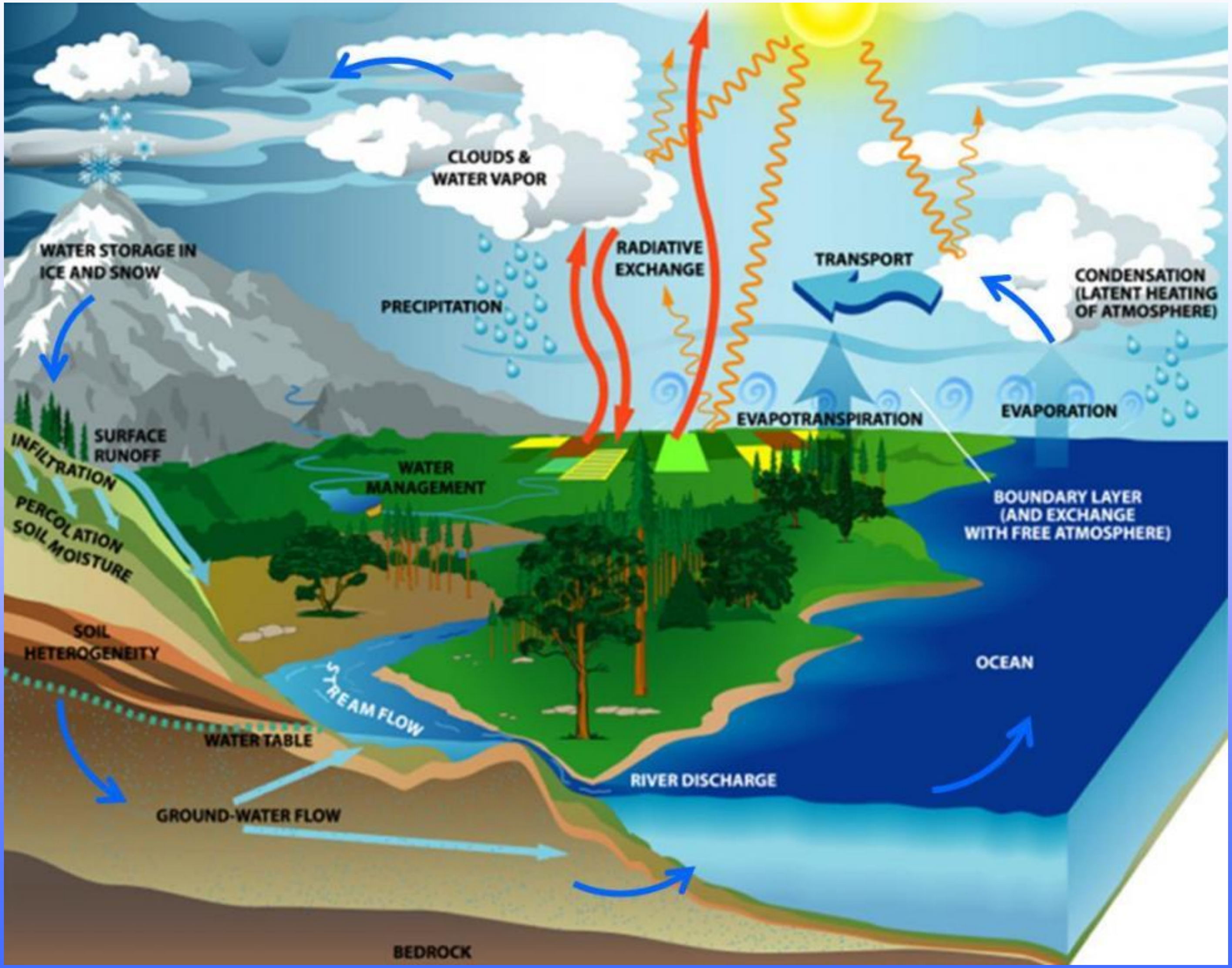
Soil Moisture Remote Sensing at NASA Present and Future

Jared Entin
NASA Headquarters

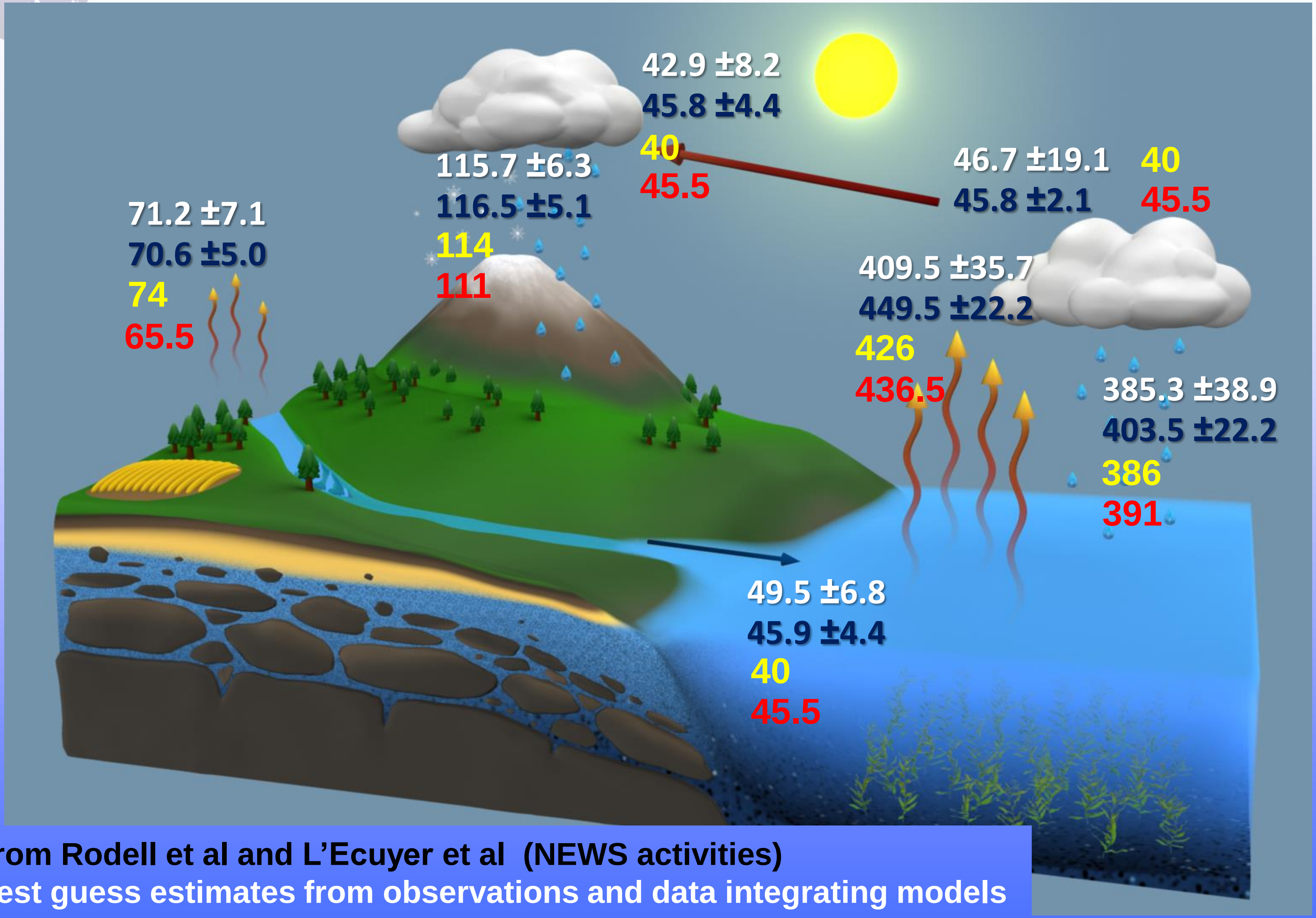
With much thanks to many people!

Water and Energy Cycle



Global, Mean Annual Water Cycle

Global mean water fluxes (1,000 km^3/yr) at the start of the 21st century



From Rodell et al and L'Ecuyer et al (NEWS activities)

