Near Surface Water Content Estimation using GPR Data: Investigations within California Vineyards

***S.S. Hubbard*[*1,2], K. Grote*[*2], I. Lunt *[*2], and Y. Rubin*[*2]**

*[*1] Lawrence Berkeley National Laboratory,*
*[*2] University of California at Berkeley*

*and recent collaboration with **Lars Pierce,** CSU Monterey Bay*

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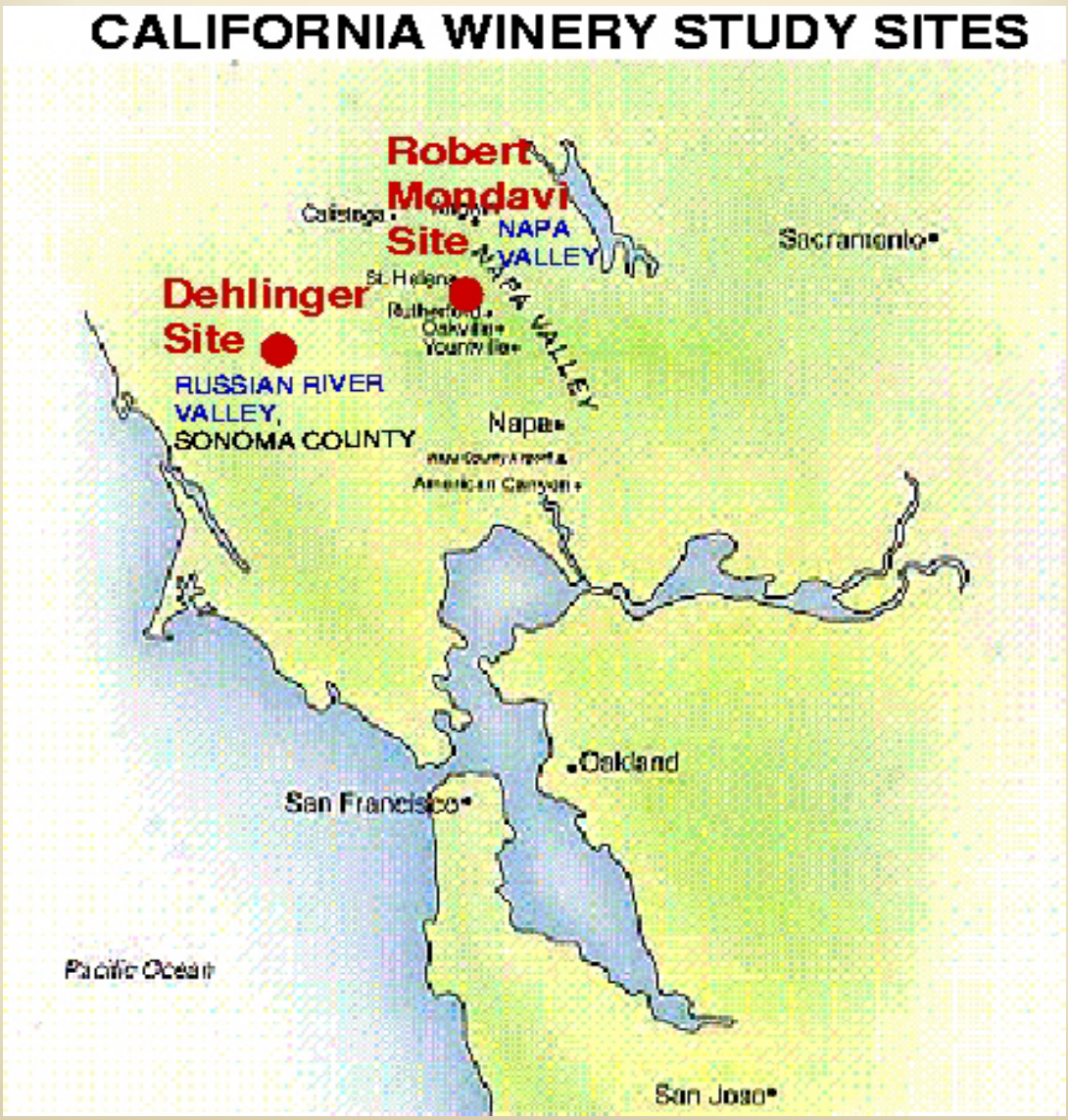
Berkeley
University of California

Outline

- **GPR background**
- **Groundwave Study, Mondavi Site**
- **Reflection Study, Dehlinger Site**
- **Use of Data for Ecosystem Modeling**



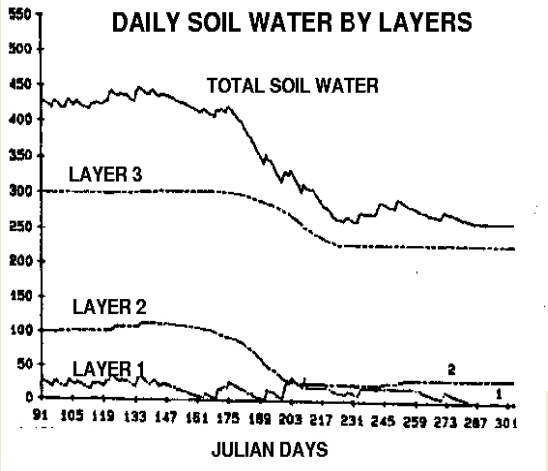
Importance of Understanding Soil Properties in Vineyards:

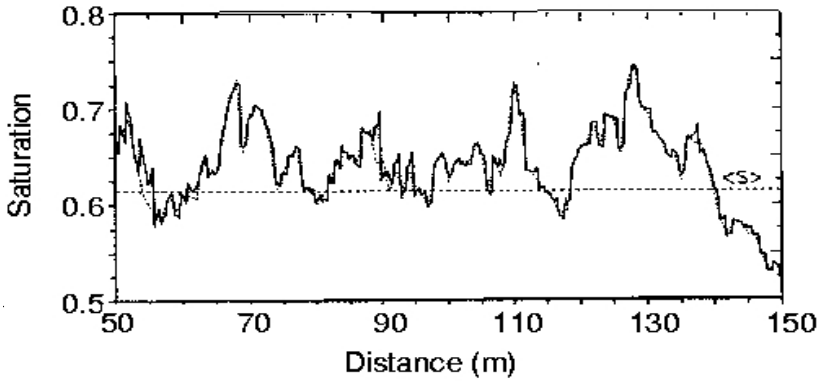
1) Improved vineyard layout;
2) Improved irrigation management;
3) Improved understanding of ecosystem responses and terroir;
4) May assist with understanding pest distribution (phylloxera).

Natural Variability of Soil Properties are Difficult to Capture using Point Measurements:

Near Surface Water Content

Regulates partitioning of precipitation into runoff, evapotranspiration, and groundwater storage



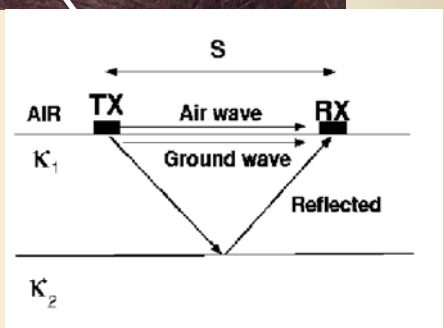


From Or and Rubin, 1990

*** Accurate Spatial and Temporal Variations in Water Content (due to soil heterogeneity, topography, land cover, evapotranspiration and precipitation) may be difficult to map using TDR or gravimetric techniques***

GPR METHOD

The velocity of the GPR waves can be used to estimate soil water content

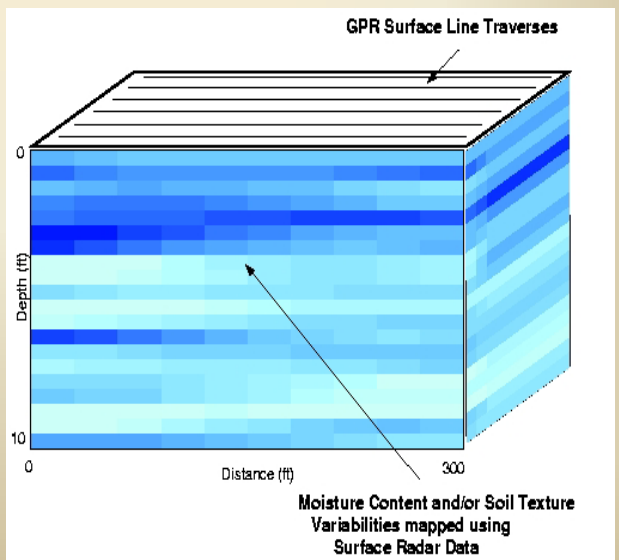


- Short pulses of High frequency EM energy
- Variations in electrical properties modify GPR attributes

$$\kappa = \left(\frac{c}{V}\right)^2$$

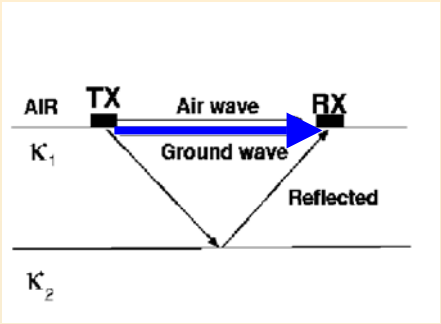
- **Relate dielectric constant to volumetric water content**

