National Aeronautics and Space Administration

Soil Moisture Active Passive Mission

SMAP

and its Application to Agriculture

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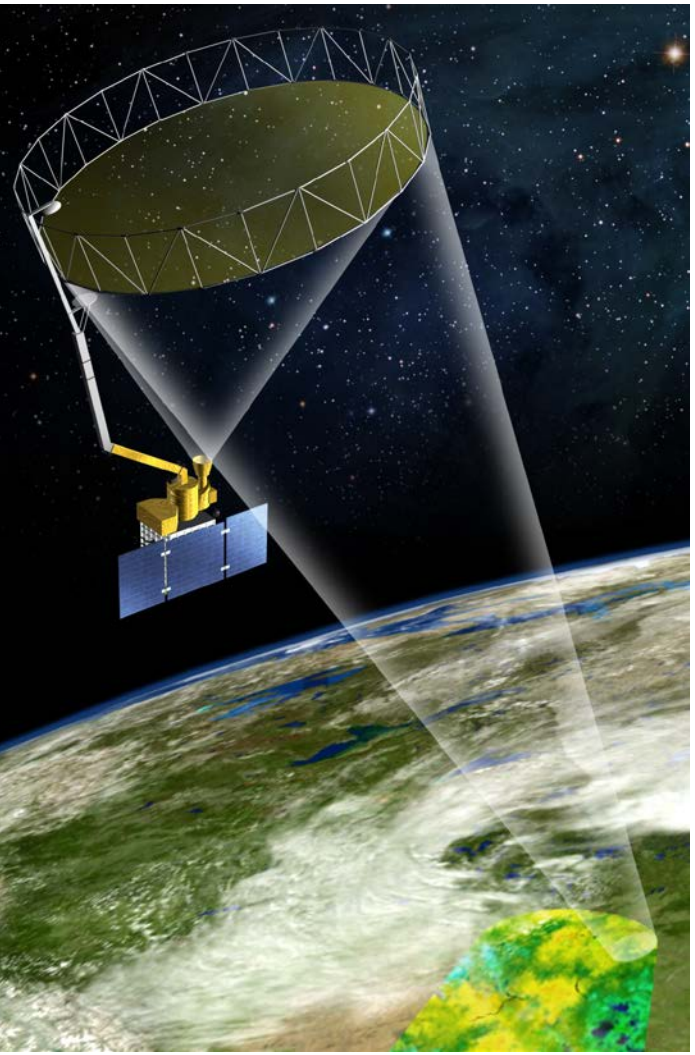
Outline of Presentation

- SMAP Overview
- SMAP Science Requirements
- Mission Science Objective
- SMAP Science Data Products
- SMAP Active-Passive 9 km Soil Moisture Product
- SMAP Calibration and Validation (Cal/Val)
- SMAP Application to Agriculture

SMAP Overview

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



NRC Earth Science Decadal Survey (2007) recommended SMAP as a tier-one mission

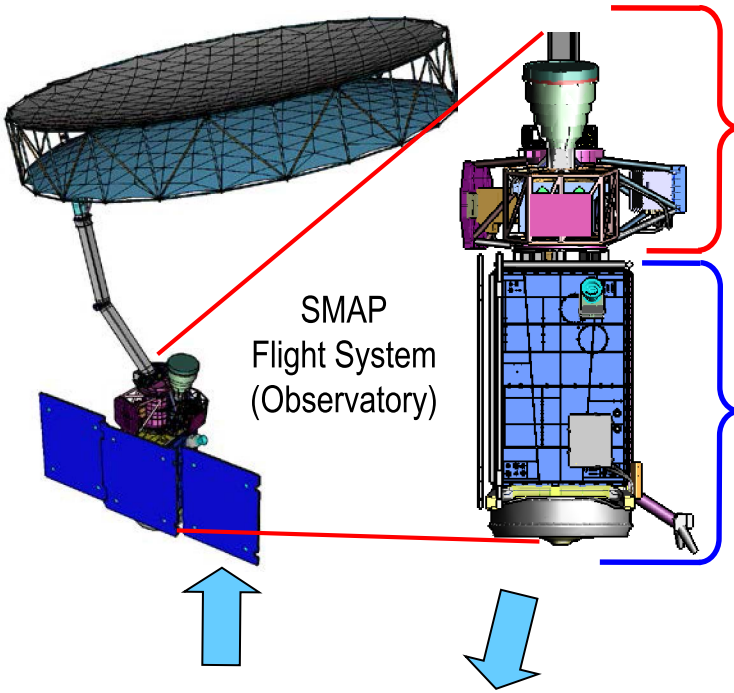
Primary Science Objectives:

- 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)
Launch	• Oct. 2014
Orbit	• Polar Sun-synchronous; 685 km altitude
Duration	• 3 years
Payload	• L-band SAR (JPL) • L-band radiometer (GSFC) • Shared 6-m rotating (13 to 14.6 rpm) antenna (JPL)

Mission Overview

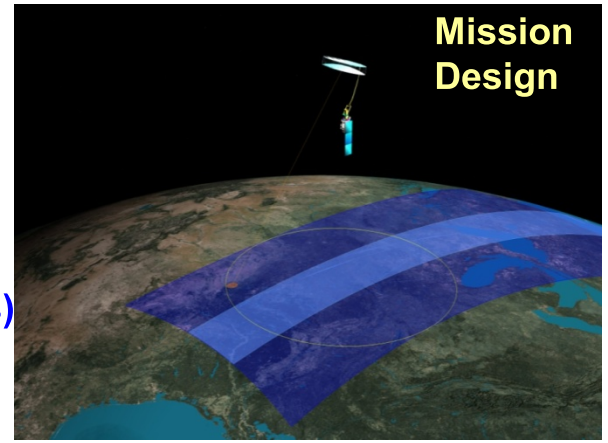


Instrument

- L-band (1.3-GHz) Radar (JPL)
- L-band (1.4-GHz) Radiometer (GSFC)
- Shared antenna (6 m diameter)
- Conical scan: 13–14.6 rpm; 40° incidence
- Contiguous 1,000-km swath width

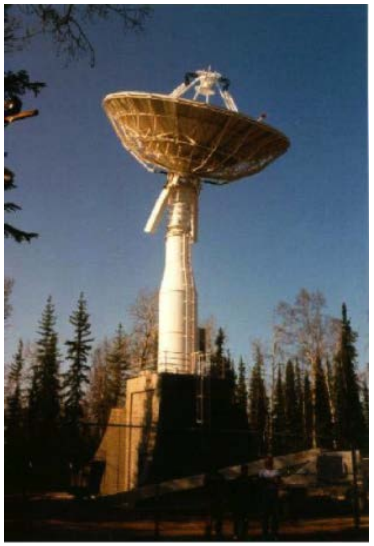
Spacecraft (& Radar Electronics)

