ERT imaging of root water uptake

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Objectives

Trial the use of electrical resistivity tomography (ERT) for mapping spatial and temporal variation in soil moisture, ultimately for evaluating the extent of root water uptake

Basics

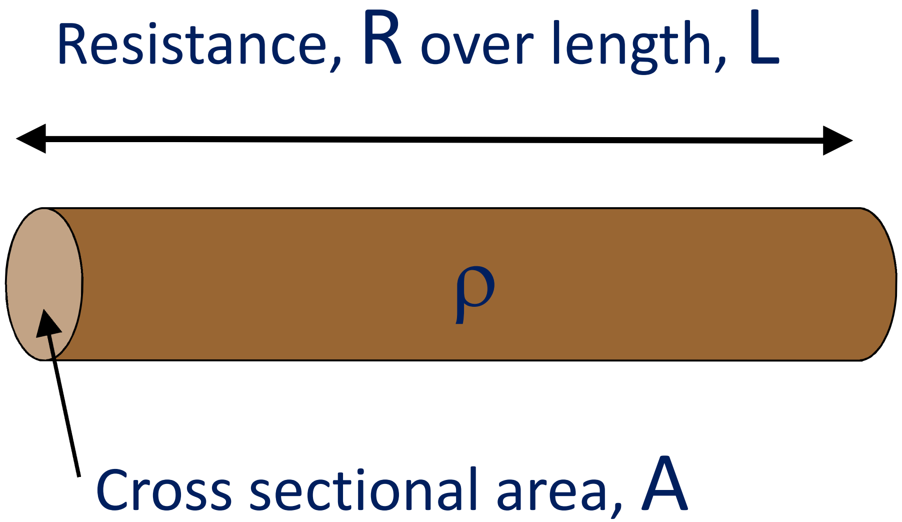
Electrical resistivity

Resistivity (ρ) in Ωm or Ohm-m (intrinsic property)

$$\text{Resistivity } (\rho) = 1 \,/\, \text{conductivity } (\sigma)$$

$$\rho = 1/\sigma \quad 1\ \Omega\text{m} \equiv 1\ \text{S/m}$$

$$\rho = \frac{R\,A}{L}$$



Soil Resistivity

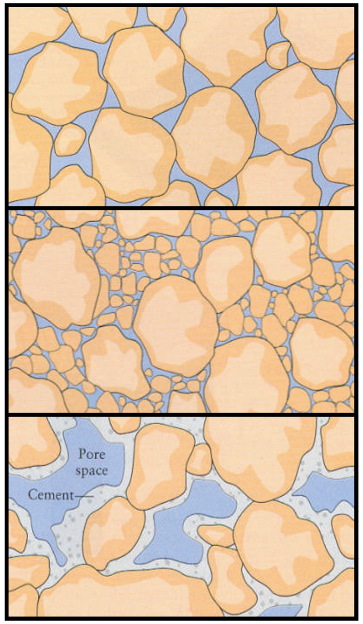
For soil resistivity depends on physical and chemical properties:

- degree of saturation (water content)
- electrical resistivity of fluid (solute concentration)
- texture (particle size distribution, mineralogy)
- arrangement of voids (porosity, pore size distribution and pore connectivity)
- temperature.

Hydrogeophysical relationships

Resistivity/conductivity

Archie's empirical law (Archie, 1942) is the most widely used.



$$\sigma = \sigma_w \phi^m S_w^n$$

Fluid conductivity — Porosity — Saturation

Formation factor:

$$F = \frac{\sigma_w}{\sigma} = \phi^{-m}$$

Cementation index:

$$1.5 \le m \le 3$$

(typically)

Saturation index:

$$1.3 \le n \le 2$$

(typically)

Valid for medium or coarse-grained soils.

Hydrogeophysical relationships

If clay fraction is significant then we must also account for surface conductivity

Pore water conductivity

particle geometry

Texture/particle size

$$\sigma = \phi^{m} S_{w}^{n} \left(\sigma_{w} + \frac{BQ_{v}}{S} \right)$$

porosity

saturation

B Equivalent ionic conductance of the clay exchange cations

Q_v Effective clay content

Hydrogeophysical relationships

But note that changes in moisture content will be easier to interpret – if fluid conductivity is constant (or temperature compensated)

Pore water conductivity

particle geometry

Texture/particle size

$$\sigma = \phi^{m} S_{w}^{n} \left(\sigma_{w} + \frac{BQ_{v}}{S} \right)$$

porosity

saturation

Resistivity imaging

Aim: Image underground soil moisture patterns both spatially and temporally using ERT.

Principle: Transmit current, *I* through two electrodes and measure a voltage with two other electrodes.

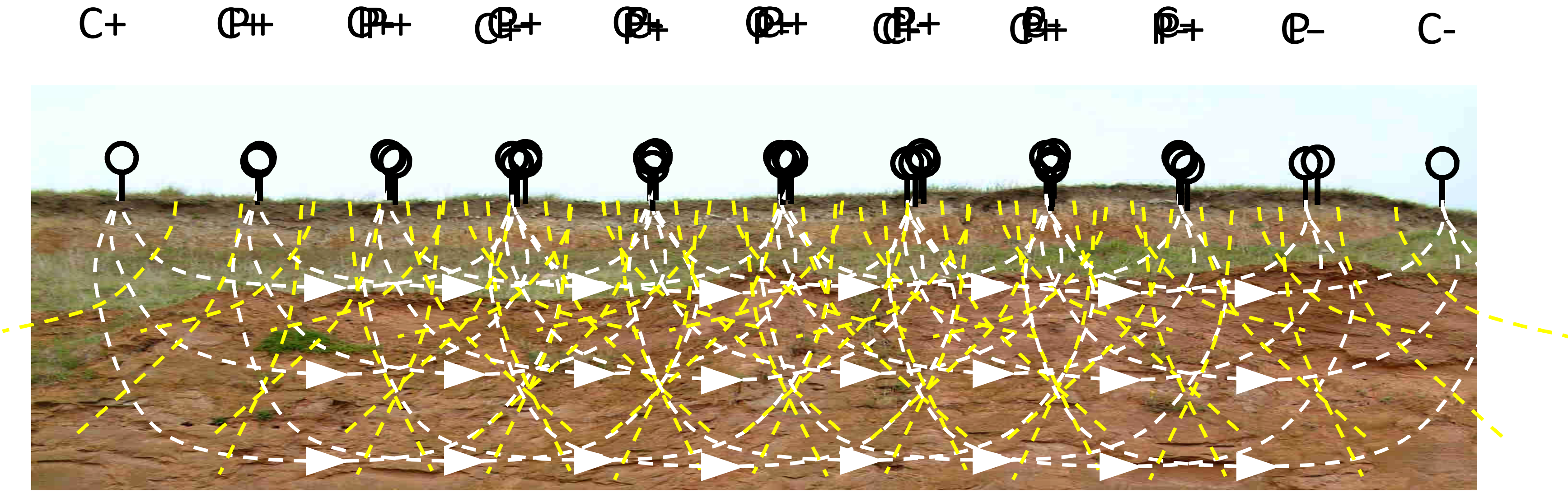
Apparent resistivity; $\rho = k\, V/I$, where k is a function of electrode spacing/geometry.

Resistivity pseudo section; contour plot of apparent resistivity data, using electrode distance and pseudo-depth parameter.

True resistivity section; contour plot of resistivity distribution obtained through the inversion of measured data (using non-linear parameter fitting scheme).

