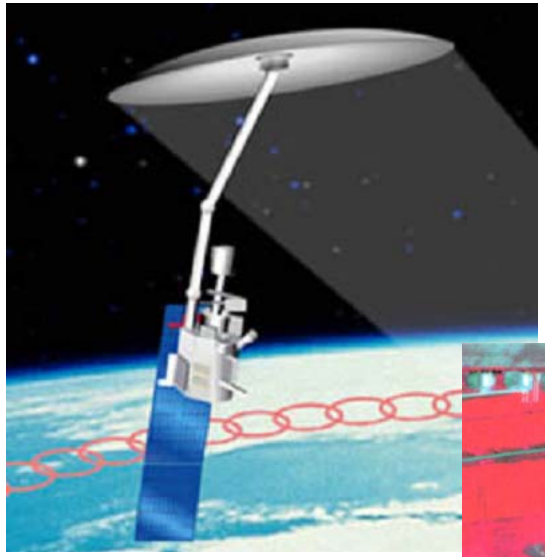
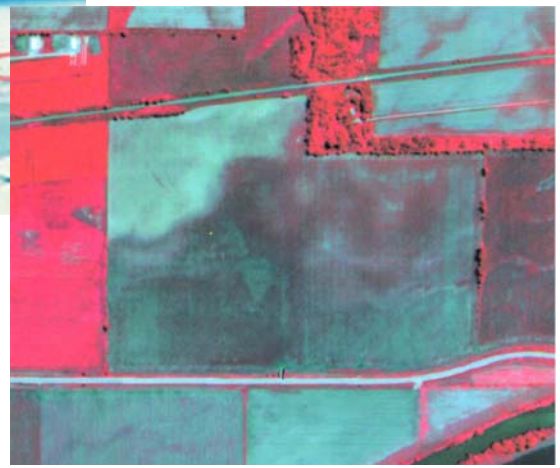
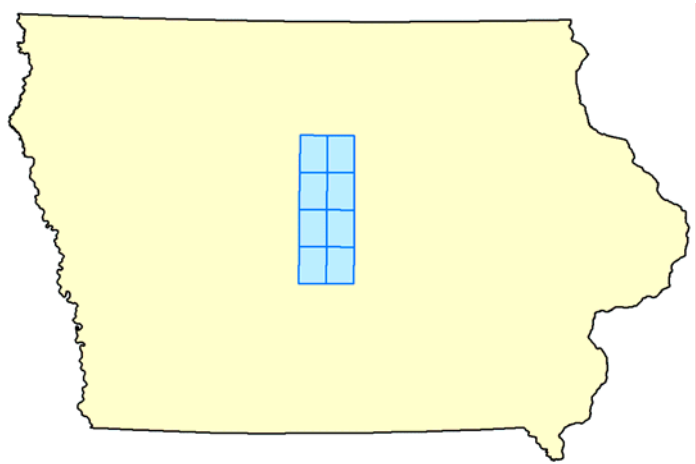
Soil Moisture Retrievals Using L-band Radiometer Observations in SMEX02: Successes and Challenges

William Crosson, Ashutosh Limaye, Charles Laymon

National Space Science and Technology Center
Huntsville, Alabama, USA



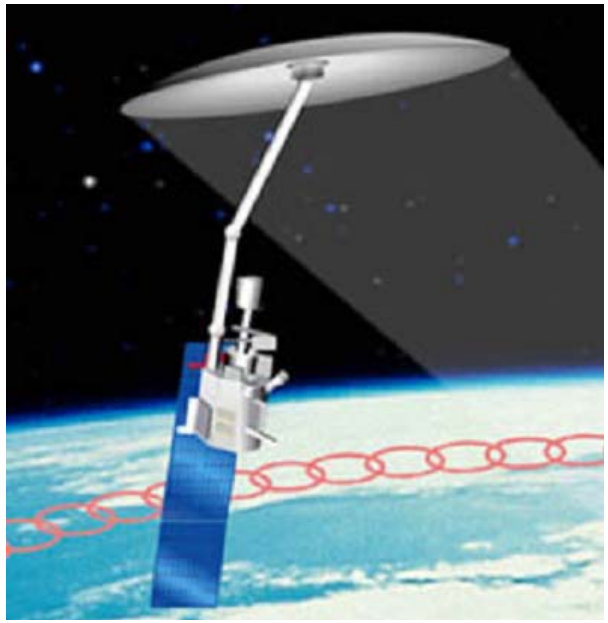




Motivation and Objective

Motivation: The future of passive satellite remote sensing of soil moisture lies in L-band sensors, led by SMOS and HYDROS which will be in space within 7 years. Some studies have been done, and others are ongoing, to assess performance of these sensors and the associated algorithms and how vegetation type and amount affect this performance.

Objective: To utilize L-band horizontally polarized brightness temperature data collected from an aircraft platform during the SMEX02 field experiment to evaluate the feasibility and limitations of soil moisture retrieval under conditions of significant vegetation biomass.



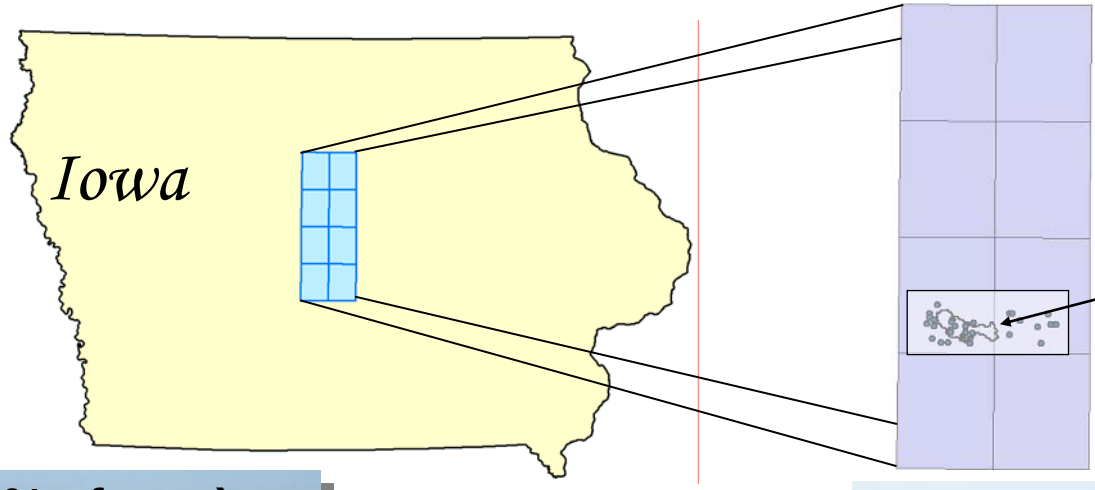
Soil Moisture Experiments in 2002 (SMEX02)

Location: Near Ames, Iowa **Time: 24 June – 13 July 2002**

Regional Area: ~5000 km^2

Walnut Creek Watershed Area: ~ 400 km^2

- **31 ground sampling sites for measuring gravimetric soil moisture, surface and soil temperatures (daily, AM), and vegetation properties (~weekly)**
- **Surface energy flux stations, lidar, and radiosonde measurements**
- **Aircraft microwave remote sensing data**



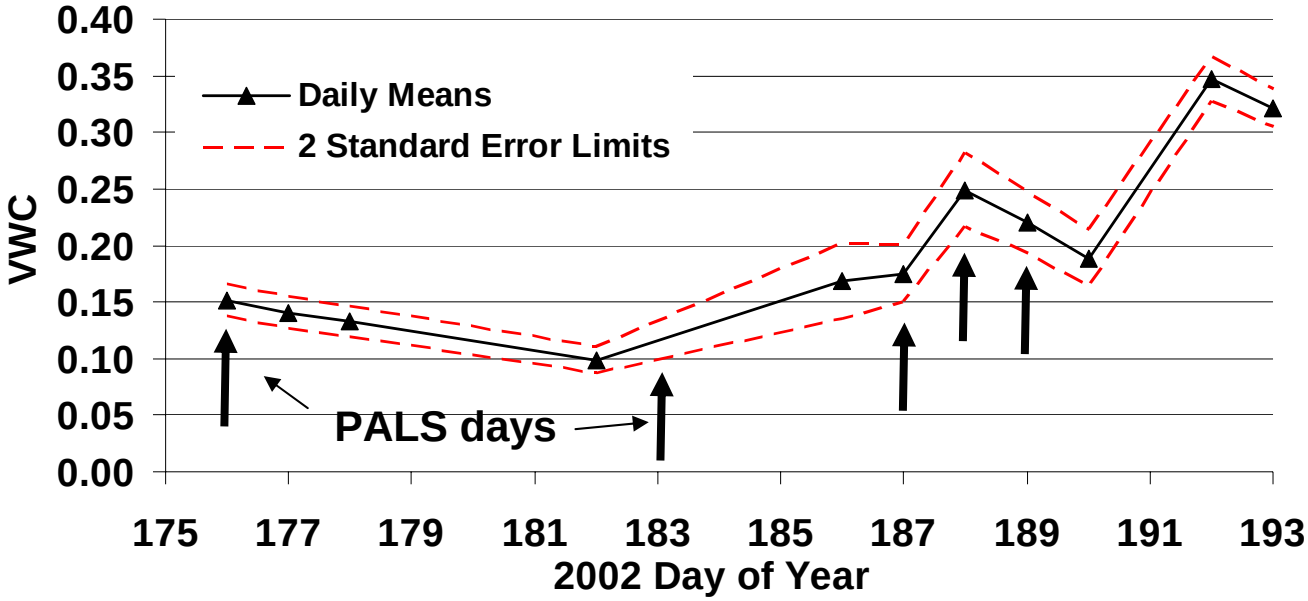
Passive and Active L- and S-band Radiometer (PALS)

