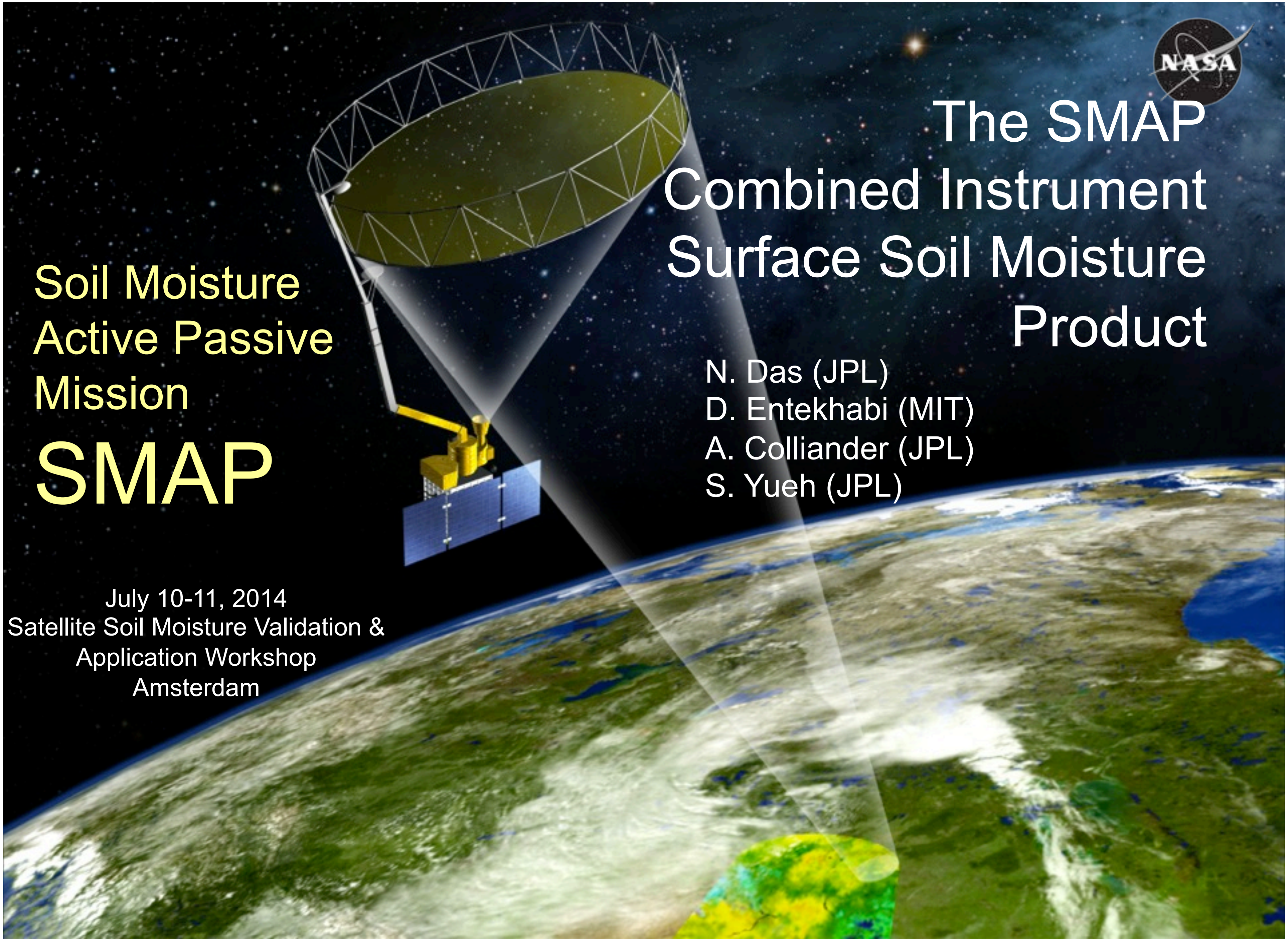
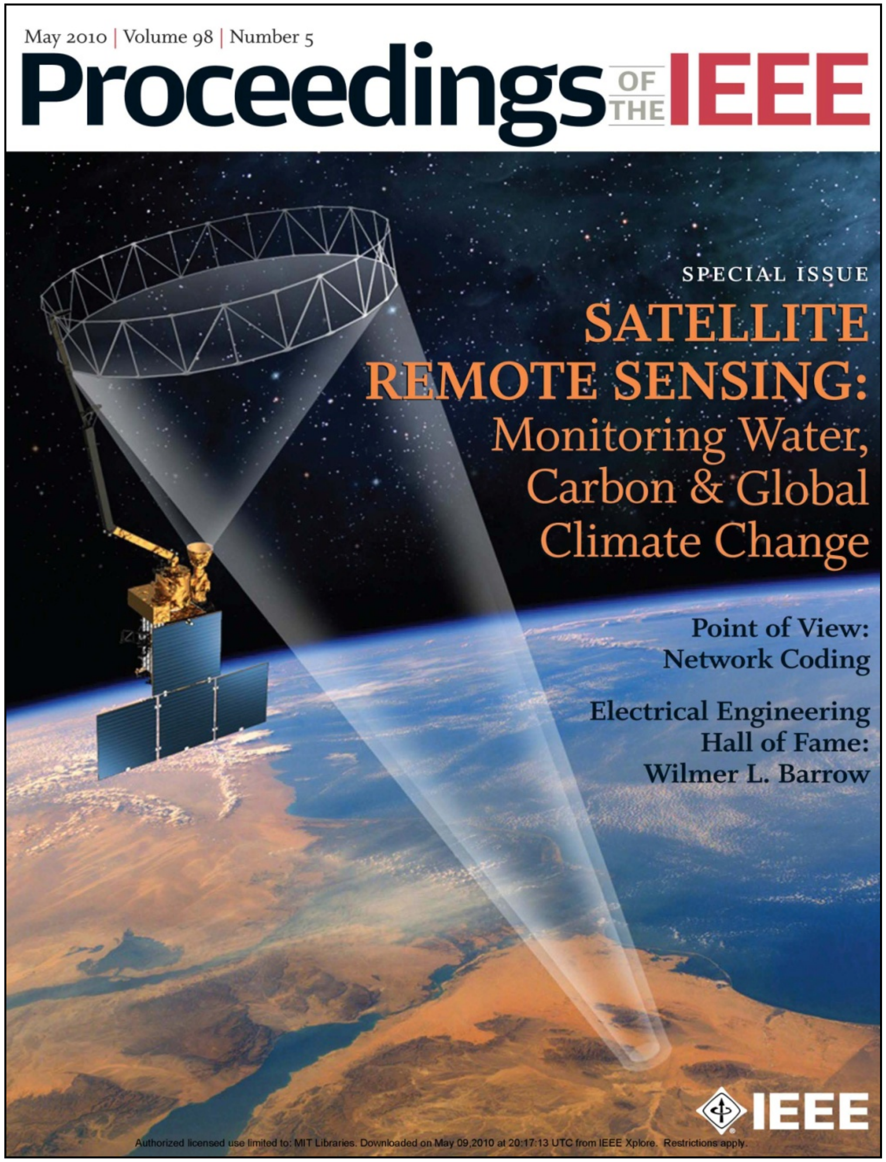

The SMAP
Combined Instrument
Surface Soil Moisture
Product
N. Das (JPL)
D. Entekhabi (MIT)
A. Colliander (JPL)
S. Yueh (JPL)
Soil Moisture
Active Passive
Mission
SMAP
July 10-11, 2014
Satellite Soil Moisture Validation &
Application Workshop
Amsterdam
NASA

Outline

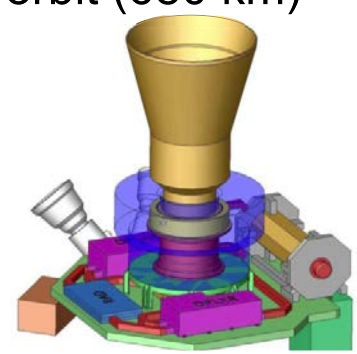
Jet Propulsion Laboratory
California Institute of Technology

- Measurements Approach Reminder
- Mission Status
- The Active-Passive Surface Soil Moisture Product
  - Technical Approach
  - Testing Results
  - Error Analysis
- SMAP Applications
- SMAP Cal/Val
- RFI
- The SMAP Handbook
- Summary

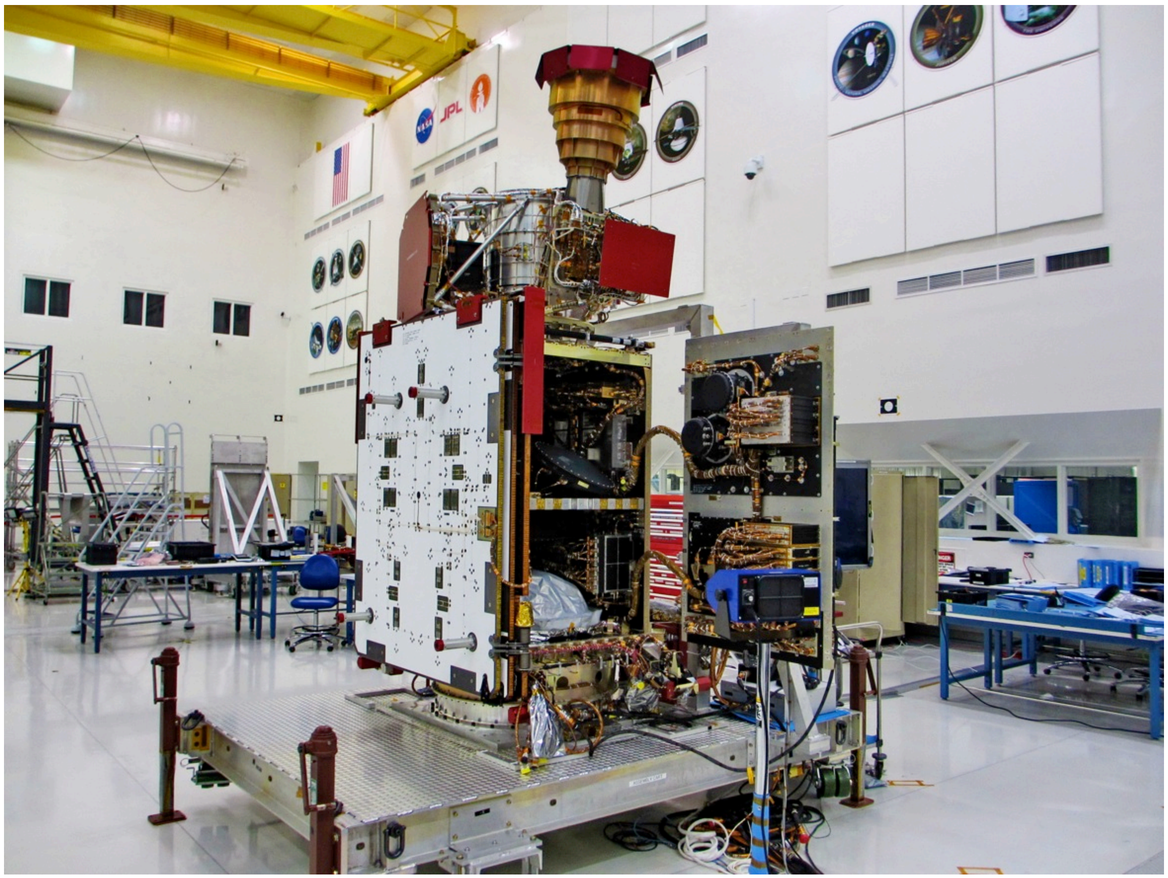
SMAP Mission Concept



- L-band unfocused SAR and radiometer system, offset-fed 6 m light-weight deployable mesh reflector. Shared feed for
  - 1.26 GHz dual-pol <u>Radar</u> VV, HH and HV at 1-3 km (30% nadir gap)
  - 1.4 GHz polarimetric (H, V, 3^{rd} and 4^{th} Stokes) <u>Radiometer</u> at 40 km (3 dB)
- Conical scan, fixed incidence angle across swath
- Contiguous 1000 km swath with 2-3 days revisit (8 days exact repeat)
- Sun-synchronous 6am/6pm orbit (680 km)
- Launch November 5, 2014

