Instrumentation for Soil Measurement: Progress and Hurdles

Colin S. Campbell, Ph.D.

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Introduction

- Outline
  - Soil moisture sensors
  - Soil water potential
  - Mars update

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Water Content Measurement

- ECH_2O high frequency sensors (EC-5, TE, TM)
  - Testing
  - Characterization
  - Calibration methods and modeling
  - Temperature dependence
  - Future: Separate real and imaginary dielectric

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Background

- First Generation Sensors: Released 2001
  - ECH_2O 10 and 20 cm soil moisture sensors
    - 10 MHz Measurement frequency
    - Required soil specific calibration for most soils
  - Improvements: 2004 to 2006
    - Stronger cable for better robustness in the field
    - Chemical sealant for physical bond between sensor surface/cable and plastic overmold
      - Kept water from harming the electronics
    - Rodent repellant: mix in sensor cable to deter animals from chewing on cables

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Background

- Second Generation of soil moisture sensors
  - ECH_2O sensors: EC-5, EC-TE and EC-TM
    - 2005: Began testing to improve soil moisture measurement
  - Change design
    - 1st generation: blade
      - Many electro-magnetic (EM) field lines stayed inside fiberglass sensor area
    - 2nd generation: prongs
      - More EM lines in soil
  - Increased measurement frequency
    - 70 MHz

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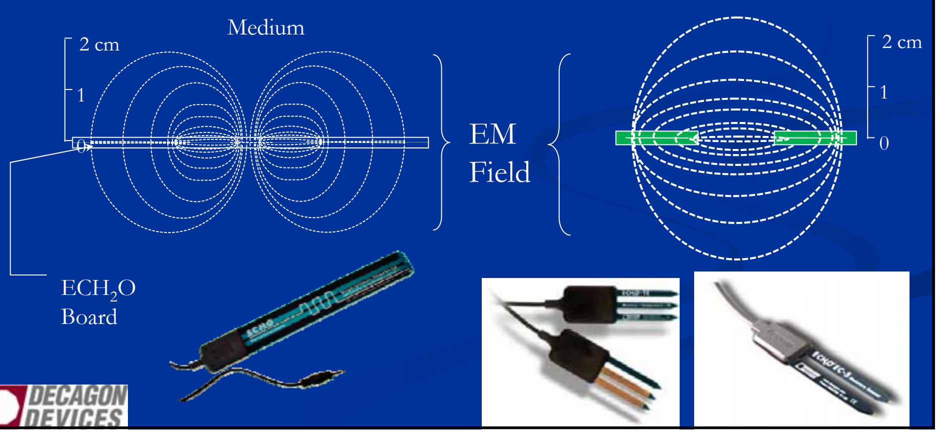
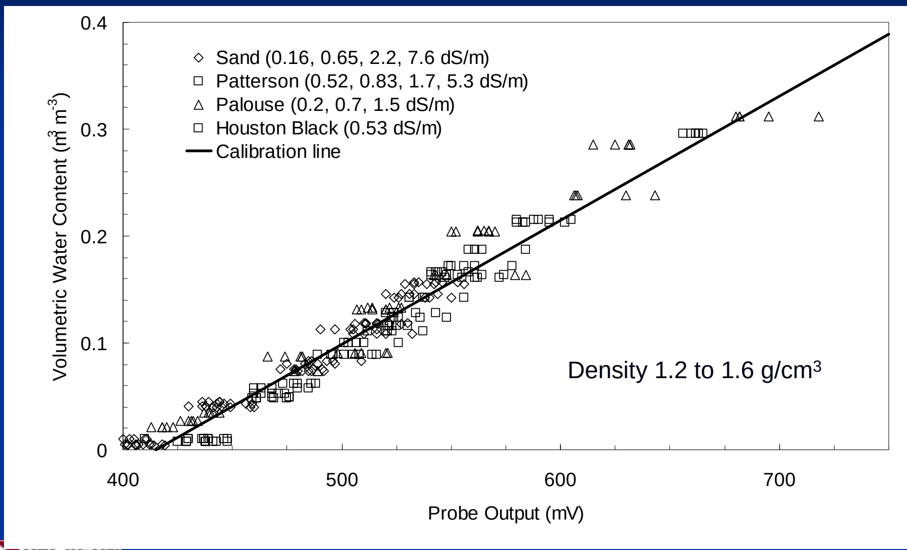
EM Field Lines in Dielectric Sensor