NSF C-130

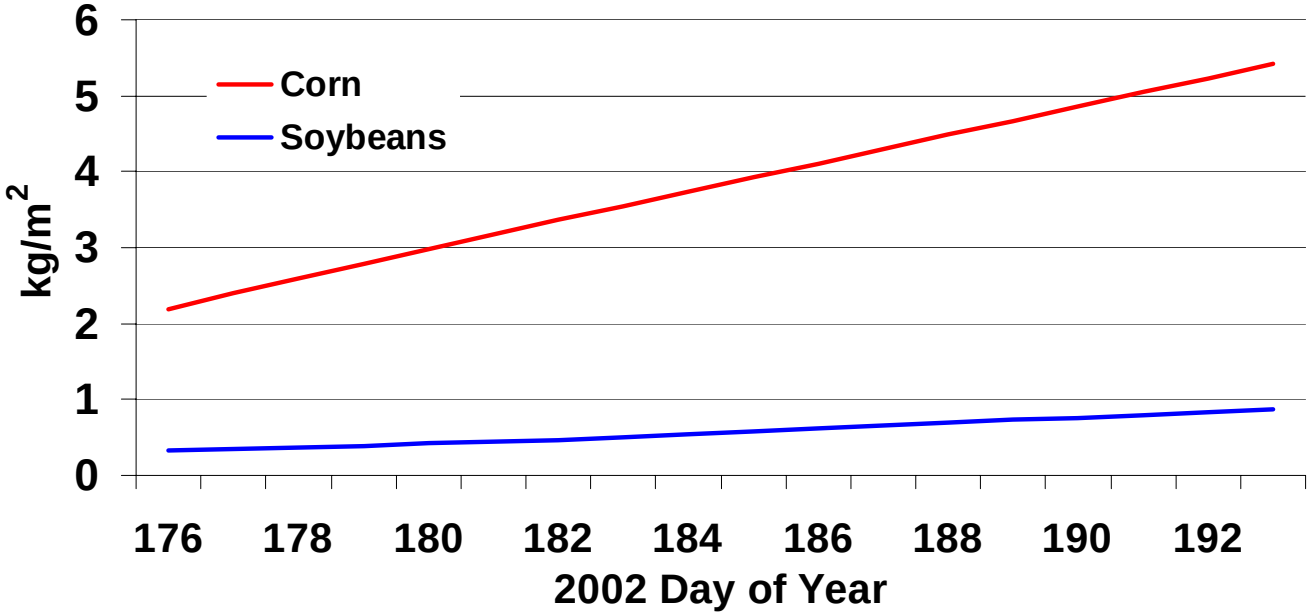
PALS Instrument System

Parameter	Radiometer	Radar
Frequency	**1.41**, 2.69 GHz	1.26, 3.25 GHz
Polarization	V and **H**	VV, VH, HH
Sensitivity	0.2 K	0.2 dB
Incidence angle	45°	45°
Spatial resolution	~ 400 m	~ 400 m

Daily Soil Moisture and Vegetation Water Content Field Site Means



Volumetric soil moisture based on gravimetric 'scoop' measurements

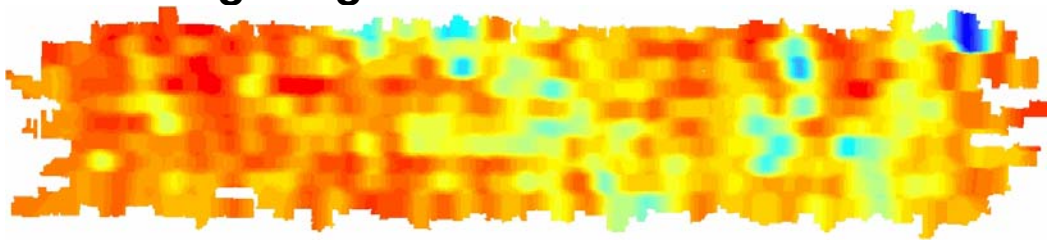


Vegetation water content based on *in situ* destructive sampling

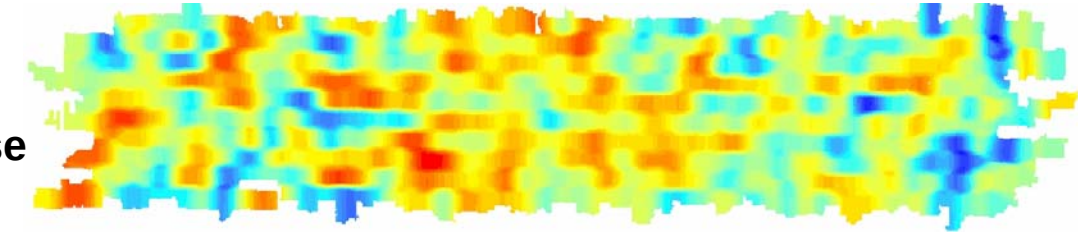
Spatial Interpolation vs. Optimal Deconvolution