Electrical resistivity tomography (ERT)

Electrical resistivity tomography (ERT) provides an assessment of lateral and vertical structure

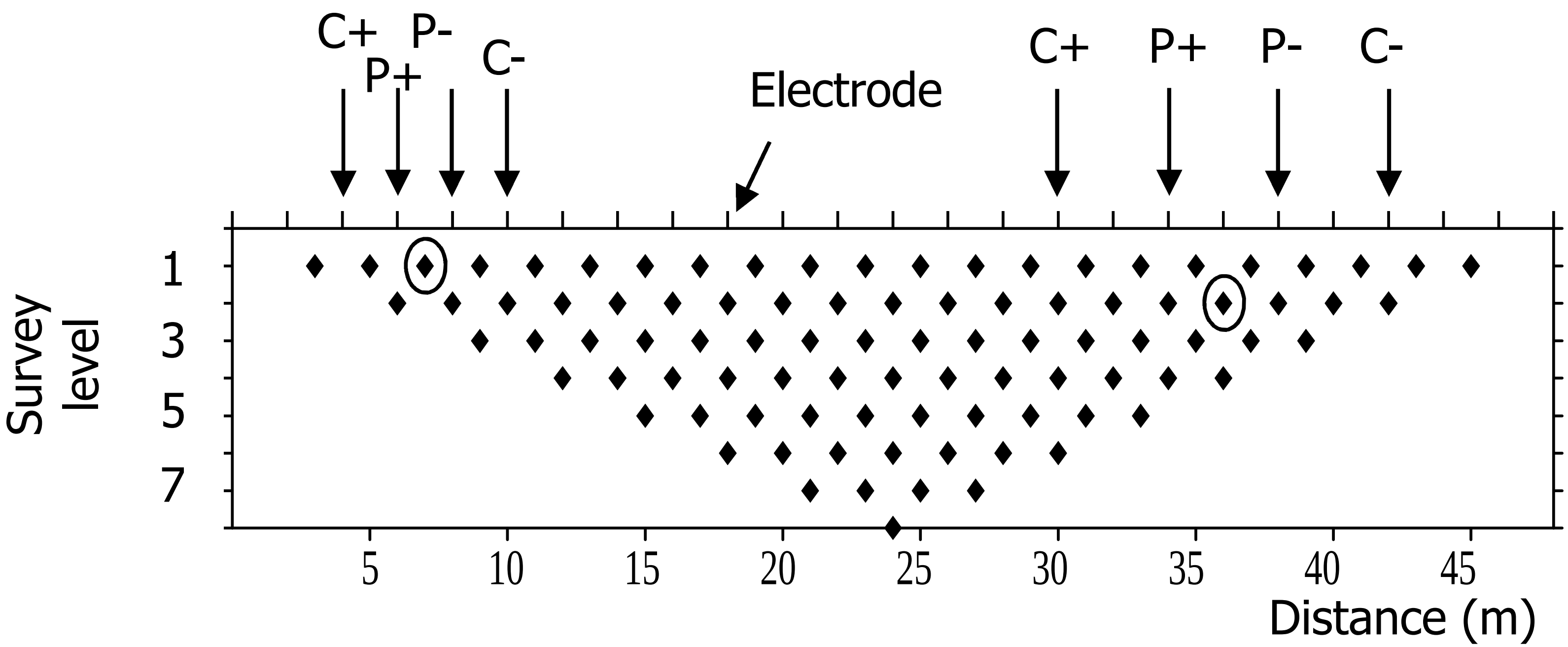


Current is injected between C+ and C-
The voltage difference between P+ and P- is measured

The voltage difference is a function of the current injected and the resistivity beneath the electrode array

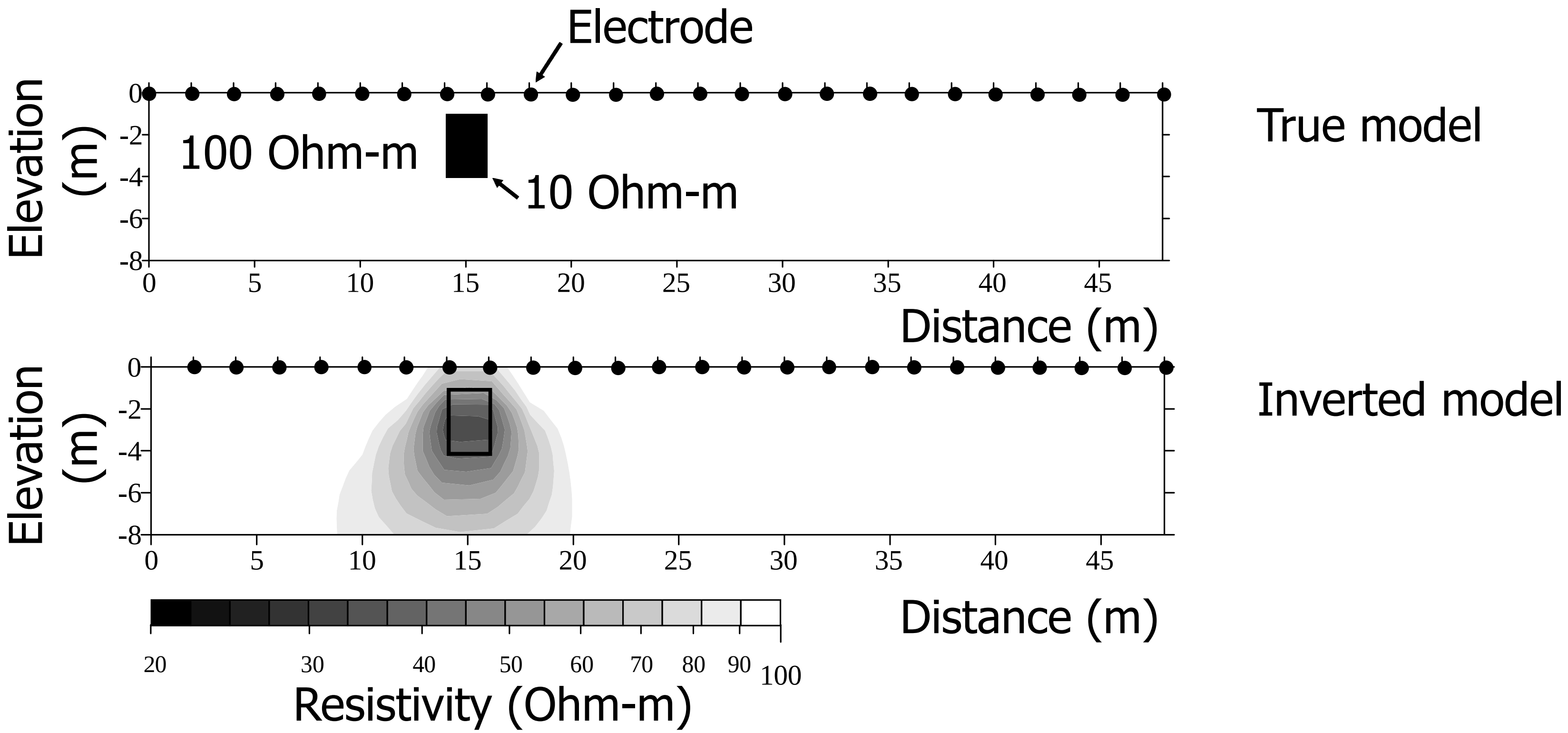
Electrical resistivity tomography (ERT)

We can change the electrode spacing and position in order to 'sense' the ground at different depths



Electrical resistivity tomography (ERT)