First Generation

Second Generation



EC-5 Mineral Soil Calibration



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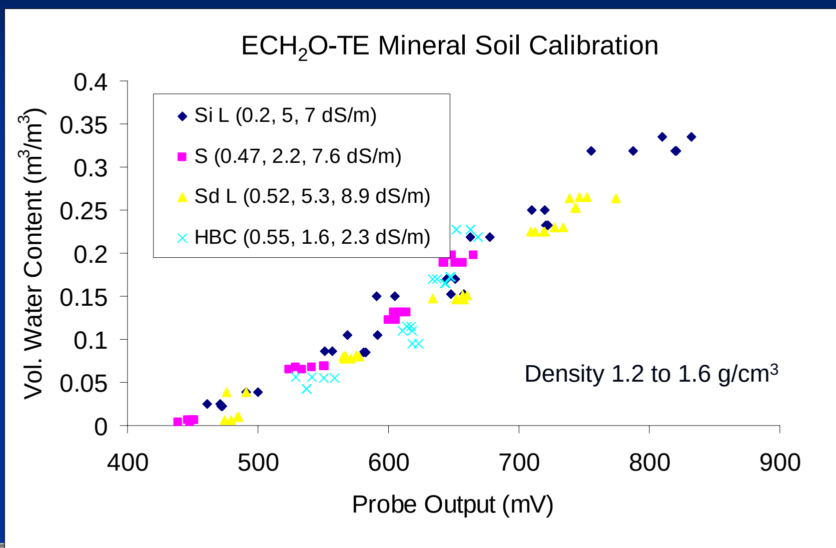
EC-TE Mineral Soil Calibration



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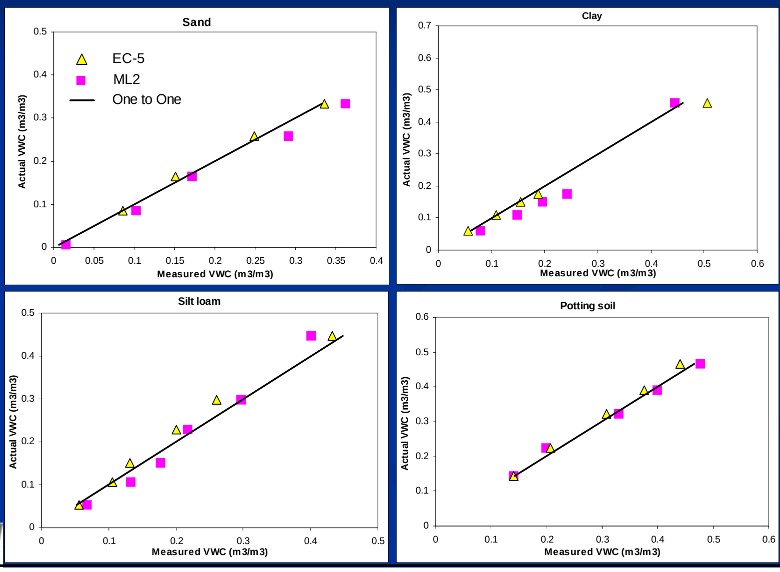
Characterization: Reproducibility in various soils



Calibration: Problem soils

- Not all soils behave as nicely as mineral soils
- Most of the variability in calibration appears to be due to density differences
  - In fact, eventually, this may be a good way to determine dry density
  - Some soils in Japan appear to be affected by this
  - Similar effects have been seen in organic media like potting soil

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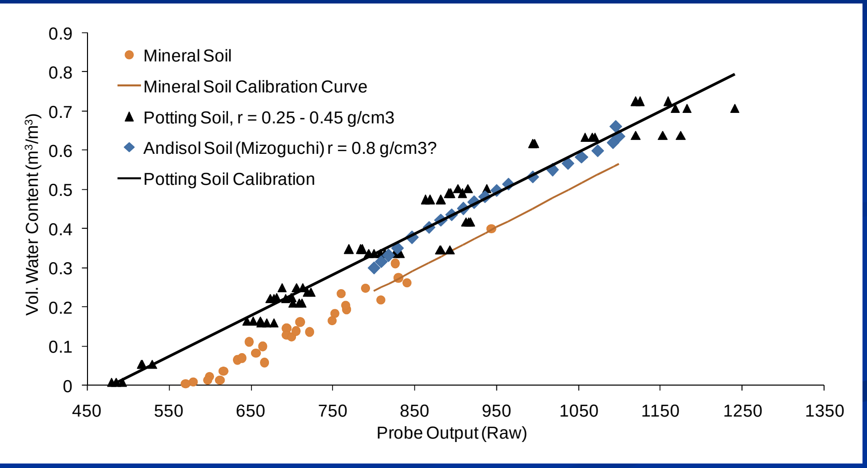
Density Effects on Calibration: Andisol