Inverse Distance Weighting

July 2
Dry Case

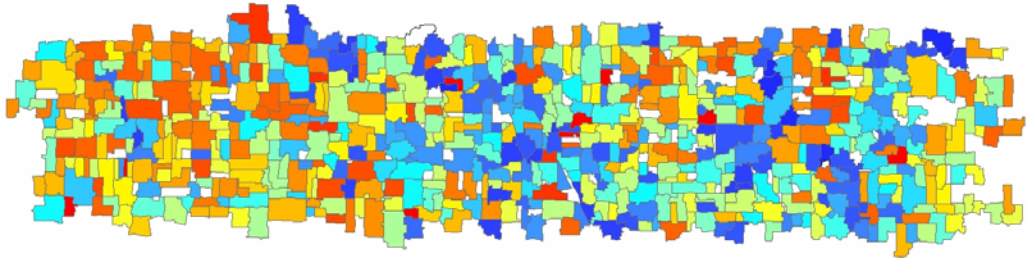


July 7
Wet Case

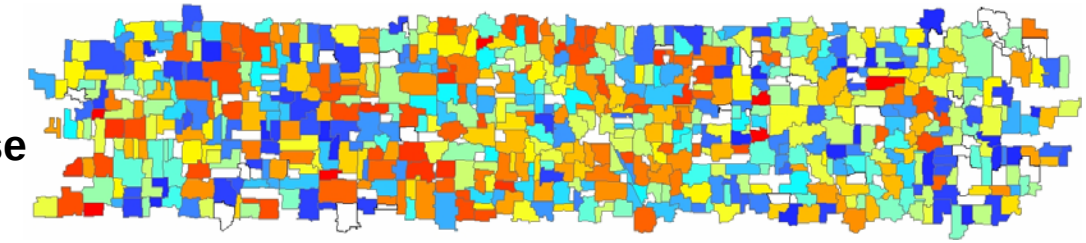


Optimal Deconvolution

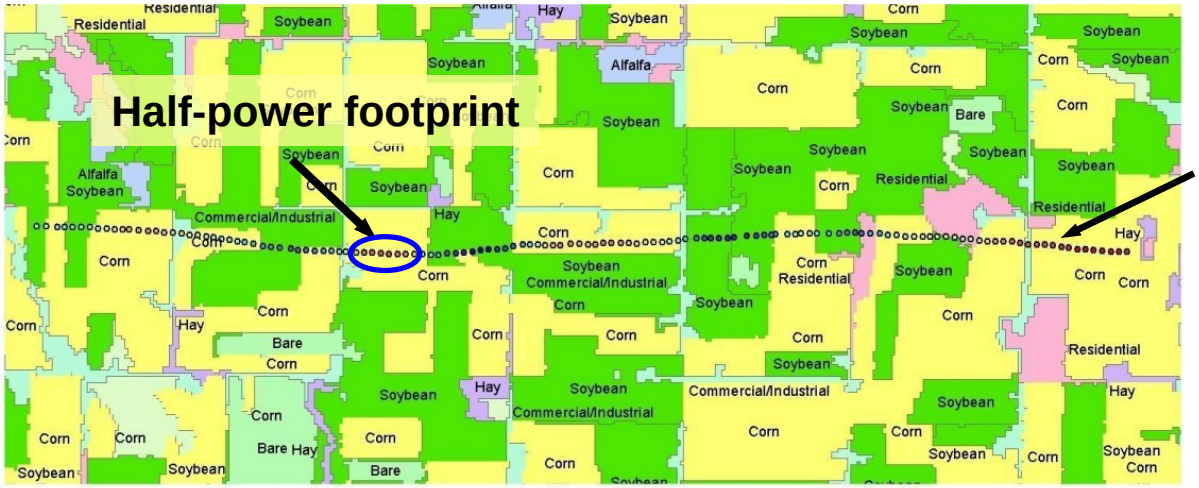
July 2
Dry Case

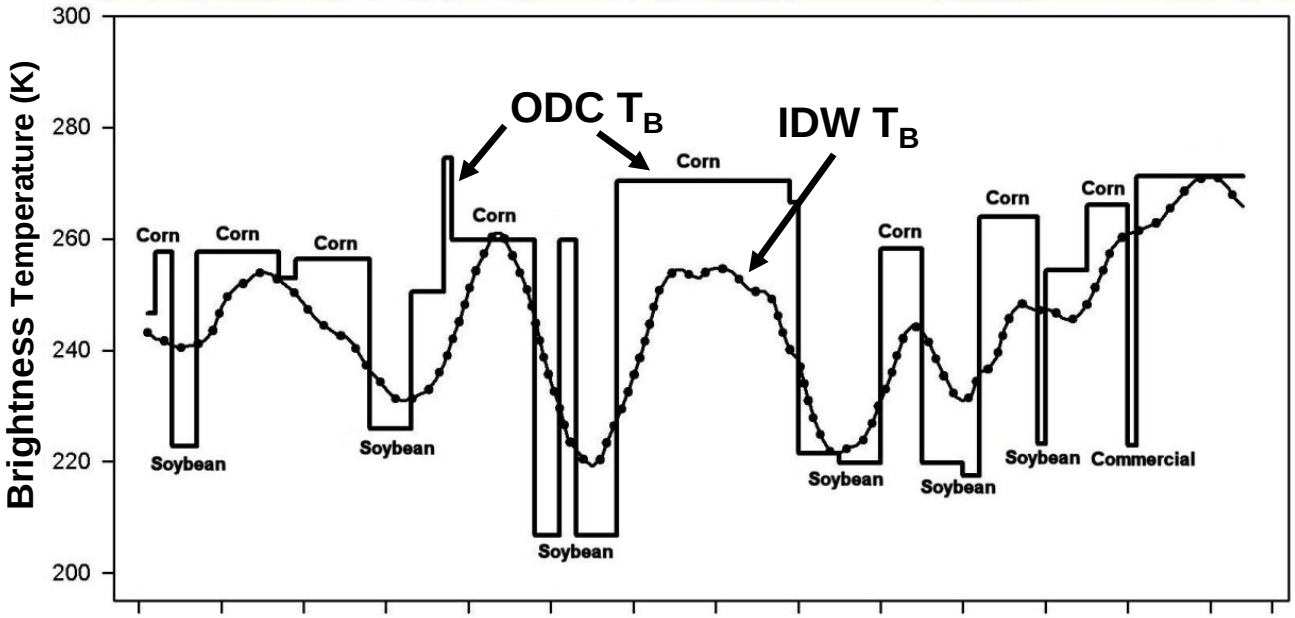


July 7
Wet Case



Comparison of Interpolation Methods





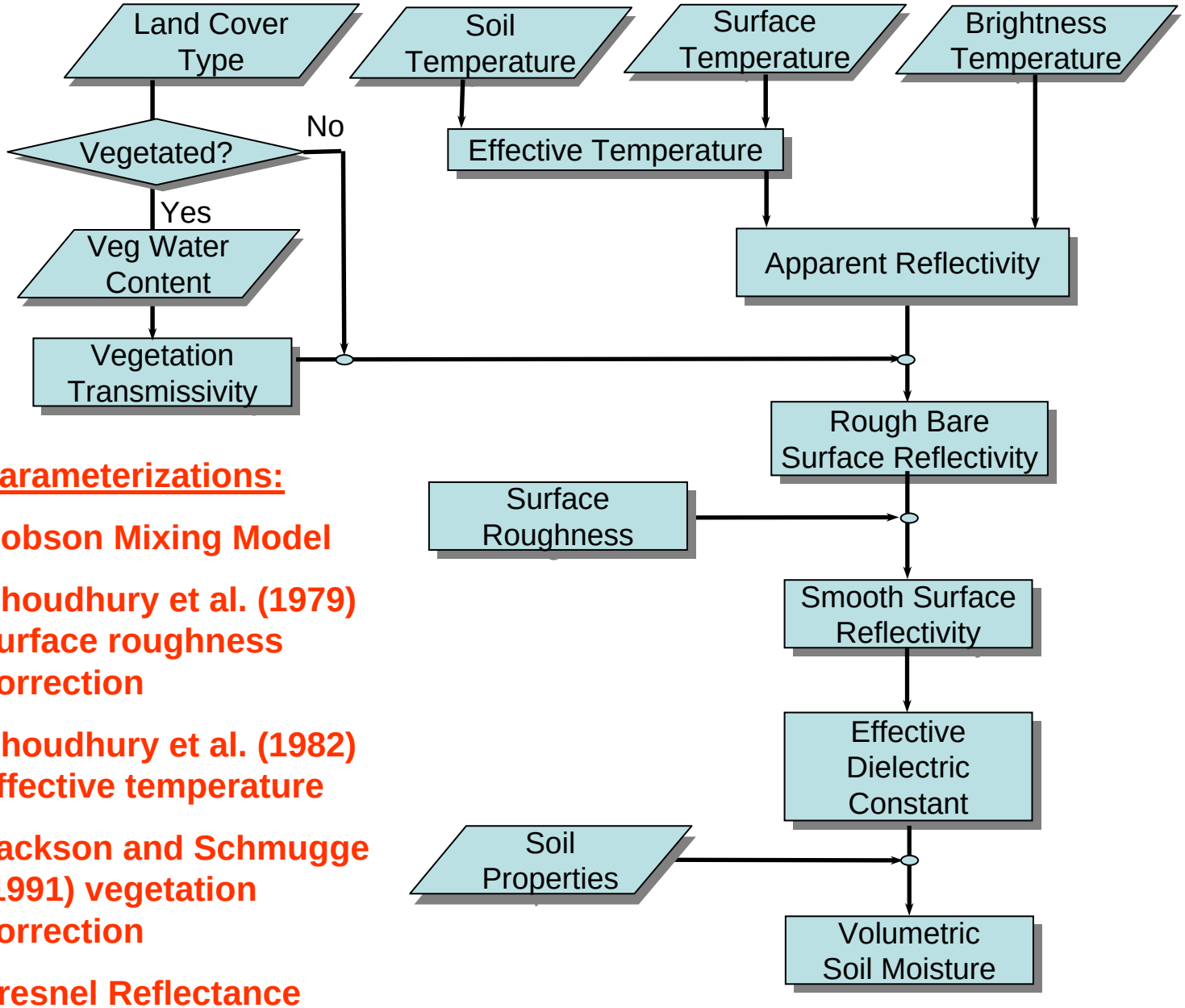
Discrete observations ('postings') along flight line

Inverse difference weighting (IDW) results in considerable smoothing, whereas optimal deconvolution (ODC) reconstructs sharp contrast between land cover types.

The IDW technique underestimates maximum and overestimates minimum T_B values.

'Pure postings' – those for which 95% of the energy comes from a single landcover segment.

