Land cover-based Optimal Deconvolution of Microwave Brightness Temperatures for Improved Soil Moisture Retrieval

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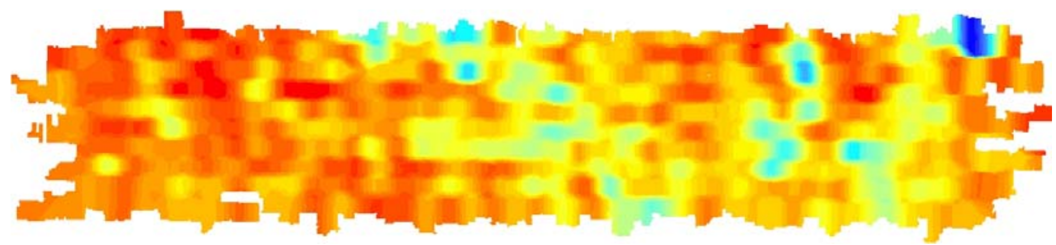
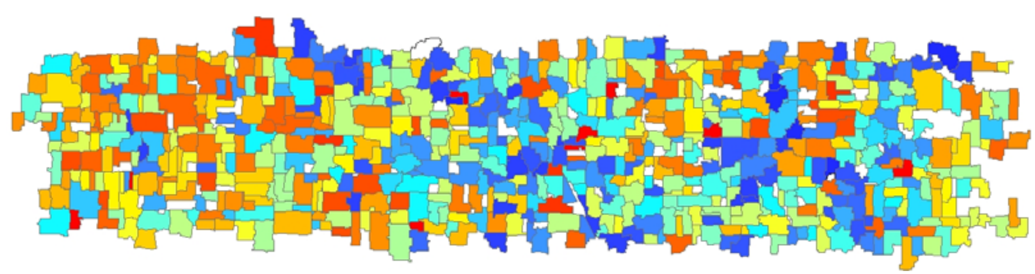




Context

- Microwave sensors measure brightness temperatures, which can be converted into soil moisture estimates.

- Several remote sensors measure brightness temperatures to aid soil moisture estimation. Some of those sensors are airborne and a select few are space based.

- Soil moisture is a highly heterogeneous property, highly dependent on physical properties of soil, as well as on the scale at which the measurements are made. Therefore validation of the soil moisture retrieval techniques is not straightforward.

- To address the scale issues, the validation efforts involve coincident measurements of soil moisture at a variety of scales including in-situ measurements, as well as airborne and space based estimation of brightness temperatures.

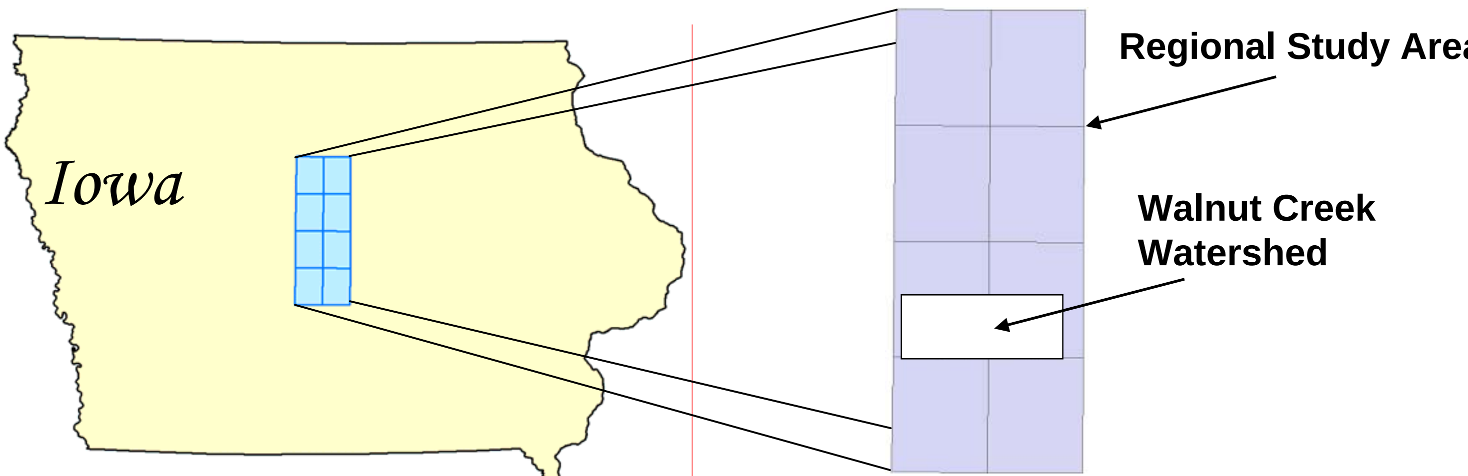
- In this presentation, we will discuss some of the microwave remotely sensed data from a airborne sensor during Soil Moisture Experiments 2002 (SMEX02).