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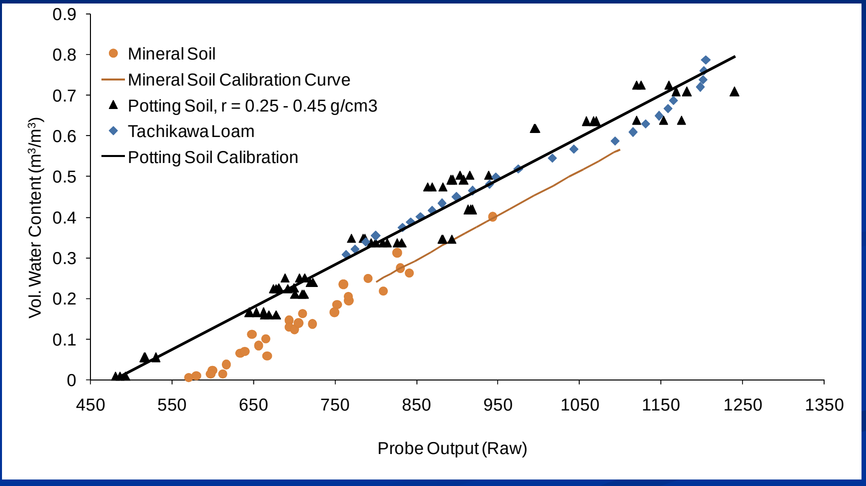
Density Effects on Calibration: Tachikawa Loam



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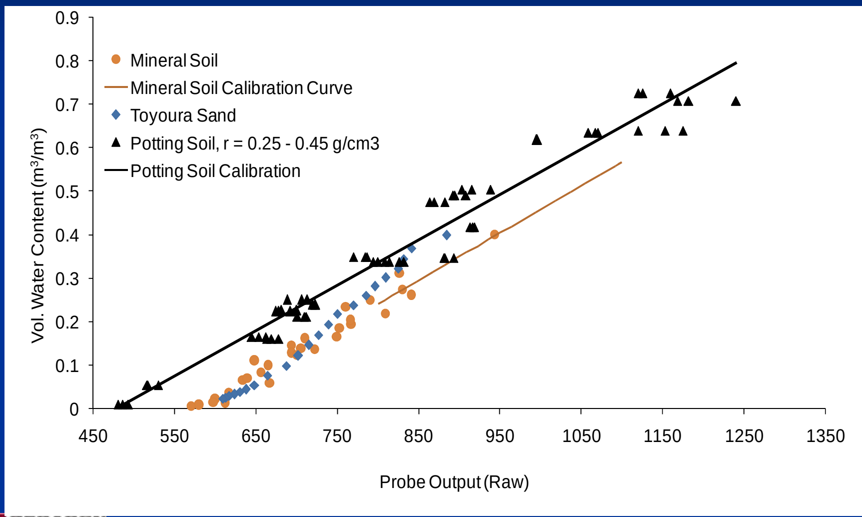
Toyoura Sand



Differences in Soil Calibration Equations

- Data suggest calibration differences may result from differences in soil density
  - Potting soil and andisol
    - Low bulk density
    - Very similar calibration curves
  - Toyoura Sand
    - Higher bulk density
    - Calibration curve was close to standard mineral soil curve
- Calibration technique may also cause differences

Dielectric Sensor Calibration

- Sensor calibration is one of the hot topics of moisture measurement in the USA
  - Many different opinions on the "right way"
    - Infiltration
    - Surface evaporation
    - Surface evaporation and transpiration (cover crop)
    - Pack and subsample

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Infiltration Method

- Basic procedure
  - Pack sensor in a known volume of soil
  - Add a known volume of water to soil surface
  - Seal surface and allow water to infiltrate into soil over time
  - Take sensor reading and repeat process

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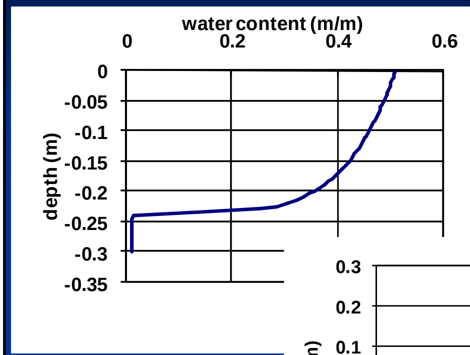
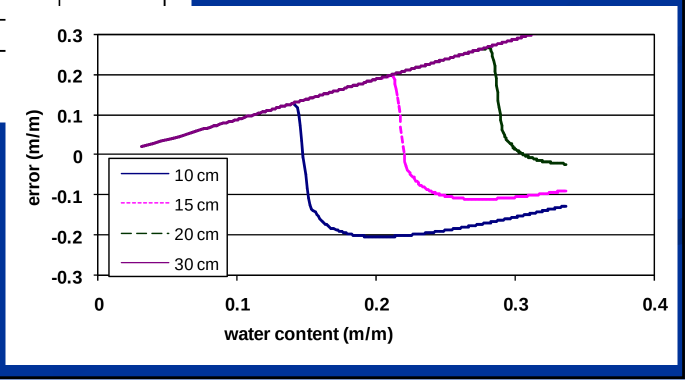
Infiltration Method



