Soil Moisture Remote Sensing: Current Capabilities and Remaining Challenges

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Currently Viable Remote Sensing Approaches for Soil Moisture Retrieval:

1) Passive Microwave
2) Active Microwave/Radar
3) Thermal

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a. Basis for Measurements
b. Challenges/Limitations
c. Current Capabilities
d. Future Enhancements (Planned Missions)

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4) Evaluation for Hydrologic Applications

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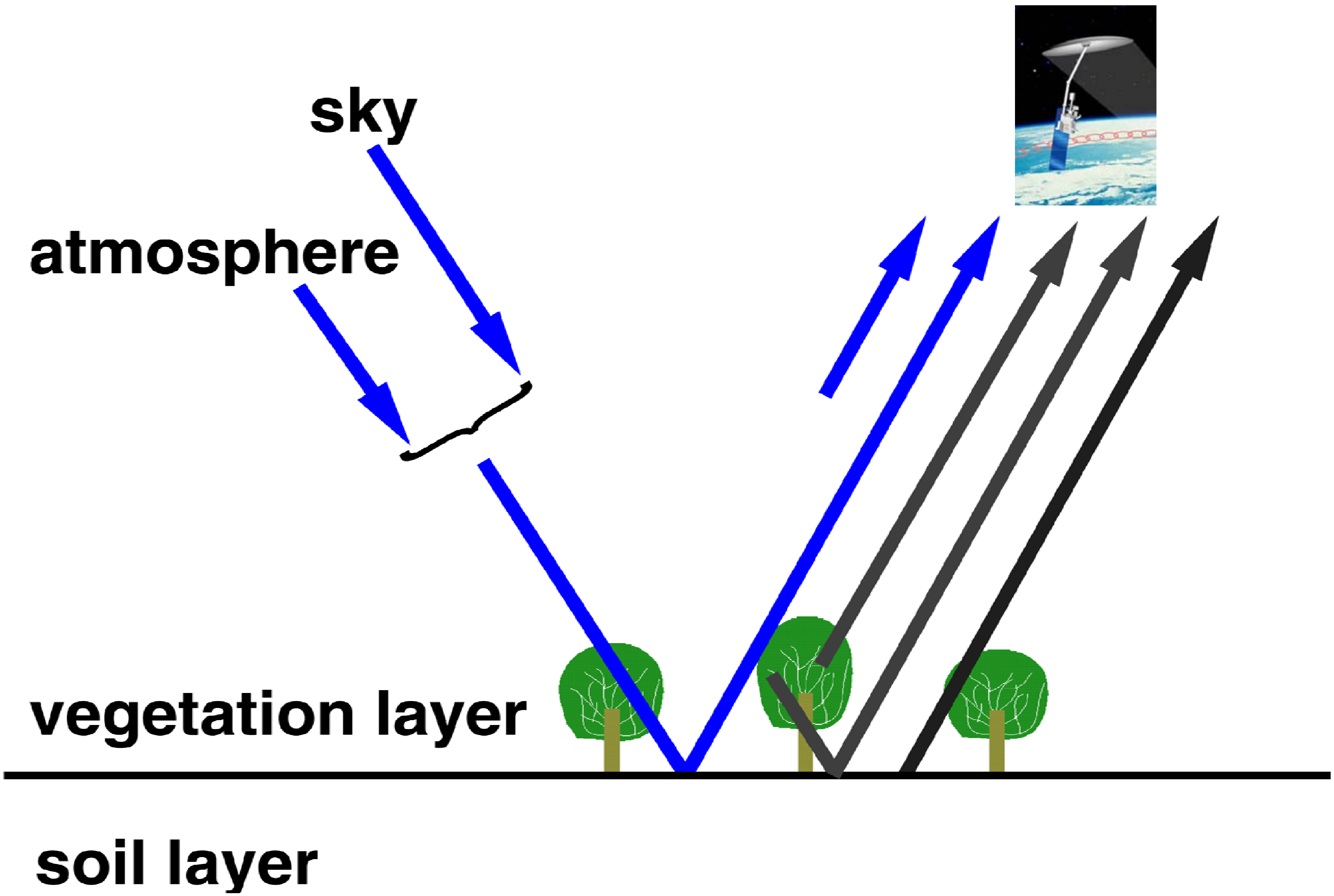
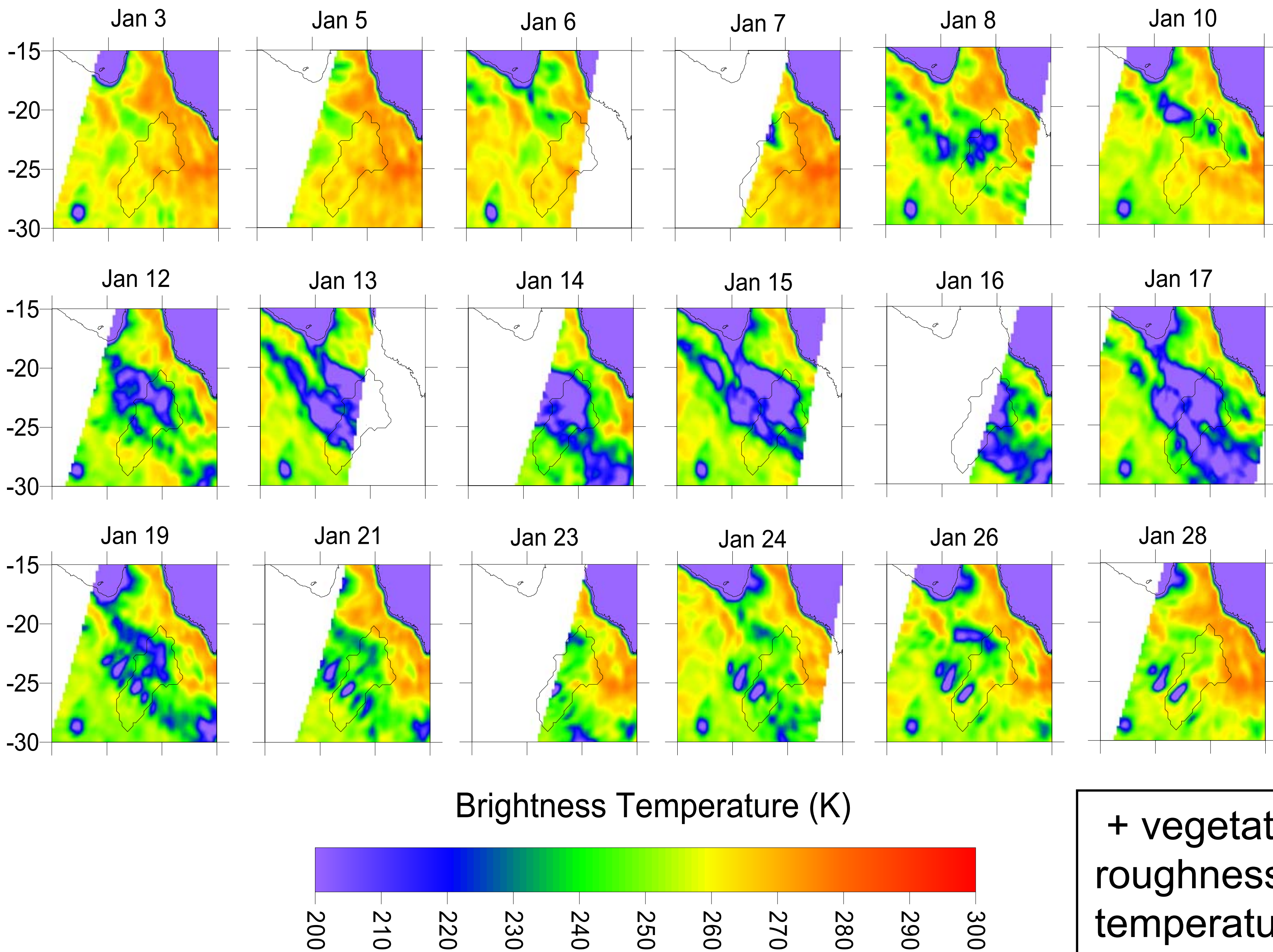


- ➢Microwave dielectric properties vary with surface wetness
- ➢Very cold sky conditions (~2 K)

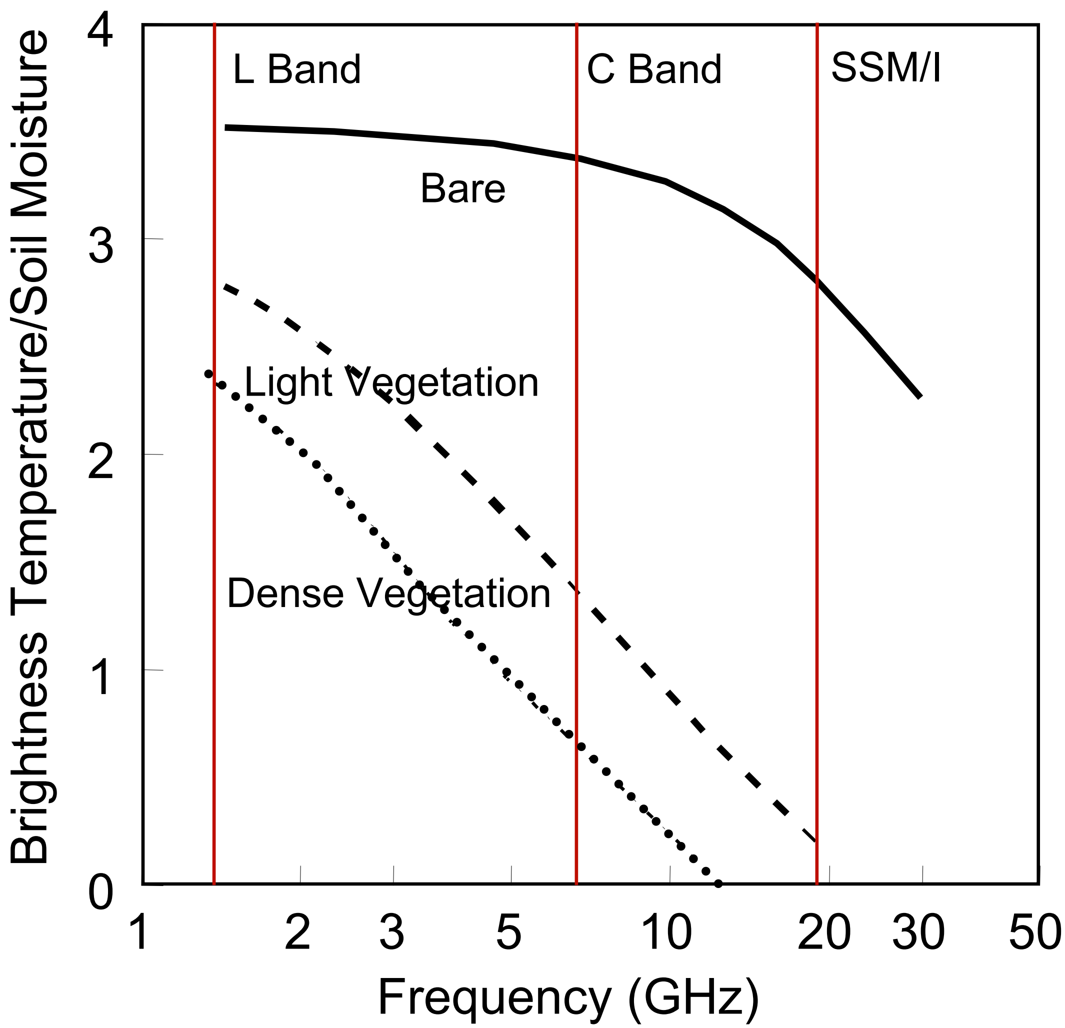
AMSR-E 6.9 GHz – Queensland, Australia (January 2003)



+ vegetation + roughness + soil temperature = soil moisture

Challenges:

1) Surface signal is attenuated by vegetation



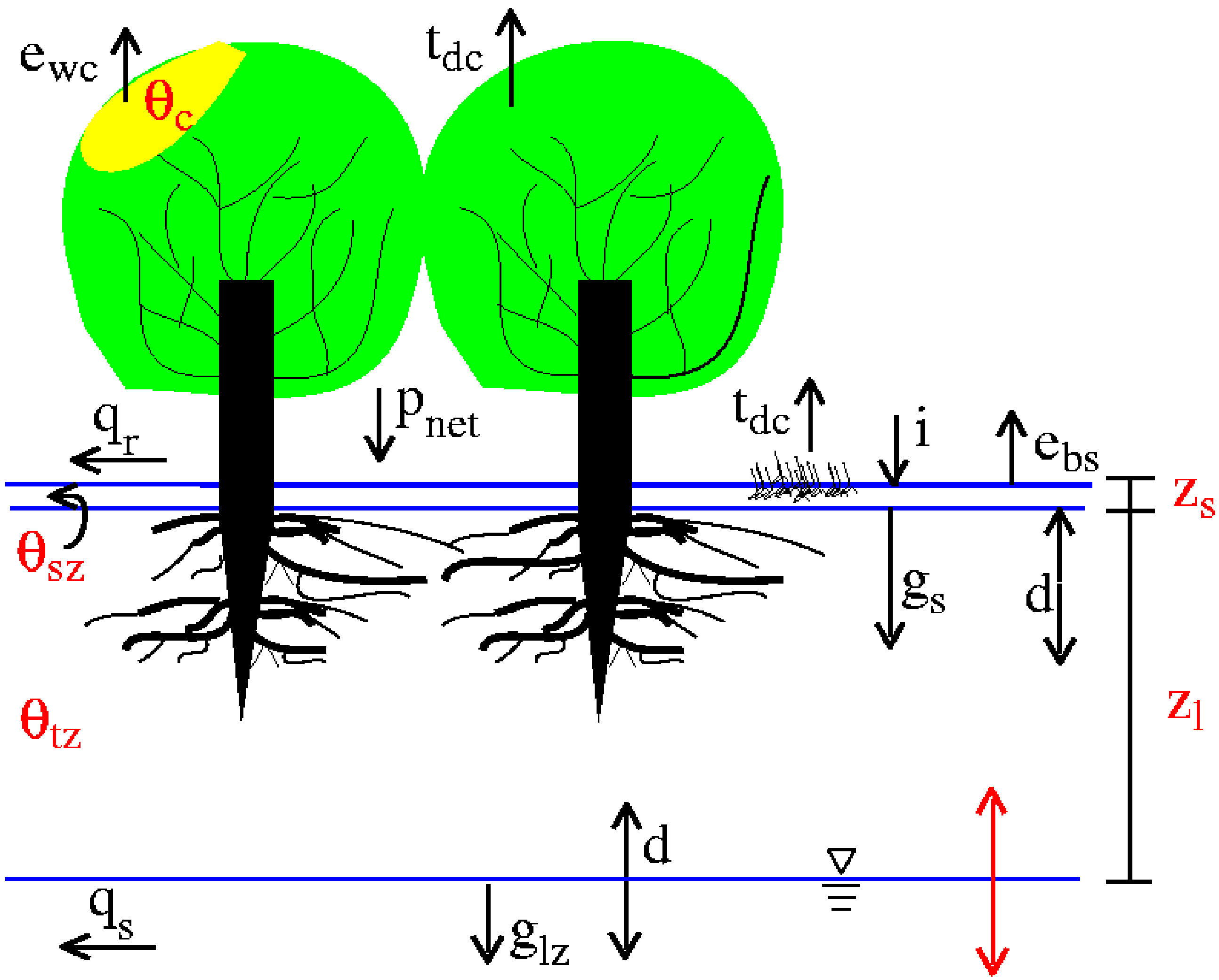
<u>Lower frequencies are preferable</u>

<u>L band < C < X</u>

T.J. Jackson, USDA

Challenges:

2) Retrievals have shallow vertical support (2-5 cm)



Challenges:

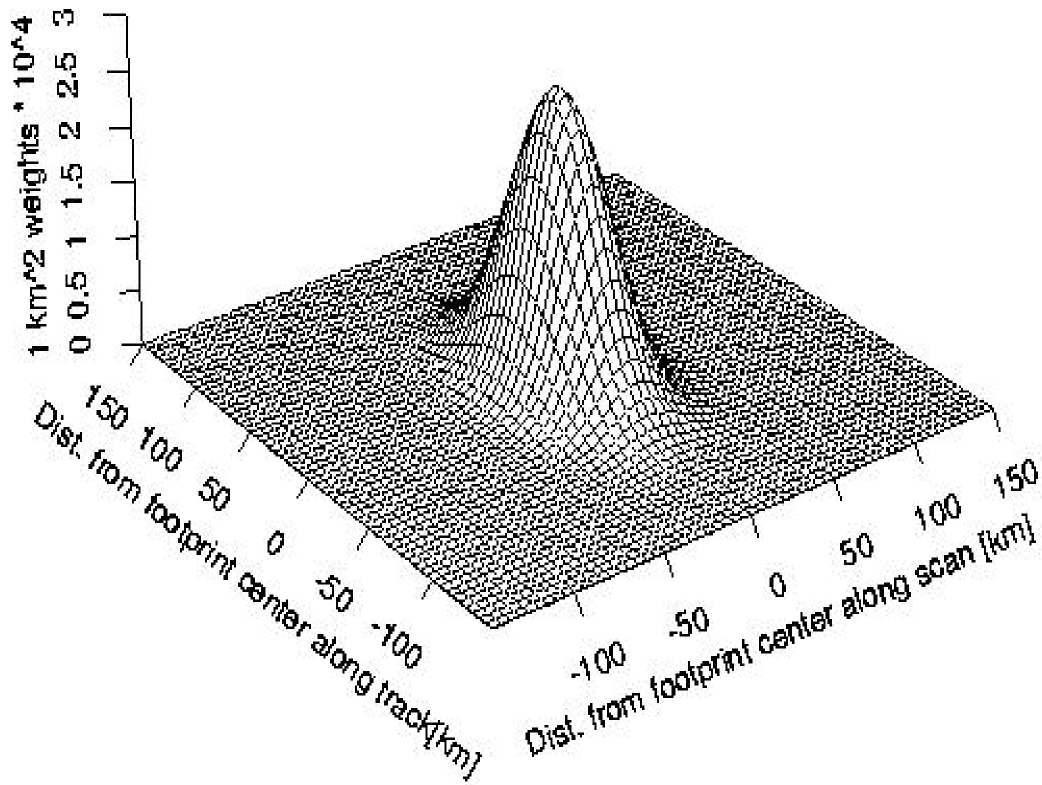
3) Retrievals have poor horizontal resolution

$\Delta x \sim \lambda/D$

λ– Wavelength

D – Antenna size

~30 to 50 km



Current Capabilities:

1) C- and X-band (e.g. TMI and AMSR-E)

2) 30-50 km resolution

3) 1-3 days

4) Single and multiple-polarization retrieval algorithms

(require ancillary surface temperature, roughness and vegetation info)

5) ~3% volumetric accuracy for low biomass (bare soil/grasslands)

~4-6% accuracy for moderate biomass (crops and shrubs)

No coverage for forested areas

Near-Future Enhancements:

1) L-band (ESA SMOS and NASA Aquarius)

(Better accuracy for vegetated surfaces)

NASA/JAXA AMSRE on AQUA

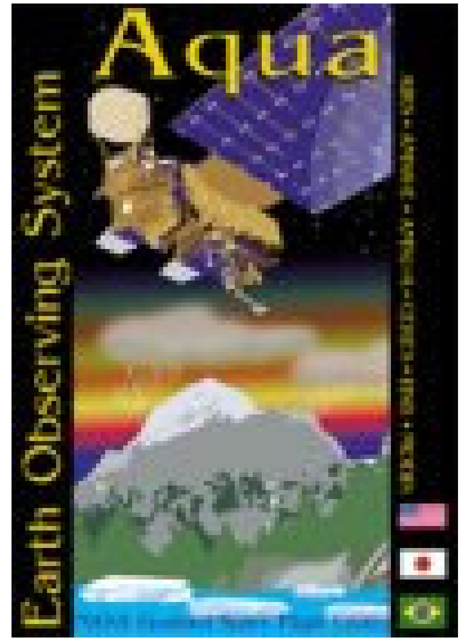
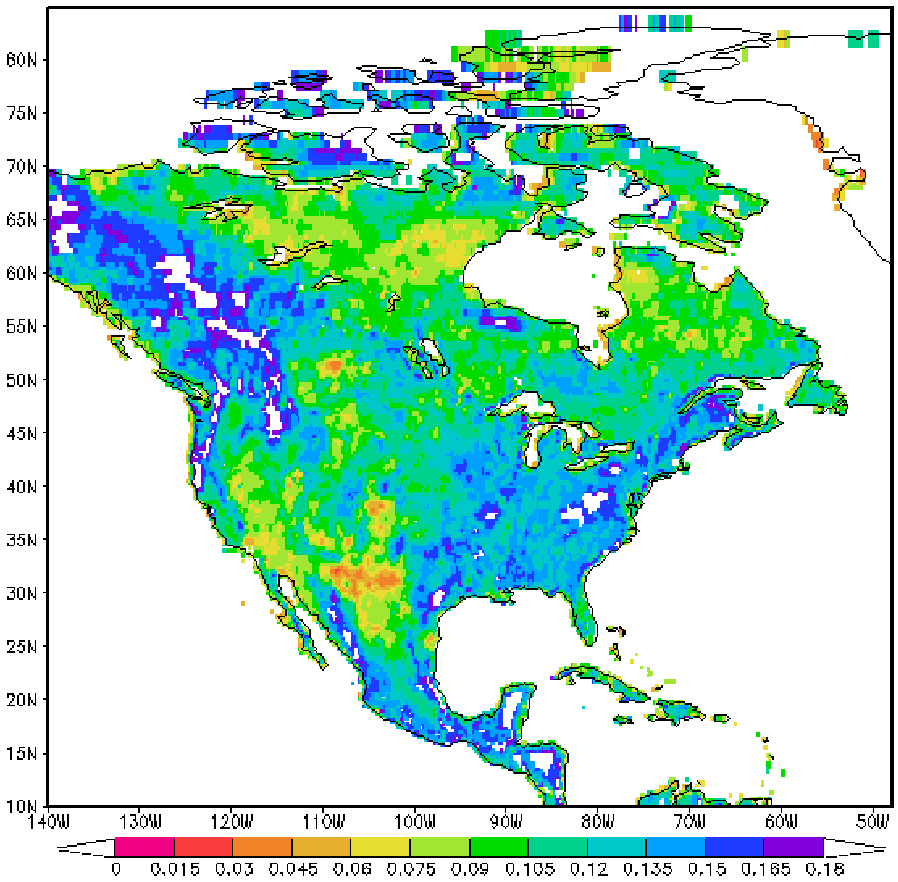


Table 1. AMSR-E PERFORMANCE CHARACTERISTICS						
CENTER FREQUENCIES (GHz)	6.925	10.65	18.7	23.8	36.5	89.0
BANDWIDTH (MHz)	350	100	200	400	1000	3000
SENSITIVITY (K)	0.3	0.6	0.6	0.6	0.6	1.1
MEAN SPATIAL RESOLUTION (km)	56	38	21	24	12	5.4
IFOV (km x km)	74 x 43	51 x 30	27 x 16	31 x 18	14 x 8	6 x 4
SAMPLING RATE (km x km)	10 x 10	10 x 10	10 x 10	10 x 10	10 x 10	5 x 5
INTEGRATION TIME (MSEC)	2.6	2.6	2.6	2.6	2.6	1.3
MAIN BEAM EFFICIENCY (%)	95.3	95.0	96.3	96.4	95.3	96.0
BEAMWIDTH (degrees)	2.2	1.4	0.8	0.9	0.4	0.18

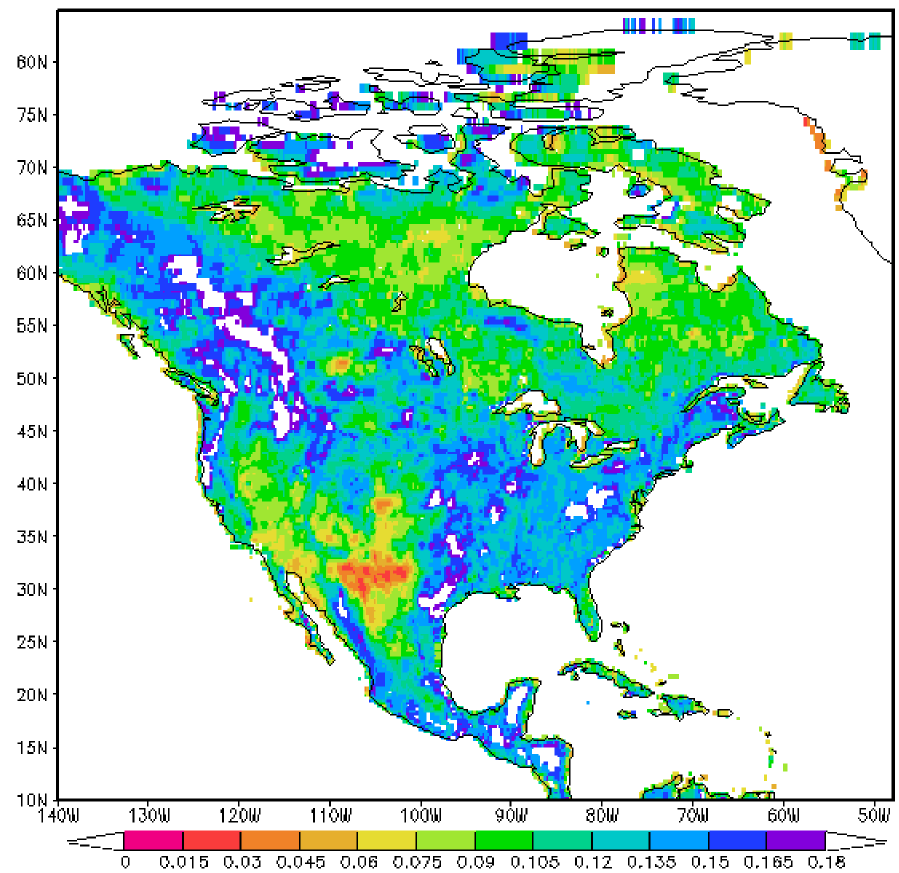
- C- and X-band
- 2002 Launch
- Severe RFI in C-band for North American (Fall back to X-band)

