Estimation of soil temperature for soil moisture retrievals using microwave observations

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Outline

- Introduction
  - Why is soil temperature important?
  - Different methodologies
- Methodology
- Results

Why is Temperature Important?

- Soil Temperature is the single most important variable in radiative transfer equations

$$T_B = e T_s$$

- Brightness temperature is directly proportional to surface temperature
- Surface temperature is variable in both space and time

Different Methodologies

- Ground observations
- Model results
- Using VIS/IR observations
- Multi-channel observations to solve for multiple parameters (soil moisture, soil temperature, vegetation)
- Use of 37 GHz

Ground Observations

- In-situ observations
- Accurate but limited coverage
- Good for field experiments
- Not possible to use in global application

Model results

- Accuracy
- Typically higher errors in near real-time as compared to re-analysis mode
- Errors of 5K can lead to 5% soil moisture errors
- Integration of model output with satellite observations

VIS/IR

- Strongly influenced by clouds
- Provides only surface temperature and not soil temperature
- Need for additional sensor on the same platform

Multi-channel approach

- Multi-channel observations are used to minimize for errors in soil moisture, soil temperature and vegetation
- Increase in TB can be due to
  - Decrease in soil moisture
  - Increase in temperature
  - Increase in vegetation
- C-band cannot be used due to presence of RFI

Use of 37 GHz V-pol

- The use of 37 GHz V-pol has shown potential to estimate surface temperature
- Passive microwave satellites usually carry 37 GHz (AMSR-E, TRMM, WindSat)
- Sensing depth of 37 GHz and X-band is different (critical for mid-afternoon overpasses)

De Jeu model

- Relationship between Surface Temperature and 37 GHz V pol
- Linear model using SMMR and Mesonet observation from Oklahoma

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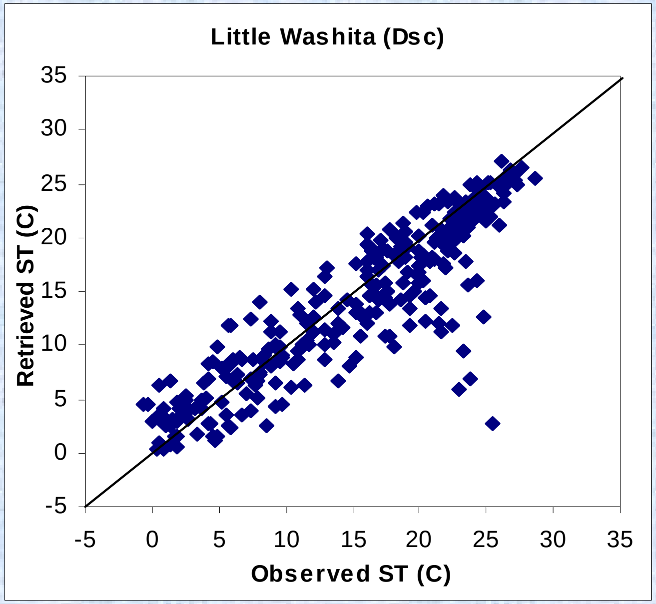
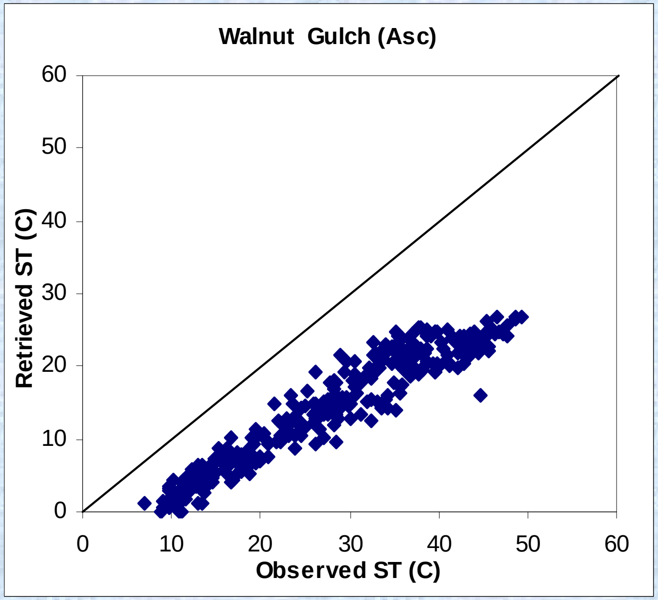
Methodology

- Use of 37 GHz V-pol to estimate shallow surface temperature (similar to De Jeu)
- Soil temperature at 0.2 cm (equivalent to penetration depth of 37 GHz)
- Use of soil physics (heat transfer) to estimate deeper soil temperature

De Jeu model

- Relationship between Surface Temperature and 37 GHz V pol
- Linear model using SMMR and Mesonet observation from Oklahoma
- Estimates for bare soil domains are poor





Methodology

- Combined daily and annual soil temperature variations can be modeled (Van Wjik, 1963) as

$$\vartheta_{day}(z,t) = \vartheta_{ay} + A_{0y}\exp(-z/D_y)\sin(\omega_y t - Z/D_y)$$
$$+ A_{0d}\exp(-z/D_d)\sin(\omega_d t - z/D_d)$$

$$\vartheta_{night}(z,t) = (\vartheta_n(z) - 1.0) + (\vartheta_s(z) - \vartheta_n(z) + 1.0) * \exp(-b * n)$$