Water content with depth in a 30 cm deep container



Error generated from assuming water content at given depth is the same as average water content

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Infiltration Method

- Discussion
  - Advantages
    - Simple
    - Low labor intensity
  - Disadvantages
    - Extremely high errors: basically does not work
    - Slow
    - Relies on even water distribution
    - Does not account for water moving below sensor measurement volume (collected at the bottom of the container)

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Surface Evaporation Method

- Basic procedure
  - Pack sensors in container of soil
  - Wet from bottom to saturation
  - Take sensor readings with container weight over time
  - Develop calibration curve
- Example
  - Center for Irrigation Technology (CIT, California State University Fresno) adopted as "SWAT" Protocol

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Surface Evaporation

- Advantages
  - Similar to field conditions
  - Automated
- Disadvantages
  - Slow (takes several weeks to complete)
  - Prone to bias
  - Soil cracking can cause significant error in results
    - Clay soil analyzed by CIT gave no useful results

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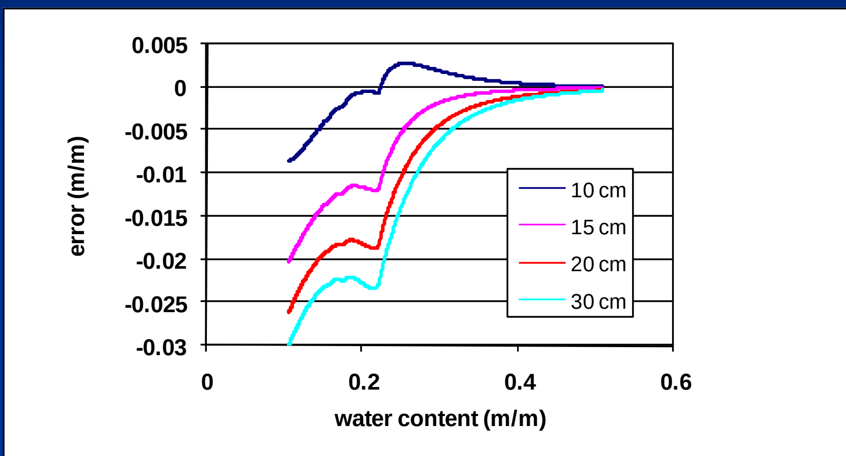
Surface Evaporation: Errors

- Thought:
  - Water does not evaporate evenly from all depths of a soil
    - Naturally, soil surface will lose more water than bottom of the container
  - What is the effect on a sensor measuring at some depth in the soil?
    - We modeled "ideal" water content with time at various depths in a container

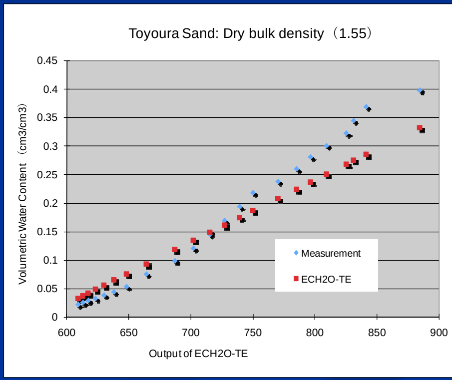
Bias in Surface Evaporation Calibration Technique



Simulated errors in water content measurement using the evaporation method for probes placed at 10, 15, 20 and 30 cm depths in a 30 cm deep soil column. The depth equal to 1/3 to column depth gives minimal error.

Surface Evaporation

- Model findings
  - Errors were less than expected
    - But this is ideal condition
  - Still, errors can be up to 3% VWC in measurement
  - Probably caused interesting shape of calibration curve



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Surface Evaporation & Transpiration

- Basic procedure
  - Pack soil and moisture sensors in a container with holes drilled in the bottom
  - Plant fast growing, deep rooting plant (rye grass and wheat have been used)
    - Plant roots will help take water evenly from soil profile
  - Weight container before wetting up for dry weight
  - Saturate soil from bottom and maintain soil moisture while plants grow
  - Allow to dry out while monitoring change in weight over time