3 Day Composites of AMSR-E Soil Moisture Over North America

09/07/06 – 09/09/06



09/16/06 – 09/18/06



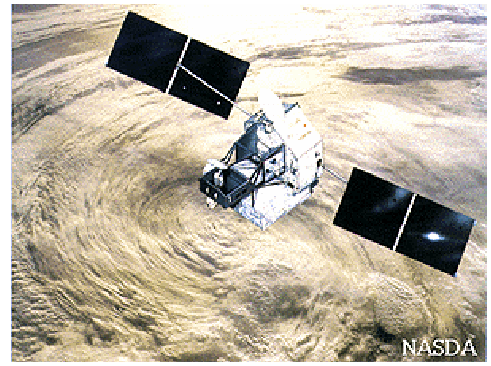
TRMM Microwave Imager (TMI)

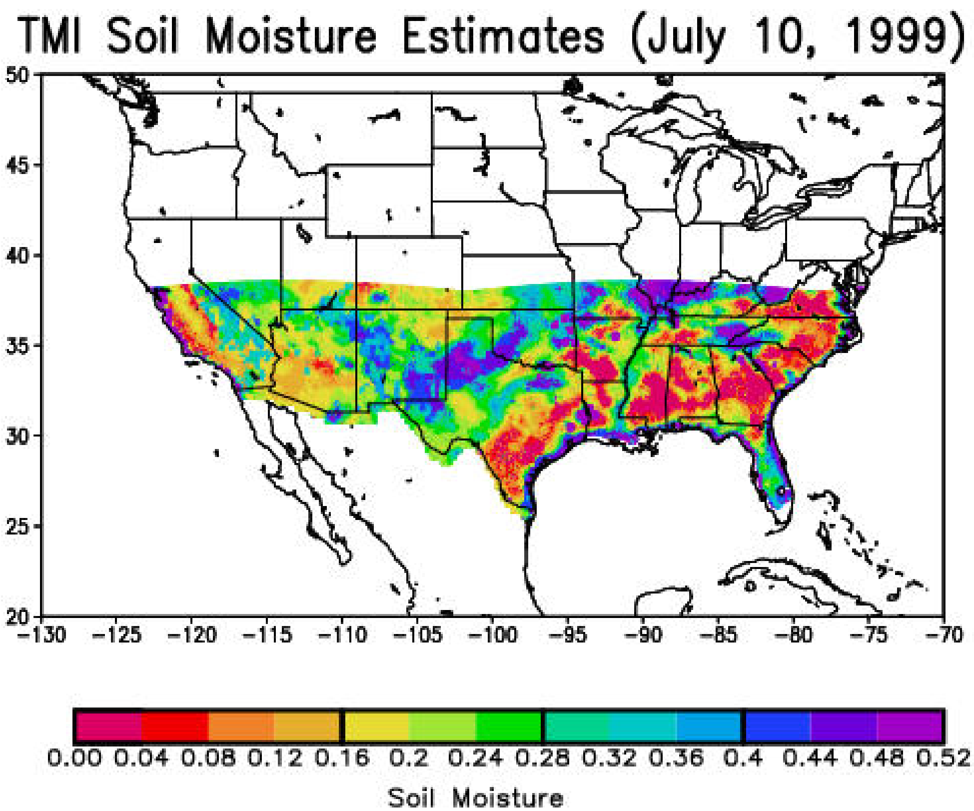
10.65 GHz Channel
38 km resolution

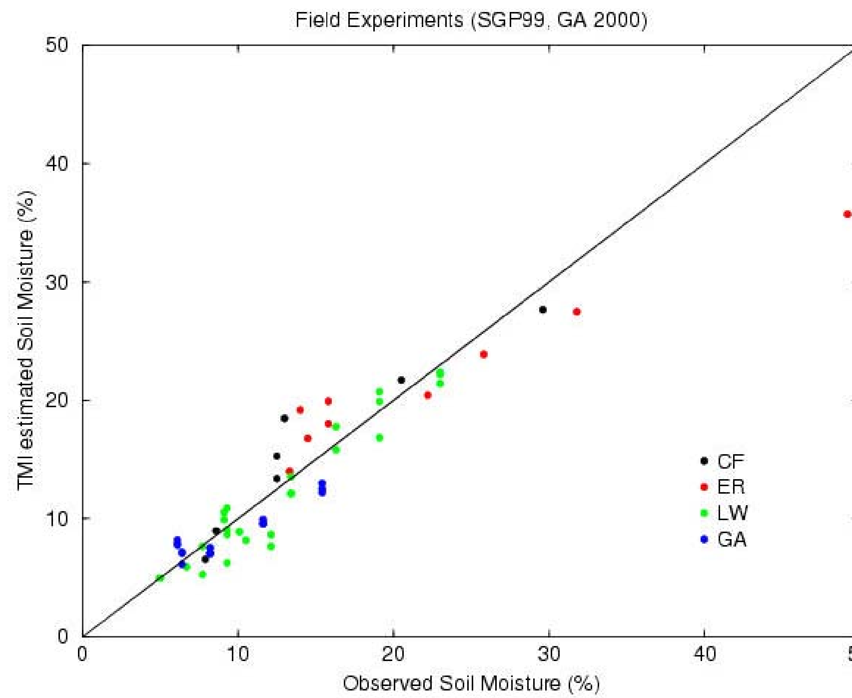
Soil moisture inversions:

Bindlish *et al.*, **RSE**, 85, 2003

Gao and Wood, IGARSS '03

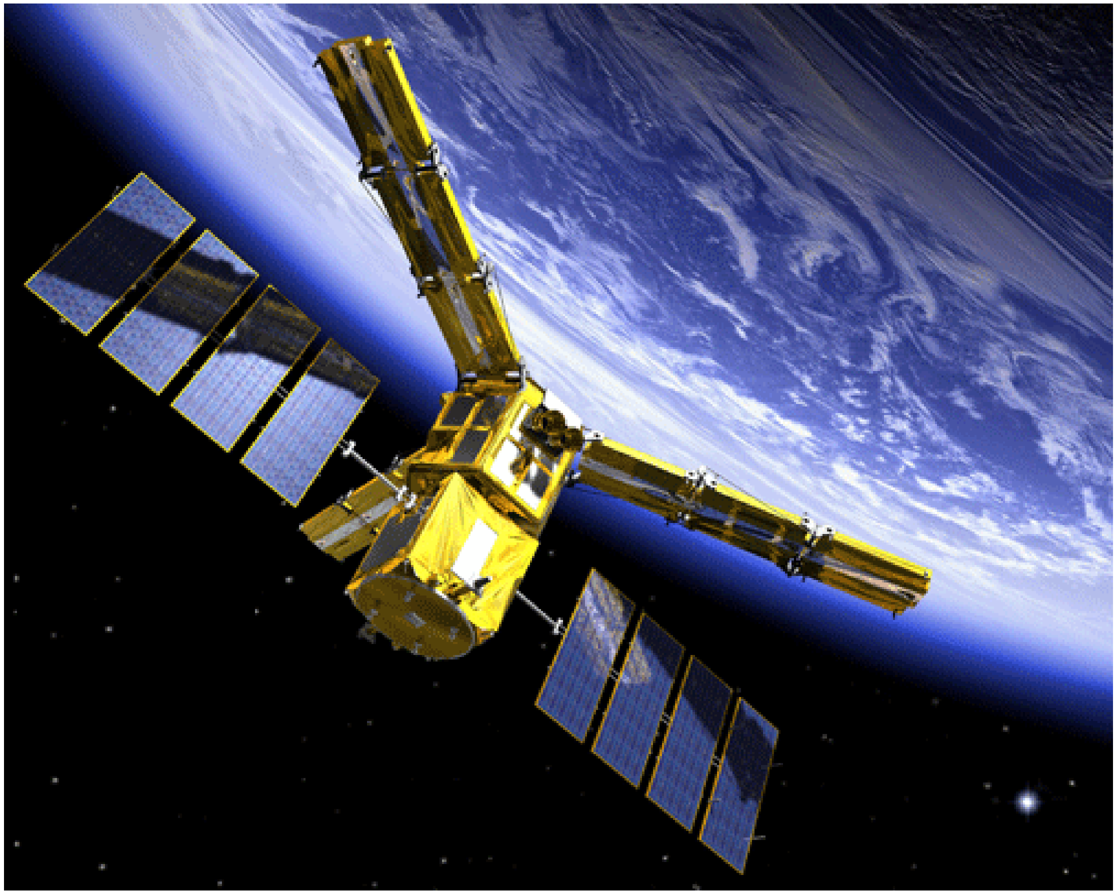




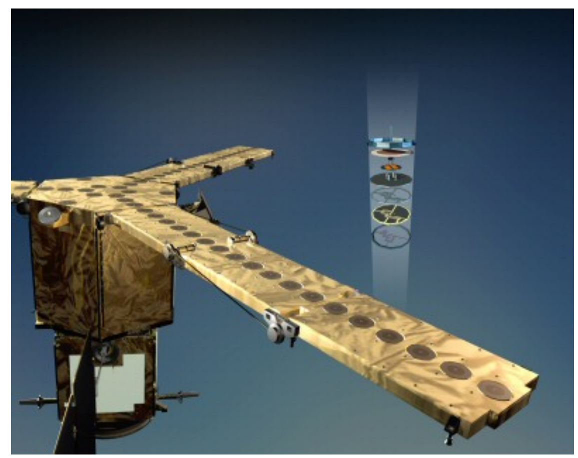


From: Bindlish *et al.*, **RSE**, 85, 2003

ESA Soil Moisture and Ocean Salinity Mission (SMOS)



- 2008/2009 launch
- L-band
- 40 km
- Global 1-3 revisit times
- Utilizes synthetic aperture technology to minimize antennae size and preclude need to spin.

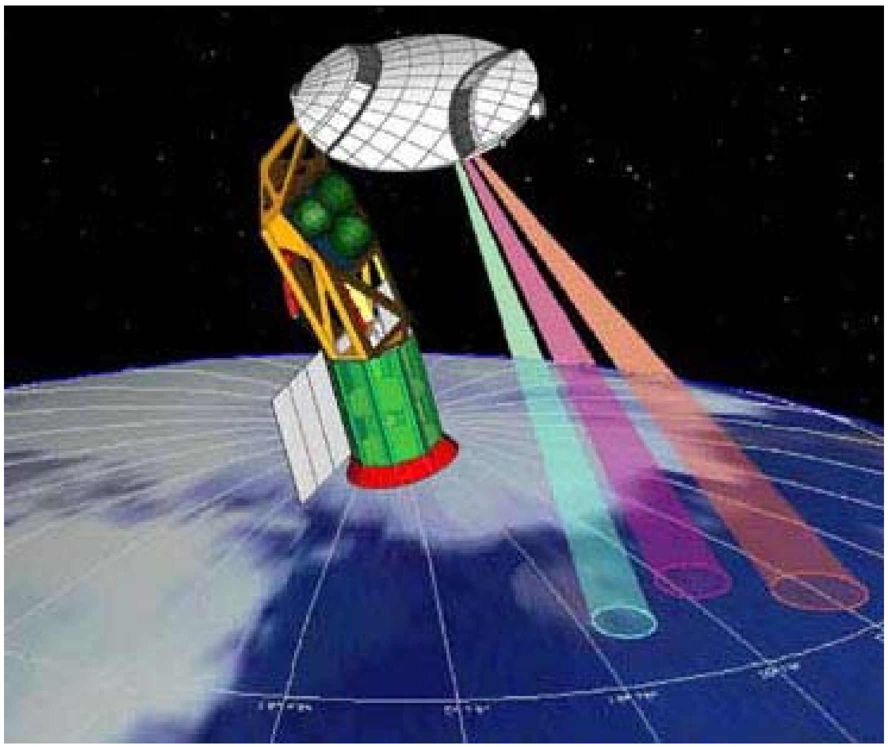


Dedicated Soil Mission/Ocean Salinity Mission

AQUARIUS

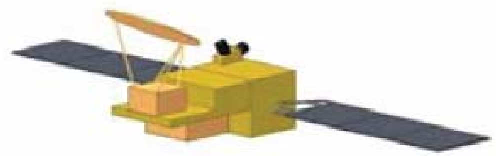
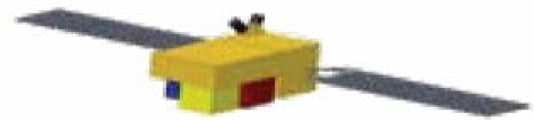
Aquarius is a focused satellite mission to measure global Sea Surface Salinity (SSS). Scientific progress is limited because conventional in situ SSS sampling is too sparse to give the global view of salinity variability that only a satellite can provide. Aquarius will resolve missing physical processes that link the water cycle, the climate, and the ocean.