- where

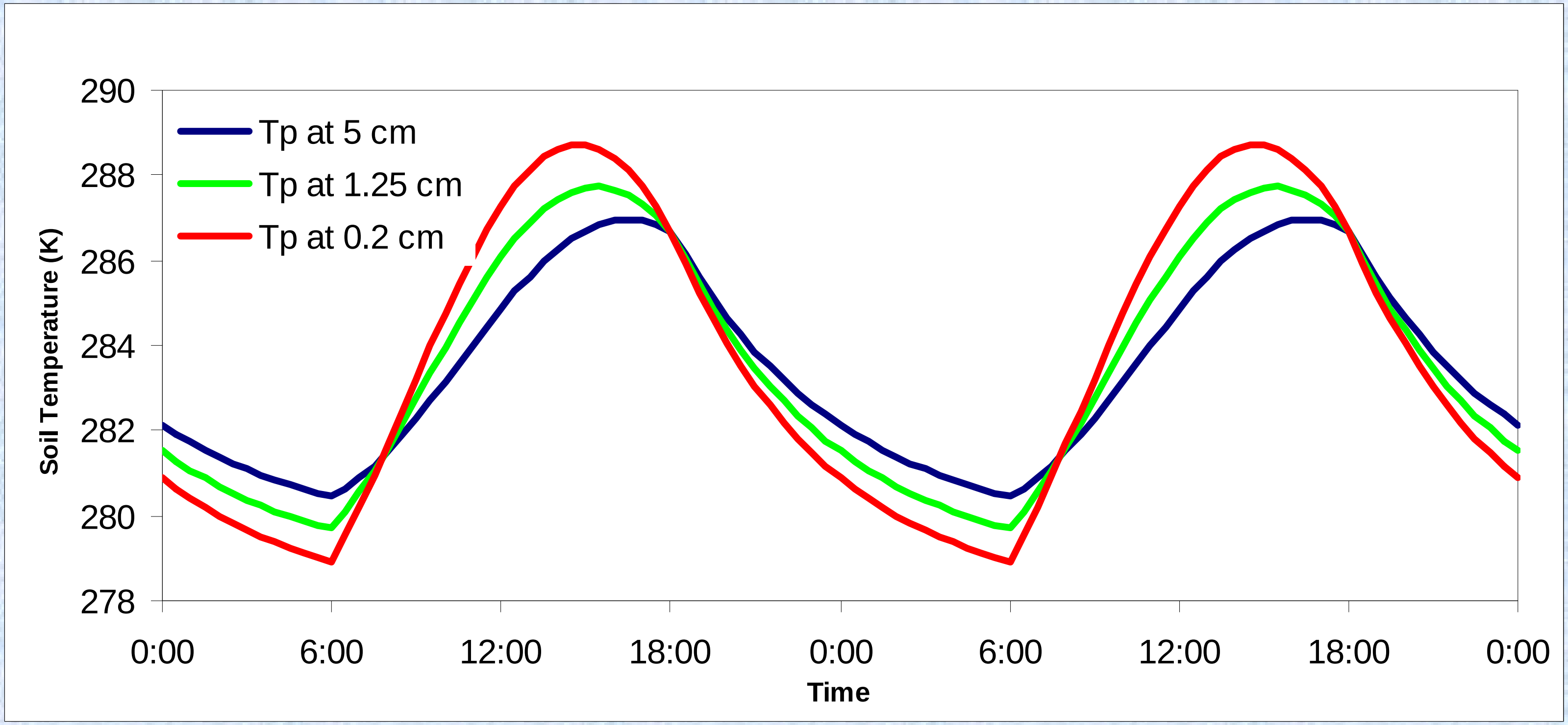
$$b = \log(1.0/(\vartheta_s(z) - \vartheta_n(z) + 1.0))/N$$

$$D = (2a/\omega)^{0.5}$$

$a = \lambda / C$ is the thermal diffusivity, λ - thermal conductivity, C – heat capacity

