Global High Resolution Soil Moisture Product from the Soil Moisture Active Passive (SMAP) Mission and its Applications

Soil Moisture Active Passive Mission

SMAP

N. Das (JPL)
D. Entekhabi (MIT)
Eni Njoku (JPL)
S. Yueh (JPL)

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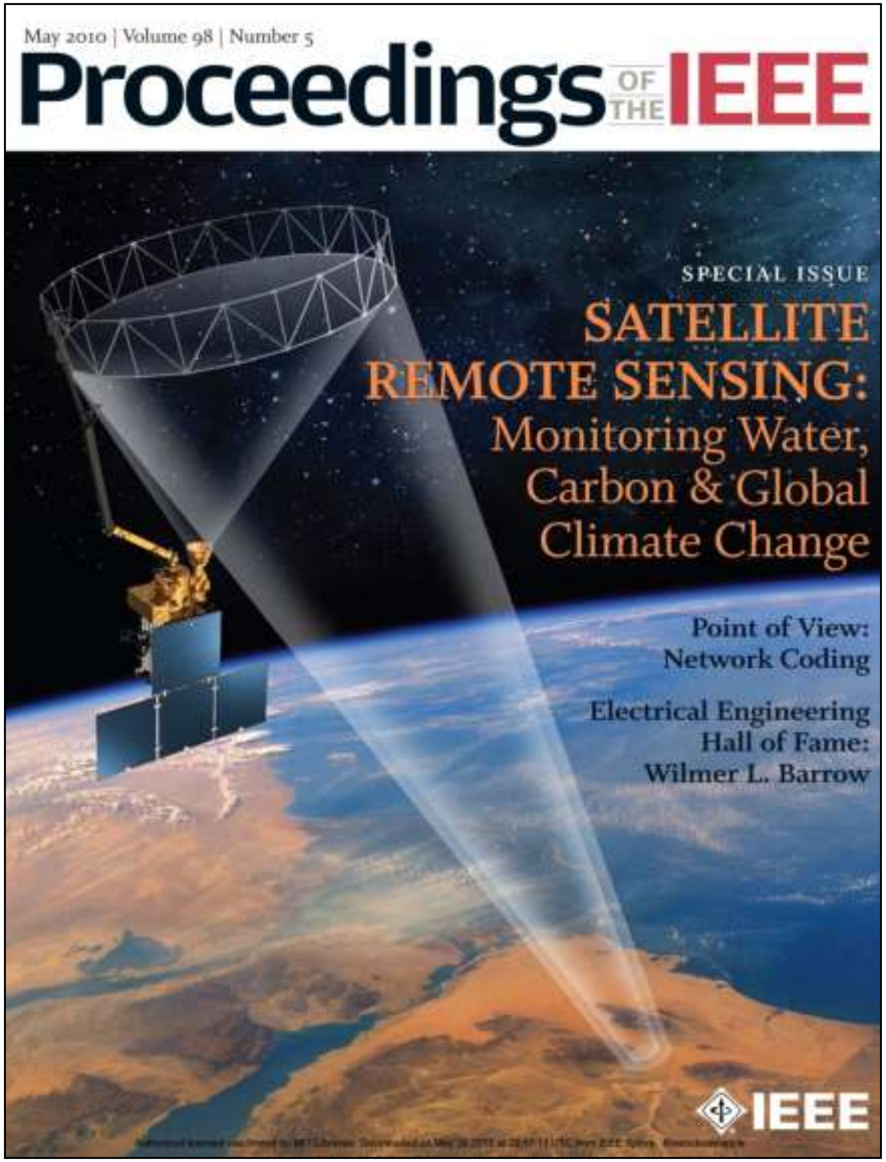
Outline

- Measurements Approach Reminder
- Mission Status
- The Active-Passive Surface Soil Moisture Product
  - Technical Approach
  - Testing Results
  - Error Analysis
- SMAP Applications
- SMAP Data Assimilation Potential (example)
- The SMAP Handbook
- Summary

SMAP Mission Concept



SMAP will provide high-resolution and frequent-revisit global observations of soil moisture and freeze/thaw state

- L-band unfocused SAR and radiometer system, offset-fed 6 m light-weight deployable mesh reflector. Shared feed for
  - 1.26 GHz dual-pol Radar VV, HH and HV at 1-3 km (30% nadir gap)
  - 1.4 GHz polarimetric (H, V, 3rd and 4th Stokes) Radiometer 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

Science Objectives & Requirements Are Stable

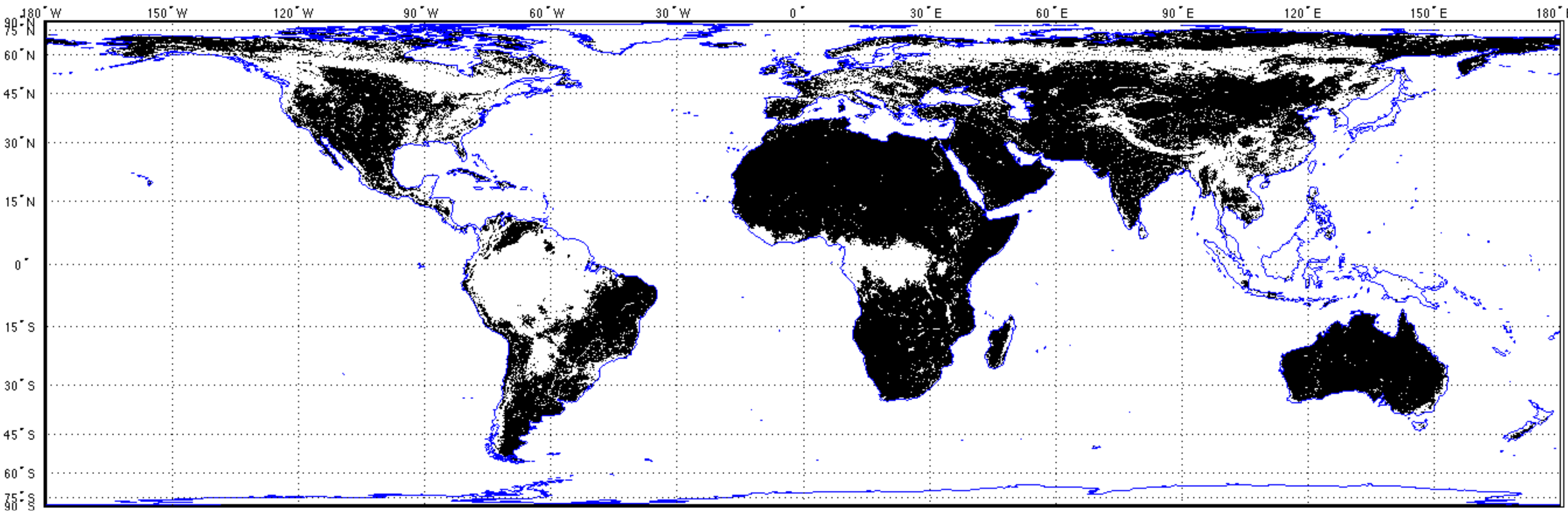
Decadal Survey Objective	Application	Science Requirement
Weather Forecast	Initialization of Numerical Weather Prediction (NWP)	Hydrometeorology
Climate Prediction	Boundary and Initial Conditions for Seasonal Climate Prediction Models	Hydroclimatology
	Testing Land Surface Models in General Circulation Models	
Drought and Agriculture Monitoring	Seasonal Precipitation Prediction	Hydroclimatology
	Regional Drought Monitoring	
	Crop Outlook	
Flood Forecast Improvements	River Forecast Model Initialization	Hydrometeorology
	Flash Flood Guidance (FFG)	
	NWP Initialization for Precipitation Forecast	
Human Health	Seasonal Heat Stress Outlook	Hydroclimatology
	Near-Term Air Temperature and Heat Stress Forecast	Hydrometeorology
	Disease Vector Seasonal Outlook	Hydroclimatology
	Disease Vector Near-Term Forecast (NWP)	Hydrometeorology
Boreal Carbon	Freeze/Thaw Date	Freeze/Thaw State

<u>Key Level 1 Requirements</u> (Derived from science objectives)

Requirement	Hydro-Meteorology	Hydro-Climatology	Carbon Cycle	Baseline Mission		Minimum Mission	
				Soil Moisture	Freeze/ Thaw	Soil Moisture	Freeze/ Thaw
Resolution	4–15 km	50–100 km	1–10 km	10 km	3 km	10 km	10 km
Refresh Rate	2–3 days	3–4 days	2–3 days[a]	3 days	2 days	3 days	3 days
Accuracy	0.04-0.06 [c]	0.04-0.06	80–70% [b]	0.04	80%	0.06	70%

[a] North of 45N latitude [b] Percent classification accuracy (binary freeze/thaw) [c] Volumetric water content, 1-σ in [cm^3/cm^3] units

Regions Where SMAP is Expected to Meet Science Requirements



<u>At 9 km</u>:

VWC ≤ 5 kg m^{-2}

Urban Fraction ≤ 0.25

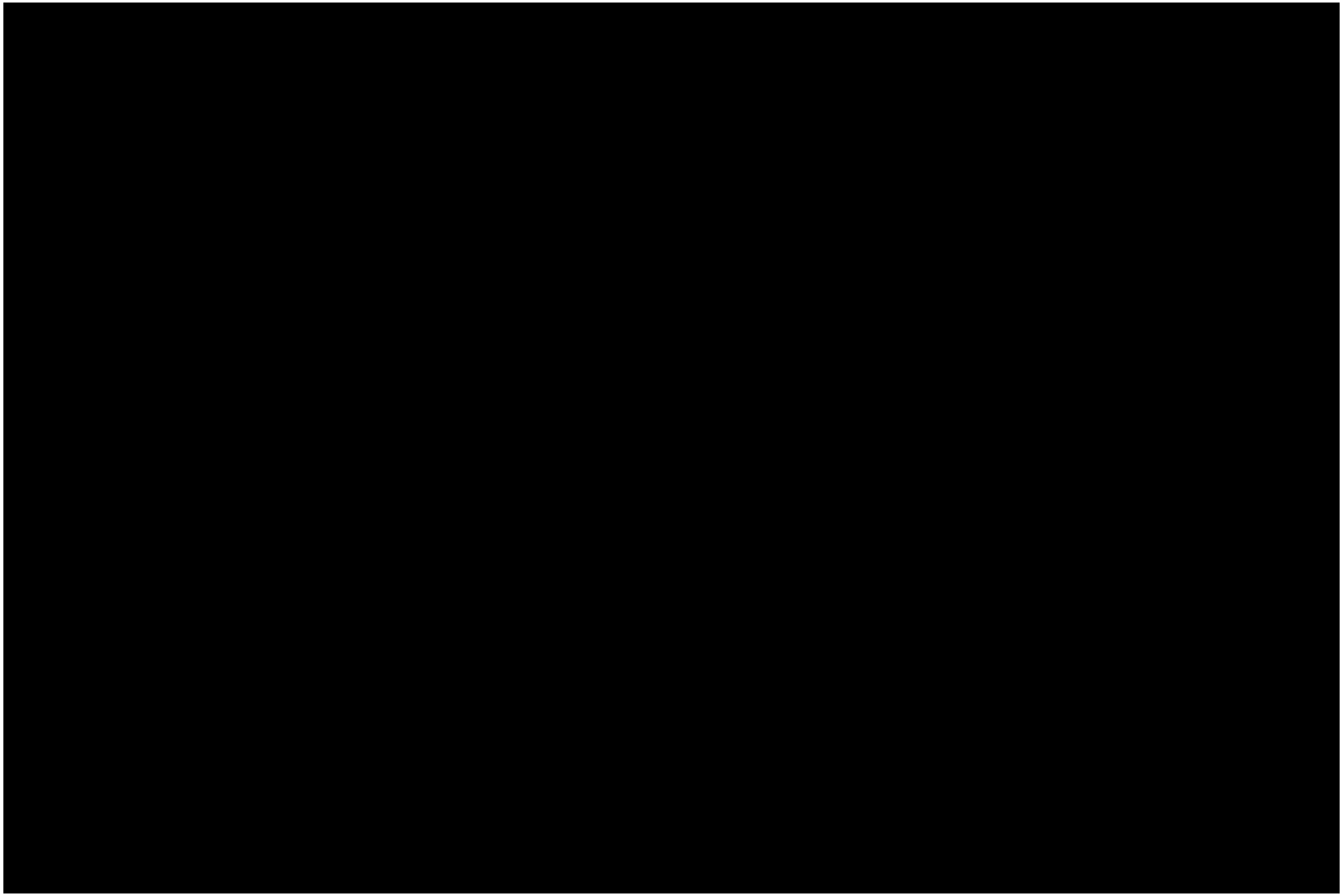
Water fraction ≤ 0.1

Elevation Slope Standard Deviation ≤ 3 deg

May 2014: Instrument and Spacecraft Integration

SMAP

Jan 2015 Launch



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

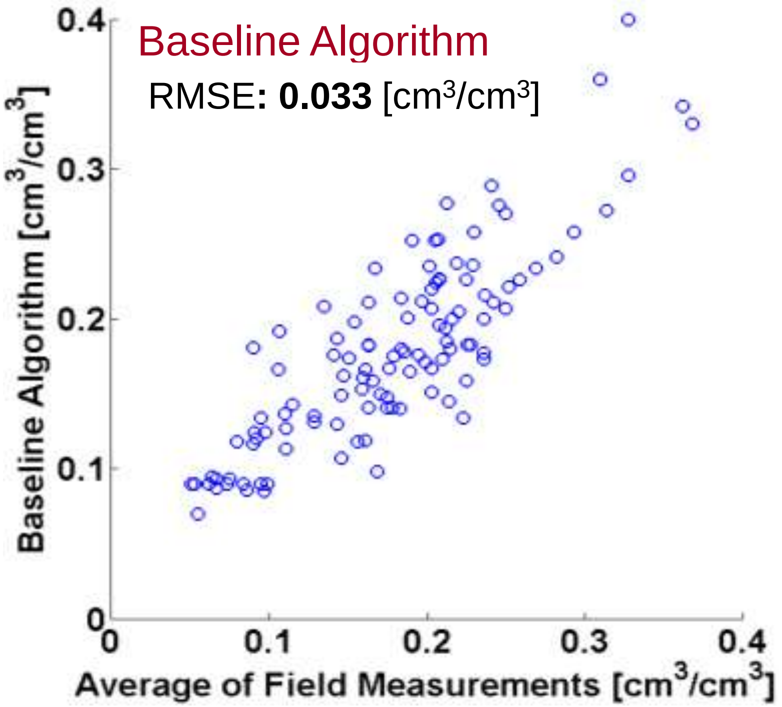
- Soil moisture retrieval algorithms are derived from a long heritage of microwave modeling and field experiments