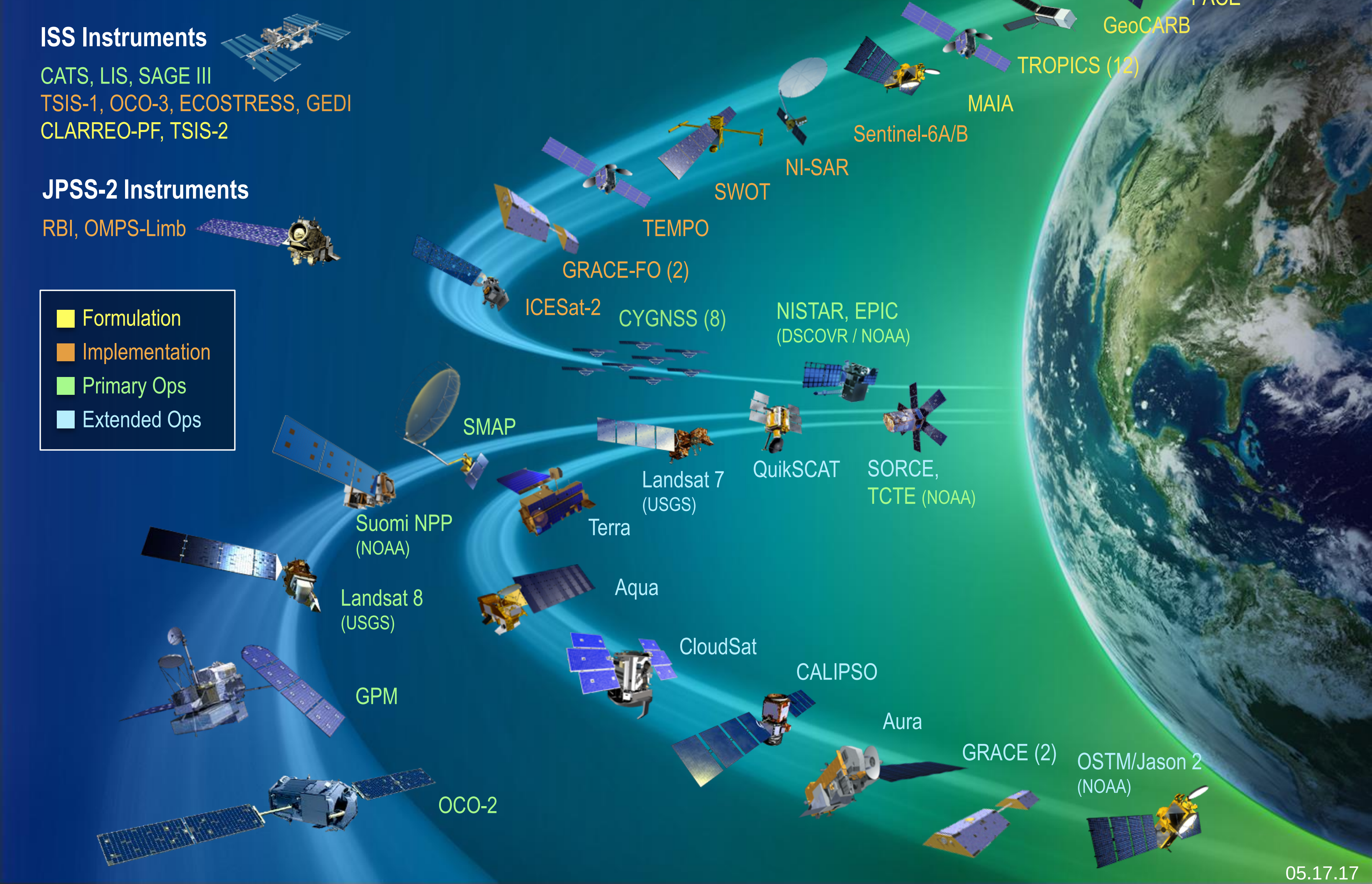
Best guess estimates from observations and data integrating models

When water balance is enforced, uncertainty decreases

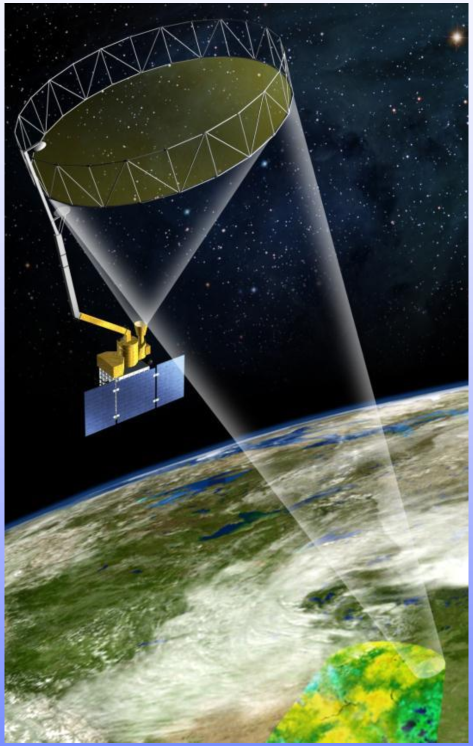
Trenberth et al. (2011) for comparison

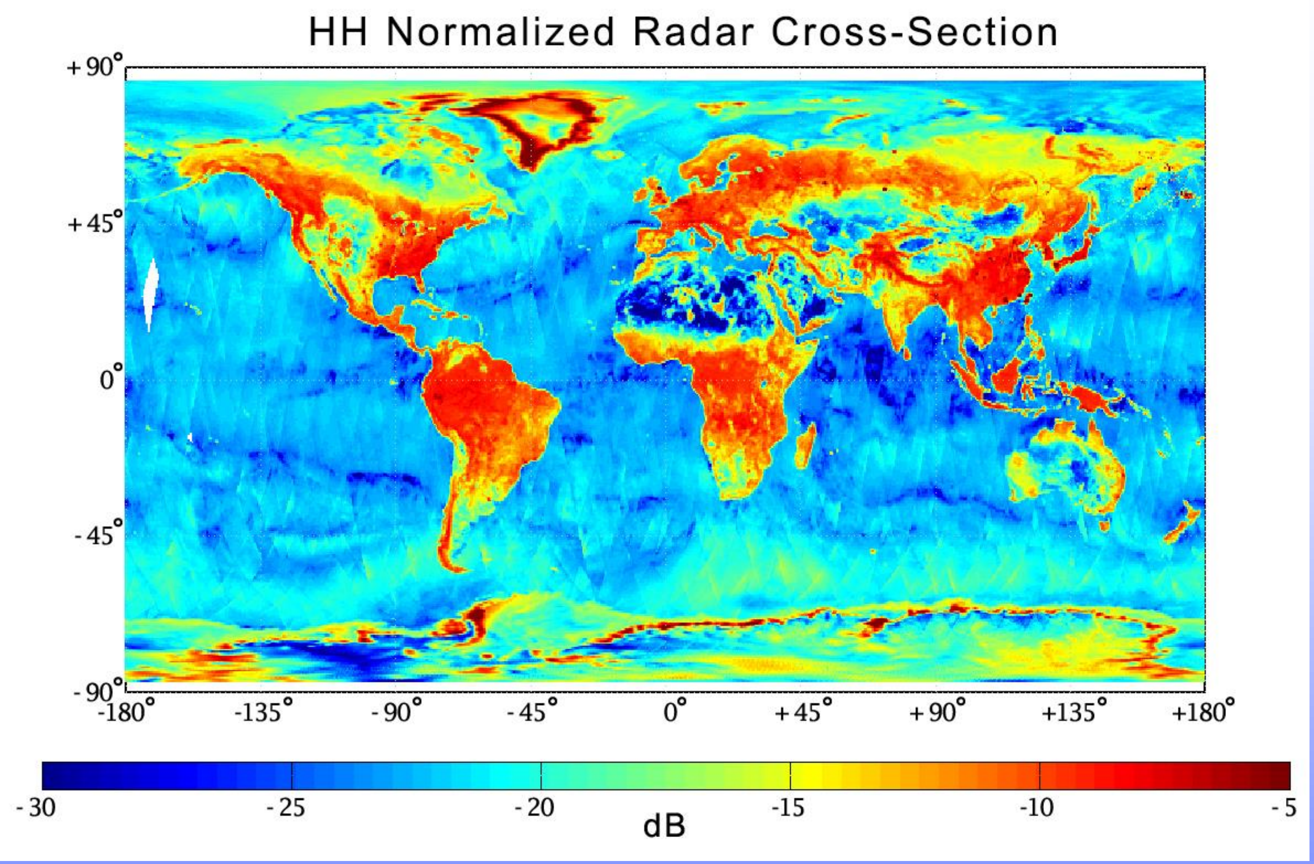
Oki and Kanae (2006) for comparison

NASA Earth Science Missions
Current and Planned



Soil Moisture Active Passive (SMAP)





SMAP radar image acquired from data from March 31 to April 3, 2015. Weaker radar signals (blues) reflect low soil moisture or lack of vegetation, such as in deserts. Strong radar signals (reds) are seen in forests.

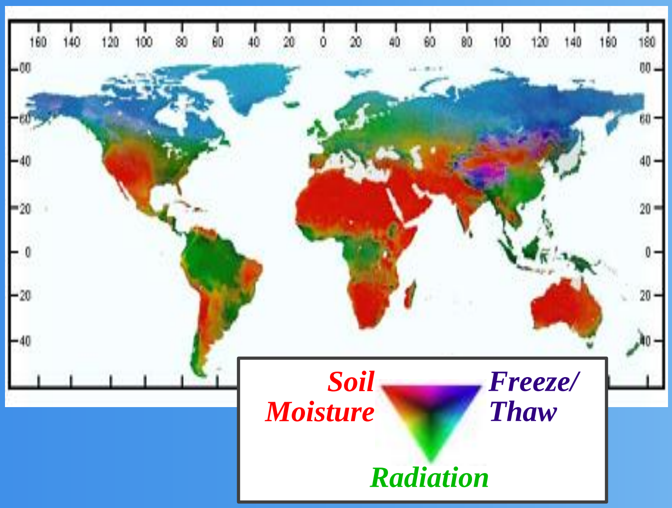
SMAP Facts

- **Resolution: 10 km (radar); 25 km (radiometer)**
- **Instruments: L-band Radiometer and (for a couple of months) Radar**
- **Launch: January 31, 2015**
- **Mission Duration: 3 years**

SMAP Mission Goals and Measurements Approach

Science Returns

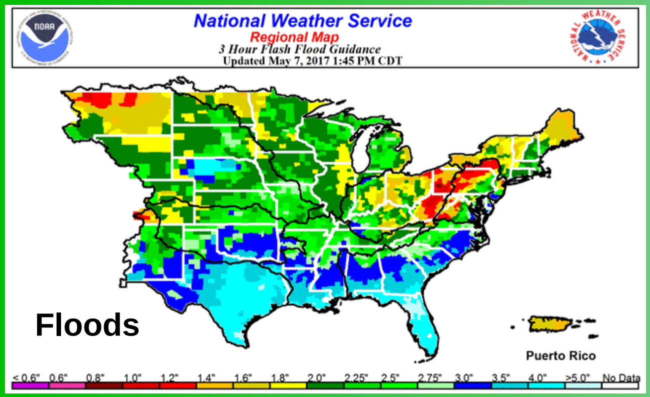
Soil Moisture *Links* the Global Land Water, Energy, and Carbon Cycles