Soil Moisture Experiments 2002 (SMEX02)

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

Walnut Creek Watershed Area: ~ 400 km²

- 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
    - L and S bands (V and H pols) on PALS
    - C and X bands (V and H pols) on PSR




Corn (50% of area)


Soybeans (40% of area)

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

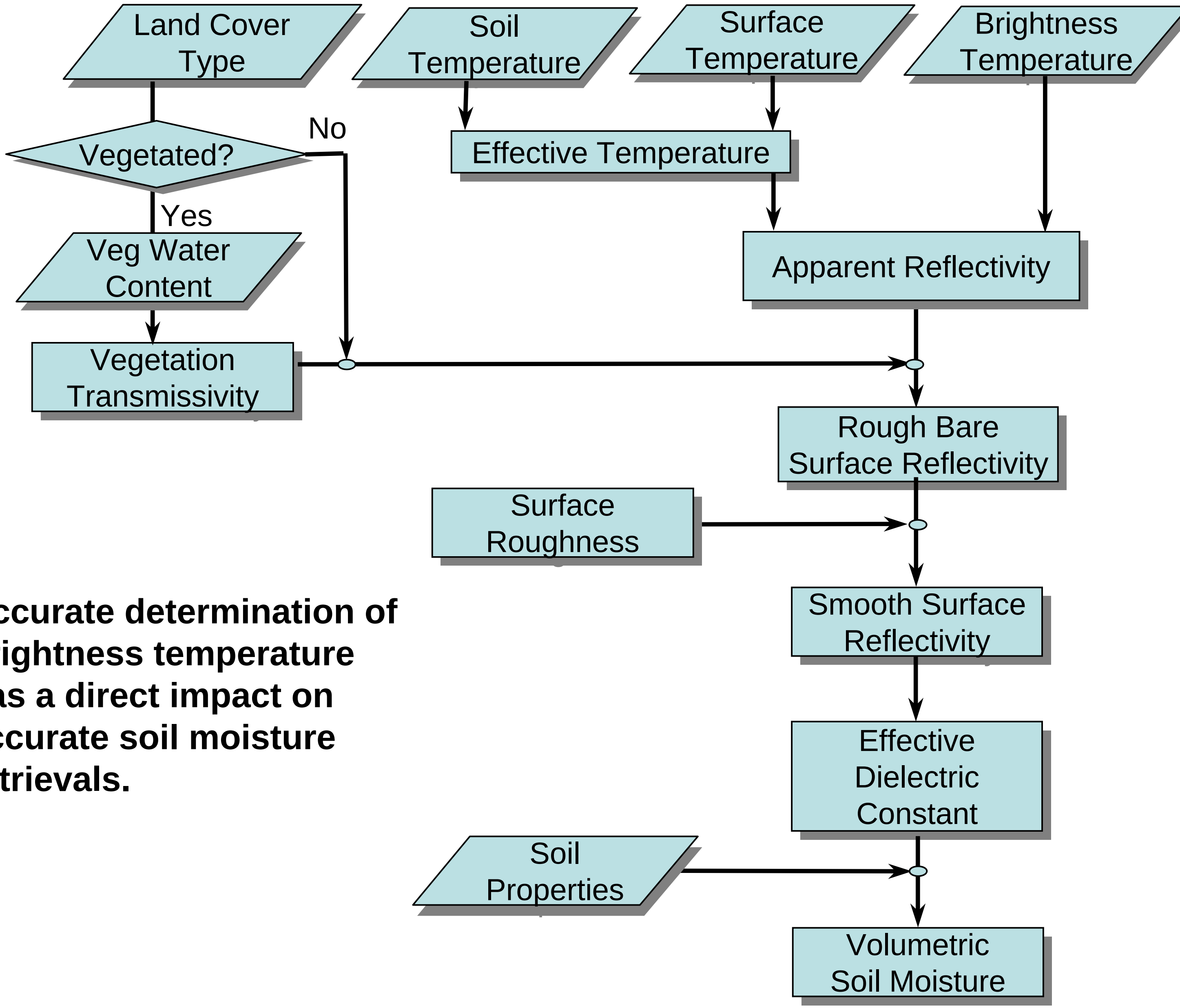
NSF C-130

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^o	45^o
Spatial resolution	~ 400 m	~ 400 m