  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



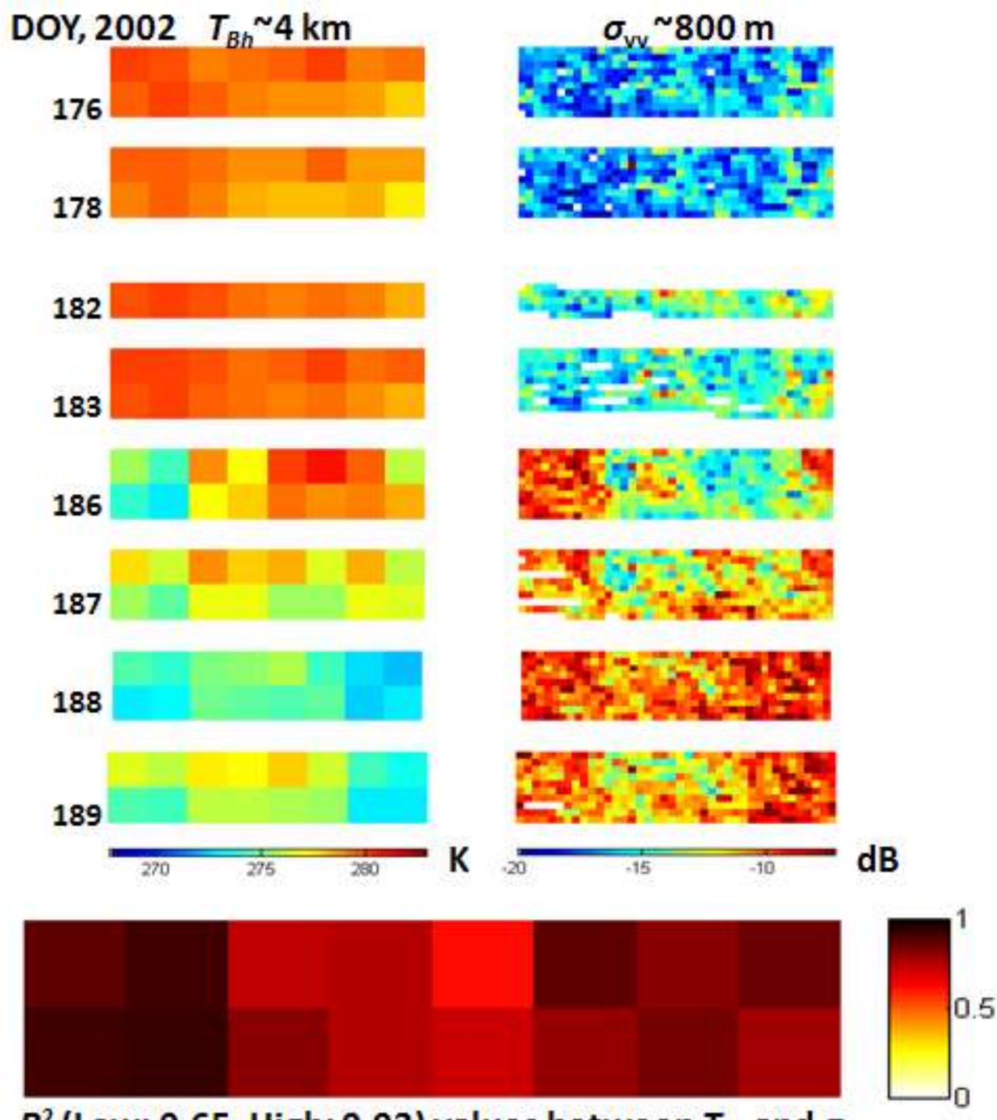
Active Passive Algorithm Fundamentals

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

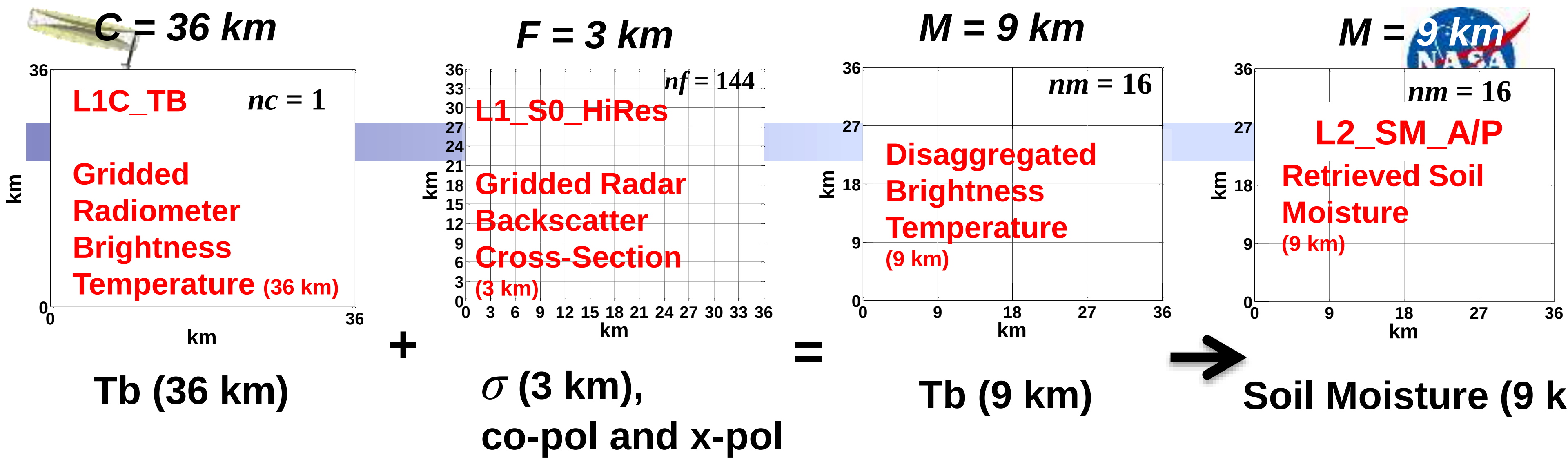
$$T_{B_p} = \alpha + \beta \cdot \sigma_{pp}$$

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}



SMAP Active-Passive Algorithm

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

$T_{B_p}(M) =$ Disaggregated brightness temperature

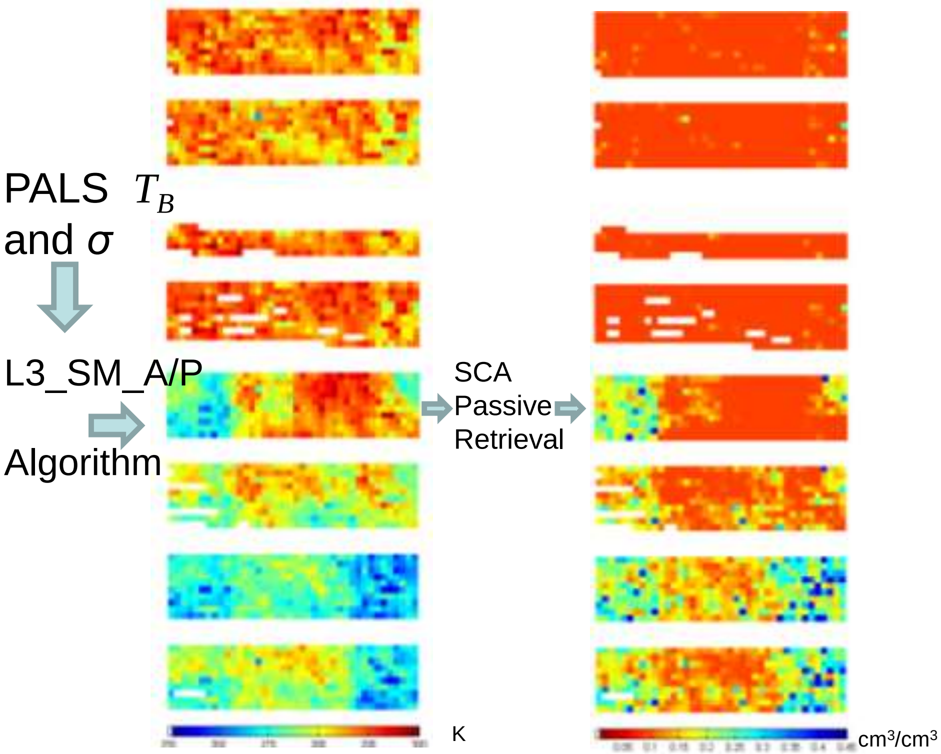
$T_{B_p}(C) +$ Parent scale-C brightness temperature

$\beta(C)\cdot\{[\sigma_{pp}(M) - \sigma_{pp}(C)] +$ Scale-C sensitivity parameter ***β*** times smaller scale-M variations in σ_{pp} mostly due to soil moisture variability

$-\Gamma(C)\cdot[\sigma_{pq}(M) - \sigma_{pq}(C)]\}$ Scale-M heterogeneity parameter ***Γ*** times scale-M variation in σ_{pq} mostly due to vegetation and roughness

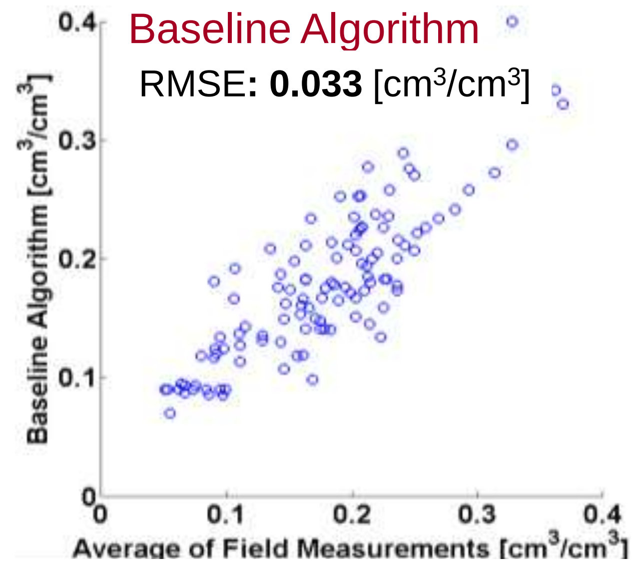
End-to-End Prelaunch Testing of Algorithm Performance

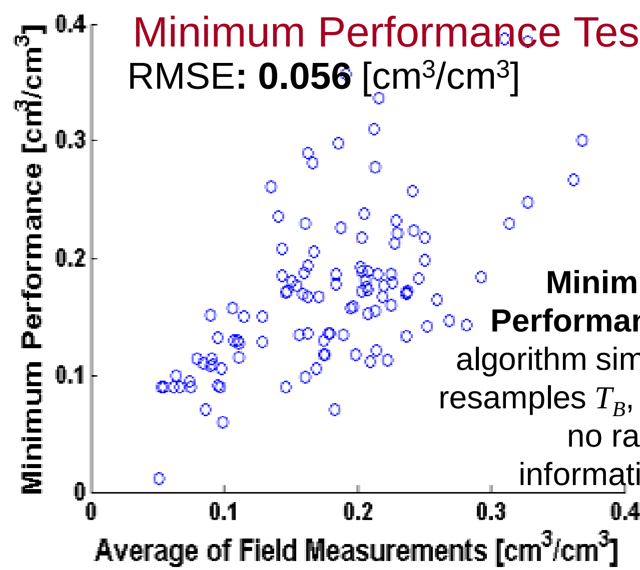
Test of Baseline Algorithm Using SMEX02 PALS Data



Disaggregated T_B (0.8 km)

Estimated Soil Moisture (0.8 km)

