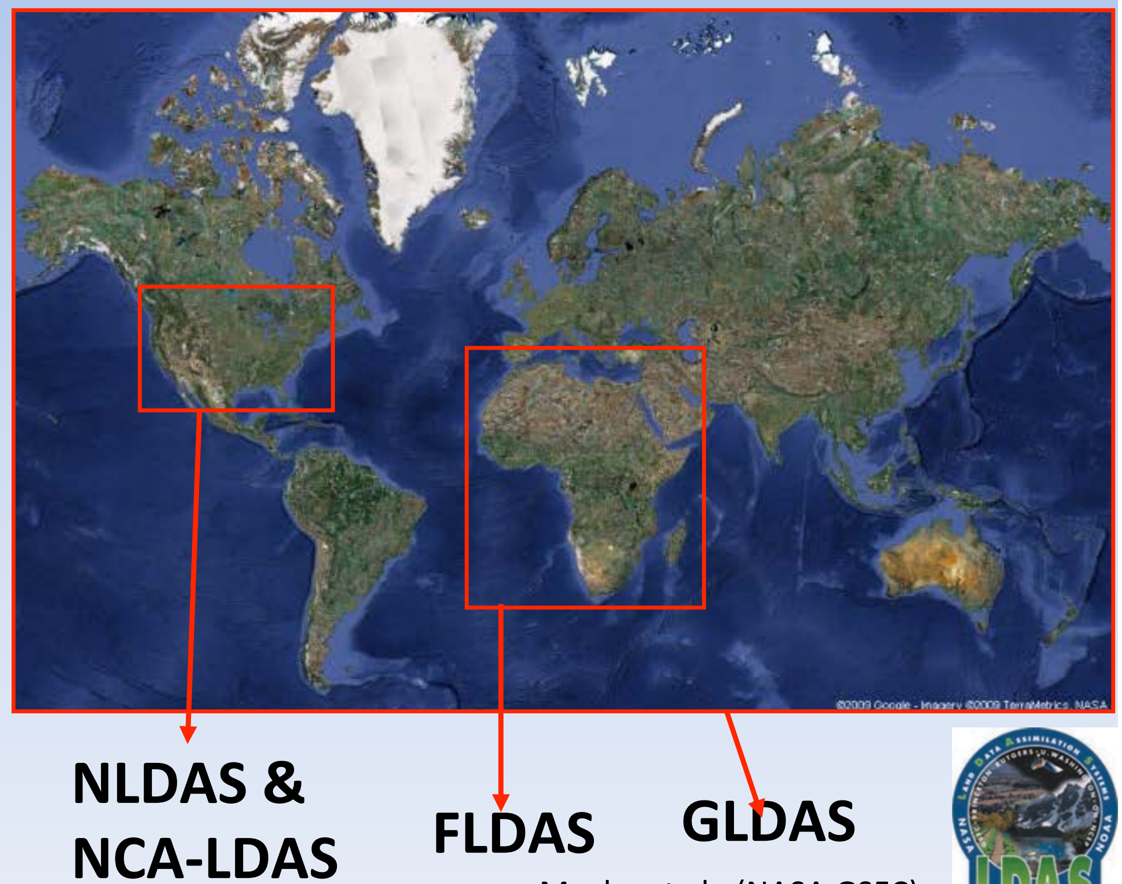
GLDAS – Global LDAS

NLDAS – North American LDAS

NCA-LDAS – National Climate Assessment LDAS

FLDAS – Famine Early Warning System Network (FEWS NET LDAS)

http://ldas.gsfc.nasa.gov/



Mocko et al., (NASA GSFC)

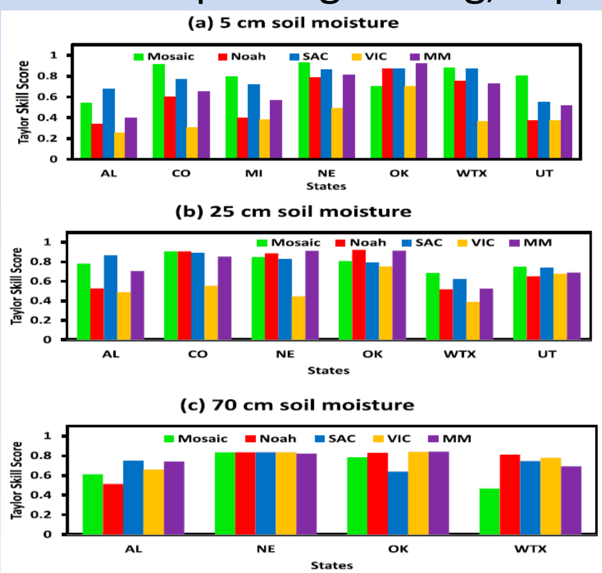
NLDAS soil moisture evaluations

NLDAS Phase 2: Four land-surface models (Noah-2.8, Mosaic, SAC, VIC-4.0.3) 1979-present, running in operations at NOAA, with a 3.5-day latency

NLDAS-2.5: NLDAS-2 LSMs with 0-day latency, becoming operational at NOAA late 2018

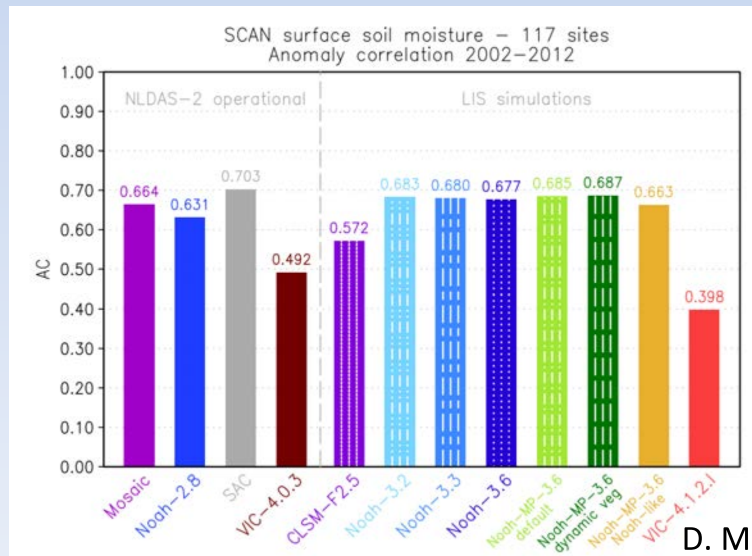
NLDAS-3.0: New/upgraded LSMs using LIS with data assimilation. See white paper on LDAS websites for details. Test data available informally; targeting 2019 for operations.

Future: Improving forcing, expanding domain, targeting 3-4km spatial resolution



(LEFT) NLDAS-2 soil moisture against North American Soil Moisture Database (NASMD)

Figure from: Xia et al., JHM, 2015

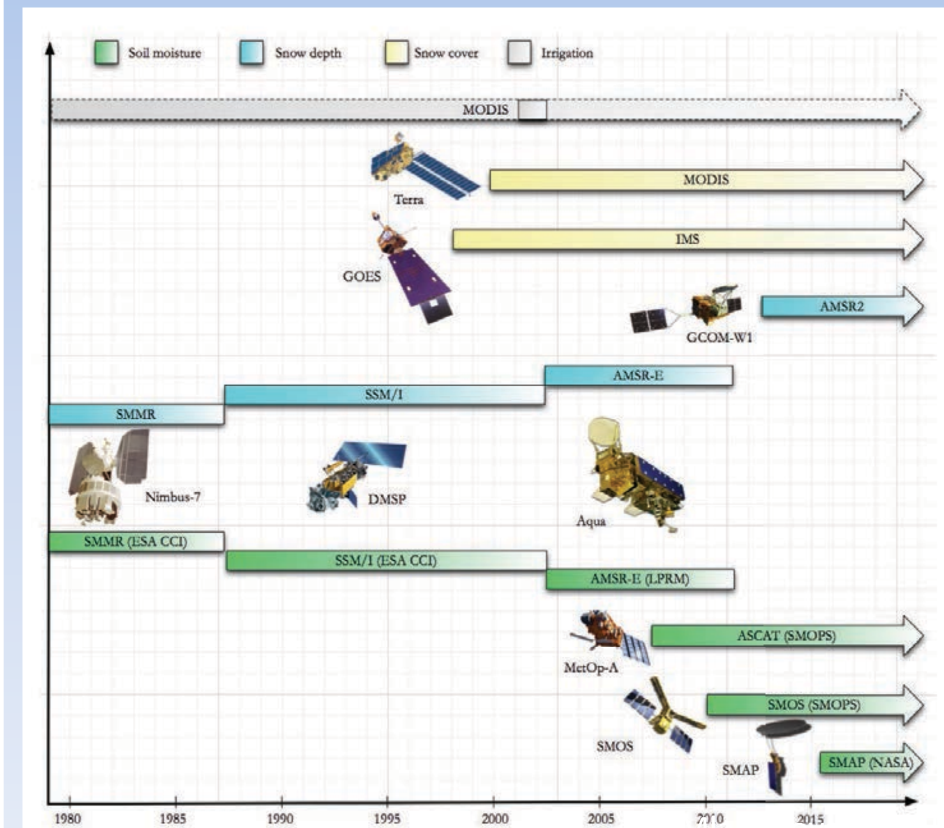


(LEFT) NLDAS-2 and NLDAS-3 candidate LSMs against SCAN for 5-cm surface soil moisture