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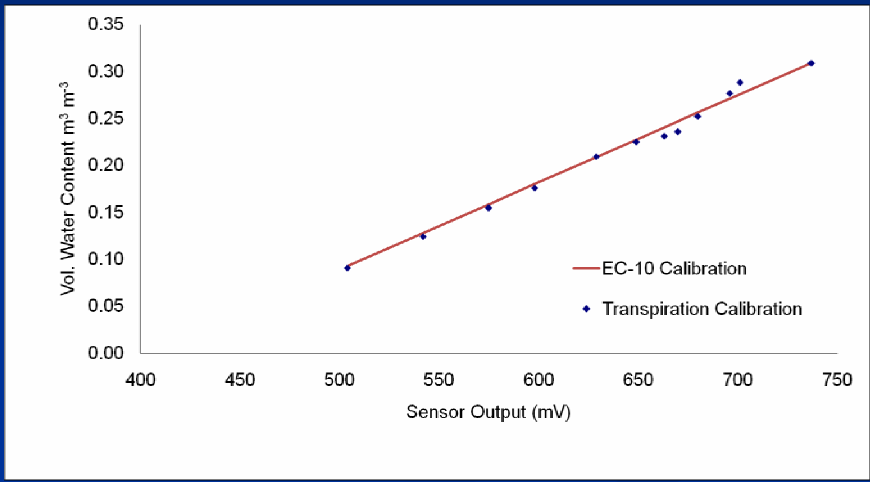
Surface Evaporation and Transpiration Technique Results



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Surface Evaporation and Transpiration

- Advantages
  - More uniform drying in soil
  - More representative of actual field situation
  - Data appear to agree well with pack and subsample technique
- Disadvantages
  - Very time consuming
  - Requires grow lights, plants, regular maintainance
  - Limited number of calibration tests at same time

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Pack and Subsample

1. Basic procedure
   1. Pore air dry soil an appropriate container
   2. Carefully pack soil around sensor (in layers)
   3. Take sensor reading
   4. Take soil subsample using a small volume sampling device (10 ml)
   5. Add enough water to soil to increase water content around 5%
   6. Repeat steps 2 through 5
   7. Weigh, dry, and weigh subsamples
   8. Graph volumetric water content vs. sensor output

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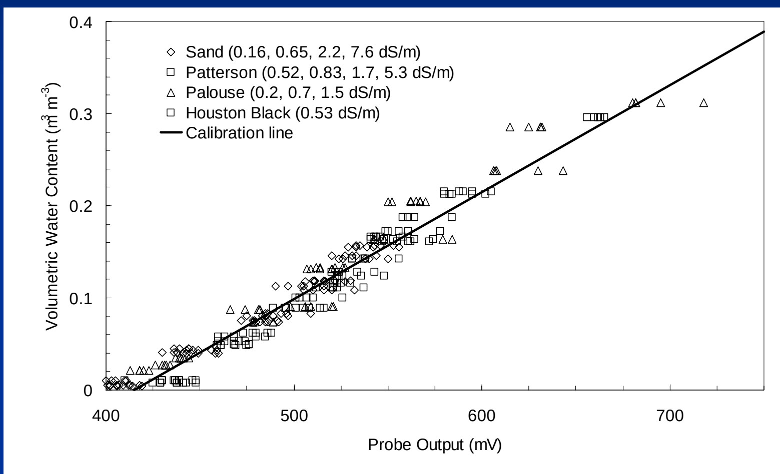
Pack and Subsample Results



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Pack and Subsample

- Advantages
  - Simple
  - Very fast (usually takes less than 2 hours)
  - Allows sampling of many soil types and electrical conductivities
  - Only approved by Methods of Soil Analysis: Physical Methods
- Disadvantages
  - Does not account for heterogeneity of the soil (rocks, cracks, etc.)
  - Not very representative of field conditions

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Calibration Summary

- Several techniques proposed for soil moisture sensor calibration
- All techniques will provide good data with careful experimentation and knowledge of pitfalls
- Pack and subsample is the technique that we have determined provides the best data and takes the shortest time
- Field sampling has shown data results consistent with lab calibrations

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Temperature Sensitivity

- Temperature affects the dielectric permittivity of the soil
  - Dielectric of water decreases with increasing temperature
  - Dielectric sensor tests have shown positive correlation with temperature
    - Could be caused by temperature effects on the imaginary portion of the dielectric through effect on electrical conductivity

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Temperature Effects

- Dielectric permittivity is the sum of real and imaginary terms

$$\varepsilon_r = \varepsilon' - j\varepsilon''$$

- Imaginary term combines a dielectric loss term (ε_l”) and an electrical conductivity term (σ)

$$\varepsilon'' = \varepsilon_l'' + \frac{\sigma}{\omega \varepsilon_o}$$

- Imaginary dielectric
  - New theories say source of temperature effects may come from dielectric loss and soil electrical conductivity through imaginary term