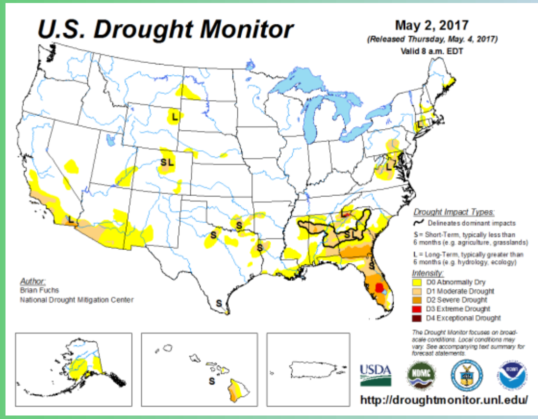


1. Estimating global surface water and energy fluxes
2. Quantifying net carbon flux in boreal landscapes
3. Reducing uncertainty of climate model projections

L-band radiometer and radar
- All-Weather
- Canopy Penetration
- Sensing Depth

Applications Returns





4. Enhancing weather forecasts
5. Improving flood prediction and drought monitoring

6 m conically scanning (14 rpm) antenna for 1000 km swath

Global coverage every 2-3 days

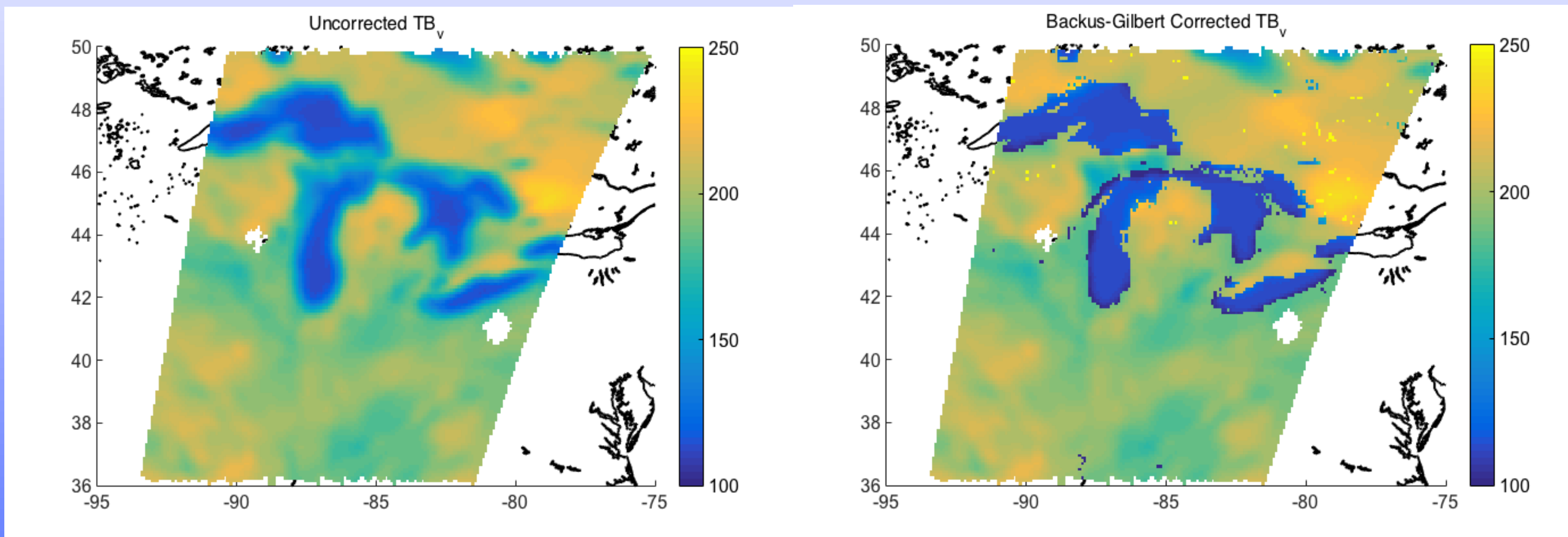
Launched January 2015

Prime mission end date: June 2018

Mission Priorities: Past and Coming Year

1. Reduction of bias between soil moisture product and ground truth
   - Update retrieval algorithm vegetation/roughness parameters
   - More compatible upscaling and sensing depth characterization of *in situ* measurements

2. Improve land brightness temperature waterbody correction



3. Release SMAP-Sentinel 1 research products and assessment reports

Soil Moisture Accuracy

CVS	ubRMSE (m^3/m^3)			Bias (m^3/m^3)			RMSE (m^3/m^3)			R			N		
	SCA-H	SCA-V	DCA	SCA-H	SCA-V	DCA	SCA-H	SCA-V	DCA	SCA-H	SCA-V	DCA	SCA-H	SCA-V	DCA
Reynolds Creek	0.042	0.040	0.054	-0.066	-0.032	-0.006	0.079	0.051	0.055	0.643	0.698	0.680	132	147	146
Walnut Gulch	0.024	0.026	0.040	-0.026	-0.004	0.017	0.035	0.026	0.044	0.708	0.787	0.771	145	188	179
TxSON	0.028	0.028	0.034	-0.061	-0.011	0.065	0.068	0.030	0.073	0.944	0.946	0.888	183	183	181
Fort Cobb	0.032	0.028	0.044	-0.071	-0.040	0.001	0.078	0.049	0.044	0.857	0.879	0.818	259	259	259
Little Washita	0.024	0.022	0.042	-0.057	-0.021	0.034	0.062	0.031	0.054	0.908	0.921	0.852	269	269	268
South Fork	0.061	0.054	0.058	-0.077	-0.066	-0.050	0.098	0.085	0.077	0.585	0.612	0.551	206	209	209
Little River	0.032	0.026	0.037	0.055	0.095	0.153	0.064	0.098	0.157	0.908	0.912	0.783	278	278	278
Kenaston	0.036	0.026	0.041	-0.060	-0.035	0.006	0.070	0.044	0.041	0.766	0.810	0.524	149	149	149
Carman	0.092	0.058	0.052	-0.086	-0.086	-0.076	0.126	0.104	0.092	0.478	0.602	0.519	158	160	160
Monte Buey	0.072	0.051	0.043	-0.023	-0.018	-0.028	0.076	0.054	0.051	0.791	0.877	0.669	98	109	111
REMEDHUS	0.034	0.037	0.048	-0.030	-0.014	0.001	0.045	0.040	0.048	0.911	0.895	0.867	194	190	182
Twente	0.065	0.051	0.050	0.006	0.021	0.038	0.065	0.055	0.063	0.877	0.885	0.805	262	266	267
HOBE	0.035	0.025	0.028	0.007	-0.018	-0.037	0.036	0.030	0.046	0.894	0.863	0.715	54	54	54
MAHASRI	0.033	0.039	0.038	-0.007	-0.008	-0.005	0.033	0.040	0.038	0.713	0.681	0.682	85	67	71
Yanco	0.046	0.040	0.043	0.004	0.026	0.044	0.046	0.048	0.061	0.963	0.966	0.950	176	178	176
SMAP L2SMP Average V4	0.044	**0.037**	0.043	-0.033	**-0.014**	0.010	0.065	**0.052**	0.063	0.796	**0.822**	0.738			
SMOS L2SMP Average V4	0.051			-0.024			0.072			0.713					

April 1, 2015 to
Oct 31, 2016

- The current baseline algorithm for L2SMP is the Single Channel-V (SCA-V).
- The performance of other algorithms are monitored to provide diagnostic information.
- Agricultural regions with rapid vegetation variations, roughness changes and possible irrigation are challenging.

SMAP/Sentinel 1 Active Passive

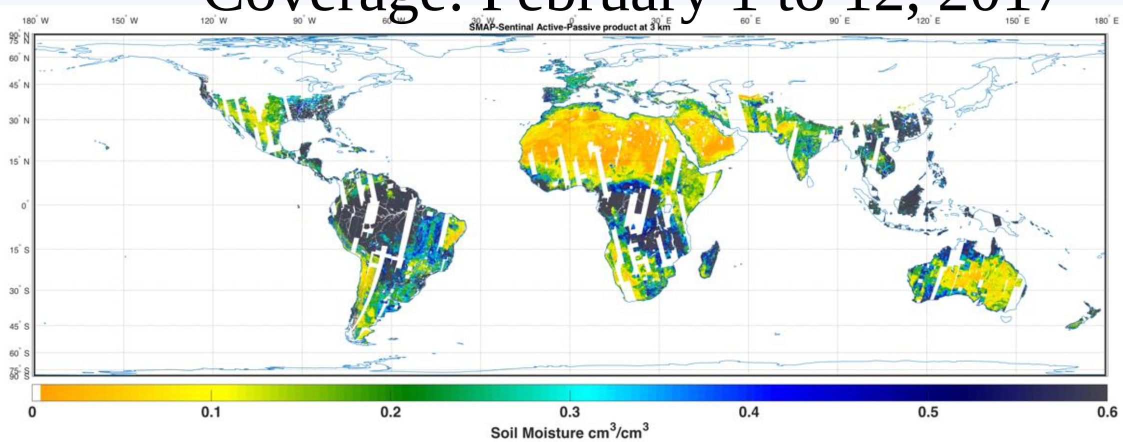
SMAP project has been actively engaging ESA's Sentinel-1 Project on the synergistic use of SMAP band radiometer and Sentinel-1 C-band SAR data to develop research soil moisture products at a spatial resolution of 3 km or better.

