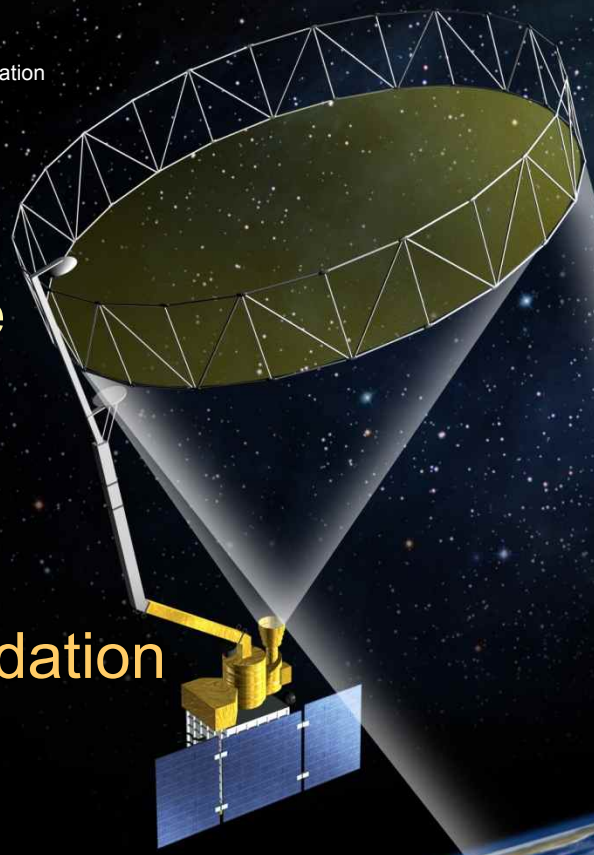
National Aeronautics and Space Administration

Soil Moisture Active Passive Mission

SMAP

Calibration/Validation Workshop

Nov. 14-16, 2012



Algorithm Summary for L2-L4 Products

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Mahta Moghaddam

Background

- SMAP is a planned NASA Earth Science Decadal Survey Mission
- Launch currently scheduled for October 2014 into a 6 am / 6 pm sun-synchronous orbit
- Will use an L-band radar & radiometer to measure global soil moisture & freeze/thaw every 2-3 days
- Baseline SMAP L2-L4 data products include:
  - -- radar-derived F/T at 3 km resolution
  - -- radiometer-only SM at 40 km resolution
  - -- combined radar/radiometer SM at 9 km resolution
  - -- value-added products (root zone SM, carbon NEE) at 9 km
- All SMAP products output on nested 1, 3, 9, 36 km EASE2 grids

Baseline Data 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	(36×47 km)	12 hrs	
L1B_S0_LoRes	Low-Resolution Radar σ_o in Time-Order	(5×30 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	

Over outer 70% of swath.

** *The SMAP project will make a best effort to reduce the data latencies beyond those shown in this table.*

* *Product directly addresses the mission L1 science requirements.*

Algorithm Needs

- All baseline SMAP products have associated algorithm(s) which require a variety of ancillary data to meet retrieval accuracies:
  - -- 0.04 cm^3/cm^3 for soil moisture within SMAP land mask
  - -- 80% classification accuracy for binary F/T in boreal latitudes
- Areas of snow/ice, frozen ground, mountainous topography, open water, urban areas, and dense vegetation (> 5 kg/m^2) are excluded from SM accuracy statistics
- Static ancillary data do not change during mission
  - -- permanent masks (land/water/forest/urban/mountain), DEM, soils
- Dynamic ancillary data require periodic updates ranging from daily to seasonally
  - -- soil T, precipitation, vegetation, surface roughness, land cover

Science Data Product Algorithm Summary

Product	Baseline Algorithm	Algorithm Options	Key Outputs
L1C_TB	Inverse-distance-squared gridding.	Nearest neighbor; drop-in-the-bucket	Gridded T_B (H, V) fore and aft on 36 km EASE2 grid.
L2_SM_P	Single-channel (H pol) version of tau-omega model	Dual-channel algorithm (retrieve SM and VWC); LPRM; single channel (V pol)	Soil moisture and water body-corrected T_B (H, V) on 36 km EASE2 grid.
L2_SM_A	Time-series datacube algorithm, using multi-datacube forward model.	Kim-van Zyl time series, Wagner change-detection	3 km gridded σ^0 (HH,VV,HV), RVI, transient water detection flag, FT flag, soil moisture, surface roughness.
L2_SM_AP	T_B disaggregation algorithm, using T_B-σ^0 regression for beta parameter.	SM disaggregation algorithm	Disaggregated T_B, aggregated σ^0, soil moisture at 9 km resolution.
L3_SM_A **L3_SM_P** **L3_SM_AP**	Composite data nearest to 6 am LST.	None	Daily composite of respective L2 data product contents on global grid.
L3_FT_A	Composite AM/PM data nearest to 6 am / 6 pm LST. Seasonal reference change-detection algorithm (from L2_FT_A).	None	Daily composite of σ^0 and FT flag data, on separate AM and PM layers, on 3 km boreal polar grid.

