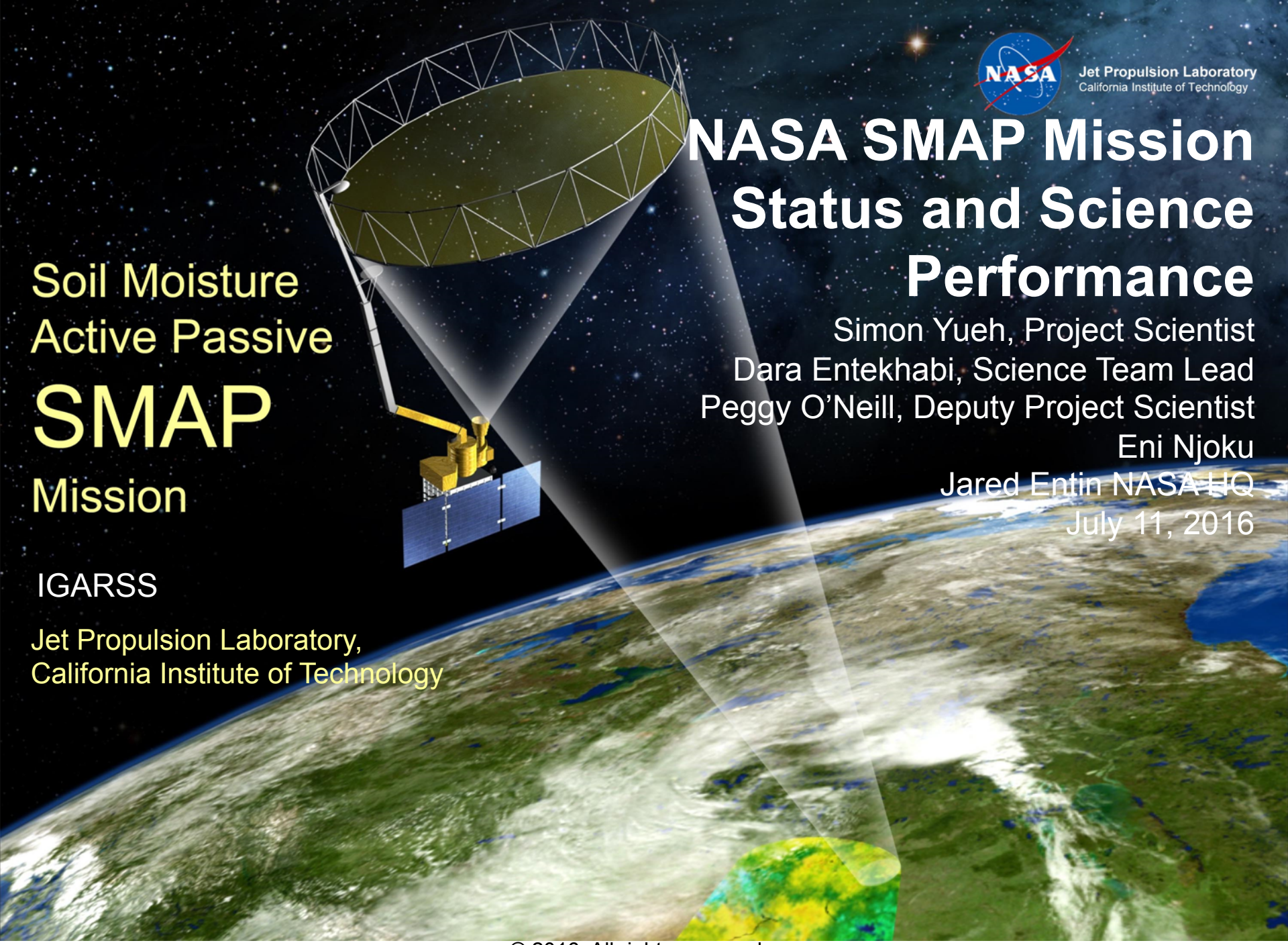

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California Institute of Technology

NASA SMAP Mission Status and Science Performance

Simon Yueh, Project Scientist
Dara Entekhabi, Science Team Lead
Peggy O'Neill, Deputy Project Scientist
Eni Njoku
Jared Entin NASA HQ

July 11, 2016

IGARSS

Jet Propulsion Laboratory,
California Institute of Technology

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Topics

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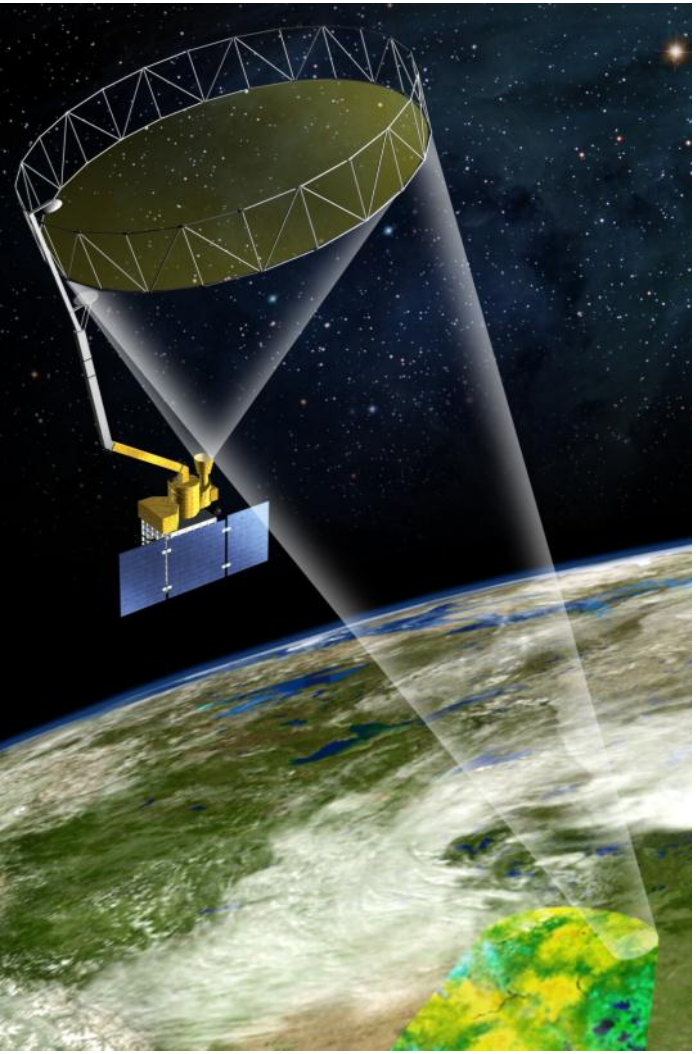
- Mission Status
- Current Baseline Radiometer Science Performance
- Science and Application Results
- Science Enhancement Tasks
  - Enhanced Resolution Passive product development
  - Radiometer-Derived F-T Product
  - SMAP Radiometer and Sentinel Radar Active-Passive Product
- Summary

Background: Project Overview



http://smap.jpl.nasa.gov/

Primary Science Objectives

- Global, high-resolution mapping of soil moisture and its freeze/thaw state to
  - Link terrestrial water, energy, and carbon-cycle processes
  - Estimate global water and energy fluxes at the land surface
  - Quantify net carbon flux in boreal landscapes
  - Extend weather and climate forecast skill
  - Develop improved flood and drought prediction capability

Mission Implementation

Partners	• JPL (project & payload management, science, spacecraft, radar, mission operations, science processing) • GSFC (science, radiometer, science processing)
Risk	• 7120.5E Category 2; 8705.4 Payload Risk Class C
Launch	• January 31, 2015 on Delta 7320-10C Launch System
Orbit	• Polar Sun-synchronous; 685 km altitude
Duration	• 3 years
Payload	• L-band (non-imaging) synthetic aperture radar (JPL) • L-band radiometer (GSFC) • Shared 6-m rotating (13 to 14.6 rpm) antenna (JPL)

NRC Earth Science Decadal Survey (2007) recommended SMAP as a Tier 1 mission

Mission Status

- Validated SMAP L1/2/3/4 data released in April.
- Science enhancement tasks continuing
  - Backus Gilbert interpolation coding completed.
  - SMAP passive freeze/thaw detection version-0 coding on testbed has been applied to data acquired since April 2015
  - Active-passive algorithm using SMAP radiometer and Sentinel-1 data
- SMAPVEX16 campaign is ongoing. The first of two operational periods in Iowa and Manitoba has been completed.
- Science and applications analysis ongoing

SMAP Passive Soil Moisture Has Been Distributed through NSIDC since Sept 2015

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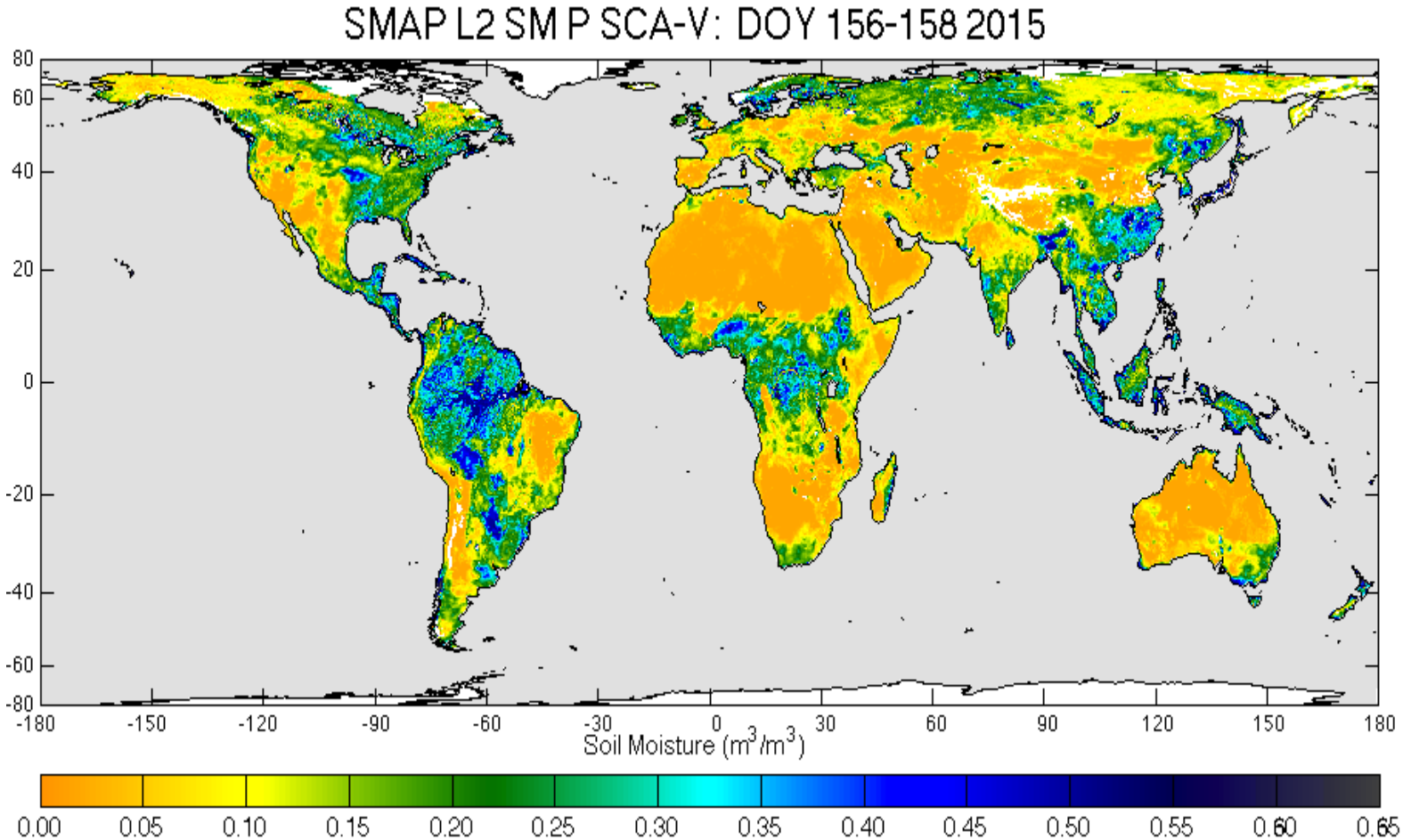
- Single channel vertical (SCA-V) polarization algorithm is the current baseline.