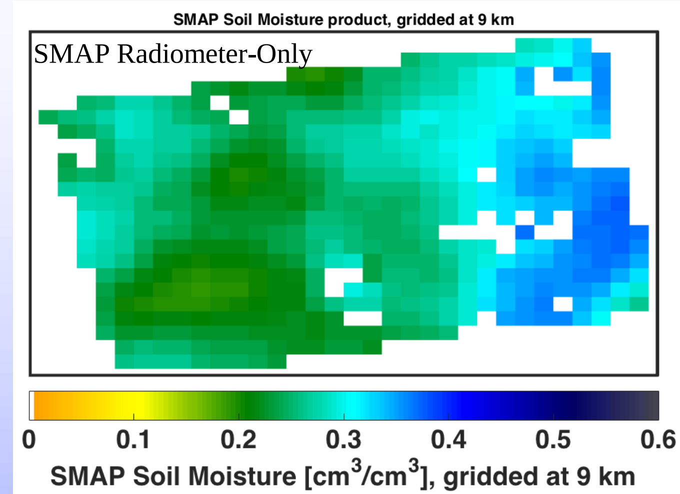
- The SMAP and Sentinel 1 soil moisture at 3 km spatial resolution is based on the existing SMAP active passive algorithm using SMAP radiometer and radar data: the high resolution radar data (SMAP radar or Sentinel-1 radar) are used to disaggregate the coarse resolution radiometer data into 3 km resolution.

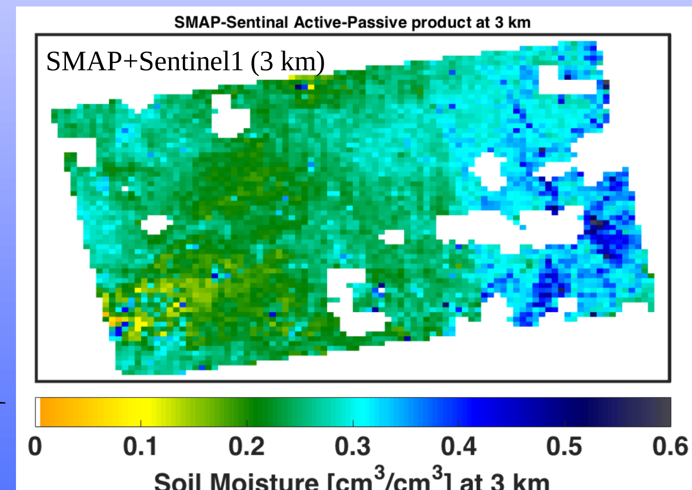
- The SMAP/Sentinel 1 soil moisture product is being evaluated using the SMAP CVS data at 3 km.

SMAP/Sentinel-1 Active Passive

Coverage: February 1 to 12, 2017





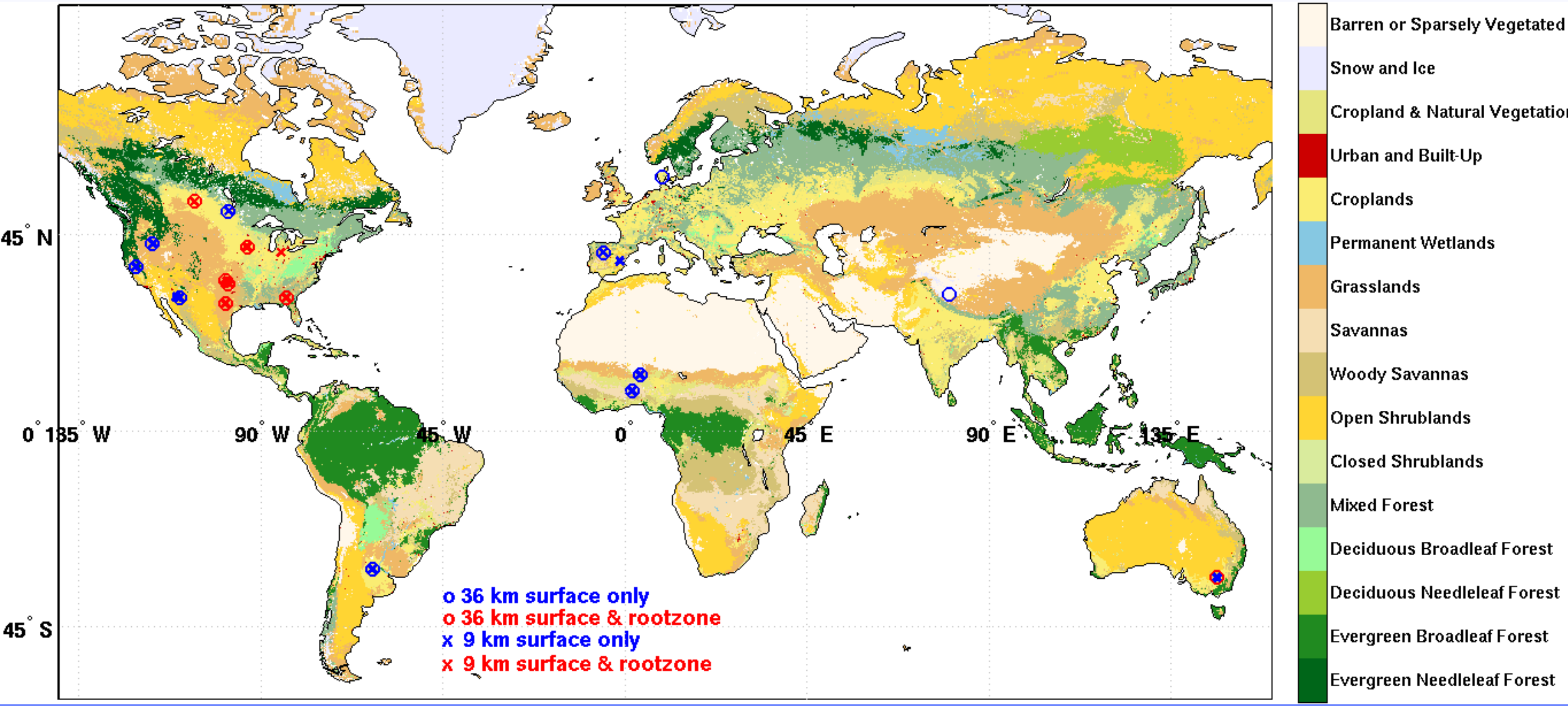


- Challenges:
  - L/C-band differences in canopy opacity*, sensing depth, and scattering phenomena
  - Validation limited to where Sentinel and CVS coincide
  - Angular variations and low temporal refresh of Sentinel-1 data

*C-band vegetation opacity is one-half of L-band opacity (confirmed by the numerical solution of Maxwell's Equation by Leung Tsang, member SMAP Science Team).

Central Texas
February 22, 2017

Level 4 Soil Moisture Products



Locations and numbers of core validation sites used for L4 soil moisture validation.

	Surface soil moisture		Root zone soil moisture	
Horizontal scale	36 km	9 km	36 km	9 km
Number of different core sites	17	17	7	6
Number of reference pixels	17	26	7	10

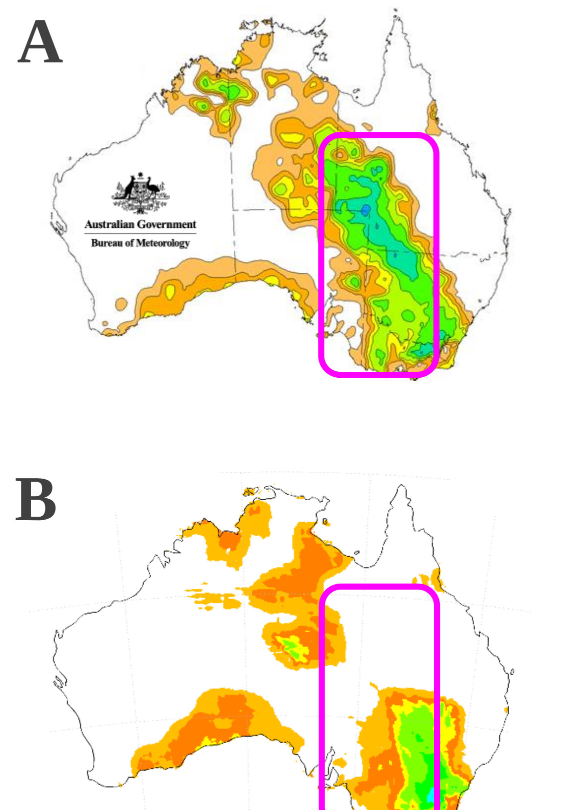
Level 4 Soil Moisture Products

Impact of SMAP observations on L4_SM product:

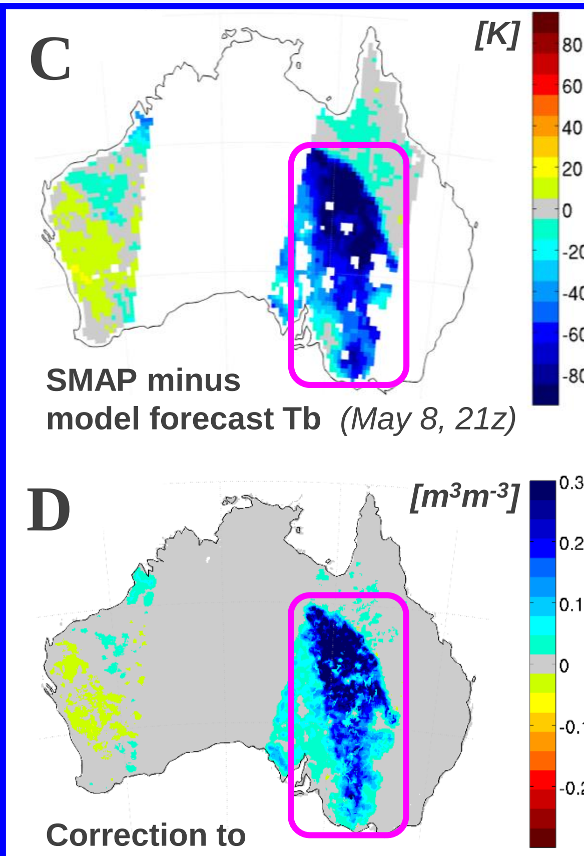
On May 8, 2016, a major rain event in the interior of Australia was observed by the Bureau of Meteorology (**A**) but poorly represented in the global input data for the L4_SM system (**B**).