Figure from: Mocko et al., NLDAS Science Testbed

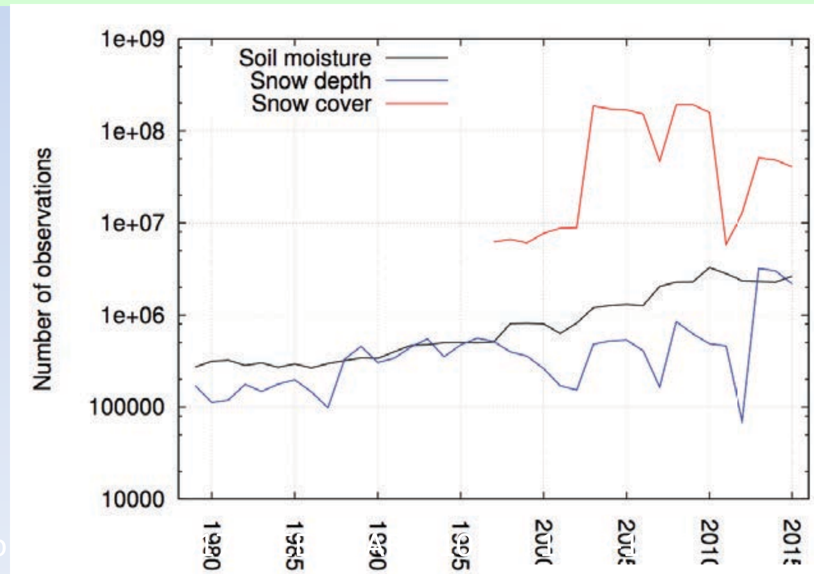
D. Mocko (NASA GSFC)

NCA-LDAS: Multivariate, Multisensor DA



Kumar et al., 2018 (JHM, early online release)

<u>Model domain</u>: Same as NLDAS (1/8th-degree over CONUS)
<u>Forcing data</u>: NLDAS Phase 2 (w/ daily CPC gauge-based precipitation)
<u>Model</u>: Noah-3.3 LSM with a 60-year spin-up, followed by a 37-year simulation; streamflow simulations using HyMAP
<u>Data assimilation method</u>: 1-d Ensemble Kalman Filter (EnKF)
<u>Time period</u>: Jan 1, 1979 to Dec 31, 2016



D. Mocko (NASA GSFC)

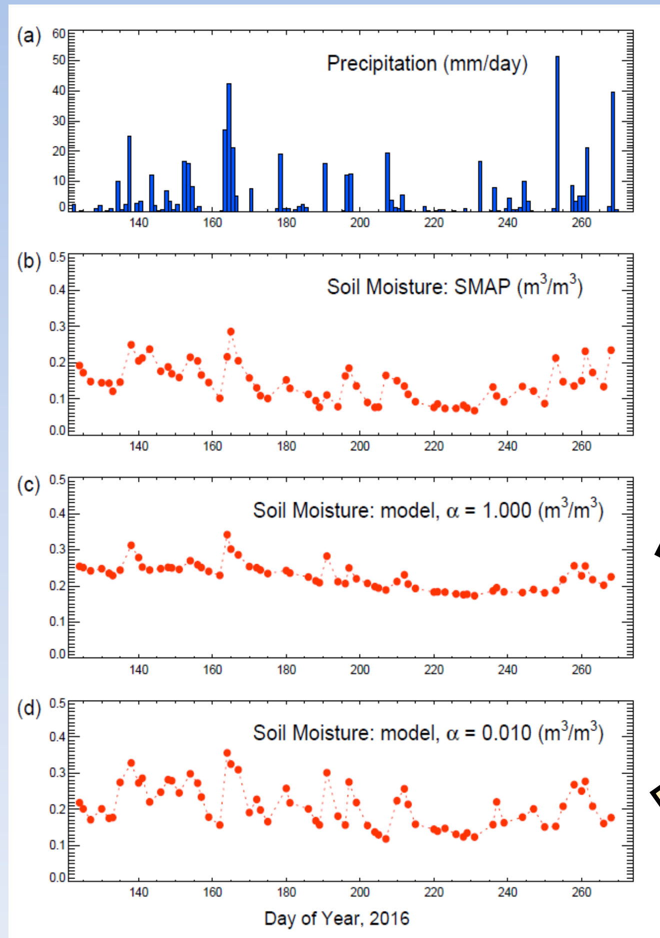
Discuss outstanding issues and challenges

Data Assimilation vs. Model Calibration

With model calibration:

1) the land model itself is changed – values of model parameter(s) are optimized.

2) SMAP data contribute to the parameter calibration but not to the updating of the prognostic states during a simulation.



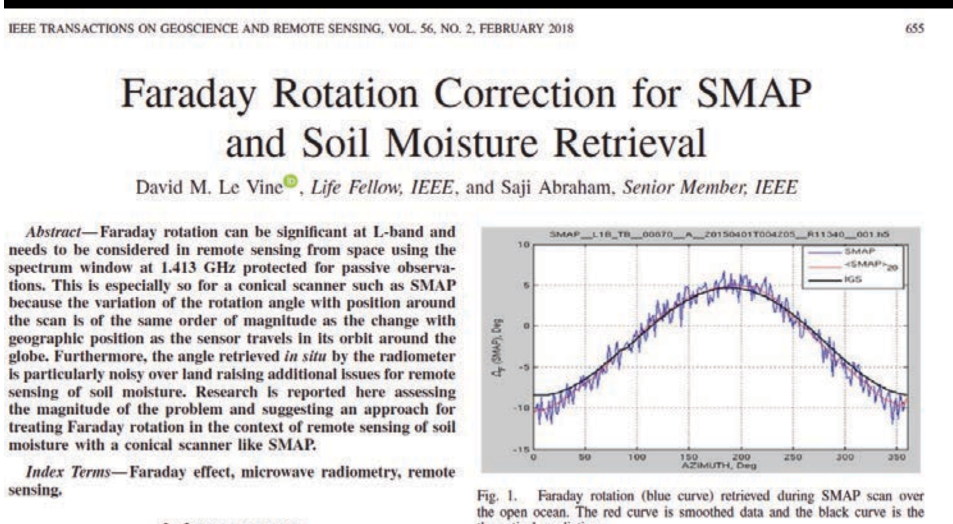
The present study focuses on the calibration of a certain recharge parameter.

The value used in the default model gives soil moisture recessions that are too slow.

Calibrating the parameter allows more realistic recessions.

Koster (NASA GSFC)

How Can SMAP Faraday Rotation be Further Corrected?


IEEE TRANSACTIONS ON GEOSCIENCE AND REMOTE SENSING, VOL. 56, NO. 2, FEBRUARY 2018

Faraday Rotation Correction for SMAP and Soil Moisture Retrieval

David M. Le Vine, *Life Fellow, IEEE*, and Saji Abraham, *Senior Member, IEEE*

***Abstract*—Faraday rotation can be significant at L-band and needs to be considered in remote sensing from space using the spectrum window at 1.413 GHz protected for passive observations. This is especially so for a conical scanner such as SMAP because the variation of the rotation angle with position around the scan is of the same order of magnitude as the change with geographic position as the sensor travels in its orbit around the globe. Furthermore, the angle retrieved *in situ* by the radiometer is particularly noisy over land raising additional issues for remote sensing of soil moisture. Research is reported here assessing the magnitude of the problem and suggesting an approach for treating Faraday rotation in the context of remote sensing of soil moisture with a conical scanner like SMAP.**

***Index Terms*—Faraday effect, microwave radiometry, remote sensing.**

Fig. 1. Faraday rotation (blue curve) retrieved during SMAP scan over the open ocean. The red curve is smoothed data and the black curve is the theoretical prediction.

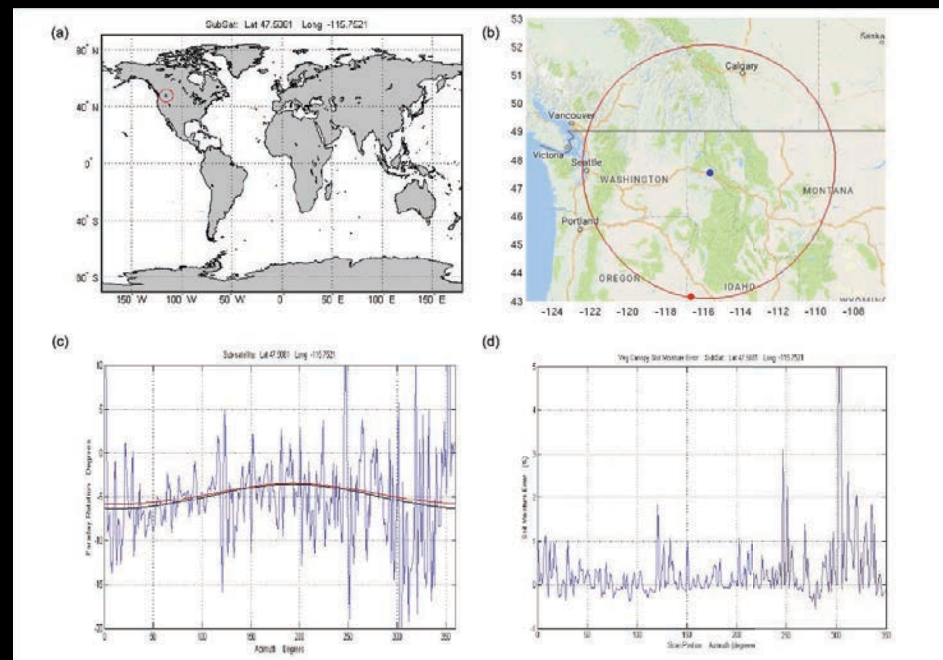
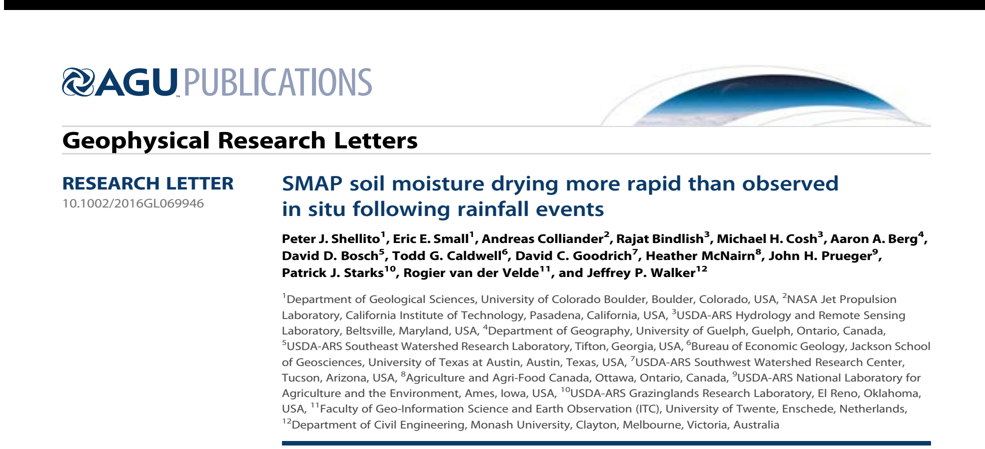