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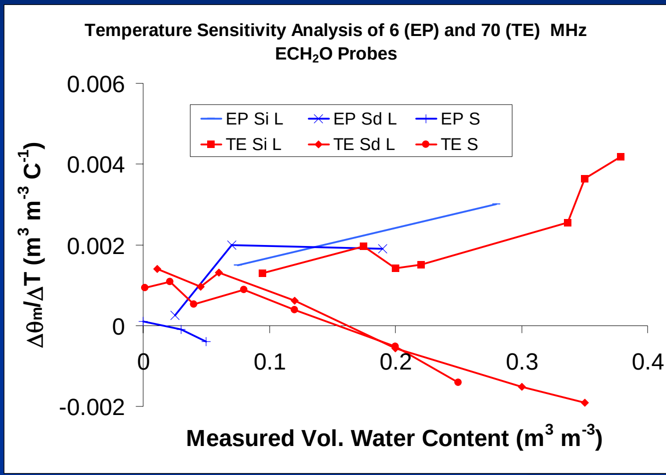
Temperature Effects for 1st vs. 2nd Generation Sensors



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Current and Future Temperature Work

- Current sensors show only a small improvement in temperature sensitivity
  - However, test have show that decreased sensitivity to EC have made temperature sensitivity very predictable within one soil type
  - Considerable success has been achieved in post processing data
- Future sensor development will focus on measuring real and imaginary dielectric separately
  - Literature shows considerable decrease in temperature sensitivity
- Initial investigations into this area look promising
  - However, this improvement will result in a more expensive sensor

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Future Work

- Decagon has hired an addition to science team to work on dielectric measurement
  - 35 years of experience in electrical engineering
- We look forward to pushing the science toward improved measurement techniques and multi-function sensors

Water Potential : Matric Potential Sensor

- History
  - Started project five years ago
    - Attempted to find matrix that had wide, reproducible pore size distribution
    - Create a dielectric sensor that would measure the water content of a static ceramic matrix and give water potential through knowledge of its moisture release curve
  - First generation (beta test) sensors had several difficulties
    - EM field reached beyond matrix so somewhat sensitive to surroundings
    - Dielectric sensor was sensitive to soil salinity
    - Differences in matrix thickness could cause sensor to sensor variation
    - Disks to protect ceramic limited water flow in

Matric Potential Sensor

- History (continued)
  - Second generation sensor
    - Used feedback from Dr. Mizoguchi, Dr. Cho and others who tested sensor
    - Changed to higher frequency circuitry to reduce EC sensitivity
    - Confined EM field between two perforated stainless steel plates
      - Holes allowed water to flow freely into ceramic
    - Added ability to shift sensor output
      - Allows each sensor to be dialed to same saturation reading

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Calibration and Testing

- Calibration has been a challenge
  - Difficult to use standards that covers range from 0 to 0.5 MPa
    - Tensiometer: 0 to 0.08 MPa
    - Pressure plate: 0 to 0.5 MPa
      - Problem: slow to equilibrate,
    - Dew point water potential: 0.1 to 300 MPa
      - Accuracy +/- 0.1 MPa from 0 to 0.5 MPa
- Current calibration method
  - 5 bar pressure plate
  - Extended range tensiometer