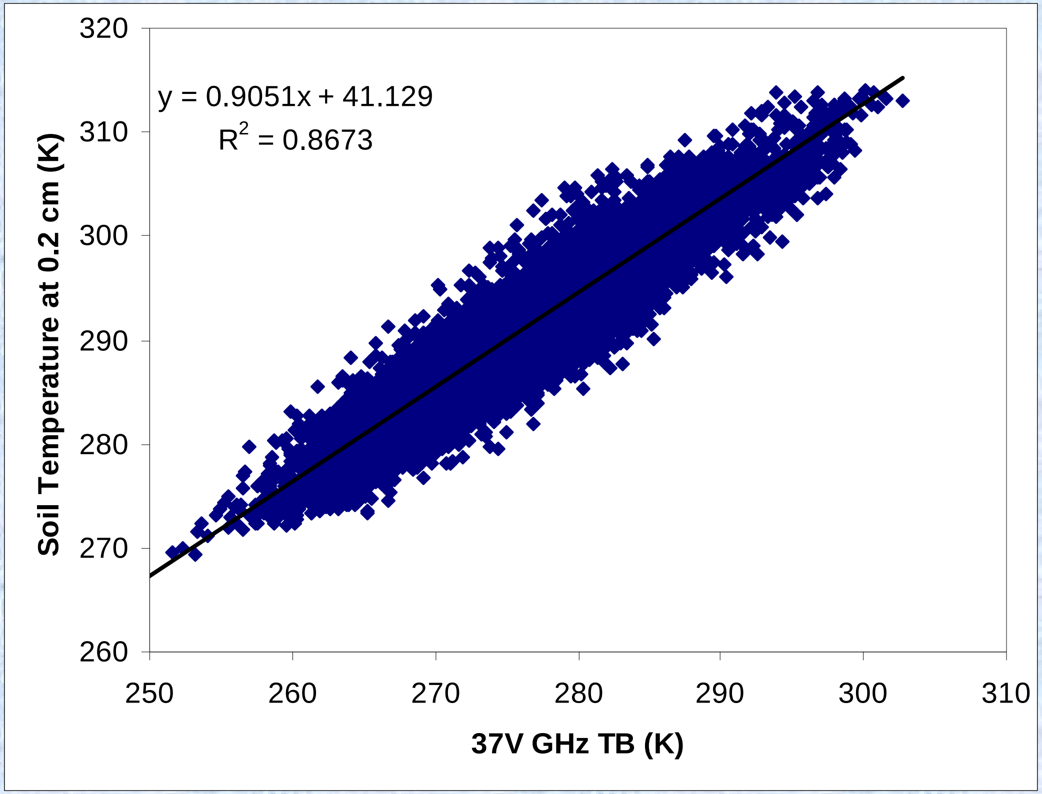
Methodology

Soil Temperature profile at different depths for Little Washita watershed



Soil Temperature at shallow depth

- Use of 37 GHz V-pol to estimate shallow surface temperature (similar to De Jeu)
- Soil temperature at 0.2 cm (equivalent to penetration depth of 37 GHz)



AMSR-E and WindSat Description

- Primary objective to study the water cycle
- Launched – May 2002
- Sun Synchronous orbit with an Ascending orbit of 1:30 PM
- Scanning Radiometer with incidence angle of 55^o
- Swath – 1445 km
- 2 day global coverage
- Data from 2002-2007 was used

- Primary objective to determine wind vector
- Launched – Jan 2003
- Sun Synchronous orbit with an Ascending orbit of 6:00 PM
- Scanning Radiometer with incidence angle of 53^o
- Swath – 1025 km
- 3 day global coverage
- Data from 2003-2005was used