June 5-7, 2015



SMAP Radiometer Soil Moisture Performance at Core Validation Sites April 2015-Junr 2016

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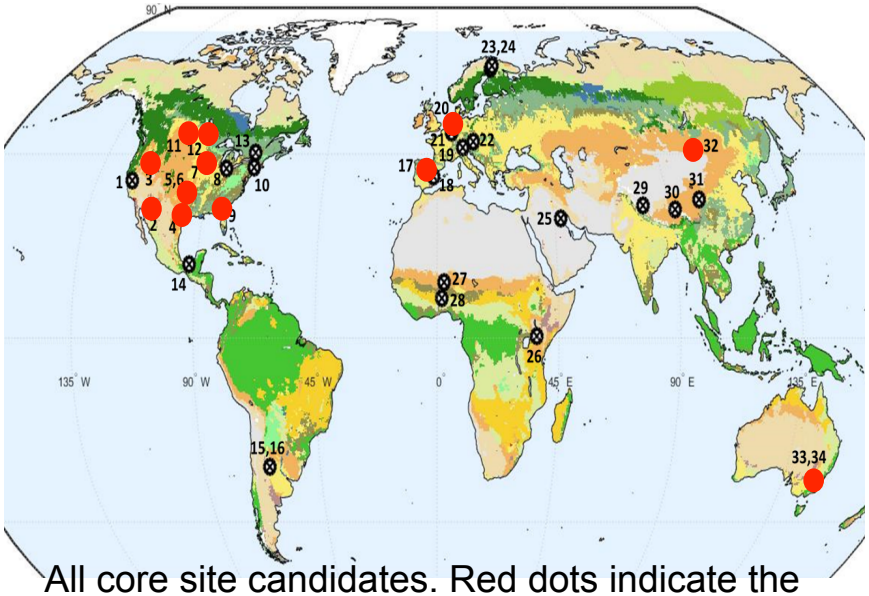
Performance Metrics

Site Name	ubRMSE (m3/m3)	Bias (m3/m3)	RMSE (m3/m3)	R
Reynolds Creek	0.041	-0.03	0.051	0.669
Walnut Gulch	0.026	-0.008	0.028	0.722
TxSON	0.028	-0.014	0.031	0.94
Fort Cobb	0.028	-0.037	0.046	0.877
Little Washita	0.022	-0.019	0.029	0.924
South Fork	0.059	-0.071	0.092	0.543
Little River	0.027	0.096	0.099	0.922
Kenaston	0.025	-0.037	0.045	0.764
Carman	0.059	-0.083	0.102	0.654
Monte Buey	0.051	0.007	0.052	0.89
REMEDHUS	0.038	-0.012	0.04	0.892
Twente	0.054	0.036	0.065	0.921
MAHASRI	0.036	-0.008	0.037	0.77
Yanco	0.035	0.017	0.039	0.938
Kyeamba	0.057	0.013	0.058	0.914
Mean	0.039	-0.01	0.054	0.823

***This performance meets the SMAP requirement of 0.04**

SMAP Core Validation Site Program

- Core Site Definition:
  - Multiple in situ sensors within satellite footprint
  - Well-calibrated in situ sensors
  - Spatial up-scaling to footprint scale established
  - Frequent access to the data



All core site candidates. Red dots indicate the sites that meet the criteria above. These sites are used for the metrics computation on the left.

Effect of RFI: Localized Analysis

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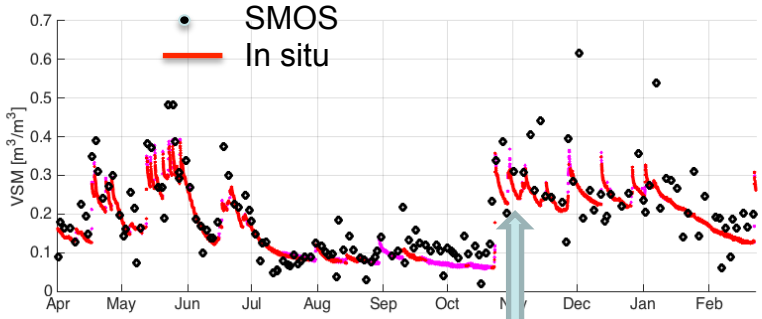
Effect of an RFI source in Texas: SMOS

- A new source of illegal RFI was detected* in the vicinity of the TxSON core site in Texas at the end of October 2015
- SMOS soil moisture measurements are sometimes irrecoverable as a consequence (SMOS measurements are noisier which can be seen in the plot below in the pre-RFI period

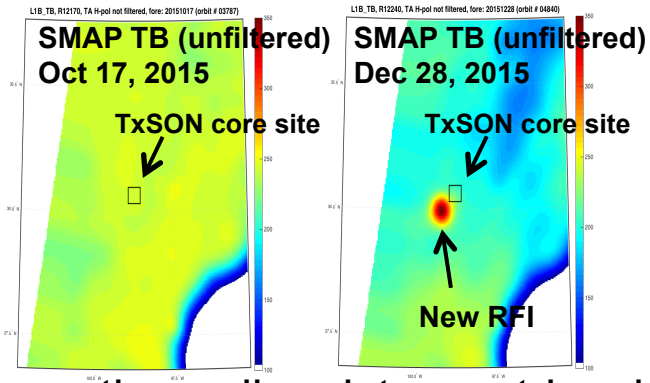


SMOS and TxSON soil moisture time-series

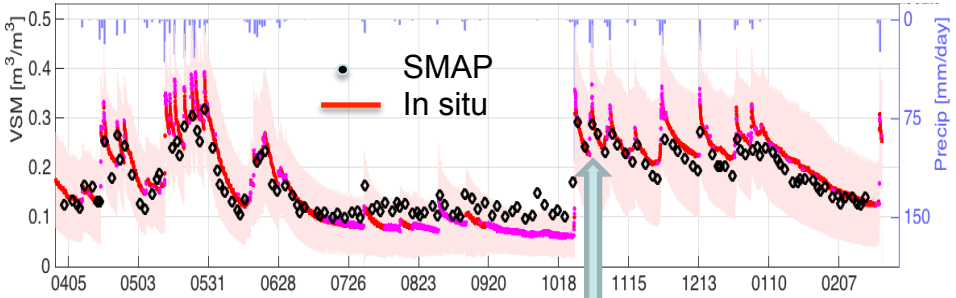
RFI source emerges

Effect of an RFI source in Texas: SMAP

Emergence of the RFI source detected:



Not impacting soil moisture retrieval because of the filtering:

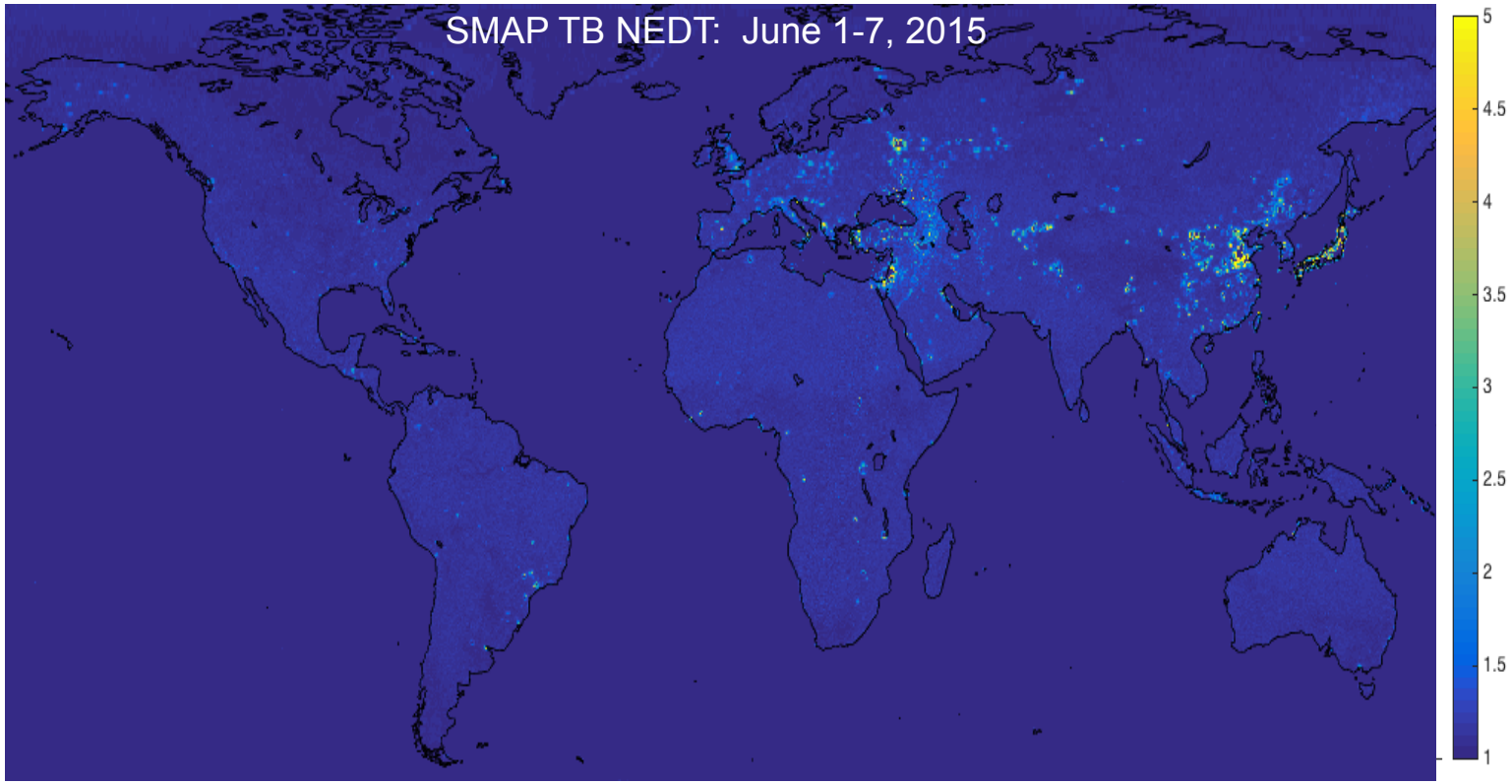


RFI source emerges

SMAP and TxSON soil moisture time-series

(*The SMAP measurements were relatively unaffected by the emergence of the RFI source in Texas. It was the SMOS team that alerted the SMAP team about the source since it corrupted the SMOS retrievals and made them unreliable.)

SMAP Radiometer NEDT After RFI Filtering



RFI filtering did not lead to significant reduction in sensitivity over most parts of the world.