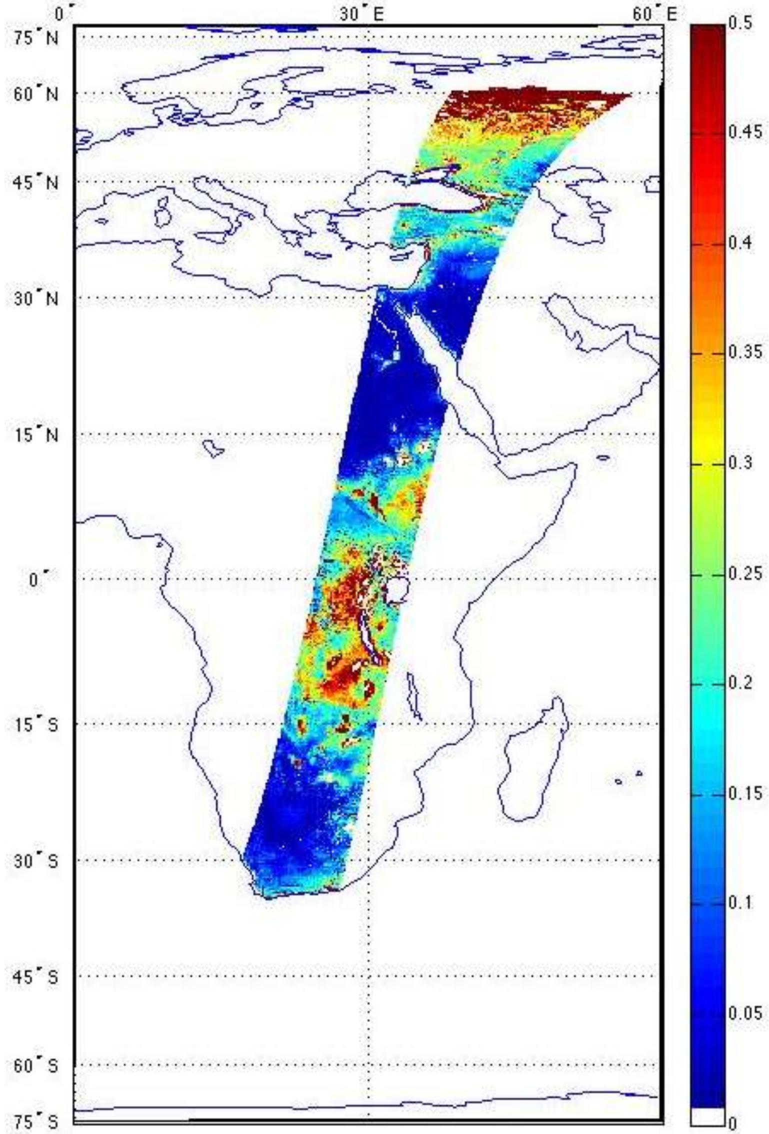




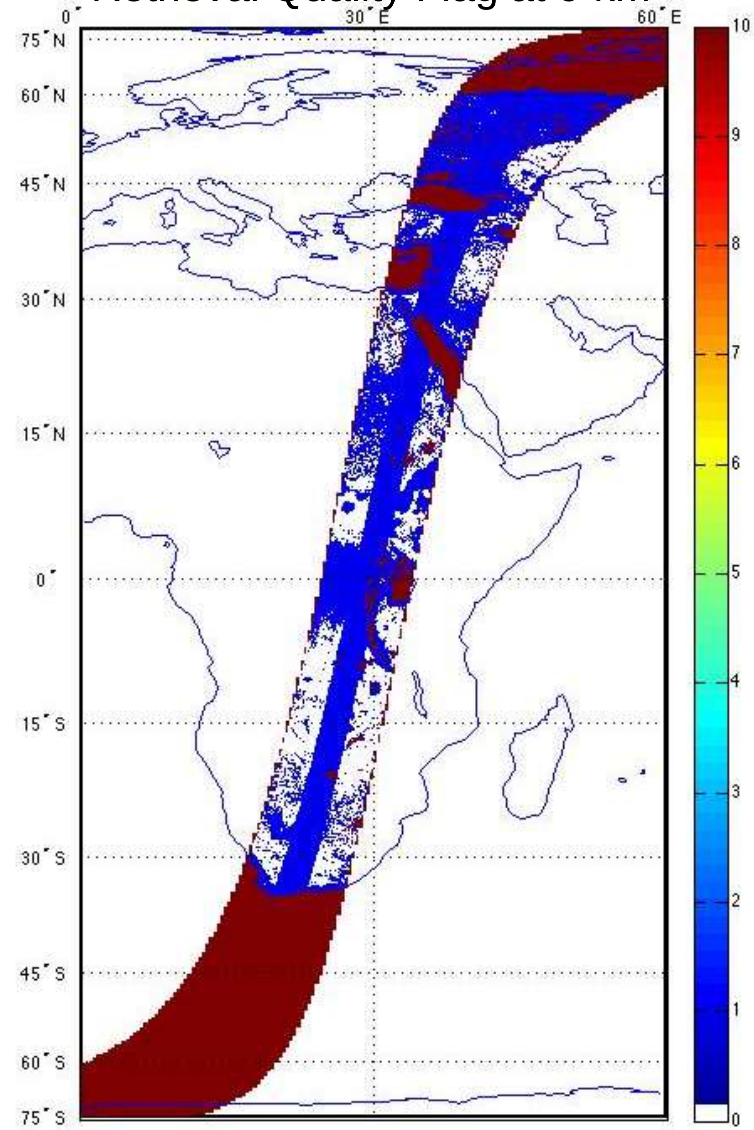
Minimum Performance algorithm simply resamples T_B, i.e. no radar information.

L2_SM_AP Product

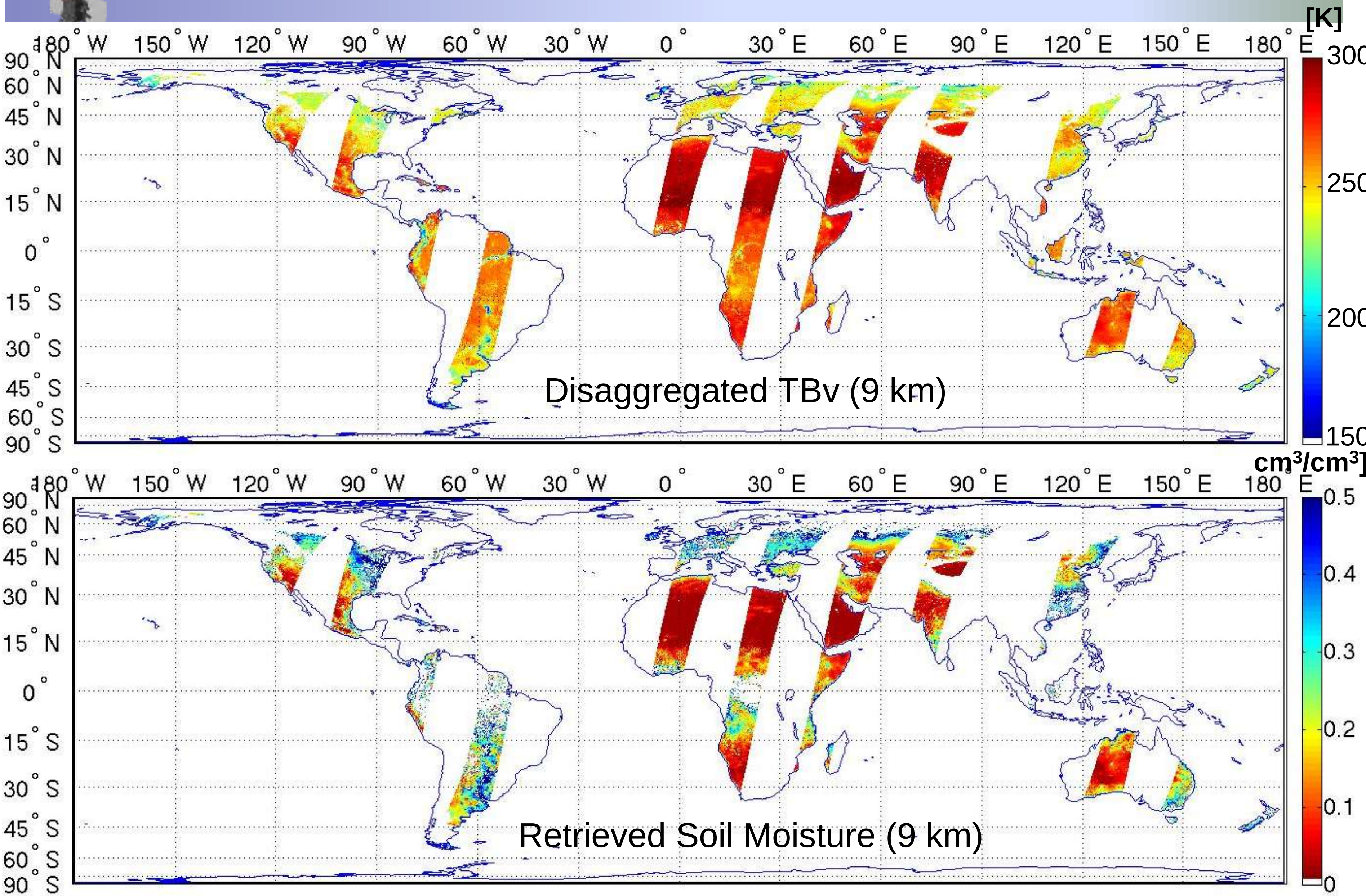
Retrieved Soil Moisture at 9 km cm^3/cm^3