AMSR-E and WindSat Description

- Multi-frequency polarimetric radiometer
- C-band contaminated with RFI

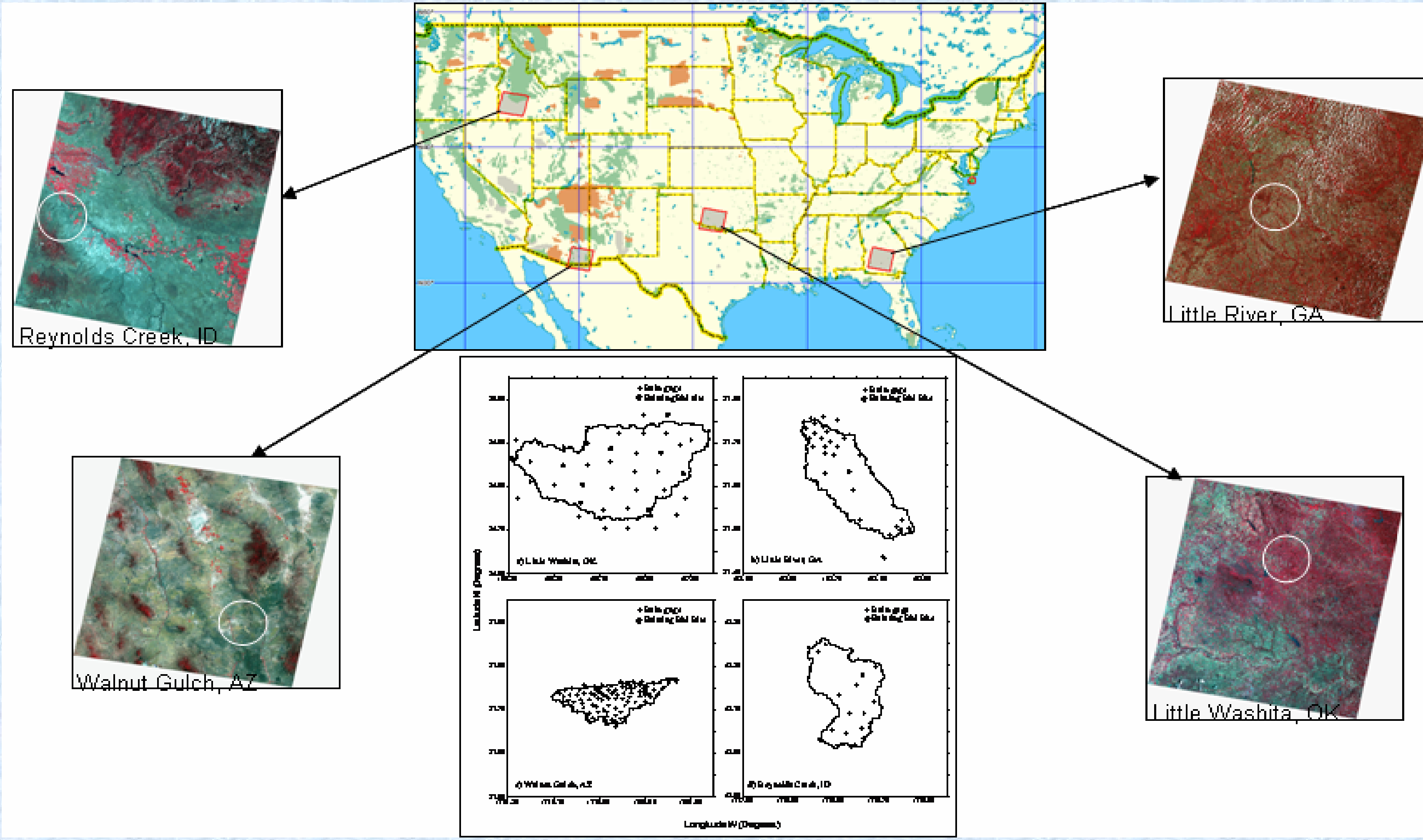
AMSR-E

Frequency (GHz)	Polarization	Footprint (Km)
6.925	V, H	75
10.75	V, H	48
18.7	V, H	27
23.8	V, H	31
36.5	V, H	14
89.0	V, H	6

WindSat

Frequency (GHz)	Polarization	Footprint (Km)
6.8	V, H	60
10.7	V, H, U, 4	38
18.7	V, H, U, 4	27
23.8	V, H	20
37.0	V, H, U, 4	13

Validation Networks



Validation Networks

Watershed	# Sites	Climate	Annual Rainfall (mm)	Topography	Land Use
Little Washita, OK	16	Sub-humid	750	Rolling	Range/ wheat
Little River, GA	29	Humid	1200	Flat	Row crop/forest
Walnut Gulch, AZ	21	Semiarid	320	Rolling	Range
Reynolds Creek, ID	19	Semiarid	500	Mountainous	Range

Little Washita

Little River

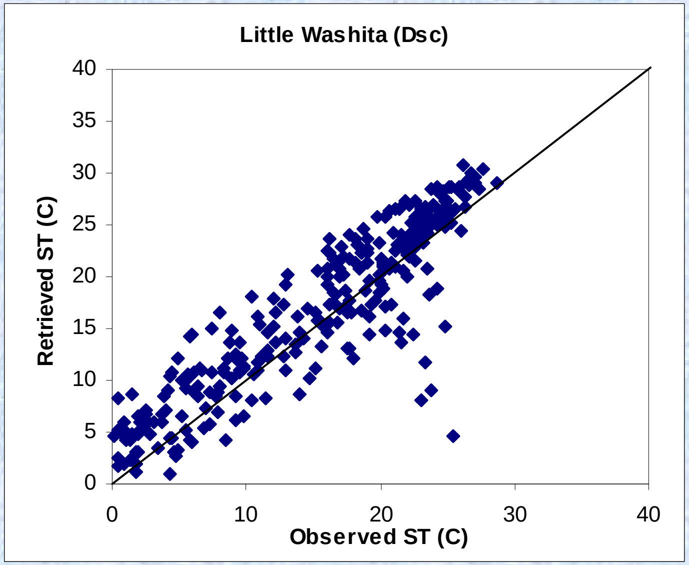
Walnut Gulch

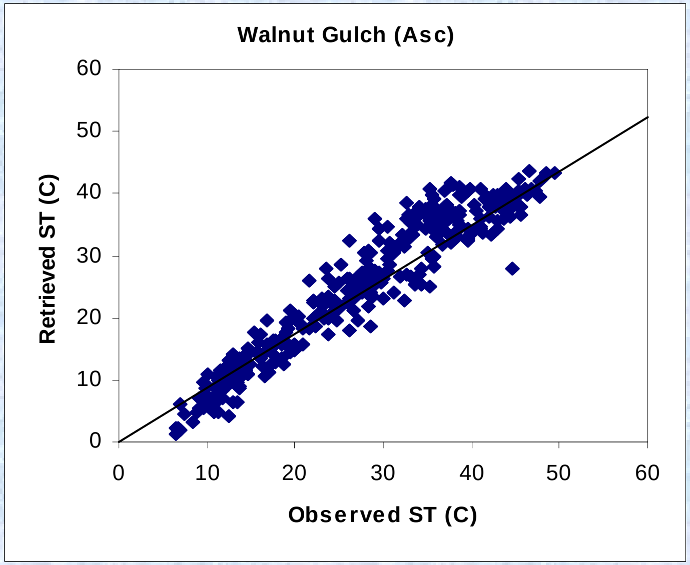
Reynolds Creek

Comparison with in-situ observations

- Only AMSR-E observations were used to develop the linear model for computing shallow soil temperature from 37 GHz V polarization
- Soil Temperature and Soil moisture observations from 2002 to 2007 were compared with AMSR-E retrievals
- The model was validated using WindSat observations
- Soil Temperature and Soil moisture observations from 2003 to 2005 were compared with WindSat retrievals
- Only limited observations in Reynolds Creek were used to exclude possible snow conditions