Due to the lack of rainfall in the L4_SM system, the soil moisture in the model forecast for 21:00 UTC was too dry, and therefore the modeled L-band brightness temperature (Tb) was too high compared to SMAP observations (**C**).

The L4_SM analysis of SMAP Tb observations thus resulted in a substantial correction of the model forecast soil moisture (**D**).



L4_SM precipitation inputs *(May 8, 0z to May 9, 0z)*



SMAP minus model forecast Tb *(May 8, 21z)*

Correction to L4_SM model forecast surface soil moisture *(May 8, 21z)*

Weather and Climate Forecast Skill

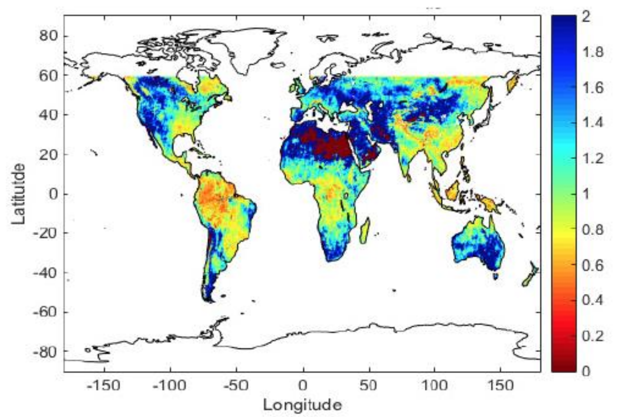
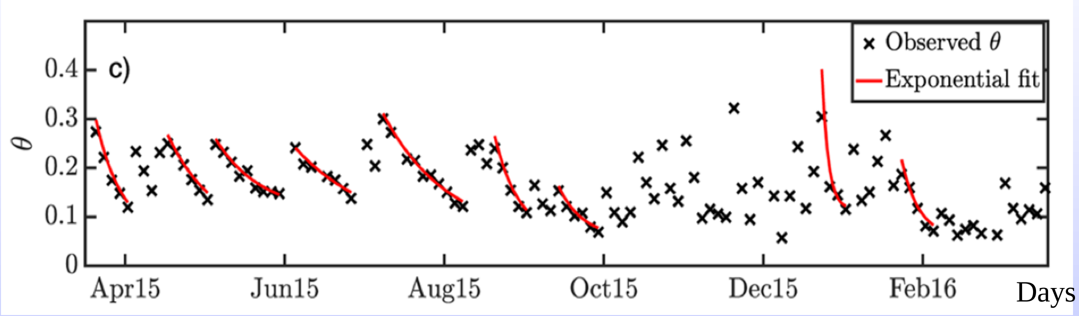
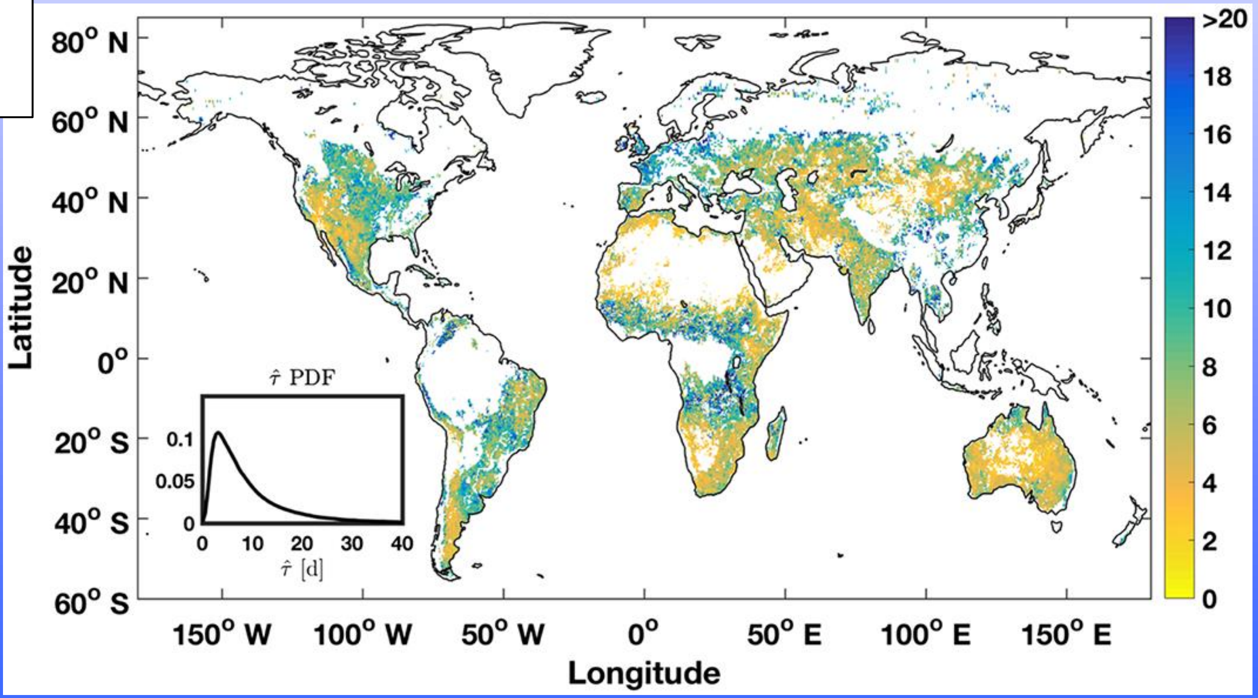


FIGURE 1.2-8: *Surface soil moisture memory expressed here in terms of half-life in days is a necessary condition for establishing land-atmosphere feedbacks that extend weather anomalies. The memory is mapped globally for the first time using SMAP observations (McColl et al. 2017).*

McColl et al., 2017b: Global characterization of surface soil moisture drydowns, 44, *Geophysical Research Letters*.





Memory of surface soil moisture can extend to days especially where land-atmosphere coupling is significant and forecast skill can be extended.

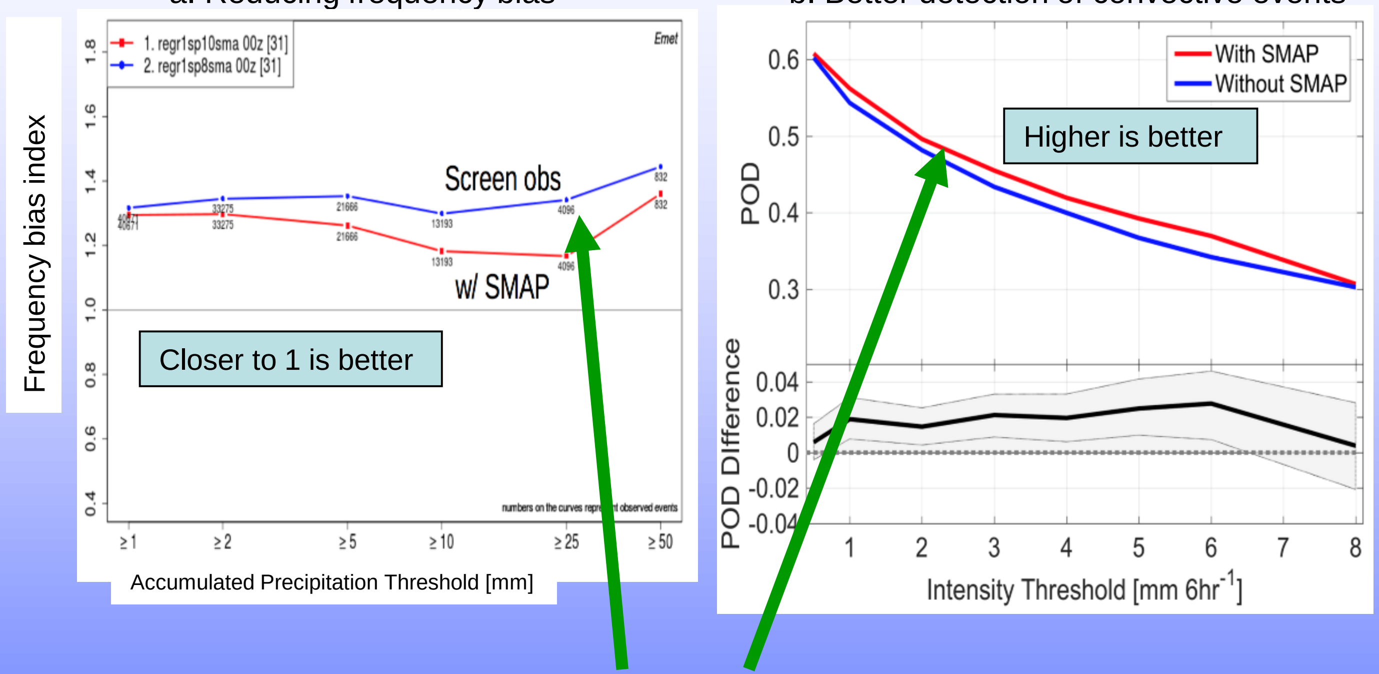
Weather and Climate Forecast Skill

SMAP Early Adopter: Environment and Climate Change Canada, Stephane Belair, Marco Carrera

Positive impact of SMAP on Precipitation forecasts

a. Reducing frequency bias

b. Better detection of convective events

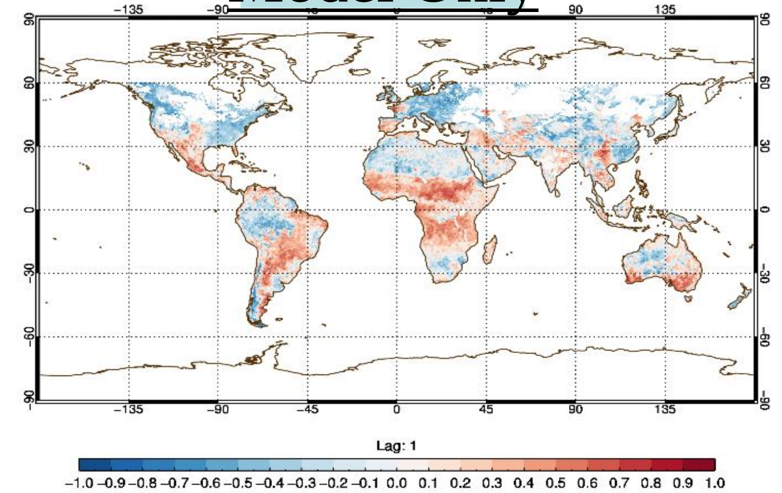


- Improvements obtained due to assimilation of SMAP data may appear small, but in the forecasting game, any true, significant increase in skill is considered a major accomplishment.
- Increase in Probability of Detection (POD) is equivalent to about quarter- to half-day gain in forecast lead-time (or equivalent to differences among NWP and models).