Retrieval Quality Flag at 9 km

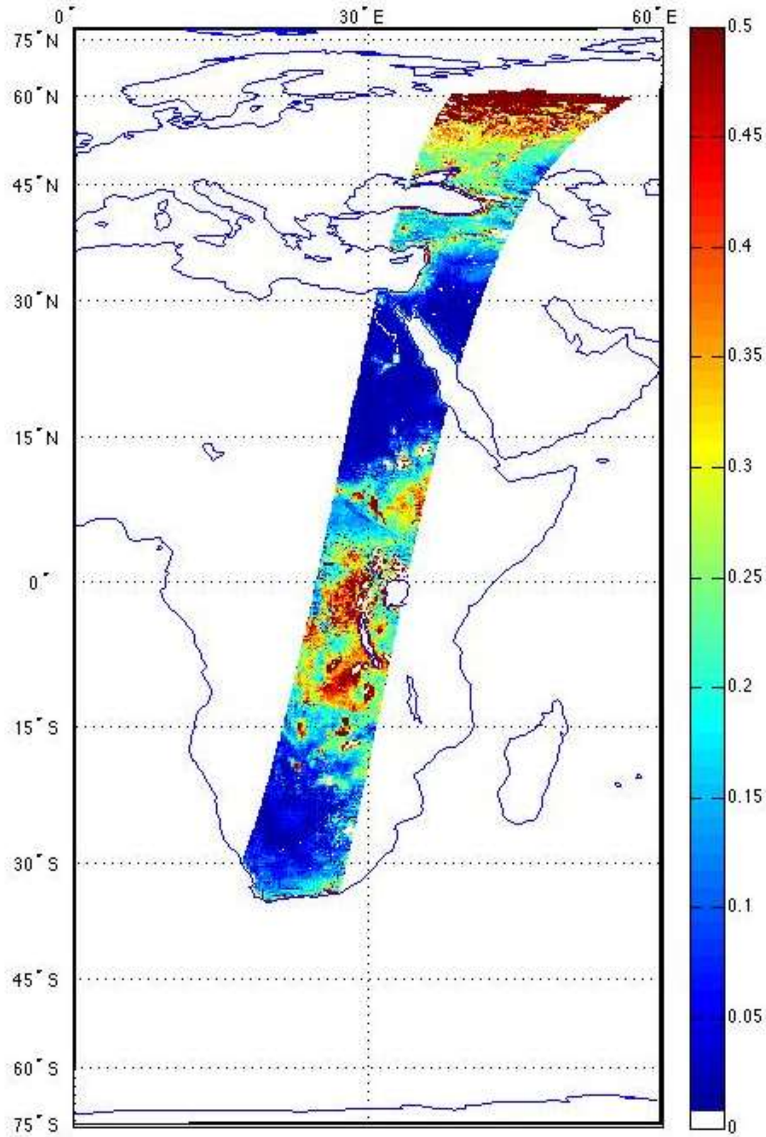


L3_SM_AP Product

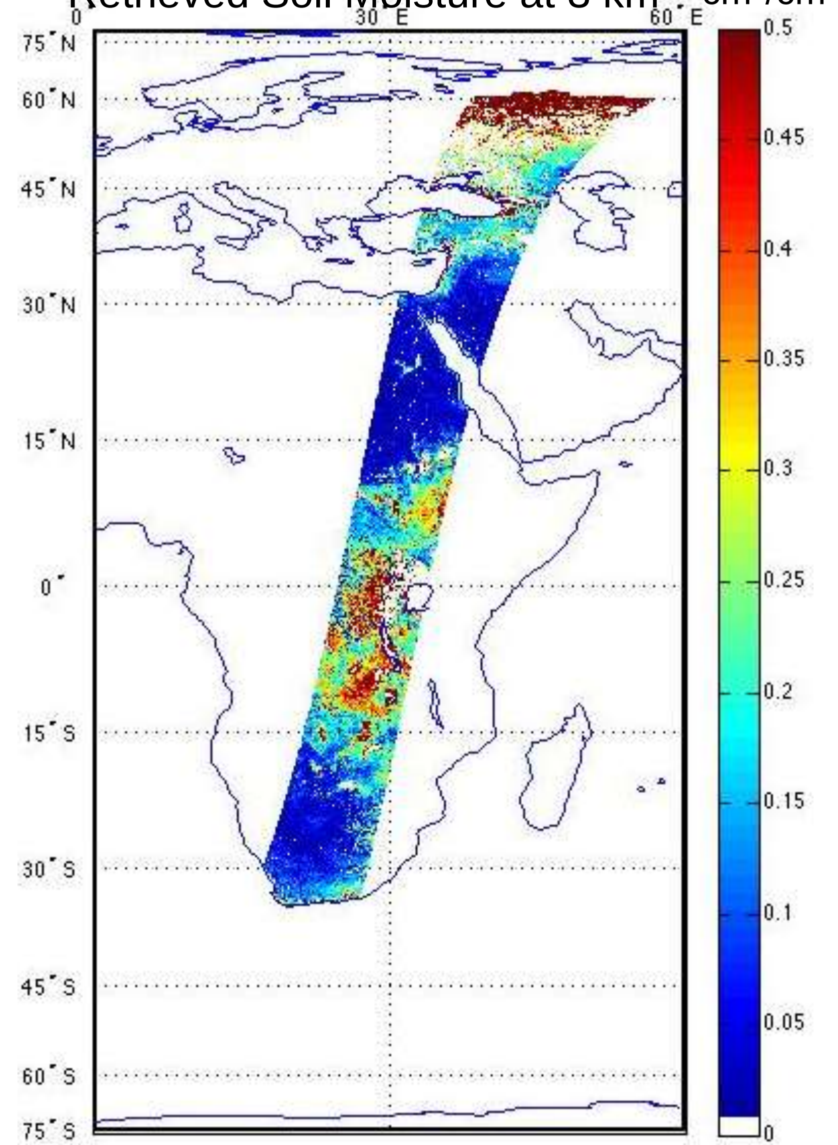


L2_SM_AP Calibration and Validation Using Simulated Data

Retrieved Soil Moisture at 9 km cm³/cm³

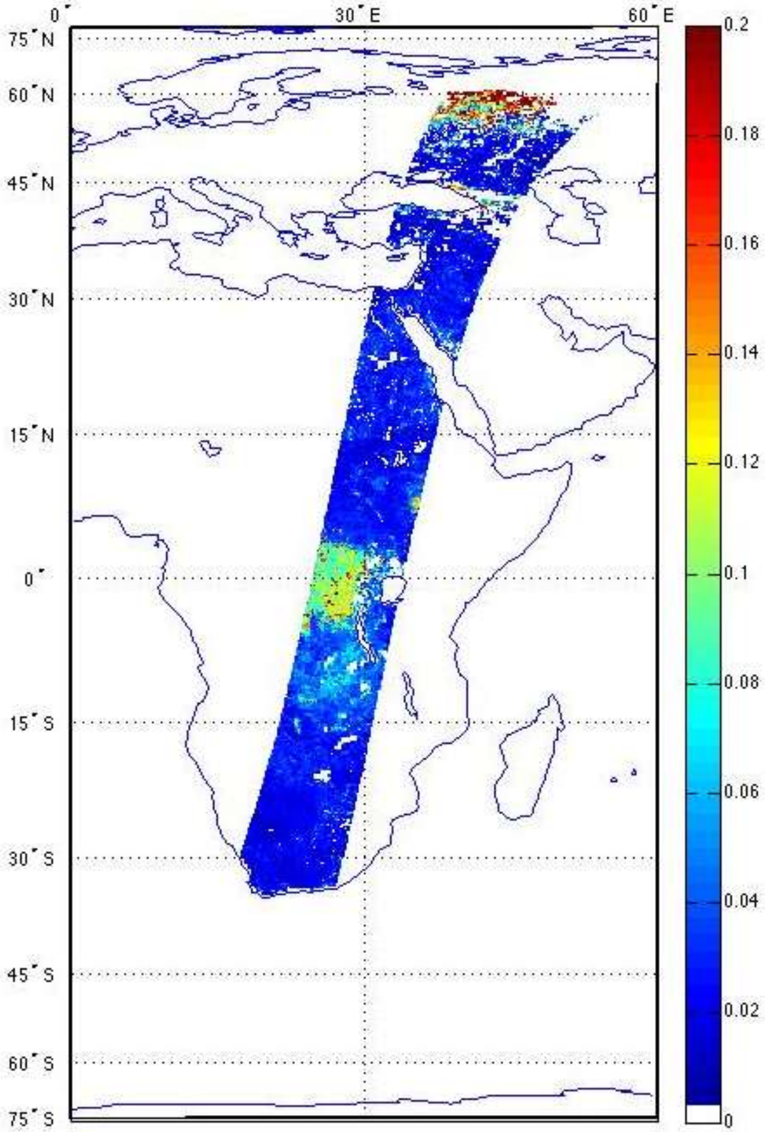


Retrieved Soil Moisture at 3 km cm³/cm³

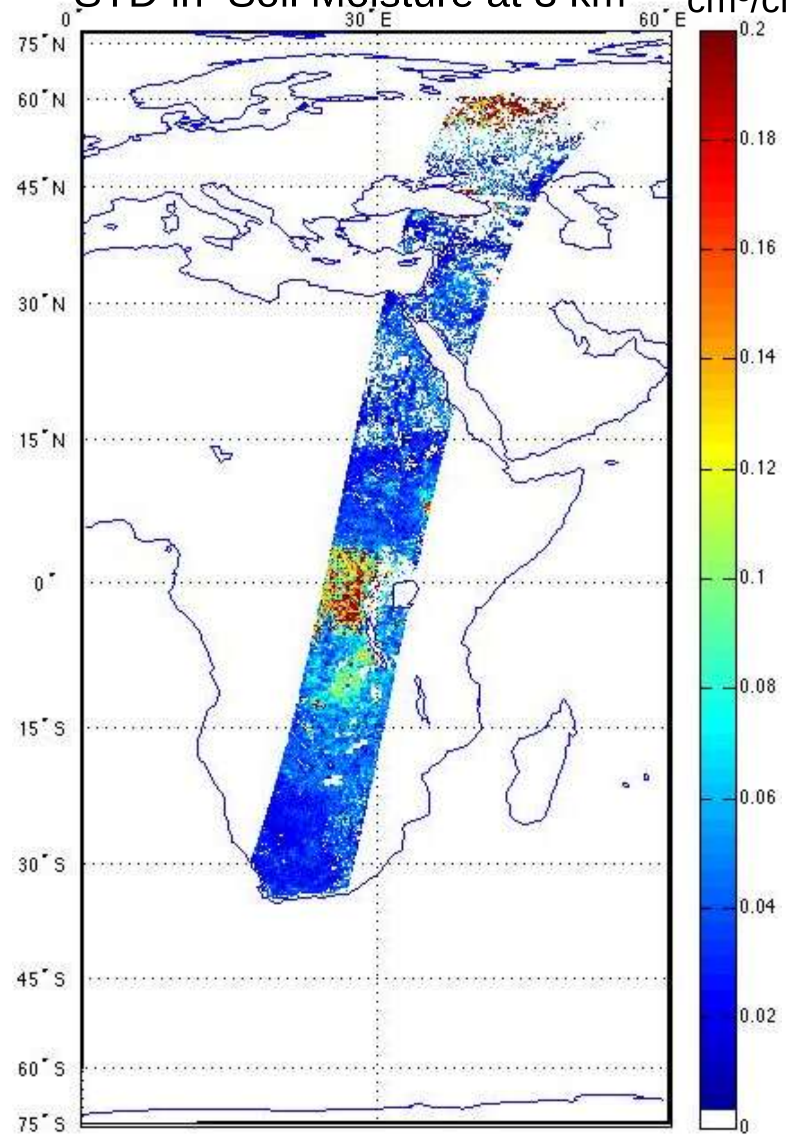


L2_SM_AP Calibration and Validation Using Simulated Data

STD in Soil Moisture at 9 km cm^3/cm^3



STD in Soil Moisture at 3 km cm^3/cm^3



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)

Soil Moisture Active Passive (SMAP) Mission

Applications Plan

Edited by