Soil Temperature comparison (AMSR-E)





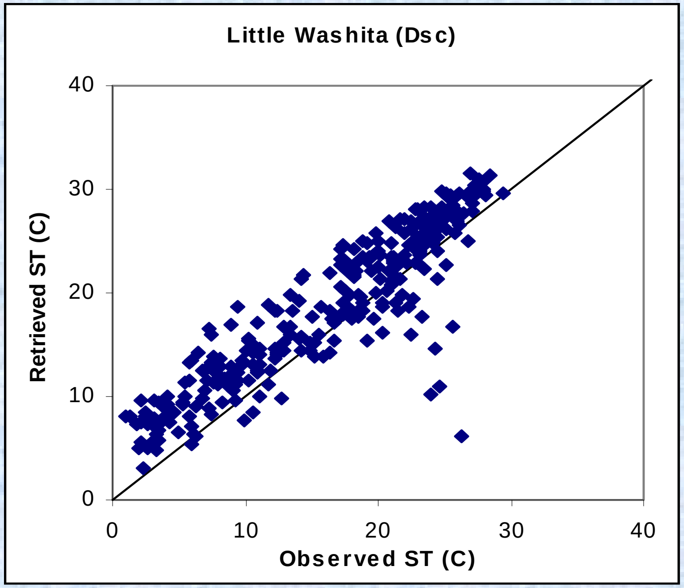
- The outliers in Little Washita are probably due to the presence of precipitation contamination
- The model performs well over different domains (in varying surface conditions)
- Estimated soil temperature for all watersheds for both Ascending and Descending orbits compared well with the observations

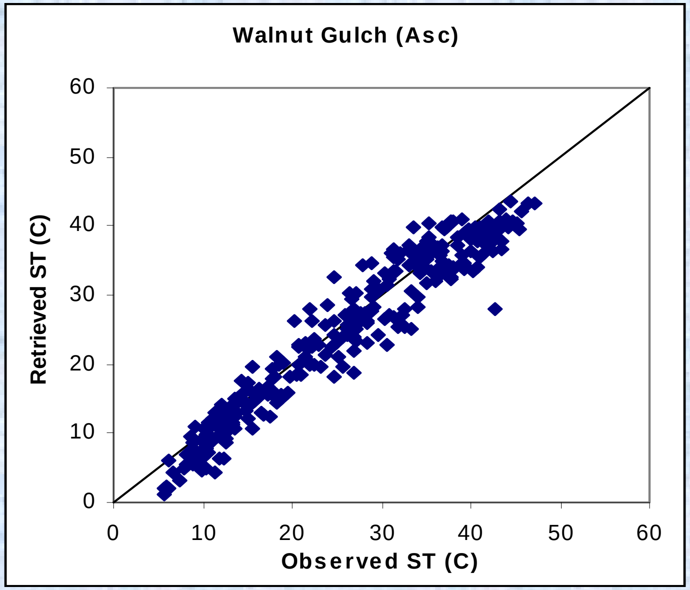
Soil Temperature Stats (AMSR-E)

Watershed name	SEE (K)	Bias (K)
Total	4.305	-1.011
Little Washita, OK (Asc)	3.295	0.960
Little Washita, OK (Dsc)	3.399	-0.019
Walnut Gulch, AZ (Asc)	4.653	-3.776
Walnut Gulch, AZ (Dsc)	2.588	-1.103
Little River, GA (Asc)	4.137	-1.297
Little River, GA (Dsc)	3.615	-2.408
Reynolds Creek, ID (Asc)	9.932	9.222
Reynolds Creek, ID (Dsc)	2.197	-1.313

Soil Temperature comparison (WindSat)

- The methodology was applied to WindSat observations (validation mode only)
- The model performed well for WindSat observations
- The methodology is robust and works for multiple satellites and observation times