SMAP and the Global Water Cycle: Tracking the Exchanges Between Land and Atmosphere

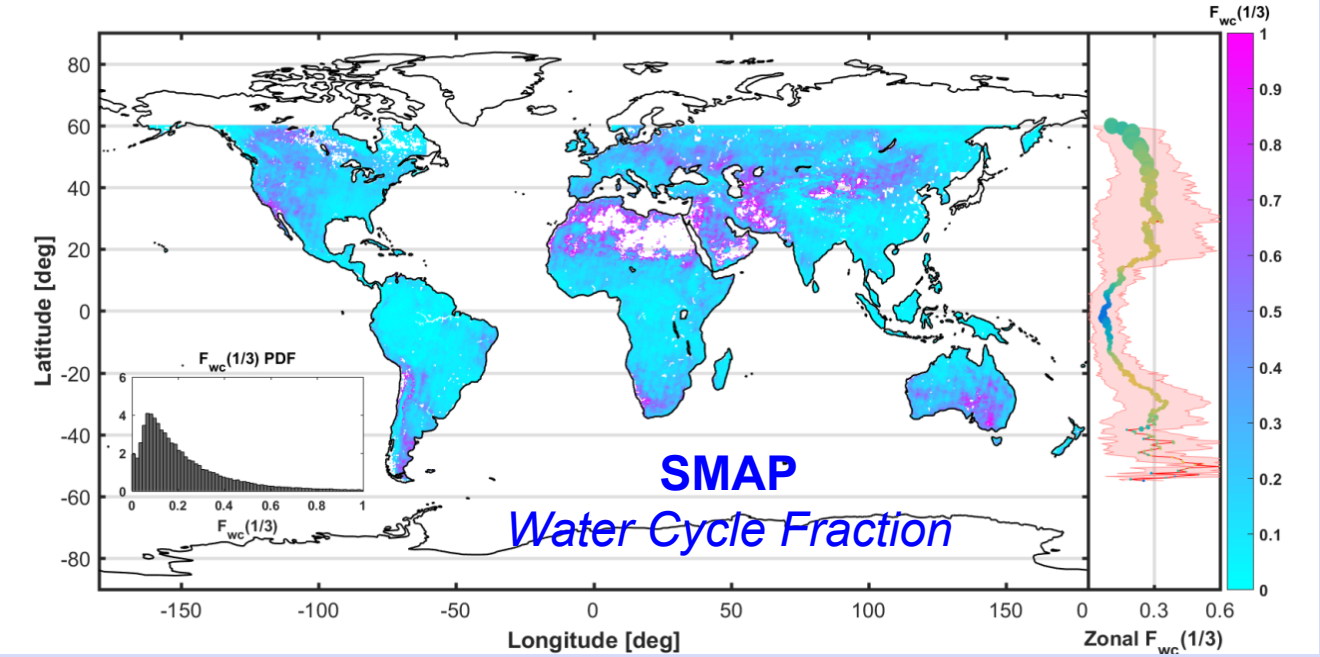
Jet Propulsion Laboratory
California Institute of Technology

McColl and Entekhabi, MIT

Even Though Soil Moisture is 0.001% of the Global *Water Budget*, it Captures About 20% of the *Water Cycle*

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

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



SMAP Results Show that the:

- Local Timing of Rainstorms
- Local Soil Texture

Control the *Water Cycle Fraction* and the Local Strength of Land-Atmosphere Coupling

Preliminary Results from CaLDAS Assessment of SMAP Data

Environment and Climate Canada, March 4, 2016

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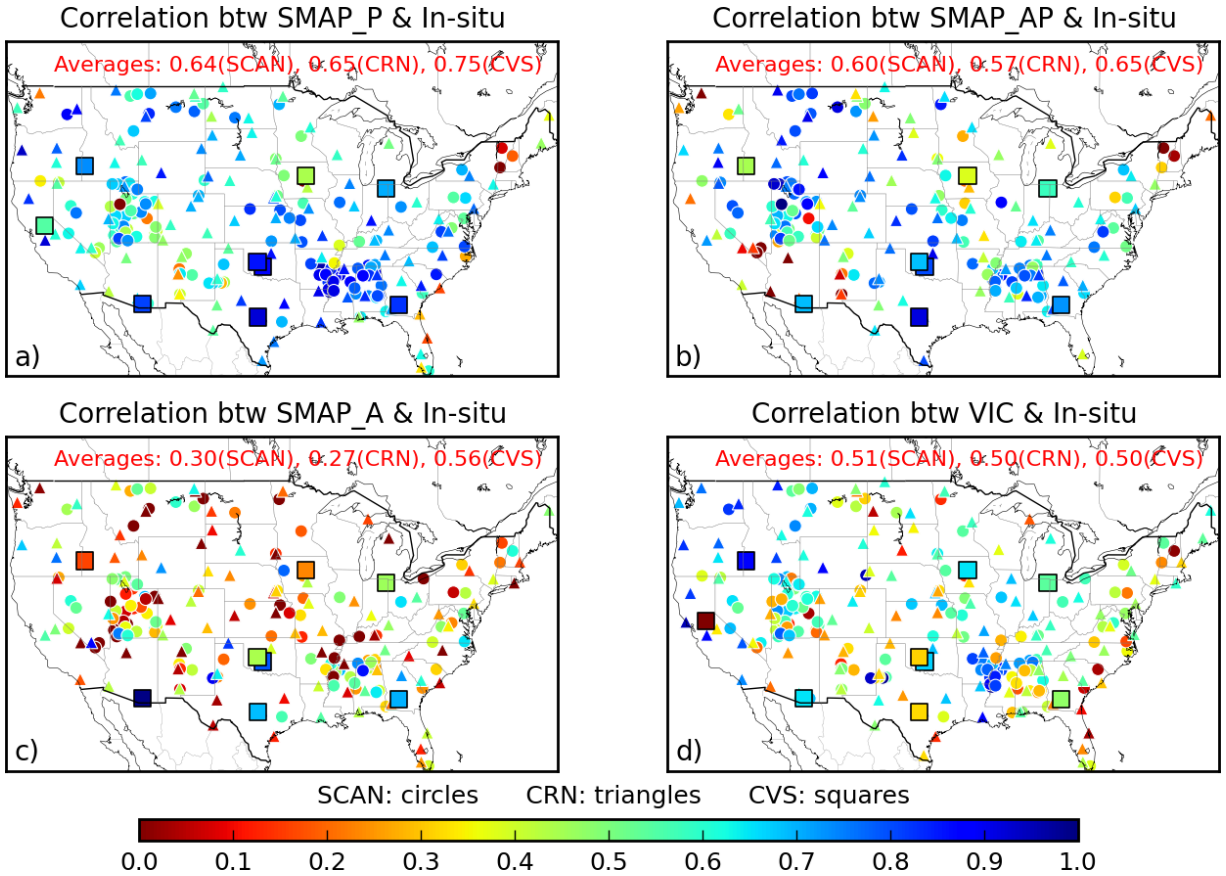
- Environment and Climate Canada (EC) has produced evaluation scores for soil moisture produced by CaLDAS-SMAP vs the current operational assimilation system (OI).
  - The evaluation was done with observations from Soil Climate Analysis Network (SCAN), US climate reference network (USCRN), and the Alberta Ag Drought Monitor (AGDM).
  - Wg and W2 stands for near-surface (0-10cm) and root-zone soil moisture.
- Assimilation of SMAP data has resulted in significant improvement in correlation and moderate reduction in standard deviation with in situ observations

Soil Moisture Verification Scores: July – August 2015

Soil Moisture Network	Correlation		STDE (m^3 m^{-3})	
	W_g	W_2	W_g	W_2
SCAN(121)	0.30; 0.50	0.26; 0.43	0.051; 0.042	0.024; 0.022
USCRN (73)	0.28; 0.52	0.21; 0.48	0.055; 0.043	0.027; 0.023
AGDM (27)	0.32; 0.59	0.13; 0.51	0.059; 0.045	0.022; 0.019

- OI-Operational
- CaLDAS-SMAP

Assessment of SMAP retrievals over sparse and core site in in CONUS (Eric Wood)
The comparisons between SMAP, in-situ observations and our 4km VIC land surface model demonstrates the high quality of the SMAP passive instrument. In fact, **for the first time satellite soil moisture retrievals over the US outperform model estimates**. This provides really high confidence that retrievals over sparse regions (e.g. Africa) can provide solid science and application data.



SMAP and Global Ecology: Dynamics of Water in the Terrestrial Biosphere

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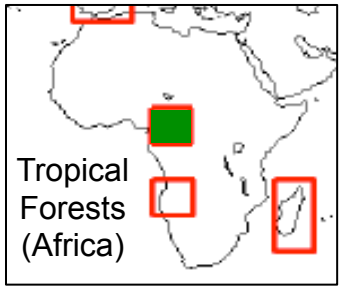
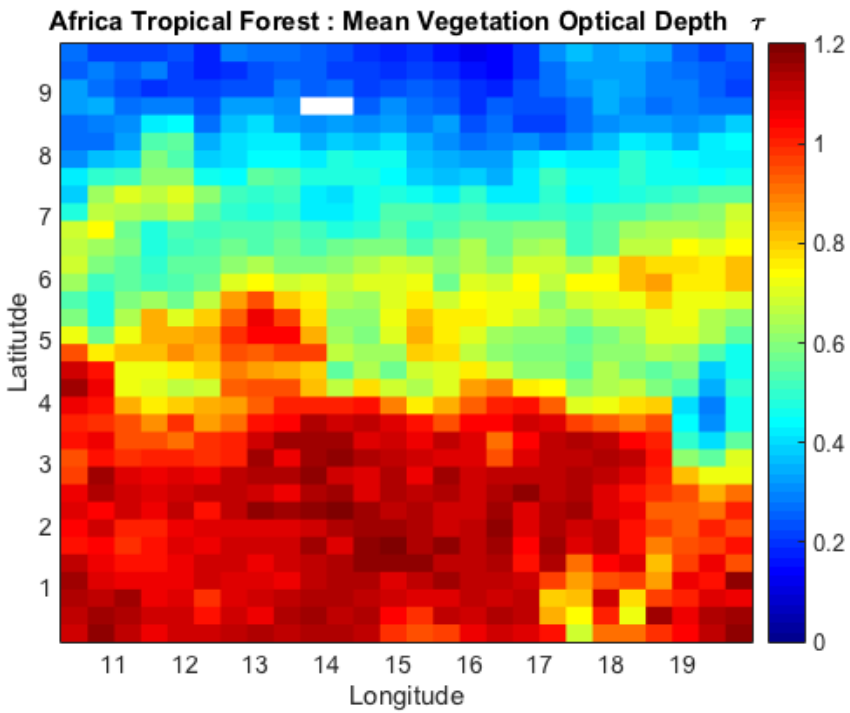
Entekhabi et al. (2016)

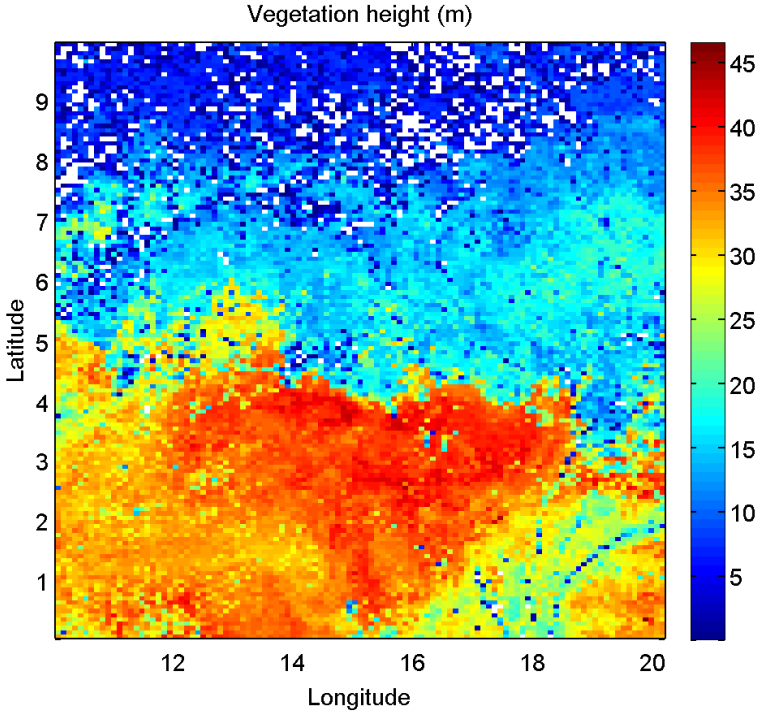
Dynamics of Water Exchanges Between the Soil and the Vegetation Canopy Yield Insights Into the Evolutionary Adaptations by Different Plant-Types to Cope with Dry-Episodes



Vegetation Microwave Opacity Based on SMAP (Dynamic)



Vegetation Height Based on ICE-Sat GLAS Lidar (Static)



SMAP Level 4 Soil Moisture (L4_SM)