PALS Instrument System

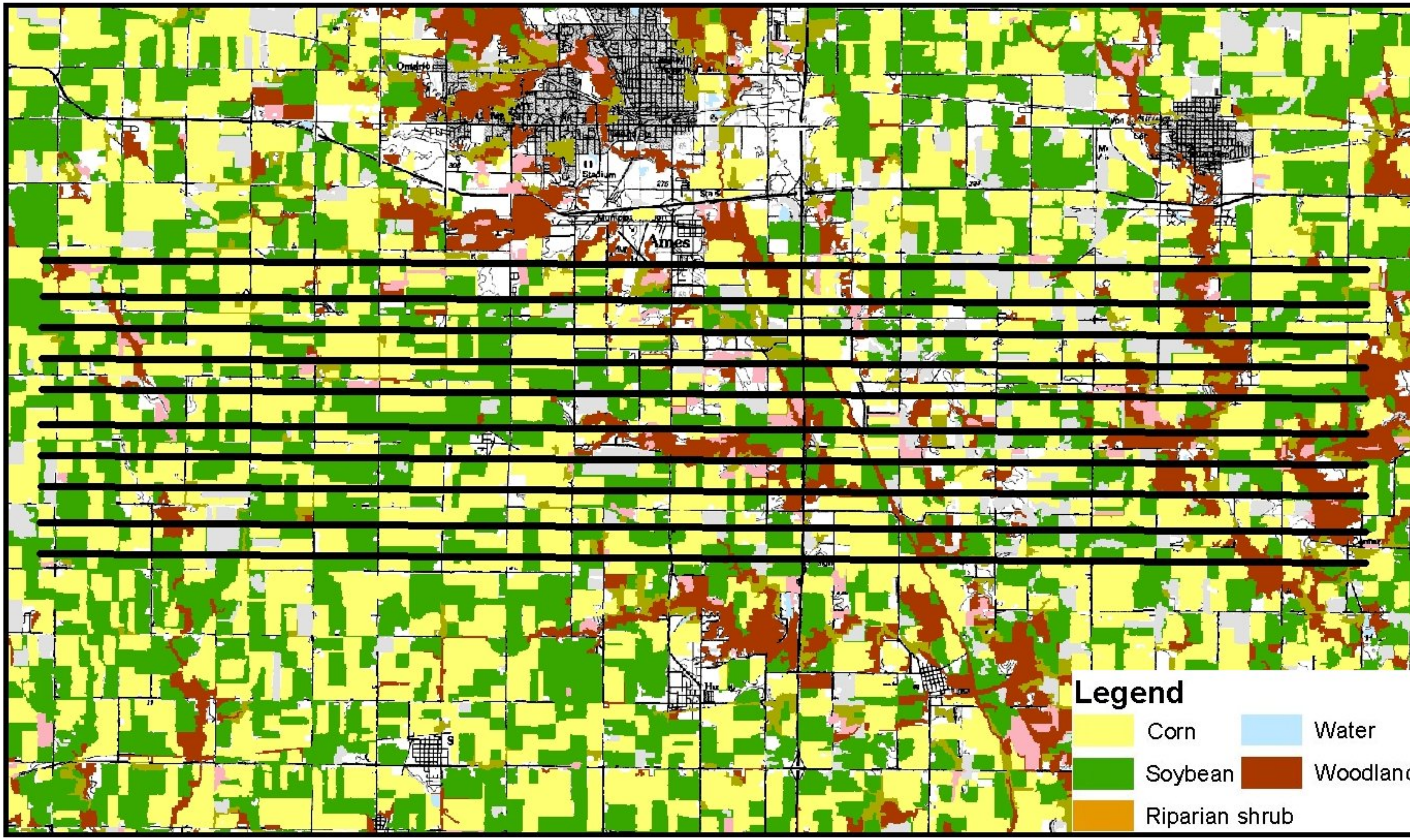
Microwave brightness temperatures measured by the PALS sensor are used in estimating the soil moisture.

Soil Moisture Retrieval Algorithm



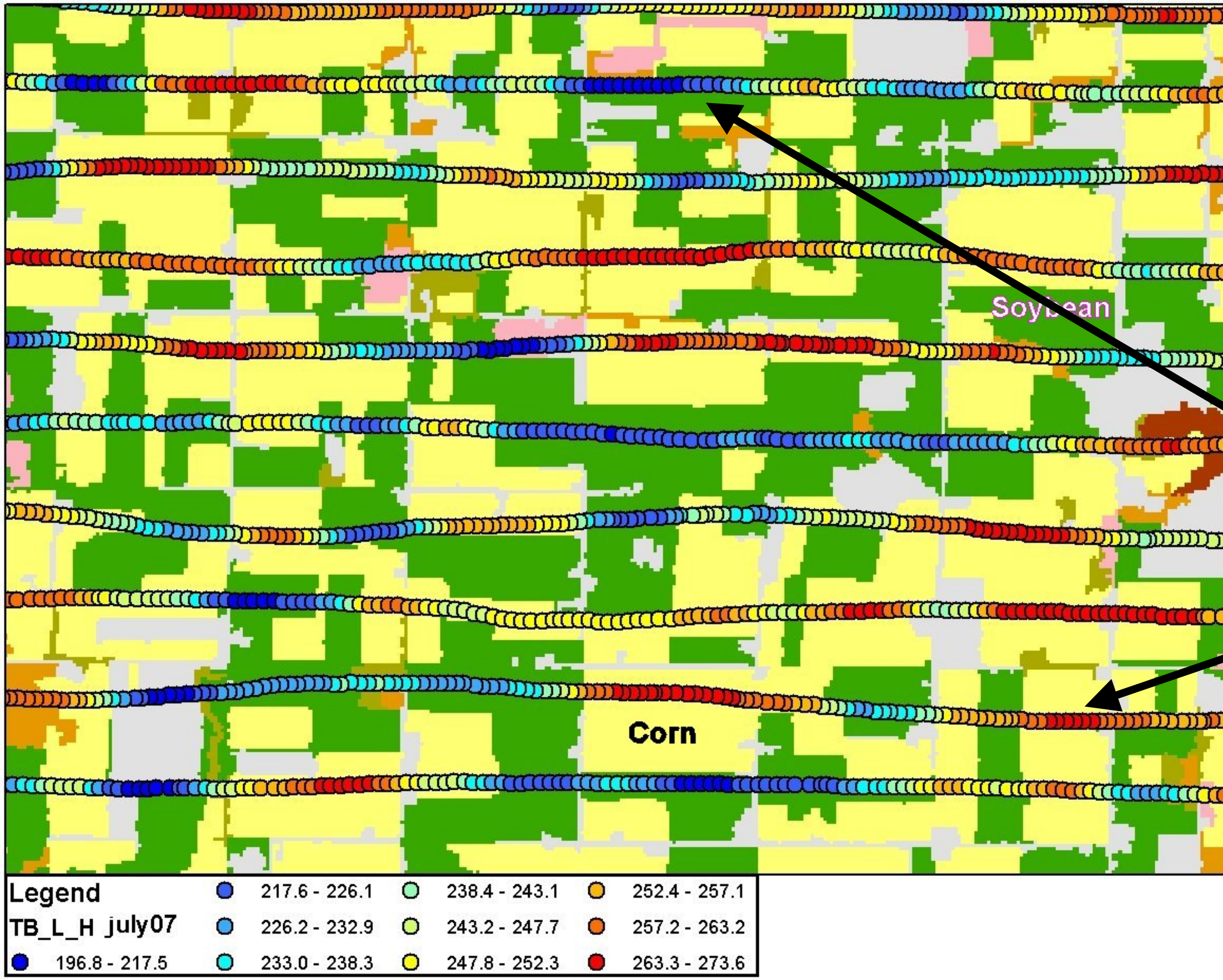
Accurate determination of brightness temperature has a direct impact on accurate soil moisture retrievals.