USDA FAS (Foreign Agricultural Service) Global Crop Assessment Decision Support System With SMAP Data

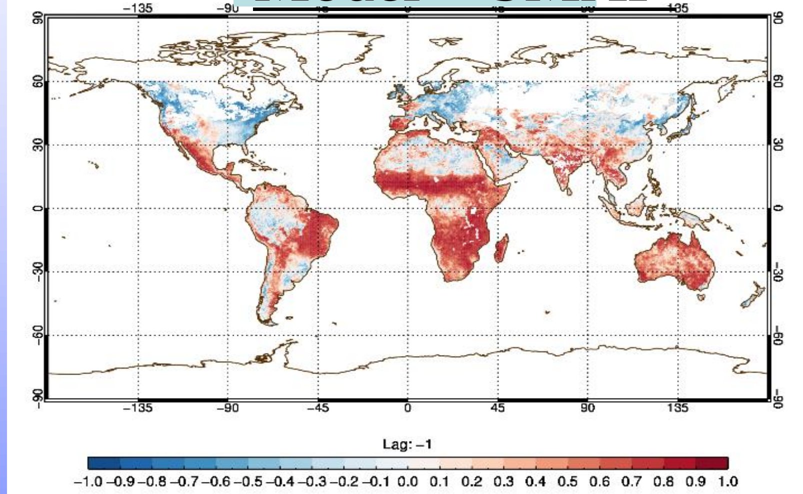
Plotted variable = Correlation between *current* monthly soil moisture levels and *future* (+ 1 month) vegetation health (NDVI).

Model Only



Correlation of *current* USDA FAS soil moisture product based on water balance modeling

Model + SMAP



Enhanced correlation observed *after* the assimilation of SMAP L3 retrievals.

Higher correlation (more red) = Improved early detection of agricultural drought

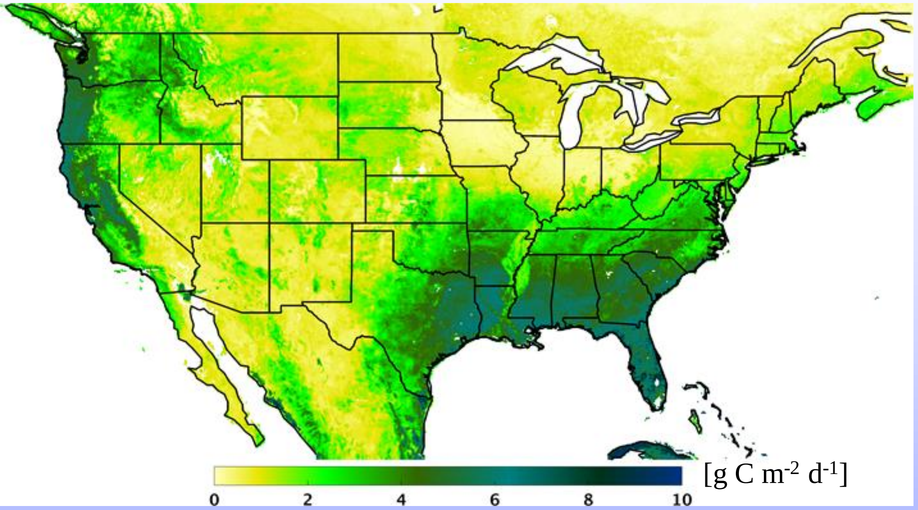
Work supported by a NASA Applied Sciences grant entitled "Enhancing the USDA Global Crop Production Decision Support System with NASA Soil Moisture Active Passive (SMAP) Satellite Observations"

PI – John Bolten (NASA/GSFC), I. Mladenova (GSFC/ESSIC), W. Crow (USDA ARS), C. Reynolds (USDA FAS)

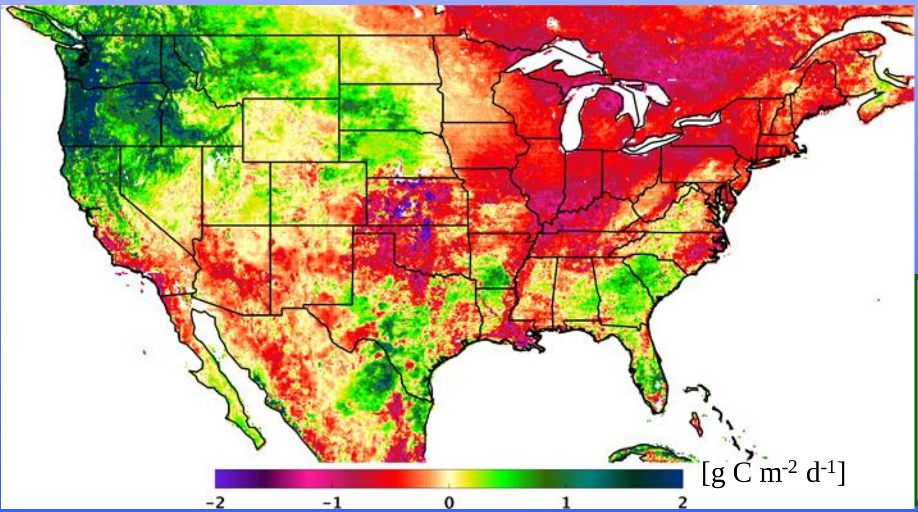
2016 ENSO Influence on US Spring Vegetation Growth

J. Kimball (Univ. Montana)

Mean Daily Vegetation Growth (April 1-14, 2016)



Vegetation Growth **Anomaly** (April 1-14, 2016)



Spring 2016 vegetation growth (GPP) patterns and anomalies based on the NASA SMAP (Soil Moisture Active Passive) mission Level 4 Carbon (L4_C) product

Top: L4_C observed mean daily growth pattern for April 1-14, 2016

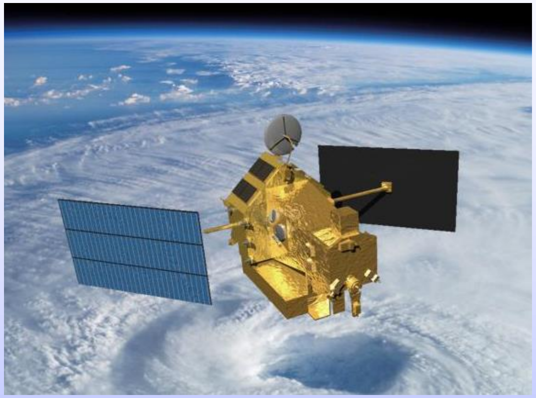
Lower: ENSO spring growth departure from normal conditions.

Higher-than-normal productivity occurred across the Northwest and the Southeast due to early spring onset and adequate moisture conditions. Enhanced productivity is evident in California Central Valley, but there is continued growth suppression across the Southwest and the Northeast from persistent droughts.

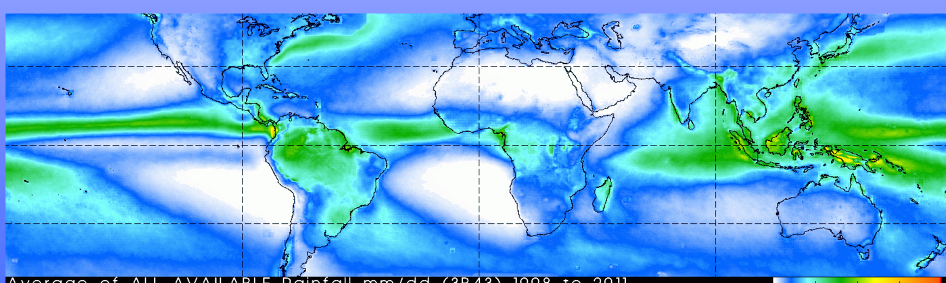
El Nino-Southern Oscillation (ENSO) impacted productivity in US forest, croplands and pastures. SMAP L4_C product maps the growth rates and anomalies associated with ENSO conditions.