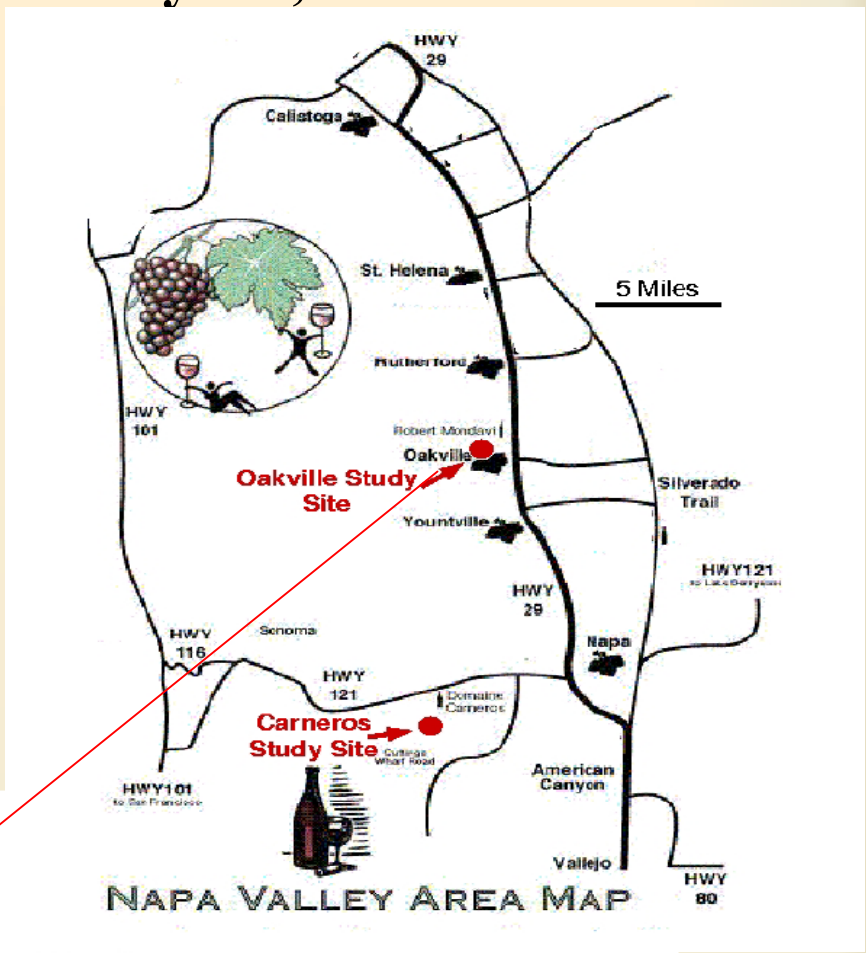
By using ground and reflected waves (and different frequencies?): Obtain 3-D moisture content data cube:



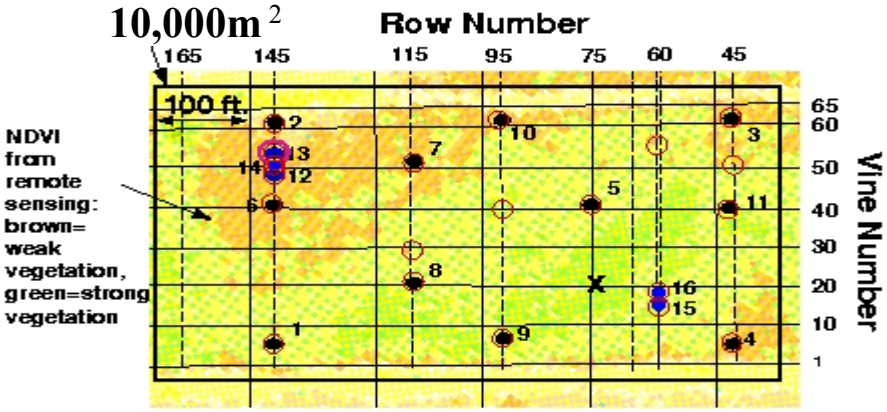
Test of ***Ground Wave*** Concept under Natural Heterogeneous Conditions:

Robert Mondavi Vineyard, Oakville CA



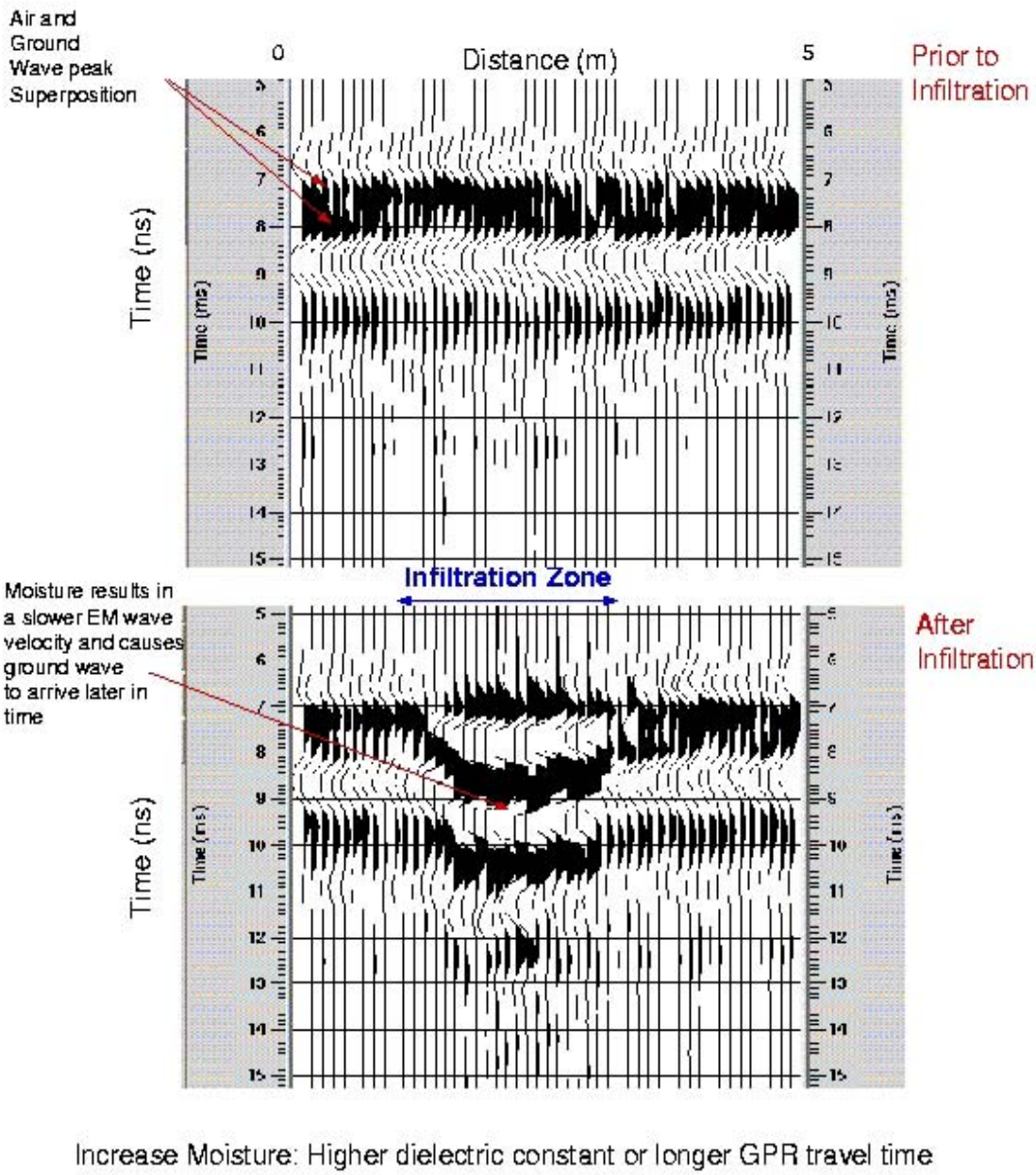


Mondavi Field Site Layout Cabernet Block, 10,000m^2



* GPR 100/200/900/450 MHz
* Crosshole GPR
* Soil Texture
* Gravimetric Measurements
* Borehole and surface resistivity
* TDR
* Neutron Probe
*Remote Sensing