Land Cover Classification



Segmentation based land cover classification using Landsat Thematic Mapper data. Black lines are PALS flight lines.

PALS Observations



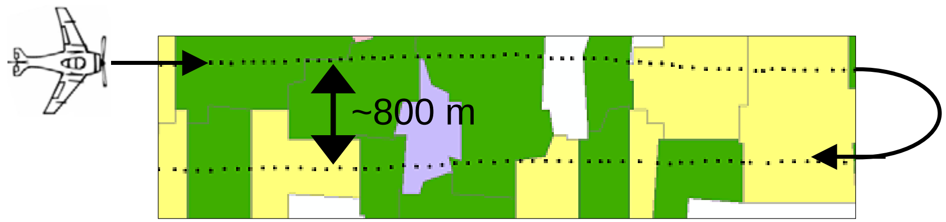
- Corn vegetation water content is significantly greater than soybeans. Consequently, brightness temperature of corn (yellow) is significantly greater than that of soybeans (green).
- Observations indicate the variations clearly, lower brightness temperature (shown as blue) when the sensor flies over large soybean fields, and higher brightness temperature (red) when the sensor flies over corn fields.
- However, the transitions are not clearly marked as field boundaries, even when the crops are clearly confined within the field boundaries.
- Averaging the observations for each field introduce a bias, depending on the crops in the adjacent fields.

- PALS radiometer measures microwave brightness temperatures. These measurements are called Postings.
- Agricultural fields are called Segments.