Soil Moisture Retrieval Algorithm



Parameterizations:

Dobson Mixing Model

Choudhury et al. (1979) surface roughness correction

Choudhury et al. (1982) effective temperature

Jackson and Schmugge (1991) vegetation correction

Fresnel Reflectance

Experiment Design

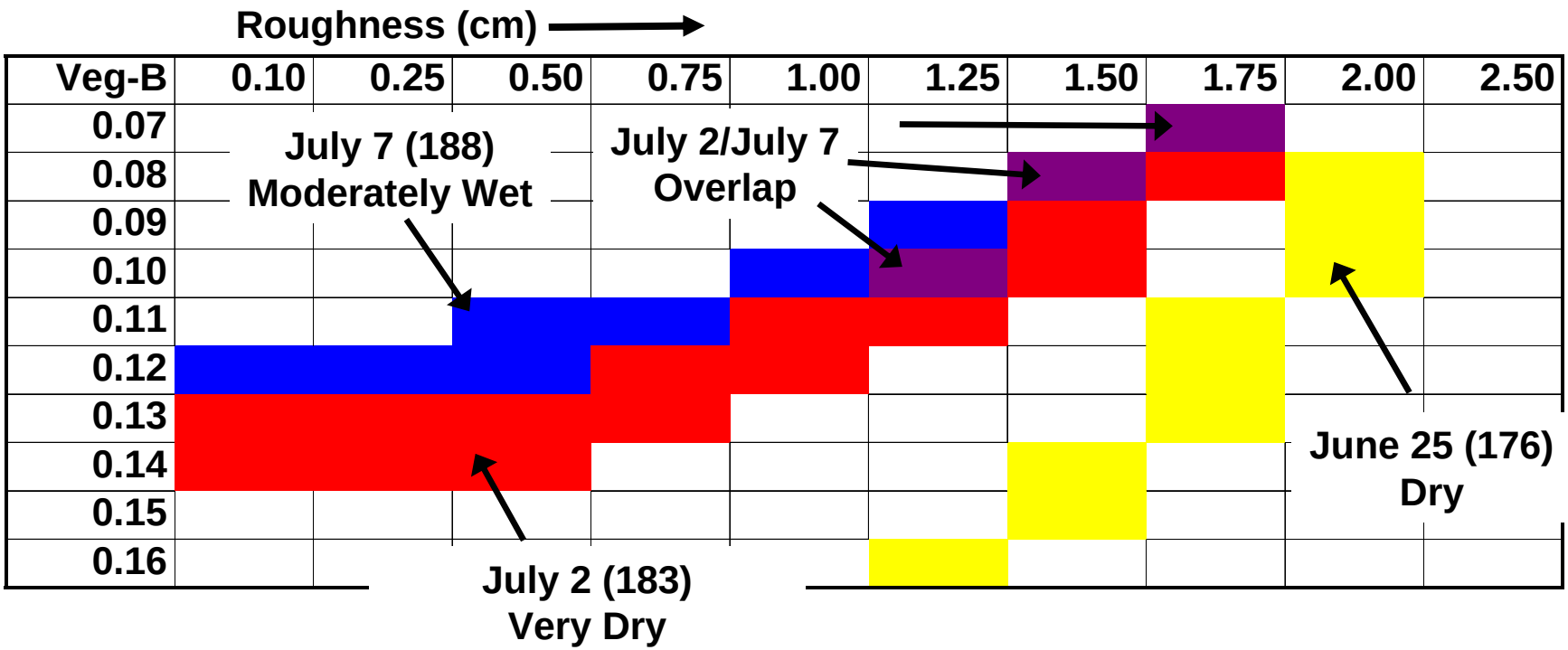
- **Retrieve:** Using input data characterizing corn and soybean conditions on each of 5 days, apply the retrieval algorithm for various points in a 3-dimensional parameter space (surface roughness, vegetation B parameter and single scattering albedo).
- **Validate:** Using observed soil moisture conditions for each crop and each day, determine the parameter combinations that yield soil moisture estimates within a defined error range about the observed mean.
- **Scale up:** Apply the retrieval algorithm for a parameter space representing composite corn/soybean conditions to simulate large-scale remote sensing in a mixed agricultural region.

Inputs representing mean conditions for given crop and day:

- Brightness temperature – Mean of PALS 'pure pixels'
- Surface and soil temperatures – Mean of observed temperatures
- Vegetation water content – Mean of values for given crop measured at field sites, interpolated between ~weekly measurements

Parameter Space Comparison – Corn

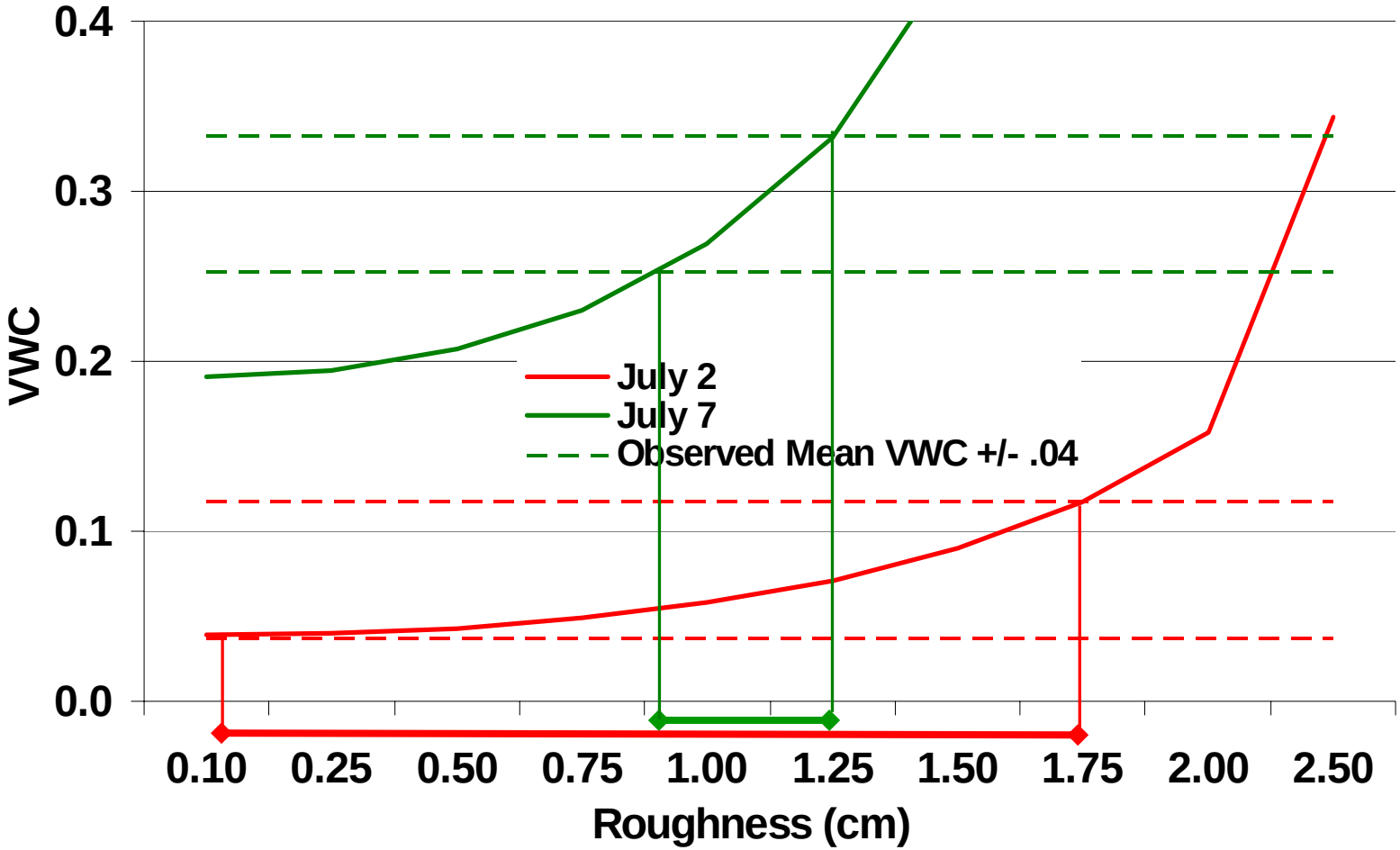
Single Scattering Albedo = 0.03



Shaded regions indicate combinations of surface roughness and vegetation B parameter that produce soil moisture values within 2 standard errors of the observed mean for the given day and crop. The observed mean is a weighted average of 0-1 cm and 0-6 cm measurements and is intended to represent the effective L-band emitting depth.

July 6 and July 8 are similar to July 7.