Fig. 11. Reynolds Creek. (a) Location of the scan. (b) Antenna boresight during scan (red dot indicates validation site). (c) Faraday rotation: SMAP (blue curve), IGS (red curve), and best fit (dark blue curve). (d) Soil moisture difference.

Saji Abraham and David LaVine (NASA GSFC)

SMAP vs Modeled Soil Moisture Dynamics



AGU PUBLICATIONS

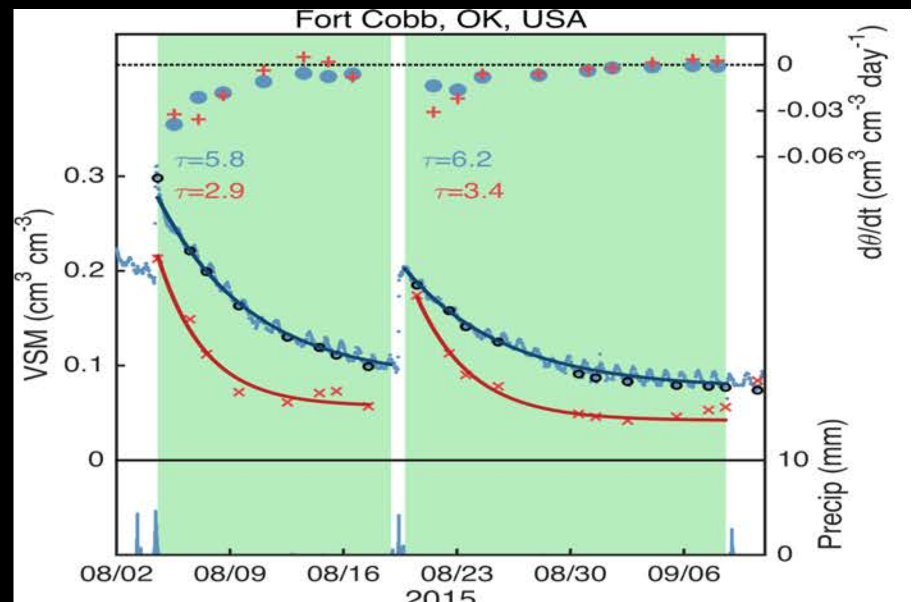
Geophysical Research Letters

RESEARCH LETTER
10.1002/2016GL069946

SMAP soil moisture drying more rapid than observed in situ following rainfall events

Peter J. Shellito[1], Eric E. Small[1], Andreas Colliander[2], Rajat Bindlish[3], Michael H. Cosh[3], Aaron A. Berg[4], David D. Bosch[5], Todd G. Caldwell[6], David C. Goodrich[7], Heather McNairn[8], John H. Prueger[9], Patrick J. Starks[10], Rogier van der Velde[11], and Jeffrey P. Walker[12]

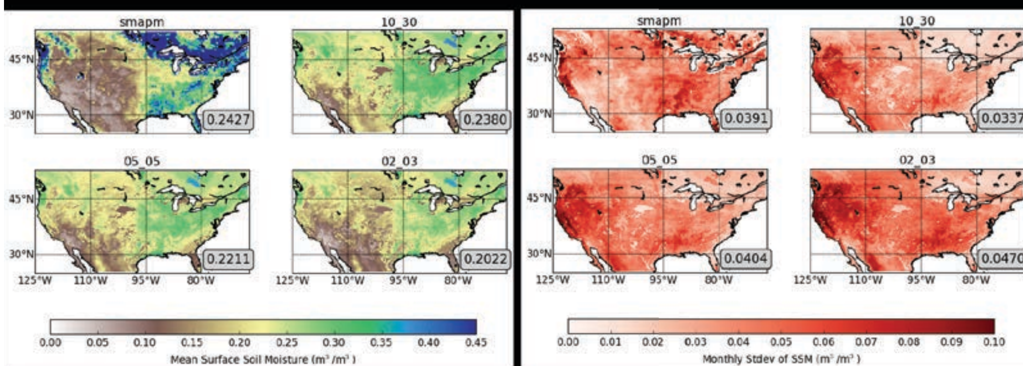
[1]Department of Geological Sciences, University of Colorado Boulder, Boulder, Colorado, USA, [2]NASA Jet Propulsion Laboratory, California Institute of Technology, Pasadena, California, USA, [3]USDA-ARS Hydrology and Remote Sensing Laboratory, Beltsville, Maryland, USA, [4]Department of Geography, University of Guelph, Guelph, Ontario, Canada, [5]USDA-ARS Southeast Watershed Research Laboratory, Tifton, Georgia, USA, [6]Bureau of Economic Geology, Jackson School of Geosciences, University of Texas at Austin, Austin, Texas, USA, [7]USDA-ARS Southwest Watershed Research Center, Tucson, Arizona, USA, [8]Agriculture and Agri-Food Canada, Ottawa, Ontario, Canada, [9]USDA-ARS National Laboratory for Agriculture and the Environment, Ames, Iowa, USA, [10]USDA-ARS Grazinglands Research Laboratory, El Reno, Oklahoma, USA, [11]Faculty of Geo-Information Science and Earth Observation (ITC), University of Twente, Enschede, Netherlands, [12]Department of Civil Engineering, Monash University, Clayton, Melbourne, Victoria, Australia



Peter Shellito (NASA GSFC)