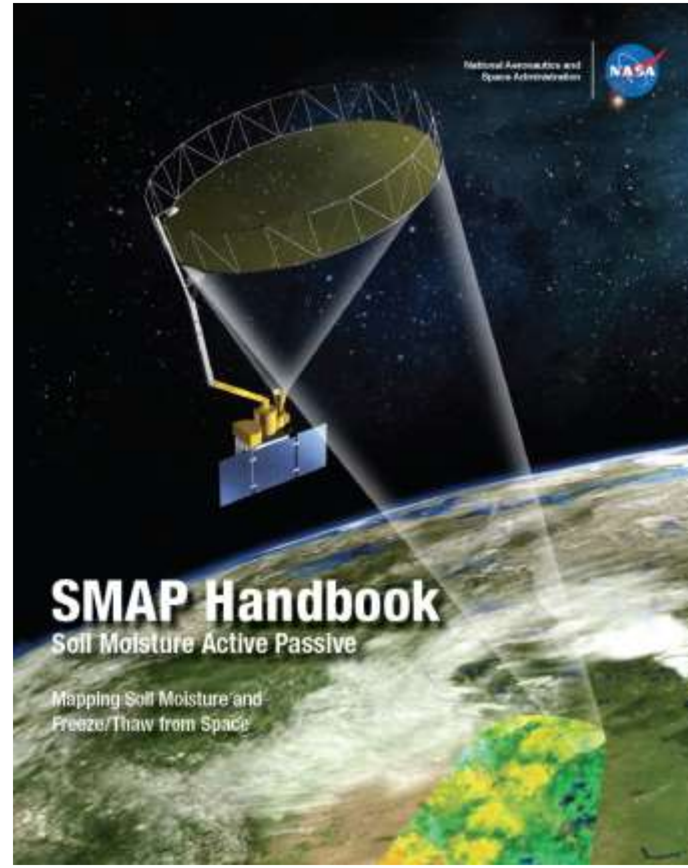
Molly Brown, Susan Moran, Vanessa Escobar, Dara Entekhabi

The SMAP Handbook

Jet Propulsion Laboratory
California Institute of Technology

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



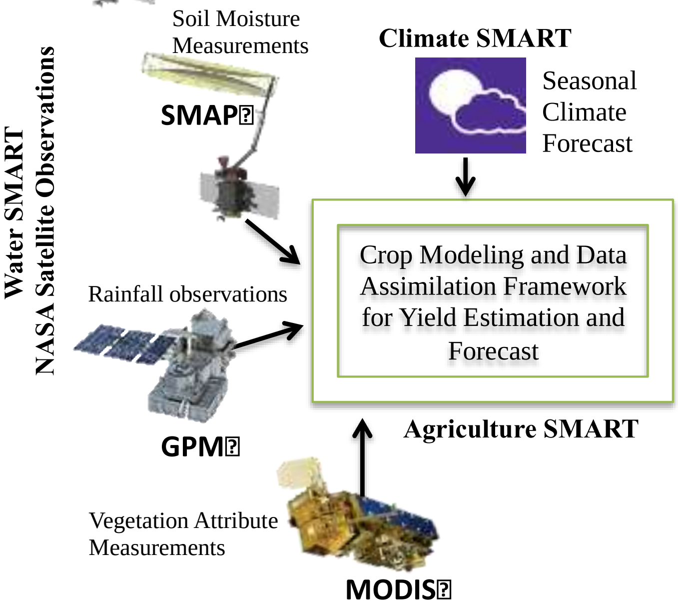
(192 Pages)

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

A Case Study Using SMAP-like Data

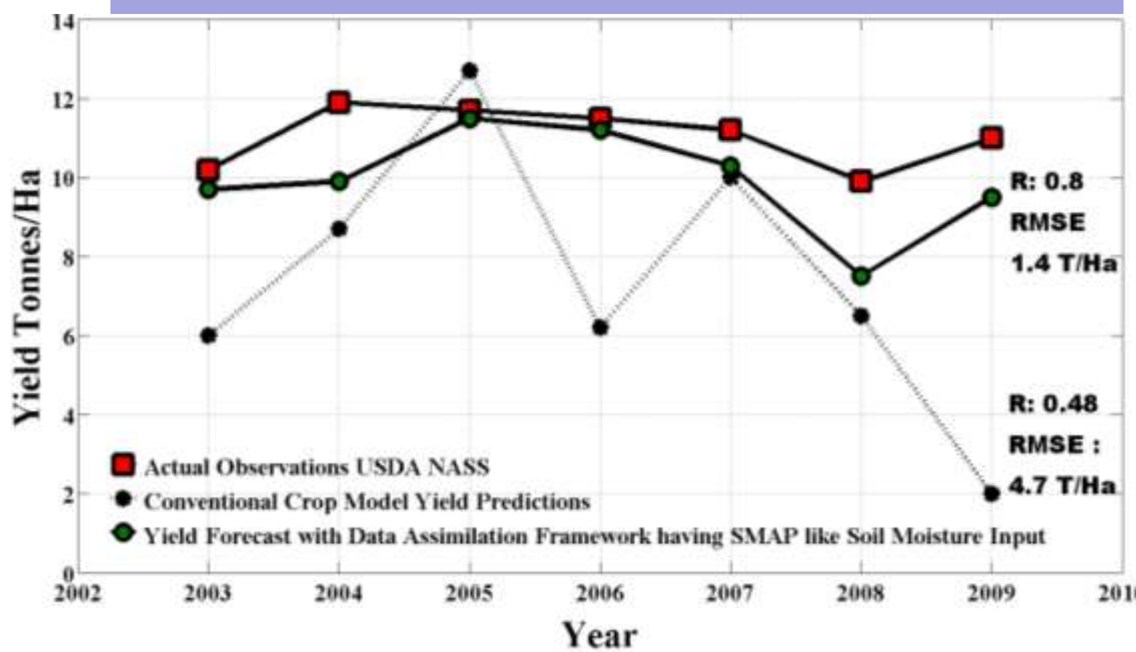
SMAP for Agricultural Crop Yield and Food Security Applications

Jet Propulsion Laboratory
California Institute of Technology



Statement of Problem: The world faces an uphill struggle in feeding a projected nine to ten billion people by 2050.