- JPL-Developed & Built
- JPL's MSAP/MSL Avionics, Power Assys with a small number of new mission unique card designs
- 1100 kg wet mass (Observatory-level)
- 1200 W capacity (Observatory-level)
- 80 kg propellant capacity
- Commercial space electronics elsewhere



- 685-km polar orbit (Sun-sync)
- 8-day repeat ground track
- Continuous instrument operation
- 2- to 3-day global coverage
- 3-year mission duration

Surface Validation

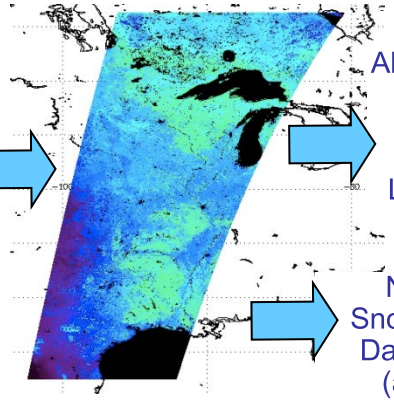


Near-Earth Network

SMAP Mission Operations
& Data Processing
(JPL, GSFC)

Science Data Products

Soil Moisture & Freeze/Thaw State Data Products



Alaska Satellite Facility Data Center (Radar L1 Products)

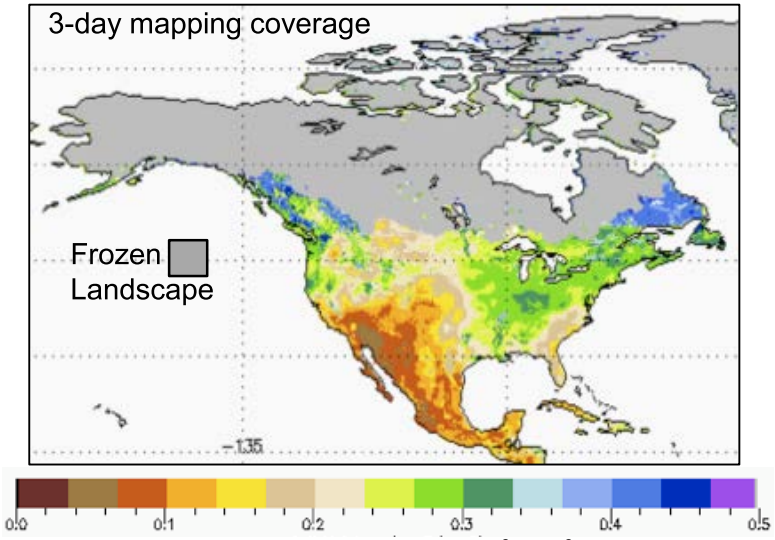
National Snow and Ice Data Center (all other Products)

SMAP Science Introduction

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

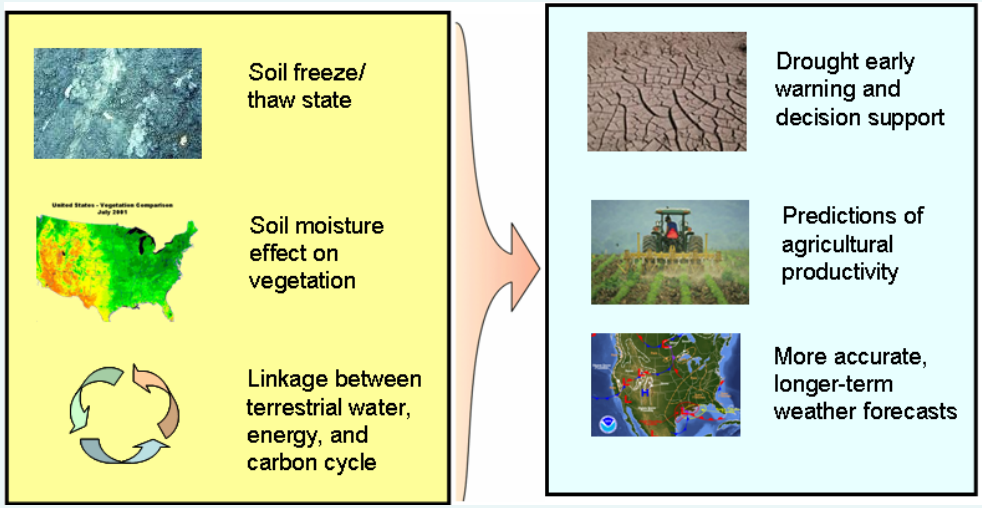
Soil moisture is defined in terms of volume of water per unit volume of soil

Freeze/thaw state is defined as the phase of the water contained within the landscape including soil and vegetation



Surface soil moisture [cm^3 /cm^3]

SMAP measurements of soil moisture and freeze/thaw state address a wide range of Earth science applications



NRC Earth Science Decadal Survey Report, 2007

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

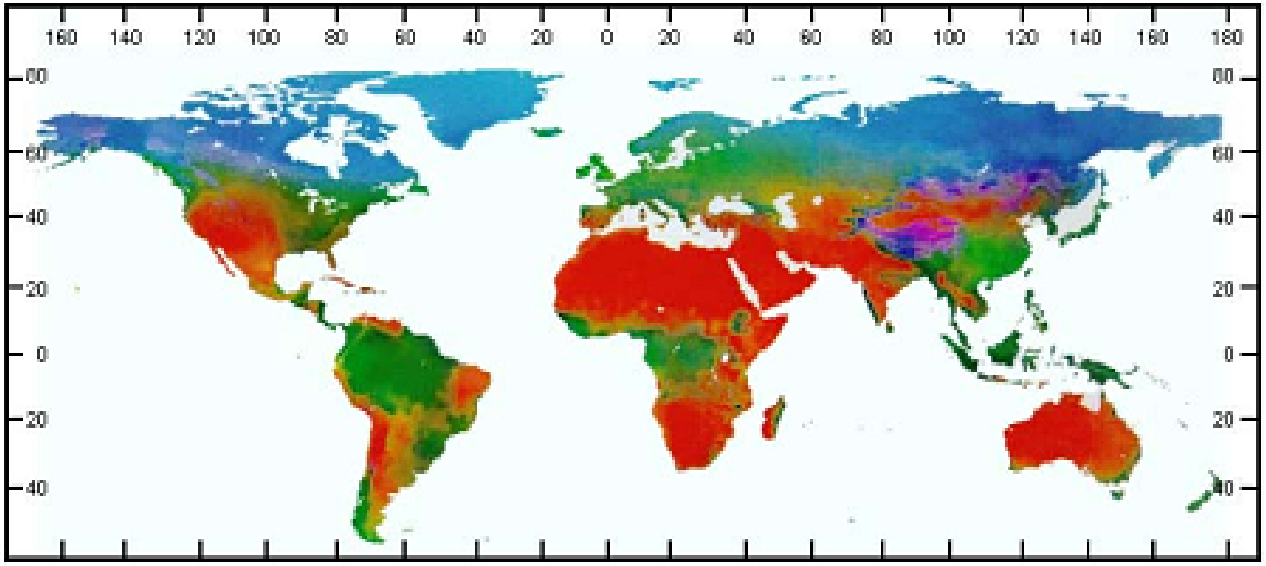
Key Level 1 Requirements (Derived from science objectives)