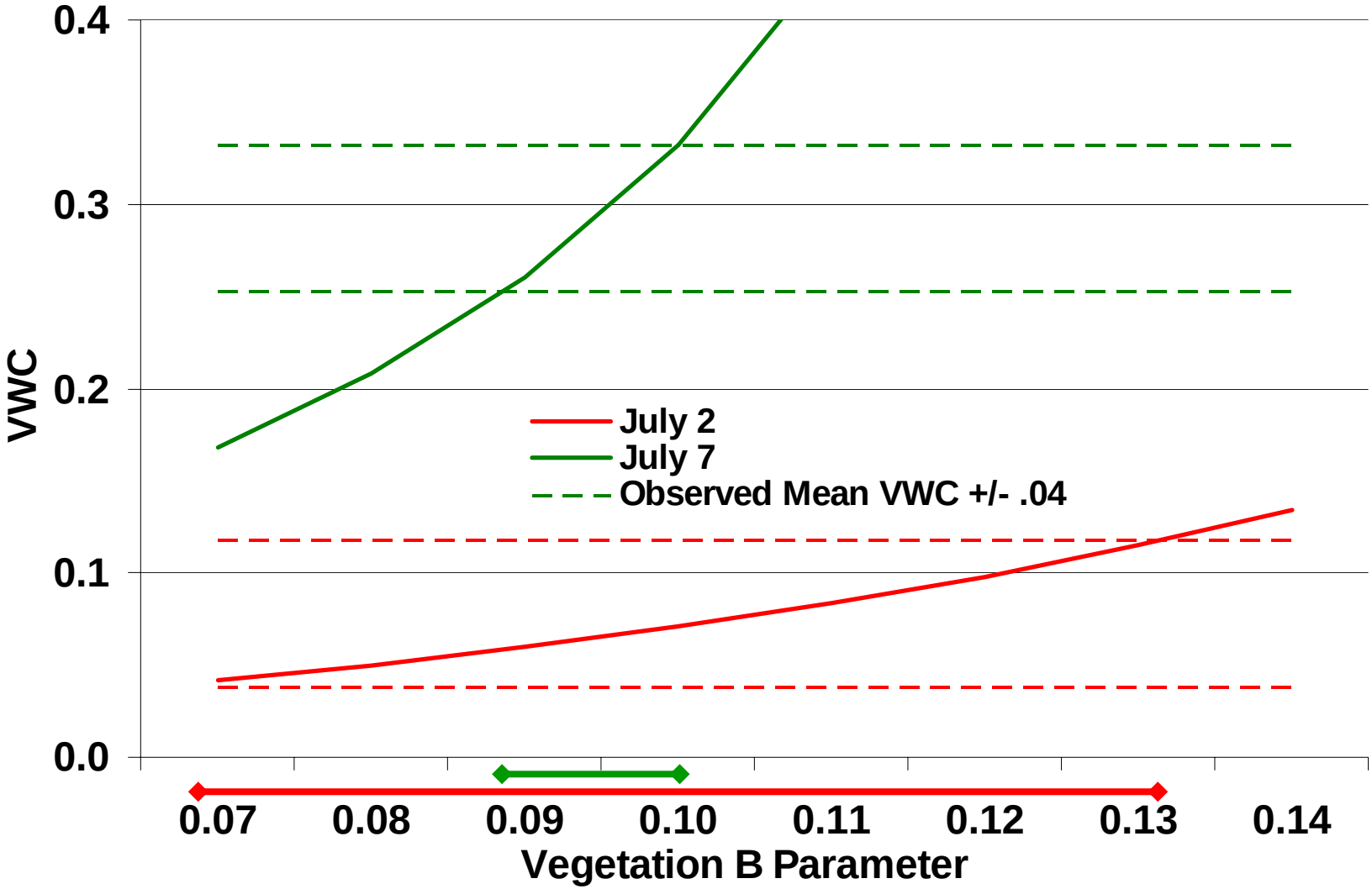
Sensitivity of Retrieved VWC to Surface Roughness
Corn; SS Albedo = .03, Vegetation B = 0.10



The design specification of HYDROS is to estimate volumetric soil moisture within ± .04 for vegetation water content below 5 kg/m^2. The range of roughness values for which retrieved soil moisture is within .04 of the observed values for each day is represented here by the horizontal bars.

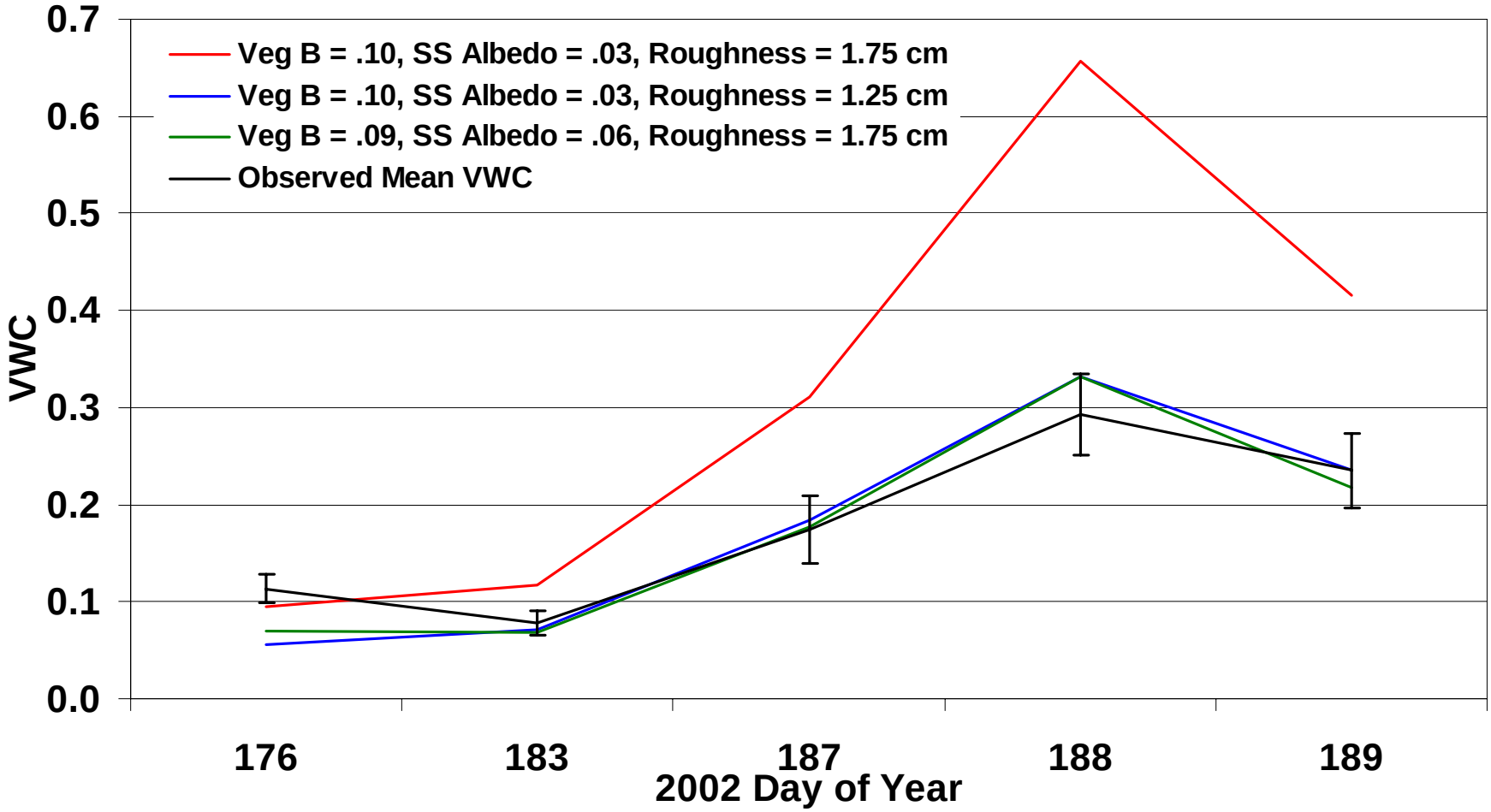
Sensitivity of Retrieved VWC to Vegetation

Corn; SS Albedo = .03, Roughness = 1.25 cm



The horizontal bars indicate the range of Vegetation B parameter values for which the retrieved soil moisture is within .04 VWC of the observed value.

Soil Moisture Retrievals Using Constant Parameters - Corn



The parameter vector that works reasonably well under dry conditions performs poorly under wet conditions, and vice versa.