900 MHz Groundwave Example under varied Moisture Conditions

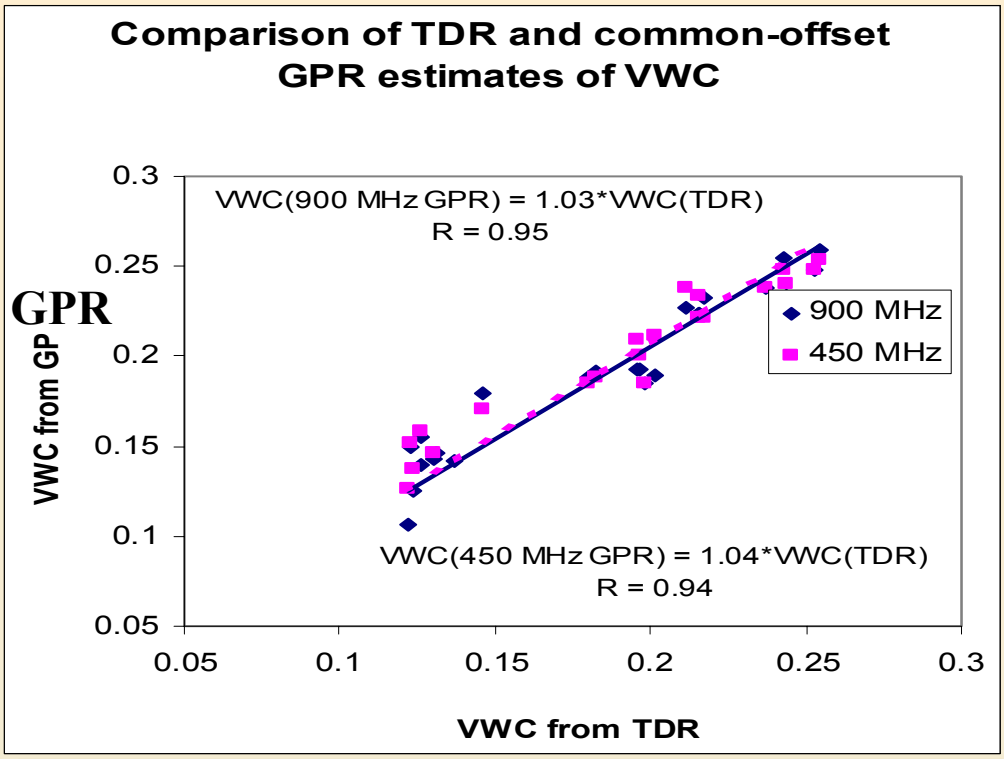


Increase Moisture: Higher dielectric constant or longer GPR travel time

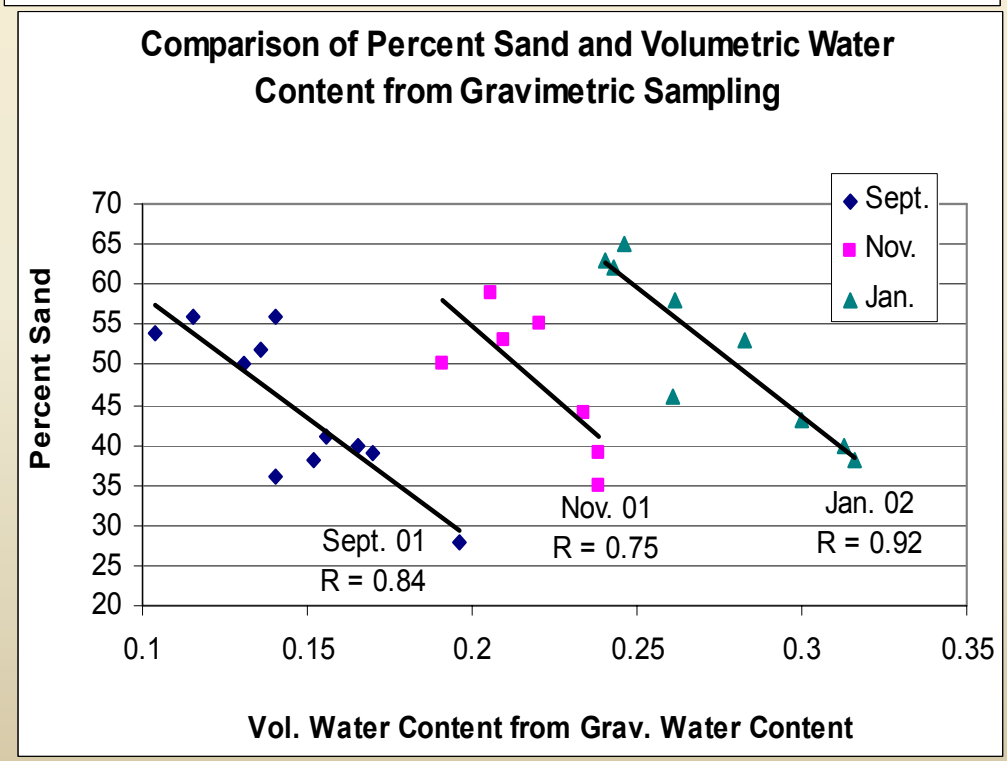
* Map GPR travel time (velocity,dielectric constant)
* Convert to volumetric water content (VWC) using a petrophysical relationship

Special Studies: GPR-obtained Volumetric Water Content (VWC) Estimates vs. TDR measurements and Soil Texture:

*Good correlation between GPR and Conventional Point Measurements



* Soil Texture influences soil moisture seasonally in a consistent manner



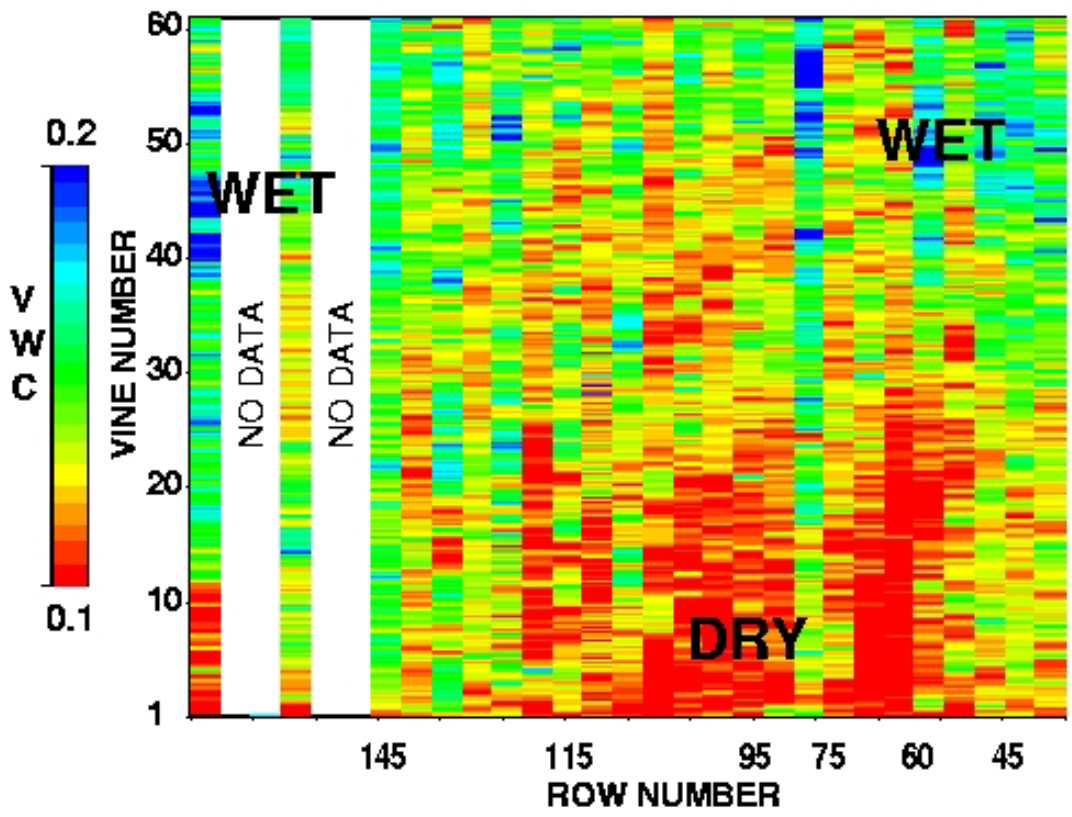
Special Study Results:

- GPR groundwave compared favorably with gravimetric and TDR 'point' samples;
- Topp's overestimated VWC compared to Site-specific petrophysical model;
- **Accuracy**: RMS error for the 900 MHz data was 0.015 m3/m3, with the highest error in dryer soils;
- Depth of **Penetration 900 Mhz**: ~10-15 cm
- Soil moisture closely linked to soil texture.

Grote et al., in submission to WRR

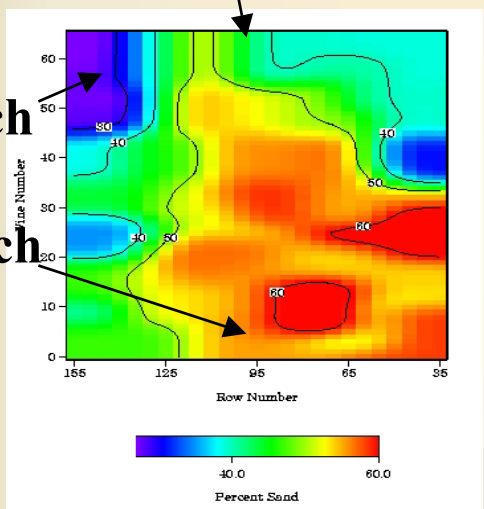
GRID ANALYSIS using Special Study Results:

VWC estimated at one point in time from 900 Mhz data over entire site

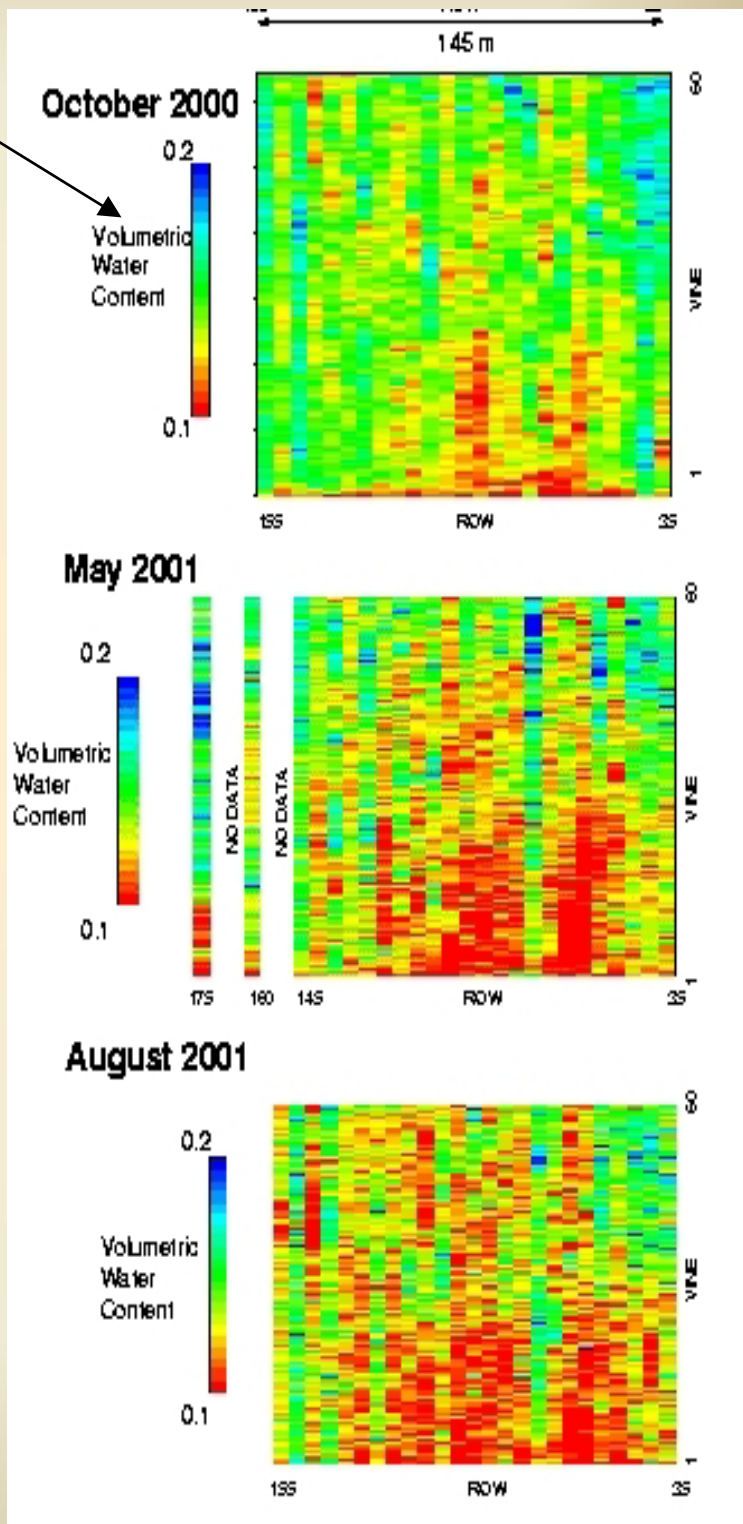


Time-Lapse Moisture Monitoring over Mondavi Site using DATA GRIDS

Volumetric Water Content estimated over Space and Time at the Robert Mondavi KeCs Block and measured soil texture