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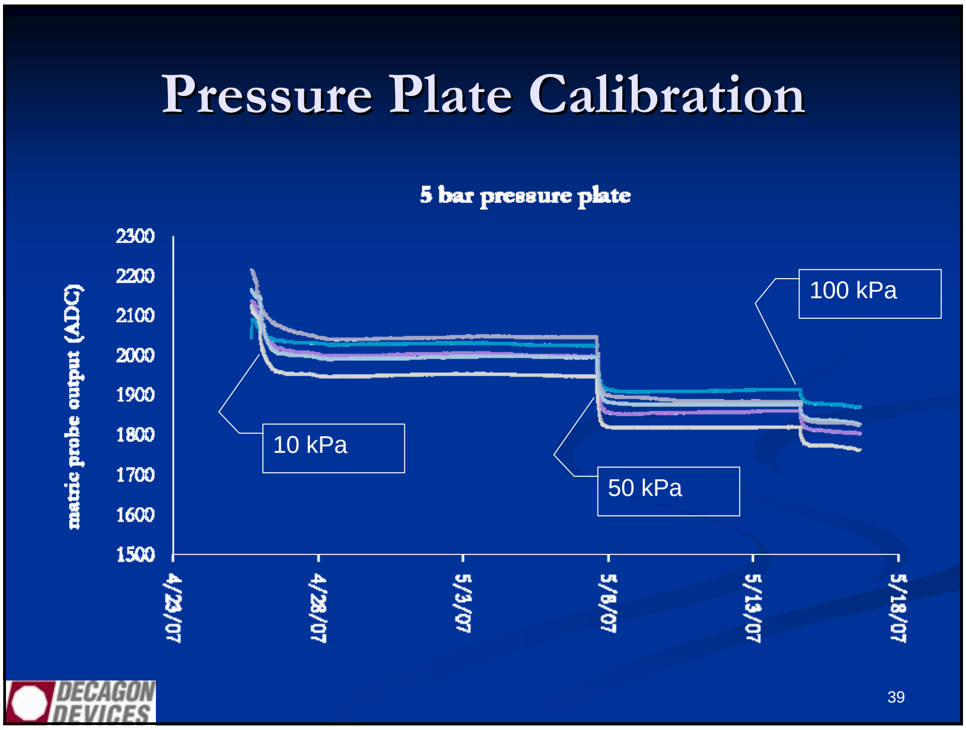
Pressure Plate Calibration
5 bar pressure plate
matric probe output (ADC)
2300
2200
2100
2000
1900
1800
1700
1600
1500
4/23/07
4/28/07
5/3/07
5/8/07
5/13/07
5/18/07
10 kPa
50 kPa
100 kPa
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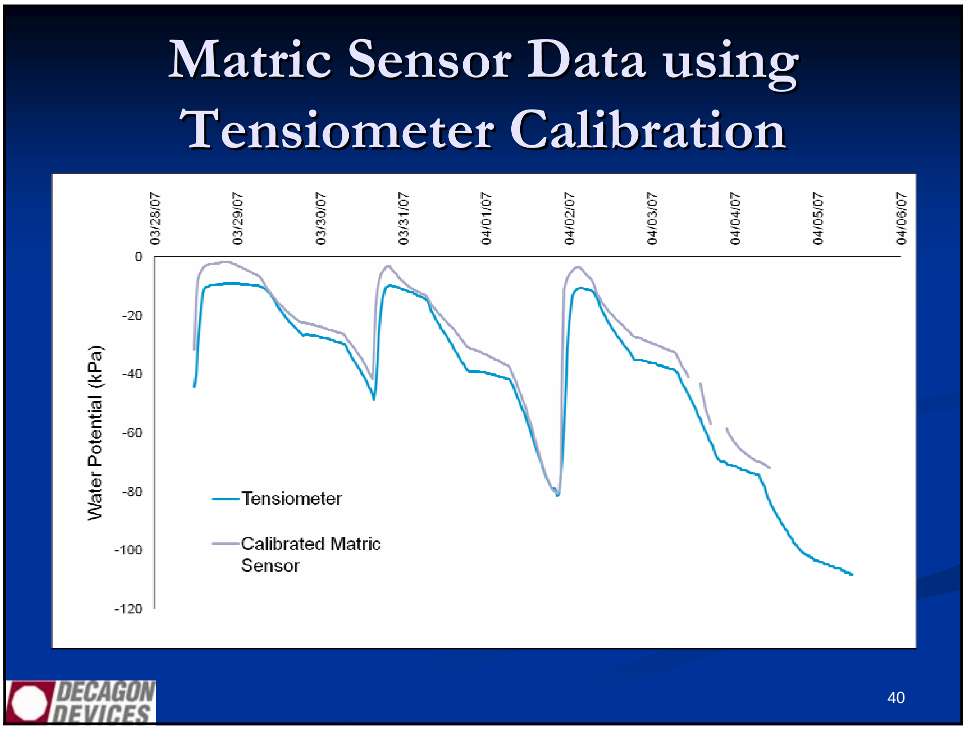
Matric Sensor Data using Tensiometer Calibration
03/28/07
03/29/07
03/30/07
03/31/07
04/01/07
04/02/07
04/03/07
04/04/07
04/05/07
04/06/07
Water Potential (kPa)
0
-20
-40
-60
-80
-100
-120
Tensiometer
Calibrated Matric Sensor
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Summary of Matric Sensor

- Calibration
  - So far sensor calibration looks quite positive
    - High sensitivity in near saturation range
    - Good agreement and repeatability with tensiometer
    - Reasonable response time
    - Reasonable repeatability between sensors
  - Once we have a satisfactory calibration we will release the sensor to market

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Decagon in Space: Martian Soil Science

Phoenix Scout Mission to Mars

- Joint project with Jet Propulsion Laboratory (NASA) and various universities
- Launches: August this year (2007)
  - 9 month journey
  - lands 2008
- Stationary lander (not like rovers)
- Mission Goals
  - Search for subsurface ice and clues to its origin
  - Search for evidence of past or episodic liquid water