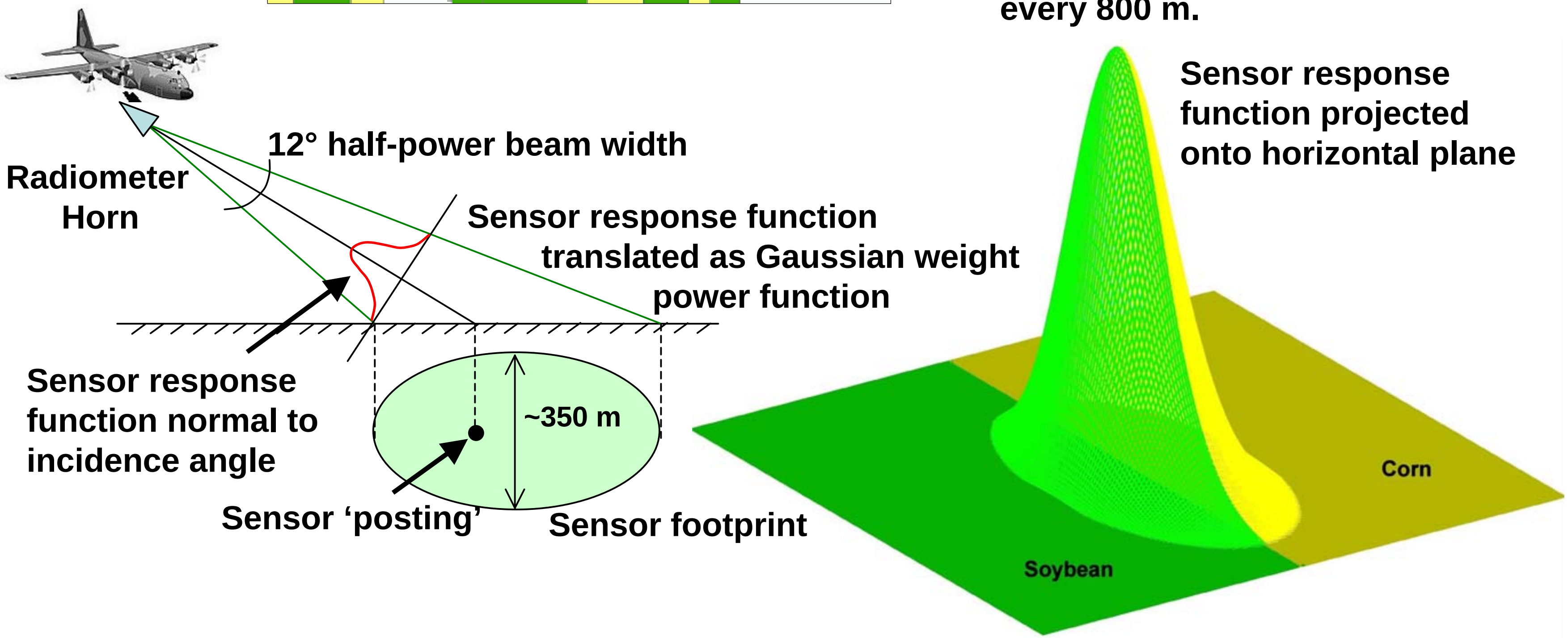
Conventional Interpolation Techniques

- There are several methods available to interpolate the point observations to field scale grids. The simplest being the averaging of all the observations (called postings here).
- The most commonly used techniques include Inverse Distance Weighted (IDW) and Krigging. In each, weights for each observation are based on the spatial distance from the observation to each grid element.
- These techniques compute the spatial interpolation independent of contextual information, such as the landcover associated with the observations. The result is a spatial dataset with a bias, the magnitude of which is related to the proximity to the nearby different field (and different brightness temperatures).

Optimal Deconvolution of Remotely-Sensed Brightness Temperature



Airplane travels along flightlines making brightness temperature observations about every 100 m. Flight lines are spaced about every 800 m.



Microwave sensors "convolve" energy received from heterogeneous surfaces. Therefore, it is important to simulate these surfaces to quantify the response from each of the underlying contributing features.

Nuts and Bolts of Optimal Deconvolution

Sensor response function can be treated as a Gaussian surface. The power at distance r from the sensor on a beam-normal plane can be computed as

$$\mathrm{P(r)} = \frac{1}{\sigma\sqrt{2\pi}} e^{\frac{-r^2}{2\sigma^2}}$$

- In other words, we treat each PALS observation as a surface with weights varying as a gaussian function.
- Sigma is the only parameter needed to estimate this surface. Knowing the sensor 3-dB beam width (angle at which the power drops by 3 dB or approximately 50%), sensor altitude and look angle, we can solve for sigma.
- We can then project the Gaussian surface on the horizontal ground, and construct an ellipse which yields 50% of the observed energy. In this study, we have expanded the ellipse to account for 95% of the energy received at the sensor.

Nuts and Bolts of Optimal Deconvolution Continued …

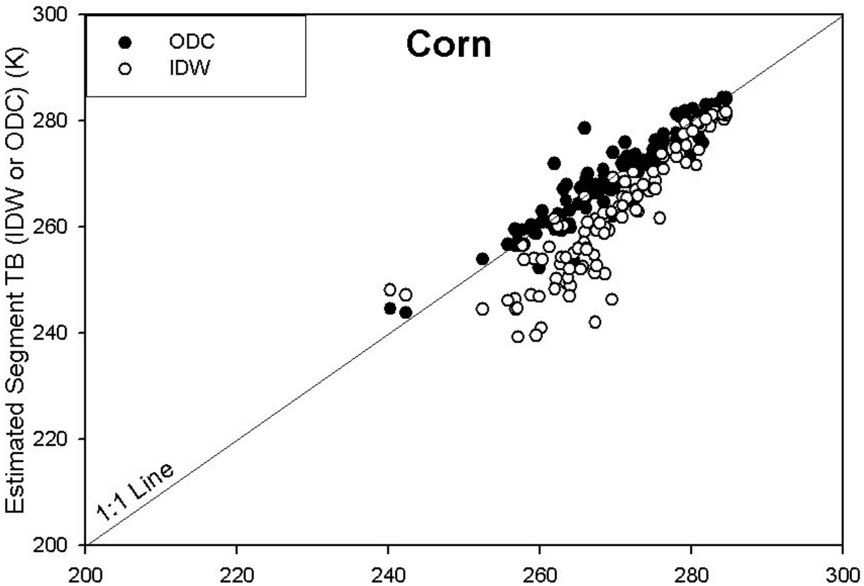
- **When these elliptical surfaces are spread over the agricultural fields (segments), we can compute the contribution from each underlying segment to the volume of each surface.**
- **Knowing the contribution of each segment fraction (Gaussian fraction), we can "reconstruct" the PALS observation. Our attempt is to make these reconstructed estimates as close to observations as possible.**
- **Since several surfaces cover the same agricultural fields (segments), but with varying contributions, the system is over-sampled. We utilize the over-sampling to minimize the difference in reconstructed and observed postings.**
- **The solution of the optimization is the brightness temperatures of the agricultural fields (segments).**