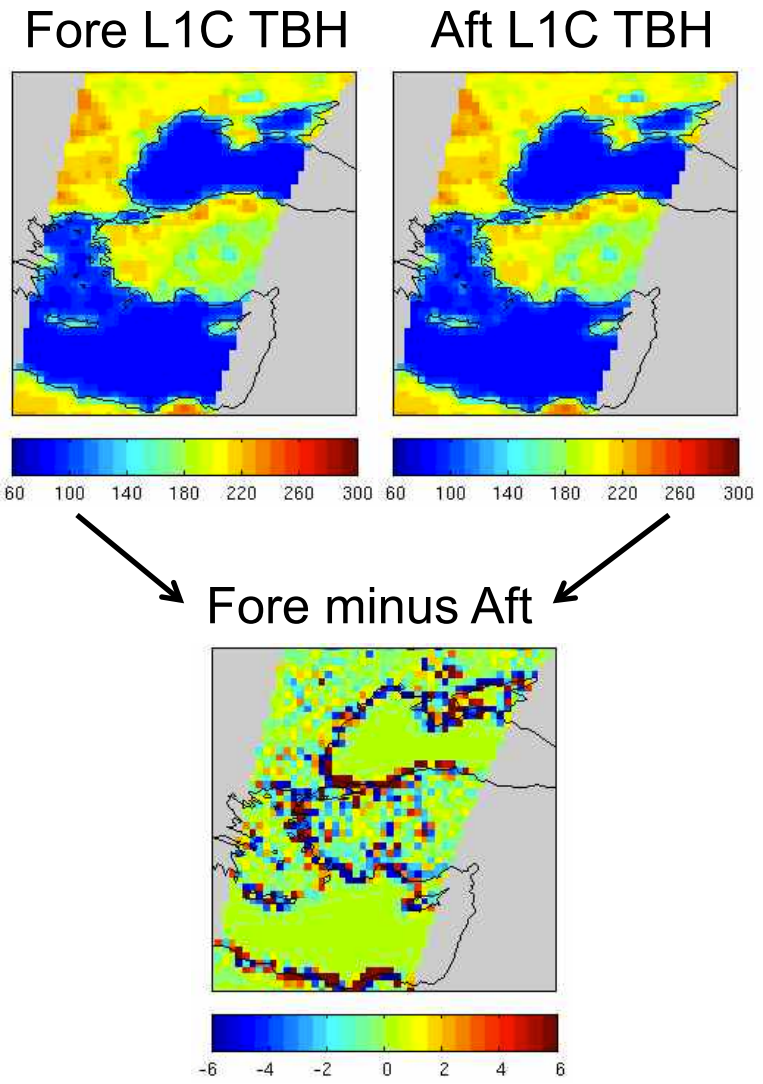
Science Data Product Algorithm Summary

Product	Baseline Algorithm	Algorithm Options	Key Outputs
L4_SM	Ensemble-based land data assimilation system.	n/a	Continuous time series of global surface and **root zone** soil moisture on 9 km EASE2 grid.
L4_C	Coupled light use efficiency & soil decomposition algorithms driven by SMAP land data assimilation & MODIS FPAR inputs.	Fire disturbance & recovery effects; FPAR estimation using lower order VI inputs (VIIRS)	Daily time series of net ecosystem CO_2 exchange (NEE) on 9 km EASE2 grid.

L1C_TB Algorithm Summary

Gridded Brightness Temperatures

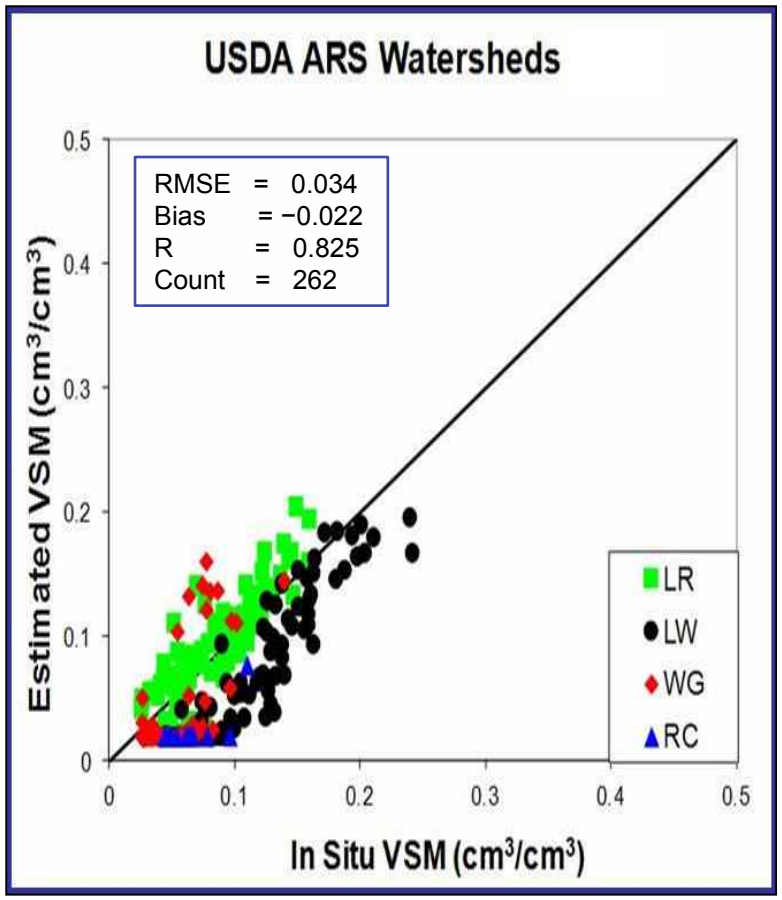
- **Motivation/Objectives**: Map SMAP L1 time-ordered TB on Earth-fixed grids as an input to SMAP L2 passive soil moisture retrieval
- **Approach**: Inverse-distance squared gridding
- **Inputs**: L1B_TB data
- **Outputs**: L1C_TB (in separate fore- and aft-look groups) on 36 km EASE2 grids
- **Domain**: Global coverage of land and ocean, ascending (6 pm) & descending (6 am) passes
- **Resolution**: 36 km EASE2 grids
- **Temporal fidelity**: 3 days (just 6 am passes); >2 days if 6 pm passes also used