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%

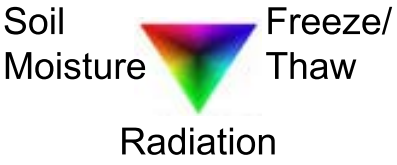
[a] North of 45N latitude [b] Percent classification accuracy (binary freeze/thaw) [c] Volumetric water content, 1-σ in [cm^3/cm^3] units

Mission Science Objectives

- Global mapping of soil moisture and freeze/thaw state to:
  - Understand processes that *link* the terrestrial water, energy and carbon cycles
  - Estimate global water and energy fluxes at the land surface
  - Quantify net carbon flux in boreal landscapes
  - Enhance weather and climate forecast skill
  - Develop improved flood prediction and drought monitoring capability



Primary controls on land evaporation and biosphere primary productivity



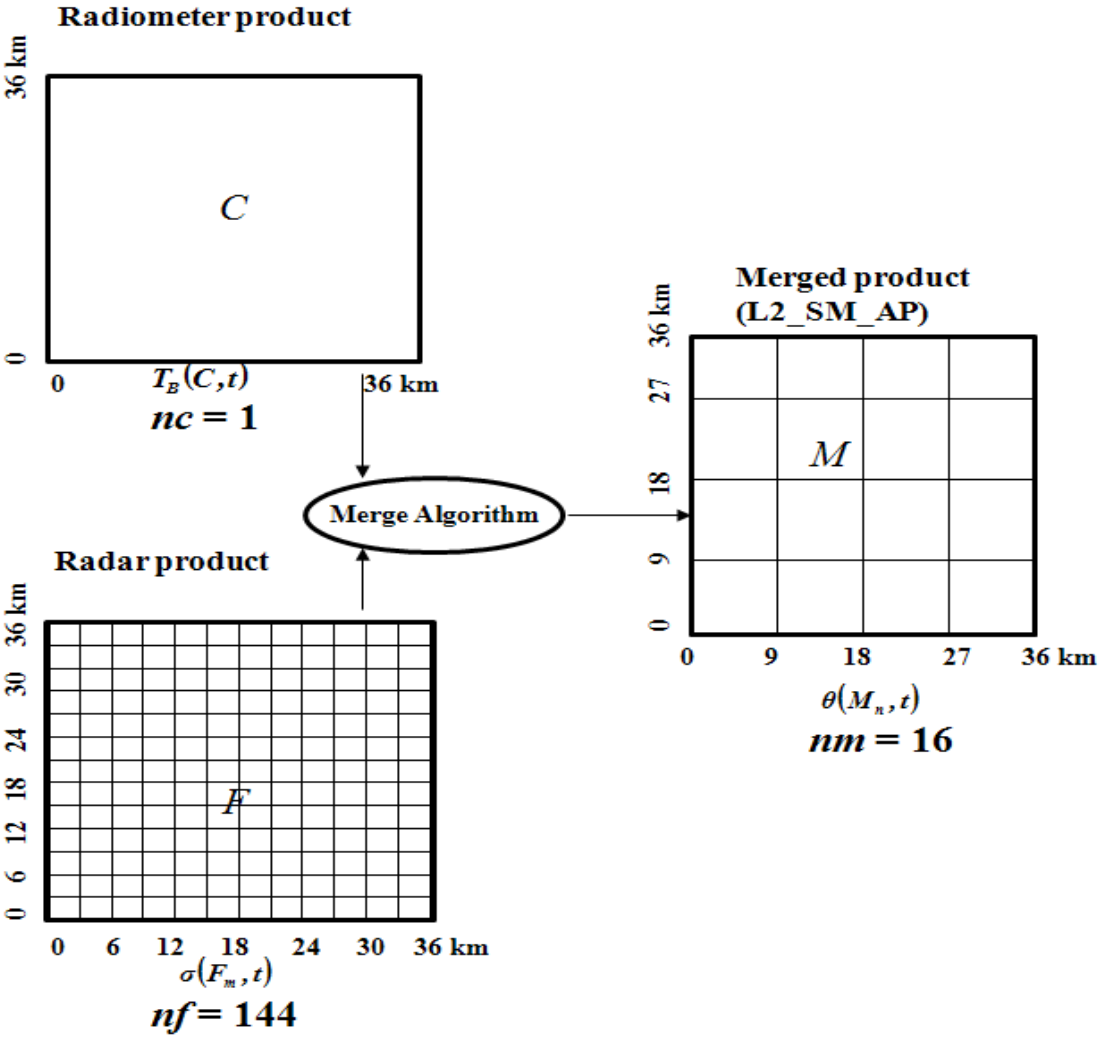
Detailed List of SMAP Science Data Products

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	(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	

* Over outer 70% of swath.

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

SMAP 9 km Soil Moisture Product



- ***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 resolution and accuracy to meet science requirements

Active-Passive Baseline Algorithm

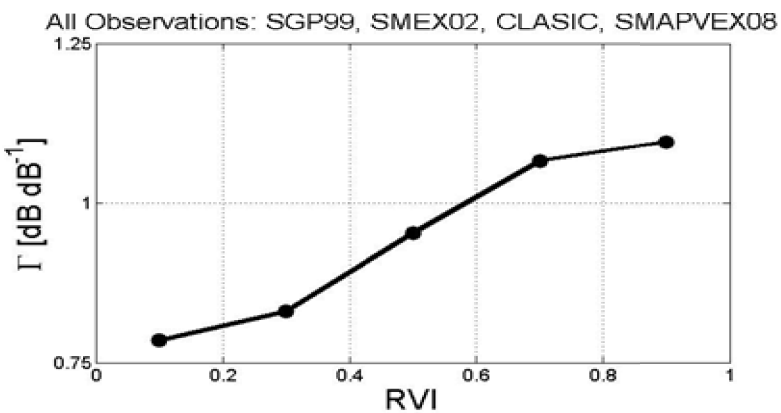
Baseline Algorithm Merged Radar-Radiometer Approach