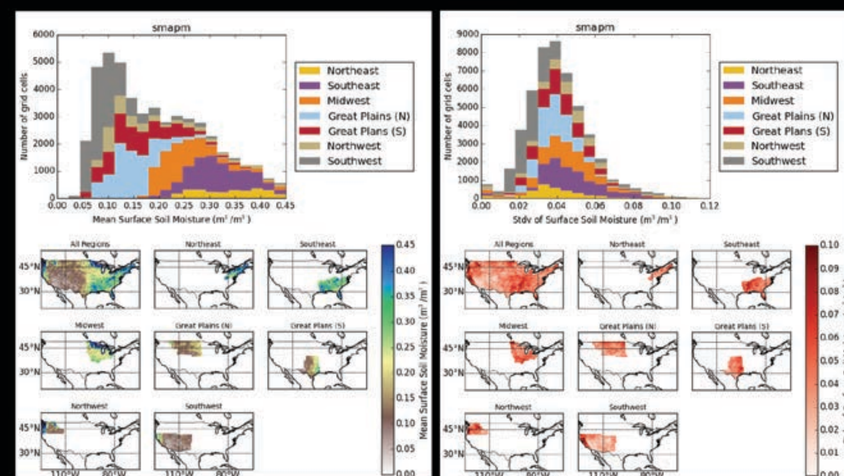
SMAP vs Modeled Soil Moisture Dynamics

Mean | **Standard Deviation**



Very slightly drier than 1 deg | **No change or slightly higher std**

1/8 degree

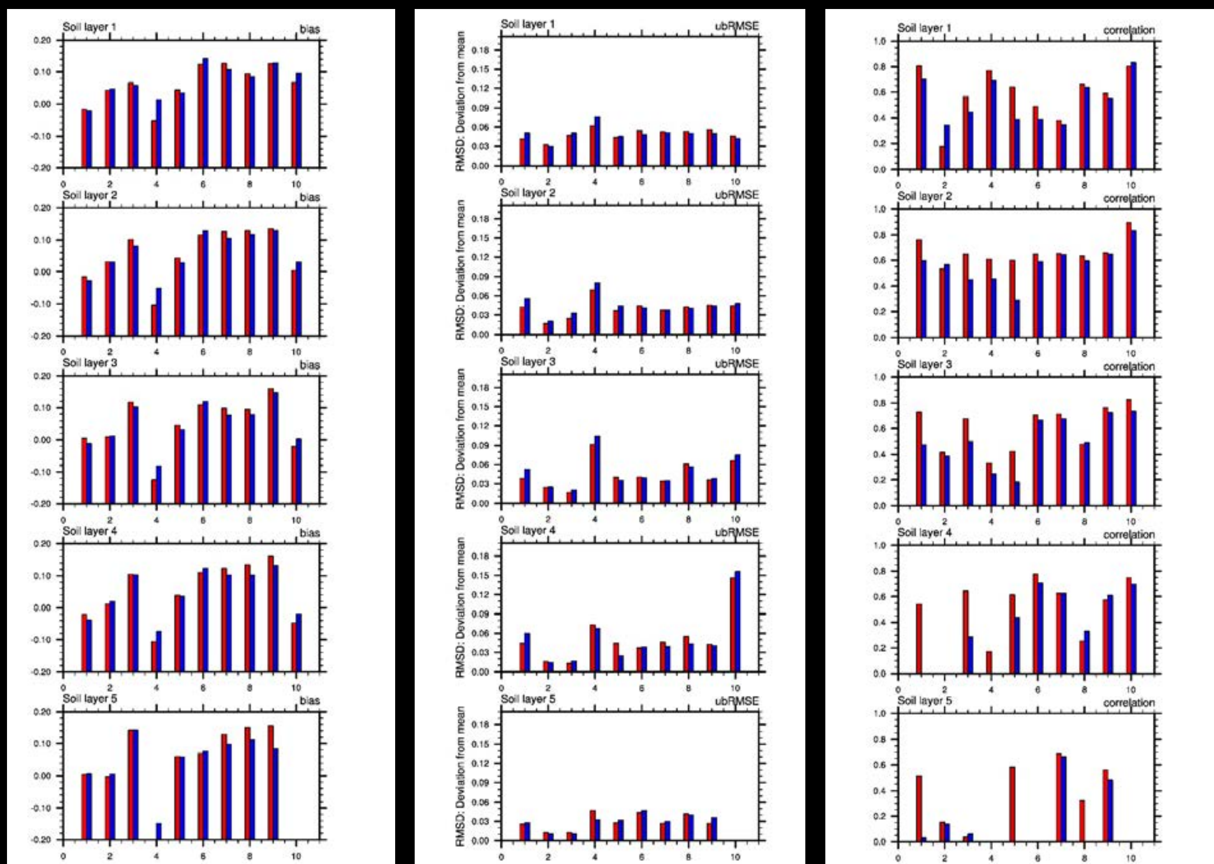


Peter Shellito (NASA GSFC)

Bias, RMSE and Correlation of Noah_MP at 10 California SCAN sites

NLDAS Noah_MP (4 layers, WRF default)

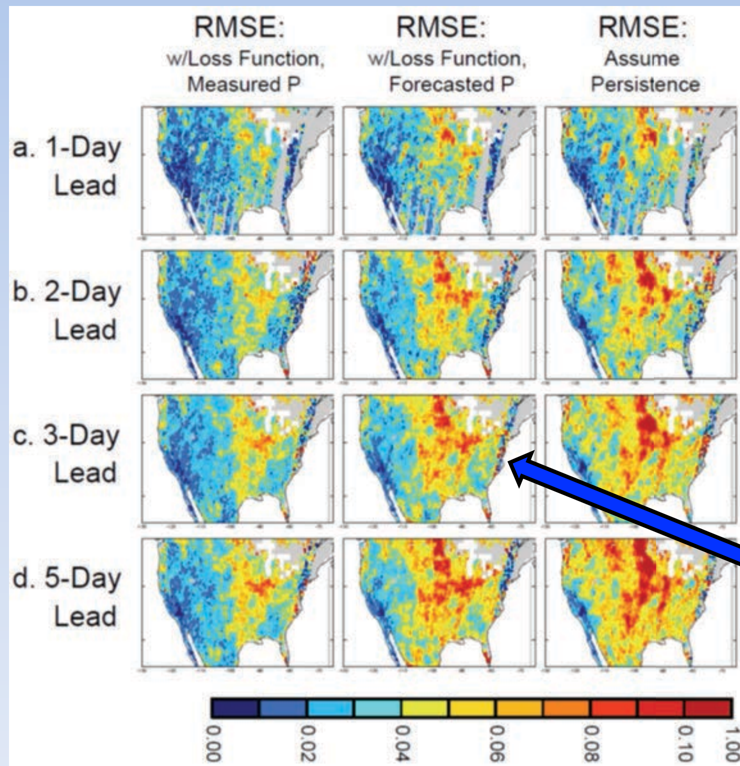
WLDAS Noah_MP (20 layers, WRF default)



- WLDAS: soil moisture and groundwater estimates at 1km resolution for the western US (PI: Matt Rodell)
- Configuration with 20 layers provides better correlation.

Bailing Li (GSFC)

Loss Functions for Improved Observations



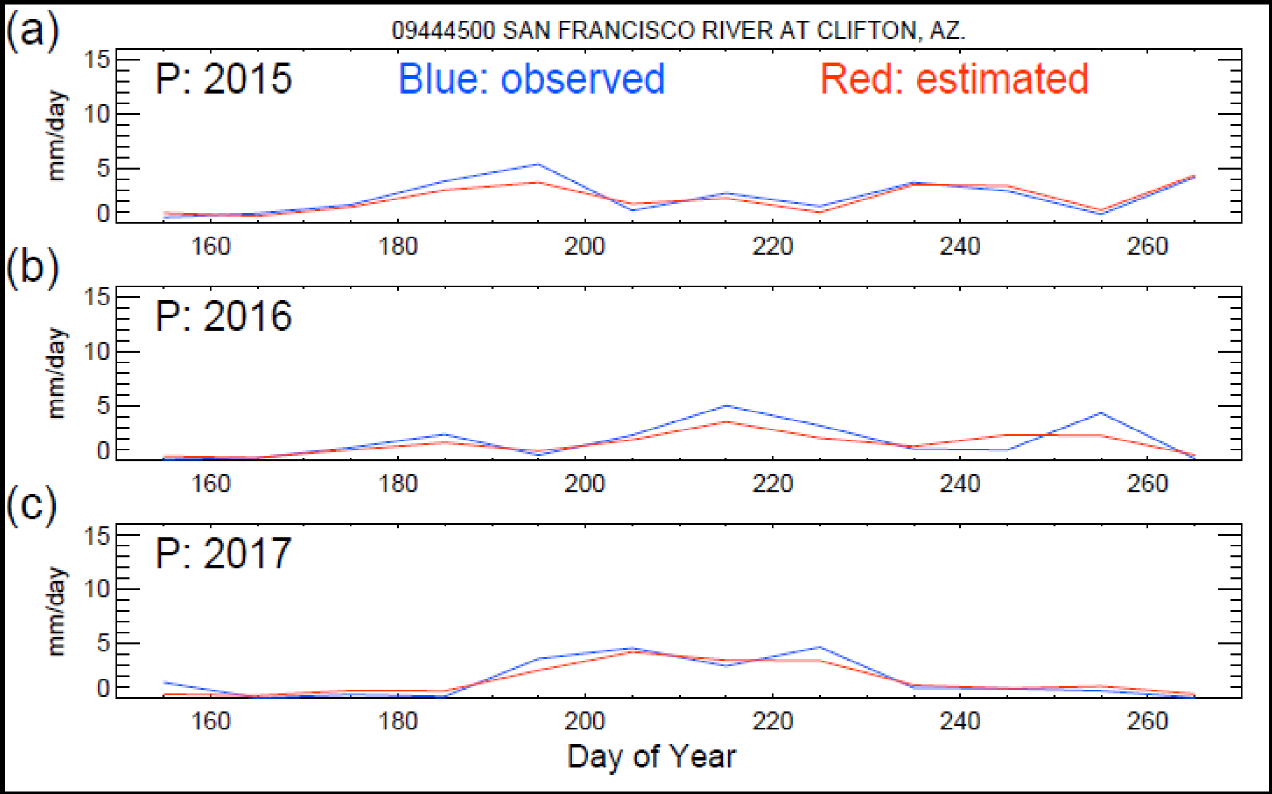
They also go down, though not as much, if you use loss functions in conjunction with precipitation forecasts (for soil moisture forecasts)….

Koster (NASA GSFC)

SMAP Retrievals Used for Precipitation Estimation

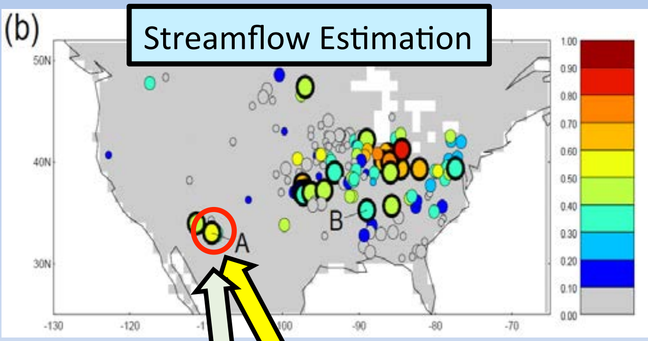
Some results! (One of the better estimations):

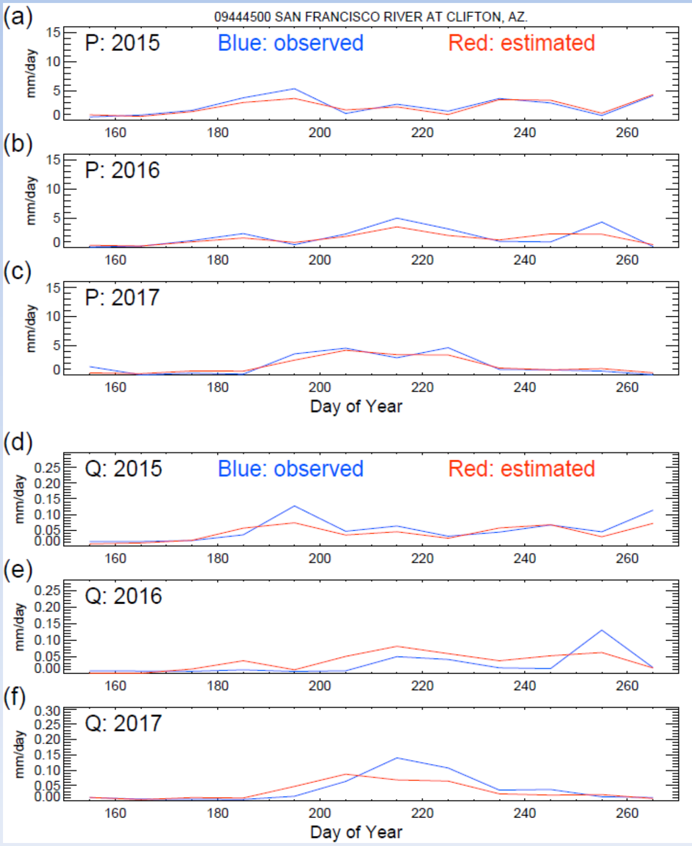
We can characterize the agreement in these time series with the square of the correlation coefficient, r^2.