ESSP



- Dedicated ocean salinity mission
- 2009 launch
- L-band
- Smaller antennae
- Does not scan (push broom)
- 200-300 km
- Weekly revisits

JAXA GCOM-W AMSR-E follow on mission

GCOM-W & -C characteristics (TBD)		
Design	GCOM-W 	GCOM-C 
Orbit (TBD)	• Sun-synchronous • Altitude: 699.6km • Inclination: 98.19deg • Ascending local time: 13:30	• Sun-synchronous • Altitude: 798km • Inclination: 99.36deg • Descending local time: 10:30
Instruments	• AMSR follow-on Microwave imager	• SGLI Near-UV ~ TIR imager
Launch Date	JFY 2010	JFY 2011
Mission Life	5 years (×3 satellites; total 13 years)	
Launch Vehicle	H-IIA	

US CMIS mission dropped/delayed from NPOESS

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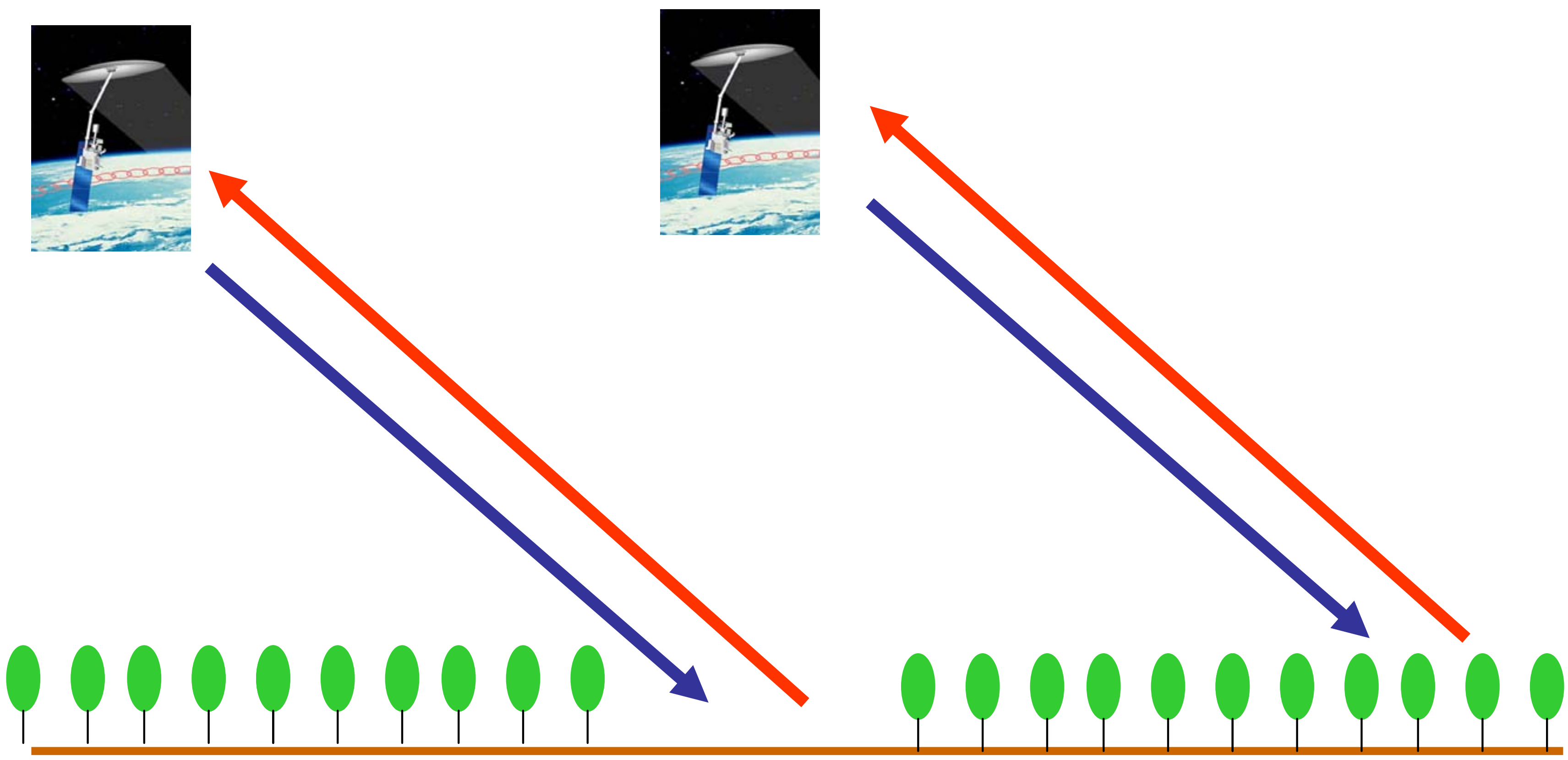
Radar Remote Sensing of Soil Moisture

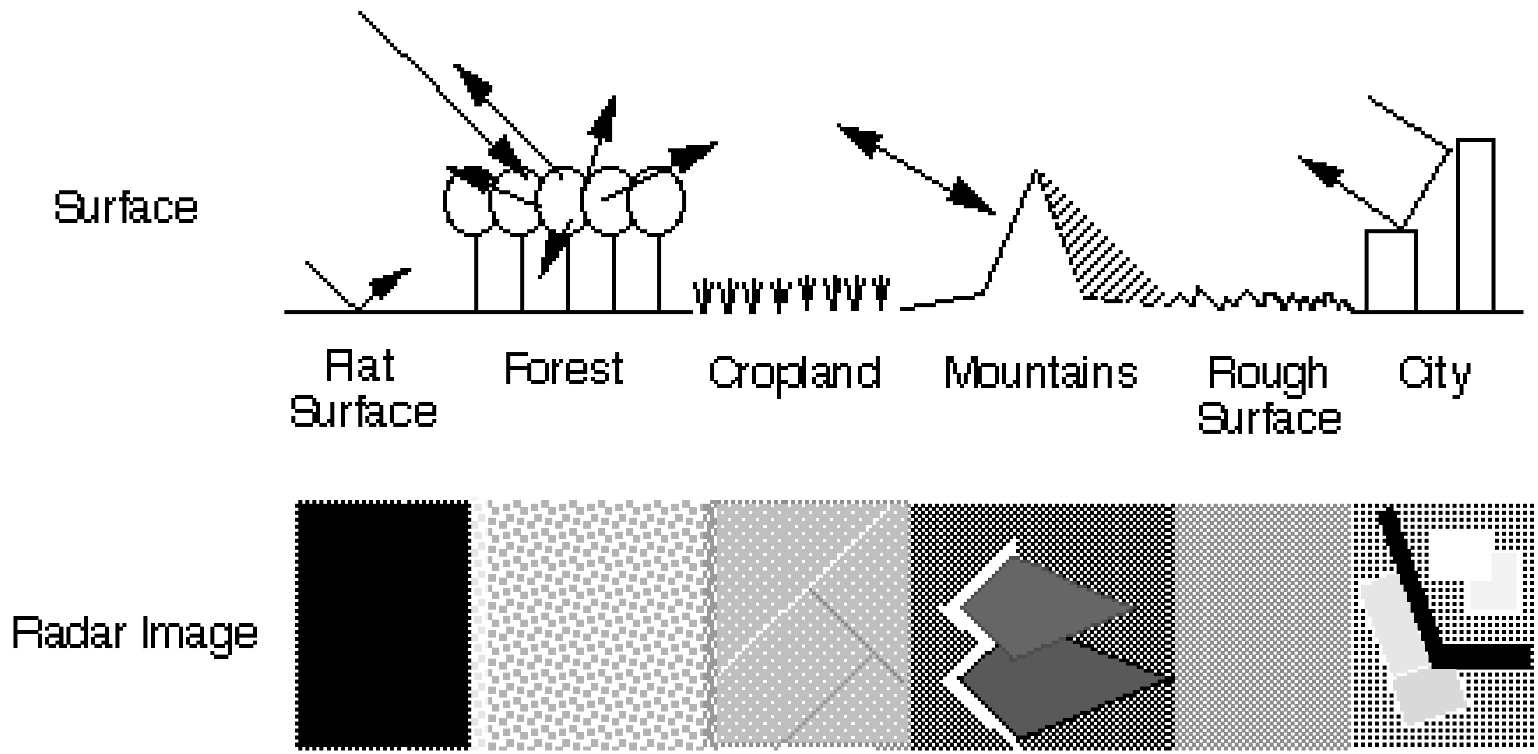


- Wetter surfaces are more reflective
- Backscatter also depends on roughness characteristics

Challenges:

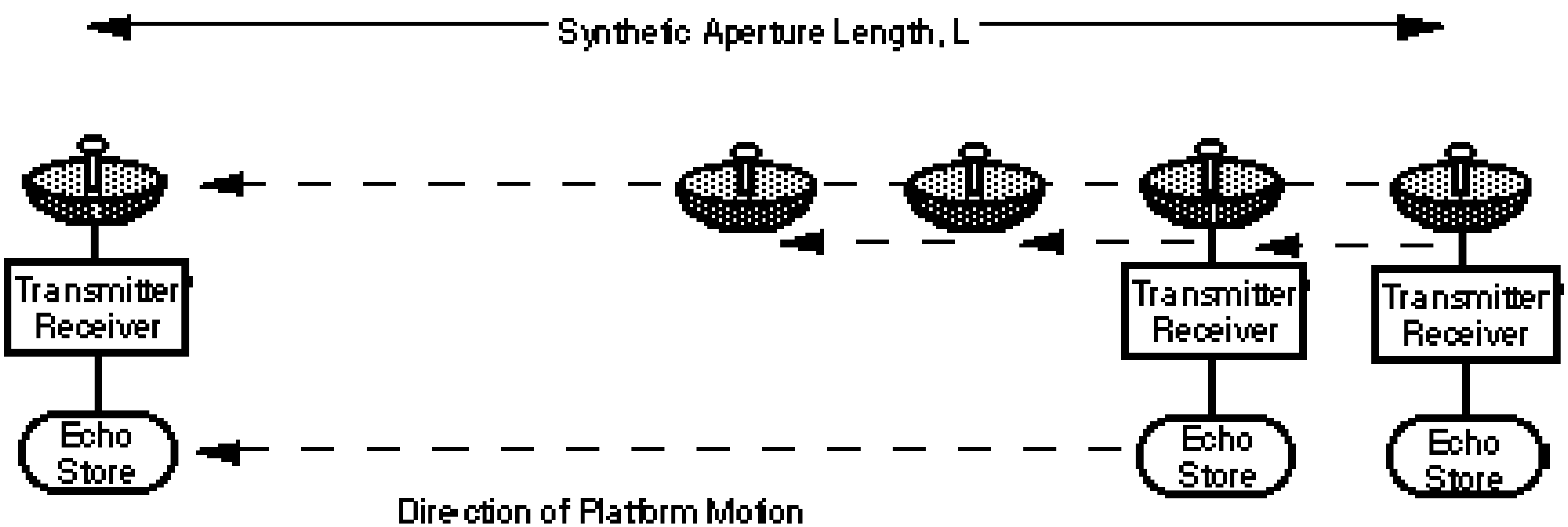
1) Surface signal is attenuated <u>and scattered</u> by vegetation

2) Backscatter sensitivity to soil roughness



Opportunity:

3) SAR techniques can increase effective antennae size and improve resolution



Ground-based resolutions on the order of 10’s of meters (SAR)

Non-SAR scatterometer approaches also possible.

Current Capabilities:

1) C-band (ERS SCAT, RADARSAT-1 and ENVISAT ASAR)

2) 50 km for scatterometers, 10-30 m for SAR

3) ~3-4% volumetric accuracy for bare soil

4) Existing retrieval algorithms are for bare soil and/or v. low biomass.