Heterogeneity in vegetation and roughness conditions within scale-*C* evaluated by estimating sensitivities in radar cross-pol:

$$\sigma_{pp}(M_j) \approx \sigma_{pp}^{e}(M_j) + \left[\frac{\partial \sigma_{pp}(M_j)}{\partial \sigma_{pq}(M_j)}\right]_C \left(\sigma_{pq}(M_j) - \sigma_{pq}(C)\right)$$

$$\Gamma = \left[\frac{\partial \sigma_{pp}(M_j)}{\partial \sigma_{pq}(M_j)}\right]_C$$

Γ estimated from hi-res radar data within a radiometer pixel



T_B-disaggregation algorithm now becomes:

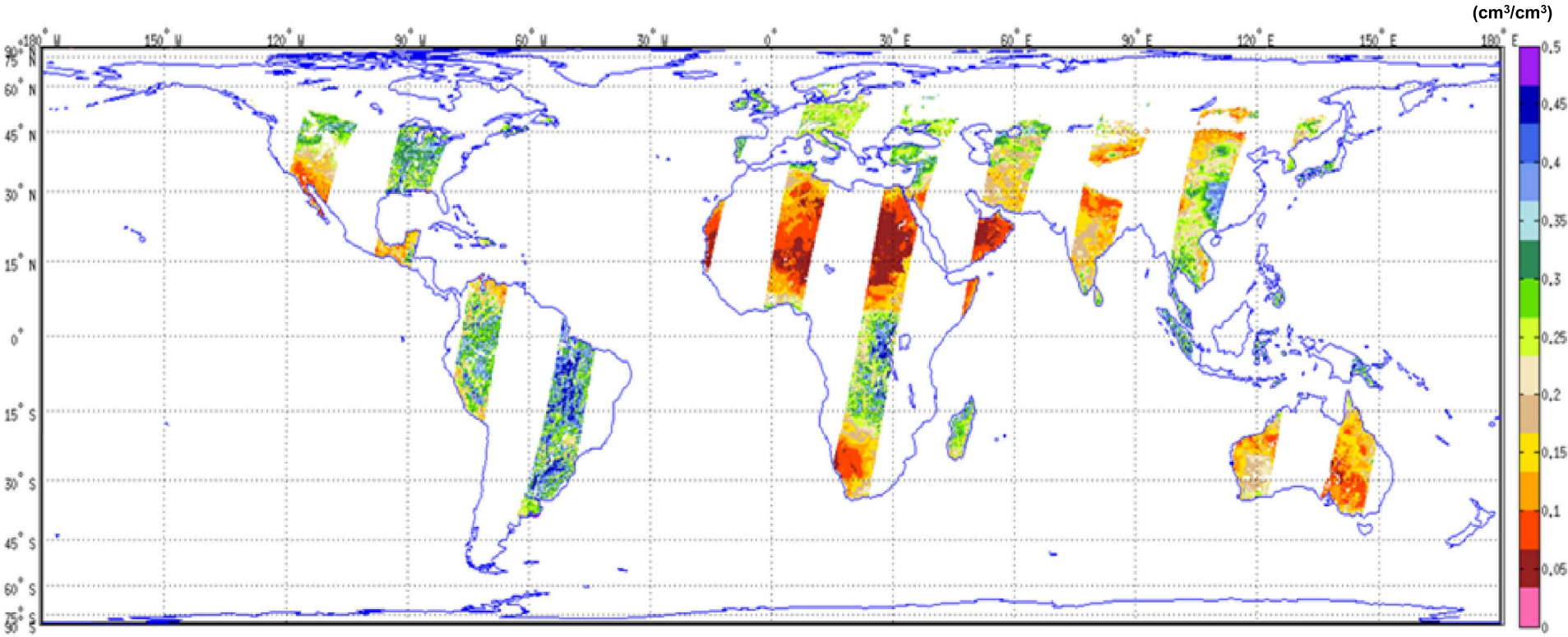
$$T_{B_p}(M_j) = T_{B_p}(C) + \beta(C) \cdot \left\{ \left[\sigma_{pp}(M_j) - \sigma_{pp}(C)\right] - \Gamma \cdot \left[\sigma_{pq}(M_j) - \sigma_{pq}(C)\right] \right\}$$

Bias is removed from $T_B(M_j)$ by imposing $T_B(C) = \sum_{i=1}^{nm} \left(T_B(M_j)\right)$

$T_B(M_j)$ is used to retrieve soil moisture at 9 km (consistent algorithm and ancillary data as radiometer algorithm

Use of GloSim in Algorithm Development

Simulated L3_SM_AP Global Composite Map of Soil Moisture (9 km) for a day in April



Cal/Val Objectives

- **Prelaunch objectives:**
  - Acquire and process data with which to calibrate, test, and improve models and algorithms used for retrieving SMAP science data products
  - Develop and test the infrastructure and protocols for postlaunch validation; this includes establishing an in situ observation strategy for the postlaunch phase
- **Postlaunch objectives:**
  - Verify and improve the performance of the science algorithms
  - Validate accuracies of the science data products as specified in L1 Requirements

Requirement	Baseline Mission	
	Soil Moisture	Freeze/Thaw
Resolution	10 km	3 km
Refresh Rate	3 days	2 days[1]
Accuracy	0.04 (cm^3/cm^3) (1-σ)	80% binary classification