Percent Sand



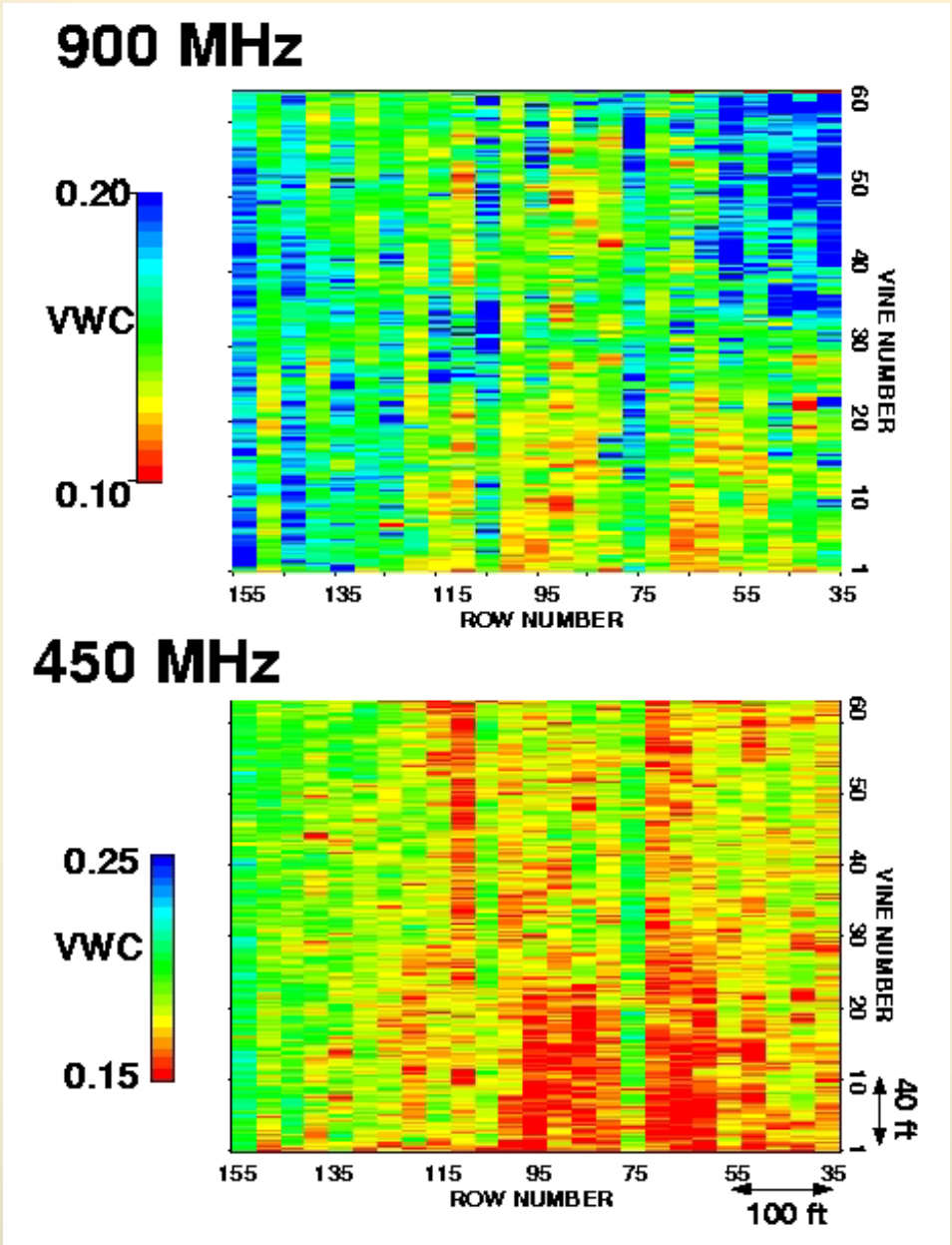
* Persistent Spatial Patterns of Soil Moisture over time

* Seasonal and Irrigation effects

*Textural control on soil Water content distribution

VWC Estimated using different Frequency GPR antennas

Sept 01



Average VWC =0.14

Average VWC = 0.18

*** 900 and 450 MHz yield similar spatial patterns**

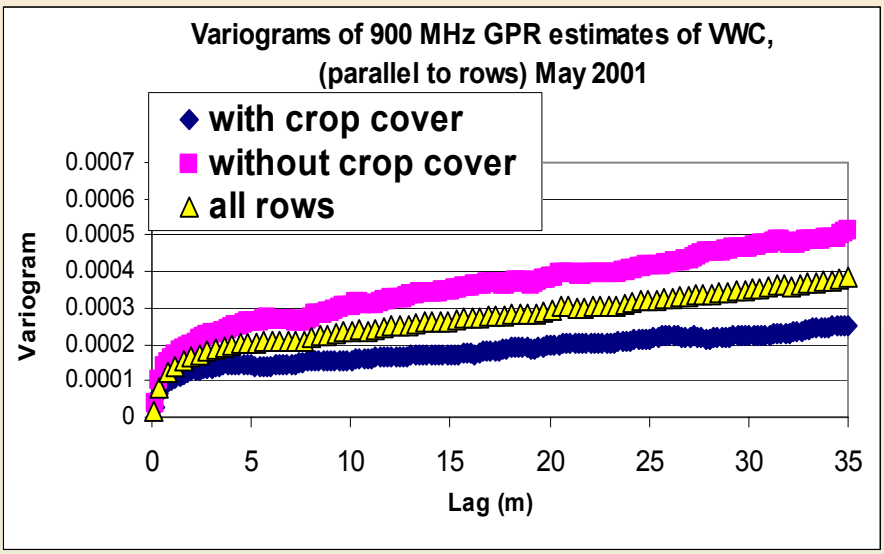
*** 450s sensing wetter (deeper) soil layer than 900s?**

Investigations of VWC Spatial Correlations

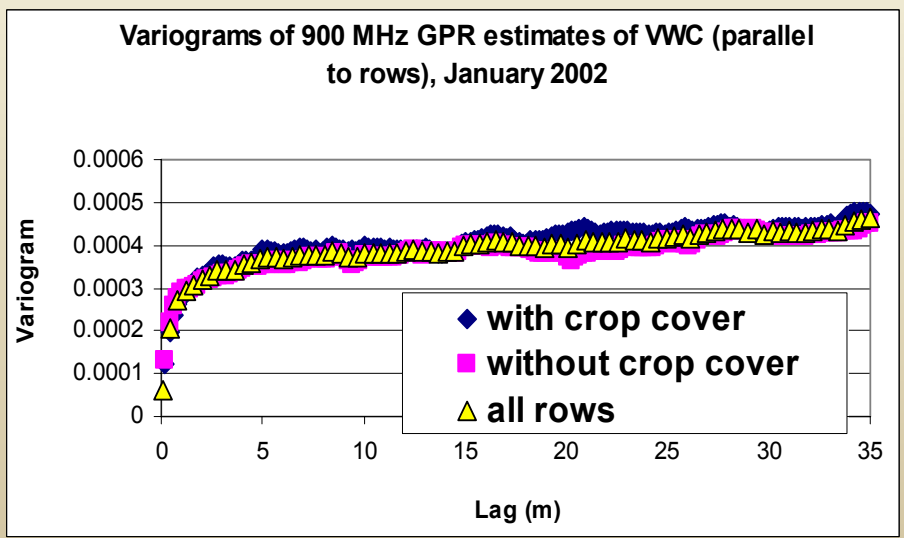
Effects of Season, Irrigation and Measurement Tool

* **SEASON**
  - Highest VWC variability during drip-irrigated times
  - Lowest VWC variability during dry season
* **MEASUREMENT TOOL**
  - Variability of 900 MHz>TDR>450MHz
  - Range estimated from 900 MHz < TDR < 450 MHz
* **CROP COVER**
  - More variability in rows with crop cover during spring
  - Effect of crop cover on VWC variability is not significant in the winter

Spring: More Variability in Crops without Cover

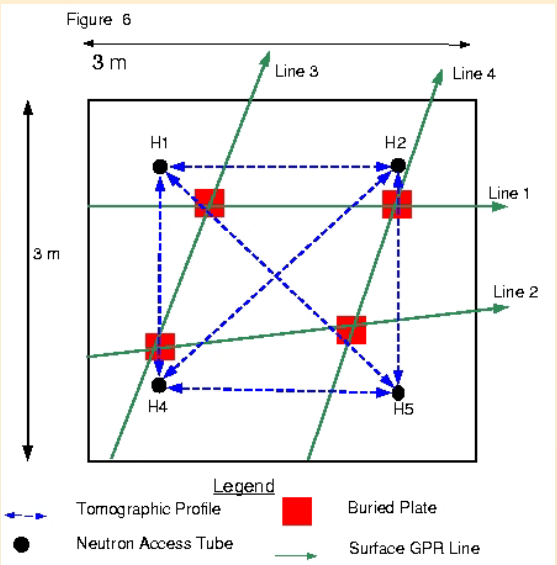


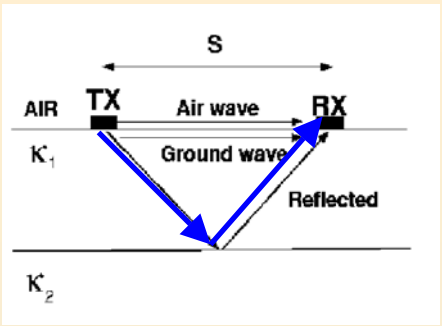
Winter: Crop Cover not Significant

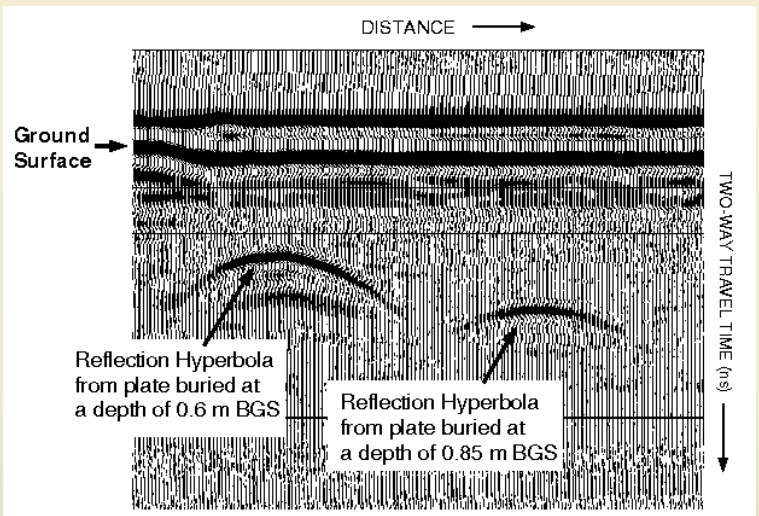


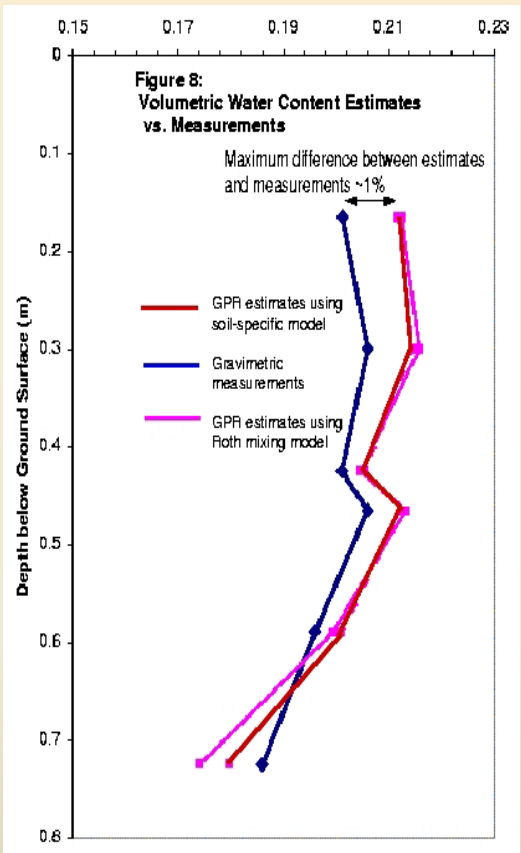
Reflection Studies under Ideal Conditions

1) Constructed 'Test Pit' with buried metal reflectors.
2) Engineered pavement layers during infiltration experiment.