L2_SM_P Algorithm

Land Surface Soil Moisture

- **Motivation/Objectives**: Obtain estimates of soil moisture in the top 5 cm of soil with an average error no greater than 0.04 cm^3/cm^3
- **Approach**: Single channel version of zero-order tau-omega model parameterized with ancillary data
- **Inputs**: L1C_TB and ancillary data
- **Outputs**: 0-5 cm surface soil moisture and water body-corrected T_B
- **Domain**: Global land area excluding regions of snow & ice, frozen ground, mountainous topography, open water, urban areas, and areas where VWC ≥ 5 kg/m^2
- **Resolution**: 36 km EASE2 grid
- **Temporal fidelity**: 3 days (6 am overpass)

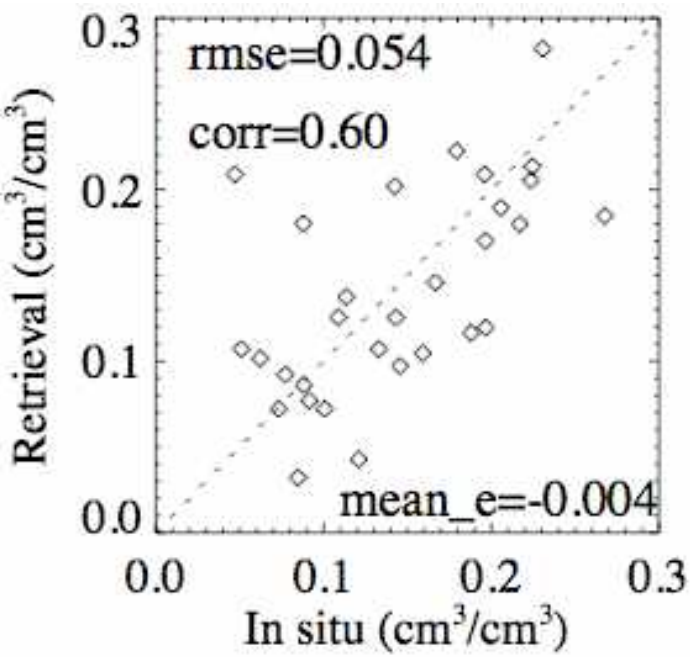


Use of SMOS T_B to Test SMAP Algorithms

L2_SM_A Algorithm

Land Surface Soil Moisture

- **Motivation/Objectives**: Obtain estimates of soil moisture in the top 5 cm of soil within an error of 0.06 cm^3/cm^3
- **Approach**: two-channel (time-series HH and VV) inversion of forward models for 16 landcover classes [data cube approach]
- **Inputs**: L1C_S0 and ancillary data
- **Outputs**: 0-5 cm surface soil moisture, surface water body (binary), radar vegetation index
- **Domain**: Global land area excluding regions of snow & ice, frozen ground, mountainous topography, open water, urban areas, and areas where VWC ≥ 5 kg/m^2
- **Resolution**: 3 km EASE2 grid
- **Temporal fidelity**: 3 days (6 am overpass)

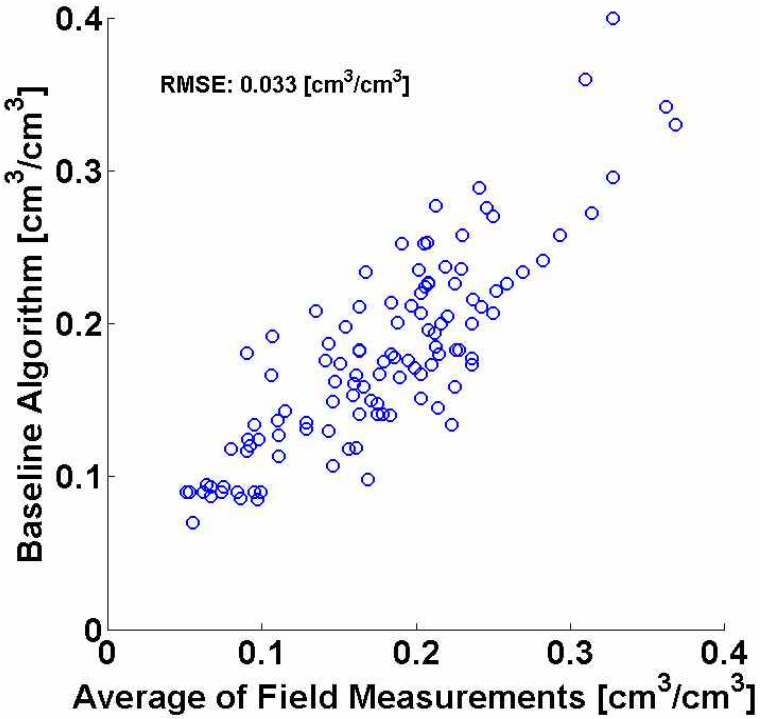


Algorithm applied to airborne scatterometer data from the SGP99 campaign over pasture landcover