[1] North of 45N latitude

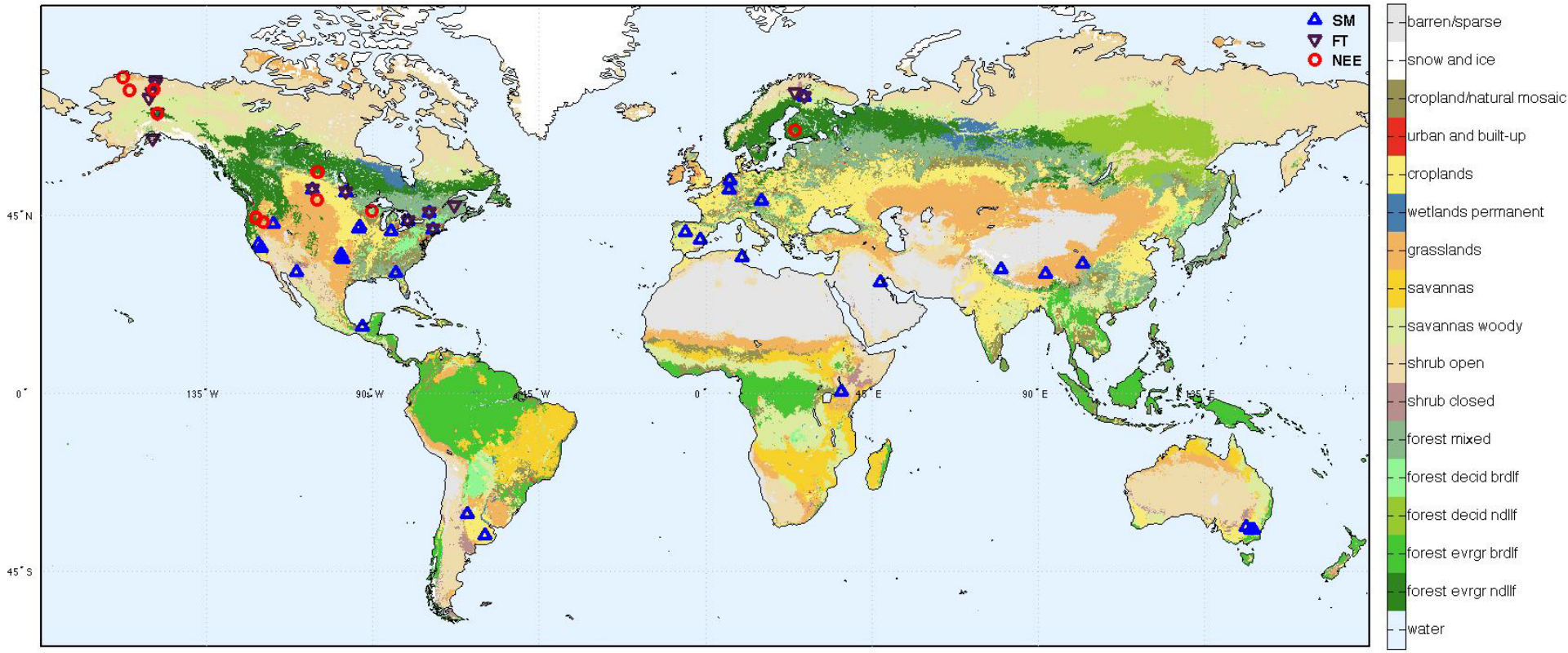
Cal/Val Deliverables

- The deliverables of the SMAP Cal/Val Program are

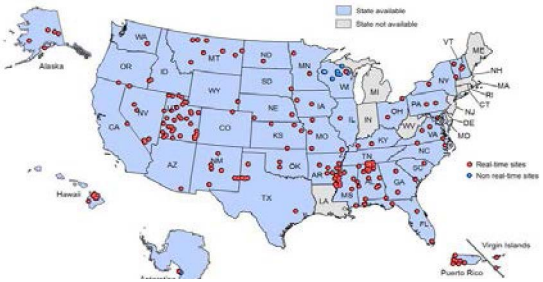
  1. SMAP Science Cal/Val Plan (Preliminary version available at PDR, Final at CDR)
  2. Field Campaign Plans (SMAPVEX12 and SMAPVEX15) (SMAPVEX12 Plan under development)
  3. Cal/Val Reports documenting data acquired, processing applied, analyses performed, and quality assessments, for prelaunch and postlaunch data acquisitions
  4. Beta and Validation reports accompanying release of each level of SMAP data products to the public archive—Level 1, Levels 2 and 3, Level 4

SMAP Cal/Val in Situ Validation Sites

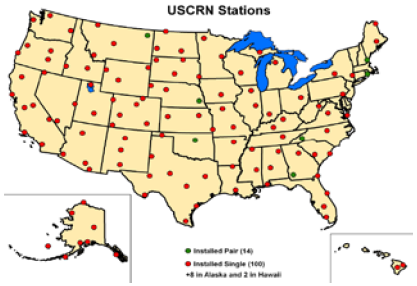
Core Site Candidates



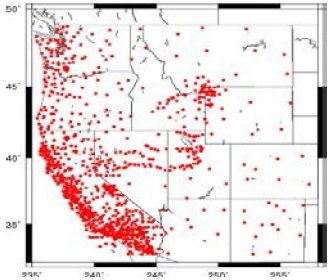
For the U.S., there are three additional in situ networks, each with > 100 sites providing point measurements (see below)



USDA Soil Climate Analysis Network (SCAN)



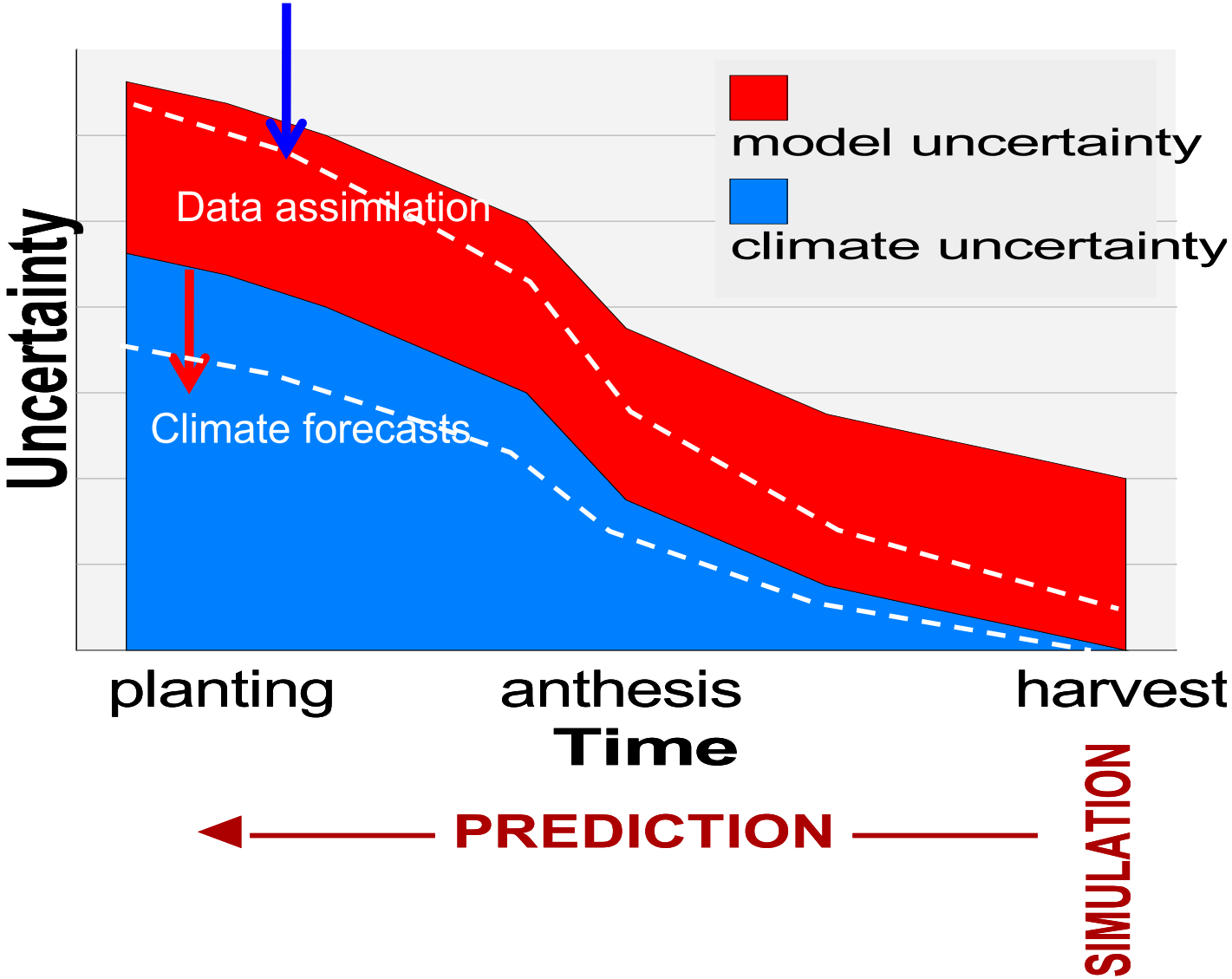
NOAA Climate Reference Network (CRN)