We then need to carry out *data inversion* in order to determine the distribution of resistivities that are consistent with the data

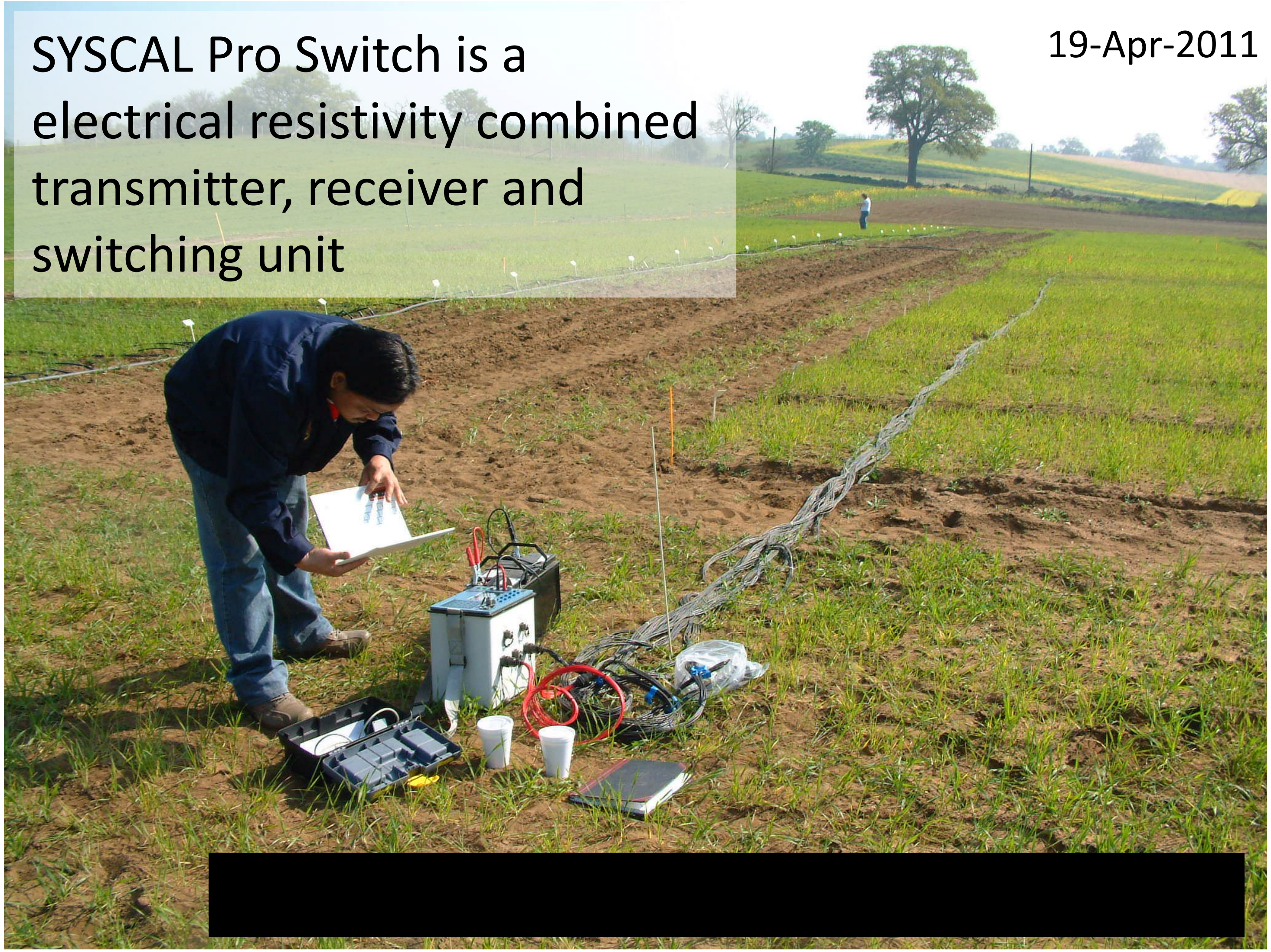


Pilot study: Wheat Drought Experiment

- Woburn, Sandy loam soil (drought prone)
- 12 wheat varieties x 2 levels of N (100 kg & 200 kg) x 2 water strategies (rain-fed (water stressed) & well-watered (irrigation tapes alternate rows)
- Plots 10 m x 1.8 m; 3 (reps) x 12 x 2 x 2 = 144 plots
- Two ERT arrays span 12 wheat plots (irrigated) & 12 un-irrigated and remain in-situ from February to mid August

2011 Pilot Study results

Electrical imaging at the Woburn site



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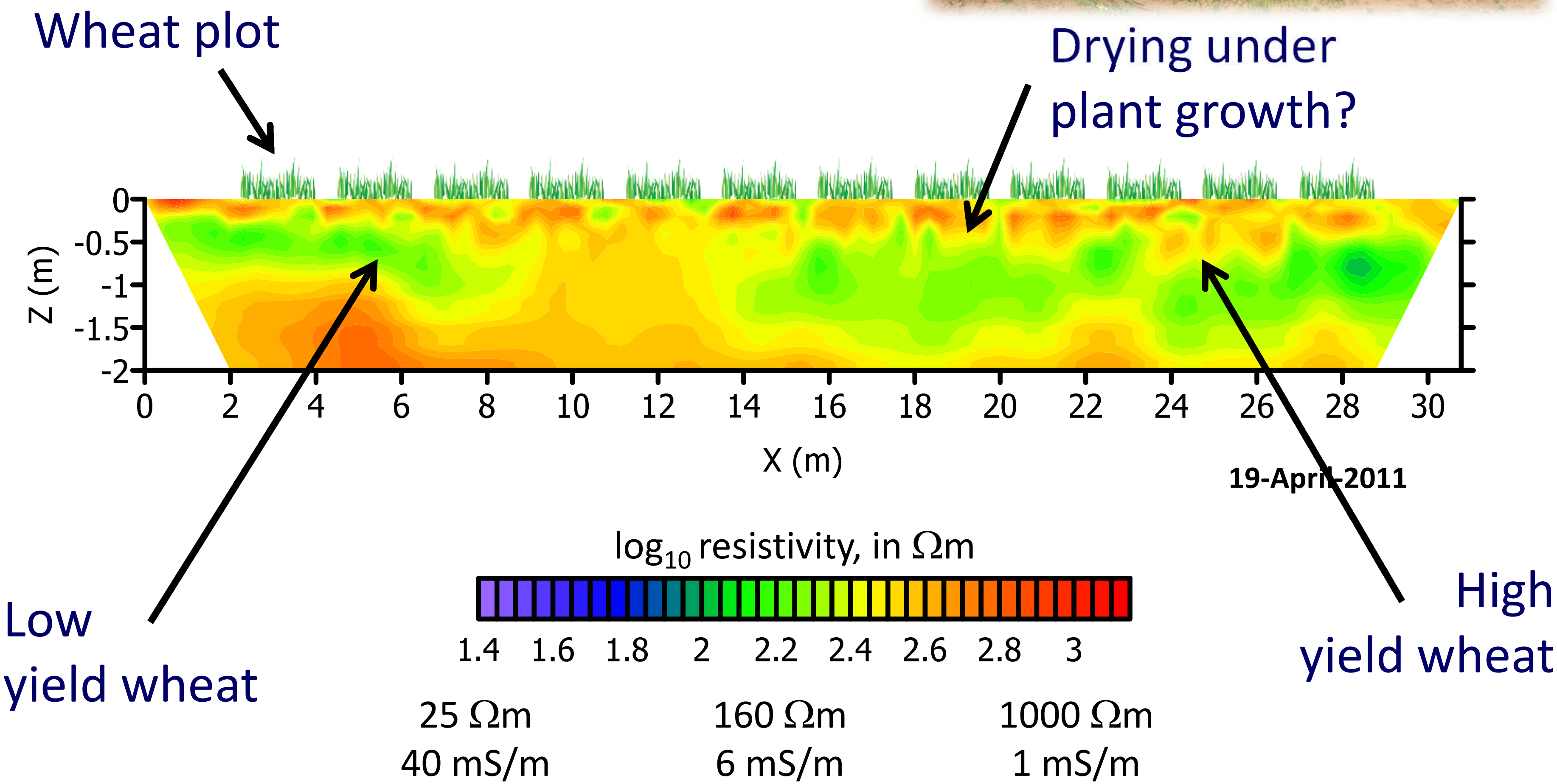
2011 results