L2_SM_AP Algorithm

Land Surface Soil Moisture

- **Motivation/Objectives:** Obtain estimates of soil moisture in the top 5 cm of soil with an average error no greater than 0.04 cm^3/cm^3
- **Approach:** $T_B(p)$ disaggregation using high resolution $\sigma^0(pp)$ that is scaled by parameters obtained from T_B-σ^0 regression. Single channel zero order tau-omega model parameterized with ancillary data then applied on the disaggregated $T_B(p)$ to retrieval soil moisture
- **Inputs:** $T_B(p)$ from L2_SM_P and $\sigma^0(pp)$ from L2_SM_A, and ancillary data
- **Outputs:** 0-5 cm surface soil moisture and disaggregated/downscaled $T_B(p)$
- **Domain:** Global land area excluding regions of snow & ice, frozen ground, mountainous topography, open water, urban areas, and areas where VWC ≥ 5 kg/m^2
- **Resolution:** 9 km EASE2 grid
- **Temporal fidelity:** 3 days (6 am overpass)



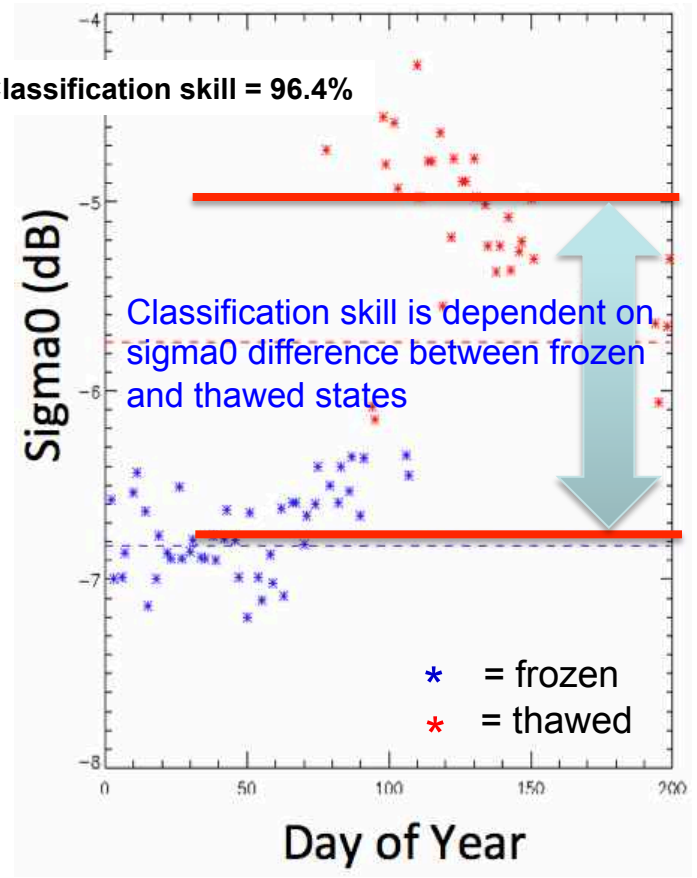
Use of SMEX02 PALS data to test the SMAP L2_SM_AP Baseline Algorithm

L3_FT_A Algorithm

Land Surface Freeze/Thaw state

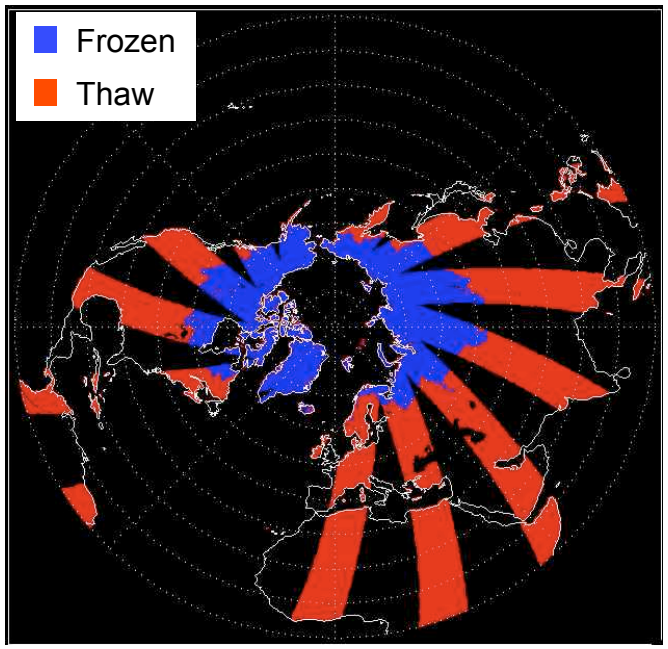
- **Motivation/Objectives**: Obtain measurements of binary F/T state in boreal (≥45N) zones with ≥80% spatial classification accuracy; capture F/T constraints on boreal C fluxes consistent with tower flux measurements
- **Approach**: Apply time series L1 radar backscatter to derive surface F/T state
- **Inputs**: Level 1 high res radar backscatter
- **Outputs**: Surface freeze-thaw state expressed as a binary value (frozen/thawed)
- **Domain**: Vegetated areas encompassing boreal/arctic latitudes (≥45°N)
- **Resolution**: 3 km baseline
- **Temporal fidelity**: 2 days (daily composite)