Grote et al., 2001

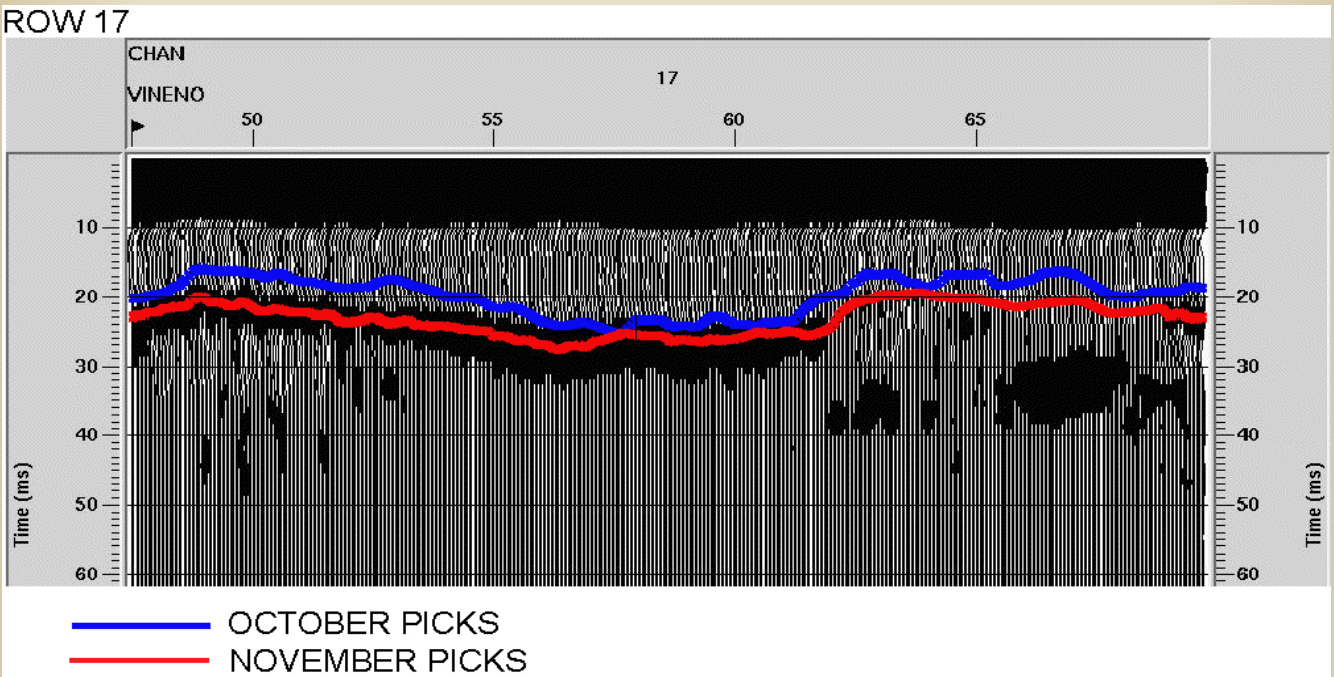
Using 900 and 1200 MHz data under constructed and engineered conditions, GPR reflection travel time data is accurate to within ~1% for estimating volumetric water content

Reflection Study under Natural Conditions
Dehlinger Site,
Russian River Valley, CA (100&200 MHz)

DATA:

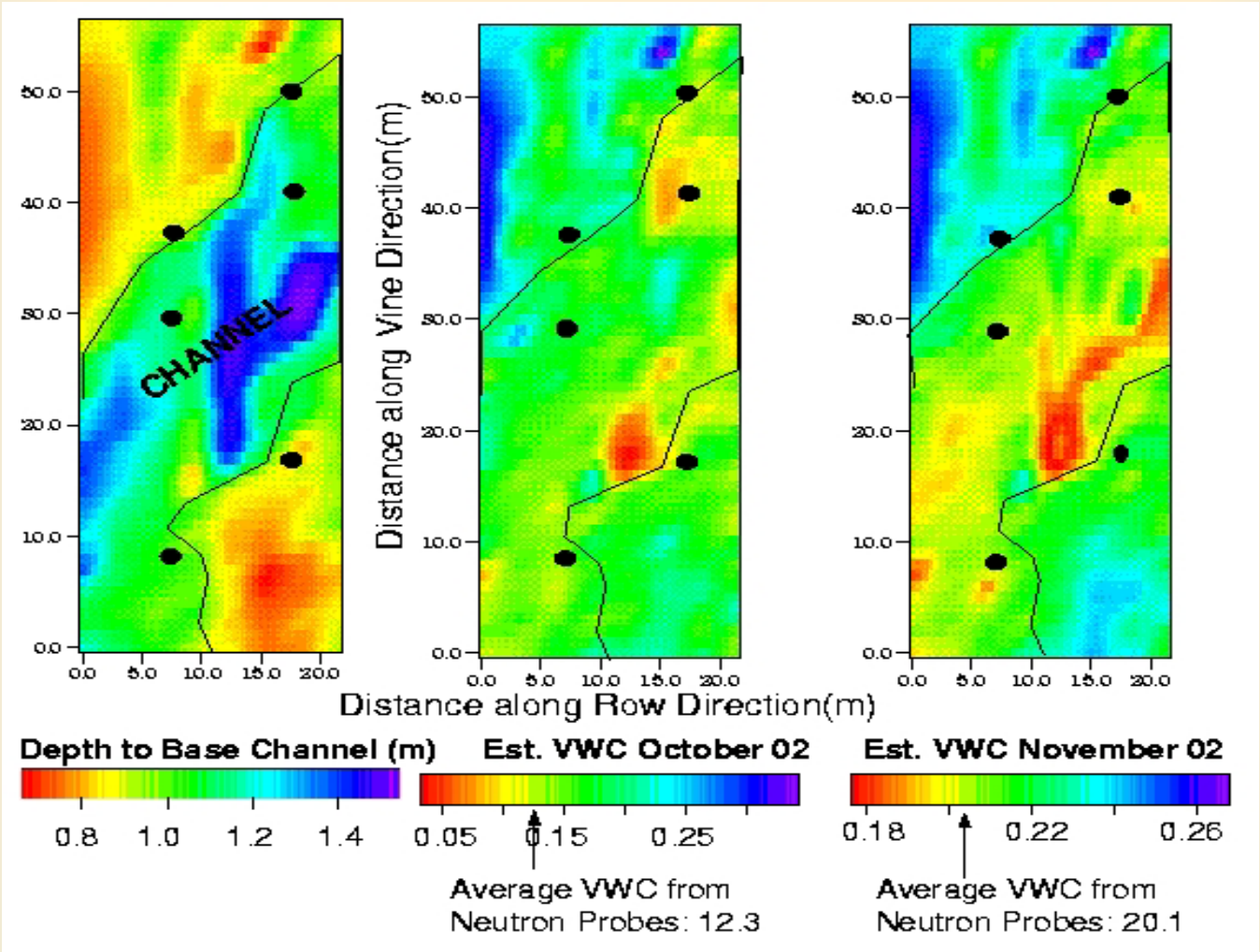
* GPR grids and detailed studies
* TDR
* Neutron Probe
* Soil Samples
* Vigor

Examples of "Base of Channel" picks on 100 MHz GPR line during October and November, 2002.



- **<u>BAYESIAN PROCEDURE for estimating the DEPTH TO BASE OF CHANNEL</u>**
  - Use co-located wellbore and GPR measurements to **develop likelihood function (L).**
  - **Estimate prior depth pdfs** using wellbore data and kriging;
  - **Estimate Depth to Base Channel** using GPR travel time data, prior depth estimates and Likelihood within **Bayesian** Approach
  - Use estimated depth structure contour map with time-lapse travel time maps to **estimate water content** above base of channel and over time.