Parameter Space Comparison – Soybeans

Single Scattering Albedo = 0.0

Roughness (cm) →

Veg-B	0.10	0.25	0.50	0.75	1.00	1.25	1.50	1.75	2.00	2.50
0.07										
0.08										
0.09										
0.10										
0.11										
0.12										
0.13										
0.14										
0.15										
0.16										

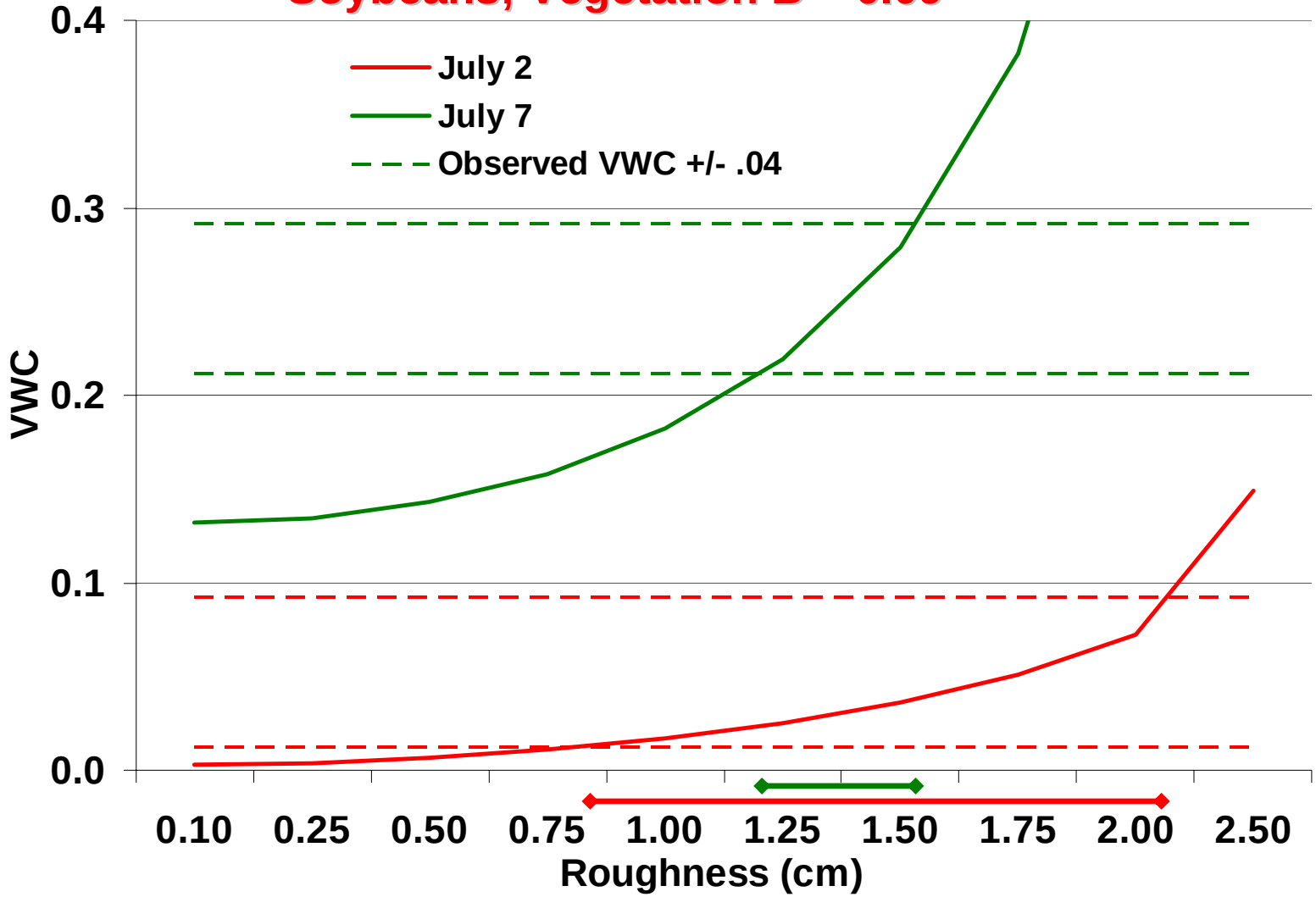
July 7 (188)
Moderately Wet

July 2 (183)
Very Dry

June 25 (176)
Dry

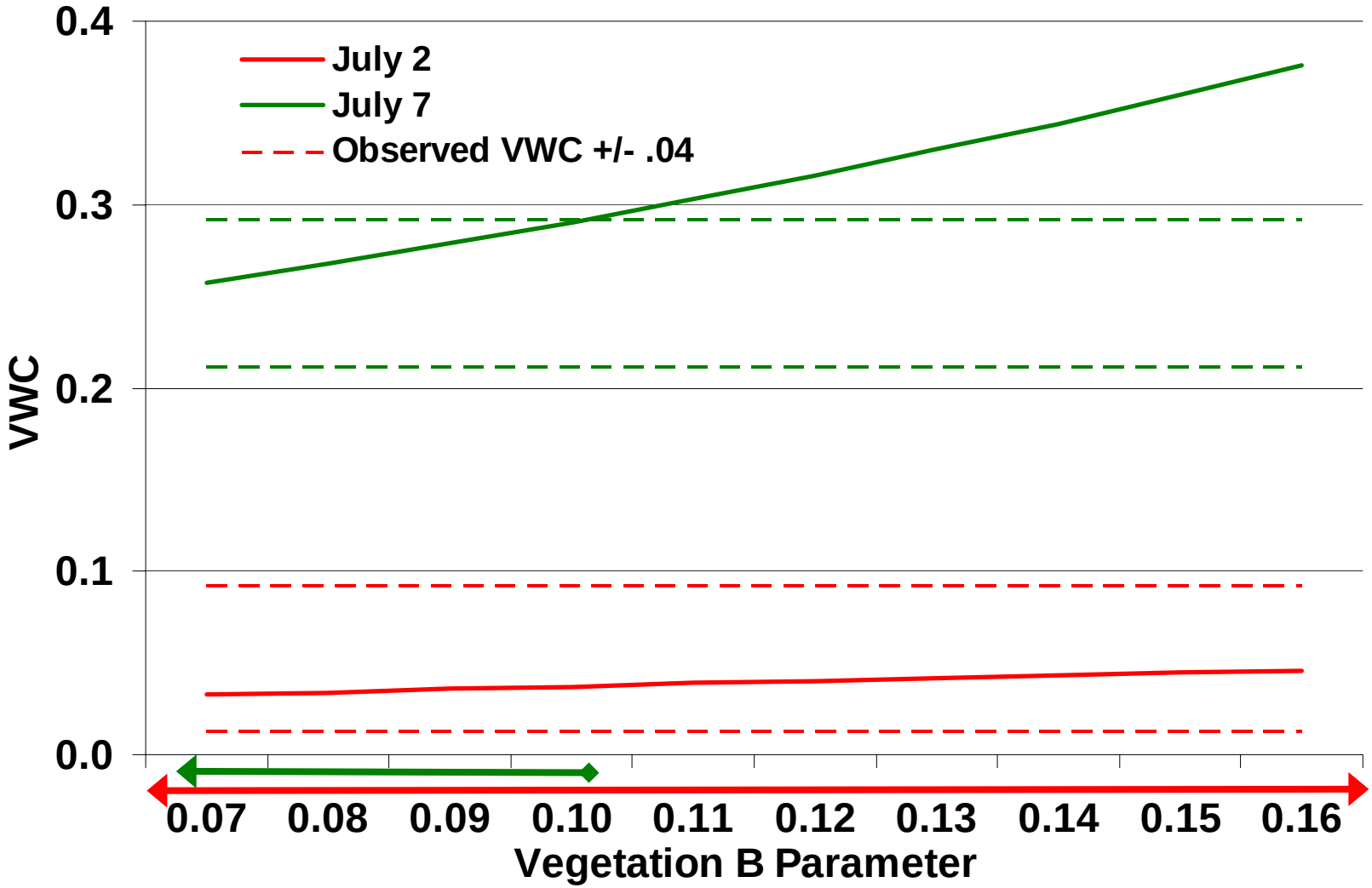
Sensitivity of Retrieved VWC to Surface Roughness