Corn Yields with Improved Estimation and Optimal Forecast



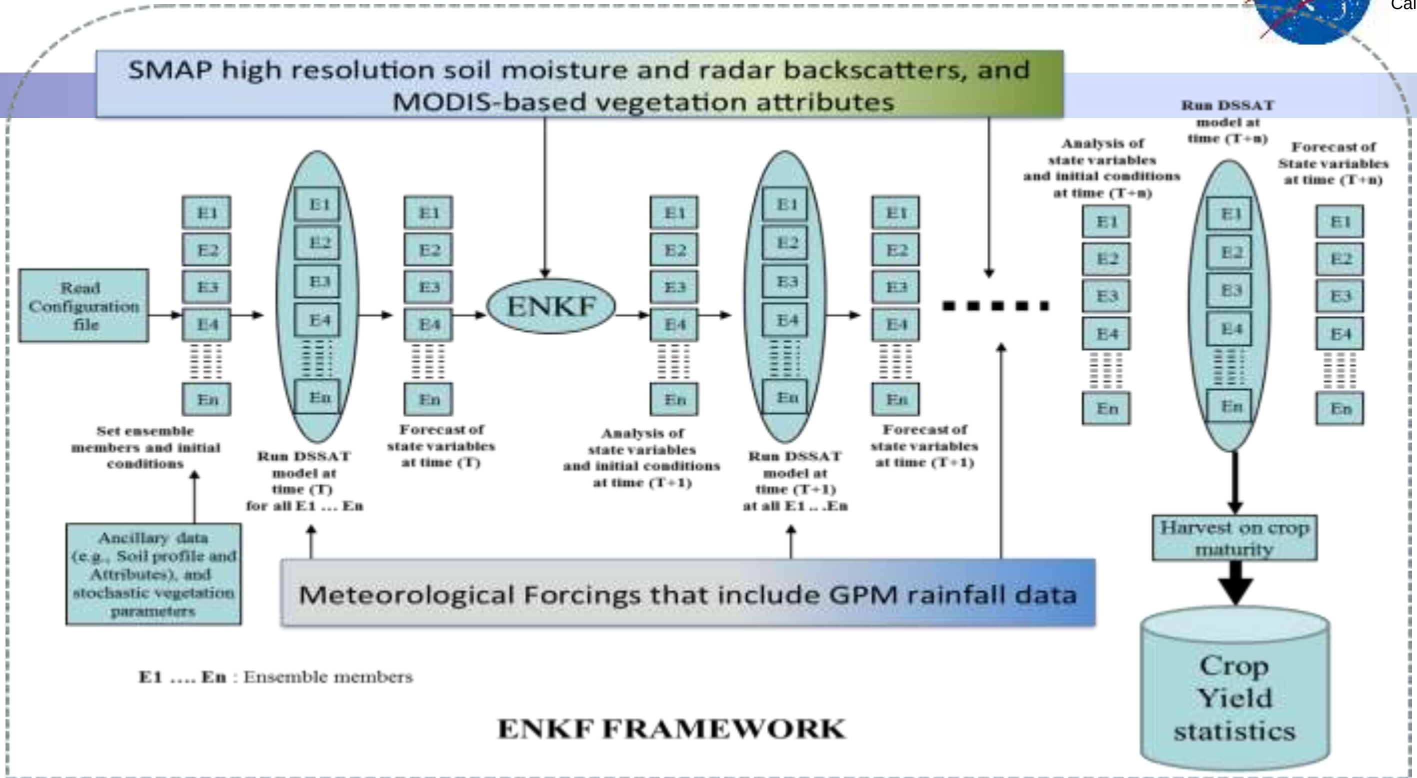
Ines, Das et al., 2013. Assimilation of Remotely Sensed Soil Moisture and Vegetation with a Crop Simulation Model for Maize Yield Prediction. RSE-D-12-00872R2: Remote Sensing of Environment. *In Press*

Water is the defining link between the climate and agriculture. To improve agricultural decision support systems and ensure food security, better quality and better use of Soil Moisture/Water information is vital.

This information will increase the lead time and skill of of crop yield forecasts.

NASA/JPL Resources and Know-how

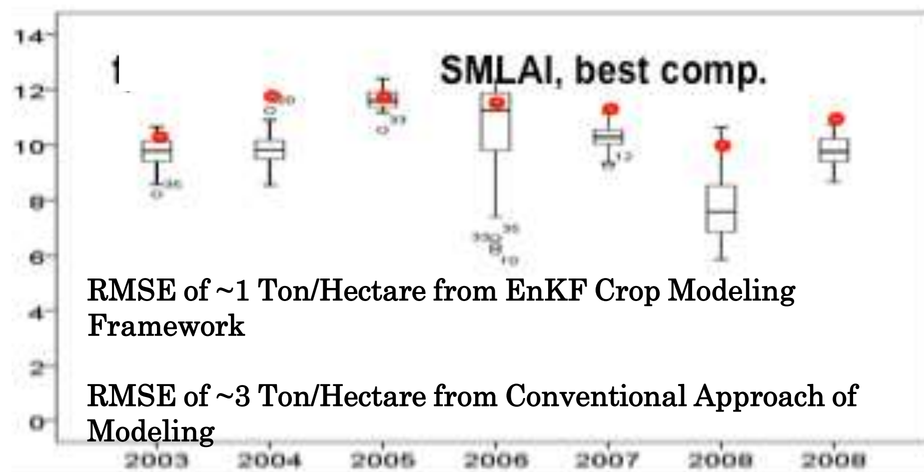
Jet Propulsio
California Institute



JPL agriculture system and data assimilation framework.

Promising results show significant improvement in crop yield estimation.

Reference: Ines, A.V.M., N.N. Das, J.W. Hansen, and E.G. Njoku. 2012, Assimilation of Remotely Sensed Soil Moisture and Vegetation with a Crop Simulation Model , Remote Sensing of Environment, under review.



Summary

- NASA SMAP mission in integration and testing (launch shipment October 2014)
- Launch manifested for January, 2015
- 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
- Focused and planned effort to promote meaningful applications

Thanks

BACKUP

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:

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

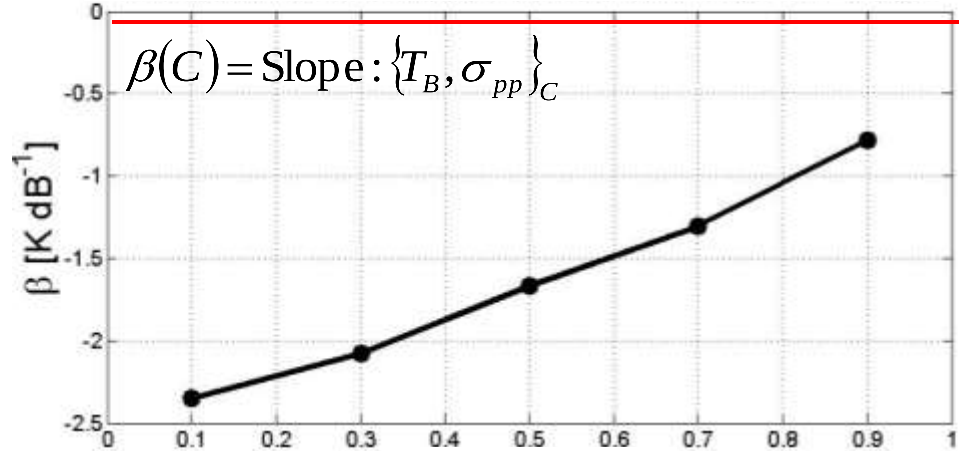
L2_SM_AP
Radar-Radiometer Algorithm

T_B-disaggregation algorithm becomes:

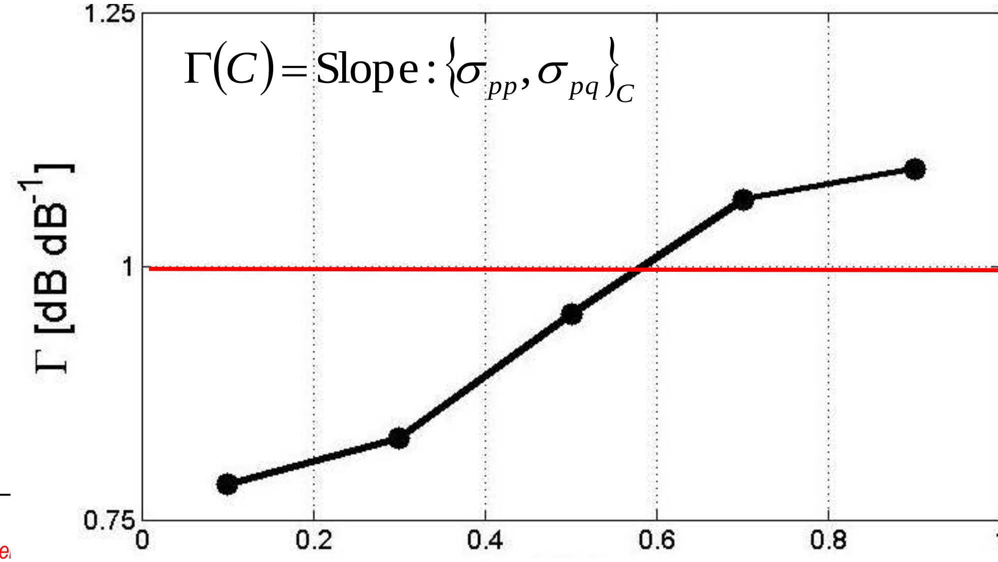
$$T_{B_p}(M) = T_{B_p}(C) + \beta(C)\cdot\{[\sigma_{pp}(M) - \sigma_{pp}(C)] - \Gamma(C)\cdot[\sigma_{pq}(M) - \sigma_{pq}(C)]\}$$