Near-Future Enhancements:

1) L-band PALSAR ALOS (JAXA)

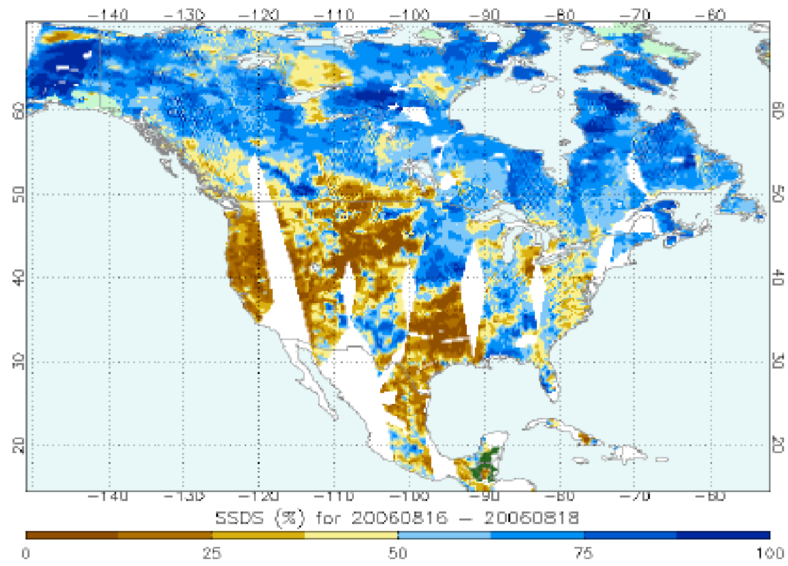
   (Longer wavelength = less volume scattering complexity)

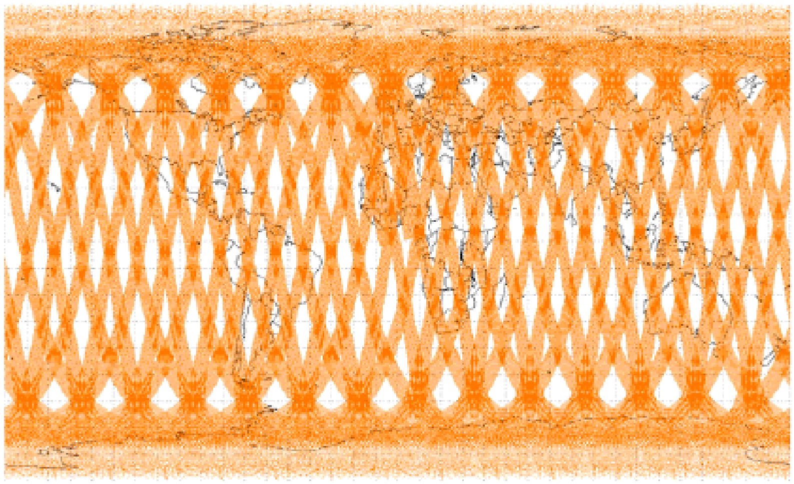
2) Dual polarization helps with vegetation/roughness problem (RADARSAT-2)

25 km Surface Soil Moisture Product

- **Relative soil moisture (0-1)**
  - Degree of saturation
  - Change detection method
    - Accounts indirectly for land cover and roughness
  - Multiple viewing capabilities
    - Correction of vegetation phenology

3-Day ERS-2 Composite (August 2006)





Daily global coverage of METOP ASCAT

W. Wagner, U-Vienna

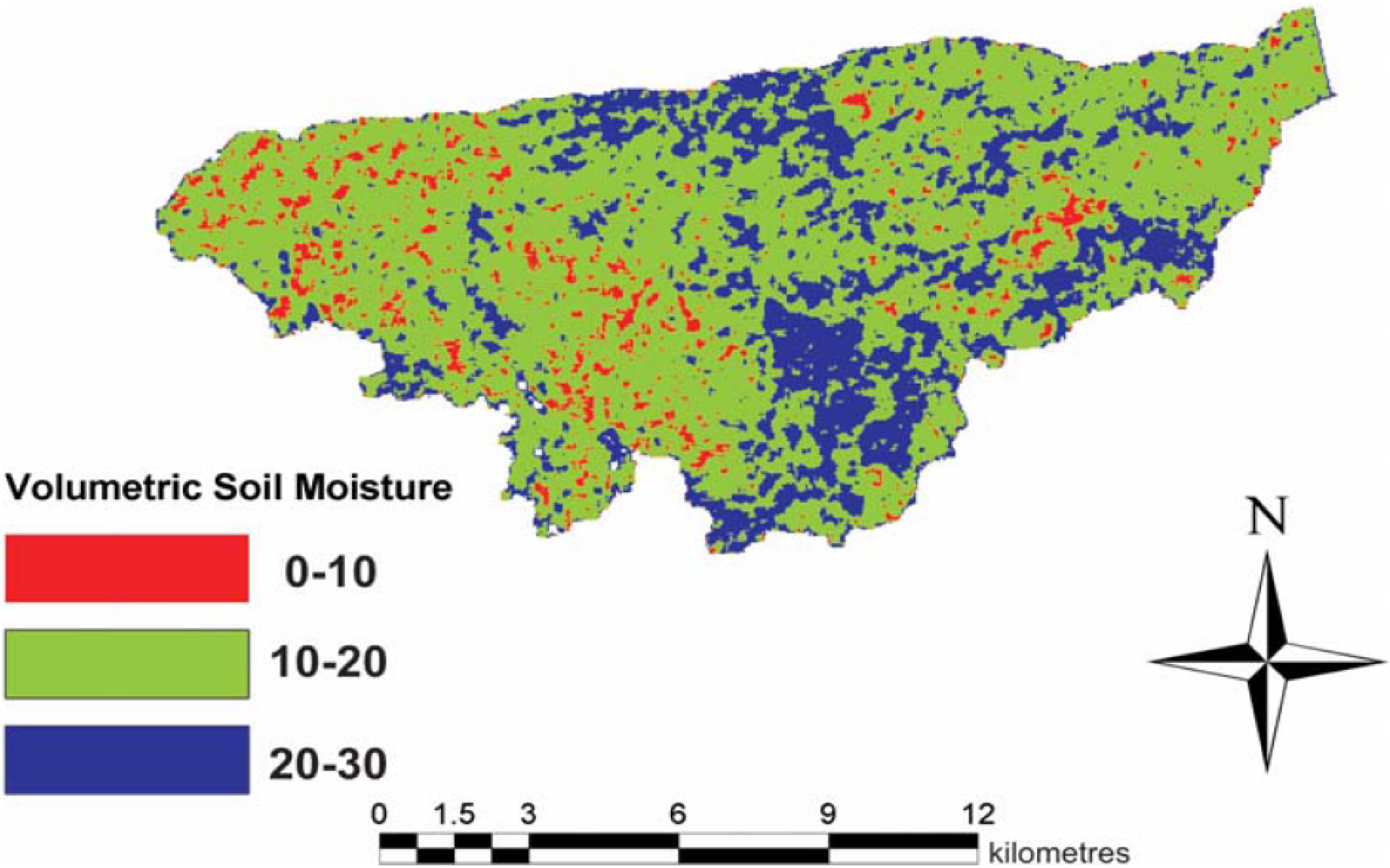
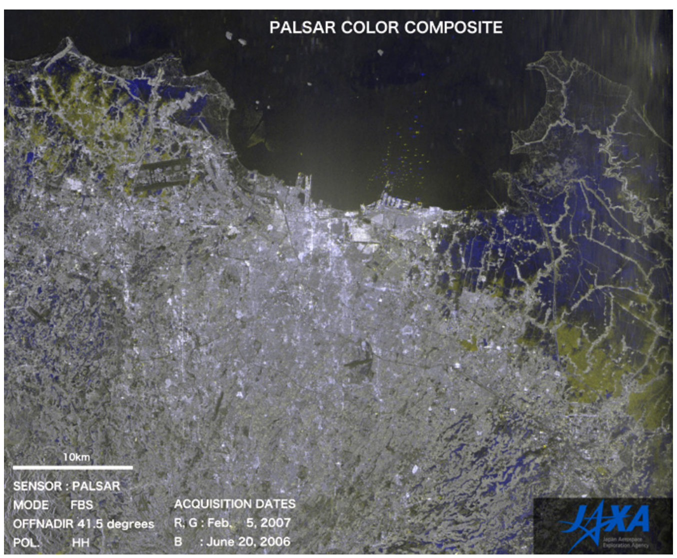


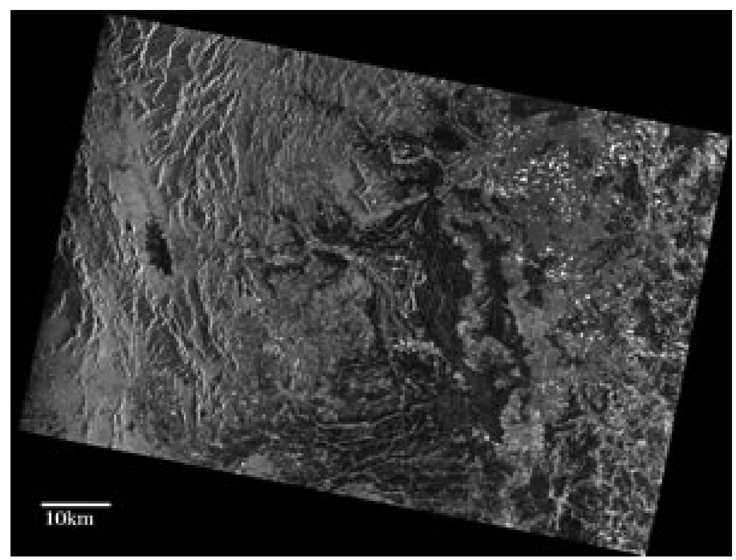
Figure 1. A surface soil moisture map of Walnut Gulch Experimental Watershed near Tucson, Arizona, derived from the time series differences in RADARSAT radar backscatter signals from wet and dry soils. Reproduced with permission from Thoma et al. (2004).

S. Moran, USDA

JAXA ALOS-PALSR Mission

- Jan 2006 launch
- L-band
- 10 – 100 m resolution (SAR)
- Dual-polarization (HH and VV)





Passive:

Coarser resolution (large antennae = cost and risk problems)

Simpler inverse modeling
(less vegetation/roughness sensitivity)

Active:

Finer resolution (with SAR-type processing)

More complex inverse modeling
(more vegetation/roughness sensitivity)

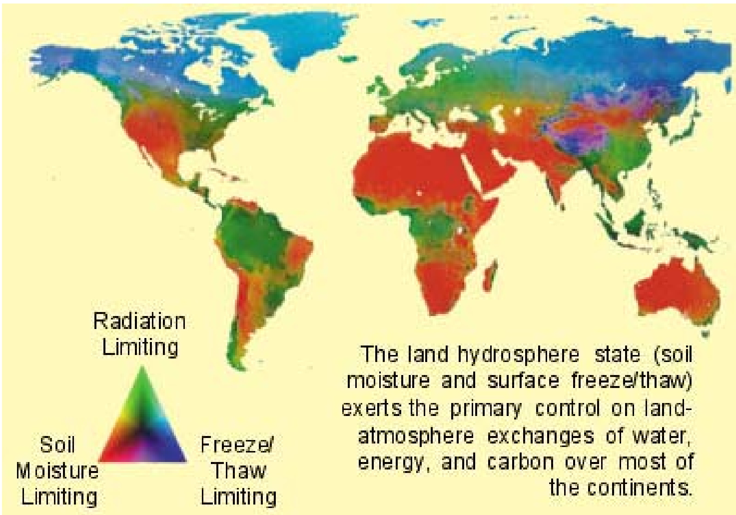
Solution:

New antennae technology (SMOS)

Combine active/passive mission (Hydros)

HYDROS

The Hydrosphere State Mission - A NASA Earth System Science Pathfinder | HYDROS will provide the first global views of Earth's changing soil moisture and land surface freeze/thaw conditions, leading to breakthroughs in weather and climate prediction and in the understanding of processes linking water, energy, and carbon cycles.