Jet Propulsion Laboratory
California Institute of Technology

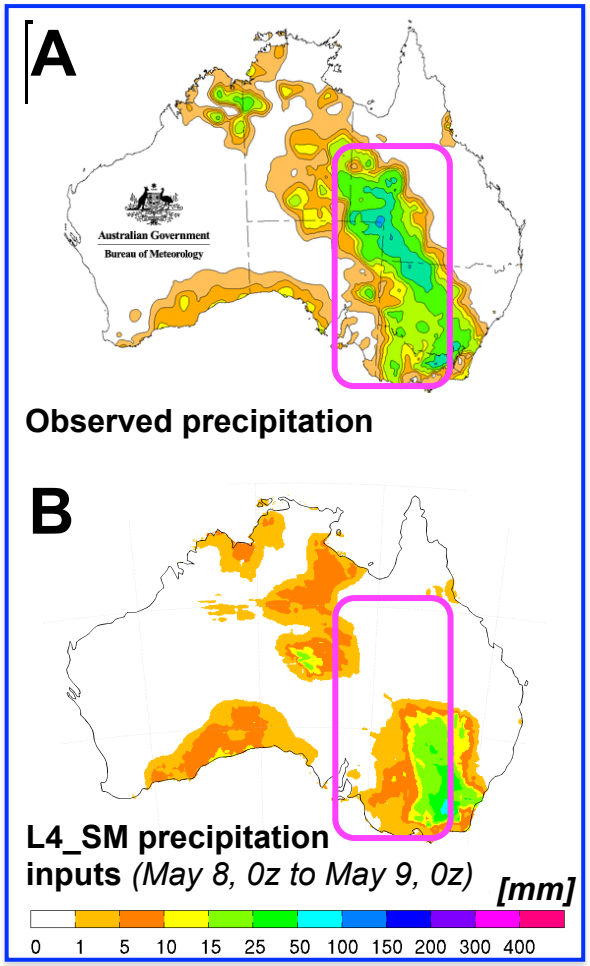
Reichle, GSFC

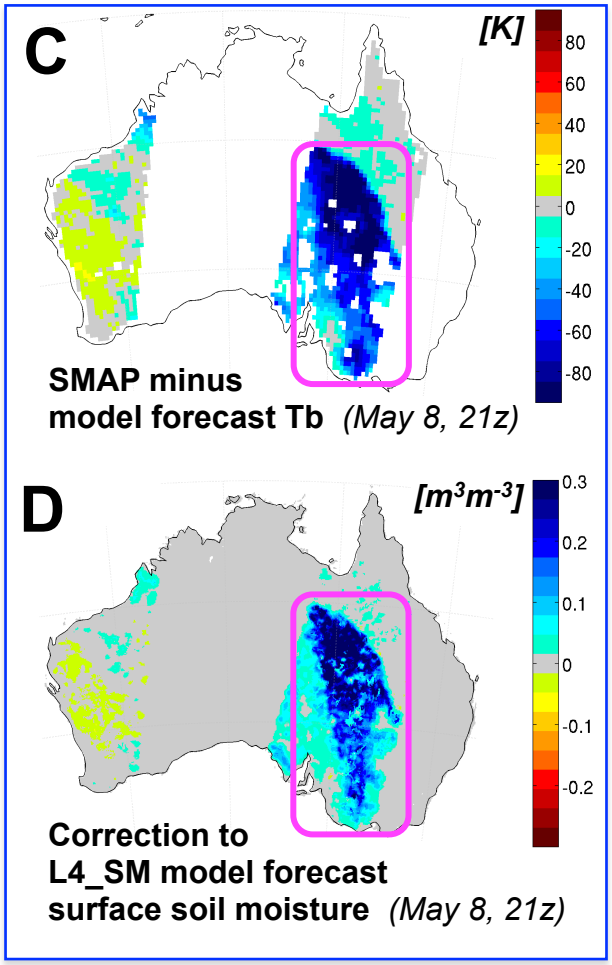
Merging SMAP observations into the GEOS-5 land assimilation system to estimate root zone soil moisture.

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 warm compared to SMAP observations (**C**).

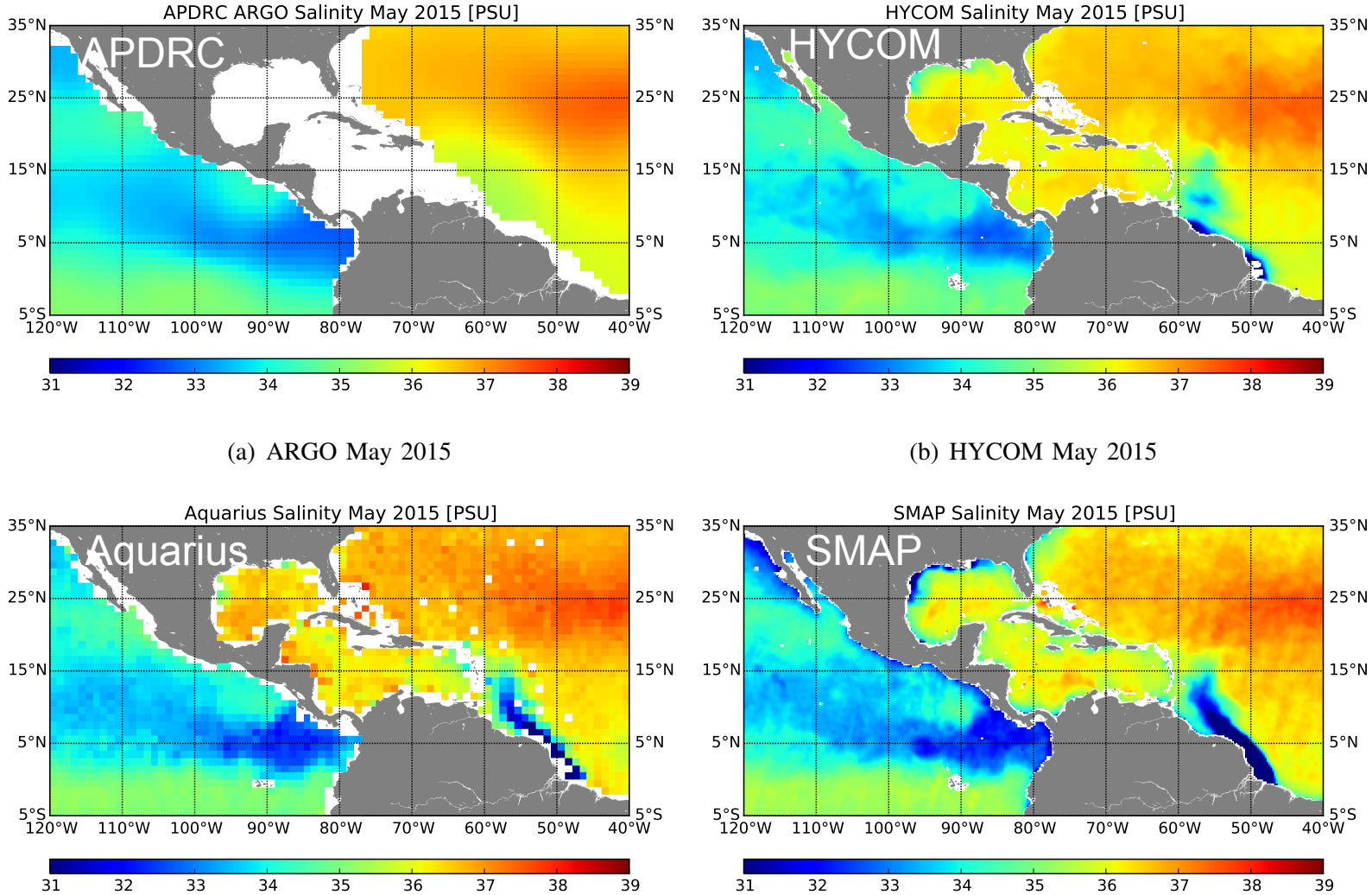
The L4_SM analysis of SMAP Tb observations thus resulted in a substantial correction of the model forecast soil moisture (**D**).





Intercomparison of Aquarius, SMAP, Hycom, and APDRC SSS (May 2015)
Fore et al., IGARSS 2016

Jet Propulsion Laboratory
California Institute of Technology



(a) ARGO May 2015

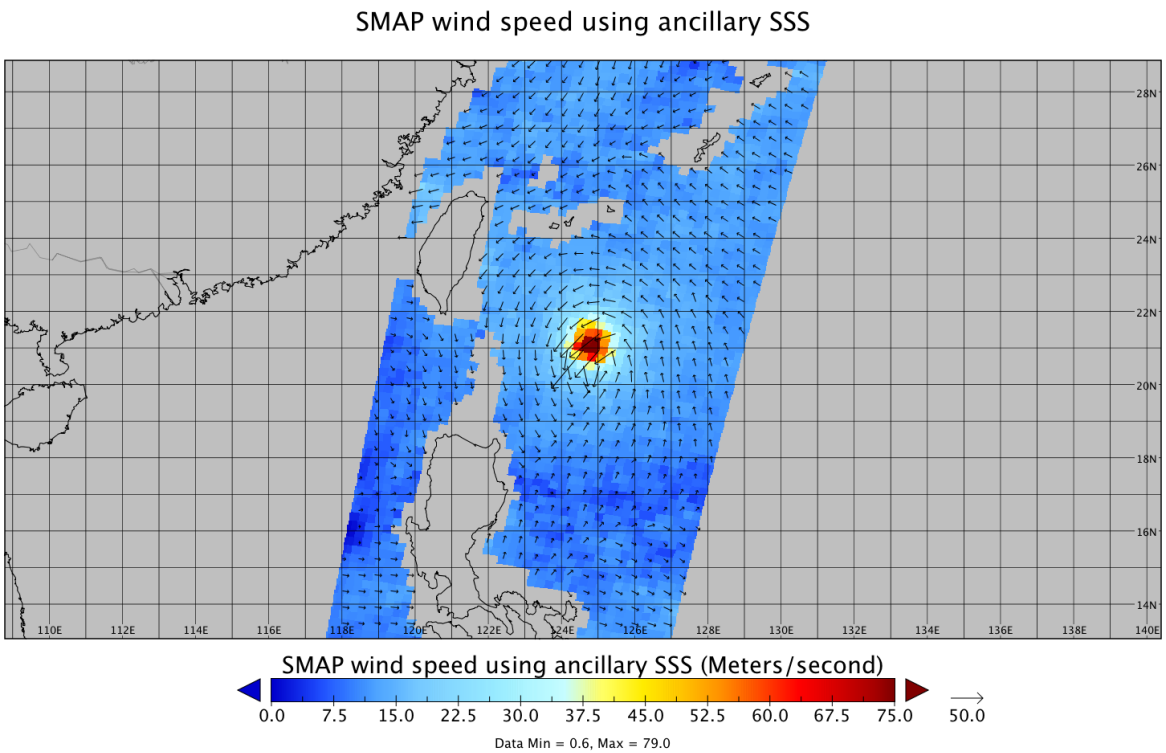
(b) HYCOM May 2015

(c) Aquarius May 2015

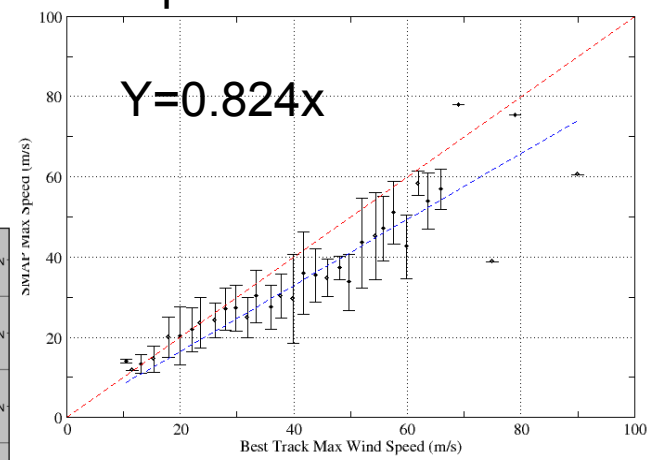
(d) SMAP T_B-only May 2015

JPL SMAP Radiometer Vector Wind for Hurricanes
Yueh et al, IGARSS 2016

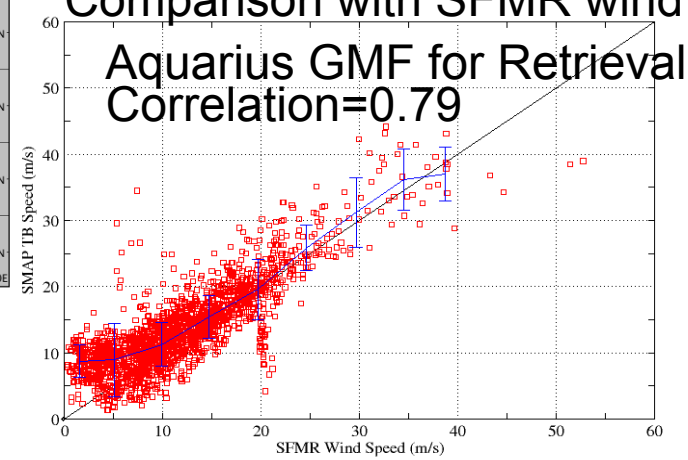
Typhoon Nepartak, July 6, 2016, 22UT
SMAP max wind speed 79 m/s
JTWC best track: 77 m/s