Electrical imaging at the Woburn site

2011 results (static measurements)

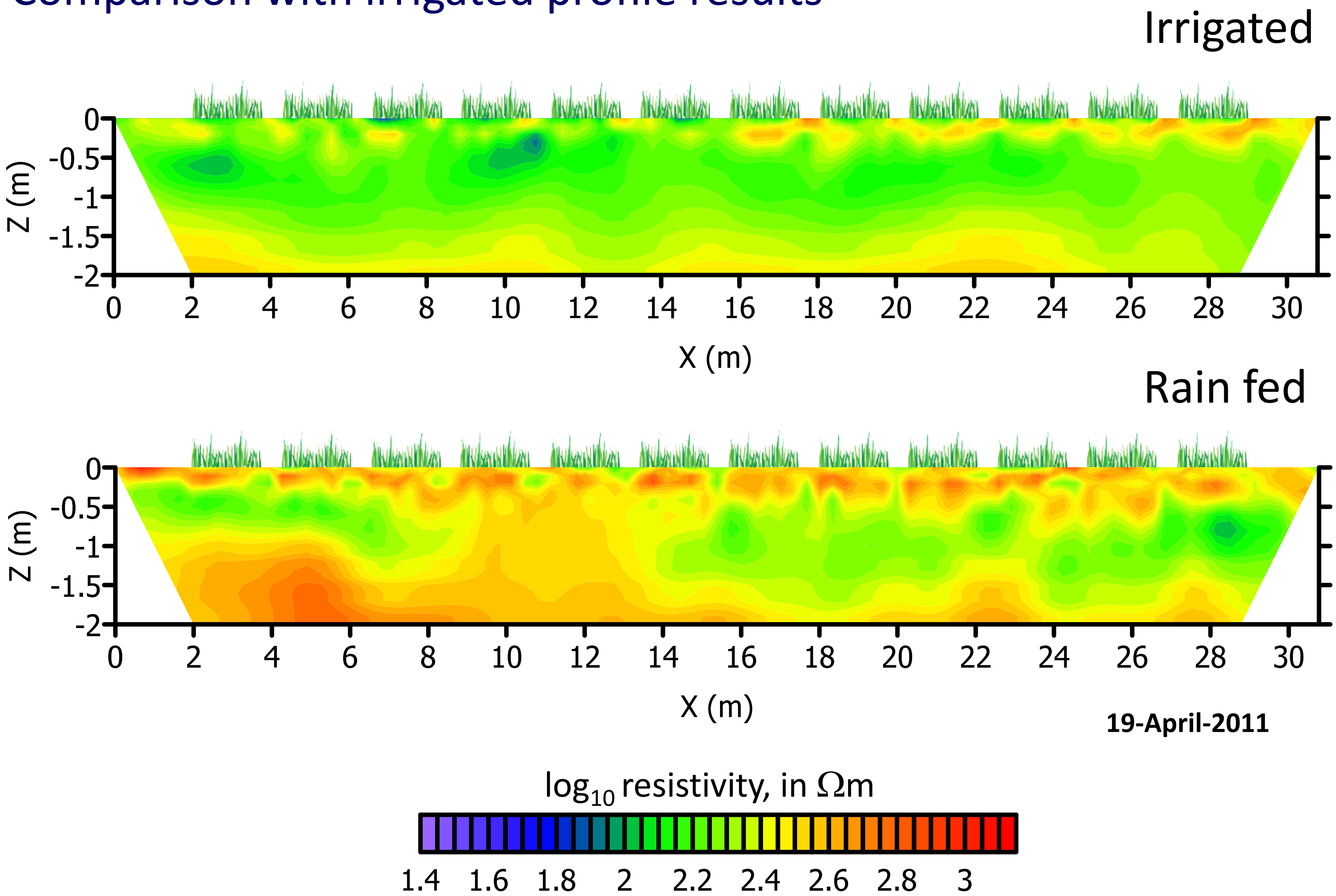
Electrical imaging at the Woburn site

Rain fed (unirrigated) results



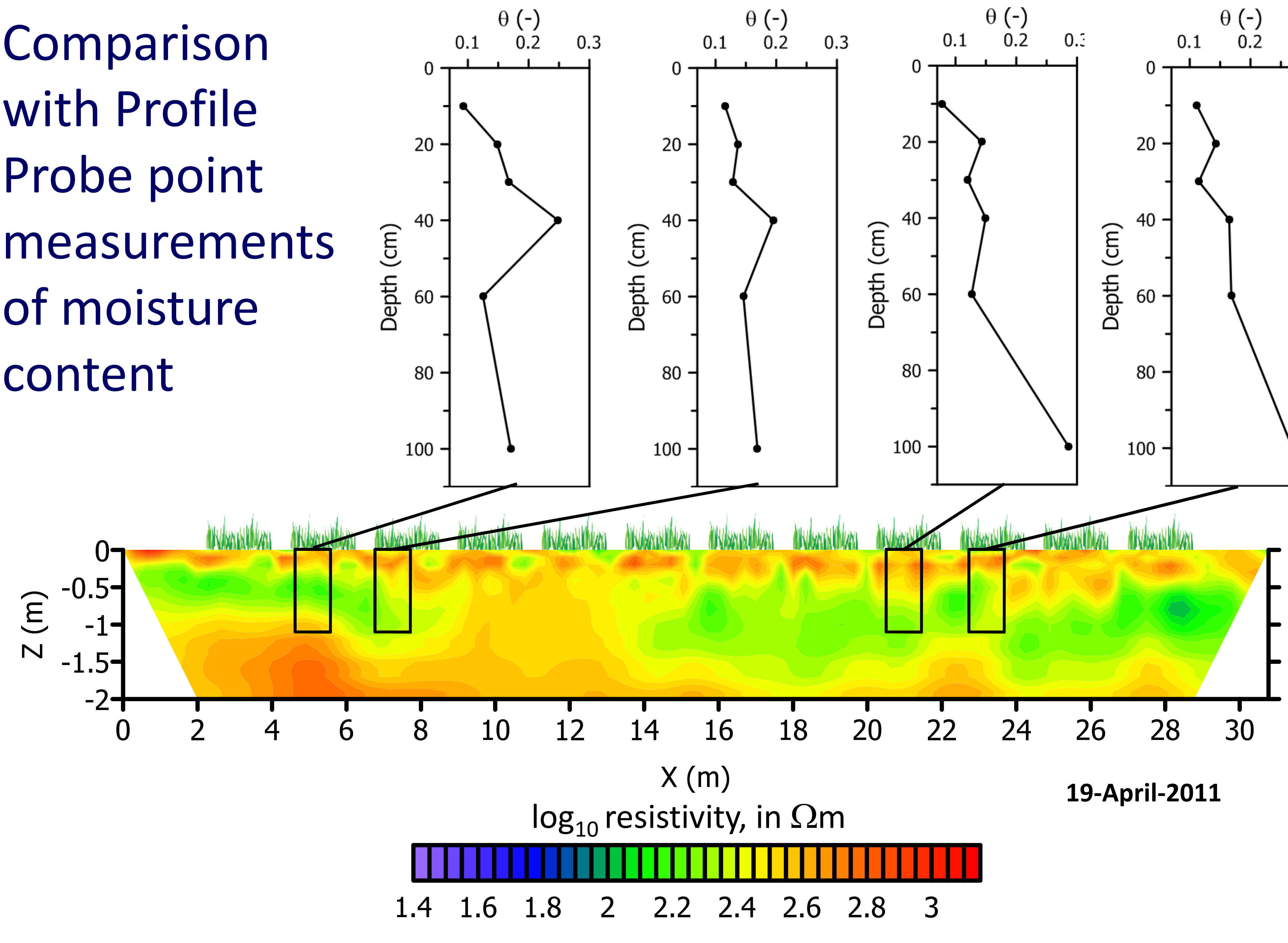
2011 results (static measurements)