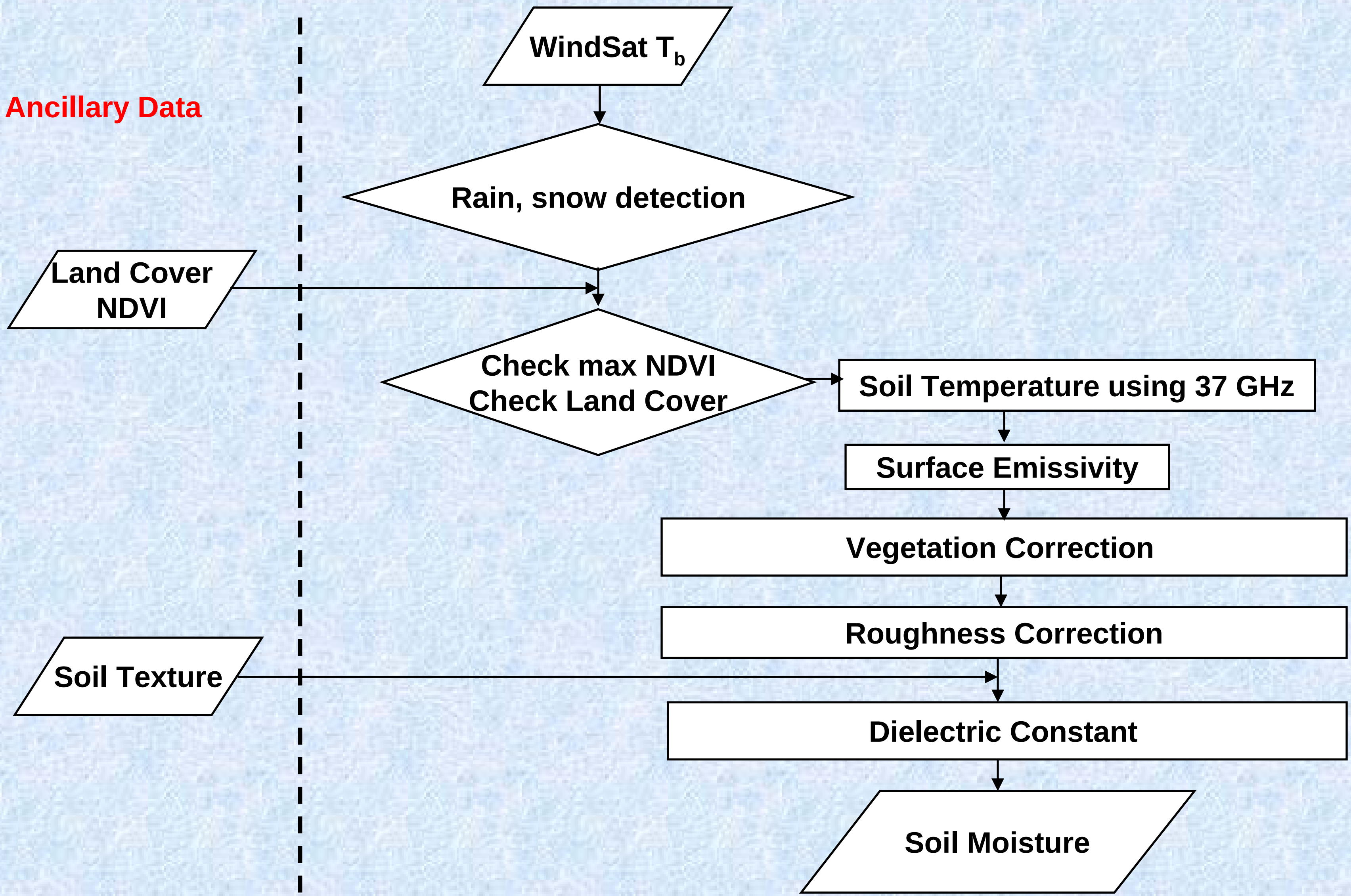




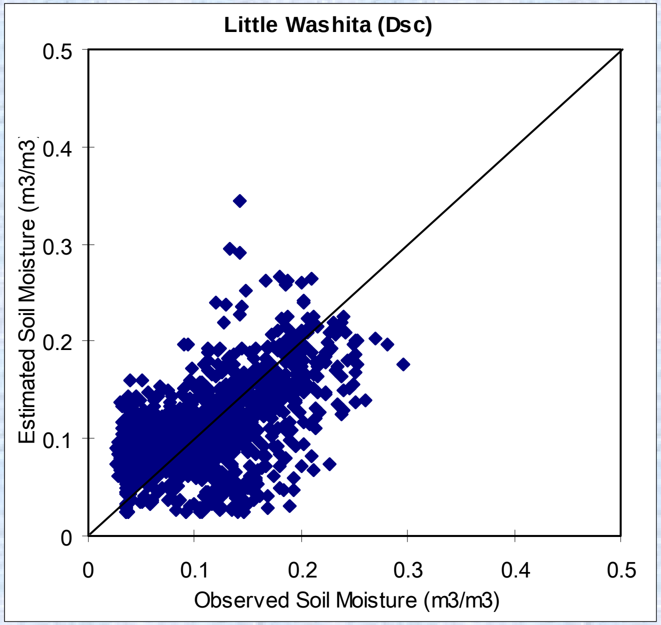
Soil Temperature Stats (WindSat)