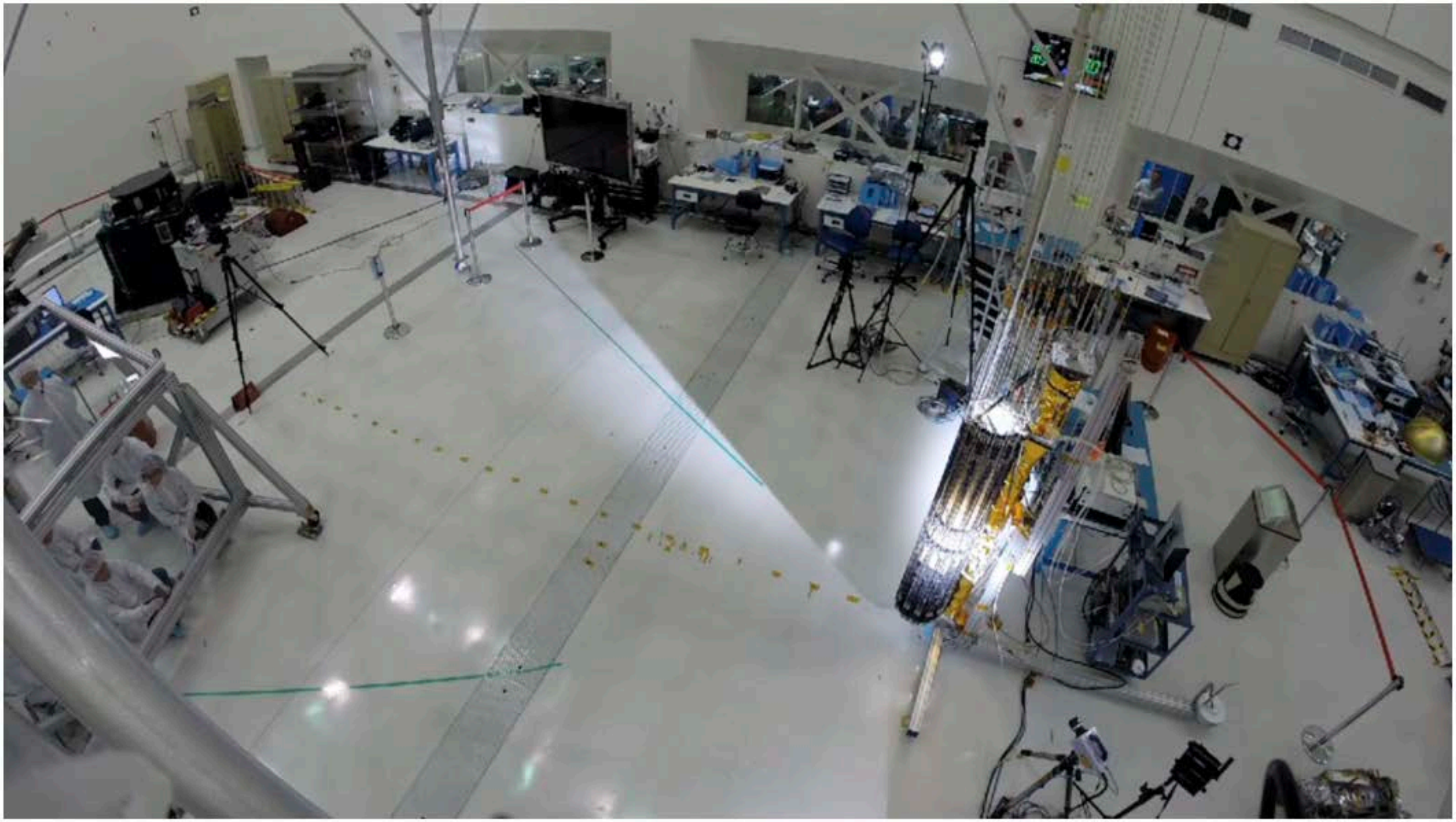


January 2014: Instrument and Spacecraft Integration

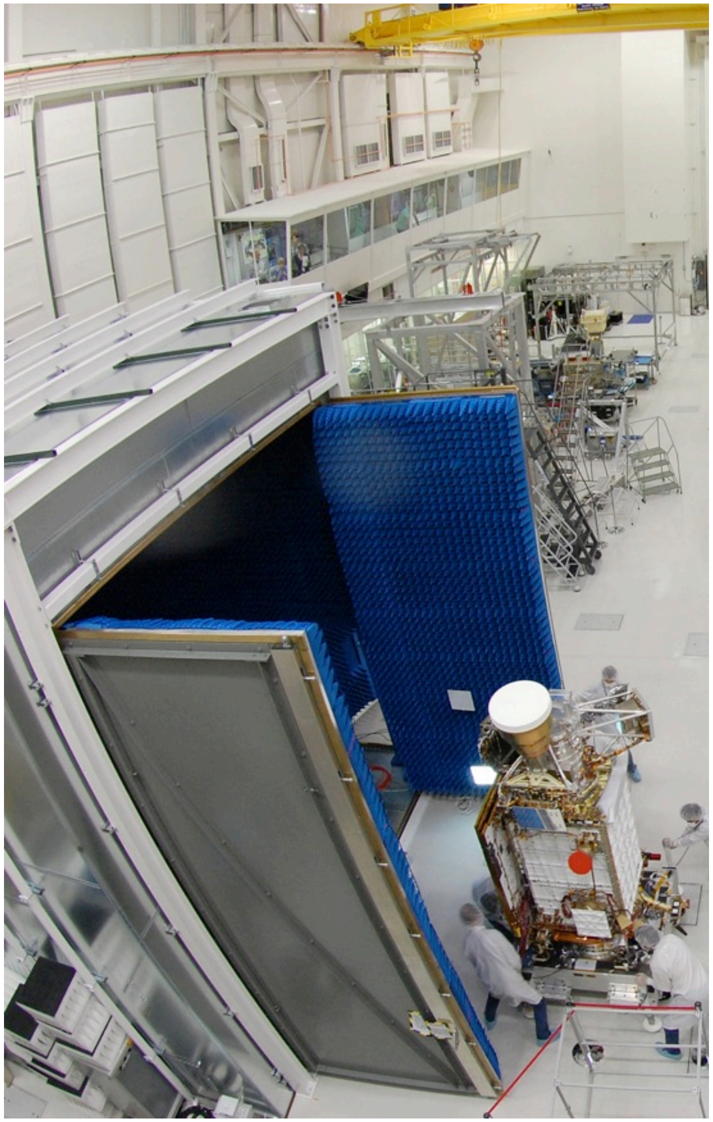


March 2014: Observatory Mate with Launch Vehicle Adapter and Separation System

April 2014: Reflector Bloom Deployment Testing



May 2014: Observatory in EMI/EMC Testing



June 2014: Mission Systems Operational Readiness Test

SMAP Science Products

Product	Description	Gridding (Resolution)	Latency**	
L1A_Radiometer	Radiometer Data in Time-Order	-	12 hrs	Instrument Data
L1A_Radar	Radar Data in Time-Order	-	12 hrs	
L1B_TB	Radiometer T_B in Time-Order	(36x47 km)	12 hrs	
L1B_S0_LoRes	Low Resolution Radar σ_o in Time-Order	(5x30 km)	12 hrs	
L1C_S0_HiRes	High Resolution Radar σ_o in Half-Orbits	1 km (1-3 km)	12 hrs	
L1C_TB	Radiometer T_B in Half-Orbits	36 km	12 hrs	
L2_SM_A	Soil Moisture (Radar)	3 km	24 hrs	Science Data (Half-Orbit)
L2_SM_P	Soil Moisture (Radiometer)	36 km	24 hrs	
L2_SM_AP	Soil Moisture (Radar + Radiometer)	9 km	24 hrs	
L3_FT_A	Freeze/Thaw State (Radar)	3 km	50 hrs	Science Data (Daily Composite)
L3_SM_A	Soil Moisture (Radar)	3 km	50 hrs	
L3_SM_P	Soil Moisture (Radiometer)	36 km	50 hrs	
L3_SM_AP	Soil Moisture (Radar + Radiometer)	9 km	50 hrs	
L4_SM	Soil Moisture (Surface and Root Zone)	9 km	7 days	Science Value-Added
L4_C	Carbon Net Ecosystem Exchange (NEE)	9 km	14 days	

L-band Active/Passive Approach

- Soil moisture retrieval algorithms are derived from a long heritage of microwave modeling and field experiments

  MacHydro'90, Monsoon'91, Washita92, Washita94, SGP97, SGP99, SMEX02, SMEX03, SMEX04, SMEX05, CLASIC, SMAPVEX08, CanEx10, SMAPVEX12

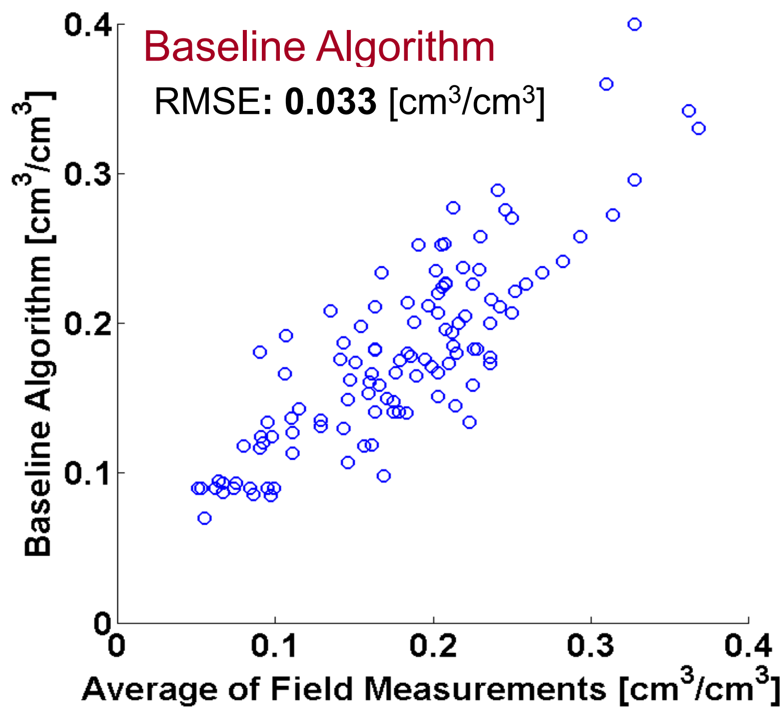
- **Radiometer** - High accuracy (less influenced by roughness and vegetation) but coarser spatial resolution (40 km)

- **Radar** - High spatial resolution (1-3 km) but more sensitive to surface roughness and vegetation

  - **Combined Radar-Radiometer** product provides intermediate 9km resolution with 0.04 [cm^3 cm^{-3}] 1-σ accuracy to meet science objectives

SMEX02 Study Region With PALS Airborne and *in situ* Ground-Truth

SMAP Baseline Active-Passive Algorithm



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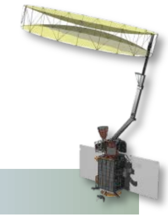
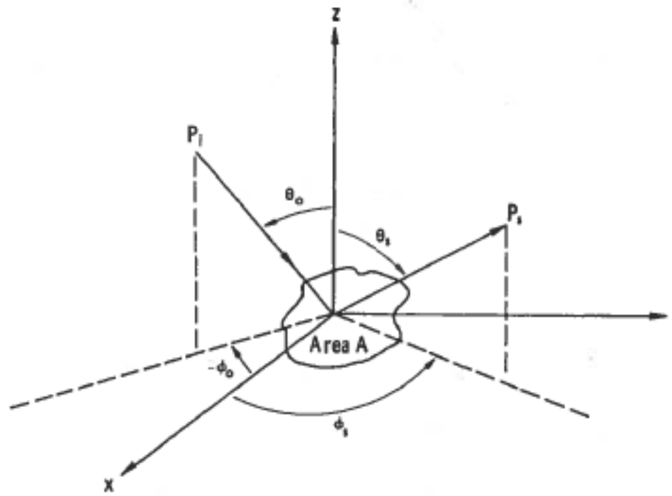
ε_p - σ_{pp} Energy Conservation



Emissivity ε of a Rough Surface is the Integral of Bistatic Scattering Cross-Section per Unit Area σ^0 Over the Upper Half-Space $d\Omega$:

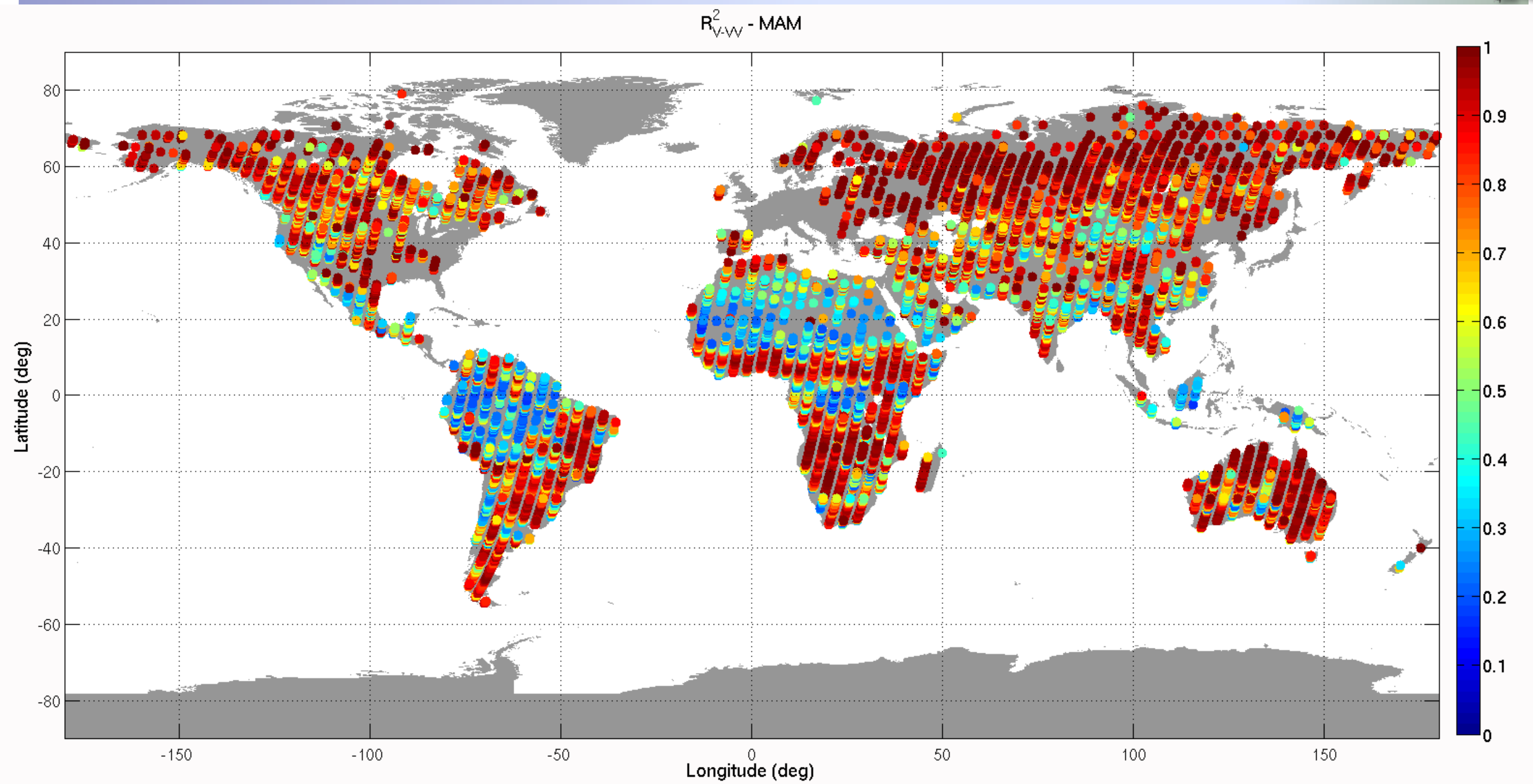
<u>Kirchhoff Radiation Law</u>

$$\varepsilon = 1 - \frac{1}{4\pi\cos(\theta_0)} \int \sigma^0 \; d\Omega$$



- Here Estimated Statistically Using Aquarius Active and Passive Measurements.
- Global and For Surfaces With Complex Mixture of Vegetation, Surface Roughness and Surface Reflectivity.