GloSim2 Thaw Transition Saskatchewan



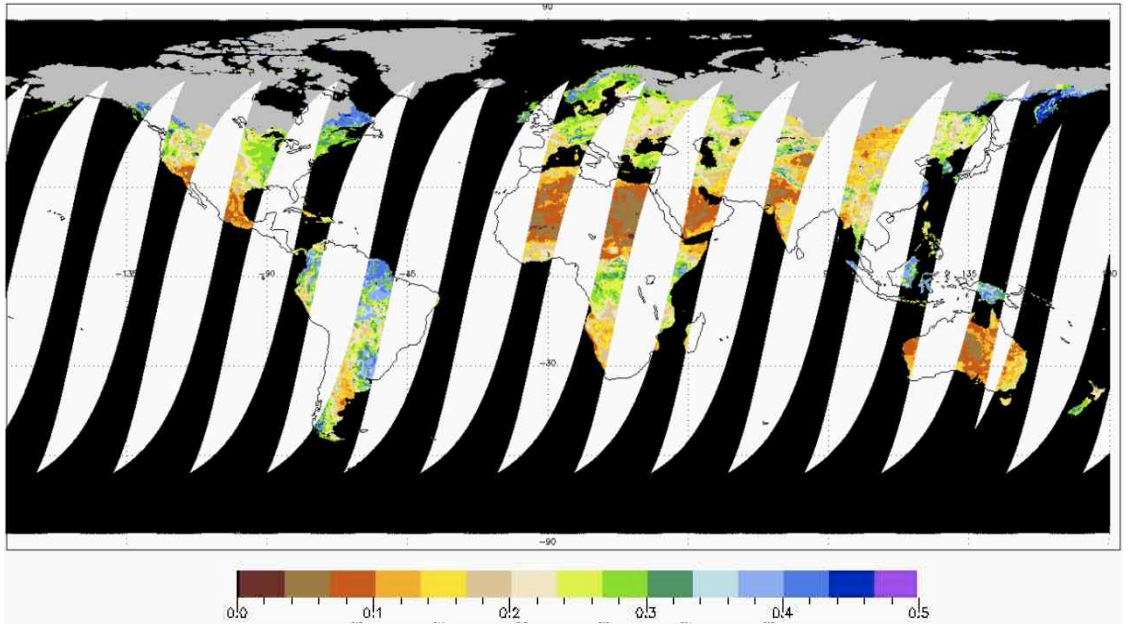
Level 3 Product Examples

L3_FT_A (3 km)



Daily Freeze/Thaw State In Polar Projection

L3_SM_P (36 km)



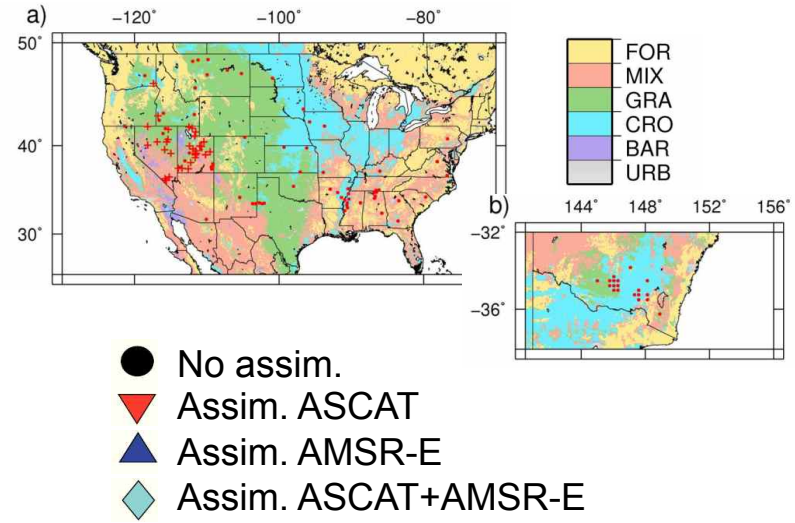
Volumetric Soil Moisture (cm^3/cm^3)

- **composite of respective L2 data products within a 24-hr period output on a global grid**
- **when orbits overlap, composite data nearest to 6 am LST**

L4_SM Algorithm

L4_SM Surface & Root Zone Soil Moisture

- **Motivation/Objectives**: Assimilating L1-L3 SMAP data into a land model driven with observation-based forcing data yields:
  - *a **root zone** soil moisture product (reflecting SMAP data), and*
  - ***complete and consistent** estimates of soil moisture & related fields*
- **Approach**: Customized version of the ensemble-based NASA GEOS-5 land data assimilation system
- **Inputs**: T_B (*L1C_TB, L2_SM_AP*) and FT (*L2_SM_A, L3_FT_A*)
- **Outputs**: Surface and root zone soil moisture, related land surface states and fluxes, error estimates
- **Domain**: Global
- **Resolution**: 9 km (cylindrical EASE2 grid)
- **Temporal fidelity**: 3-hourly



Skill (R) of root zone soil moisture
(Draper et al. 2012, doi:10.1029/2011GL050655.)