GPS Network (~100 of the points will be used)

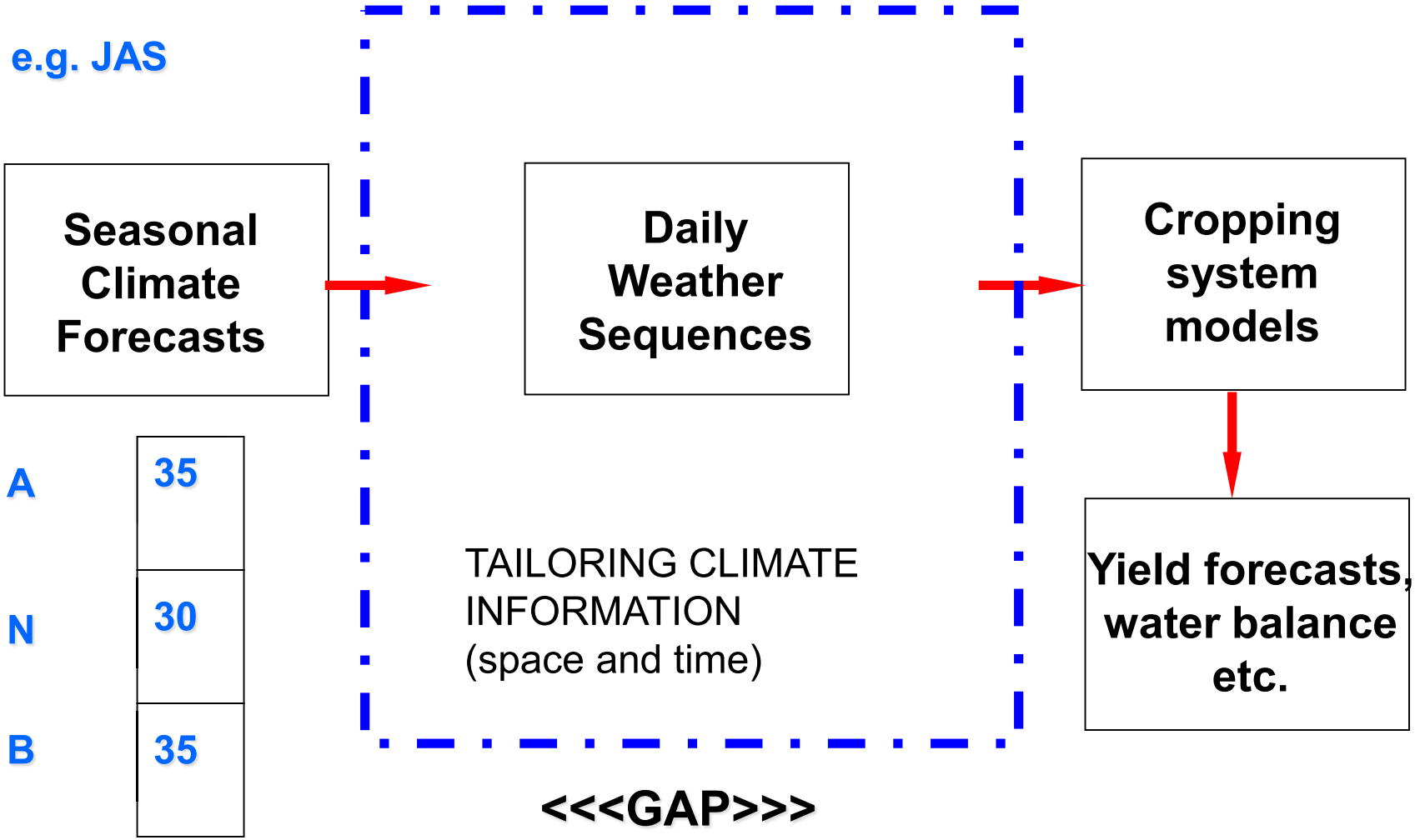
SMAP Application to Agriculture

Anatomy of Crop Yield Prediction Uncertainty

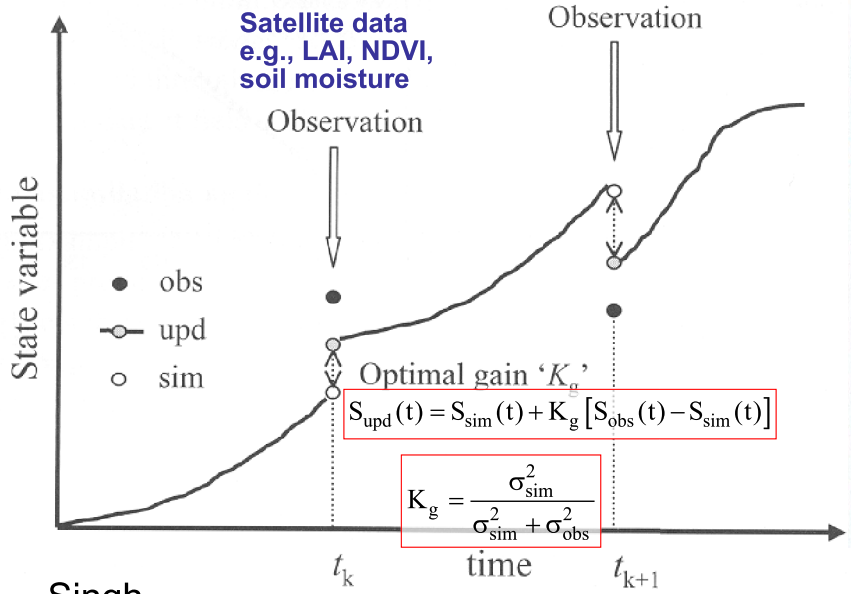


Hansen et al., 2006

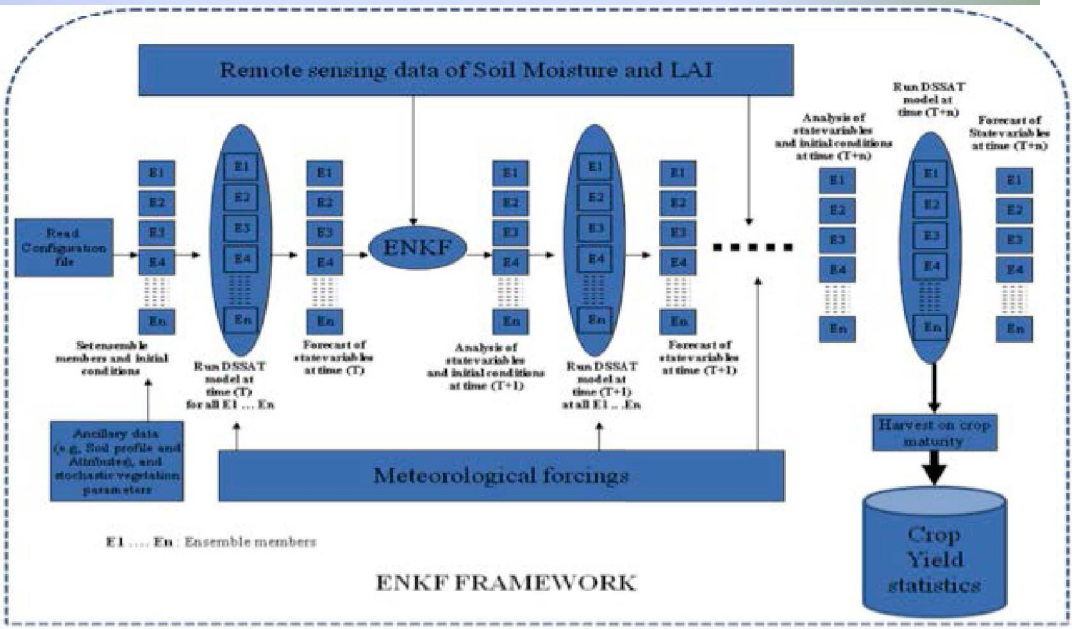
Linking climate information to decisions



Remote Sensing Data Assimilation



Singh