Strength of ε_V - σ_{VV} Relationship in Aquarius Measurements



Percentage Explained-Variance (R^2)

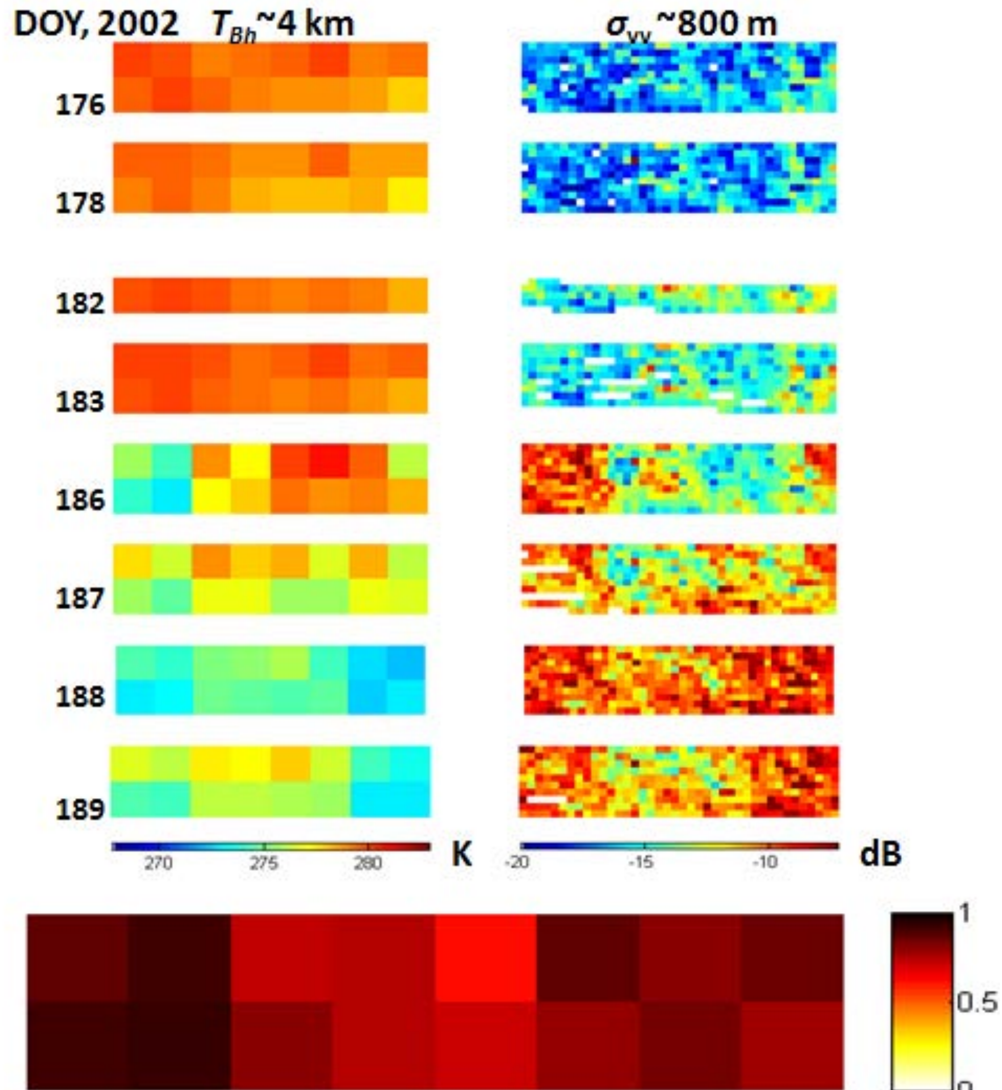
Active Passive Algorithm Fundamentals

Start with the basic premise that *temporal* variations in σ_{pp} are also reflected in variations in T_{B_p}:

$$T_{B_p} = \alpha + \beta \cdot \sigma_{pp}$$

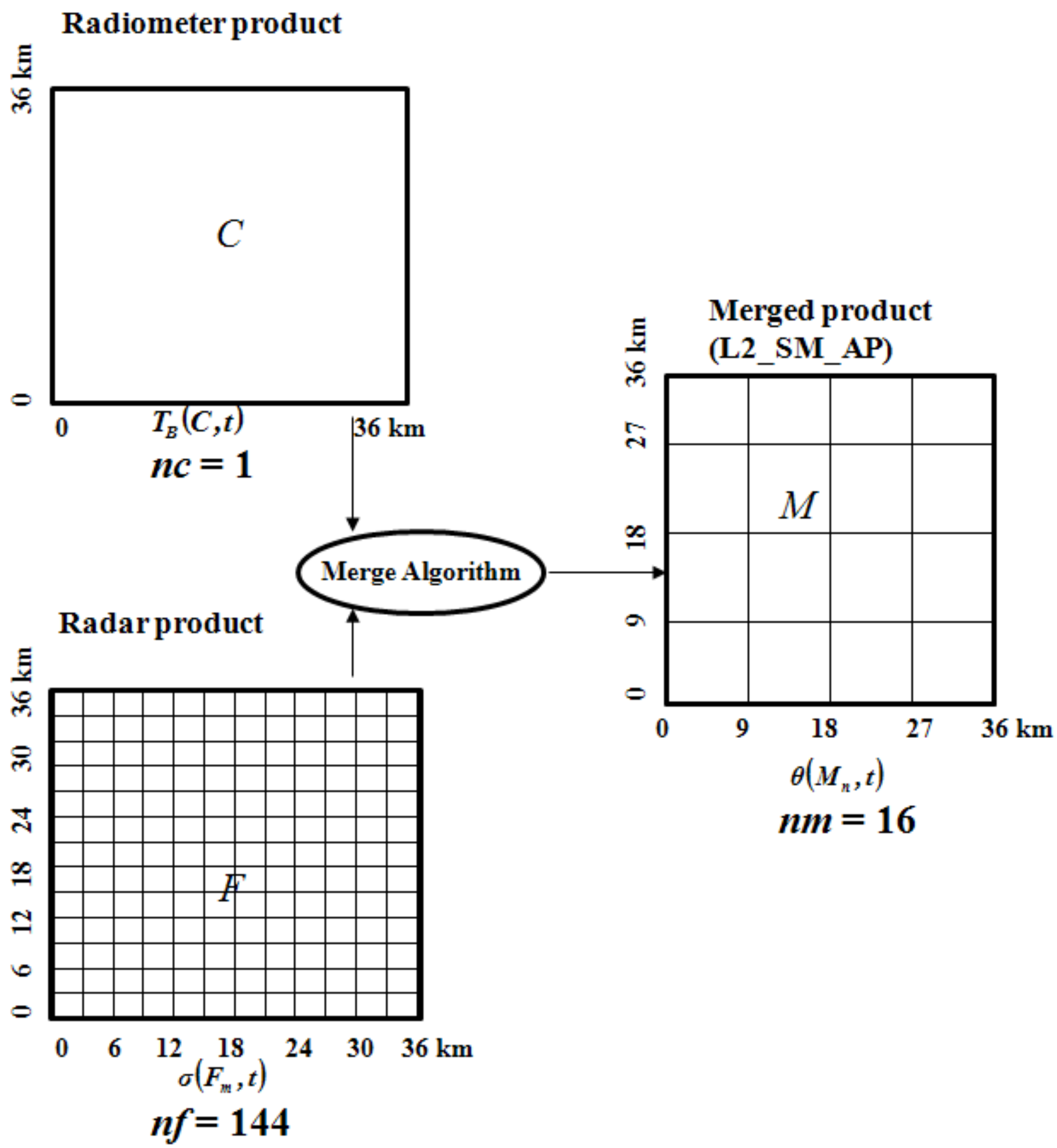
Parameter β [K dB^{-1}] is a sensitivity parameter.

SMEX02 PALS Observations



R^2 (Low: 0.65, High: 0.93) values between T_{Bh} and σ_{vv}

Multiple Scales Notation



Brightness Temperature Disaggregation Algorithm

Evaluate $T_{B_p} = \alpha + \beta \cdot \sigma_{pp}$ at scales C and M:

$$T_{B_p}(C) = \alpha(C) + \beta(C) \cdot \sigma_{pp}(C)$$

$$T_{B_p}(M) = \alpha(M) + \beta(M) \cdot \sigma_{pp}(M)$$

Subtract one from another:

$$T_{B_p}(M) - T_{B_p}(C) = [\alpha(M) - \alpha(C)] + \beta(M) \cdot \sigma_{pp}(M) - \beta(C) \cdot \sigma_{pp}(C)$$

Add and subtract $\beta(C) \cdot \sigma_{pp}(M)$ to rewrite as:

$T_{B_p}(M) =$	Disaggregated brightness temperature
$T_{B_p}(C) +$	Parent scale-C brightness temperature
$\beta(C) \cdot [\sigma_{pp}(M) - \sigma_{pp}(C)] +$	Scale-C sensitivity parameter β times smaller scale-M variations in σ_{pp}
$[\alpha(M) - \alpha(C)] + [\beta(M) - \beta(C)] \cdot \sigma_{pp}(M)$	Contribution of scale-M variations of the parameters

Heterogeneity of Parameters

Subgrid scale (scale-M) variability in parameters

$$\left[\alpha(M)-\alpha(C)\right] \quad \text{and} \quad \left[\beta(M)-\beta(C)\right]$$

are related to vegetation and soil texture heterogeneities.

They are proportional to $\sigma_{pq}(M)-\sigma_{pq}(C)$ through the sensitivity:

$$\left.\frac{\partial \sigma_{pp}}{\partial \sigma_{pq}}\right|_{C} \equiv \Gamma(C)$$

Their partial contribution to $\sigma_{pp}(M)$ is $\Gamma(C)\cdot\left(\sigma_{pq}(M)-\sigma_{pq}(C)\right)$

which in units of brightness temperature is:

$$\beta(C)\cdot\left[\Gamma(C)\cdot\left(\sigma_{pq}(M)-\sigma_{pq}(C)\right)\right]$$

L2_SM_AP
Radar-Radiometer Algorithm

T_B-disaggregation algorithm becomes:

$$T_{B_p}(M) =$$

$$T_{B_p}(C) +$$

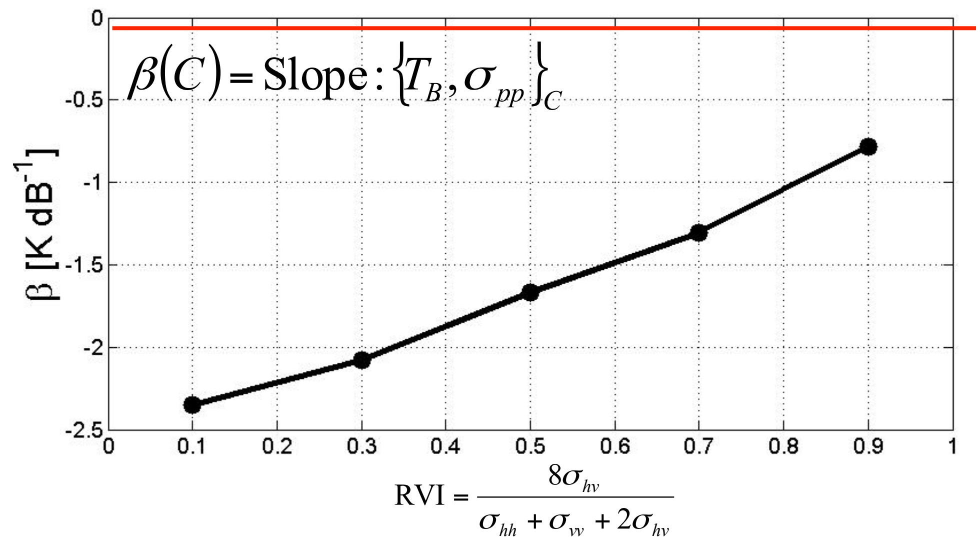
$$\beta(C) \cdot \{[\sigma_{pp}(M) - \sigma_{pp}(C)] -$$

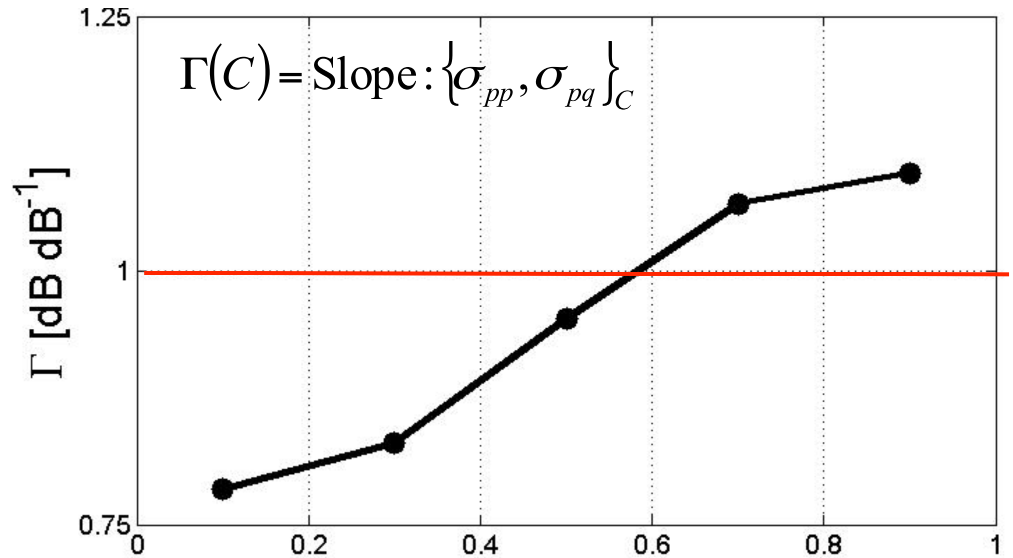
$$\Gamma(C) \cdot [\sigma_{pq}(M) - \sigma_{pq}(C)]\}$$

$T_B(M_j)$ is used to retrieve soil moisture at 9 km

Based on PALS Observations From:

SGP99, SMEX02, CLASIC and SMAPVEX08



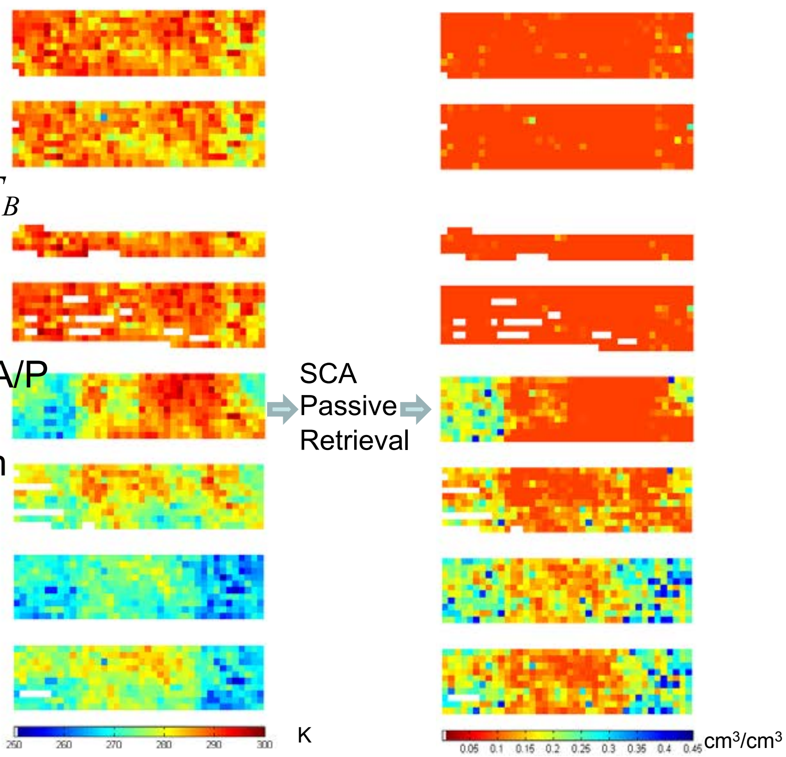


End-to-End Prelaunch Testing of Algorithm Performance

Test of Baseline Algorithm Using SMEX02 PALS Data

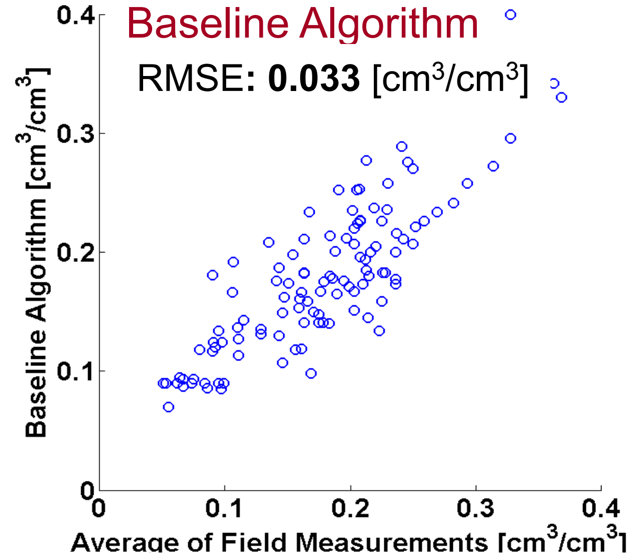
PALS T_B and σ

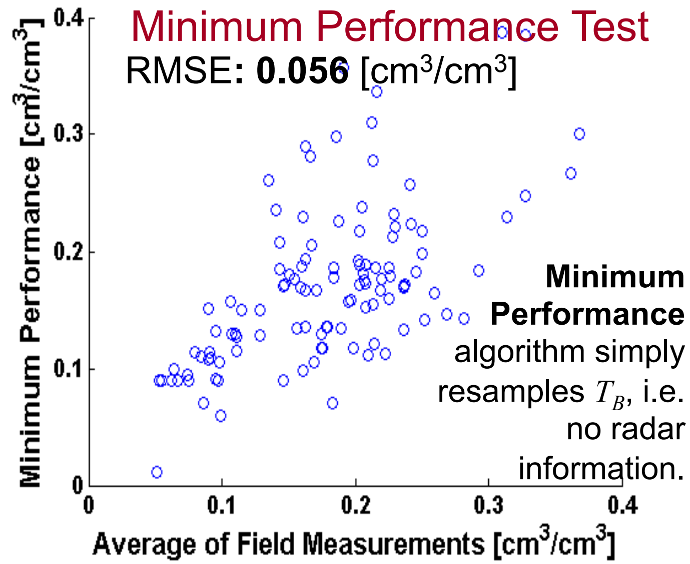
L3_SM_A/P Algorithm



Disaggregated T_B (0.8 km)

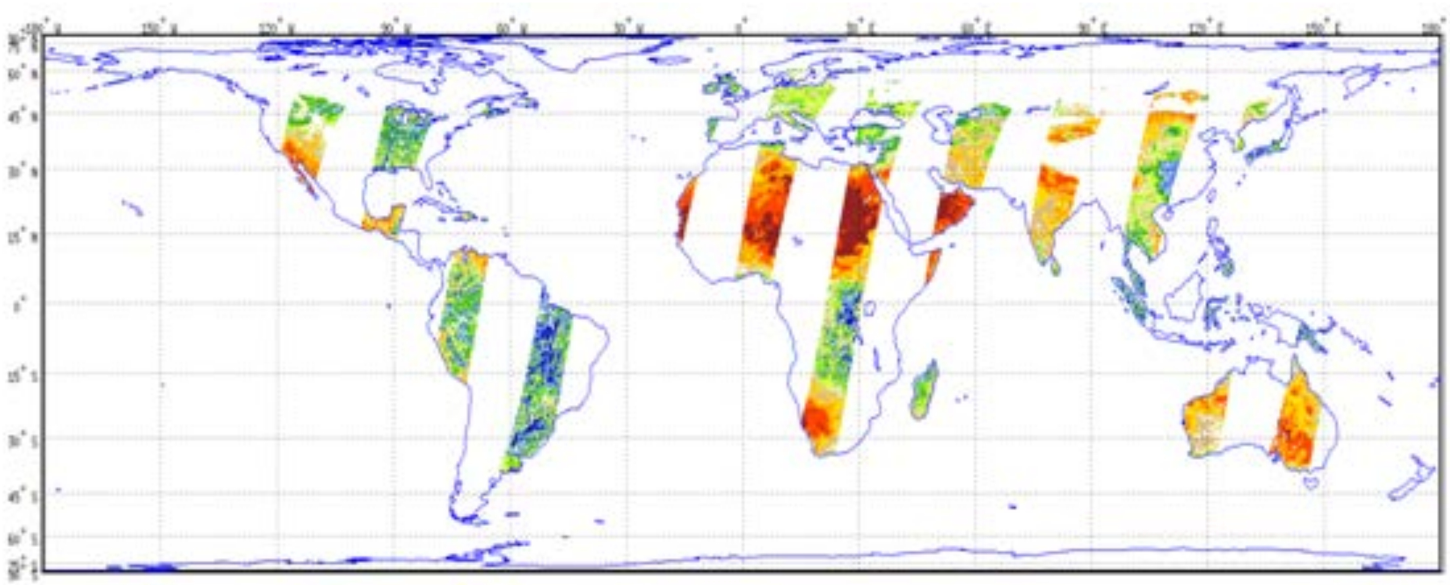
Estimated Soil Moisture (0.8 km)





T_B and m_v Error Performance Tool

- For Off-Line Error-Performance Studies
- For On-Line Evaluation at Each Data Granule (Each Location and Overpass)



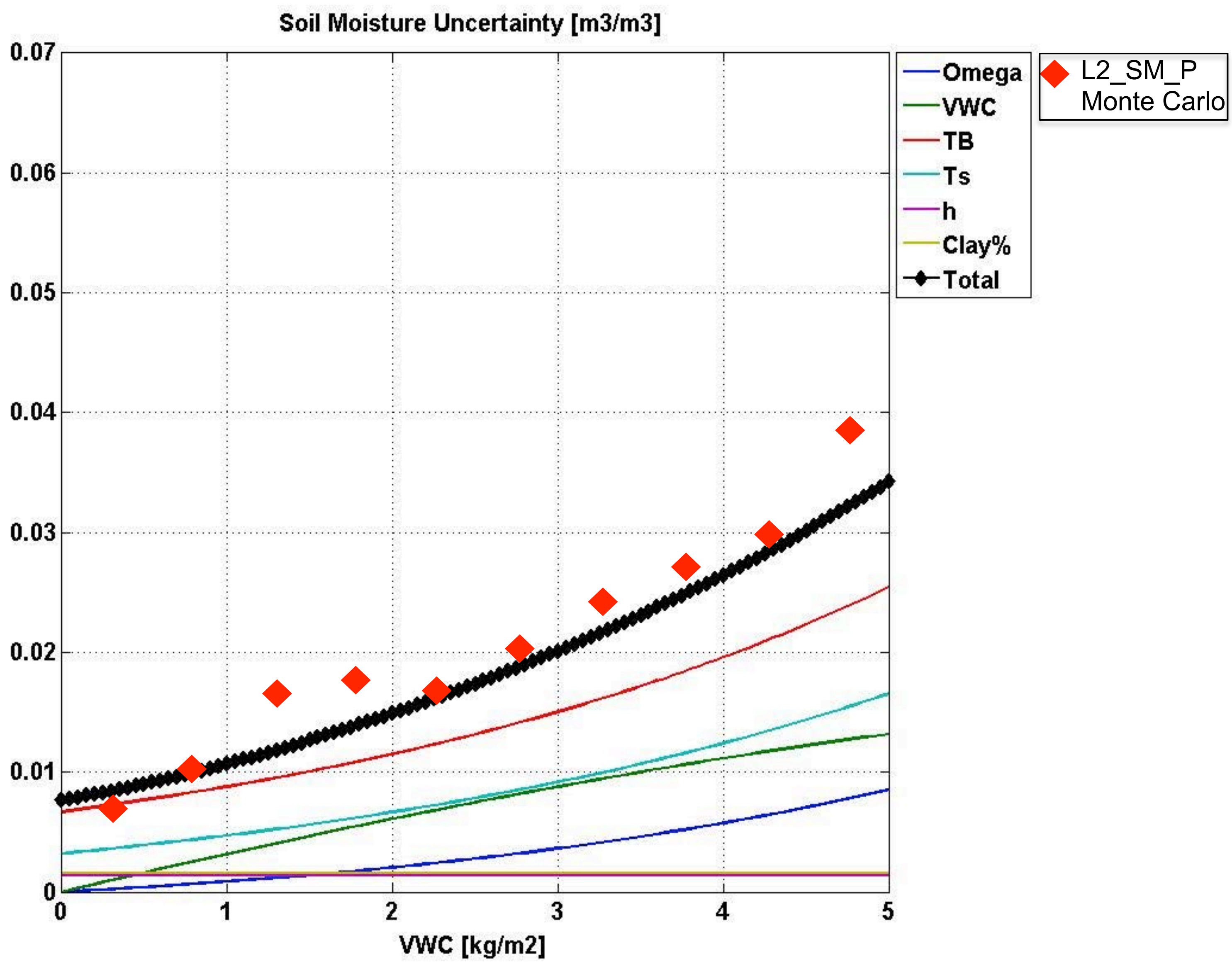
- Accounting for dependence on local conditions (vegetation, water fraction, soils)
- $RSS\ \ T_B$ and m_v terms included in the data product fields

L2_SM_AP Error Budget: T_B Formulation

Radiometer Brightness Temperature Uncertainty	$\Delta^2_{T_{B_{36km}}}$
Radar Backscatter Cross-Section Uncertainty	$+\beta^2\left[\frac{10}{\ln 10}\right]^2\left[\frac{1}{N_{Land}^{3km\to 9km}}\right]\left[K^2_{pp_{3km}}+\Gamma^2 K^2_{pq_{3km}}\right]$
Brightness Temperature Water-Body Correction Uncertainty	$+\frac{\Delta^2_{f_{36km}}}{\left(1-f_{36km}\right)^4}\left[3\Delta^2_{f_{36km}}T^2_{B_{Water}}+\left(T_{B_{Land}}-T_{B_{Water}}\right)^2\right]$
AP Algorithm Parameters (β , Γ) Uncertainty	$+\Delta^2_\beta\sigma^2_{pp_{9km}}+\sigma^2_{pq_{9km}}\left[(\beta^2\Delta^2_\Gamma)+(\Gamma^2\Delta^2_\beta)\right]$
RSS Disaggregated Brightness Temperature Uncertainty	$=RSS^2_{T_{B_{9km}}}$

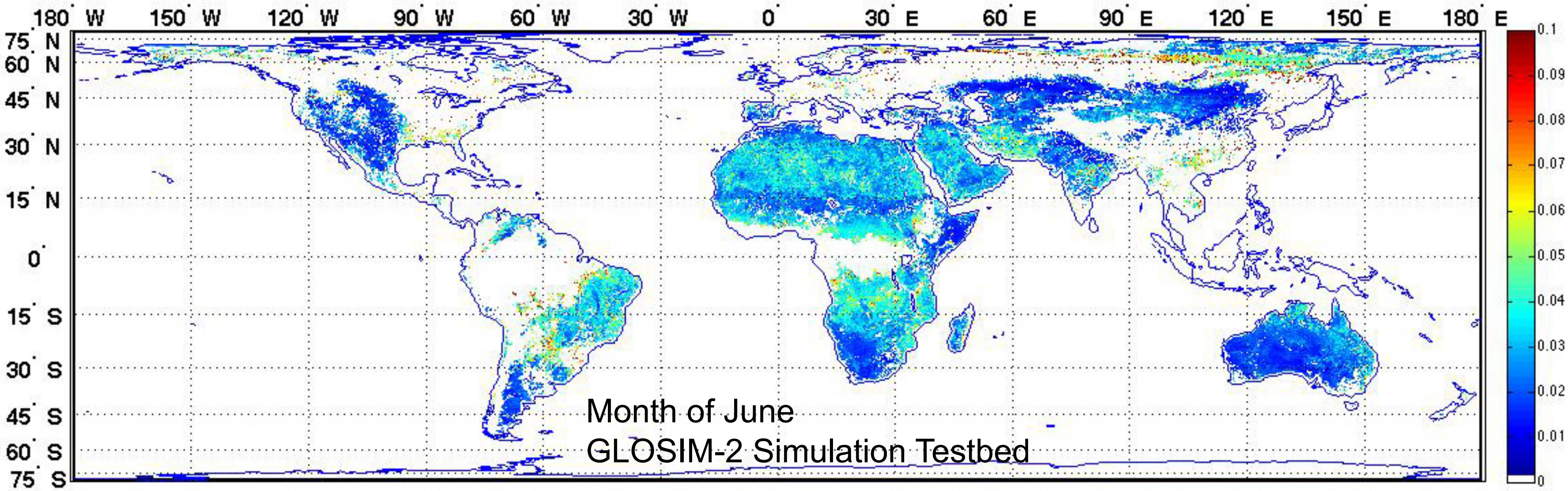
where $$\Delta^2_\beta=\frac{1}{s^2_{T_B}\left(N_w-1\right)}\left[s^2_{T_B}+\beta^2 s^2_{\sigma_{pp}}-r\beta s_{T_B}s_{\sigma_{pp}}+\sigma^2_{T_B}+\beta\sigma^2_{\sigma_{pp}}\right]$$ and $$\Delta^2_\Gamma=\frac{1}{s^2_{\sigma_{pp}}\left(N_{3:36}-1\right)}\left[s^2_{\sigma_{pp}}+\Gamma^2 s^2_{\sigma_{pq}}-r\Gamma s_{\sigma_{pp}}s_{\sigma_{pq}}+\frac{10^2}{\log^2 10}\frac{K^2_{pp}}{N_L}+\Gamma^2\frac{10^2}{\log^2 10}\frac{K^2_{pq}}{N_L}\right]$$

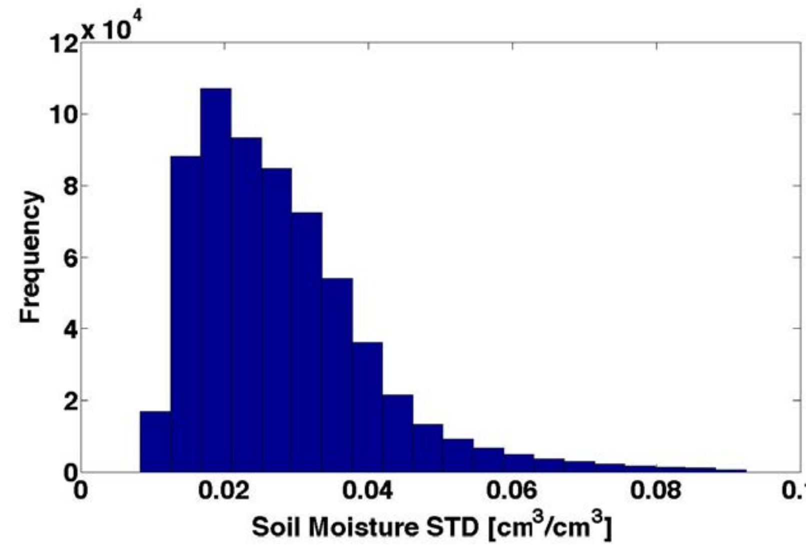
Comparisons



Algorithm Performance and Margin

Global Distribution of L2_SM_AP 1-σ Uncertainty:





Uncertainty due to errors in parameters, water body contamination, statistical estimation error, etc.