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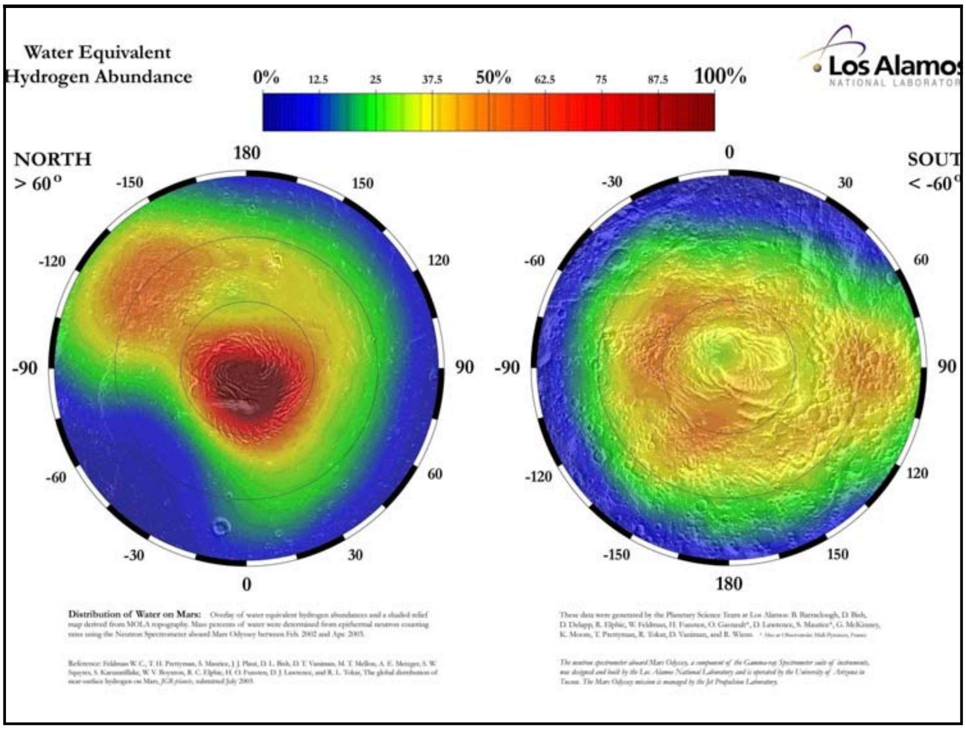

Thermal and Electrical Conductivity Probe (TECP)

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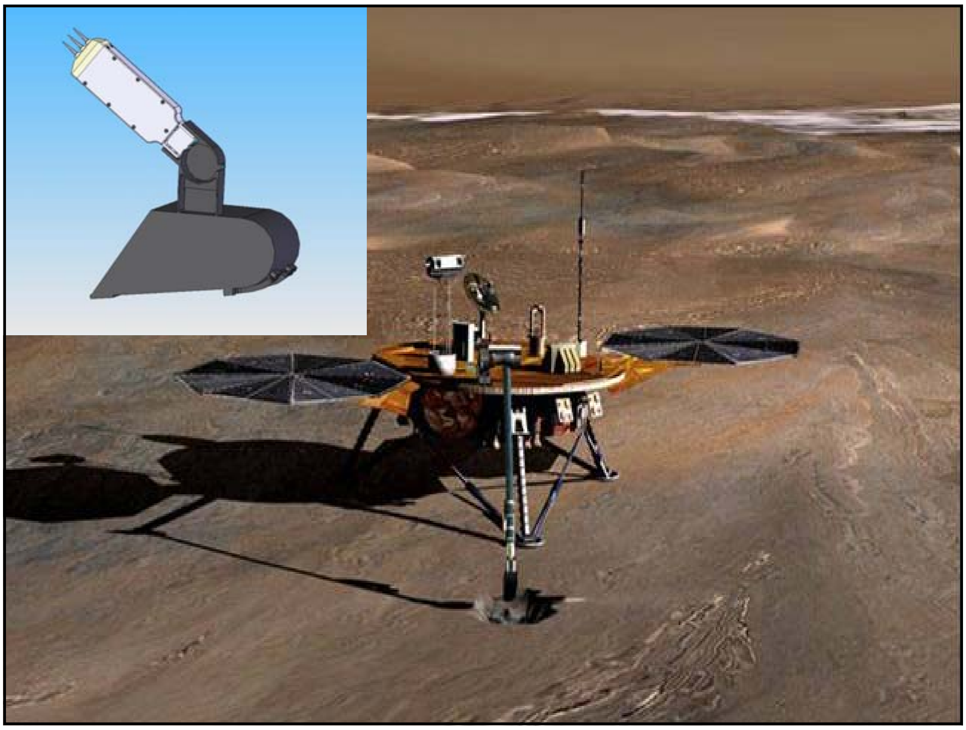

Mars Mission Status

- On schedule to launch in August
  - Decagon sensor is bolted to lander arm and system is being prepared for launch
  - Even NASA makes mistakes
    - Burned up our flight unit by plugging TECP in wrong!
- Next work will be interpreting data from landing next year
  - (we are hoping it lands safely)

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