Comparison with best track



Comparison with SFMR wind



Good agreement with best track and SFMR winds in 2015

Topics

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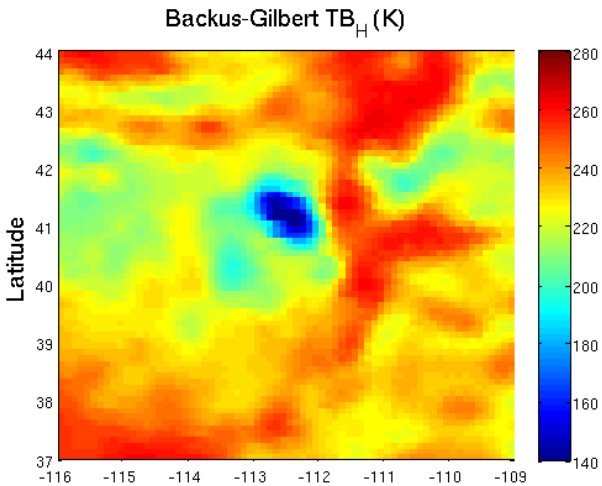
- Mission Status
- Current Baseline Radiometer Science Performance
- Science and Application Results
- **<u>Science Enhancement Tasks</u>**
  - Enhanced Resolution Passive product development
  - Radiometer-Derived F-T Product
  - SMAP Radiometer and Sentinel Radar Active-Passive Product
- Summary

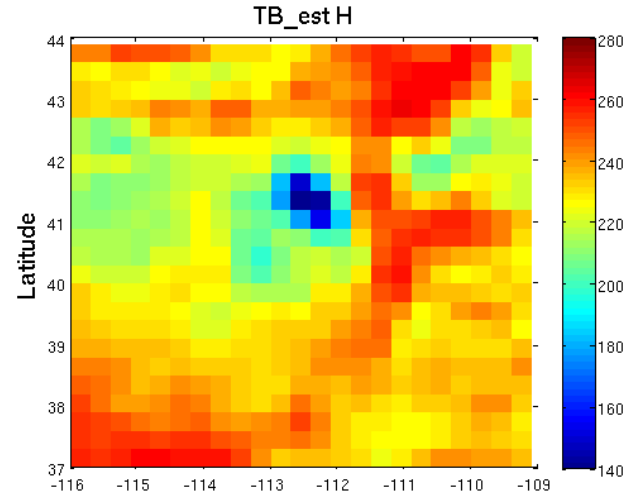
Radiometer Resolution Enhancement Results Using the Backus-Gilbert (BG) Algorithm

Jet Propulsion Laboratory
California Institute of Technology

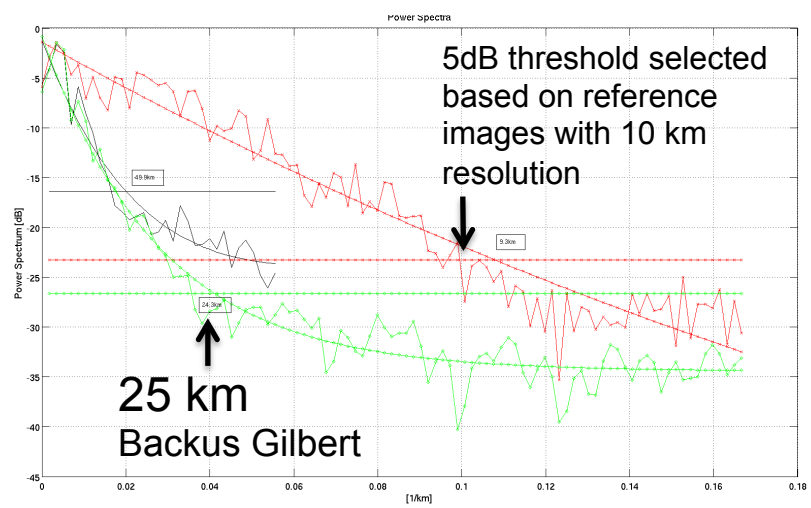
Backus Gilbert Optimum Interpolation 0.1x0.1 deg



Simulated SMAP data binned on 0.3x0.3 deg grid
Similar to nominal SMAP grid



- Use high-fidelity SMAP radiometer simulator to provide test- and evaluation-data
- Apply the BG algorithm to optimally interpolate the data on 3 km swath grid
- Spectral analysis of the BG indicates a spatial resolution of **25 km** (5 dB threshold above noise floor)



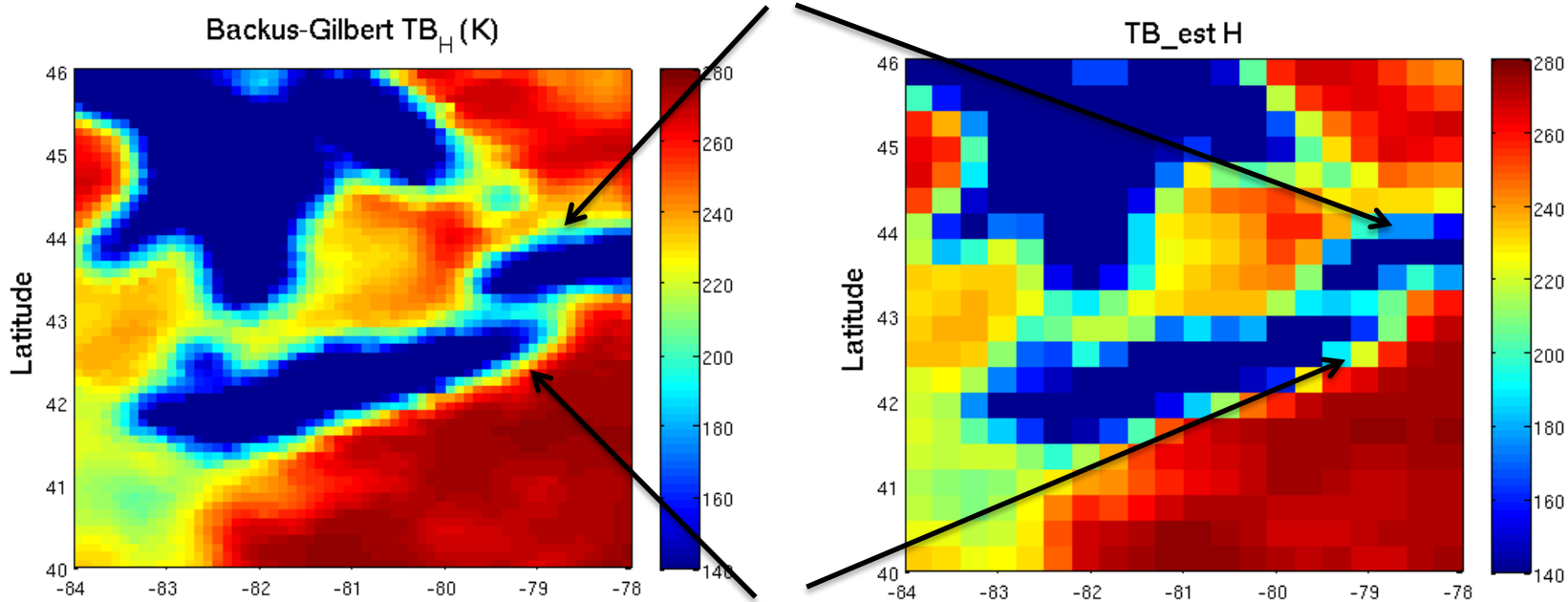
Backus-Gilbert Resolution Enhancement Reduces Land Surface Heterogeneity Error (Case 3)

Jet Propulsion Laboratory
California Institute of Technology

Backus Gilbert Optimum Interpolation 0.1x0.1 deg

Simulated SMAP data binned on 0.3x0.3 deg grid
Similar to nominal SMAP grid

Difference of ~10-30 K



Difference of ~20-30 K

- Backus-Gilbert provides better resolution of features with sharp boundaries than the SMAP 0.3 deg gridded product.
- BG reduces the spatially averaging errors due to inland water body brightness temperature contrasts

Soil Moisture Retrieval from Backus-Gilbert TB

L2_SM_P_BG

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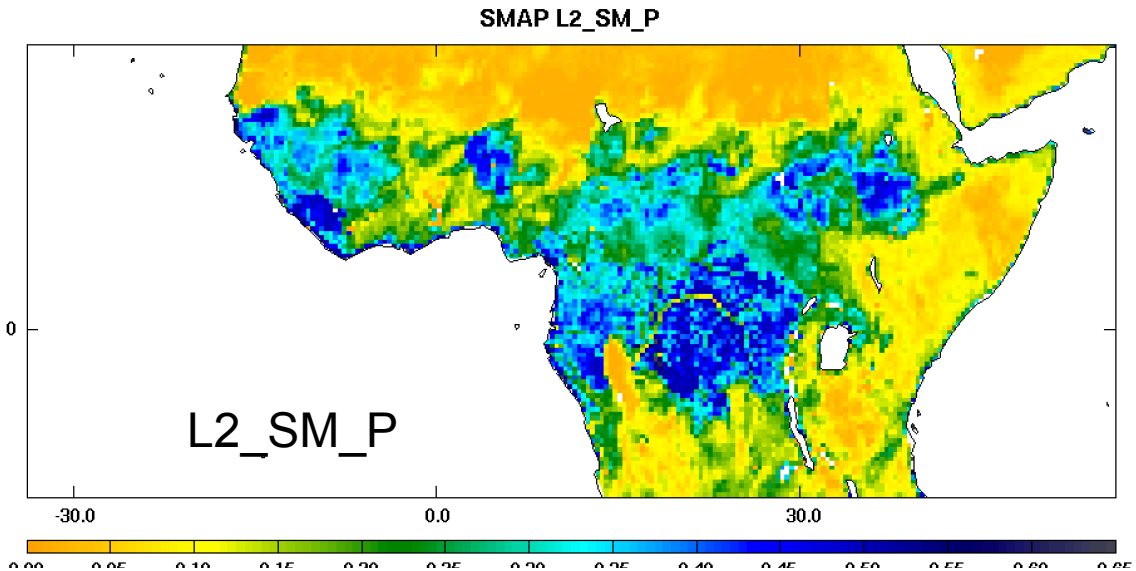