Precipitation

Tropical Rainfall Measurement Mission (TRMM)

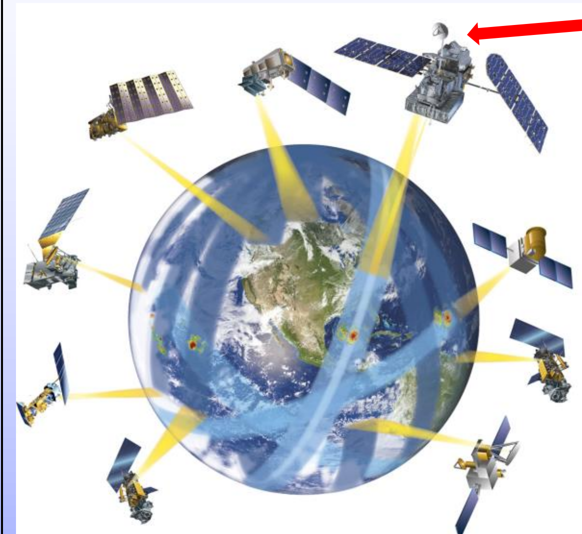


- Global (50S-50N) precipitation measurement
  - 10 ↔ 85 GHz radiometers
  - 13.6 GHz precipitation radar
  - Nov 1997 to Apr 2015



TRMM 14-year mean rainfall

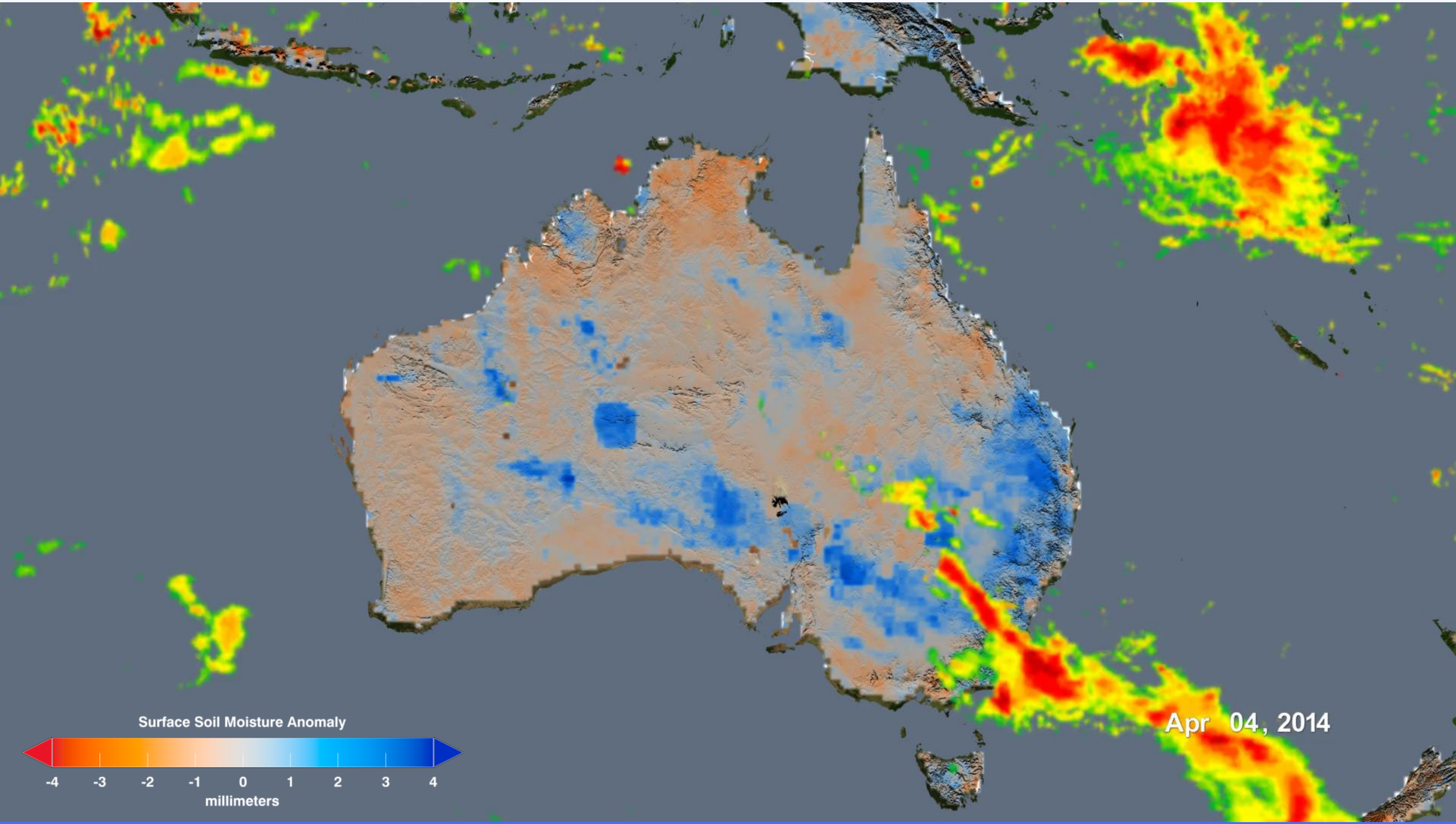
Global Precipitation Measurement (GPM)



The GPM Core Observatory will provide improved measurements of precipitation from the tropics to higher latitudes

- Launched Feb 28, 2014
- Uses inputs from an international constellation of satellites to increase space and time coverage
- Improvements:
  - Longer record length
  - High latitude precipitation
    - including snowfall
  - Better accuracy and coverage

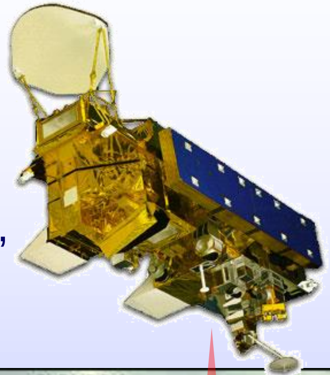
Pairing GPM and Satellite-Based Soil Moisture to Illustrate 'Precipitation Memory'

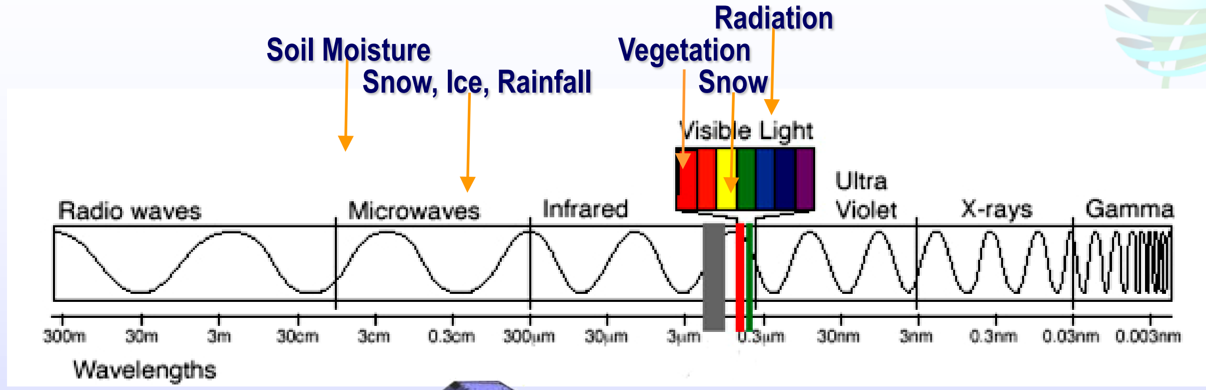


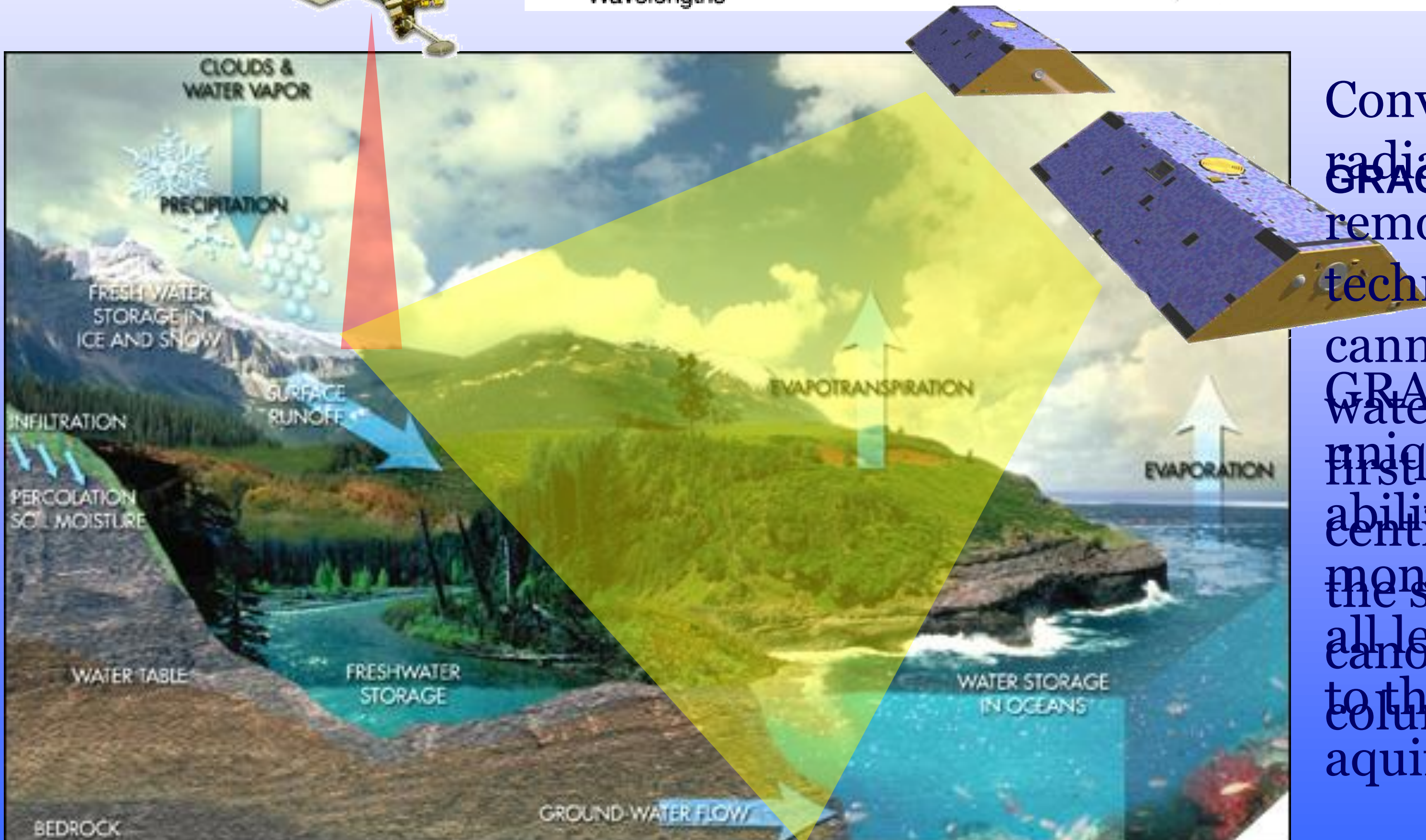
Source: John Bolten (NASA/GSFC)

Gravity Recovery and Climate Experiment (GRACE)

Aqua:
MODIS,
AMSR-E,
etc.