Comparison with irrigated profile results



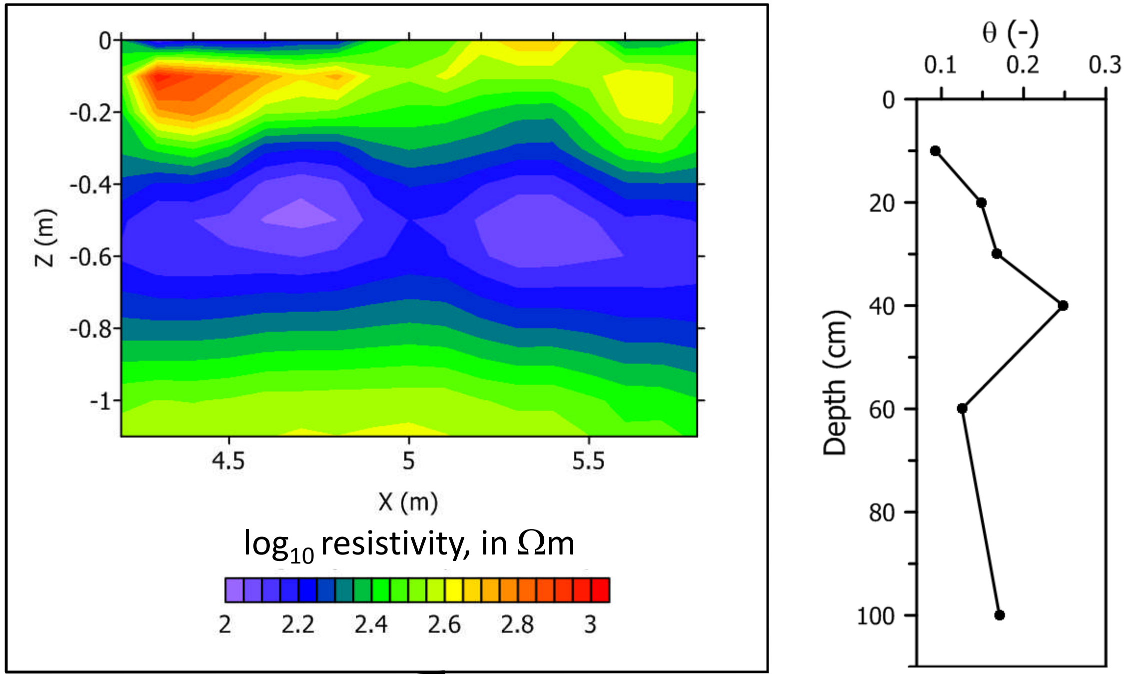
2011 results (static measurements)

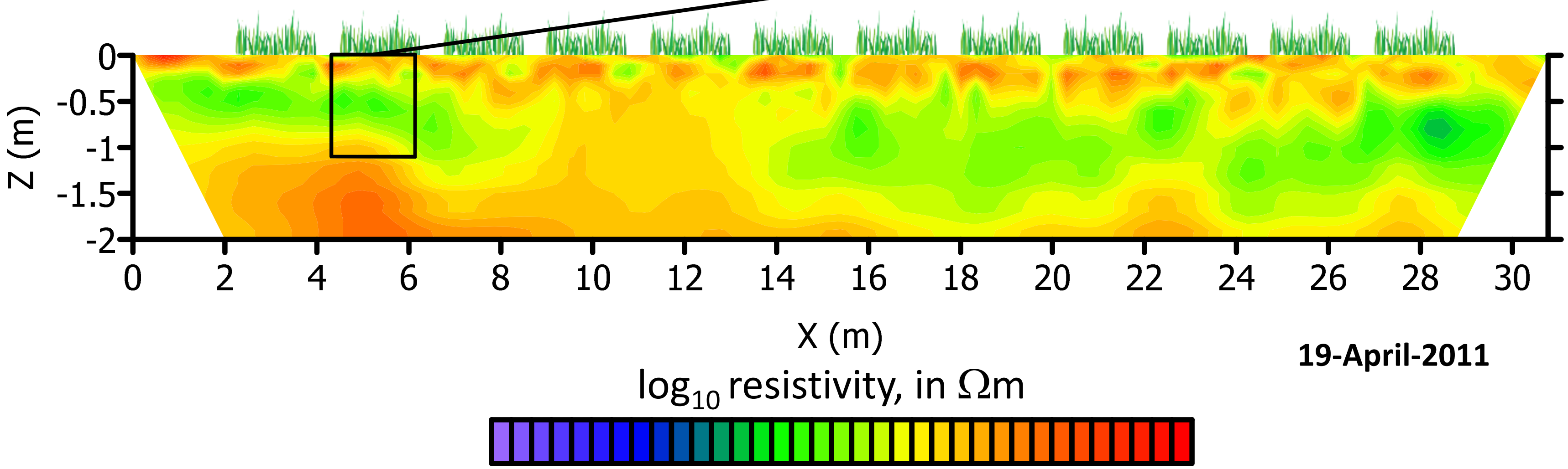
Comparison with Profile Probe point measurements of moisture content



2011 results (static measurements)