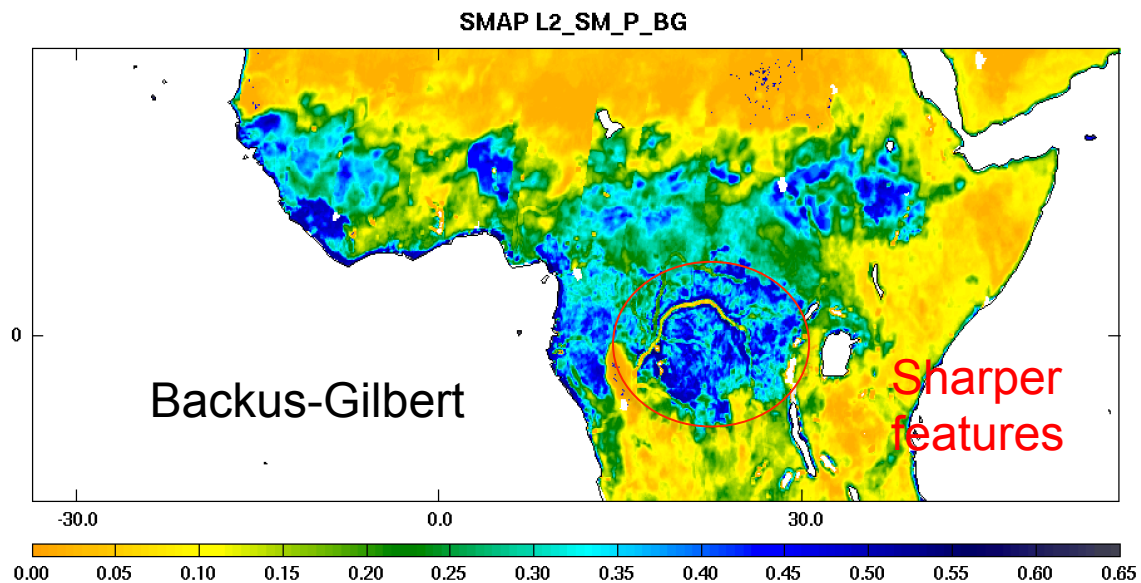

Passive FT for SMAP

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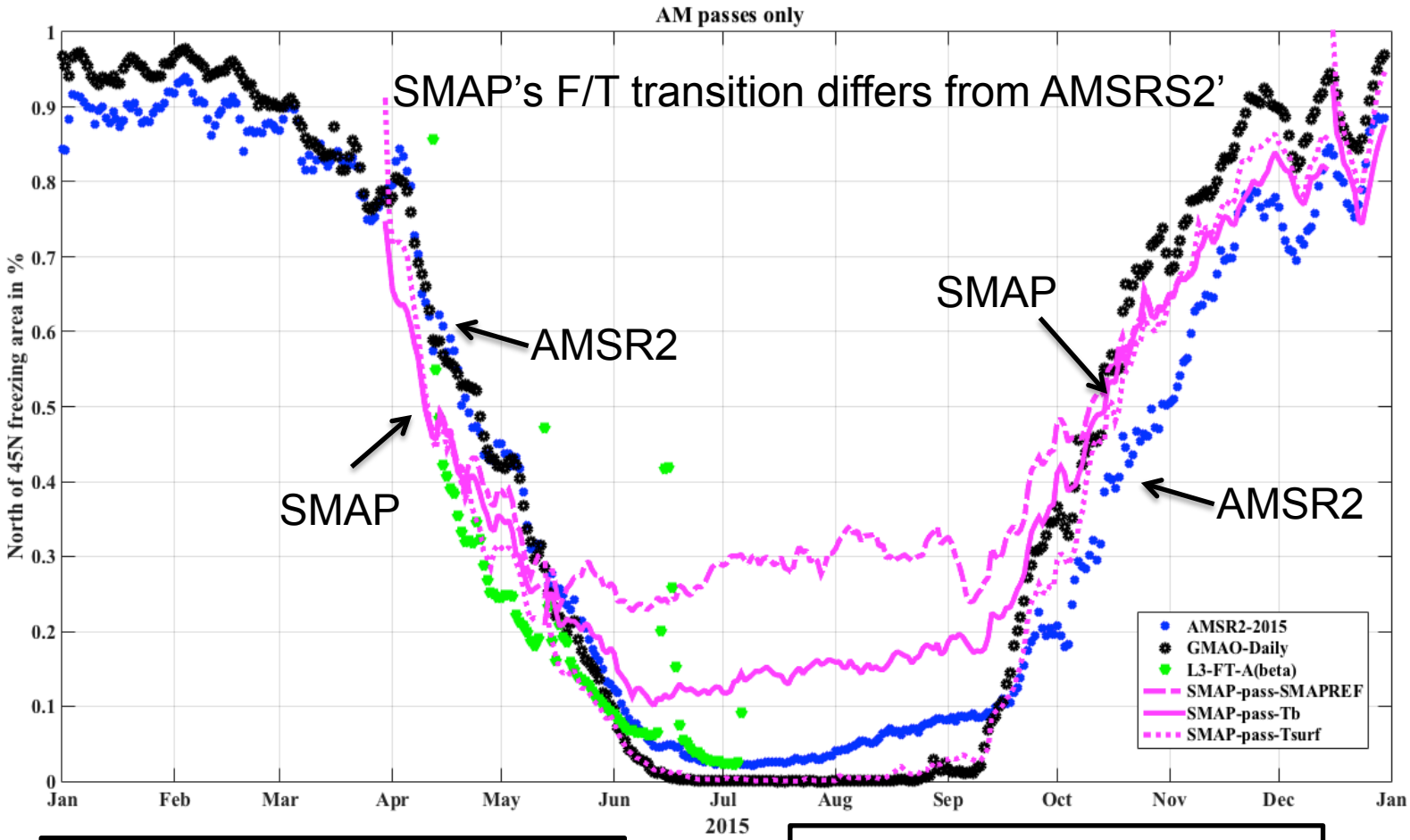
California Institute of Technology

With the loss of the radar, there are three primary capabilities that can be recovered by using the radiometer data for FT retrieval:

- ***SMAP Passive FT products complement existing AMSR-2 FT products***
- ***Autonomous SMAP-derived FT flag for passive soil moisture retrievals in L2_SM_P***
  - Passive FT flag replaces radar FT flag in L2_SM_P product
- ***Global FT state input to L4_C, via the FT flags in L3_SM_P***
  - Augment L3_SM_P with PM orbits to provide transition states

Any future resolution enhancements of the radiometer data (L1C_TB*) can also be incorporated in this plan.

Cross-Product Comparison (GMAO, AMSR2, L3-FT-A, L3-FT-P)

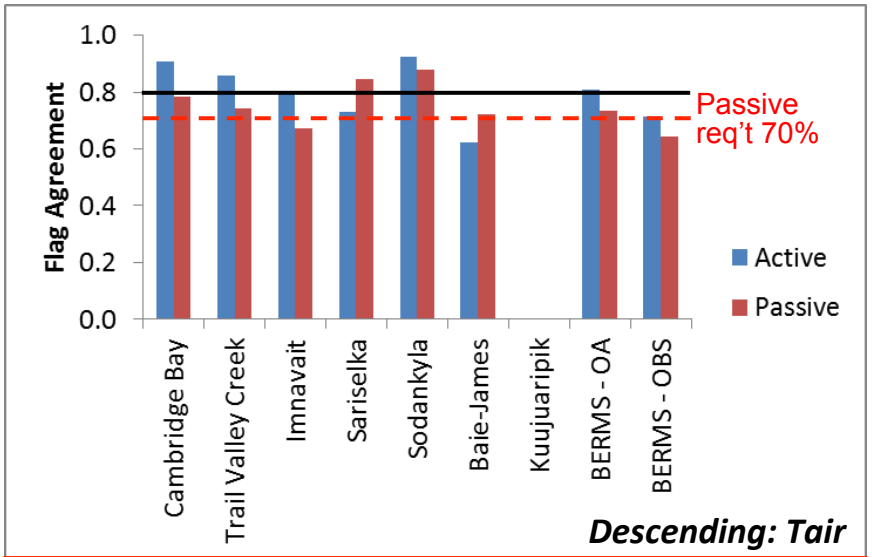


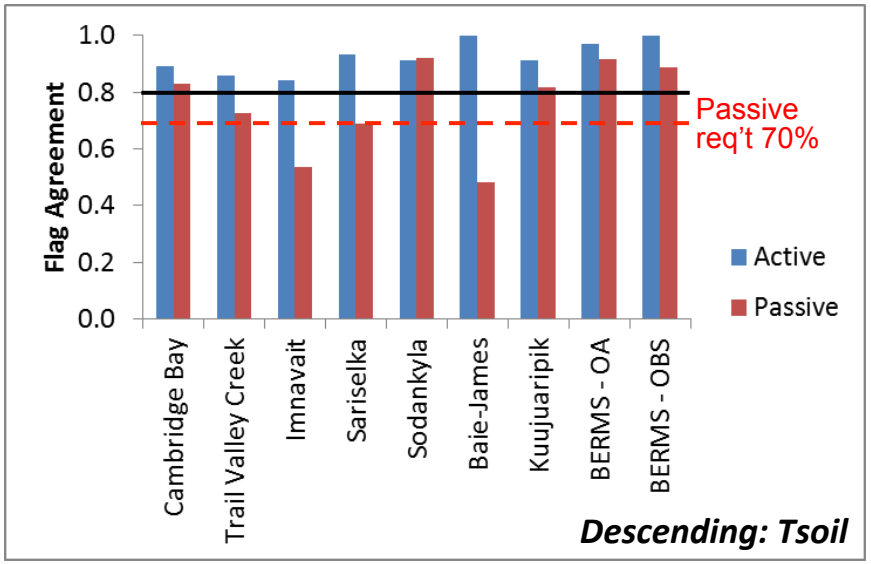
SMAP-pass-TB:
TBv/TBh > 273K, thaw

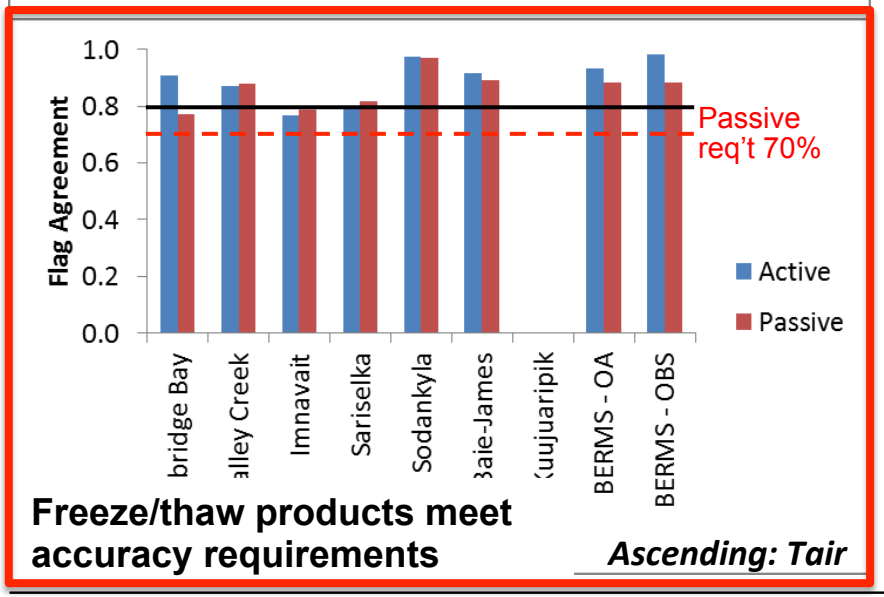
SMAP-pass-Tsurf:
if Tsurf > 5C, thaw
if Tsurf < - 5C, freeze

Summary of Freeze/Thaw Performance Assessment

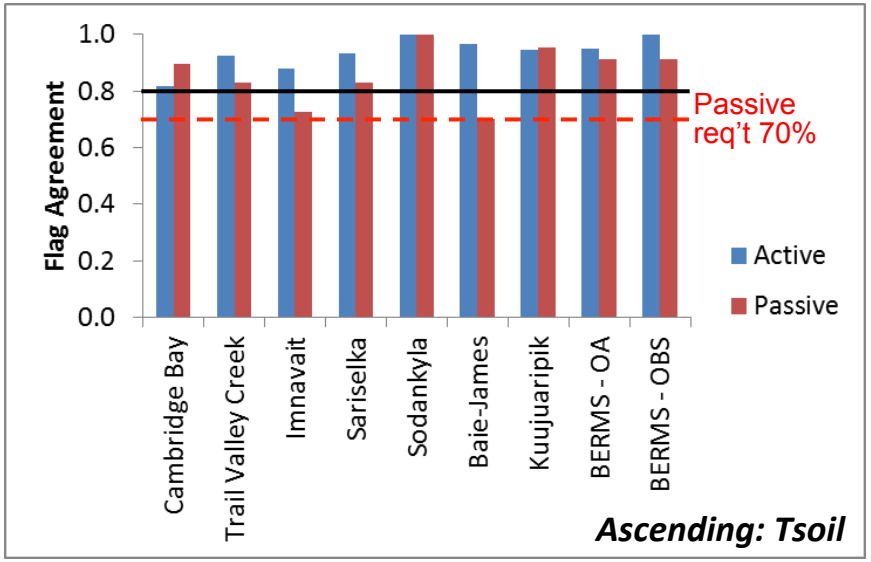
Jet Propulsion Laboratory
California Institute of Technology