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

Based on PALS Observations From:
SGP99, SMEX02, CLASIC and SMAPVEX08

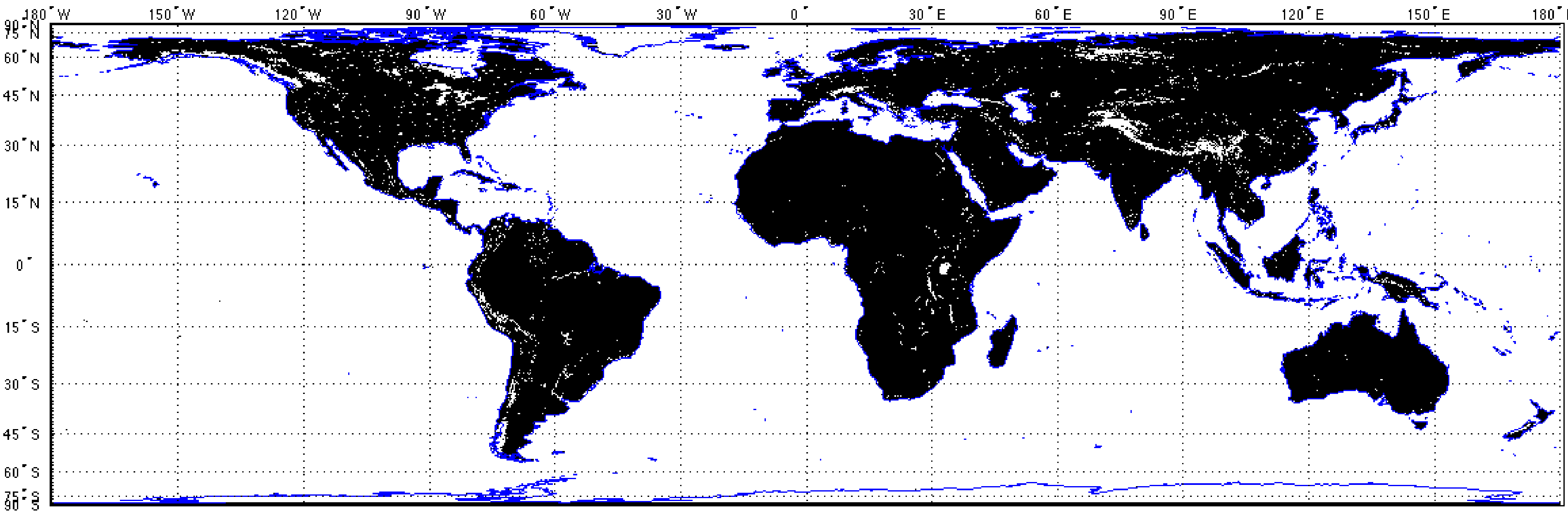


$$\text{RVI} = \frac{8\sigma_{hv}}{\sigma_{hh} + \sigma_{vv} + 2\sigma_{hv}}$$



SMAP Retrievable Mask at 9 km

Regions Where SMAP Soil Moisture Algorithms Will be <u>Executed</u>



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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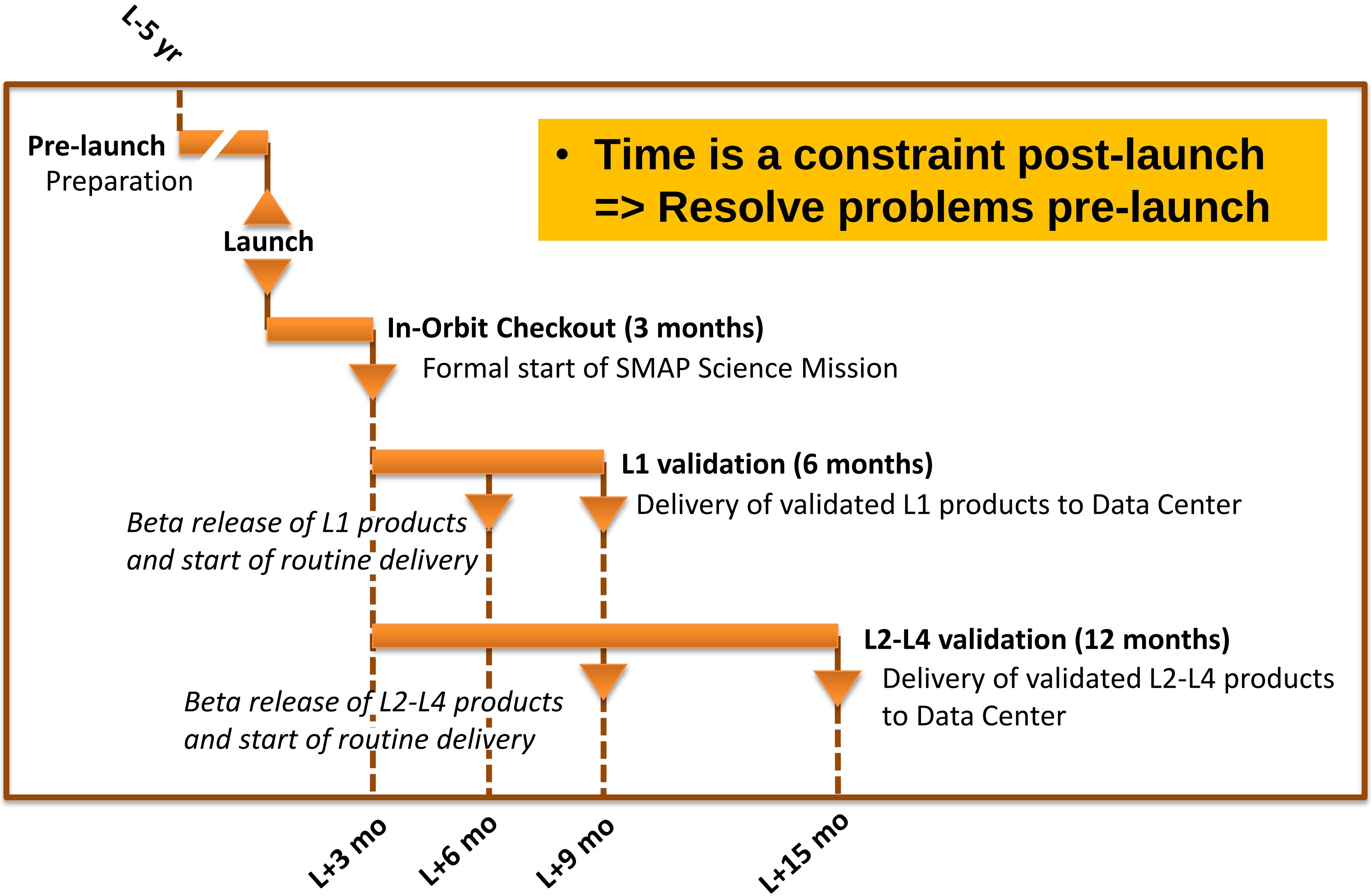
SMAP Cal/Val Timeline



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

Jet Propulsion Laboratory
California Institute of Technology

L2_SM_AP Error Budget: T_B Formulation

Radiometer Brightness Temperature Uncertainty	$\Delta^2_{T_{B_{36km}}}$
Radar Backscatter Cross-Section Uncertainty	$+\beta^2\left[\frac{10}{\ln 10}\right]^2\left[\frac{1}{N^{3km\rightarrow 9km}_{Land}}\right]\left[K^2_{pp_{3km}}+\Gamma^2 K^2_{pq_{3km}}\right]$
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 $\Delta^2_\beta=\frac{1}{\sigma^2_{T_B}\left(N_w-1\right)}\left[\sigma^2_{T_B}+\beta^2\sigma^2_{\sigma_{pp}}-\rho\beta\sigma_{T_B}\sigma_{\sigma_{pp}}+\sigma^2_{T_B}+\beta\sigma^2_{\sigma_{pp}}\right]$ and $\Delta^2_\Gamma=\frac{1}{\sigma^2_{\sigma_{pp}}\left(N_{3:36}-1\right)}\left[\sigma^2_{\sigma_{pp}}+\Gamma^2\sigma^2_{\sigma_{pq}}-\rho\Gamma\sigma_{\sigma_{pp}}\sigma_{\sigma_{pq}}+\frac{10^2}{\log^2 10}\frac{K^2_{pp}}{N_L}+\Gamma^2\frac{10^2}{\log^2 10}\frac{K^2_{pq}}{N_L}\right]$

Comparisons