Randy Koster (NASA GSFC)

Streamflow Estimation





Precipitation estimates (from before)

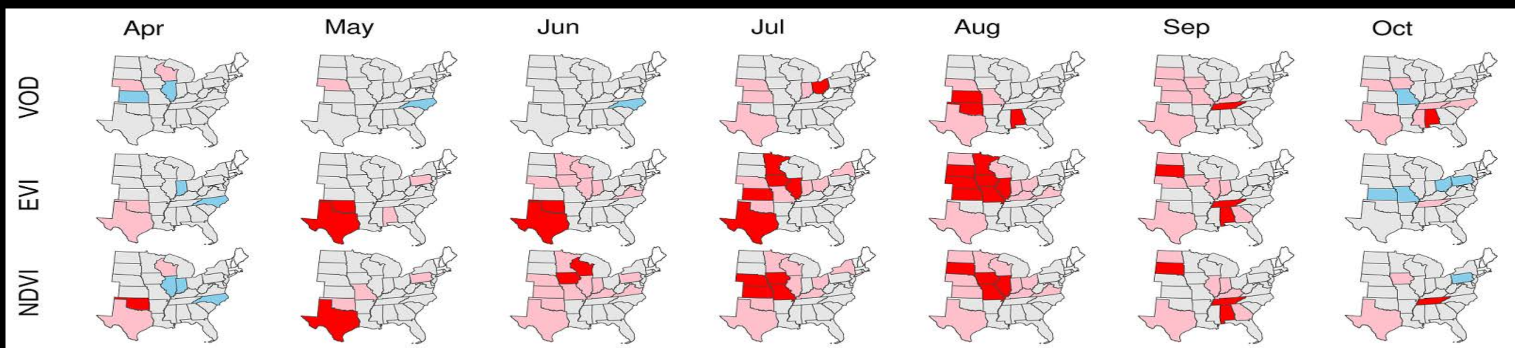
Streamflow estimates capture some of the observed behavior.

Randy Koster (NASA GSFC)

Technologies and Strategies for Environmental Monitoring, Assessment, and Prediction

Can we Improve our Estimation of End Of Season Yield Using Satellite Observations?

Vegetation indices

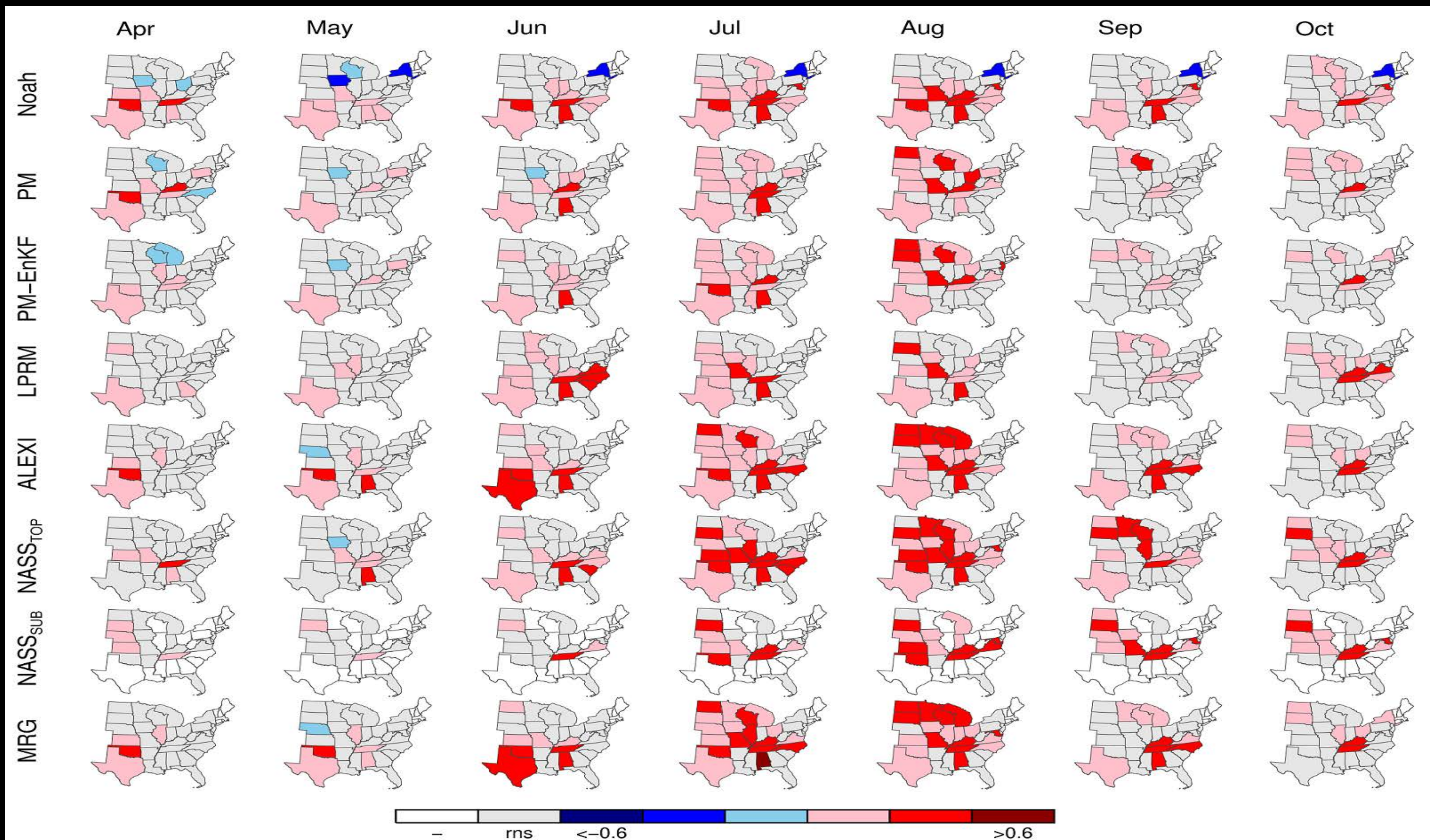


Warm colors indicate high correlation with end of season yield

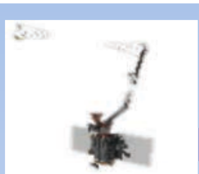
Mladenova, I. E., J. D. Bolten, et al. 2017. IEEE JSTARS, 10 (4): 1328-1343

Can we Improve our Estimation of End Of Season Yield Using Satellite Observations?

Soil moisture and ET

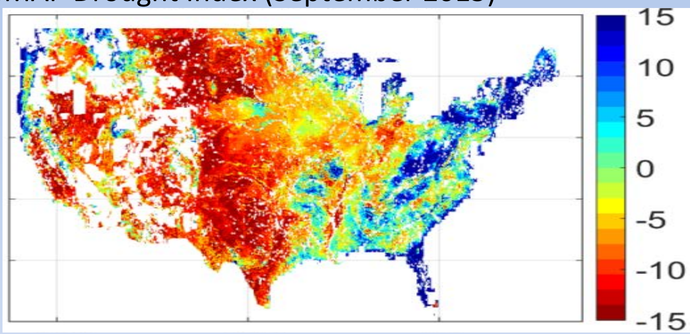


Mladenova, I. E., J. D. Bolten, et al. 2017. IEEE JSTARS, 10 (4): 1328-1343

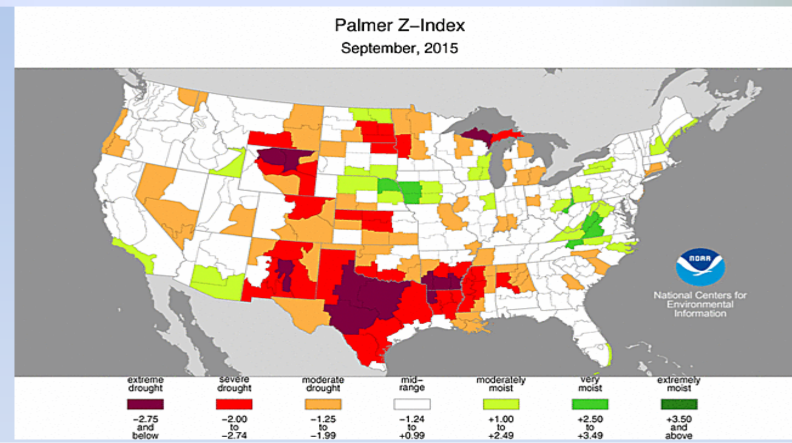


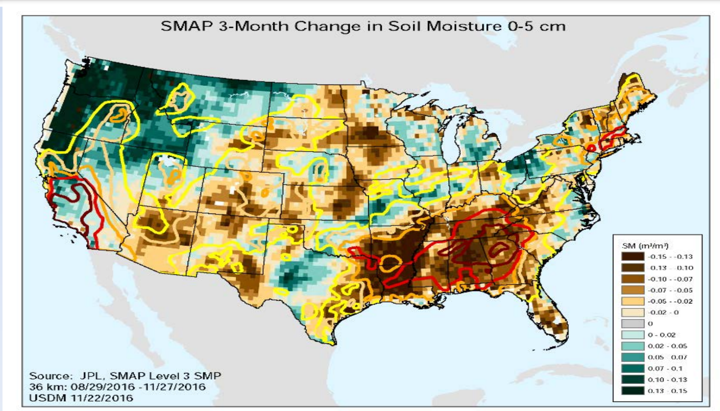
Mapping Drought

SMAP Drought Index (September 2015)