L4_C Algorithm

Net Ecosystem CO_2 Exchange (NEE)

Motivation/Objectives: Quantify NEE variability for major biomes; Link NEE to primary moisture & thermal constraints to productivity & ecosystem respiration

Approach: Apply LUE & soil Decomp. Algs. driven by SMAP & other ancillary inputs

Inputs: FT (L3_FT_A); SM & T (L4_SM); Rs, VPD, Tmn (GMAO); FPAR (MODIS, VIIRS)

Outputs: NEE (validated); GPP, Rh, SOC, environmental constraint metrics (research)

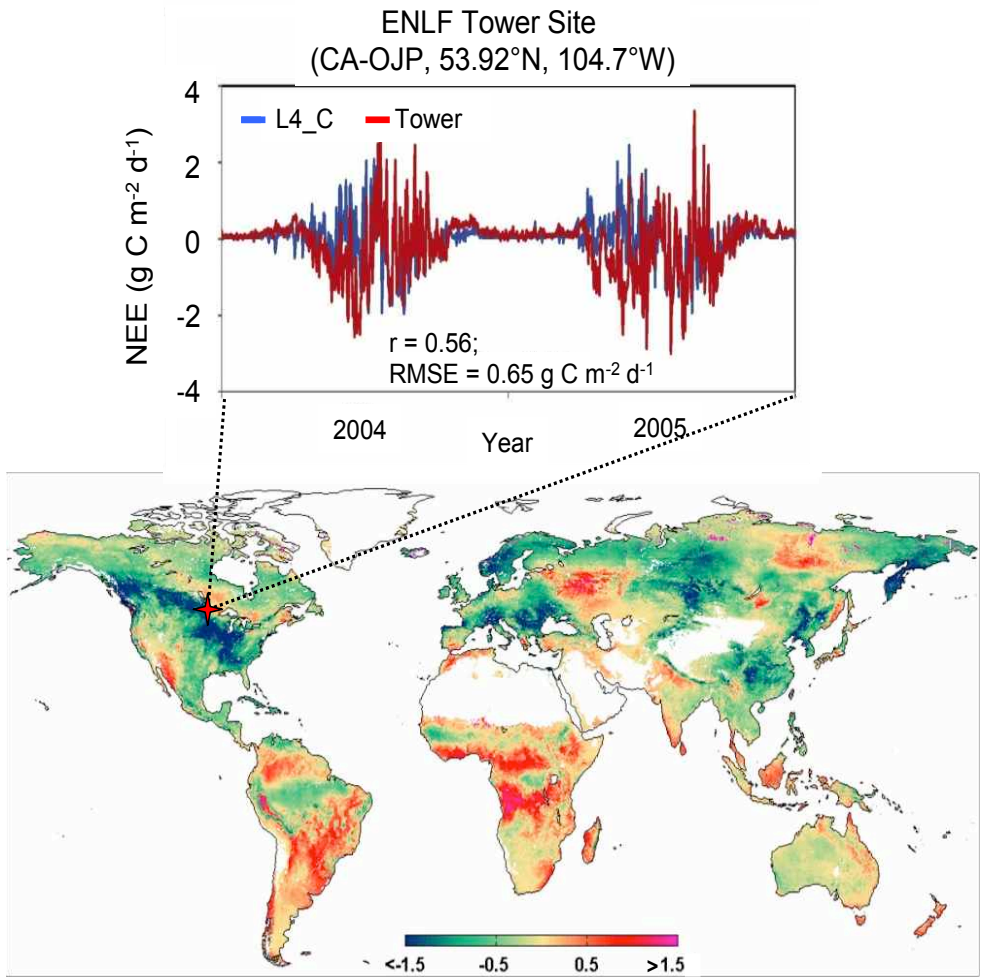
Domain: Global vegetated areas

Resolution: 9 km (1 km processing)

Temporal fidelity: Daily

Accuracy: Emphasis on boreal land areas; NEE RMSE ≤ 1.6 g C m^{-2} d^{-1} relative to tower observations

L4_C Product Example



L4_C NEE (DOY 196, g C m^{-2} d^{-1})

L2/3_SM Validation Approach

Methodology	Data	Importance	Metric
Core Sites	Grid Cell averages for each overpass (time-continuous)	Primary	RMSE, Bias, Anomaly Correlation
Sparse Networks	Spatially scaled grid cell values for each overpass (time-continuous)	Secondary: Pending results of scaling analyses	RMSE, Bias, Anomaly Correlation
Satellite Products	Soil moisture products (SMOS, GCOM-W, SAOCOM, Aquarius)	Secondary	Pattern matching, correlation
Model Products	Global soil moisture model outputs (ECMWF, NCEP, GEOS-5)	Secondary	Correlation
Field Experiments	Detailed soil moisture estimates for limited set of conditions (in situ and airborne)	Primary	RMSE, Bias, Correlation