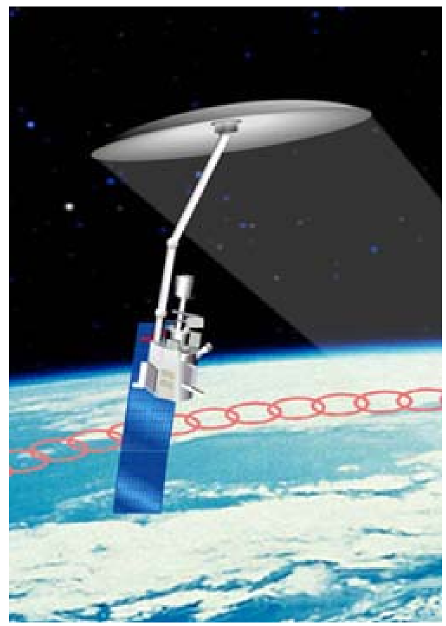
MEASUREMENT REQUIREMENTS:

- **Spatial Resolution:**
  - Hydroclimatology soil moisture at 40km
  - Hydrometerology soil moisture at 10km
  - Freeze/thaw condition at 3km
- **Temporal Sampling:** Global in 2-3 days (2 days Above 50N)
- **Mission Duration:** 2 years

INSTRUMENT:

- L-band active/passive system
- Wide swath (1000 km) with constant look angle (39°)

	Radar		Radiometer
Polarization	VV, HH and HV		V, H and U
Resolution	3 km	10 km	40 km
Relative Error	1.0 dB	0.45 dB	0.64° K



- Dara Entekhabi - PI (MIT)

Partner	Role
MIT	Mission Science
JPL	Project Implementation; Science Products
GSFC	Radiometer; Science Products, DAAC
ASI	Radar Components
CSA	Antenna Components
IPO	Ground Data Systems
DoD	Reflector Assembly
Science Team	Science Data Products

Canceled in December 2005, Revived as SMAP in the 2006 NRC Decadal Survey

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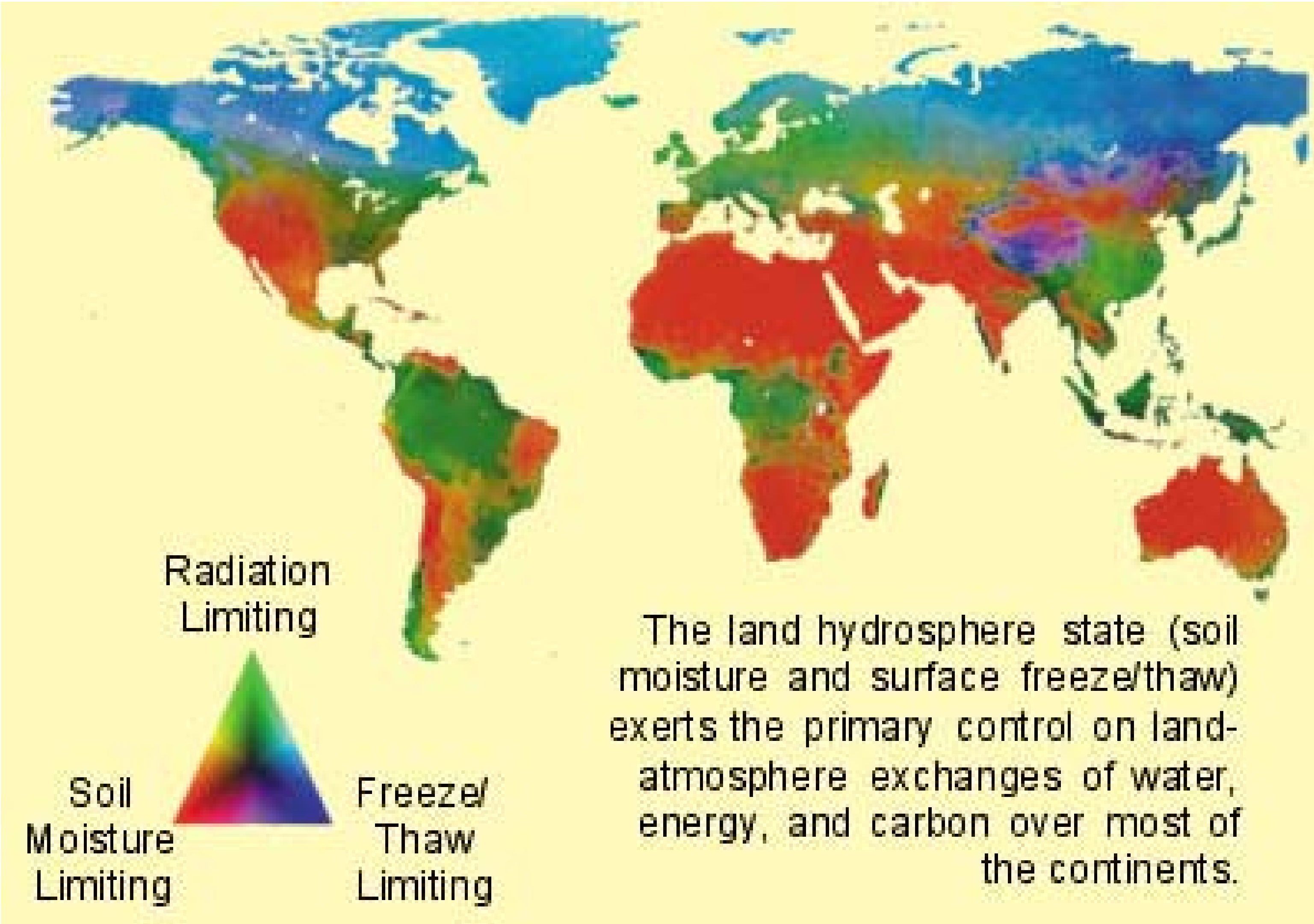
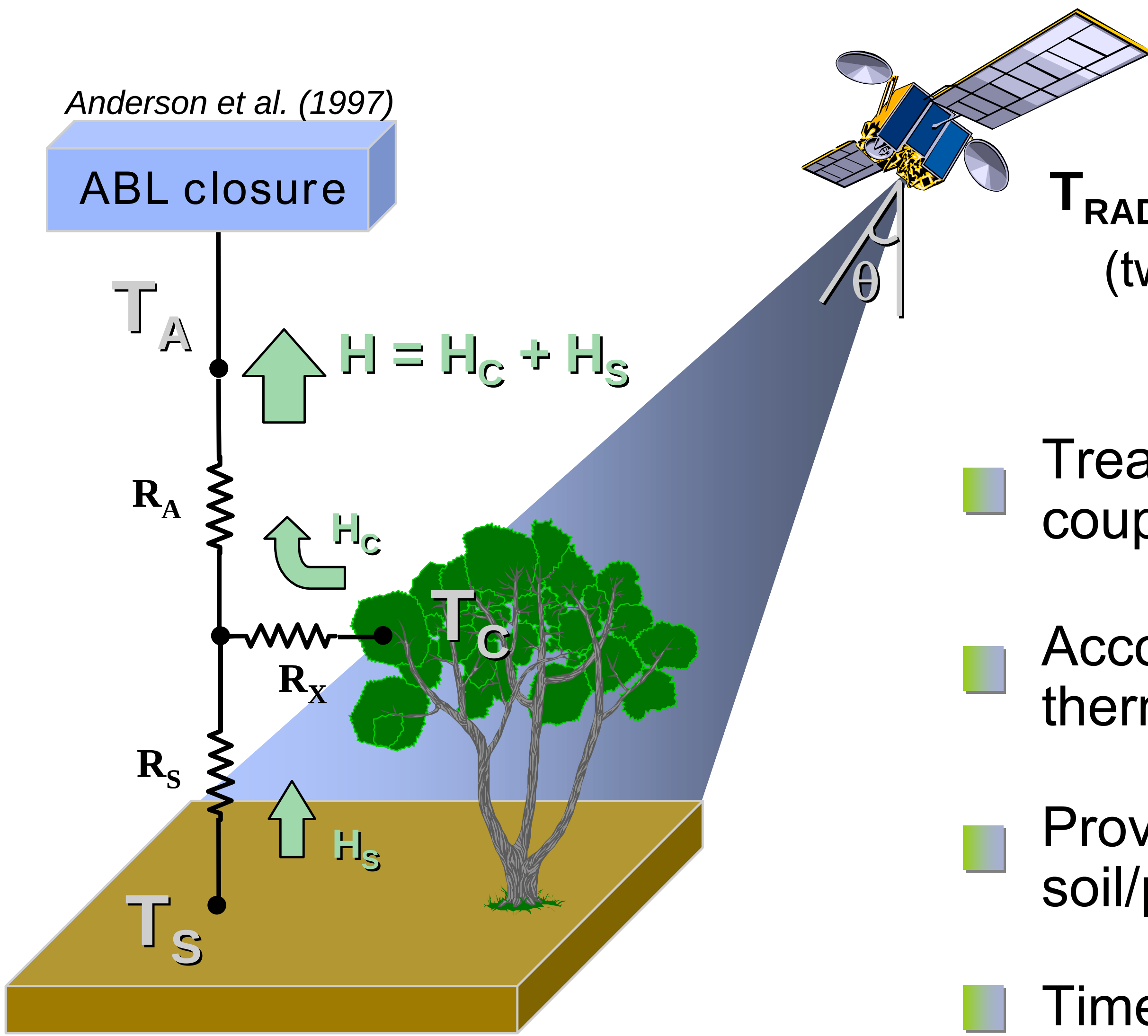
S. Running, U-Montana



- Large areas of strong moisture/energy flux coupling
- Use thermal-based observations to infer energy flux (and root-zone soil proxy)

Atmosphere-Land Exchange Inverse Model (ALEXI)

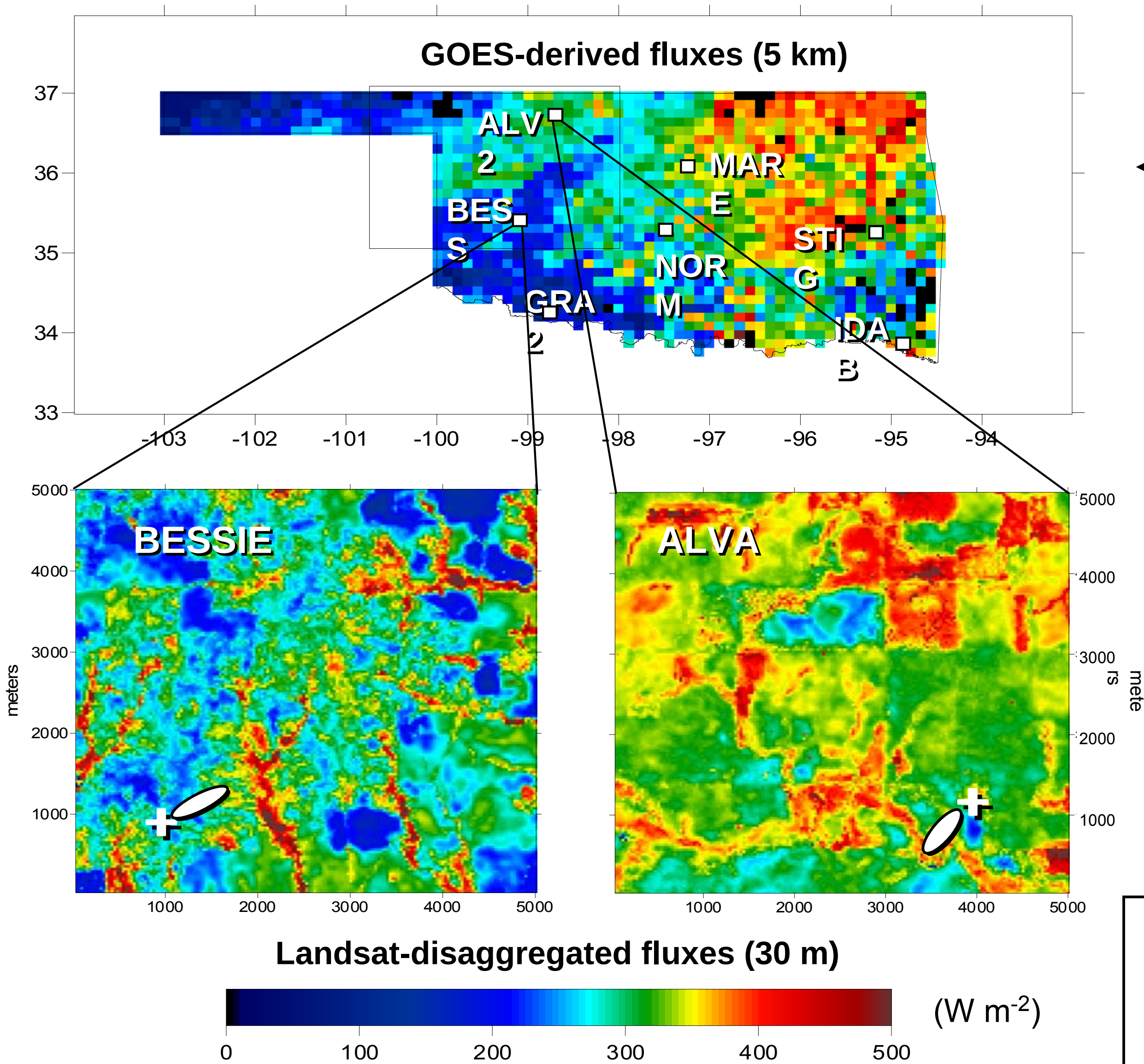


$$T_{RAD}(\theta) \sim f_c(\theta)T_c + [1-f_c(\theta)]T_s$$

(two-source approximation)

- Treats soil/plant-atmosphere coupling differences explicitly
- Accommodates off-nadir thermal sensor view angles
- Provides information on soil/plant fluxes and stress
- Time-differential ABL closure

B. Kustas/M. Anderson, USDA



← 5-km GOES

← 30 m Landsat TM

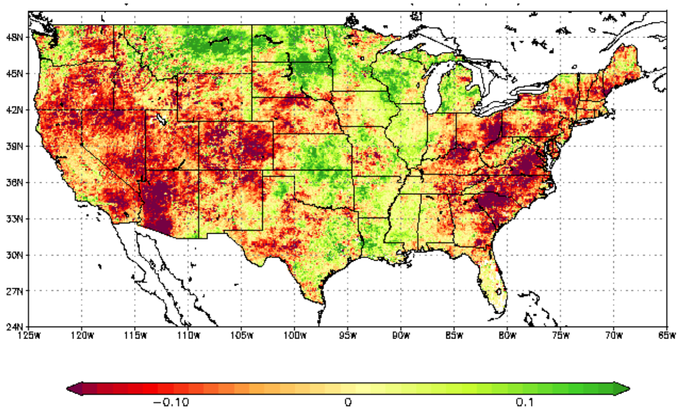
Fine-scale resolution (<100 m)