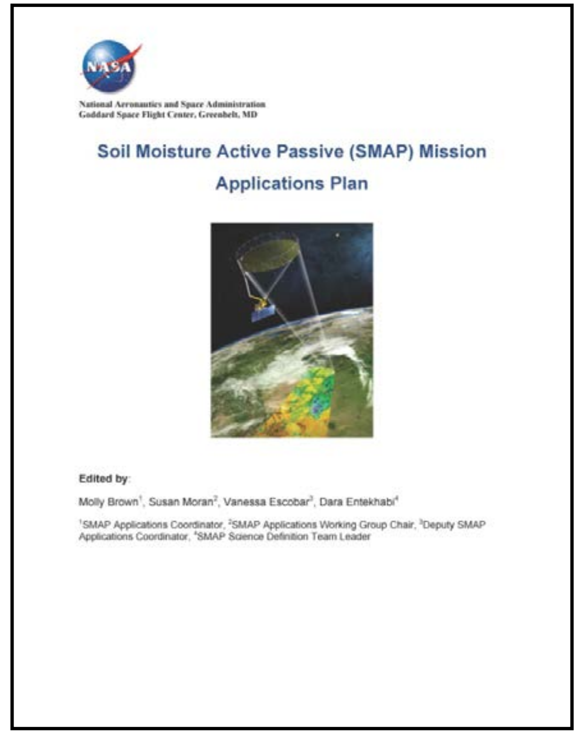
Does not include structural model and ground-truth upscaling errors.

SMAP Applications Development Approach

A primary goal of the NASA SMAP Mission is to engage SMAP end users and build broad support for SMAP applications through a transparent and inclusive process.

Toward that goal, the SMAP Mission:

1. Formed the SMAP Applications Working Group (150+ Members)
2. Developed the SMAP Applications Plan (right)
3. Hired a SMAP Applications Manager
4. Held SMAP Applications Workshops at User Home Sites (e.g., NOAA, USDA, USGS)
5. Developed the "Early-Adopter" Program (30+ Members)


National Aeronautics and Space Administration
Goddard Space Flight Center, Greenbelt, MD

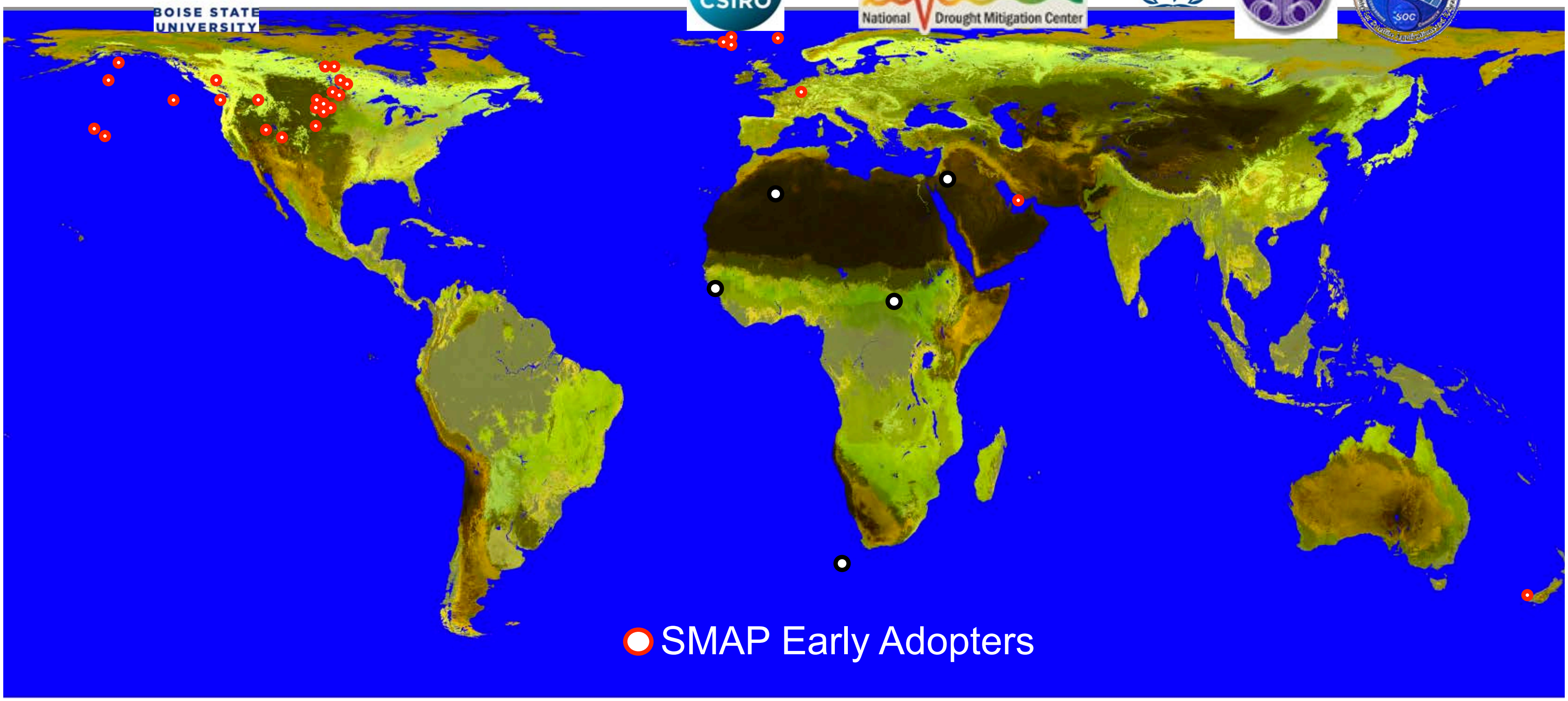
Soil Moisture Active Passive (SMAP) Mission
Applications Plan

Edited by:
Molly Brown[1], Susan Moran[2], Vanessa Escobar[3], Dara Entekhabi[4]

[1]SMAP Applications Coordinator, [2]SMAP Applications Working Group Chair, [3]Deputy SMAP Applications Coordinator, [4]SMAP Science Definition Team Leader

Early Adopters

Willis
StormCenter Communications, Inc.
Agrisolum Limited Connecting Farmers
Boise State University
CRREL
USGS
Universität Bremen
EXELIS
aer Atmospheric and Environmental Research
Agriculture and Agri-Food Canada
YorkshireWater
CUNY The City University of New York
IRI
CSIRO
USDA Foreign Agricultural Service
uae
SPoRT
ECMWF
National Drought Mitigation Center
NYC Environmental Protection
Forest Service U.S. Department of Agriculture
Georgia Tech
WFP
HRC
NCEP National Centers for Environmental Prediction
John Deere
Environment Canada
NOAA NESDIS STAR



Applications Value in Mission (So Far)

How have Early Adopters benefited the SMAP Project?

- AER Inc. provided feedback on the ***value*** of the SMAP 3-day revisit and long time series and the suitability of SMAP products for mapping inundation related to quantification of greenhouse gas emissions
- NDMC provided ***guidance*** on soil moisture anomaly metrics that would work for drought monitoring applications
- Develop algorithms and tools for use of SMAP L1 data products for maritime applications (sea-ice, coastal salinity, high winds)

How has the SMAP Project benefited the Early Adopters?

	’11, ‘12	‘13, ‘14
Tested ***ingestion*** of SMAP simulated data into their operations:	8	3
Submitted ***applied research*** to the JHM Special Issue:	9	2

- Two North America agricultural monitoring agencies – Canada AAFC and USDA NASS – have developed ***prototypes*** for integrating SMAP soil moisture products into their operational stream
- Data-denial experiments used to quantify impact of data on famine early-warning and flood prediction agency applications

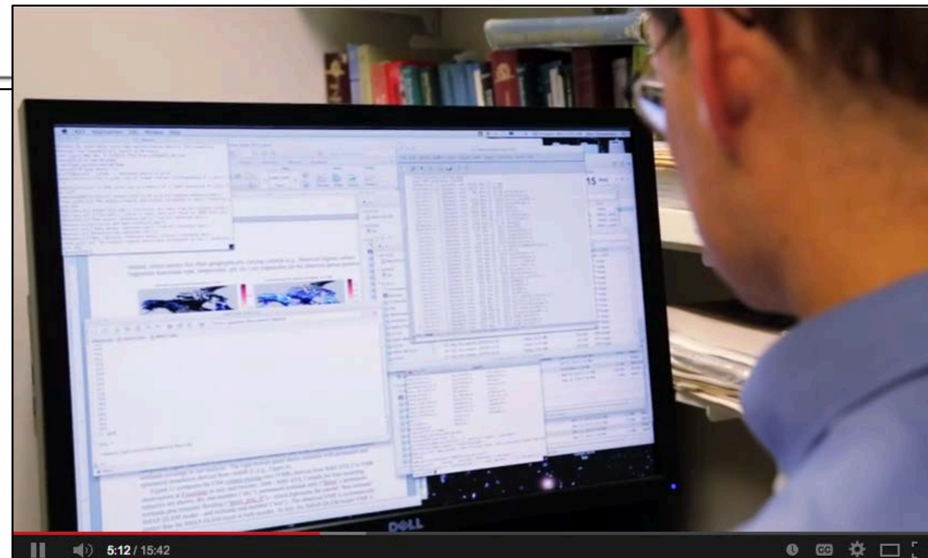
Early Adopter Video

[SMAP Early Adopters video]

This diverse group represents a cross-section of end-users of SMAP data who collaborate to ensure integration of SMAP data into operations that affect our day-to-day lives. Examples include the U.S. Forest Service, the UN World Food Programme, and the U.S. Department of Agriculture.

VTT files: English (VTT, 18 KB) | Italian (VTT, 18 KB) | Spanish (VTT, 19 KB)

Early Adopters



SMAP Early Adopters

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

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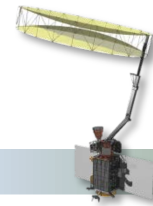
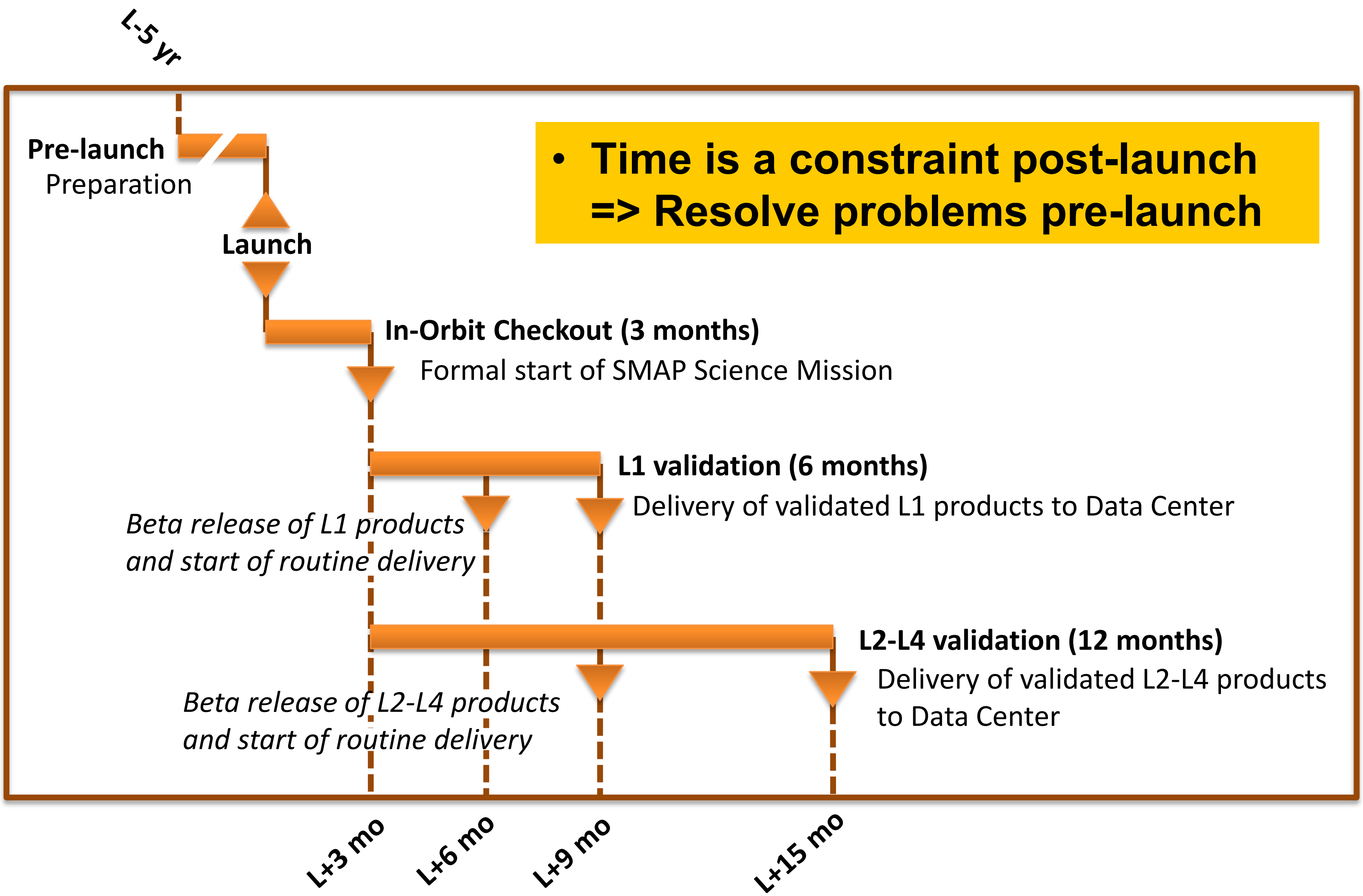
SMAP Cal/Val Timeline