In some cases the comparison with point measurements is straightforward

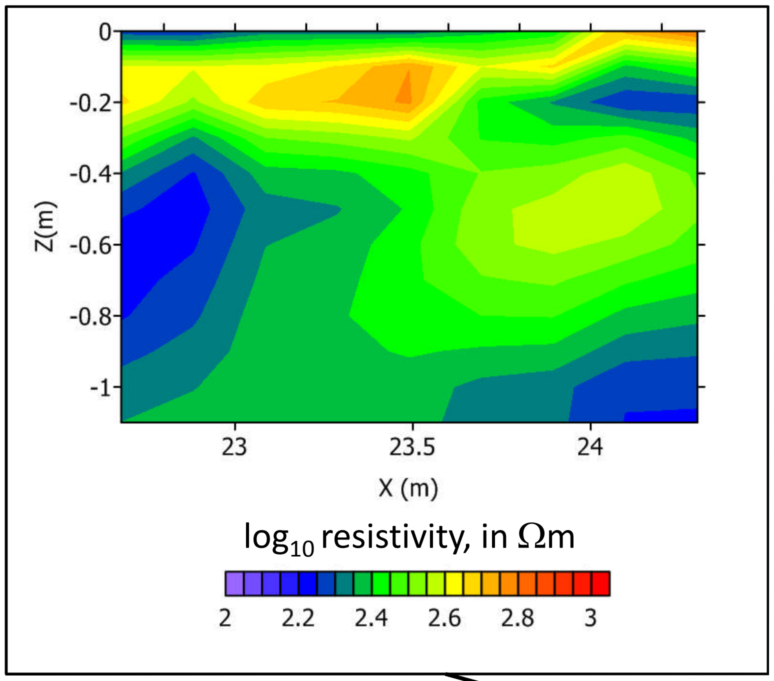


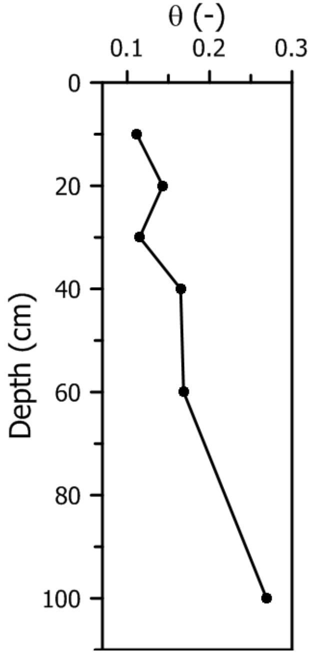


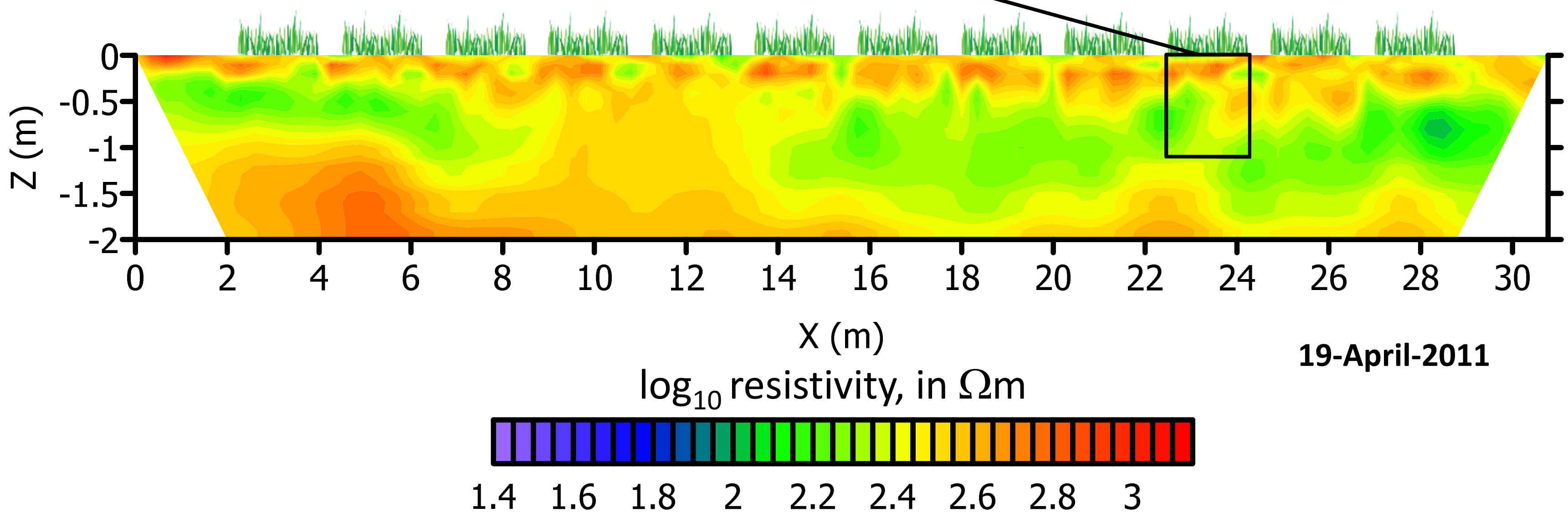
2011 results (static measurements)

But not in all cases.

What do we compare against here?







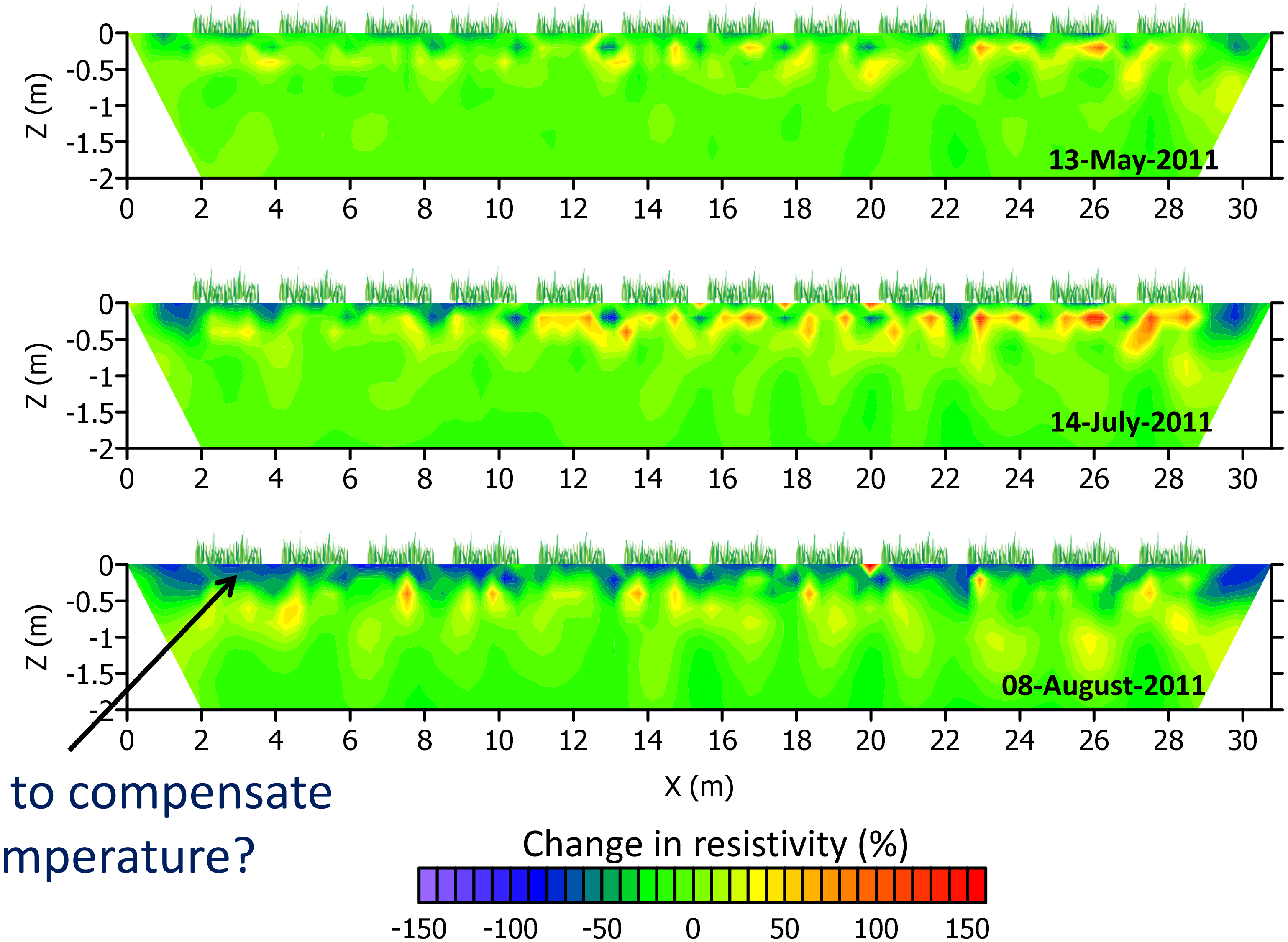
19-April-2011

2011 results (dynamic measurements)