Source: Vue , Mista and Entekhabi





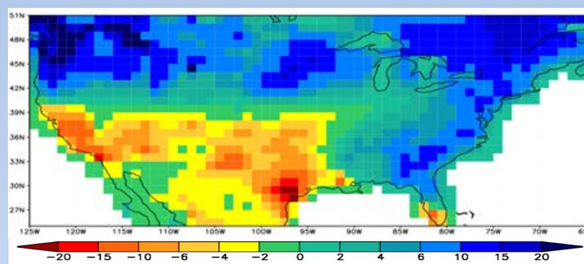
SMAP Soil Moisture Change
(August-November 2016)

Available to Weekly Drought Monitor authors

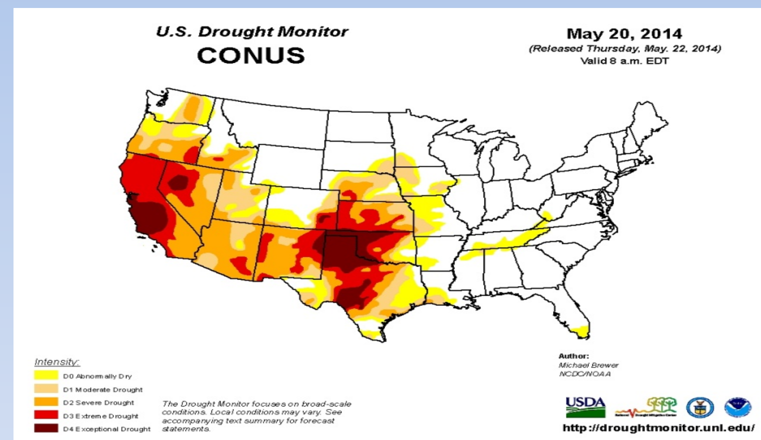
N. Das (NASA JPL)

GRACE Data Assimilation for Drought Monitoring

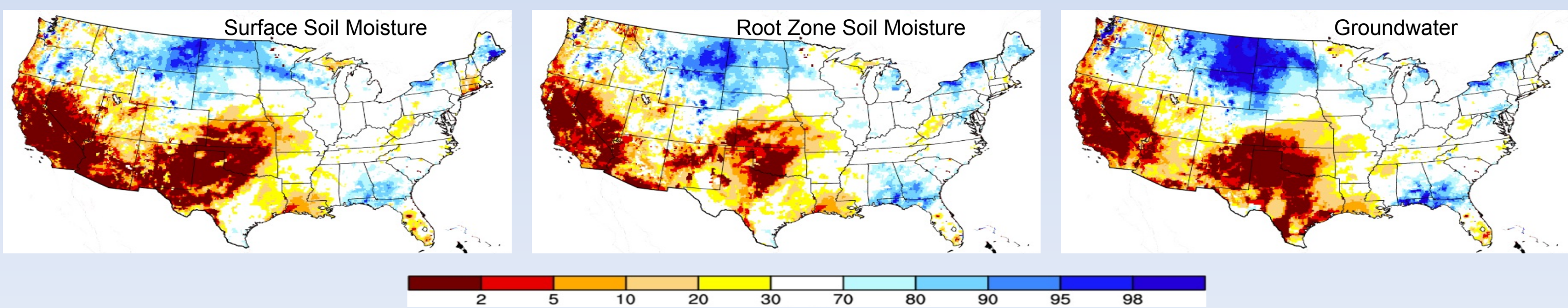
GRACE terrestrial water storage anomalies (cm equivalent height of water) for May 2014 (Tellus CSR RL05 scaled).



Process integrates data from GRACE and other satellites to produce timely information on wetness conditions at all levels in the soil column, including groundwater. For current maps and more info, see http://nasagrace.unl.edu/



U.S. Drought Monitor product for 20 May 2014.



Drought indicators from GRACE data assimilation (wetness percentiles relative to the period 1948-present) for 19 May 2014.

Rodell (NASA GSFC)

Satellite Enhanced Snowmelt Flood Predictions in the Red River of the North Basin (RRB)

University of New Hampshire, ***Jennifer M. Jacobs***

Objective

Enhance the NOAA's National Weather Service's (NWS) North Central River Forecast Center's (NCRFC) snowmelt flood predictions capacity in the Red River of the North Basin (RRB). The RRB borders eastern North Dakota and western Minnesota.

- **Model**: The Community Hydrologic Prediction System (CHPS) with the Sacramento Soil Moisture Accounting (SAC-SMA) model and SNOW-17 snow model
- Initial State Variables: Soil moisture (SM), Freeze-Thaw FT), Snowpack, snow covered area (SCA)
- **Challenges**

- Ground observations of soil moisture and snow water equivalent (SWE) are relatively scarce in the RRB, which makes accurate forecasting difficult.
- Lack of antecedent SM conditions prior to winter onset causes errors in airborne gamma SWE estimates
- Lack of understanding of snowmelt processes and soil infiltration during soil freeze and thaw

Status

1. Comparison of SMAP with CHPS modeled soil moisture

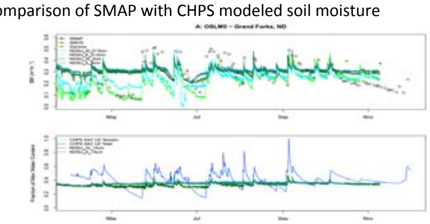


Figure 2. Time series of SMAP SM, CHPS SM fraction, and ground-based SM in the Grand Forks, ND

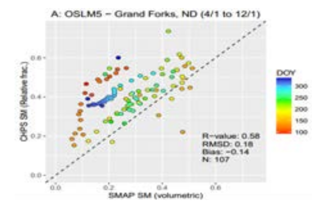


Figure 3. Scatter plot between SMAP and CHPS upper zone SM fraction from 4.1 to 12.1, 2016 in the Grand Forks, ND

2. Daily SM products in the RRB are provided to NOAA forecasters biweekly

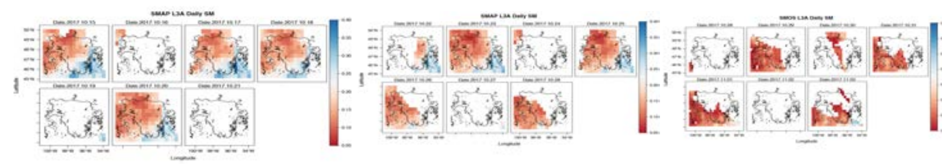


Figure 3. Daily SMAP SM values in the RRB for the three weeks leading to the first freezing conditions capture strong drying conditions. Weeks 1 (10/15 to 10.21), 2 (10.22 to 10.28), and 3 (10.28 to 11.3) from left to right.

Methodology/Approach

1. SMAP SM is being used to support modifications to the SAC-SMA model state in CHPS and evaluated using streamflow outputs with the USGS data.

2. SMAP SM is being compared to airborne gamma observations and used identify wetting and drying after Fall baseline SM flights

3. SMAP FT identification freeze onset date by subbasin

- SMAP FT will be compared to in-situ observations
- SMAP SM values prior to freeze onset date will extracted to adjust state and frozen soil hydraulic parameters

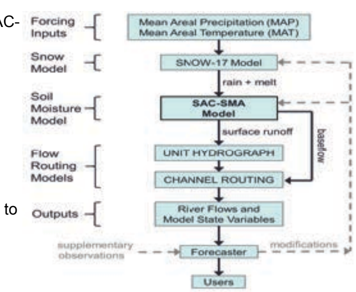


Figure 1. CHPS flood forecasting model and procedures (Modified from diagram by CBRFC)

Schedule and Issues

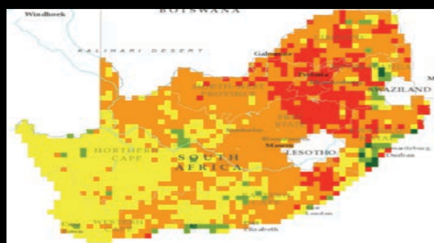
- Evaluation of SMAP SM with CHPS SM (**ongoing)**
- SMAP SM support of gamma baseline SM updates (**ongoing)**
- Assimilation of SM from SMAP into the NCRFC flood forecasting model will be conducted to update SAC-SMA upper zone moisture (Spring - Summer 2018).
- SMAP FT identification freeze onset date by subbasin (In Progress)

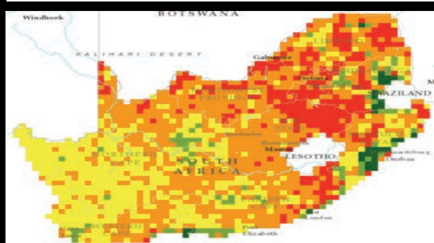
Team Membership

SMAP Soil Moisture Products Released in Google Earth Engine and the USDA Global Crop Assessment Decision Support System

Iliana E. Mladenova , Nazmus Sazib, and John D. Bolten, Hydrological Sciences Lab , NASA GSFC