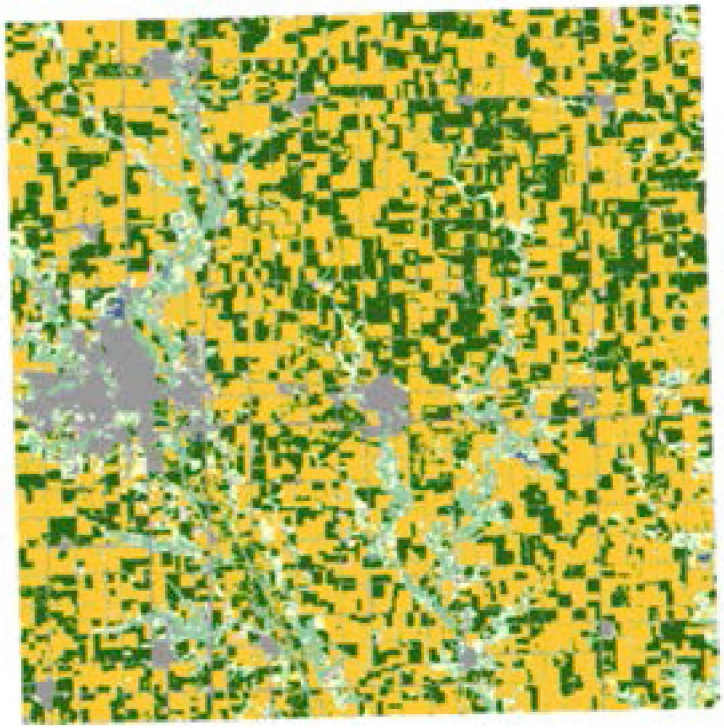


EnKF-DSSAT-CSM for maize prediction

MODELING STRATEGY: (STORY Co. Iowa, 2003-2009)

- Open loop – DSSAT-CSM-Maize was run without data assimilation
- Data assimilation with AMSR-E soil moisture (SM)
- Data assimilation with MODIS leaf area index (LAI)
- Data assimilation with SM + LAI
- Compositing results