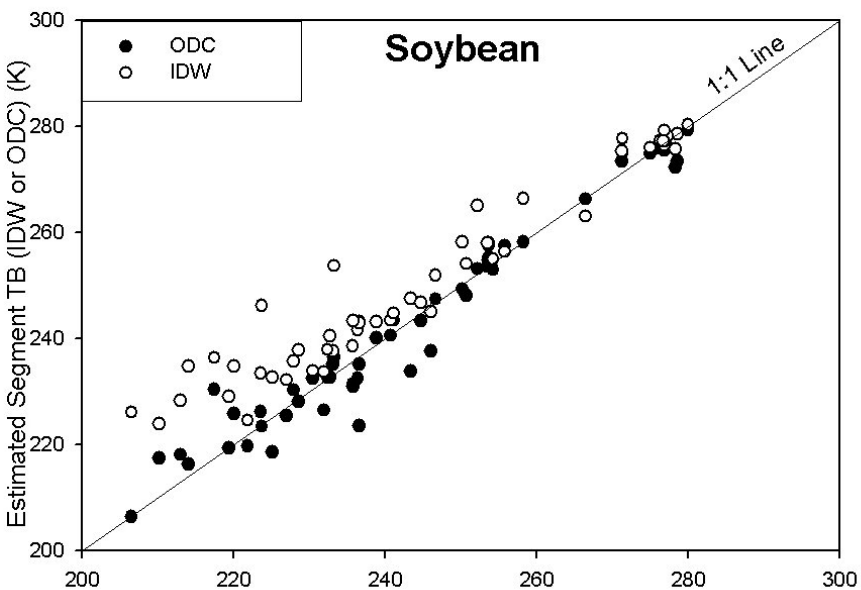
$$\text{Minimize} \quad \sum_{\text{All PALS postings}} \left| \text{ODC Reconstructed posting TB} - \text{observed posting TB} \right|$$

Where

$$\text{ODC Reconstructed posting TB} = \sum_{\substack{\text{All underlying} \\ \text{landcoversegments}}} (\text{Gaussian fraction}) * (\text{Segment TB})$$

Pure Posting Analysis





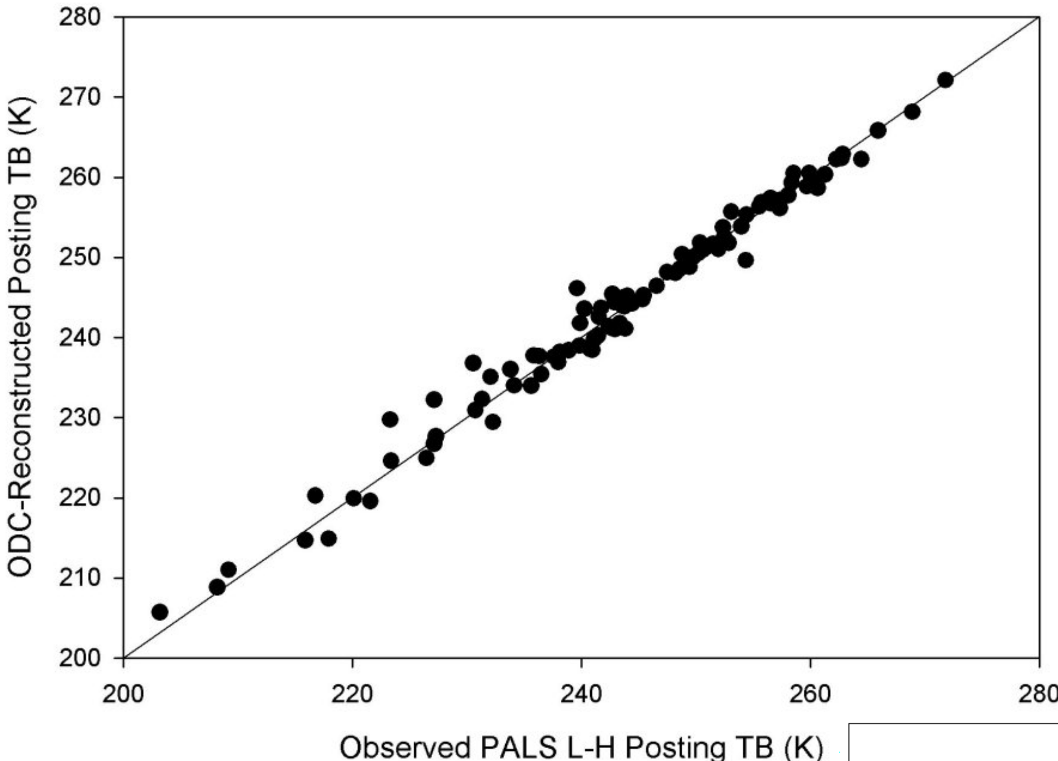
ODC results presented here do not include pure postings to avoid contamination.

- Pure Postings are those in which the Gaussian elliptical surface is wholly contained within a single segment. In other words, all the signal for that posting came from the same agricultural field.
- These pure postings give the best estimate of the brightness temperature of that segment.
- Conventional interpolation techniques, such as IDW, tend to have reduced dynamic range.