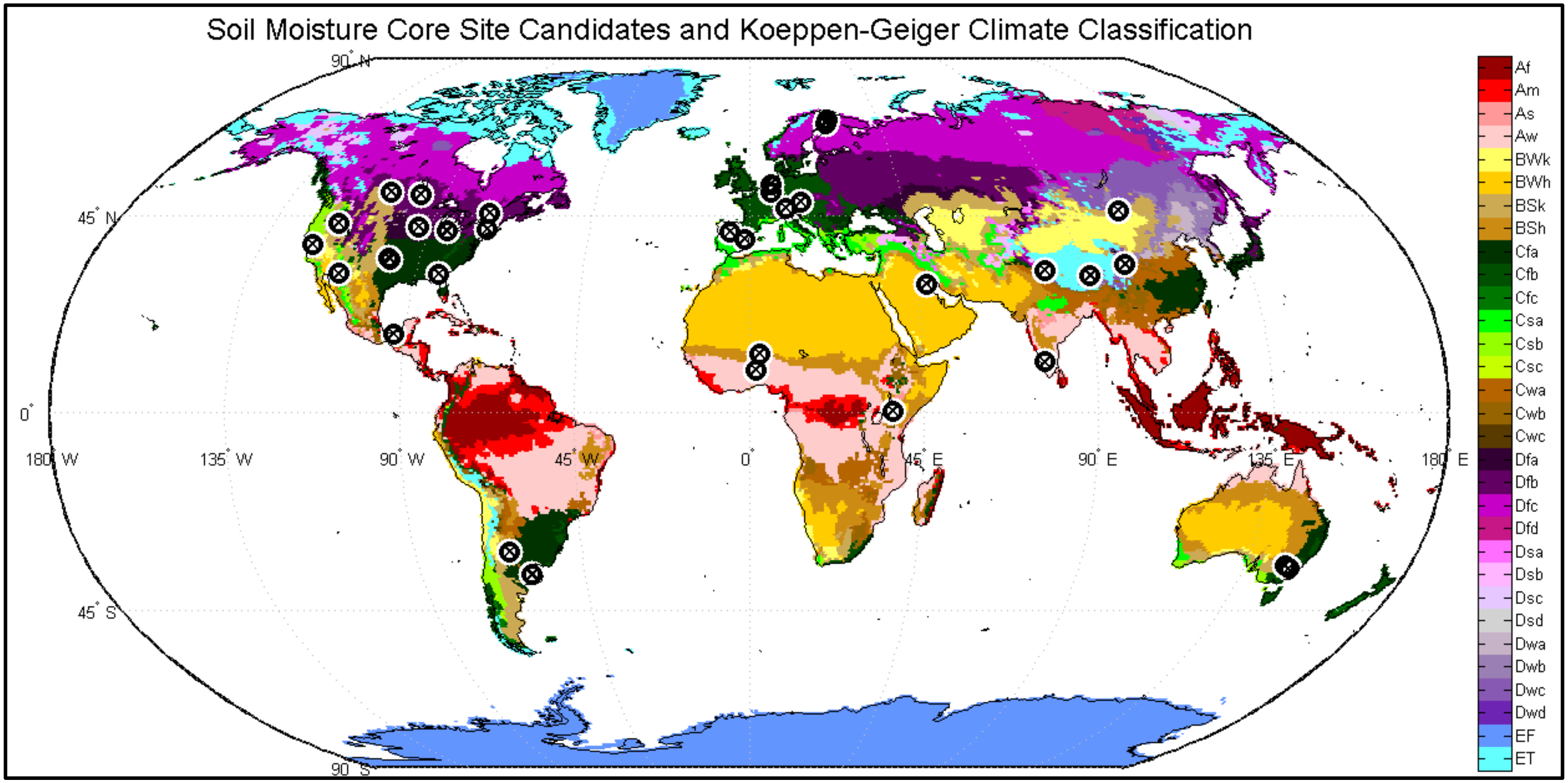




SMAP Cal/Val Partners

- Pre-Launch Airborne Experiments With PALS Simulator (SGP99, SMEX02, CLASIC, SMAPVEX08, SMAPVEX10, SMAPVEX12)
- Post-Launch SMAPVEX15 and SMAPVEX16
- Sparse In Situ Networks (Extended Triple Collocation)
- Intense SMAP Core Cal/Val Sites (Partners Through NASA Dear Colleague Letter [no funds] Issued 2010)
- About 34 Core Cal/Val partners
  - Process Tested During Two Rehearsals

SMAP Cal/Val Partners



- Relevant land cover and climate classes are covered with the Cal/Val Partner sites

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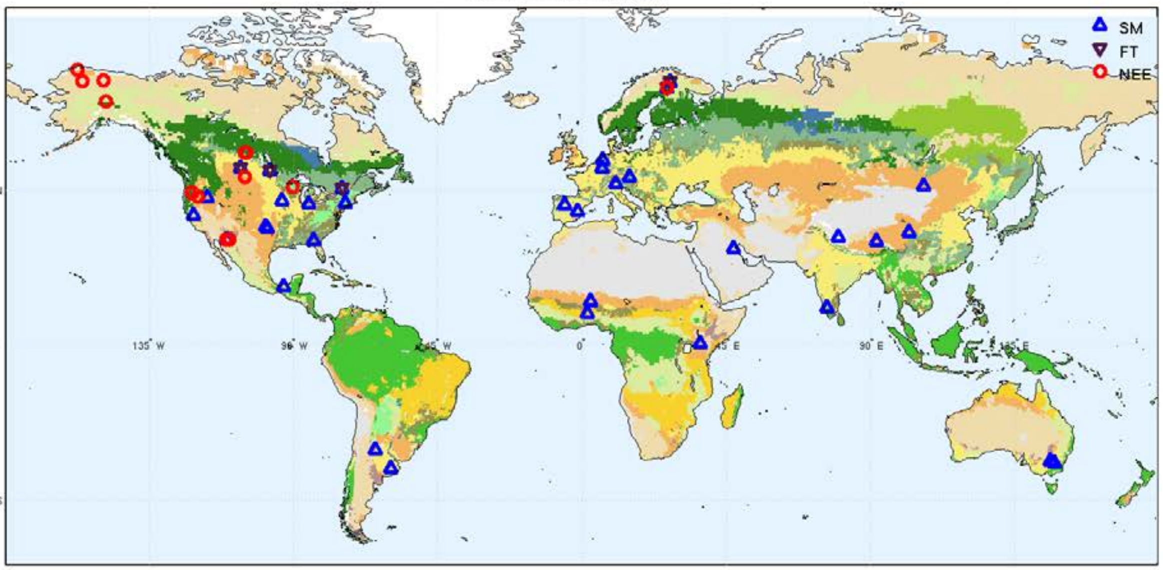
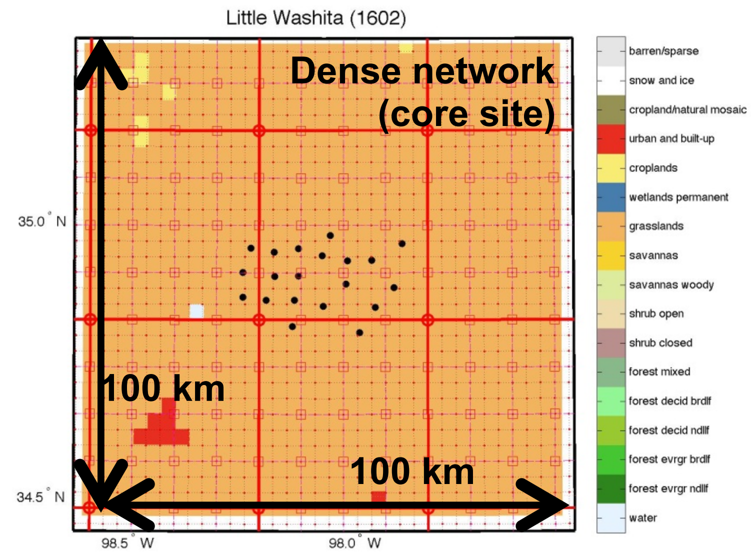
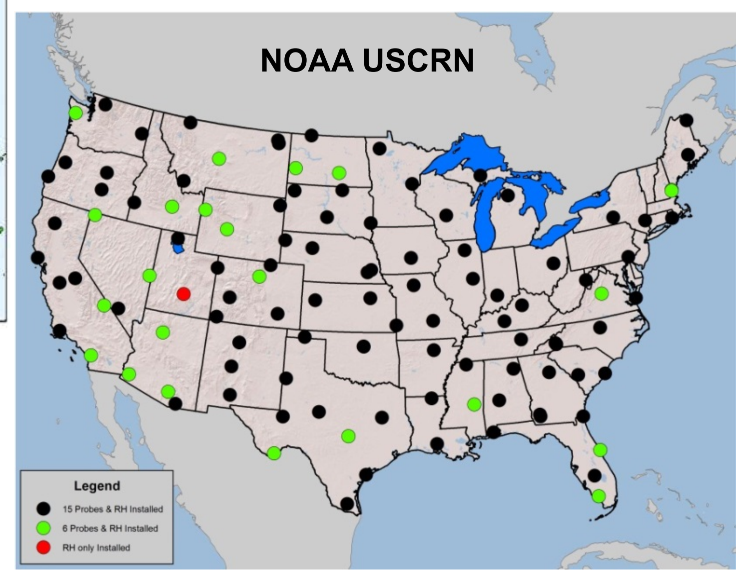
SMAP Geophysical Product Cal/Val Approach

- Primary calibration and validation approach is utilization of dense in situ soil moisture measurement networks (means multiple soil moisture measurement within the 3-km to 36-km SMAP footprint)







- Supplemental approach will utilize large-scale sparse networks (one measurement within footprint), and global remote sensing and model-based soil moisture data products

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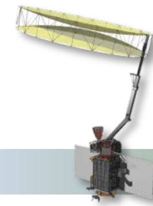
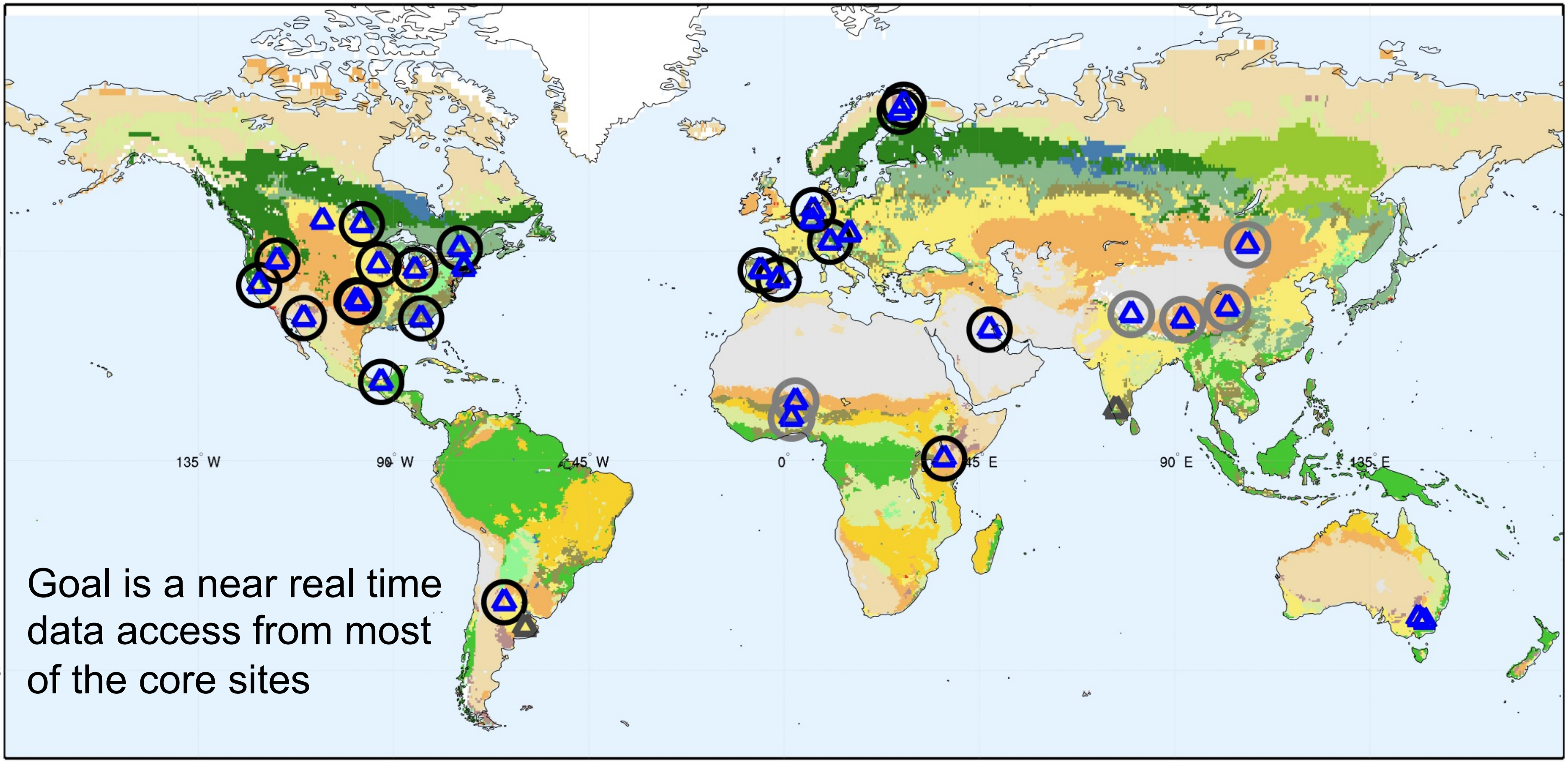
Cal/Val Rehearsal Objectives



- Phase 1
  - Emphasizes development of validation methodologies and tools
    - Test calibration and validation methods that the team plans to use during mission cal/val
    - Resolve external validation resource issues
  - Researchers run code on available hardware in SMAP Science Data System (SDS)
- Phase 2
  - Emphasizes effective use of tools in an operational setting
    - Ensure that the tools function in the operational environment
    - Ensure that tools operate on selected input appropriately
    - Ensure that tools generate anticipated output
  - *Continue Phase 1 activities and expand to all products*
  - Team members run code on same hardware to be used during cal/val