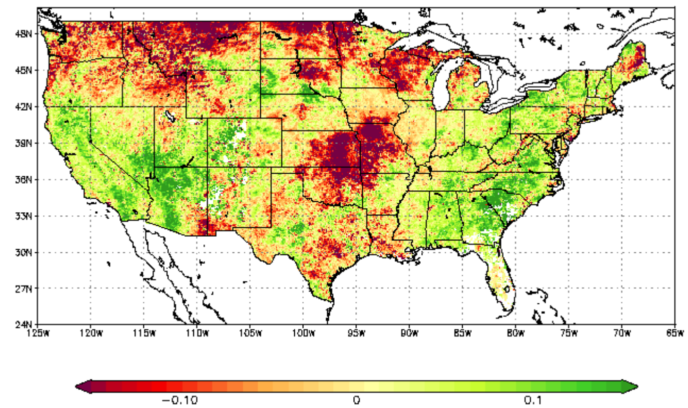
ET/PET reflects root-zone soil moisture availability

M. Anderson, USDA

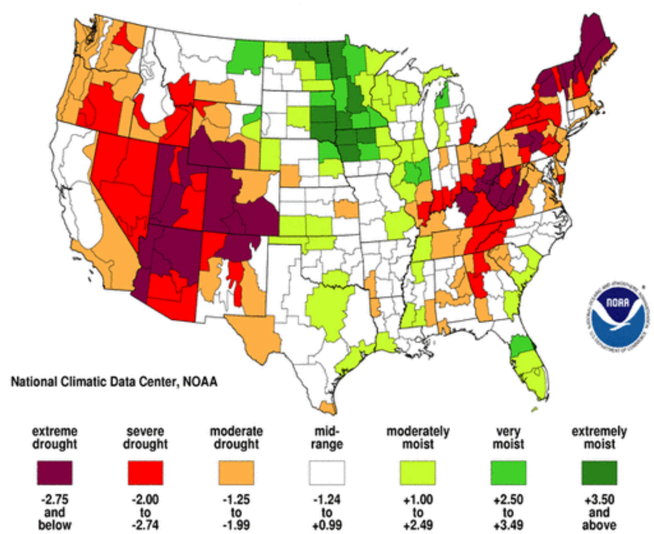
“Climatological” deviation in fPET

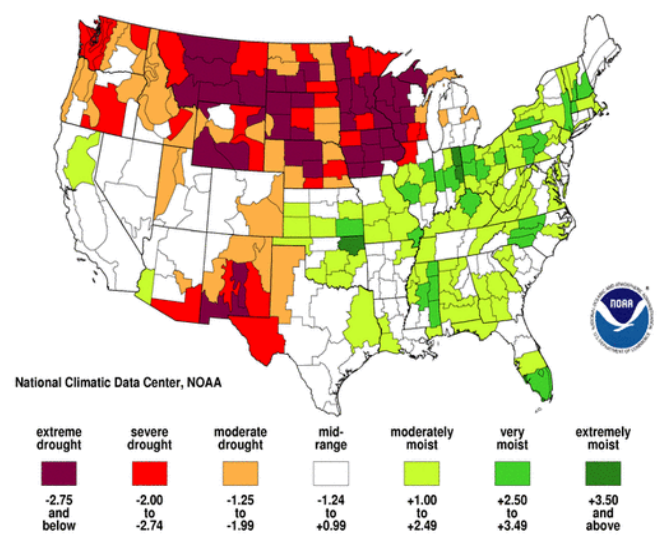
28-day ALEXI composite





Palmer Drought Index





Aug 2002

Aug 2003

M. Anderson, USDA

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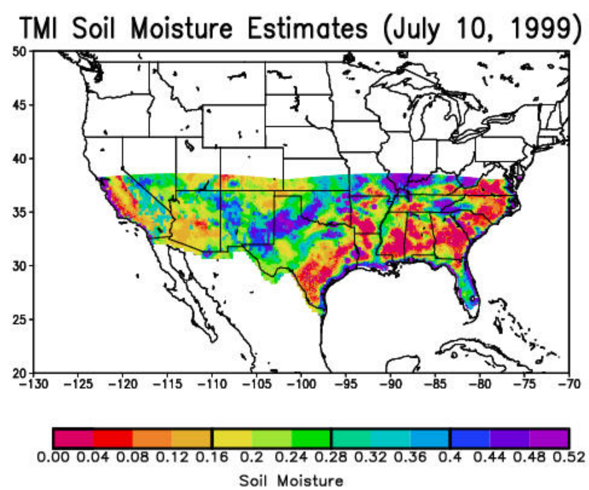
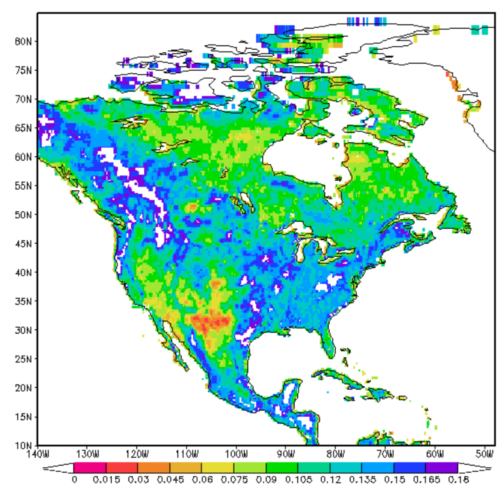
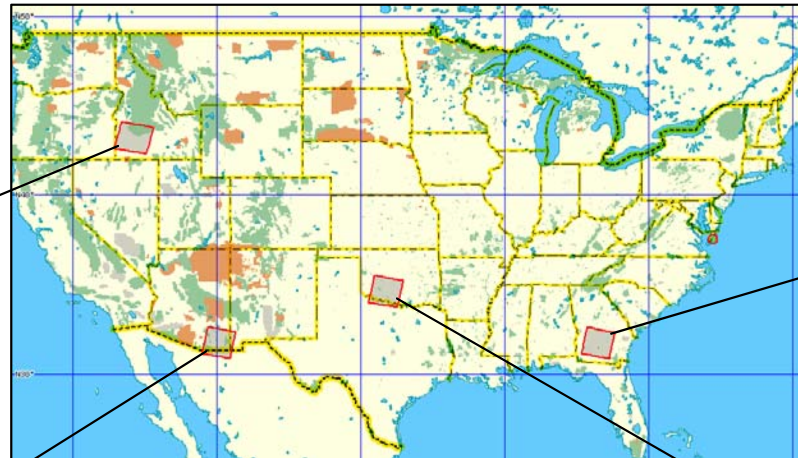
4) Added Value for Hydrologic Applications?