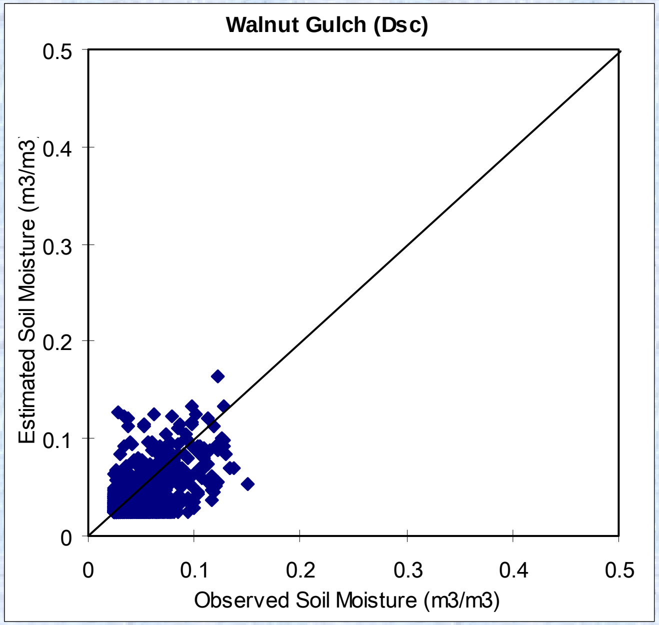
Watershed name	SEE (K)	Bias (K)
Total	3.751	0.897
Little Washita, OK (Asc)	2.924	1.442
Little Washita, OK (Dsc)	4.457	2.947
Walnut Gulch, AZ (Asc)	5.008	-3.066
Walnut Gulch, AZ (Dsc)	3.373	3.031
Little River, GA (Asc)	3.099	-0.518
Little River, GA (Dsc)	2.516	-0.167
Reynolds Creek, ID (Asc)	3.776	2.937
Reynolds Creek, ID (Dsc)	4.962	4.568