Freeze/thaw products meet accuracy requirements



Preliminary SMAP Sentinel-1 AP Results

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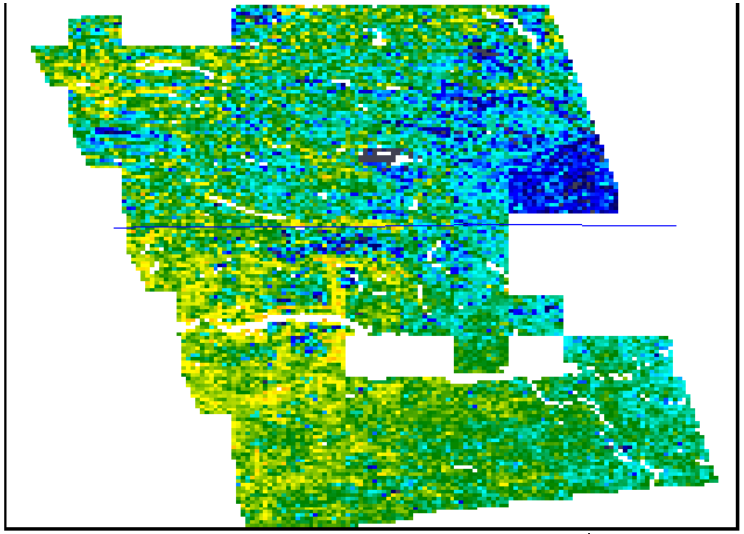
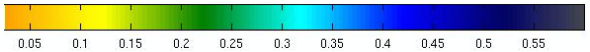
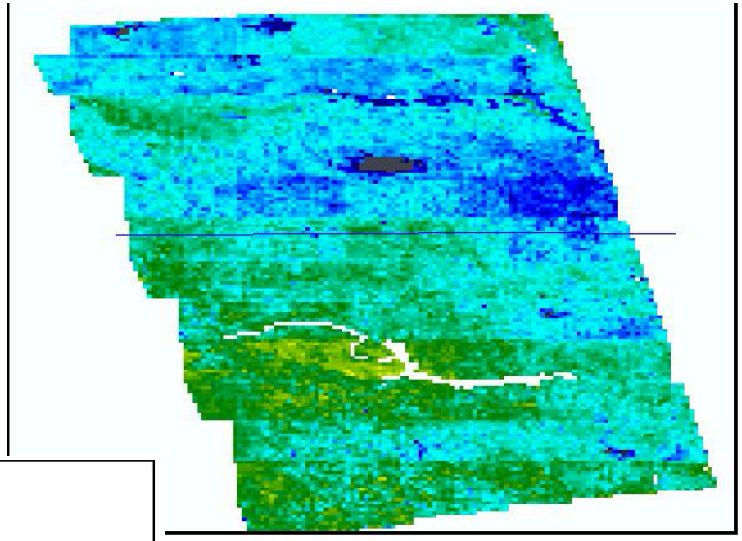
3 [km] SMAP Radar+Radiometer



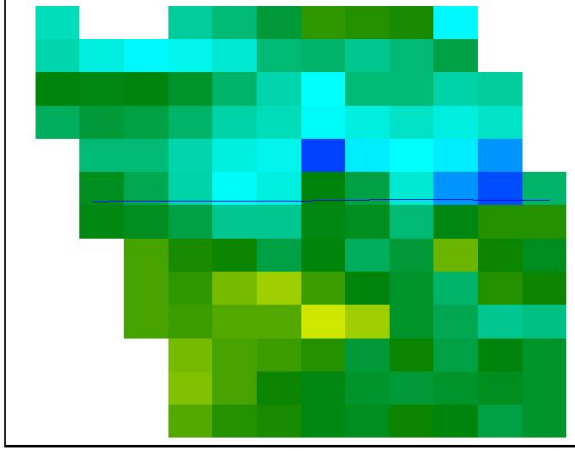


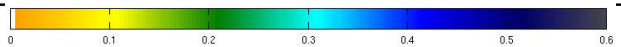
Soil Moisture [$cm^3\ cm^{-3}$]

3 [km] SMAP Radiometer+Sentinel Radar



36 [km] SMAP Radiometer





- Based on SMAP AP algorithm
- Parameters tuned from L-band to C-band using May-June data and theoretical model
- Some wet bias with respect to the SMAP AP product

Southern Canada

(Example from period with SMAP radar and radiometer data acquisition)

Source: N. Das (JPL)

SMAP-Sentinel Joint Retrievals Validation

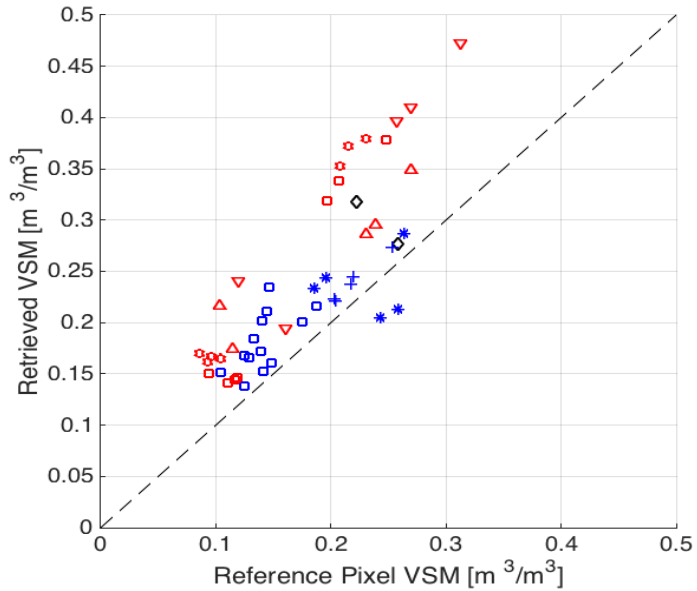
Jet Propulsion Laboratory
California Institute of Technology

L2_SM_SP3km-BL (-)

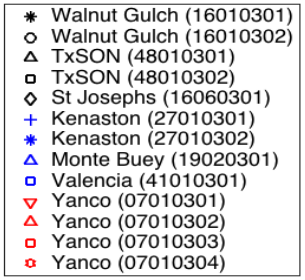
2015/04/13 - 2015/07/08

Performance Metrics

Ref Pixel	ubRMSE	Bias	RMSE	R
Walnut Gulch (1601-03-01)	NaN	NaN	NaN	NaN
Walnut Gulch (1601-03-02)	NaN	NaN	NaN	NaN
TxSON (4801-03-01)	NaN	NaN	NaN	NaN
TxSON (4801-03-02)	NaN	NaN	NaN	NaN
St Josephs (1606-03-01)	0.038	0.057	0.069	-1.000
Kenaston (2701-03-01)	0.003	0.021	0.021	0.989
Kenaston (2701-03-02)	0.041	0.008	0.042	0.098
Monte Buey (1902-03-01)	NaN	NaN	NaN	NaN
Valencia (4101-03-01)	0.022	0.040	0.046	0.621
Yanco (0701-03-01)	0.044	0.119	0.127	0.950
Yanco (0701-03-02)	0.022	0.073	0.076	0.949
Yanco (0701-03-03)	0.047	0.075	0.088	0.983
Yanco (0701-03-04)	0.040	0.105	0.112	0.994
MEAN:	**0.032**	**0.062**	**0.073**	**0.573**
SMAP AP Soil Moisture REQUIREMENT:	**<0.04**			



- Preliminary SMAP/Sentinel-1 soil moisture meets the SMAP AP ubRMSE requirement
- Wet bias to be reduced



Source: A. Colliander

Planned Science Product Update Schedule

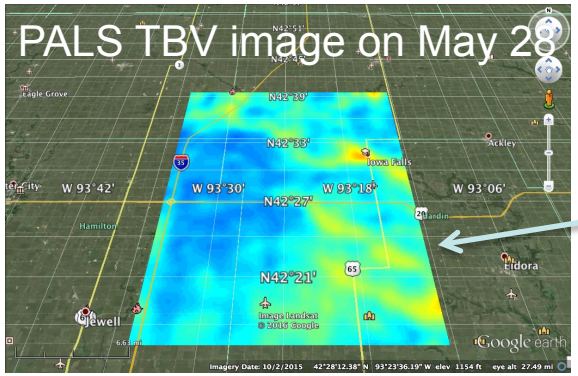
Jet Propulsion Laboratory
California Institute of Technology

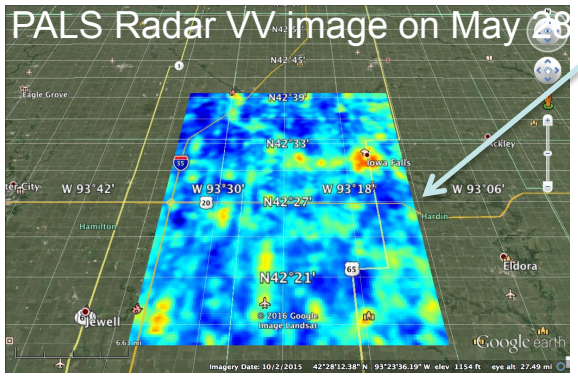
Data Product		4/16 V2	12/16 V1_E	3/17 V3, V1_E	3/18 V4, V2_E
L1B_TB	Baseline products with annual updates	✓		✓	✓
L1C_TB		✓		✓	✓
L2/3_SM_P		✓		✓	✓
L4_SM		✓		✓	✓
L4_C		✓		✓	✓
L1B_S0_LoRes	SMAP radar products with final delivery in April 2016	✓			
L1C_S0_HiRes		✓			
L2/3_SM_A		✓☛			
L2/3_SM_AP		✓			
L3_FT_A		✓			
L1B_TB_E (Enhanced resolution)	Science recovery products		✓		✓
L1C_TB_E (Enhanced resolution)			✓		✓
L2/3_SM_E (Enhanced resolution)			✓		✓
L3_FT_P (Enhanced resolution)			✓		✓
L3_SM_SP (SMAP/Sentinel-Passive)				✓	✓

SMAP and Sentinel-1 Collaboration on SMAPVEX16 Campaign

Jet Propulsion Laboratory
California Institute of Technology

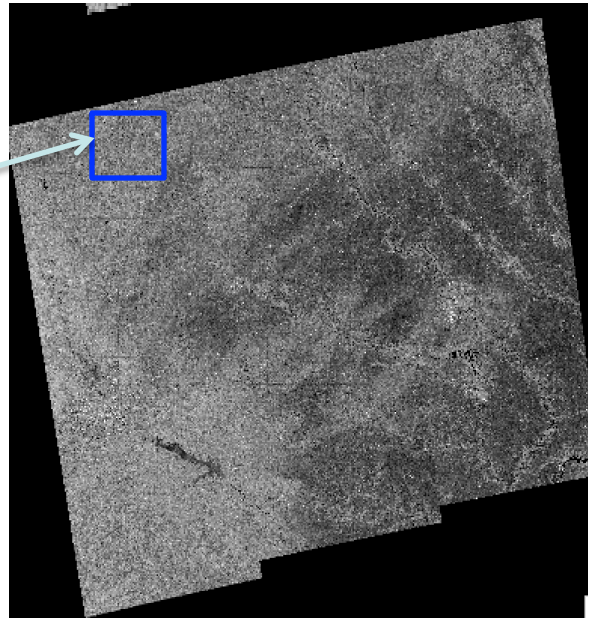
- SMAPVEX16 campaign is being held at Iowa and Manitoba from late May through mid-August 2016
- NASA/JPL Passive-Active L-band Sensor (PALS) is being flown on Airborne Imaging DC-3 over the test sites.
- Sentinel-1A has included the SMAPVEX16 test sites in their data acquisition plan