May 5 – July 1 2014

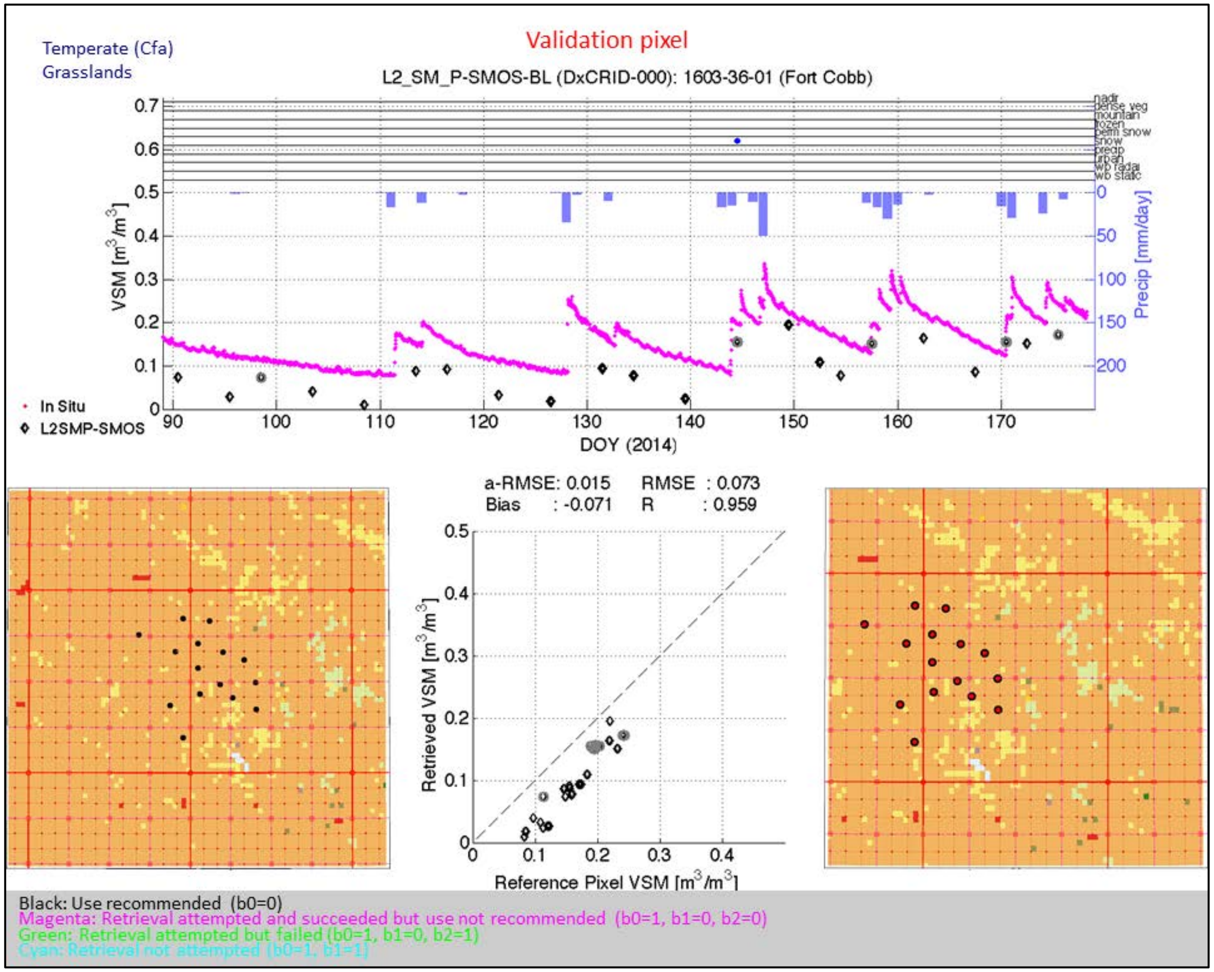
Cal/Val Partner Data Transfer Readiness for Soil Moisture Core Sites



Black circles: Near real-time data access established
No circle: Near real-time data access being established (expected to be completed by launch)
Grey circles: No near real-time data access available (data available at the end of Cal/Val Phase)
Grey triangles: installations on-going, but expected to provide useful data at some point during the Cal/Val Phase

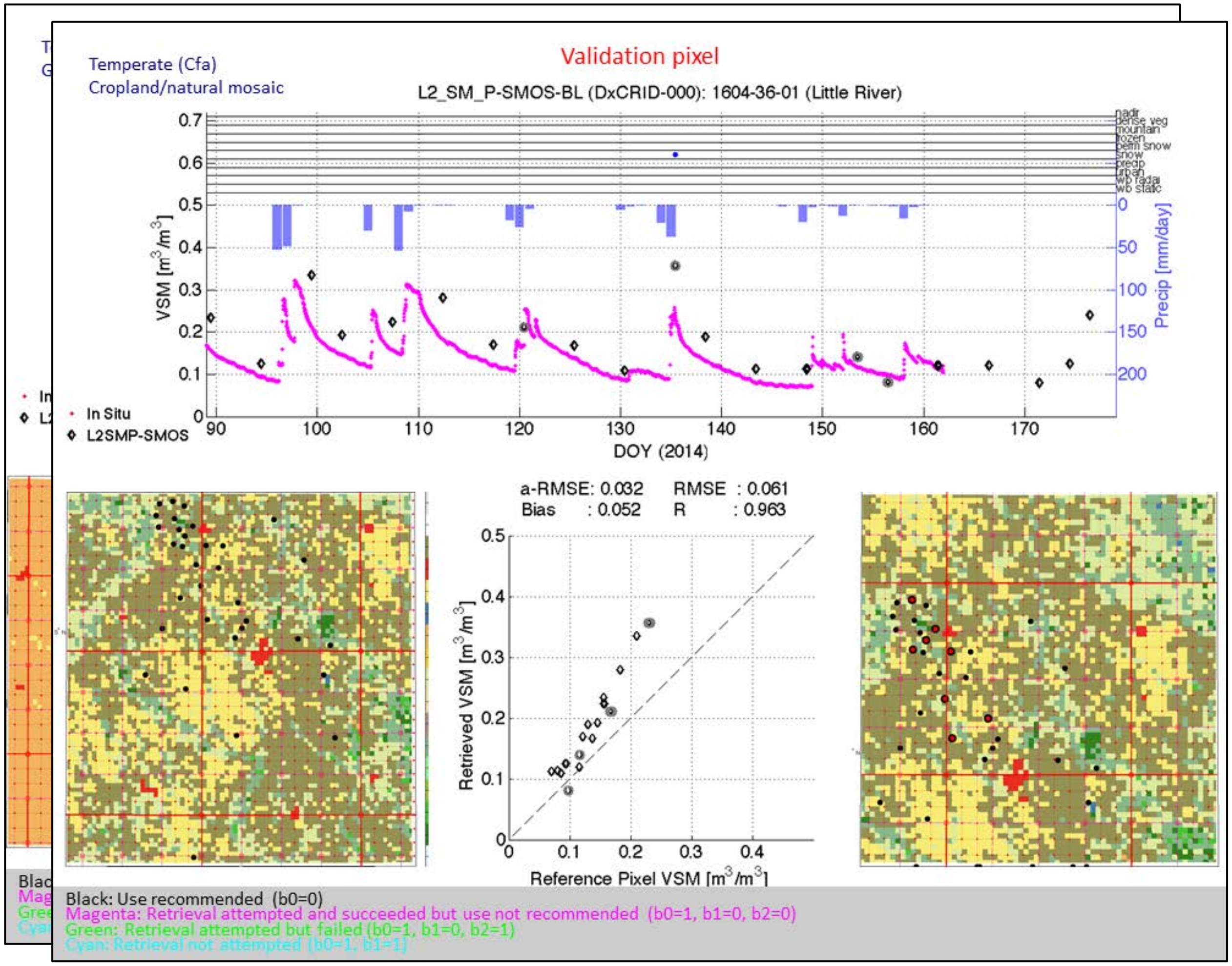
CVR2 Results

- Examples of core site comparisons (SMOS TB based L2_SM_P product)



CVR2 Results

- Examples of core site comparisons (SMOS TB based L2_SM_P product)

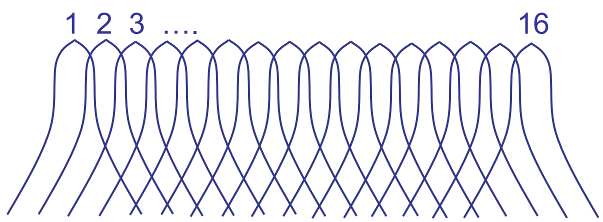


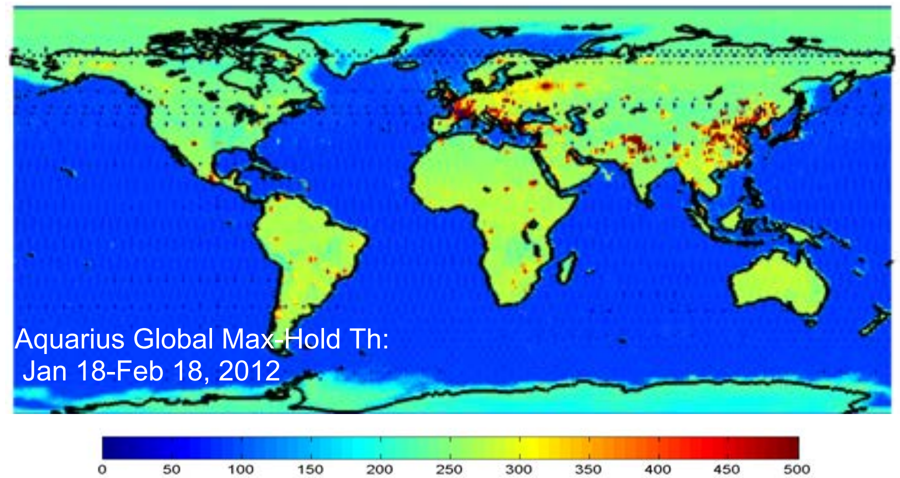
SMAP's RFI Detection-Mitigation

Aggressive Approach to Radio-Frequency Interference (RFI) Detection and Mitigation

SMAP radiometer's Multi-layer defense:

1. Spectral and Temporal Sesolution (16x10 Spectograph)
2. Time-Domain Kurtosis
3. Acquire 3rd and 4th Stokes Parameters

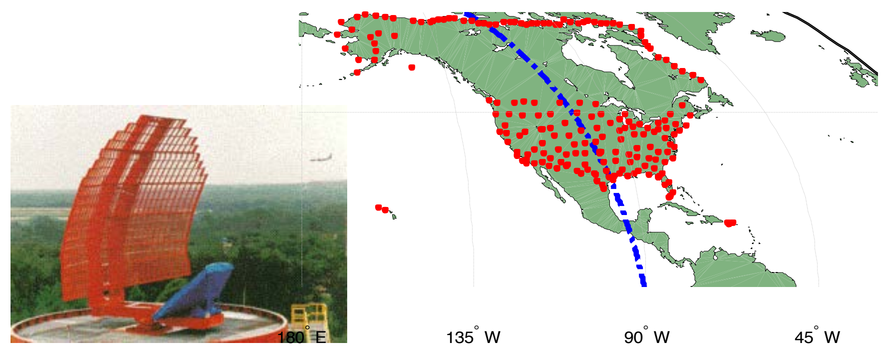




SMAP radar RFI:

- Land emitters
- Radio navigation signals (GPS, GLONASS, COMPASS, GALILEO)

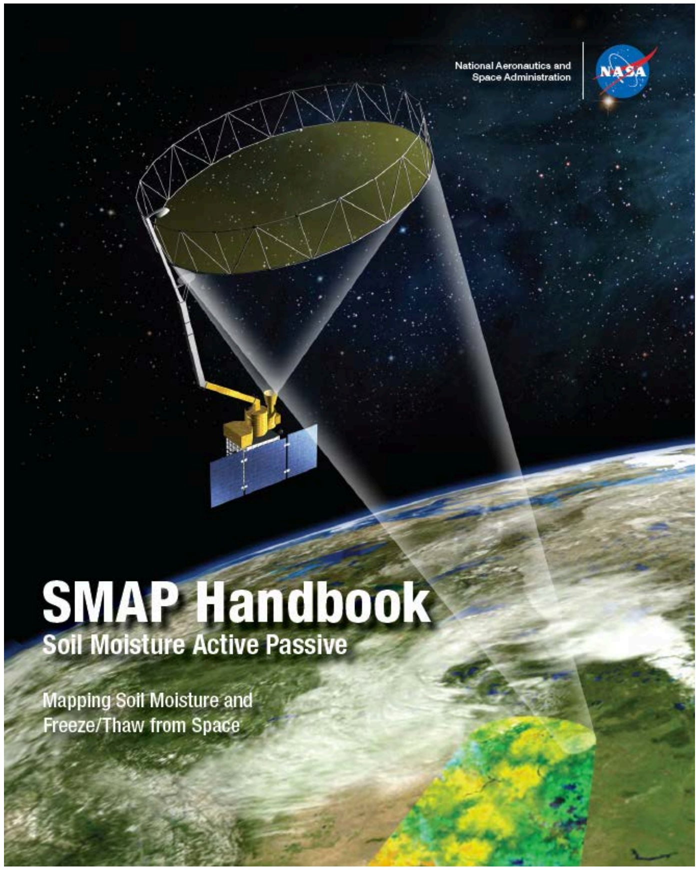
Approach with tunable radar instrument



The SMAP Handbook

Chapters

1. Introduction and Background
2. Mission Overview
3. Instrument Design and Data Products
4. Soil Moisture Data Products
5. The Value-Added Data L4_SM Product
6. Carbon Cycle Data Products
7. Calibration and Validation Plan
8. Applications and Applied Science
9. SMAP Project Bibliography



(192 Pages)

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

Summary

- NASA SMAP mission in integration and testing (launch shipment August 2014)
- Launch manifested for November 5, 2014
- L-Band active-passive instruments meeting requirements and holding well
- Active-passive algorithm for high resolution (9 km) surface soil moisture estimation exercised and testing using heritage airborne and simulation testbed
- Developed error analysis tool for science product
- Aggressive RFI detection and mitigation hardware and software development
- With SMOS and Aquarius global L-band radiometry ~decade-long
- Focused and planned effort to promote meaningful applications
- Cal/Val approach organized and tested in two rehearsals

WE1.06: Soil Moisture-SMAP Mission (Special Session)
Time: Wednesday, July 16, 08:20 - 10:00
Location: 206-A