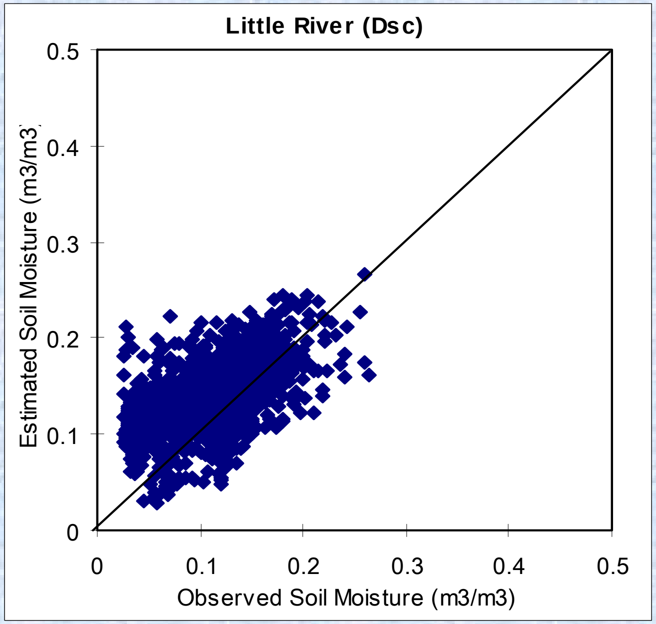
Soil Moisture Algorithm

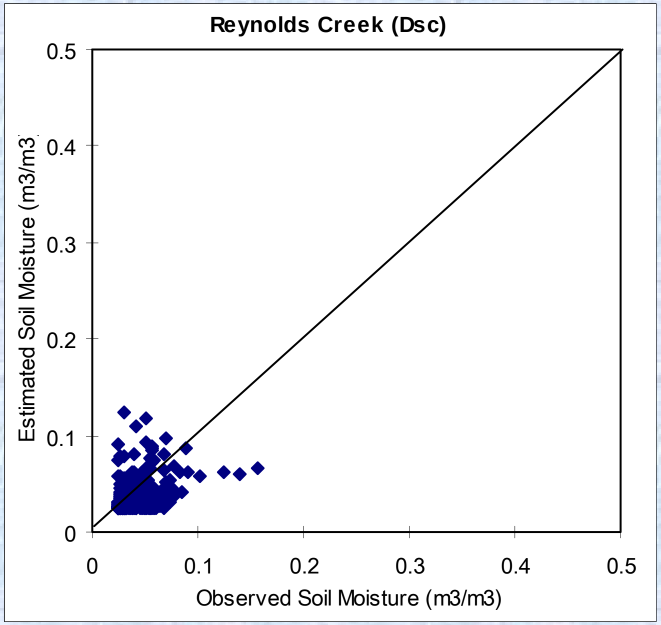


AMSR-E Soil Moisture







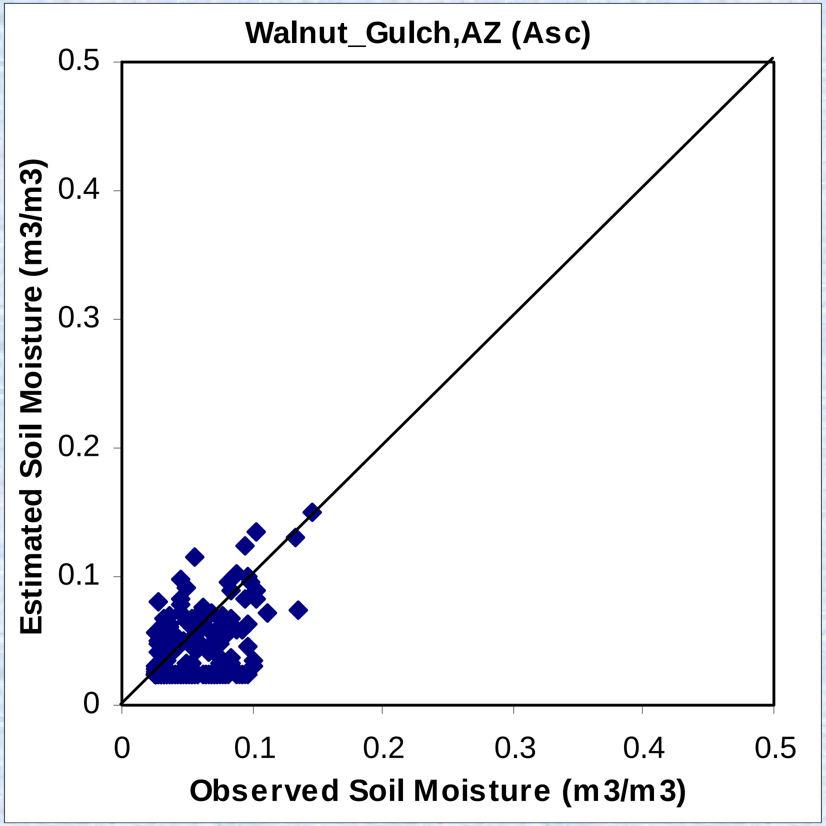


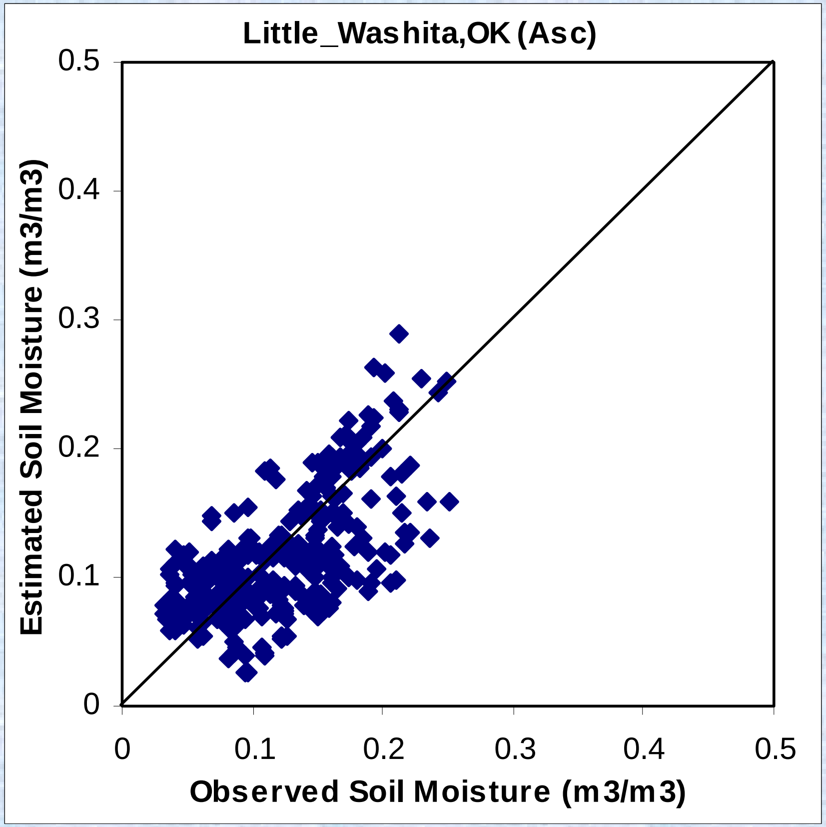
AMSR-E Soil Moisture

Watershed	SEE	Bias	R	N
Walnut Gulch, AZ	0.020	-0.006	0.602	1071
Little Washita, OK	0.051	-0.001	0.526	1094
Little River, GA	0.052	0.033	0.555	1197
Reynolds Creek, ID	0.018	-0.003	0.385	385

- Walnut Gulch watershed (semi-arid) has a small range (~0.1) of observed soil moisture (sandy soils). NDVI ~0.16-0.30
- Little Washita and Little River exhibit a large dynamic range (~0.25). Little Washita NDVI ~0.25-0.50, Little River NDVI ~0.34-0.55
- Reynolds Creek analysis was limited to July to Sept observations to minimize the effect of snow cover. NDVI ~0.26-0.4

WindSat Soil Moisture





WindSat Soil Moisture

Watershed	SEE (m3/m3)	Bias (m3/m3)
Little Washita, OK (Asc)	0.041	-0.003
Little Washita, OK (Dsc)	0.055	-0.010
Walnut Gulch, AZ (Asc)	0.023	-0.010
Walnut Gulch, AZ (Dsc)	0.025	0.009
Little River, GA (Asc)	0.039	0.023
Little River, GA (Dsc)	0.049	0.035
Reynolds Creek, ID (Asc)	0.023	-0.007
Reynolds Creek, ID (Dsc)	0.025	0.014

Summary

- The methodology is independent of site location and relies on thermal properties of soil
- AMSR-E and WindSat provides a robust demonstration of the retrieval model
- In-situ observation networks at four research watersheds have provided valuable datasets that can be used to validate satellite soil moisture retrievals
- WindSat (validated) estimated soil temperature were more accurate than AMSR-E (used in calibration). Soil temperature profile is more uniform at 6 AM/PM. Future soil moisture missions (SMOS, SMAP) focus on this overpass time.