CORN	Pure	ODC	IDW
Mean	269.97	269.59	262.99
Min	240.20	243.88	239.27
Max	284.58	284.35	281.71
Std dev	8.92	9.00	11.81
r^2		0.88	0.78
MAE		2.25	7.21
RMSE		3.19	8.85
t-test w/Pure		Not a Significant Difference	Significant Difference

SOYBEANS	Pure	ODC	IDW
Mean	244.79	244.32	250.8
Min	206.52	206.38	223.88
Max	279.99	279.34	280.28
Std dev	21.22	20.76	17.46
r^2		0.96	0.86
MAE		2.71	6.29
RMSE		4.10	8.56
t-test w/Pure		Not a Significant Difference	Significant Difference

Omit-One Analysis

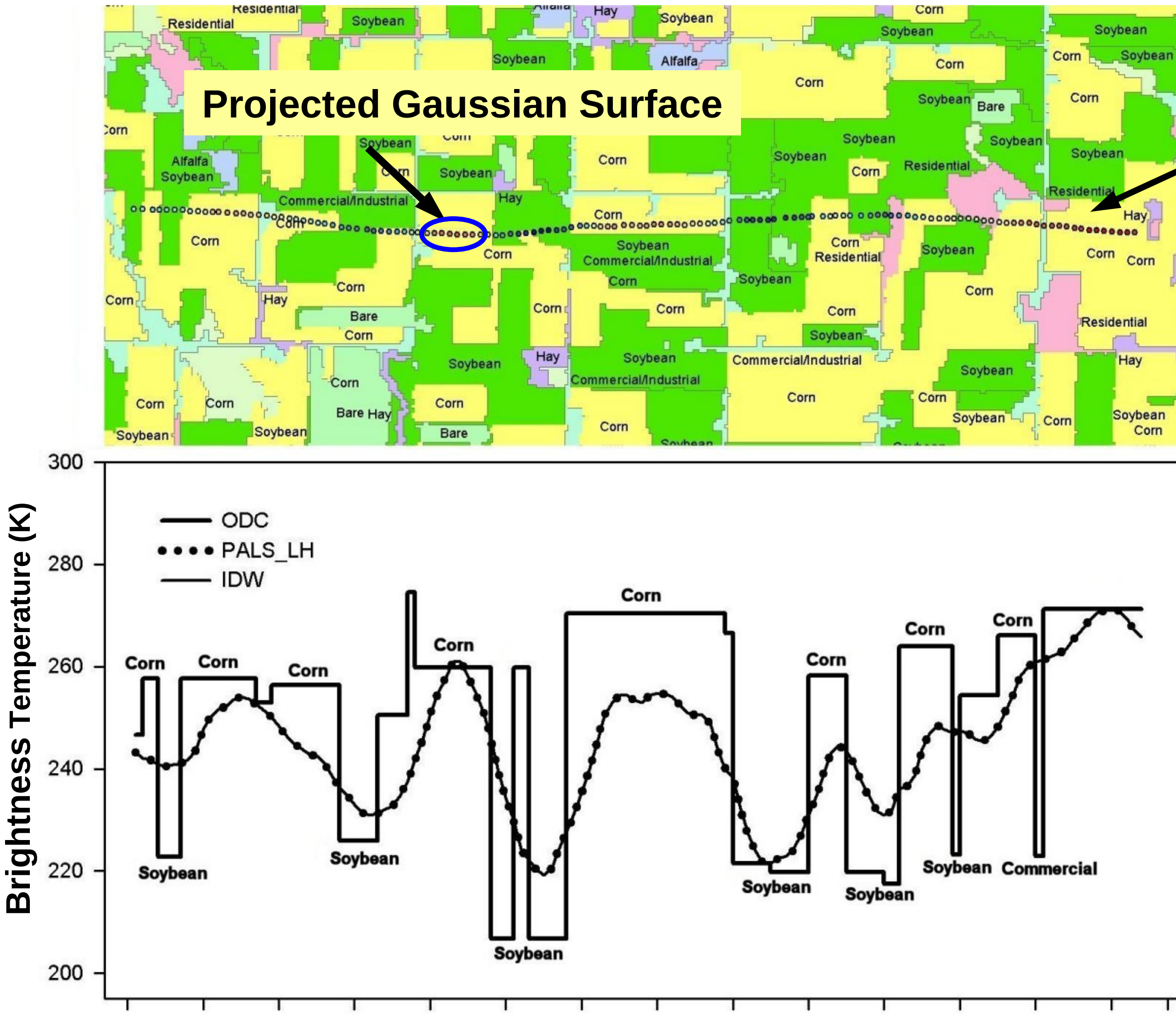


- **Pure postings are few, because the observed signal must come from one agricultural field. However, most of the observations receive signal from more than one field (and crop type).**
- **Majority of the observations receive energy from mixed crop types, therefore we need another method to quantify the effectiveness of ODC.**

- **Randomly omitting one observation from ODC analysis, computing the reconstructed posting, and comparing that with the omitted observed provides an independent assessment of ODC.**

	ODC Reconstructed Postings	Omitted Observed Postings
Mean	244.26	244.02
Min	205.67	203.20
Max	272.11	271.80
Std Dev	13.53	13.84
r^2	0.98	
MAE	1.32	
RMSE	1.88	
t-test w/ Obs	Not a Statistically Significant Difference	