Preliminary Estimation of Volumetric Water Content above Base of Channel Reflector using 100 MHz GPR Reflection Data DATA GRIDS



Validation

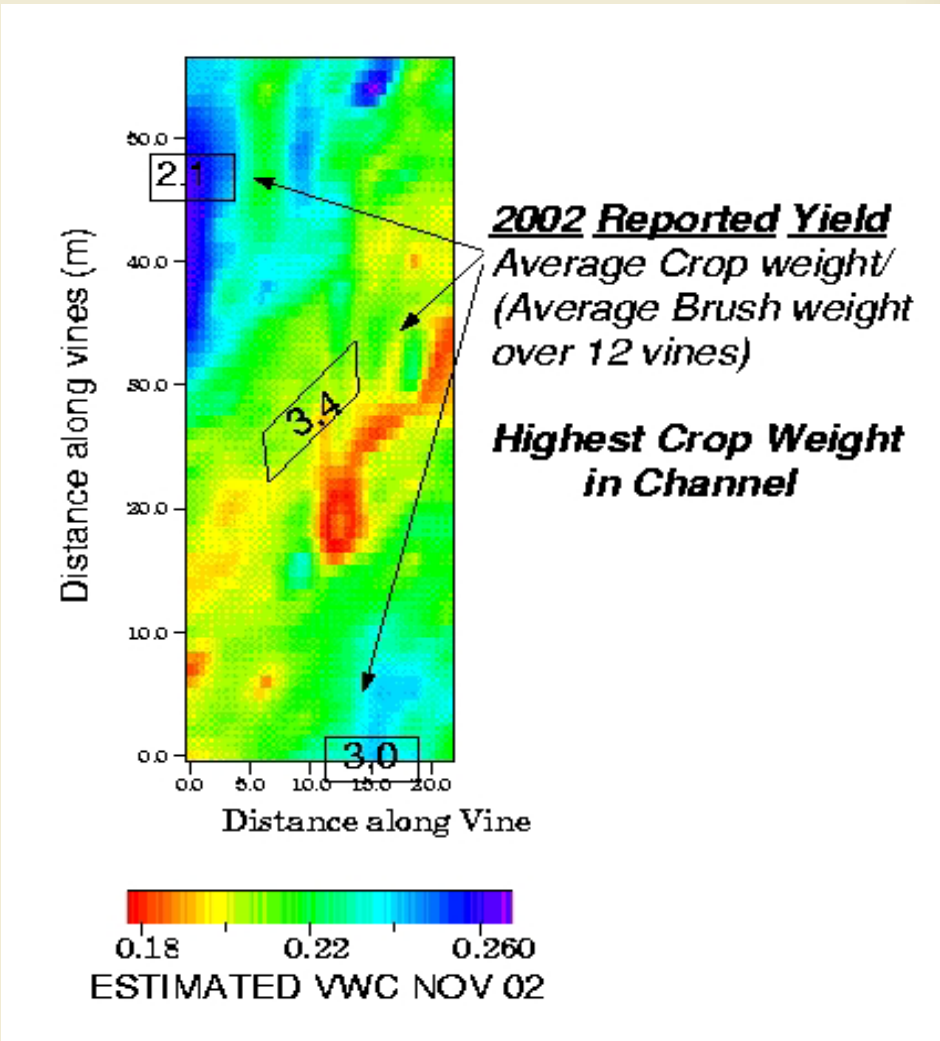
Campaign	Abs. VWC Error
Oct. 02	0.016
Nov. 02	0.03

Reflector Summary:

* Errors reasonable;
* Need good reflector and good depth constraints;
* More difficult than groundwave approach but capable of providing deeper VWC estimates.

Objective: Determine value of GPR-obtained parameter estimates to ecosystem prediction using water balance models.

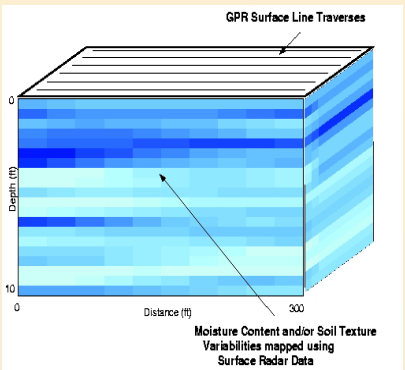
Observed: Variations in Vigor and Yield

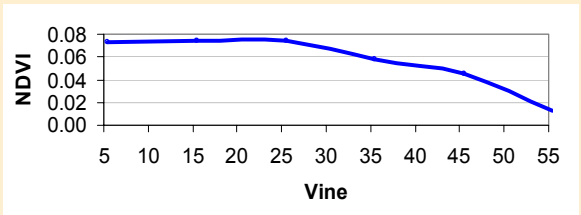


INVESTIGATE:

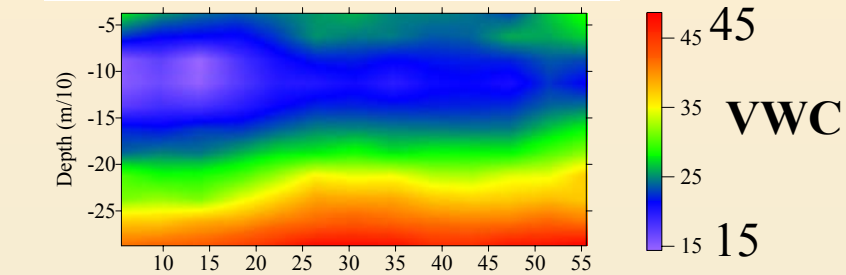
* What depth zone and hydrogeologic parameters most influence NDVI?
* How significant are the spatial variabilities of hydrogeological parameters on the ecosystem and responses and on viticulture?

Comparison of VWC, Soil Texture and NDVI along a single 2-D vertical slice (along a vineyard row) from ground surface to the water table (3m):



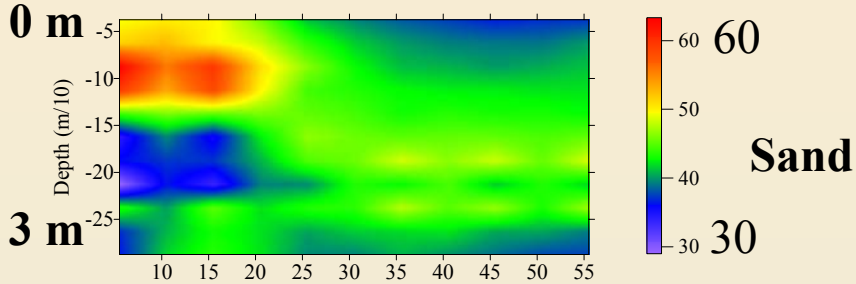


NDVI



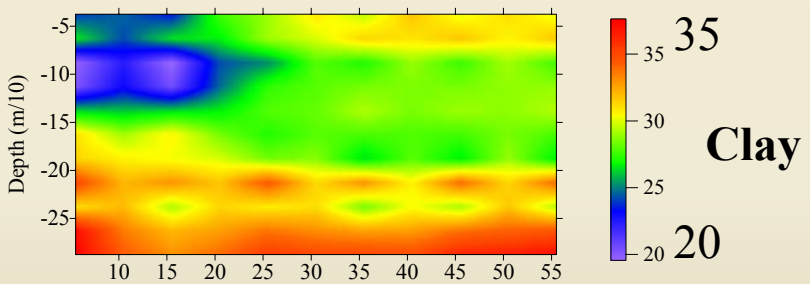
VWC

0 m

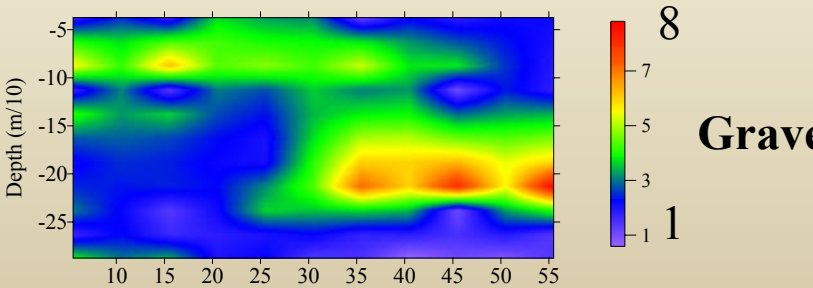


Sand

3 m



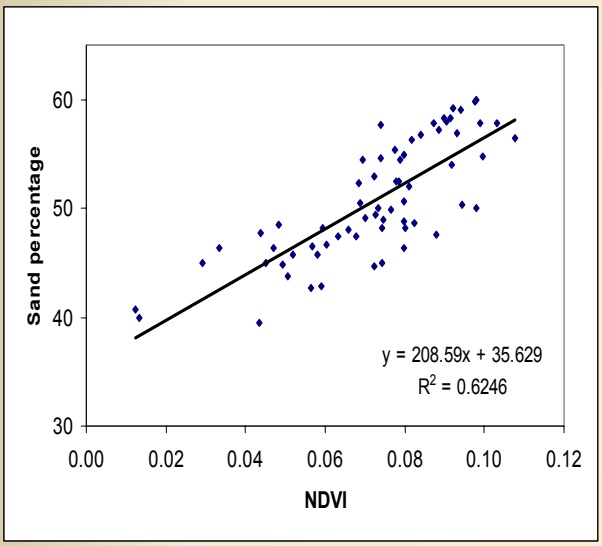
Clay

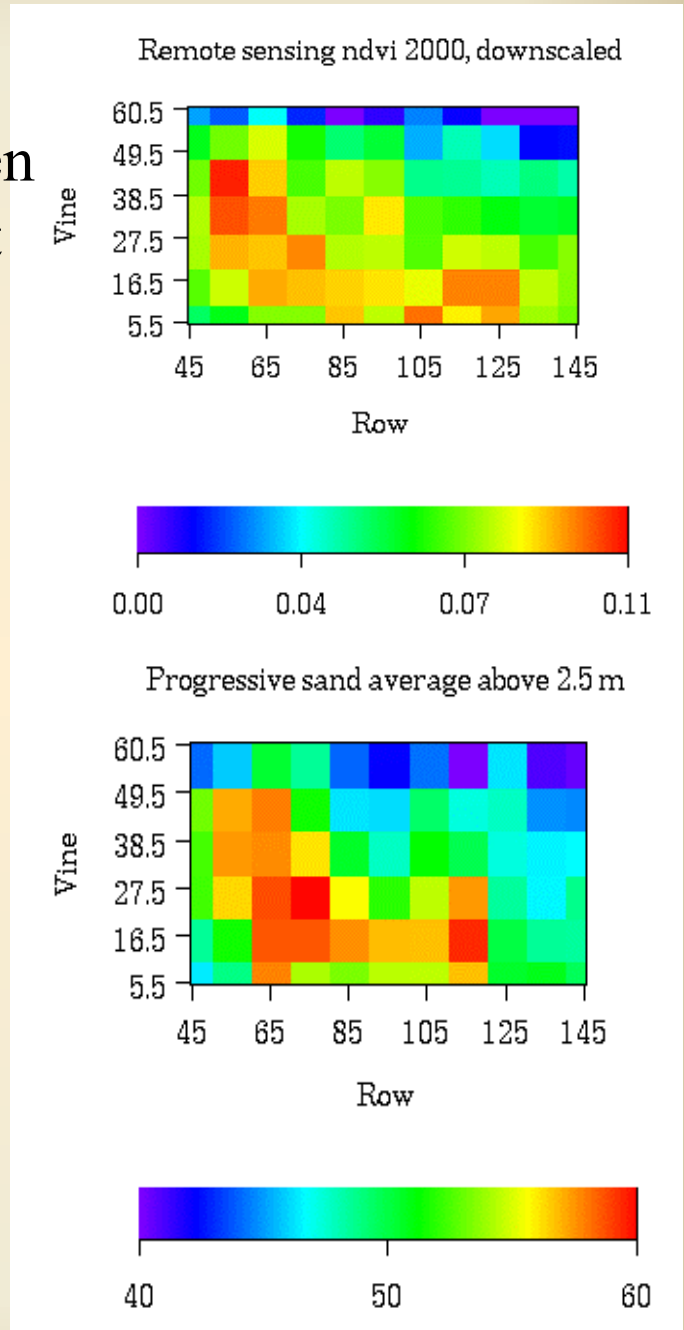


Gravel

NDVI vs. Sand Content

Good correlation between NDVI and Sand Content from 0-2.5 m bgs





* **Soil texture correlated with NDVI/vigor**

* **Zone of greatest influence: 0-2.5m BGS**

Variable soils properties as input to Numerical Vineyard Soil Irrigation Model (VSIM)