2011 results (dynamic measurements)

Change in resistivity from 19-April-2011

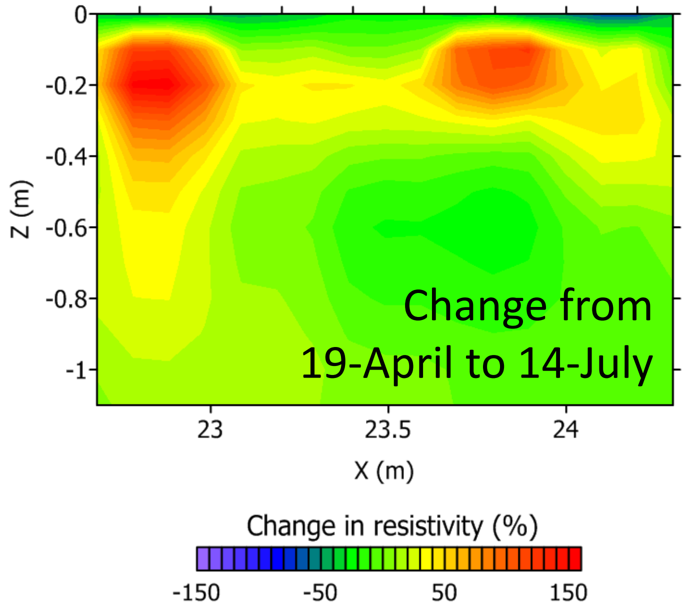
Rain-fed

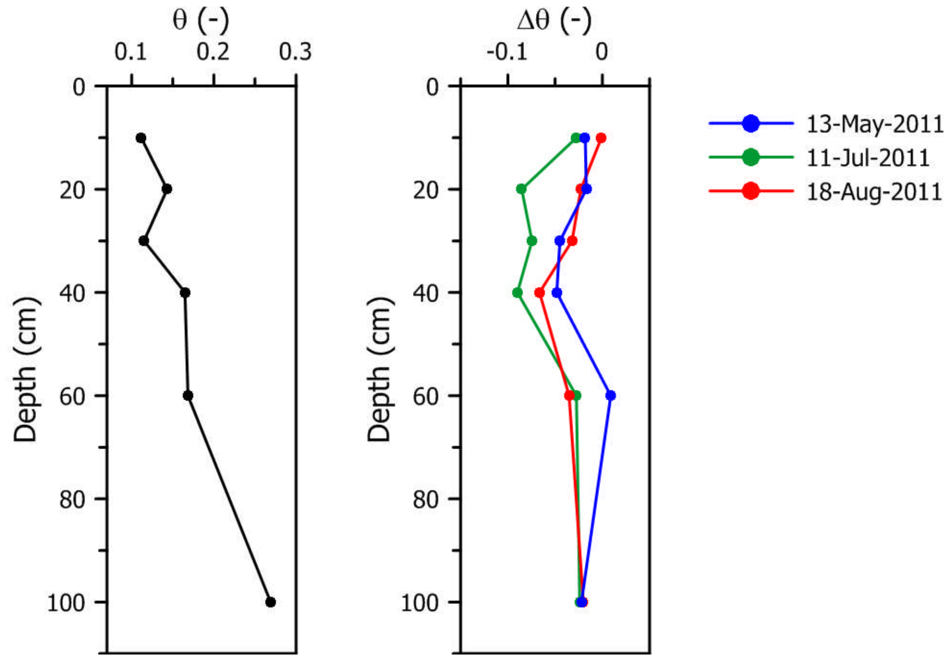


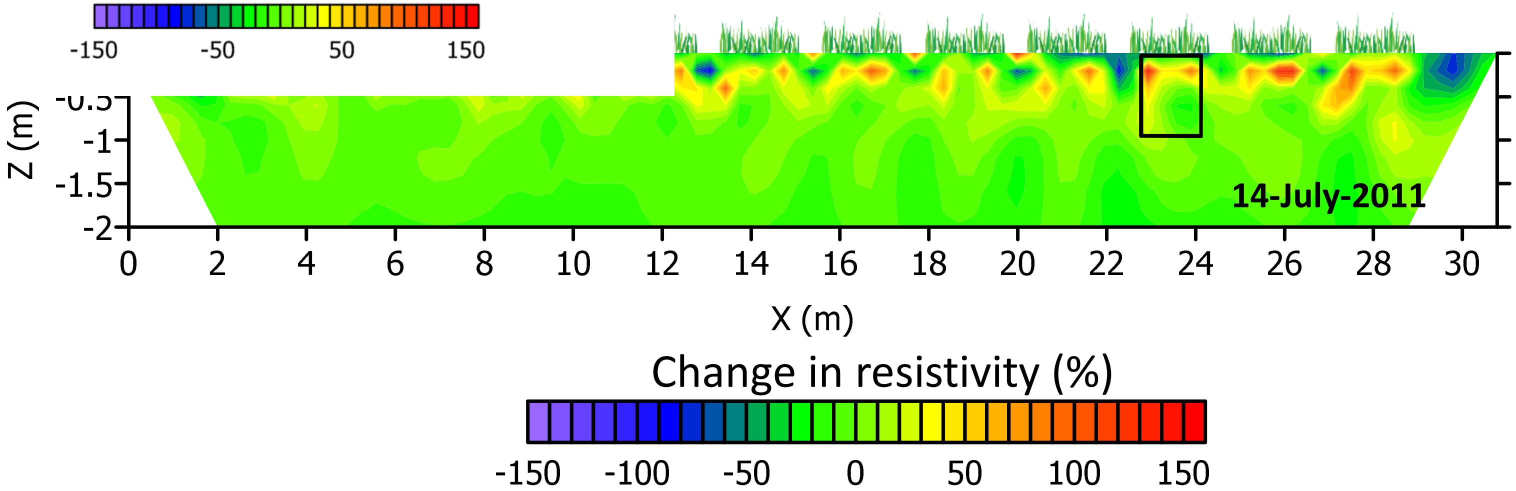
Need to compensate for temperature?