Spatial Comparison of ODC with IDW



Part of a PALS flight line

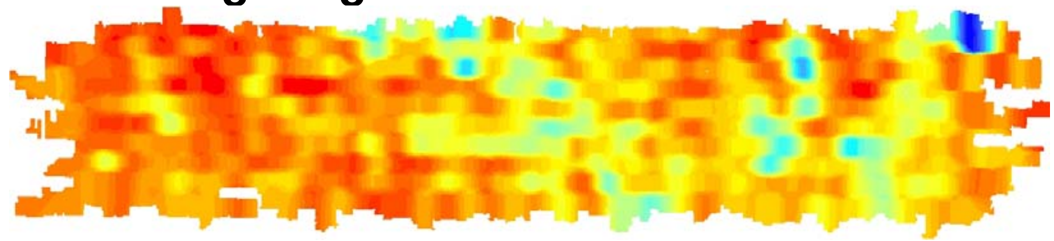
Inverse difference weighting (IDW) results in considerable smoothing, whereas optimal deconvolution (ODC) reconstructs sharp contrast between land cover types.

The IDW technique underestimates maximum and overestimates minimum brightness temperature values.

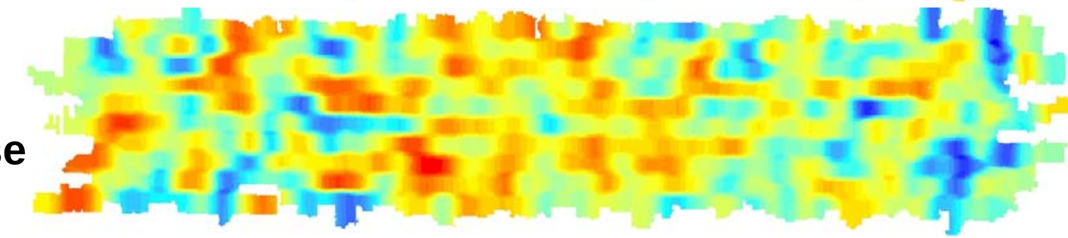
Spatial Comparison of ODC with IDW Continued …

Inverse Distance Weighting

July 2
Dry Case

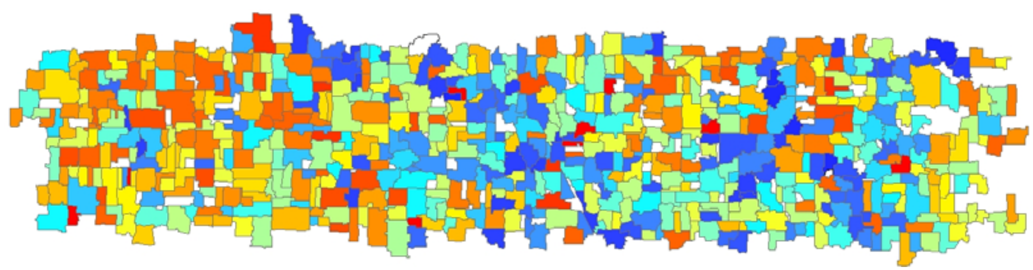


July 7
Wet Case

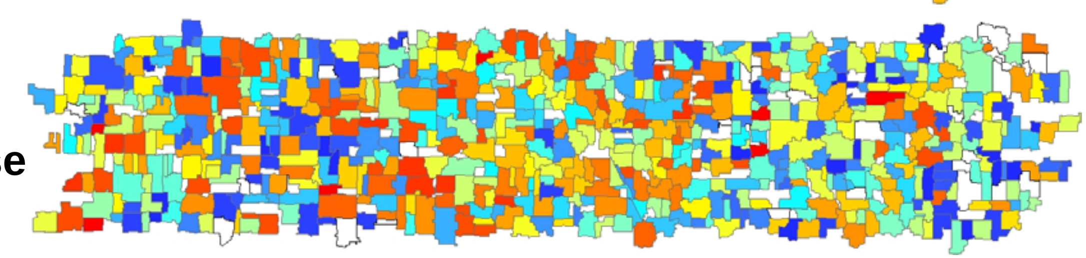


Optimal Deconvolution

July 2
Dry Case



July 7
Wet Case



Soil Moisture from Microwave Brightness Temperatures

- Accurate estimation of microwave brightness temperatures are critical for improving the soil moisture retrievals.

- ODC technique improves on the existing methodology of spatial estimation of the brightness temperature, which is expected to improve soil moisture retrievals.

- With all the other parameters held constant, soil moistures retrieved using the ODC estimated brightness temperatures compare better with the in-situ measurements that the IDW. When compared with in-situ measurements, mean absolute error as well as root mean square error reduced significantly. More rigorous analysis of the retrieval parameters and their sensitivities need to be performed.

Soil Moisture	Observed	ODC	IDW
Average	0.208	0.247	0.28
MAE		0.153	0.208
RMSE		0.172	0.314

Next ?

- **ODC technique has significant potential for application to data from other microwave sensors.**

- **We are currently working on Polarimetric Scanning Radiometer (PSR) data from SMEX02.**

- **ODC technique can be of significant help in delineation of water bodies and other large feature extraction and analysis of data from space based sensors such as AMSR-E, SMOS and Hydros.**