SMAP South Fork 36 km domain

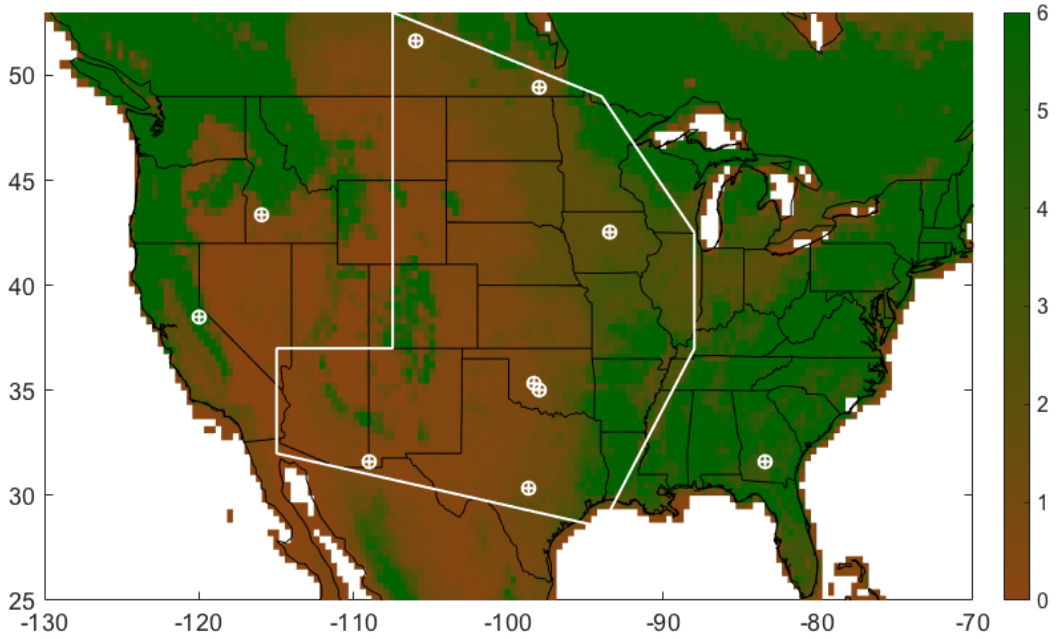
Sentinel-1A VV image in Iowa on May 27, 2016



Sentinel 1A VV [-20, 0dB] gray scale

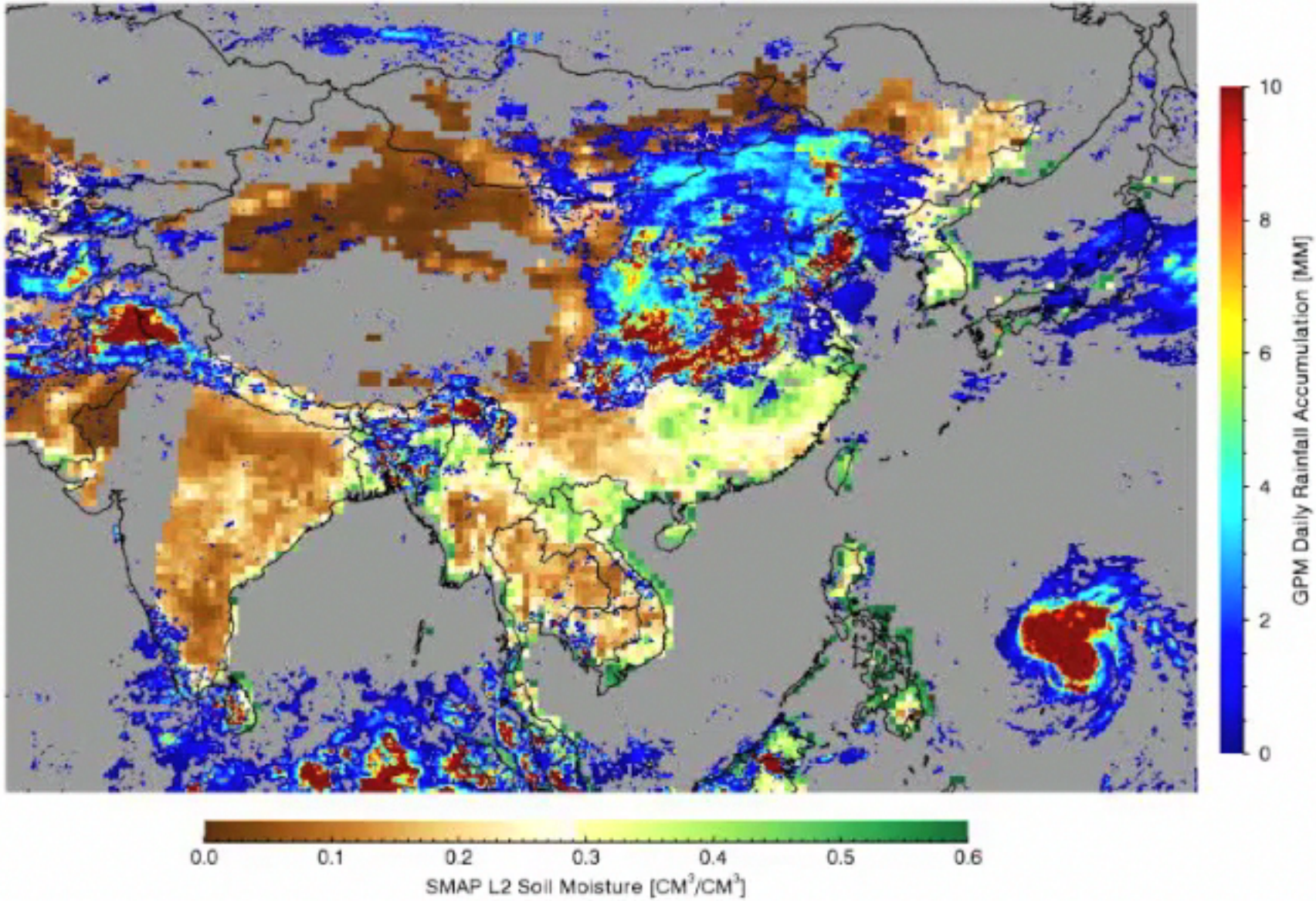
Collaboration with Sentinel-1 Project

- Sentinel-1A has started data acquisition to support the SMAPVEX16 campaign
- Sentinel-1B will acquire data over an expanded region in US starting in July during the commissioning phase. The region in the polygon encloses the priority/relevant core cal/val sites, US croplands and relevant Midwest areas of land-atmosphere coupling.

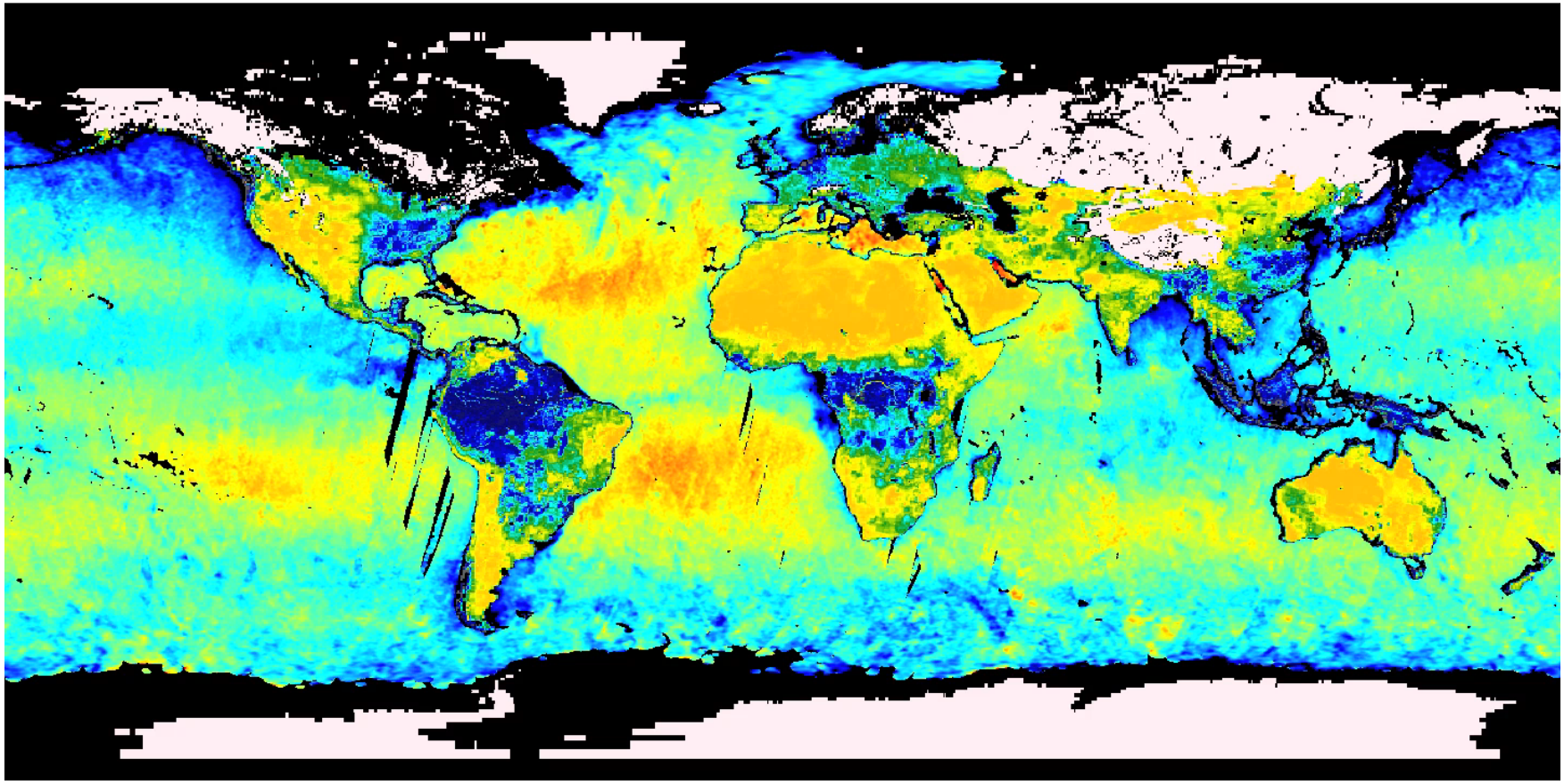


SMAP Soil Moisture and GPM Rain Accumulation

04/01/2015



SMAP: Soil Moisture + Sea Surface Salinity
Mar 29 - Apr 05, 2015



cm3/cm3 (soil moisture)

0.0 0.1 0.2 0.3 0.4 0.5 0.6

psu (sea surface salinity)

30.0 32.0 34.0 36.0 38.0 40.0

Summary

Jet Propulsion Laboratory
California Institute of Technology

- SMAP radiometer has been performing exceptionally well
- Radiometer soil moisture products released at the end of April meet 0.04 ubRMSE requirements
- Operational processing codes for radiometer resolution enhancement algorithm (Backus Gilbert) and soil moisture retrieval being developed
- New passive freeze/thaw products will meet requirements
- Preliminary soil moisture retrievals from 2+ months of SMAP/Sentinel-1 data are very encouraging –algorithms being tested using a longer time series
- Establishing strong collaboration with the Sentinel-1 project
- Many science and and applications of SMAP data demonstrated

SMAP Related Sessions and Papers

- 37 papers with “SMAP” in the title in IGARSS
- SMAP Special Session (MO3.L4, MO4.L4) – Room 309B
- SMAP Soil Moisture Session (TU1.L4) – Room 309B
- SMAP Application Session (TH1.L4 and TH2.L4) – Room 309B
- International Spaceborne Imaging TC Meeting, which is L-Band Inter-Comparison Working Group
  - The time/location is: Tuesday, 17:30, RM 306B