L4_SM Validation Approach

Methodology	Data	Importance	Metric
Core Sites	Observed grid cell average values (time-continuous)	Primary	**RMSE**, bias, correlation
Sparse Networks	Observed values (time-continuous)	Primary	**Correlation**, RMSE, bias
Satellite Products	Orbit-based match-ups (SMOS, ASCAT, …)	Secondary: Pending cont'd operation	**Correlation**, RMSE, bias
Model Products	Global modeling and assimilation systems (ECMWF, NCEP, …)	Primary	RMSE, bias, correlation, assim. diagn.
Field Experiments	Detailed estimates for a very limited set of conditions	Secondary	**RMSE**, bias, correlation

L3_FT_A & L4_C Validation Approach

Methodology	Data	Importance	Metric
Core Sites	Grid Cell averages for each overpass	Primary	Classification accuracy over site (FT); RMSE, bias, correlation (L4_C)
Sparse Networks	Spatially scaled grid cell values for each overpass	Primary	Classification accuracy over site (FT); RMSE, bias, correlation (L4_C)
Satellite Products	PALSAR 2, Aquarius, ASCAT, SMOS, AMSR-E	Secondary: Pending cont'd operation	Classification accuracy (FT); correlations, RMSE, bias (C)
Model Products	GMAO GEOS-5 temperatures	Secondary	Classification accuracy (global FT); sensitivity diagnostics (C)
Field Experiments	Detailed estimates for a very limited set of conditions	Secondary	Classification accuracy (FT); correlations, RMSE, bias (C)

Summary

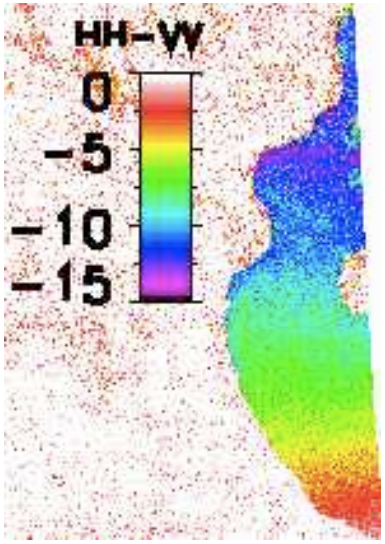
- All SMAP products are generated by algorithms which are described in Algorithm Theoretical Basis Documents (ATBDs)
- Initial Release v.1 of the ATBDs are posted on the SMAP website
  http://smap.jpl.nasa.gov/science/dataproducts/ATBD/
- An Algorithm Selection Review will take place ~ September, 2013 to select the algorithm for each data product that will be the primary production algorithm at the time of launch in October, 2014
- ATBDs will be updated as warranted under configuration control throughout the mission

BACKUP

Ancillary Parameter Choices

Anticipated Primary Sources of Ancillary Parameters		
1	Soil Temperature	GSFC GMAO [consistency ↔ L2-L4]
2	Surface Air Temperature	GSFC GMAO
3	Vegetation Water Content (VWC)	MODIS NDVI [T. Jackson/R. Hunt approach]
4	Soil Attributes (sand & clay fraction)	Combination of HWSD (global), regional data sets (STATSGO-US, ASRIS-Australia, NSD-Canada), FAO
5	Urban Area	GRUMP data set – Columbia University
6	Open Water Fraction	a priori static water fraction from MODIS MOD44W to be used in conjunction with open water fraction from SMAP HiRes radar
7	Crop Type	combination of USDA Cropland Data Layer, AAFC-Canada, Ecoclimap-Europe
8	Land Cover Class	MODIS IGBP; crop class will be further subdivided into four general crop types
9	Precipitation	GSFC GMAO
10	Snow	Snow & Ice Mapping System (IMS) - NOAA
11	Mountainous Area [DEM]	GMTED-2010
12	Permanent Ice	MODIS IGBP
13	b, ω, and τ Vegetation Parameters	land cover-driven table lookup
14	h Roughness Parameter	land cover-driven table lookup

Open Water Fraction



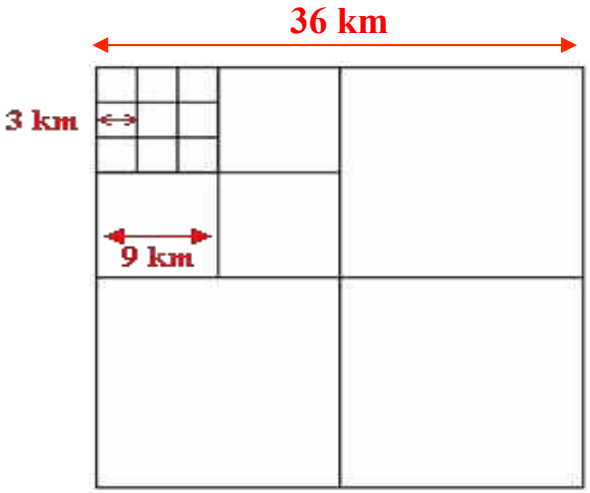
Partial UAVSAR ratio image of Mono Lake. ~7% detection error (10% carried in error budget)

Open water (both permanent & transient) in a SMAP footprint is a potential large error source for SMAP retrieval algorithms if its presence is not detected & corrected for