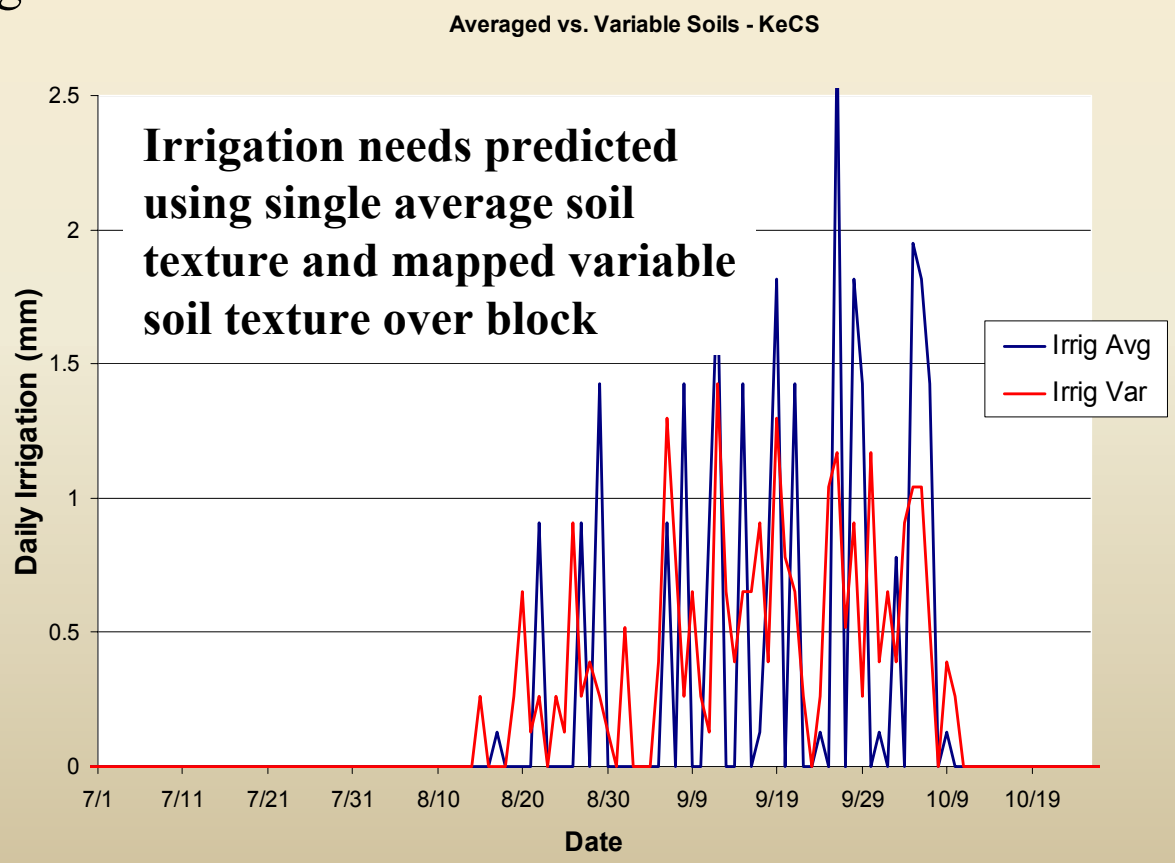
VSIM water balance model modified from Forest-BGC model (Running and Coughlan, 1988)

Uses as input:

Soil texture, irrigation data, climate and ET data (CIMIS), crop coefficient, and LAI estimated from NDVI (Johnson et al., 2000)

Calculates:

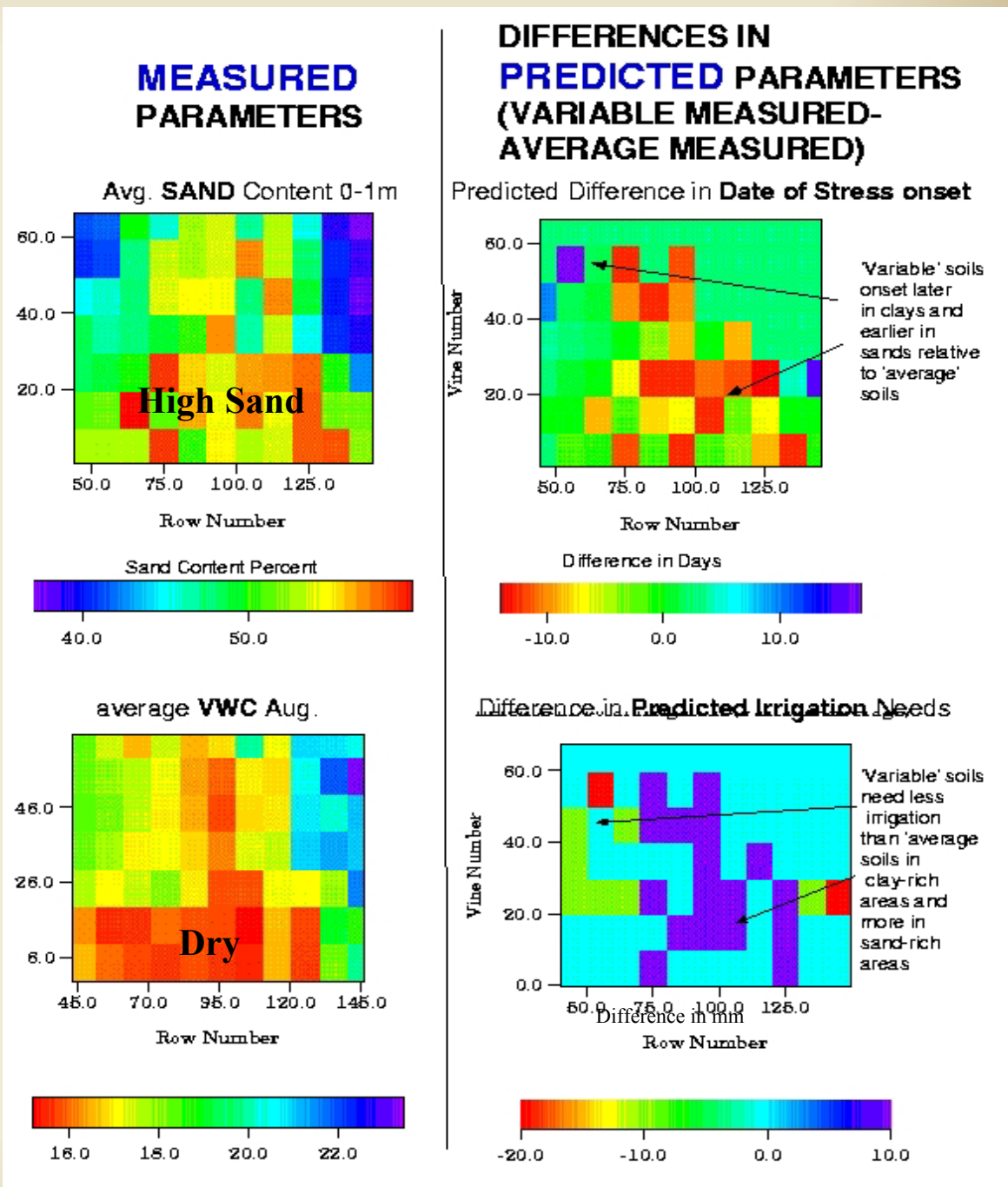
Daily and Cumulative LWP, irrigation needs, and date of significant stress onset.



Preliminary Comparison of Sand Content and VSIM Predictions using homogeneous and spatially-variable soils data

Most Influential Parameters:

1) Sand
2) VWC
3) NDVI



Preliminary:

Variable Soil Parameters appear to make a SIGNIFICANT difference to the prediction!

Summary

* GPR groundwave and reflection travel time data yield high resolution, minimally-invasive and sufficiently accurate information about soil water content for precision agriculture applications;
* Groundwave methods are more straightforward than reflection methods, but they only image the shallow subsurface;
* Variable soil texture/moisture appear to influence ecosystem parameters.

Potentially Useful for:

(1) Improved design of vineyard layout;
(2) Development of improved irrigation strategies;
(3) Better understanding of ecosystem dynamics and terroir.

Thanks to Field Crew:

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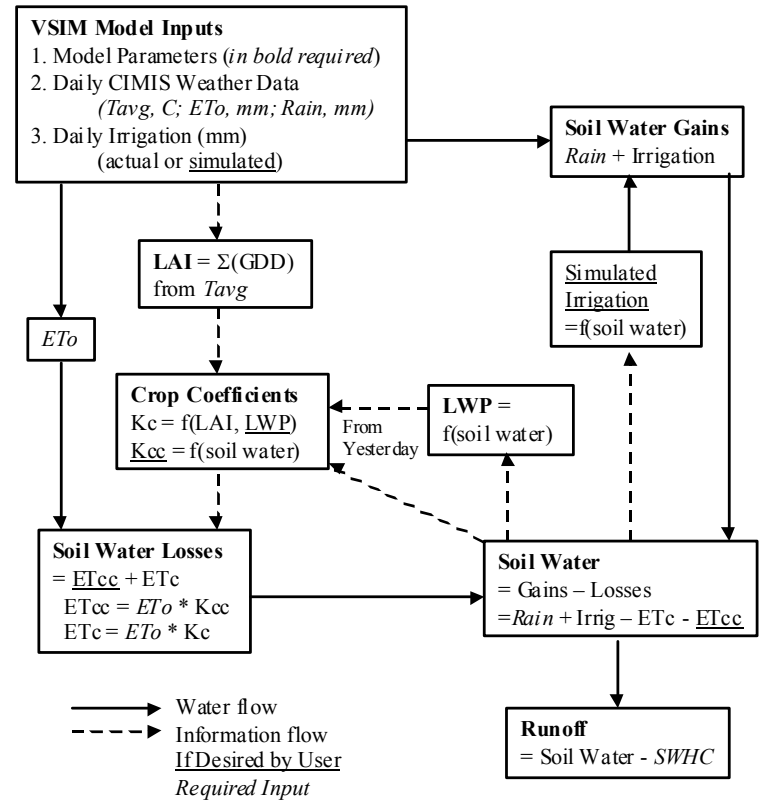
John Peterson
Wing Yee Wu
Jens Tronicke
Jimmy Moreno
Papia Nandi
Hank Fung