Assessing Drought condition across South Africa

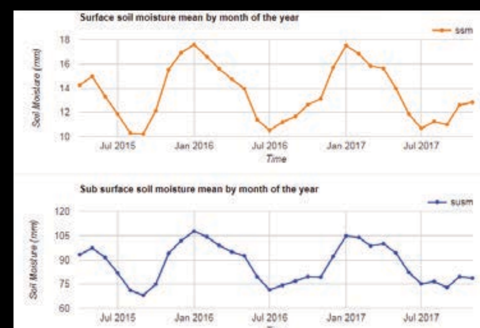


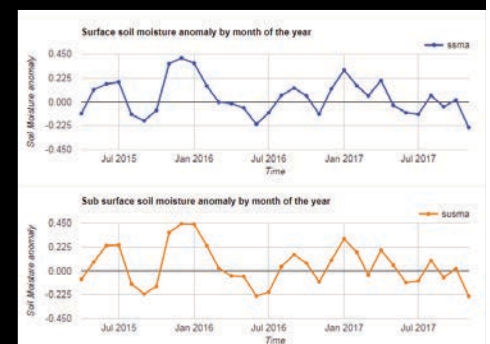


2018/01/13-2018/01/15

Soil moisture anomaly

Soil moisture products sample over the U.S. using GEE tools





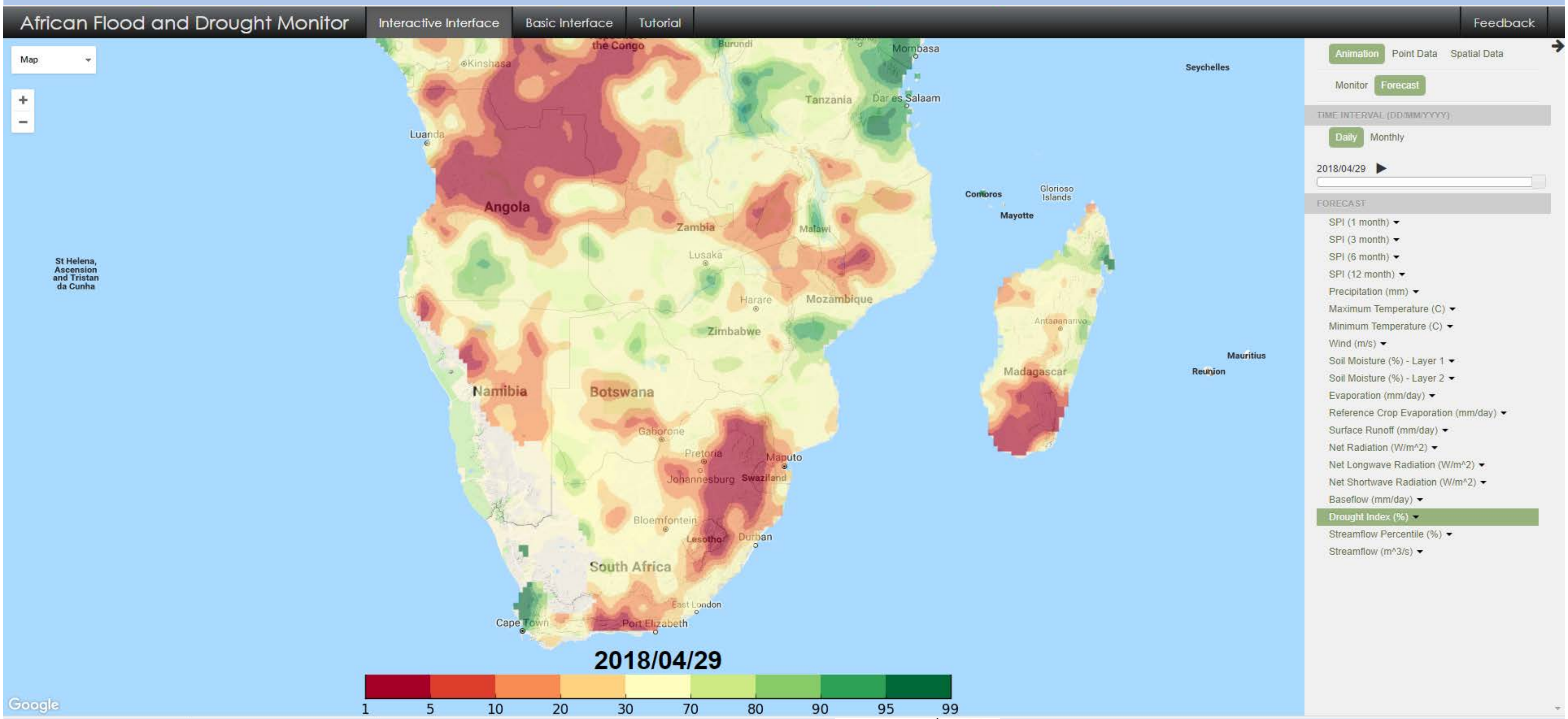
Objective:

To provide soil moisture products to the U.S. Department of Agriculture (USDA), Foreign Agricultural Services (FAS) for advancing the agricultural productivity forecasting ability of the Crop Condition Data Retrieval and Evaluation Data Base Management System.

Highlights:

- SMAP-based product has been approved by USDA FAS and is being operationally delivered to USDA FAS (Feb, 2018)
- The SMOS- and SMAP-based products and customized analytical tools have been vetted by Google and are on the public-facing Google Earth Engine. This is the first model-enhanced global soil moisture dataset available on Google Earth Engine (March, 2018).

African Drought Monitor: Soil moisture Drought Index



http://stream.princeton.edu

Princeton Climate Analytics

PRINCETON UNIVERSITY

United Nations Educational, Scientific and Cultural Organization

International Hydrological Programme

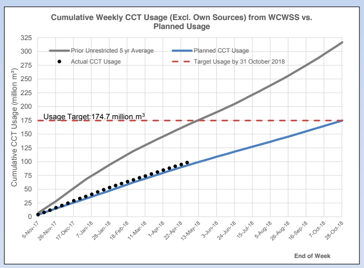
Cape Town: From Data to Decision Making…

City of Cape Town: Water Dashboard

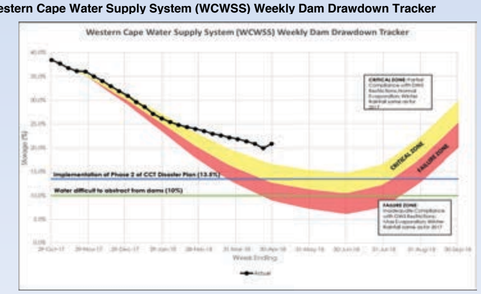
30 April 2018

DAM STORAGE (%)	WEEKLY DAM LEVEL CHANGE (%)	AVG DAILY PRODUCTION ALL WATER SOURCES (Ml/d)	AVG DAILY PRODUCTION WCWSS LARGE DAMS ONLY (Ml/d)
20.9	0.9 ⬆ increase since last week	505 (Target 450Ml/d)	479

Water Usage From Large Dams Comprising The Western Cape Water Supply System (WCWSS)



Western Cape Water Supply System (WCWSS) Weekly Dam Drawdown Tracker



Disclaimer: The data depicted above is indicative and has been based on the City's own assessment of water use from the WCWSS. It is subject to official verification by the National Department of Water and Sanitation.

Water Stored in Major Dams Comprising Western Cape Water Supply System (WCWSS)

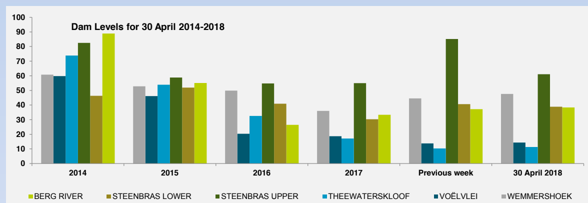
MAJOR DAMS	STORAGE						
	CAPACITY Ml	% 30 April 2018	% Previous week	% 2017	% 2016	% 2015	% 2014
BERG RIVER	130 010	38.3	37.1	33.3	26.5	55.1	88.9
STEENBRAS LOWER	33 517	38.8	40.6	30.3	40.9	51.9	46.3
STEENBRAS UPPER	31 767	61.1	85.1	54.9	54.8	58.8	82.5
THEEWATERSKLOOF	480 188	11.3	10.3	17.1	32.5	53.8	73.8
VOËLVLEI	164 095	14.4	13.8	18.7	20.4	46.2	59.7
WEMMERSHOEK	58 644	47.6	44.5	36.0	49.9	52.8	60.8
TOTAL STORED	898 221	187 939	179 711	204 695	284 391	472 978	645 479
% STORAGE		20.9	20.0	22.8	31.7	52.7	71.9

NOTES:

1) Capacity of the major dams of the Western Cape Water Supply System is 99.6% and that of the minor dams 0.4% of the combined capacity of the major and minor dams. Kindly note that all the Major Dams show gross capacity.

2) All figures are for 30 April for each year except for those in the second column, which gives the figures for the previous week of this year.

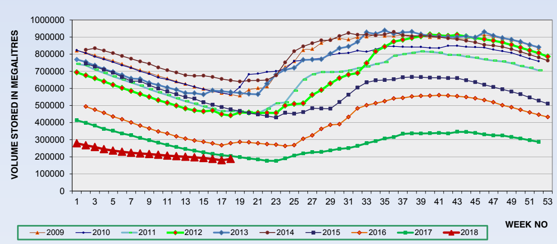
3) The last 10% of a dam's water is difficult to use, the useable water in the dam is approximately 10% less than the dam level.