- use SMAP HiRes radar to determine open water fraction
- a 3 dB threshold is applied to HH to VV ratio to distinguish water from land
- this SMAP parameter can be supplemented by static permanent water body data sets like MODIS MOD44W and JERS-1/PALSAR (for boreal latitudes)
- the water fraction is then used to correct TB for a mix of land & water in the grid cell

SMAP Spatial Grids

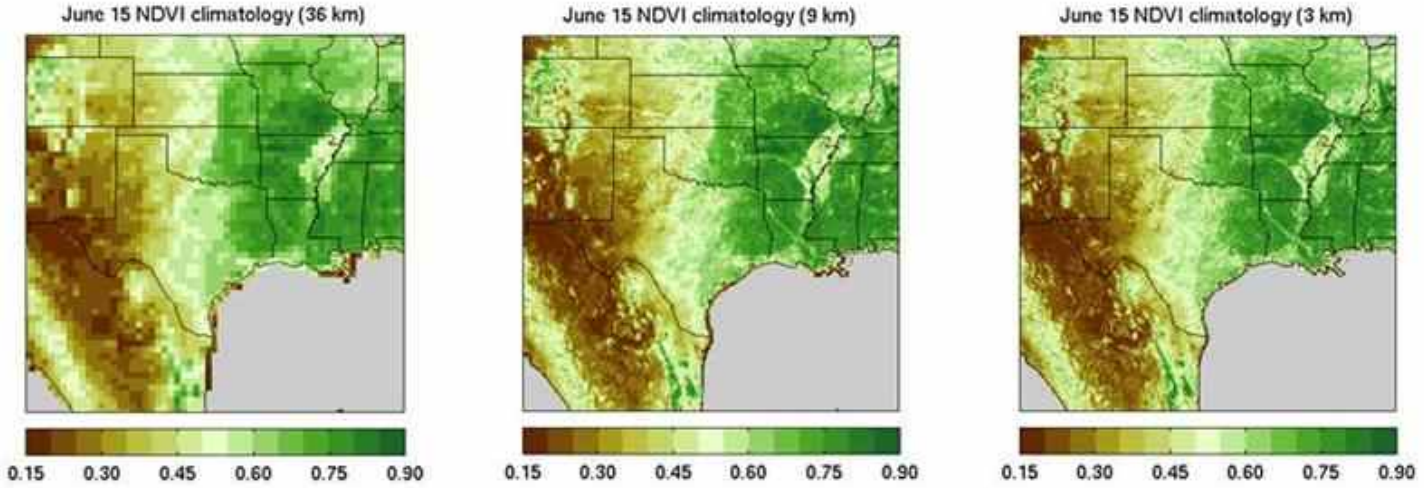
(a) Perfect nesting in SMAP EASE2 grids



- **All SMAP baseline products will be output on one of the SMAP standard EASE2* grids**
- **SMAP grids are perfectly nested to facilitate working between different products at different scales**

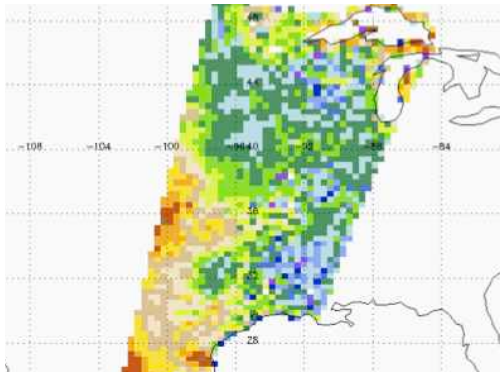
** Equal-Area Scalable Earth 2 grid*

(b) Example of ancillary NDVI climatology data displayed on the SMAP 36-km, 9-km, and 3-km EASE grids

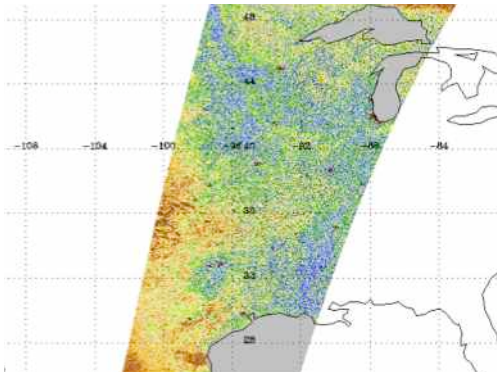


SMAP L2 SM products

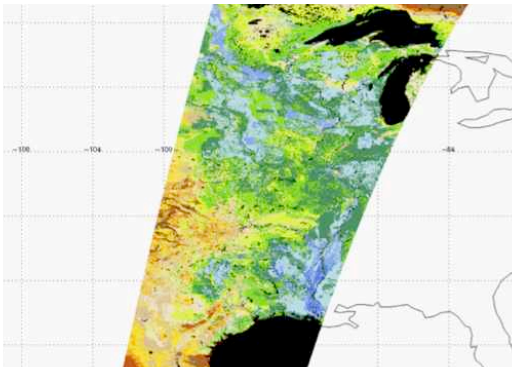
36 km Radiometer
L2_SM_P



3 km Radar
L2_SM_A



9 km Combined
L2_SM_A/P



Volumetric Soil Moisture (cm^3/cm^3)

Partial orbit example of the three SMAP L2 surface soil moisture products