WE1.06.1: NASA SOIL MOISTURE ACTIVE PASSIVE MISSION DEVELOPMENT

WE1.06.2: PRE-LAUNCH PHASE 2 REHEARSAL OF THE CALIBRATION AND VALIDATION OF SOIL MOISTURE ACTIVE PASSIVE (SMAP) GEOPHYSICAL DATA PRODUCTS

WE1.06.3: EVALUATION OF SMAP RADIOMETER LEVEL 2 SOIL MOISTURE

WE1.06.4: SEASONAL PARAMETERIZATIONS OF THE TAU-OMEGA MODEL USING THE COMRAD GROUND-BASED SMAP SIMULATOR

WE1.06.5: ACTIVE AND PASSIVE L-BAND MICROWAVE REMOTE SENSING FOR SOIL MOISTURE – A TEST-BED FOR SMAP FUSION ALGORITHMS

Selected Other Contributed Papers

Active-Passive Soil Moisture

TH1.06.1 Paper Number: 2996
Title: DISAGGREGATION OF BRIGHTNESS TEMPERATURES USING RADAR OBSERVATIONS DURING THE SMAPVEX12 CAMPAIGN

TH1.06.2 Paper Number: 3429
Title: RADAR-RADIOMETER SOIL MOISTURE ESTIMATION WITH JOINT PHYSICS AND ADAPTIVE REGULARIZATION IN SUPPORT OF SMAP

RFI

MO3.09.5 Paper Number: 3087
Title: PERFORMANCE OF THE RADIO FREQUENCY INTERFERENCE (RFI) DETECTION AND MITIGATION ALGORITHMS FOR THE SOIL MOISTURE ACTIVE PASSIVE (SMAP) RADIOMETER

MO3.09.4 Paper Number: 3255
Title: RADIO FREQUENCY INTERFERENCE OBSERVATIONS USING AN L-BAND DIRECT SAMPLING RECEIVER DURING THE SMAPVEX12 AIRBORNE CAMPAIGN

Cal/Val

WE3.06.4 Paper Number: 3830
Title: A CONCEPT FOR INTRODUCING SI-TRACEABILITY INTO L-BAND OBSERVATIONS OF ANTARCTICA FOR INTER-CALIBRATION APPLICATIONS INVOLVING SMOS, AQUARIUS, AND SMAP

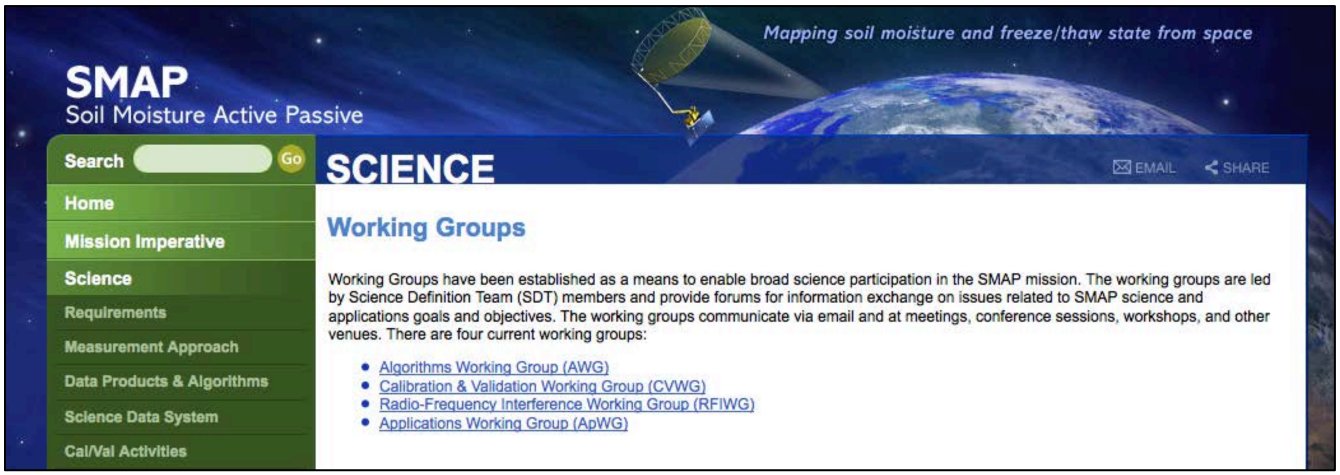
TUP.Q.119 Paper Number: 2743
Title: SOIL MOISTURE ACTIVE/PASSIVE (SMAP) RADIOMETER LEVEL 1B CORRECTION ALGORITHMS
TH1.06.2 Paper Number: 3429

WE2.08.1 Paper Number: 3809
Title: SCANNING L-BAND ACTIVE PASSIVE (SLAP): A NEW AIRBORNE SIMULATOR FOR SMAP

Science Working Groups

Jet Propulsion Laboratory
California Institute of Technology

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



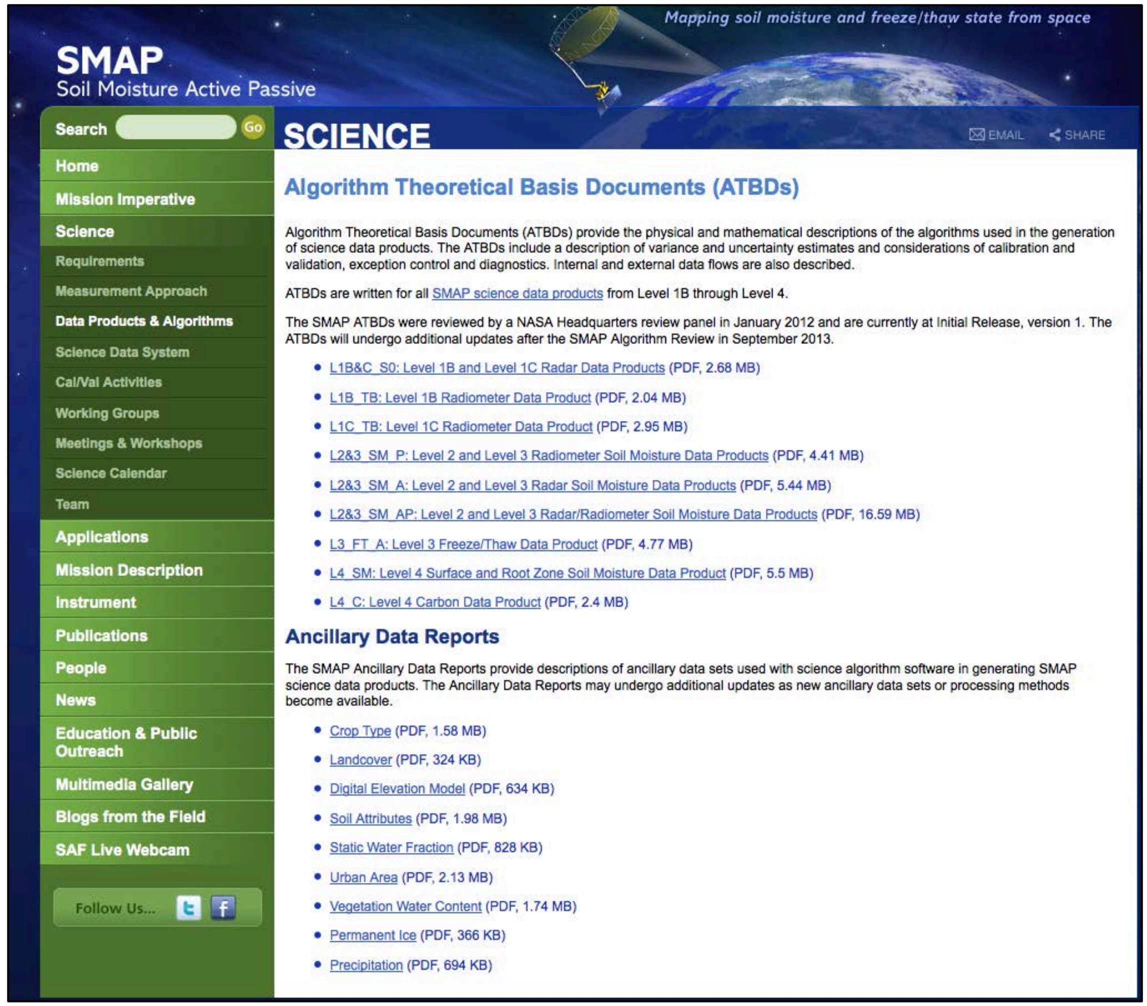
1. Algorithms Working Group (AWG)
2. Calibration & Validation Working Group (CVWG)
3. Radio-Frequency Interference Working Group (RFIWG)
4. Applications Working Group (ApWG)

Project Science Documents Availability

Jet Propulsion Laboratory
California Institute of Technology

<u>Online:</u>

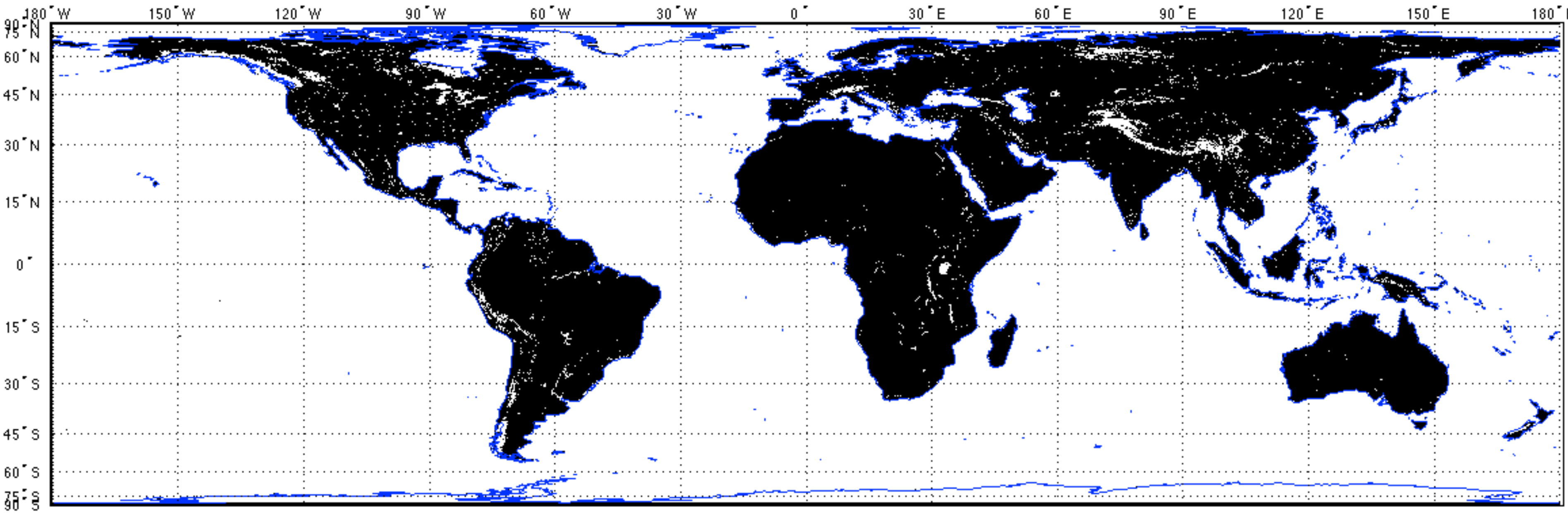
ATBDs x 9
Ancillary Data Reports x 9
Cal/Val Plan
Applications Plan



http://smap.jpl.nasa.gov/science/dataproducts/ATBD/

SMAP Retrievable Mask at 9 km

Regions Where SMAP Soil Moisture Algorithms Will be Executed



Retrievable Mask (Black Colored Pixels) Prepared with Following Specifications:

a) Urban Fraction < 1
b) Water Fraction < 0.5
c) DEM Slope Standard Deviation < 5 deg

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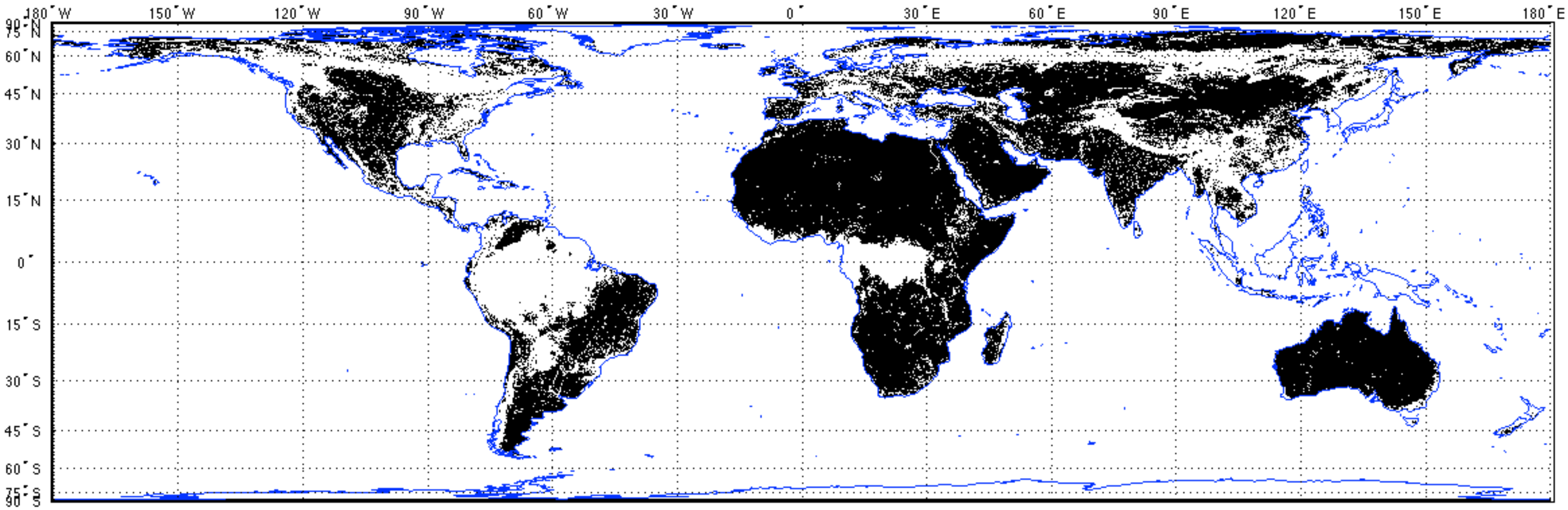
SMAP L1 Mask at 9 km

Regions Where SMAP Soil Moisture Retrievals Are Expected to Meet L1 Requirements



Retrievable Mask (Black Colored Pixels) Prepared With Following Specifications:

a) VWC ≤ 5 kg/m^2
b) Urban Fraction ≤ 0.25
c) Water Fraction ≤ 0.1
d) DEM Slope Standard Deviation ≤ 3 deg