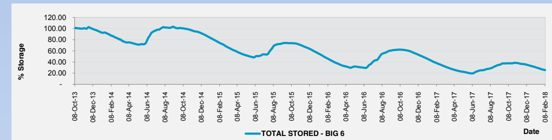
Water Stored in Minor Dams Within Cape Town

MINOR DAMS	STORAGE						
	CAPACITY Ml	% 30 April 2018	% Previous week	% 2017	% 2016	% 2015	% 2014
ALEXANDRA (Table Mountain)	126	68.0	60.8	30.7	33.0	0.0	45.7
DE VILLIERS (Table Mountain)	243	56.0	57.3	44.5	74.4	47.1	97.3
HELY-HUTCHINSON (Table Mountain)	925	77.2	70.1	98.8	72.6	0.0	30.4
KLEINPLAATS (Simon's Town)	1 368	38.8	38.8	41.2	31.2	26.3	54.2
LAND-EN-ZEEZICHT (Helderberg)	451	89.9	88.2	76.0	13.6	0.0	0.0
LEWIS GAY (Simon's Town)	182	68.5	58.4	12.9	1.5	65.5	33.6
VICTORIA (Table Mountain)	128	37.9	39.9	71.1	20.6	0.0	98.1
WOODHEAD (Table Mountain)	954	58.0	57.9	72.4	79.3	48.4	51.2

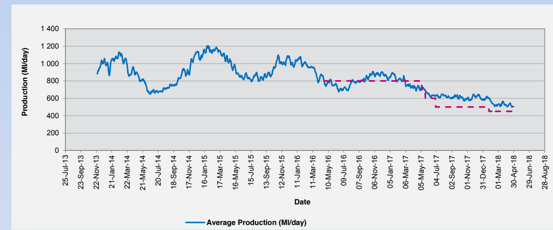
Ten Year Graph Indicating Volume of Water Stored in Major Dams Comprising Western Cape Water Supply System (WCWSS)



Percentage Water Stored in Major Dams (WCWSS)



CCT Daily Average Water Production (7 Day Avg)



CCT Water Quality Sample Pass Rate

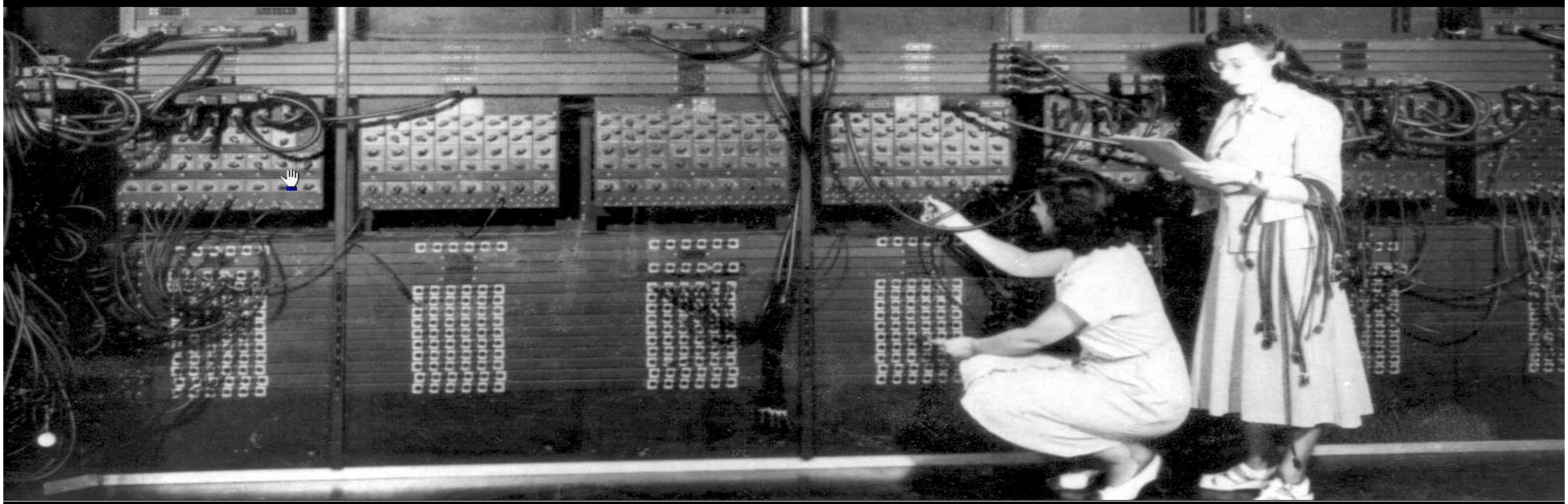
Month	Water Quality Compliance (%)	Target (%)
Jan-17	99.63	98
Feb-17	99.64	98
Mar-17	99.67	98
Apr-17	99.67	98
May-17	99.71	98
Jun-17	99.65	98
Jul-17	99.62	98
Aug-17	99.59	98
Sep-17	99.57	98
Oct-17	99.49	98
Nov-17	99.44	98
Dec-17	99.43	98
Jan-18	99.38	98

Notes:
This table shows CCT drinking water quality compliance according to the South African National Standard 241:2015. Compliance, measured against all prescribed chemical and microbiological components, consistently exceeds the very high CCT target of 98%. (Overall compliance percentages of continuous sampling and analysis are released on a monthly basis. The latest available is for January).

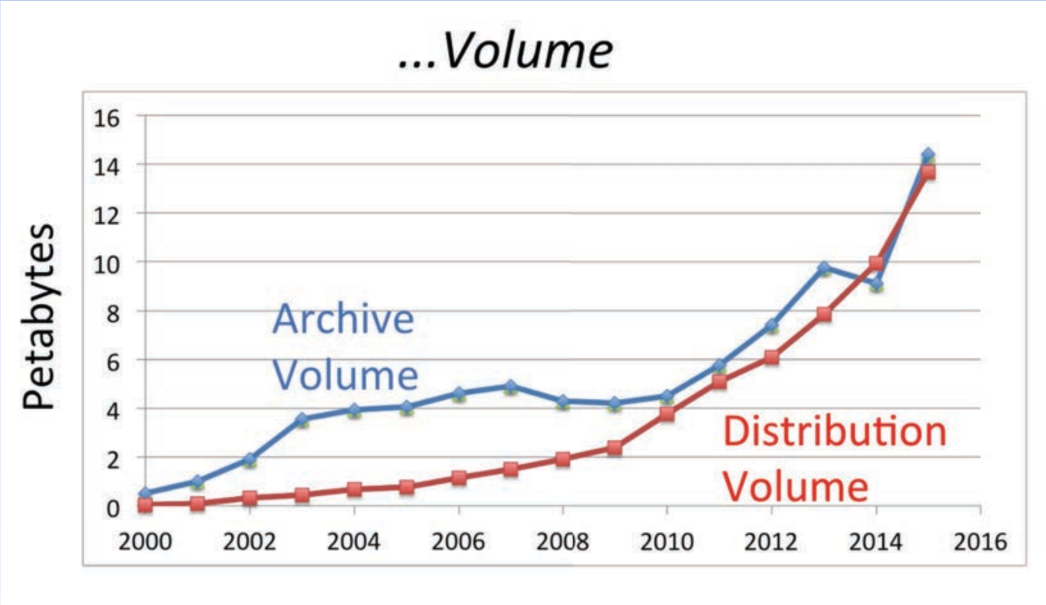
Rainfall

RAINFALL (mm)	23-Apr	24-Apr	25-Apr	26-Apr	27-Apr	28-Apr	29-Apr	Apr Total*	Apr LT Average
Blackheath Upper	8.2	0.0	23.0	1.0	32.0	0.0	0.0	76.3	47.6
Brooklands	20.0	0.0	28.0	0.0	0.0	0.0	0.0	71.0	64.9
Newlands	32.5	0.0	23.5	70.0	5.0	0.0	0.0	167.0	123.6
Steenbras	6.8	0.1	23.8	0.0	5.5	0.0	0.0	53.1	79.4
Table Mountain (Woodhead)	27.0	0.0	23.0	2.5	10.5	0.0		109.7	127.3
Theewaterskloof	2.5	0.0	13.0	0.3	2.0	0.0	0.0	19.1	56.4
Tygerberg	9.0	2.5	39.7	1.2	2.7	0.0	0.0	67.9	40.8
Voëlvlei	10.0	0.0	3.0	11.0	10.0	0.0	0.0	45.0	45.1
Wemmershoek	40.2	0.0	38.0	15.9	0.0	0.0	1.5	139.3	62.5
Wynberg	27.0	0.0	25.5	5.0	3.0	0.0	0.0	86.1	83.3

Notes: *Total/cumulative rainfall for month indicated above
LT: Long Term



NASA Satellite Data Volumes



EOSDIS FY2015 Metrics	
Unique Data Products	9,462
Distinct Users of EOSDIS Data and Services	2.6 M
Average Daily Archive Growth	16 TB/day
Total Archive Volume (as of Sept. 30, 2015)	14.6 PB
End User Distribution Products	1.42 B
End User Average Daily Distribution Volume	32.1 TB/day

High Performance Computing and The Rise of the Cloud

NEX

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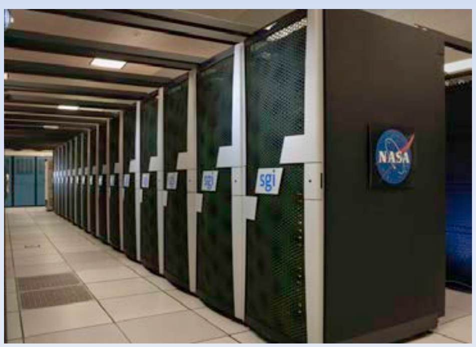

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NASA Applied Sciences Program Water Resources

Earth Science Serving Society

The goal of the ASP Water Resources application area is to apply NASA satellite data to improve the decision support systems of organizations and user groups that manage water resources. The ASP Water Resources application area partners with Federal agencies, academia, private firms, and international organizations.

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https://appliedsciences.nasa.gov/

Thank You

John Bolten
NASA Applied Sciences Program
Water Resources

john.bolten@nasa.gov

MOISST, Lincoln, NE
June 5, 2018