Maize yield simulation

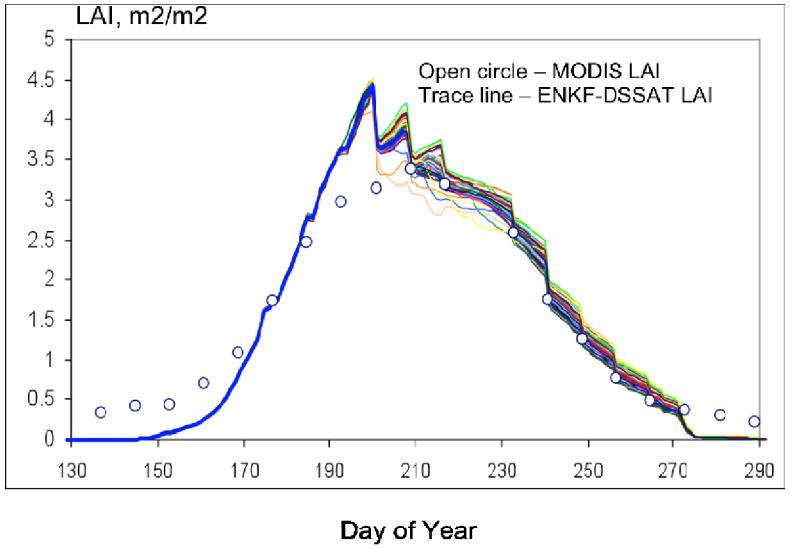


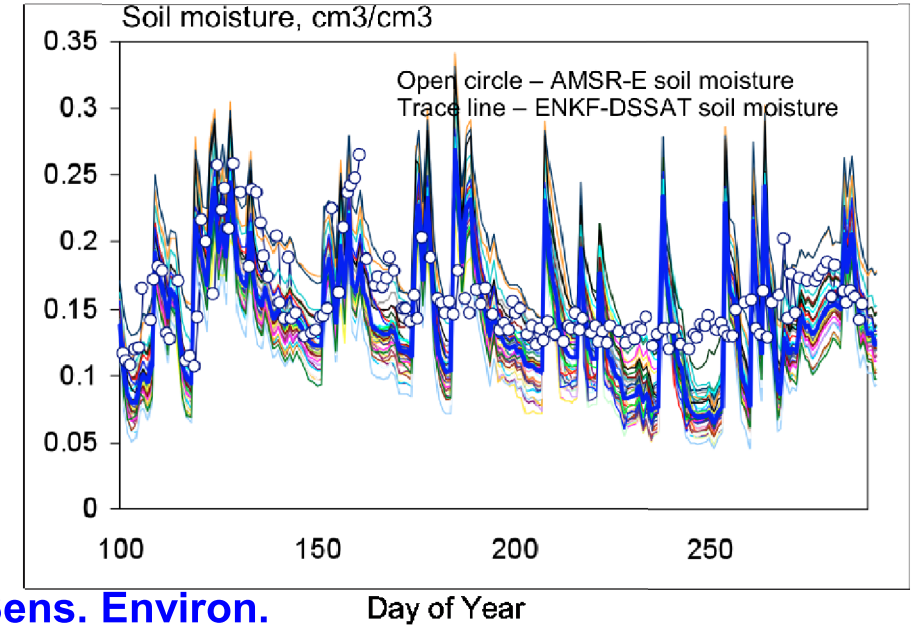
Yellow: maize; Green: soybean

Land cover map, **Story County, Iowa, USA (2008)**

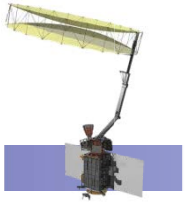
http://nassgeodata.gmu.edu/CropScape/

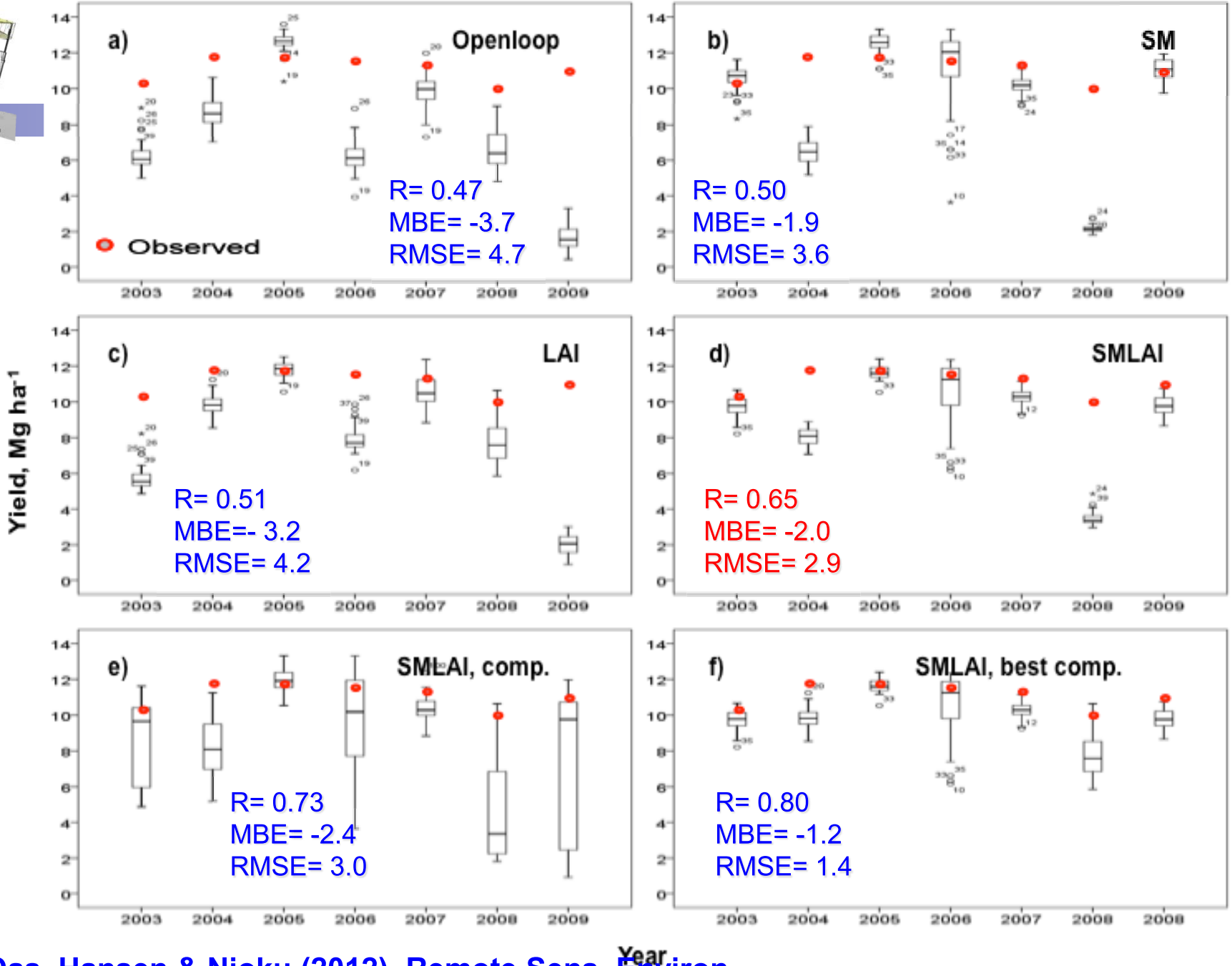
(2003)





Ines, Das, Hansen & Njoku (2012), Remote Sens. Environ.





Ines, Das, Hansen & Njoku (2012), Remote Sens. Environ.

Challenges

- Large-scale, homogenous agro-ecosystem (works OK)
  – E.g., Story, Co. Iowa
- Complex, heterogeneous agricultural system (needs innovation)
  – this is important to address if in the context of smallholder agriculture in developing countries
  – E.g., farming practices in the India subcontinent
  – Area fractions of target crops grown are small
  – Cropping overlap with other crops grown in the study area

INNOVATIONS NEEDED (with NASA-JPL):
– Un-mixing RS vegetation signature
– Downscaling RS soil moisture data

Thanks