Thanks to Daniel Bosch (Mondavi), Lee Johnson (NASA/CSU)& Tom Dehlinger and Marty Hedlund (Dehlinger)

End of Presentation
~Thank You~

VSIM Model: Daily Process Flowchart



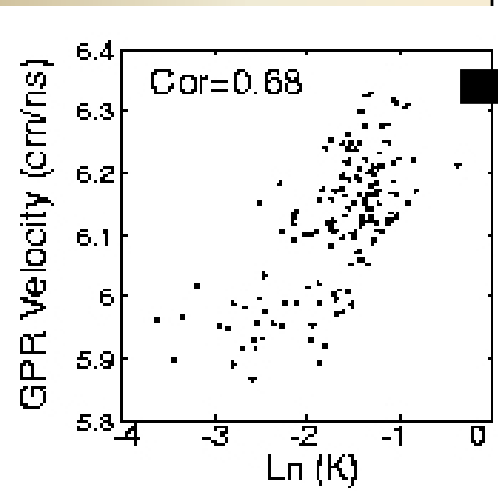
Abbreviations:

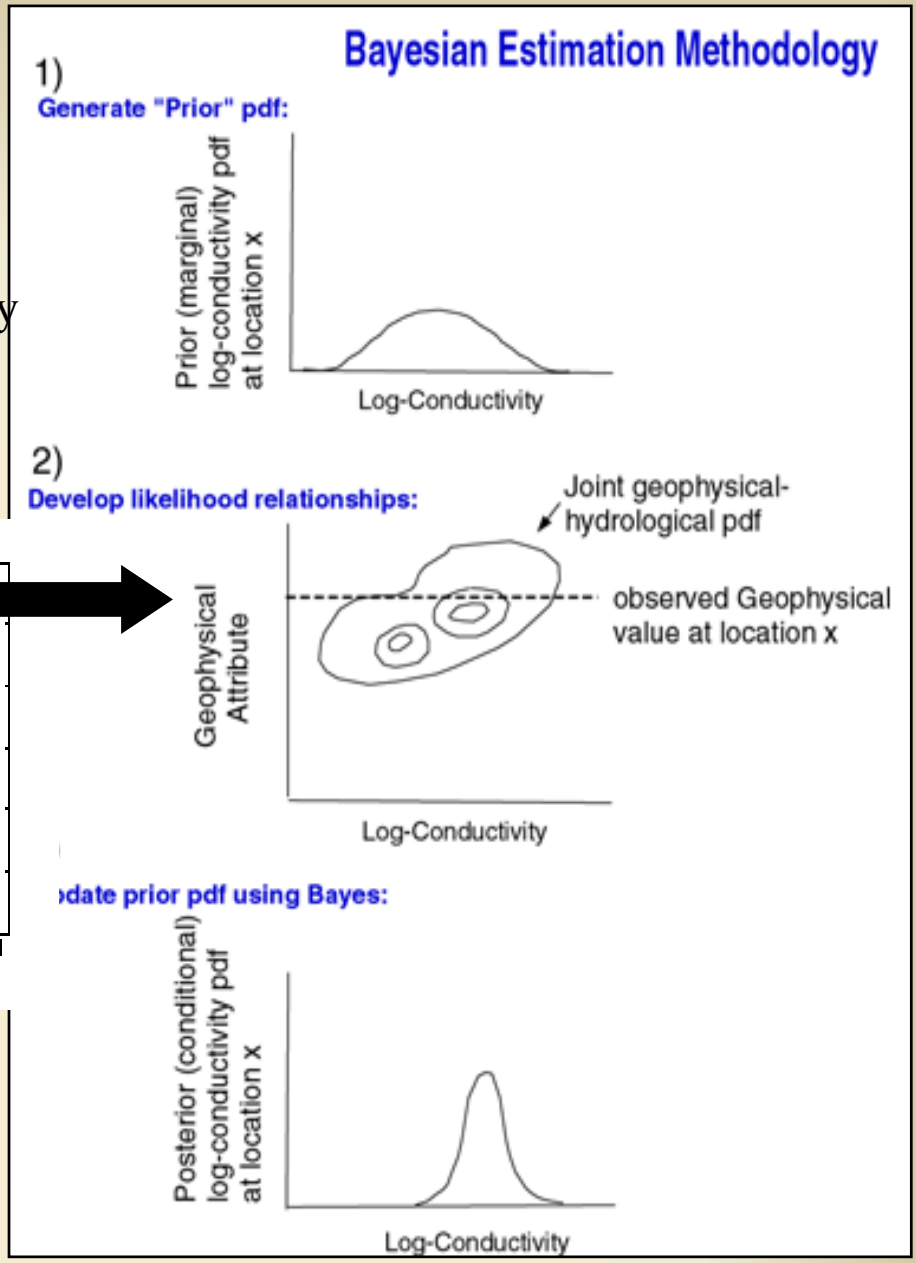
ETc = Vine Crop Evaporation	Kcc = Cover Crop Coefficient
ETcc = Cover Crop Evaporation	LAI = Leaf Area Index
ETo = Daily Potential Evaporation	LWP = Leaf/Soil Water Potential
Σ(GDD) = Growing Degree Day Sum	Tavg = Daily Average Air Temp
Kc = Vine Crop Coefficient	SWHC = Soil Water-holding Capcity

Figure 1. VSIM Model Daily Process Flowchart

***seismic and radar velocities** are co-linear and positively correlated with K

* **attenuations** are not well correlated with K





AT EACH LOCATION:

Update prior information (from wellbore data) using geophysical information and petrophysical relationship within a Bayesian framework.

BAYES:

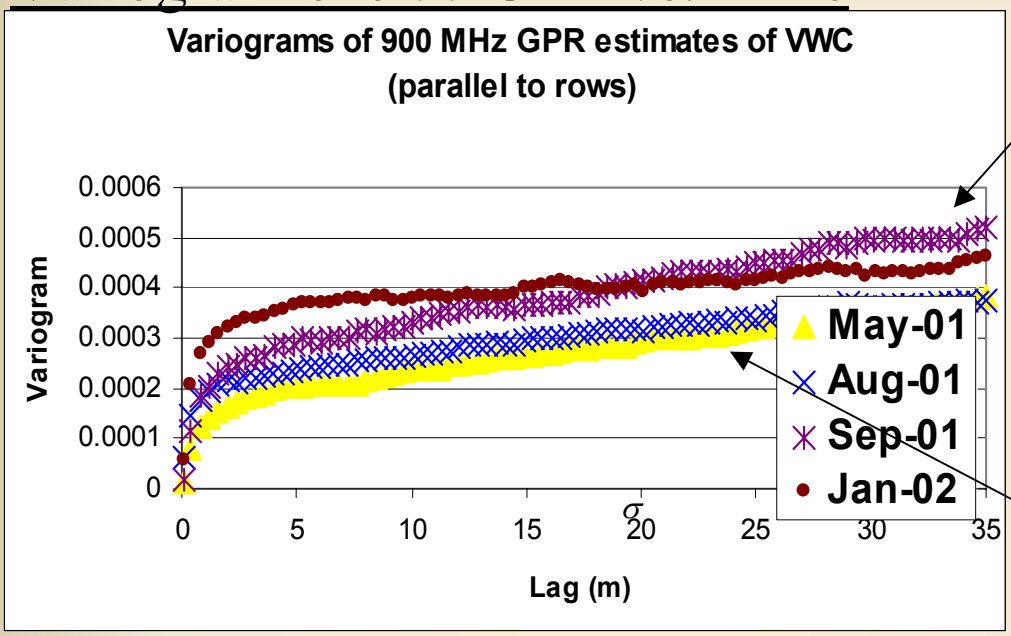
$$f_{y,posterior} = C\, L[y|v_g]\, f_{y(prior)}$$

*** Chen, Hubbard and Rubin WRR 2001**

Estimating Spatial Variability using Measured GPR & TDR Data:

Effects of Season, Irrigation and Measurement Tool

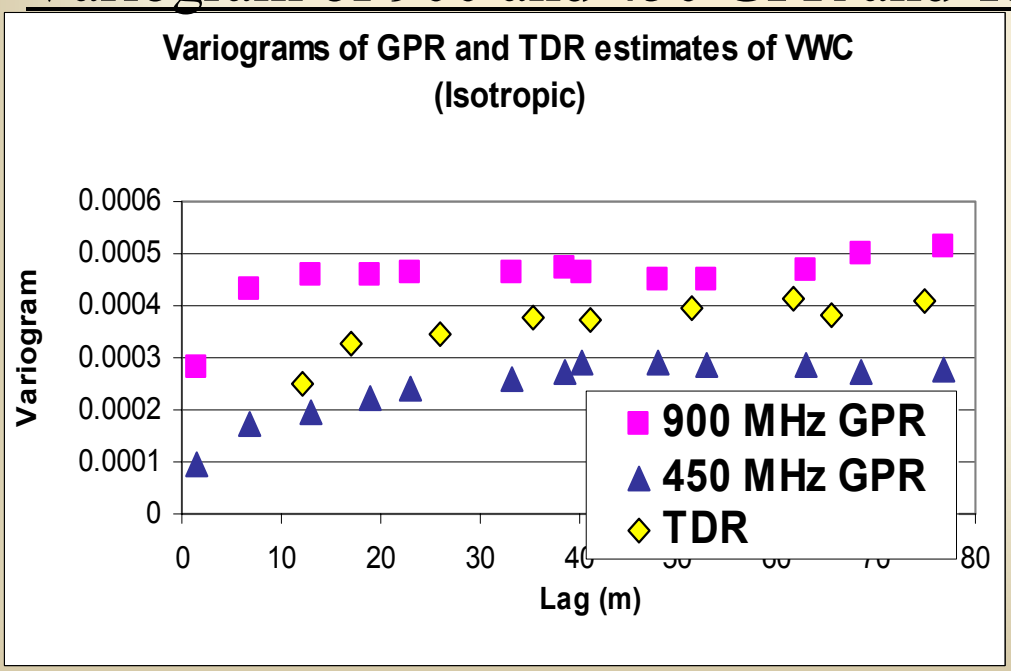
Variogram of 900 GPR vs. Time



Highest Variance during Drip irrigation (Sept.)

Lowest variance during dry season

Variogram of 900 and 450 GPR and TDR



Variance: 450<TDR<900

Lag: 900<TDR&450