Soybeans; Vegetation B = 0.09

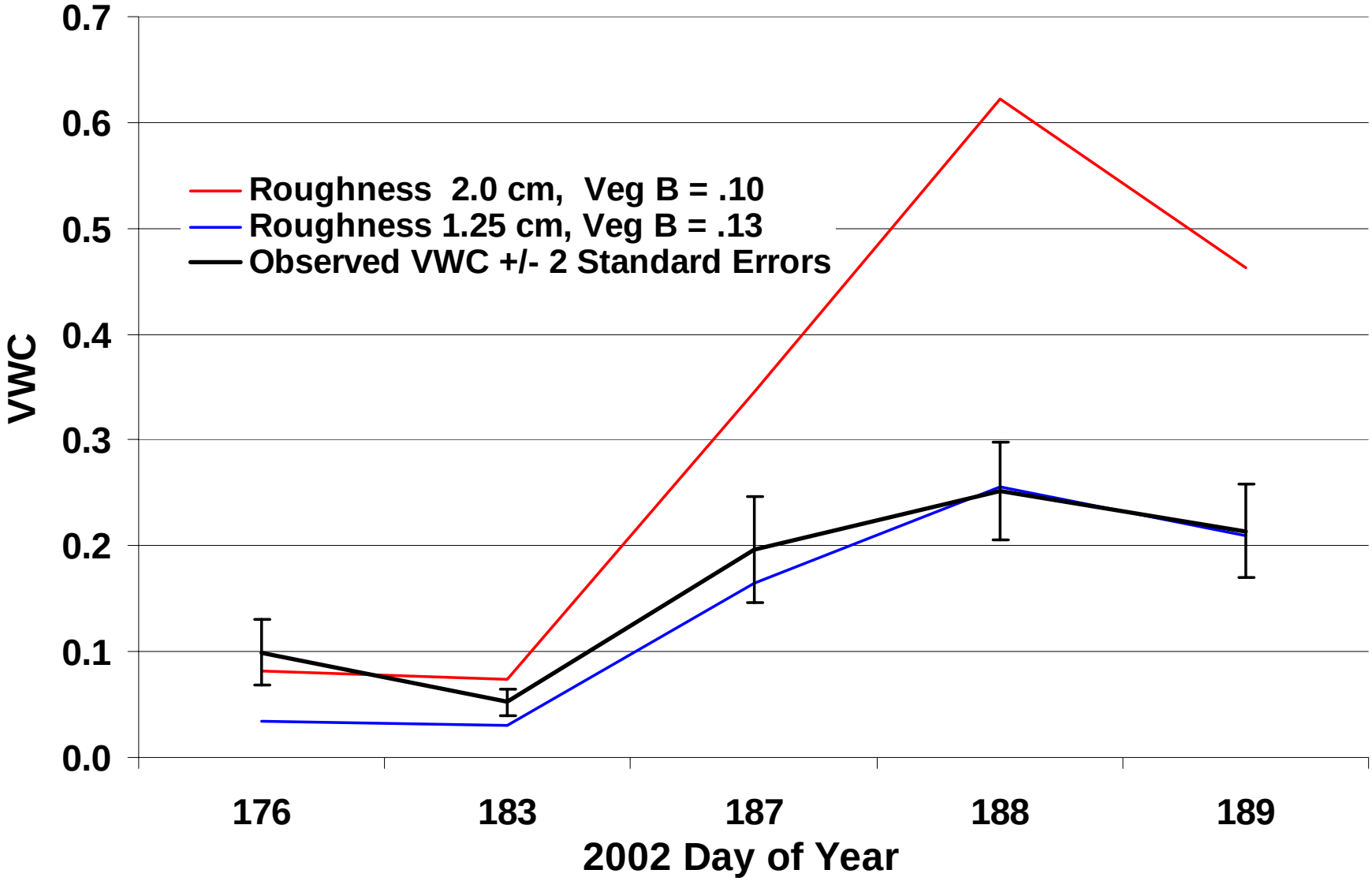


Sensitivity of Retrieved VWC to Vegetation

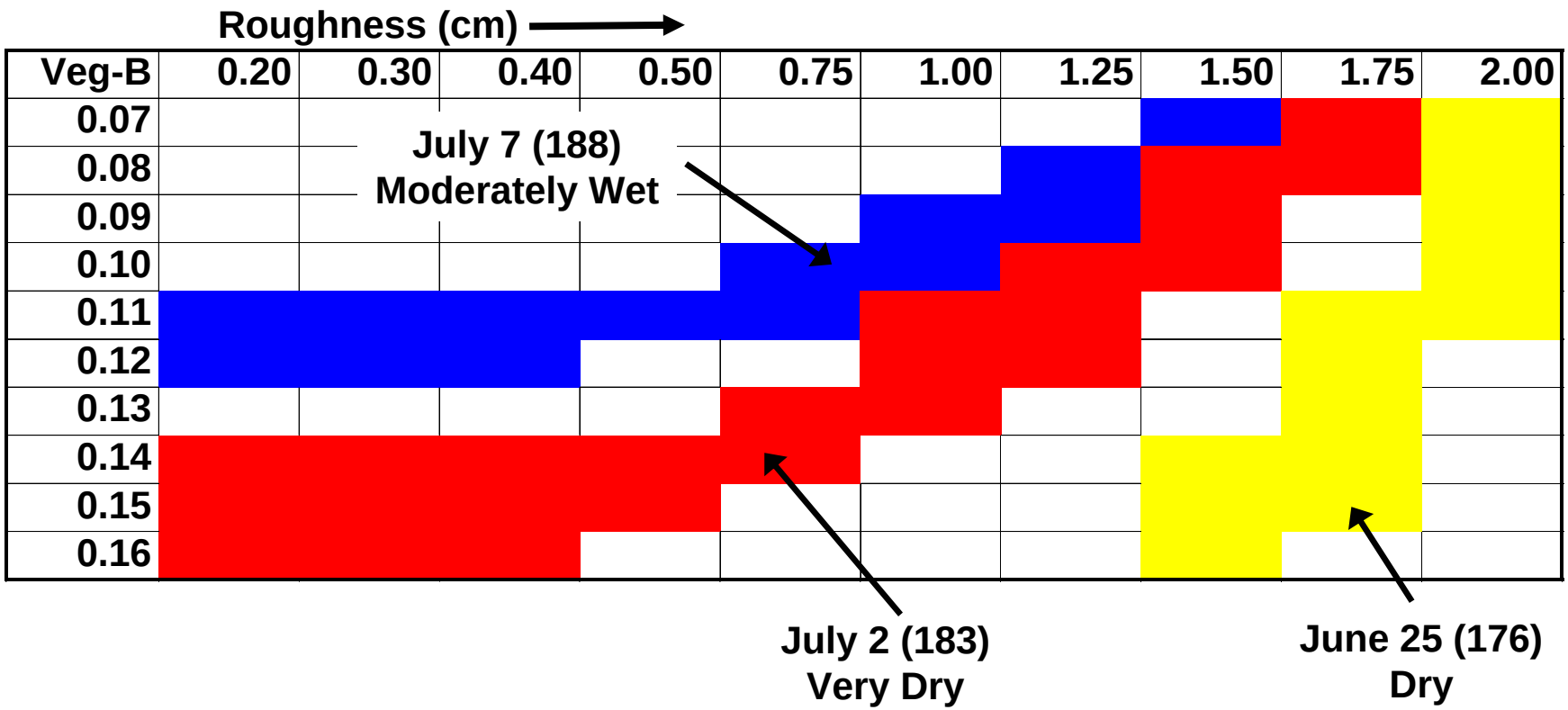
Soybeans; Roughness = 1.5 cm



Soil Moisture Retrievals Using Constant Parameters - Soybeans

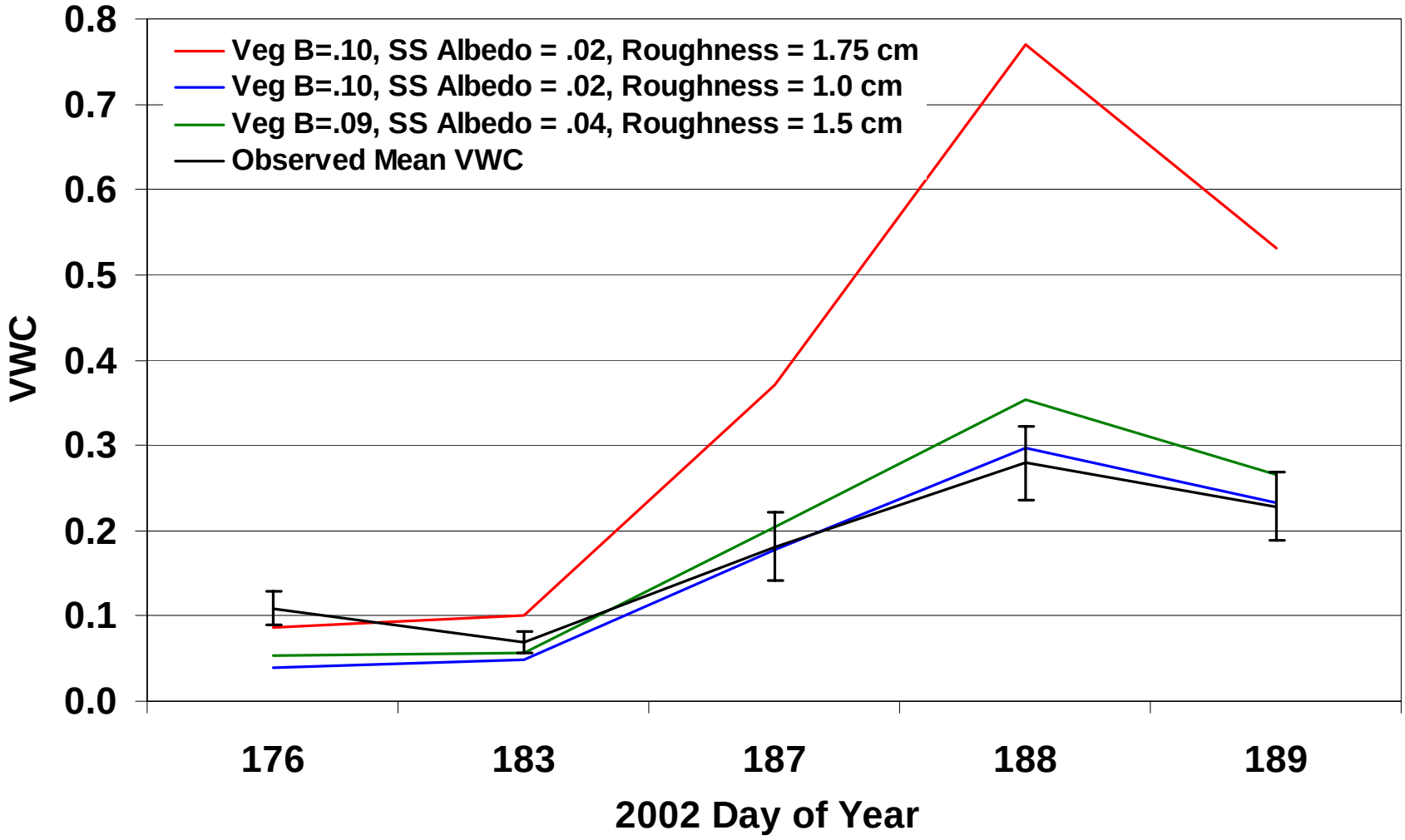


Parameter Space Comparison
Corn/Soybean Composite
Single Scattering Albedo = 0.02

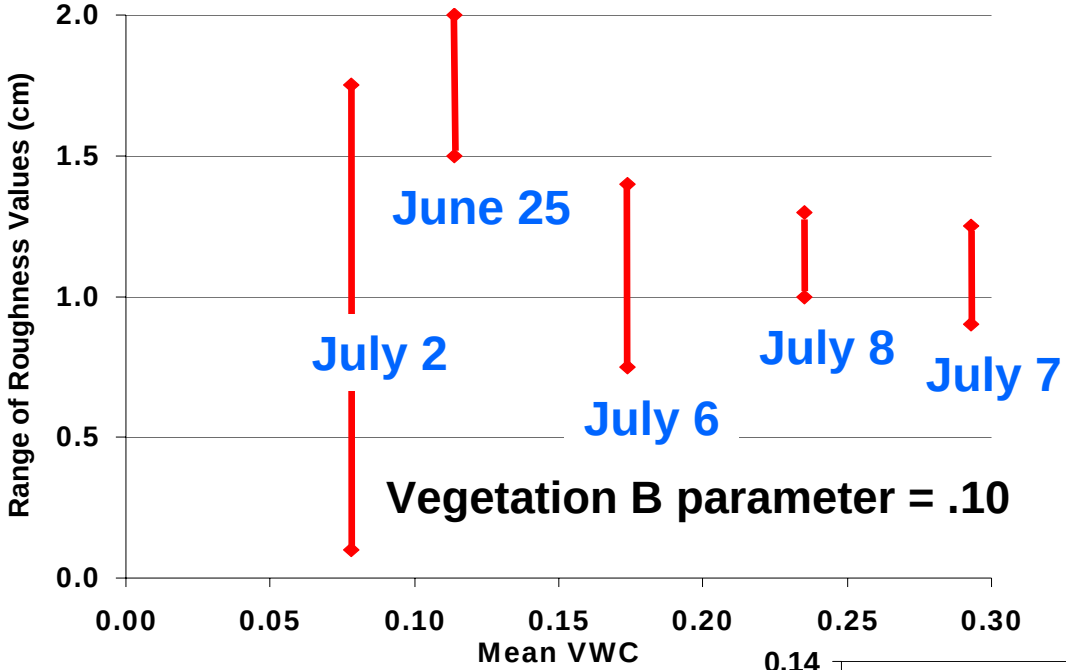


Inputs for corn/soybean composite conditions were computed as weighted averages from the corn and soybean values.
This simulates a satellite footprint sampling the entire study area.

Soil Moisture Retrievals Using Constant Parameters – Corn/Soybean Composite



Acceptable Parameter Ranges as Function of Soil Moisture - Corn

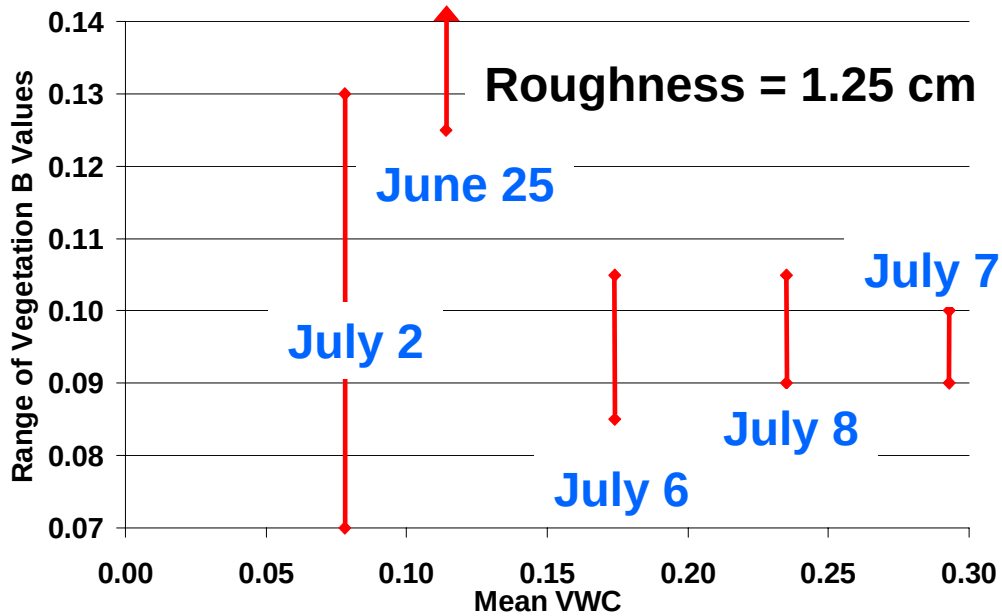


Illustrations of the range of parameter values that produce retrievals within .04 of the observed VWC.

Single scattering albedo = .03.

Due to increasing sensitivity, valid parameter ranges narrow with increasing VWC.

June 25 is anomalous …?



Conclusions

- Using a single-frequency, single-polarization soil moisture retrieval algorithm, there is no parameter vector (surface roughness, vegetation B parameter, single scattering albedo) that produces soil moisture values for aggregate corn and soybean fields that are within two standard errors of the observed values for each of the five days for which complete PALS L-band coverage is available.

- For three days that are relatively wet, excellent retrievals were obtained with a single parameter vector. For each of the two dry days, different sets of parameter vectors were required to produce acceptable results.

- The inability to obtain accurate soil moisture retrievals with a single parameter vector does not appear to be related to errors in brightness temperatures.

- Under wet conditions, retrieved soil moisture for corn is seen to be very sensitive to all three parameters. For dry conditions, sensitivity is lower, but not negligible.

Conclusions

• For soybeans, retrieved soil moisture is extremely sensitive to surface roughness but not very sensitive to the B parameter. Again, sensitivity is highest under wet conditions.

• Parameter sensitivities for large-scale corn/soybean composite conditions are very similar to those for corn.

• For both corn and soybeans, higher surface roughness values are indicated on the dry days than for the wet days. This is consistent with some previous studies, but the physical explanation is still speculative – 'dielectric roughness', surface cracking …?

• To meet the HYDROS design specification of ± .04 VWC for moderately wet soils in agricultural areas, the required accuracies in parameters seem to be approximately:

± 15% for surface roughness
± 5% for vegetation B parameter (or for vegetation water content)
± .03 for single scattering albedo