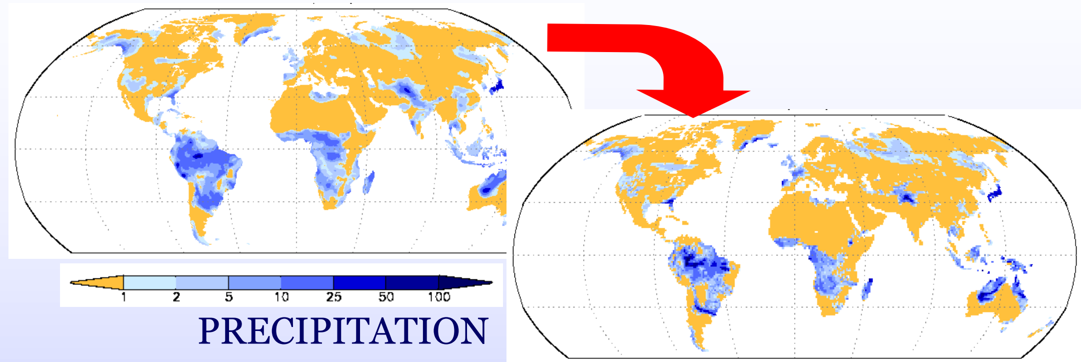
Conventional radiation-based remote sensing technologies cannot sense water below the first few centimeters of the snow-canopy-soil column

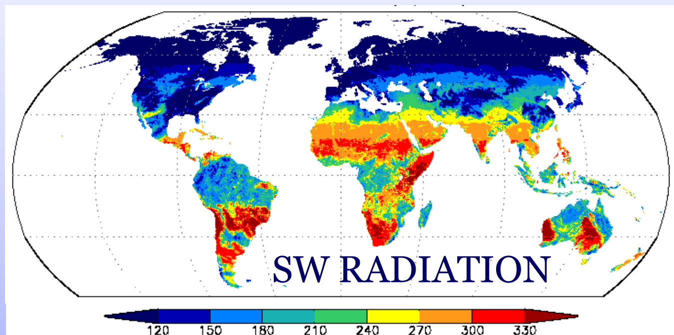
GRACE

GRACE is unique in its ability to monitor water at all levels, down to the deepest aquifer

Data Integration Is Critical for Maximizing the Value of Water Cycle Data: LDAS Example

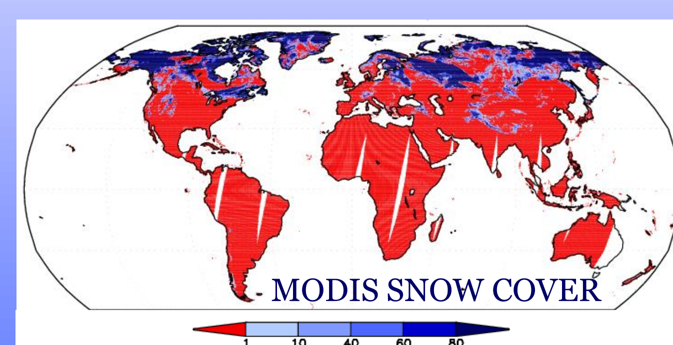
INTERCOMPARISON and OPTIMAL MERGING of global data fields

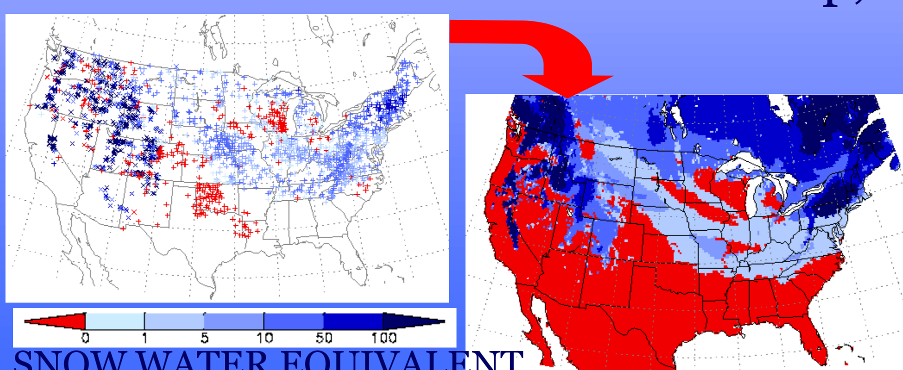




Satellite derived meteorological data used as land surface model FORCING

ASSIMILATION of satellite based land surface state fields (snow, soil moisture, surface temp, etc.)





Ground-based observations used to VALIDATE model output

Images from NASA's GLDAS
http://ldas.gsfc.nasa.gov/

Matt Rodell
NASA GSFC

Land Data Assimilation Systems

North American LDAS

- NOAA, NASA, (and 6 other US institutions) 1998-present
- 1/8 degree resolution, central North America

Global LDAS

- NASA (and NOAA) 2000-present
- 1/4 and 1.0 degree resolutions, all land 60S-90N

Land Information System (LIS)

- NASA 2002-present
- Software configurable for any domain and resolution
- Multiple data assimilation options
- Can be run uncoupled or coupled to an atmospheric model
- Adopted by all other NASA LDAS projects & NOAA & AFWA

Others: MERRA-Land; European LDAS; Middle East North Africa (MENA) LDAS; South American LDAS; LDAS-University of Tokyo; etc.

SMD/ESD Applied Sciences Program

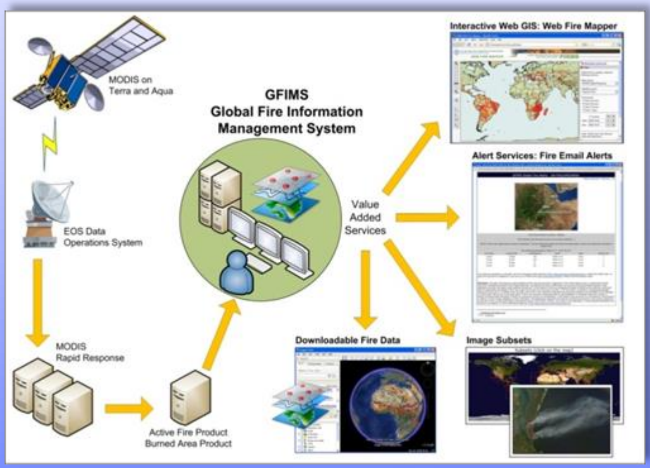
Applications Themes

Health

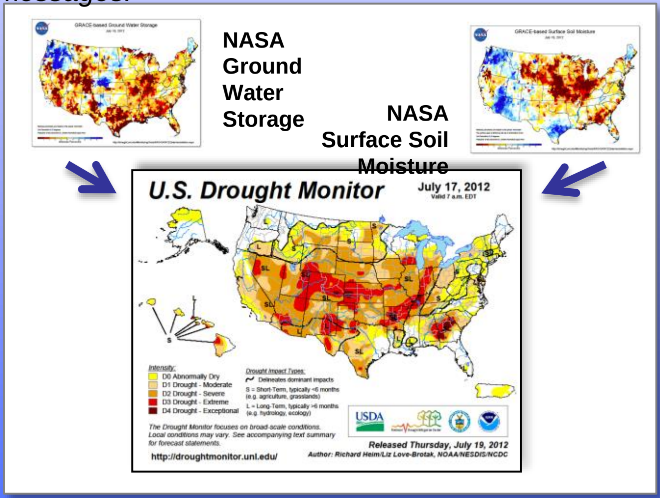
Water

Disasters

Eco-Forecasting



United Nation's system now using data from NASA's Terra and Aqua satellites to identify fires and send alerts to remote areas via SMS and text messages.



USDA/NOAA managed weekly U.S. Drought Monitor now using NASA GRACE data as part of analysis in creation of national and state-level maps..

Future NASA Water Cycle Missions

The 2017 Decadal Survey in Earth Science will likely guide NASA activities to support Nwater cycle missions for the next ten years and those missions relevant to soil moisture

- Already planned missions:
  GRACE Follow On (2017); SWOT (2021); NISAR (2022)
  Biomass(2021)

- Community input was gathered and now being considered
- Gaps: Evapotranspiration (EcoStress/LandSat (TC) series/Modis/ViiRs)?
- Gaps: Snow depth/water equivalent?
- Another attempt at a soil moisture radar and/or root-zone?*
- Precipitation and other continuity missions?

*Will work with other communities,
both within the USA and International, for
L-band Radiometer continuity.

THANK YOU!