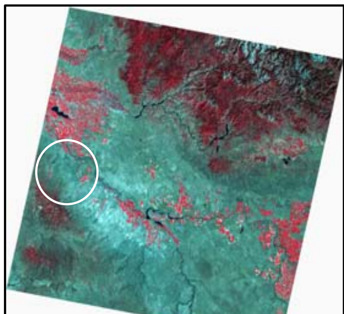




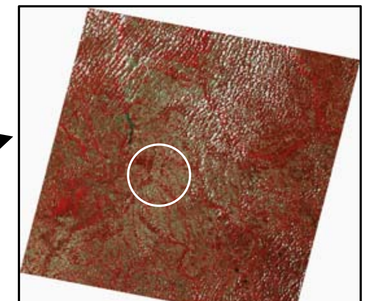
AMSR-E Soil Moisture Validation

AMSR-E SMEX03,05 U.S. Soil Moisture Validation Sites

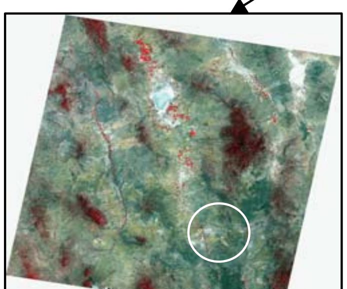




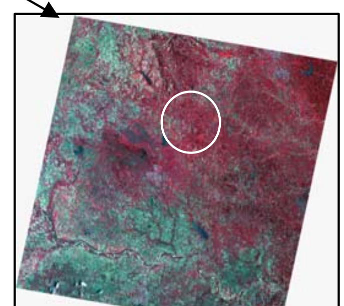
Reynolds Creek, ID



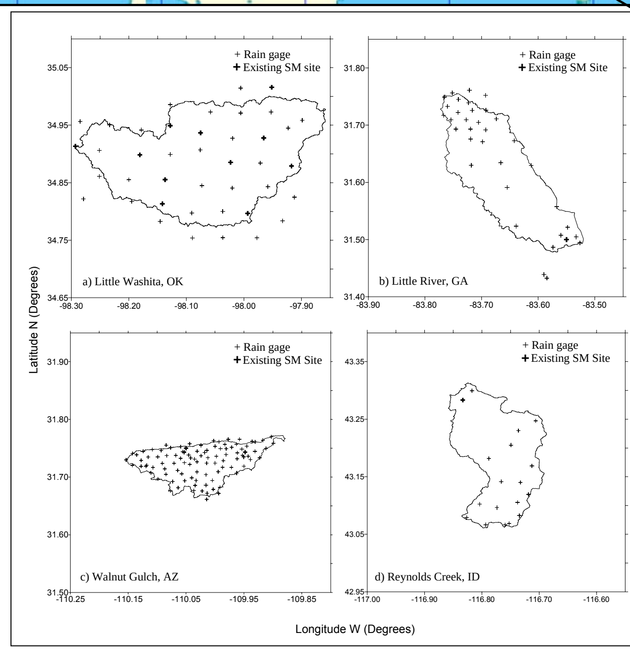
Little River, GA



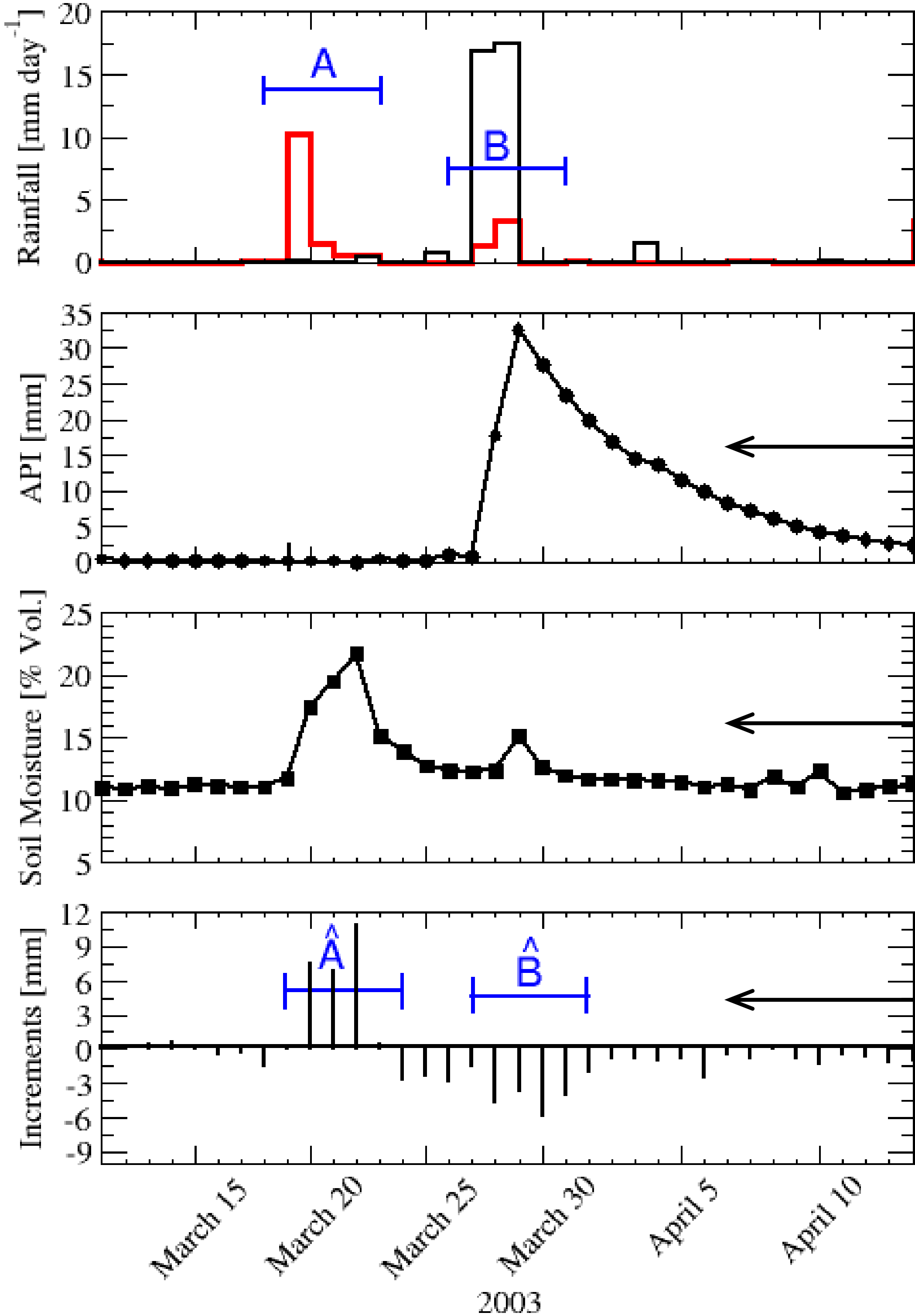
Walnut Gulch, AZ



Little Washita, OK



T. Jackson, USDA



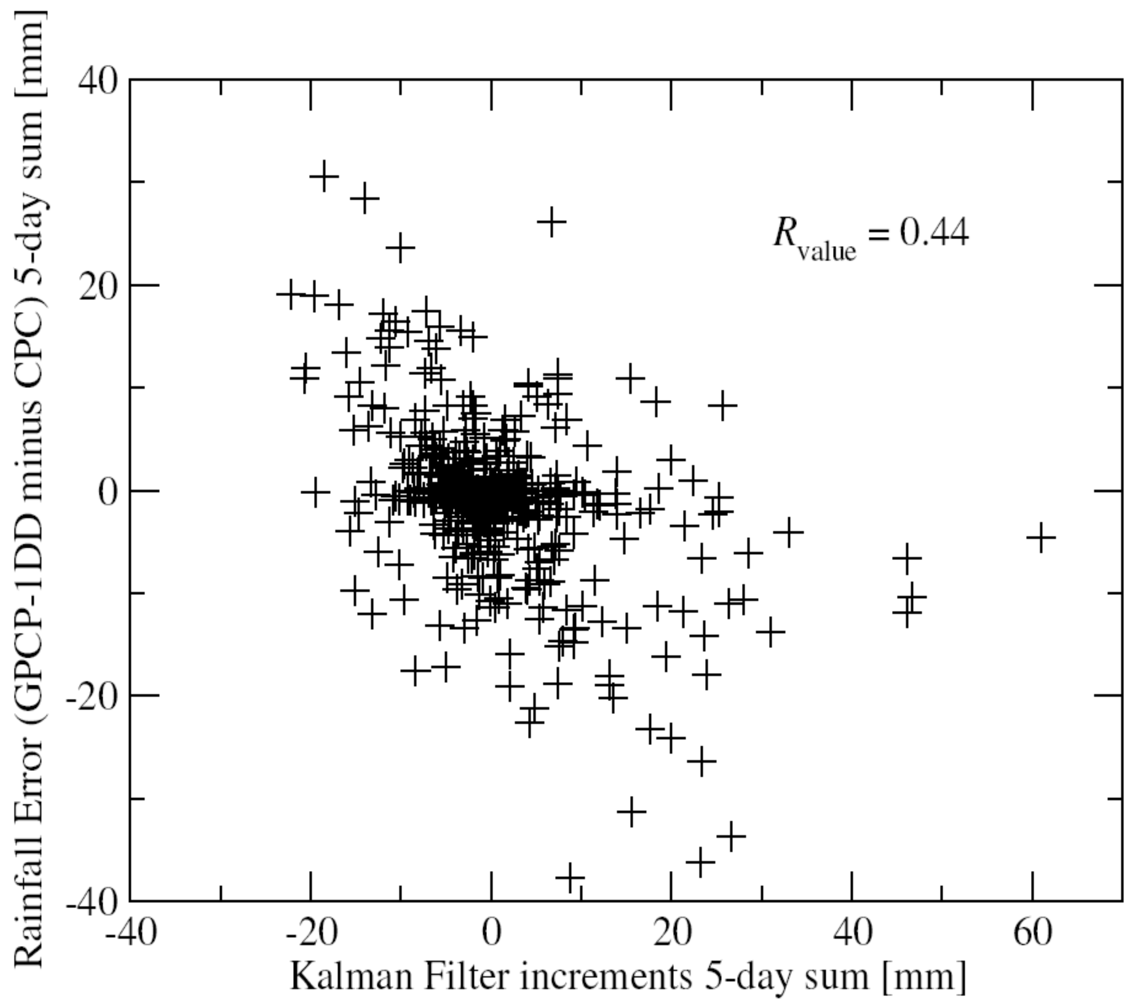
CPC - Gauge product, US only.

GPCP-1DD - Satellite-based product, global.

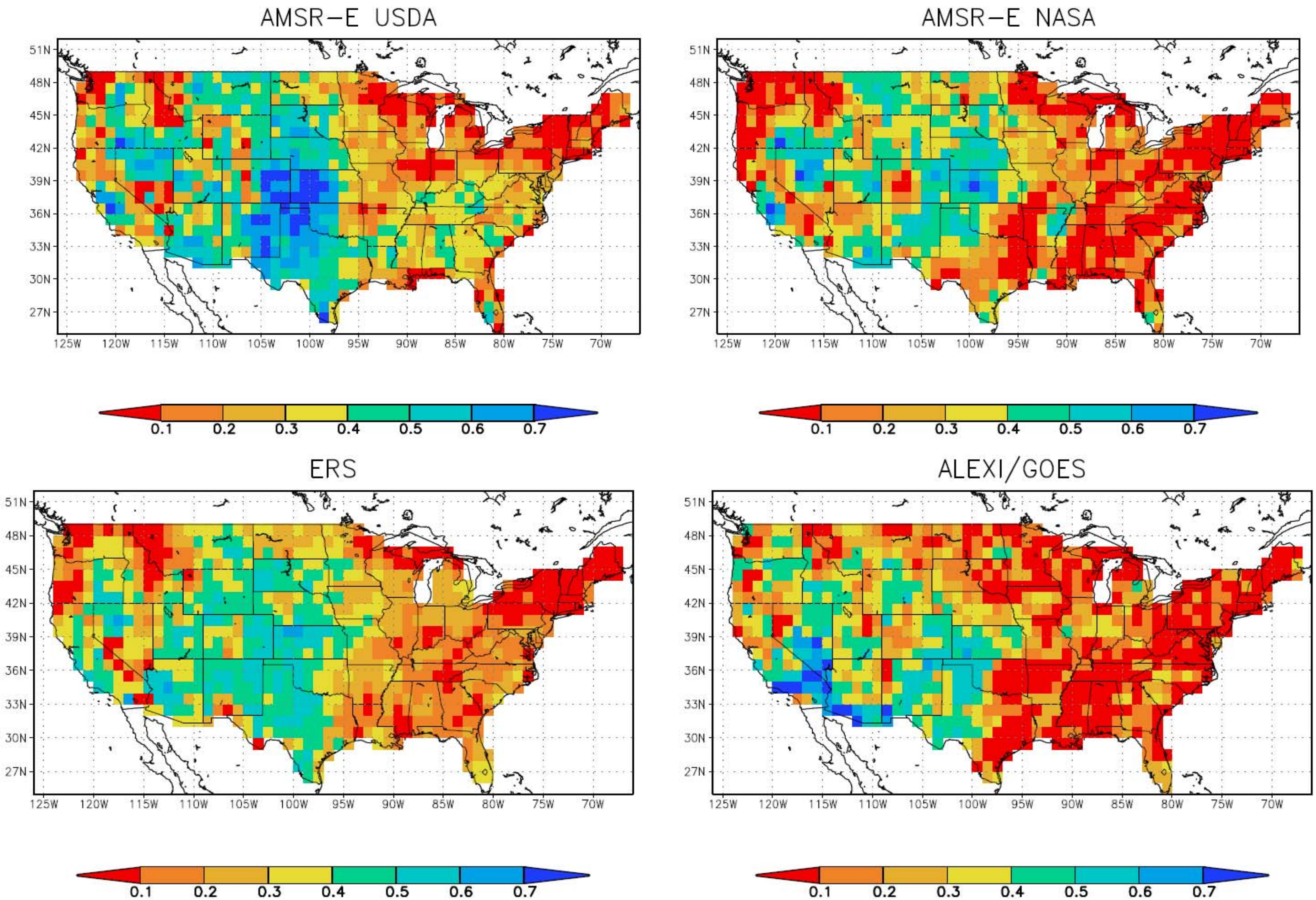
Run baseline model with GPCP-1DD rainfall

Remotely-sensed soil moisture

Kalman filter analysis increments



- Correlation (R_{value}) quantifies remote sensing contribution to land surface model.
- Calculation requires high-quality rainfall data, but NOT ground-based soil moisture observations.


AMSR-E USDA
AMSR-E NASA
ERS
ALEXI/GOES
51N
48N
45N
42N
39N
36N
33N
30N
27N
125W
120W
115W
110W
105W
100W
95W
90W
85W
80W
75W
70W
0.1
0.2
0.3
0.4
0.5
0.6
0.7

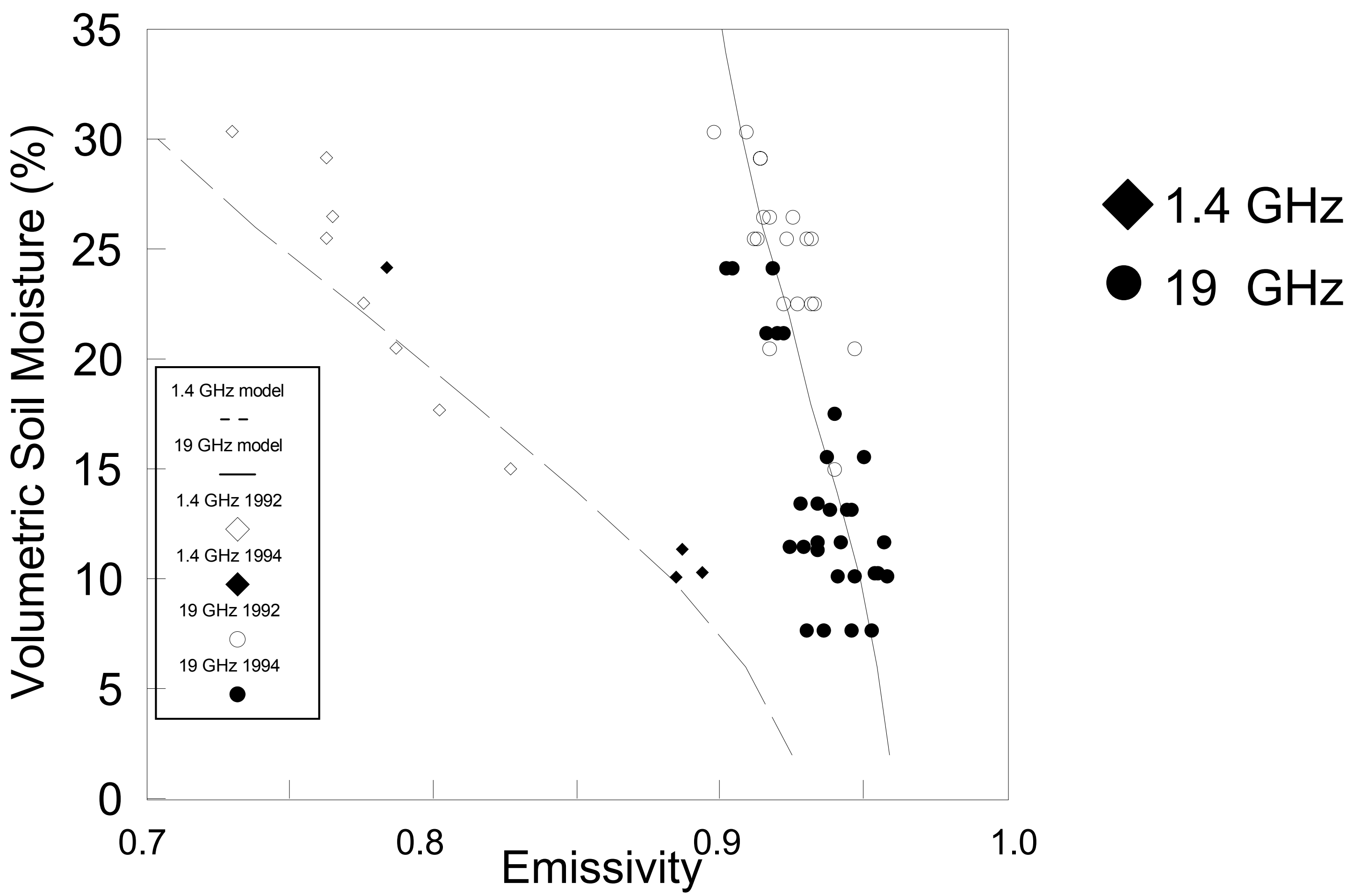
Thank you….

USDA-ARS HRSL
Hydrology & Remote Sensing Lab
Beltsville, Maryland, USA

USDA
Agricultural Research Service

Challenges:

1) Surface signal is attenuated by vegetation



P. O'Neill, NASA GSFC