2011 results (dynamic measurements)

Change in moisture content
from 19-April-2011







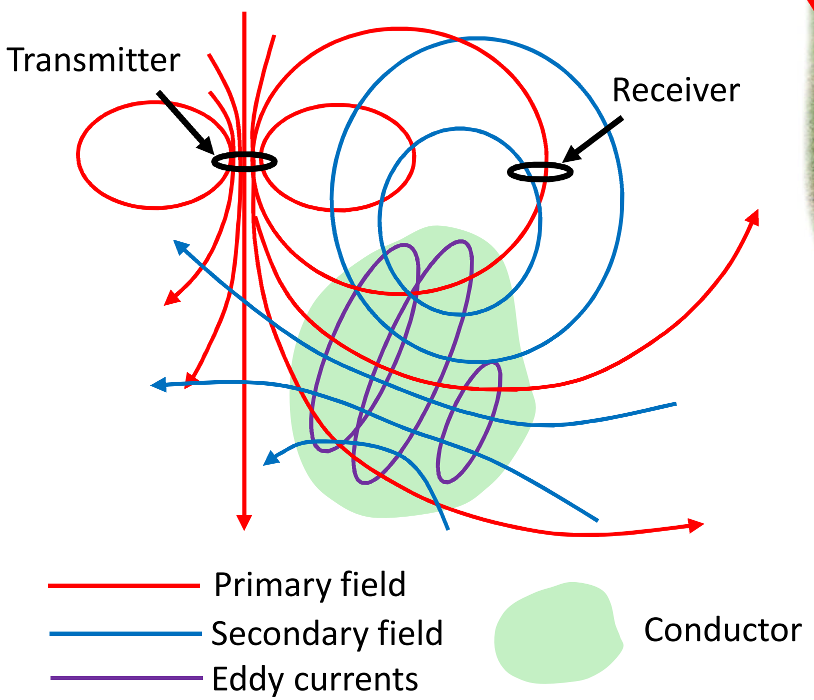
Current plans

Following promising results of water extraction patterns under experimental wheat crop, we aim to:

- Determine relationships between electrical conductivity and soil water content for test sites.
- Carry our ERT surveys on contrasting soils/plants (monitoring program) and assess ability to estimate moisture content from electrical conductivity.
- Apply EMI at same sites/conditions and develop a measurement protocol for its use in mapping soil water content variation at the field scale, and over time.

Electromagnetic Induction (EMI)

Transmitter creates primary electromagnetic field



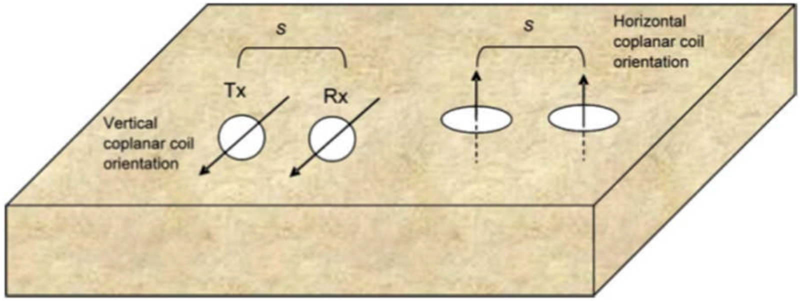
GPS tracks location

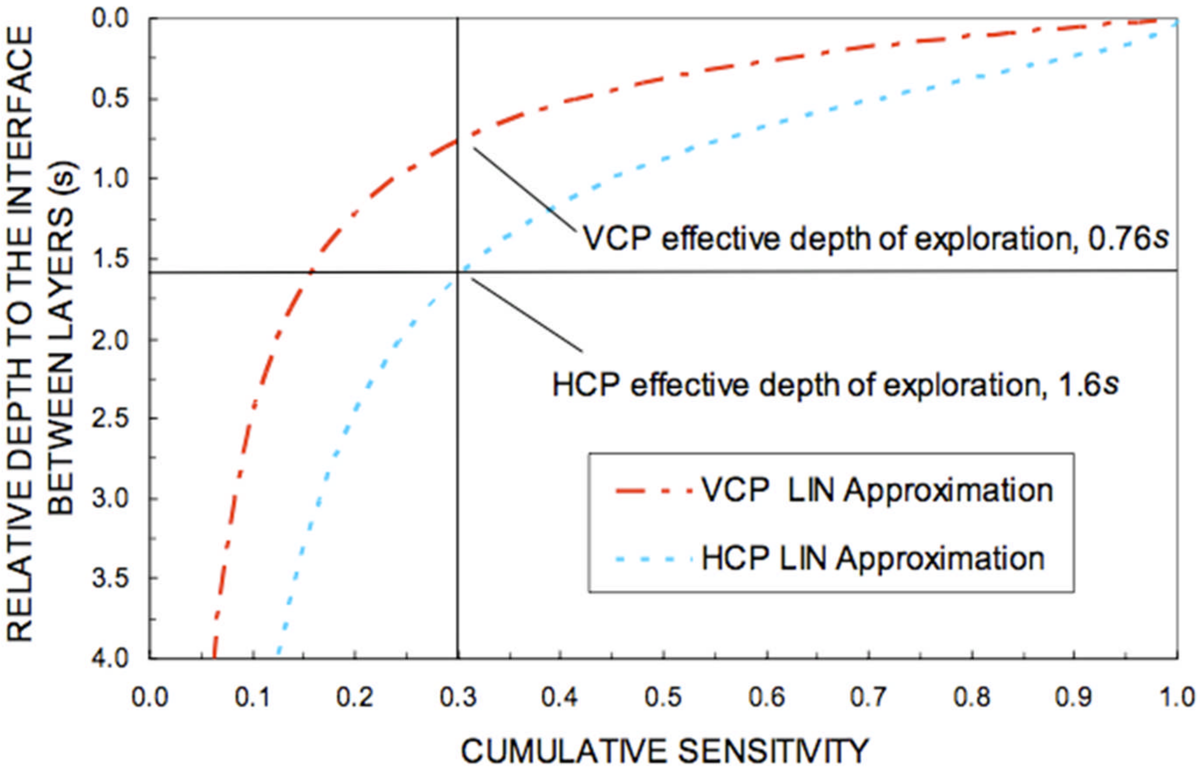
Data logger

Receiver measures secondary field created in the ground (which is a function of the electrical conductivity of the ground)

Electromagnetic Induction (EMI)

Orientation of the coils also allows us to change the depth of investigation





Callegary et al.(2007)

Electromagnetic Induction (EMI)

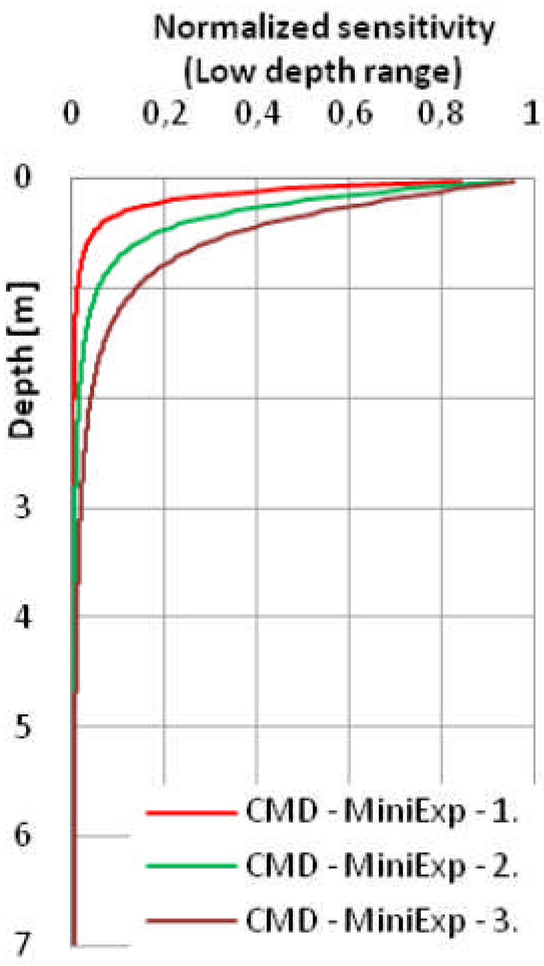
Traditionally EMI instruments have been deployed using one depth of investigation – useful for reconnaissance type surveys.

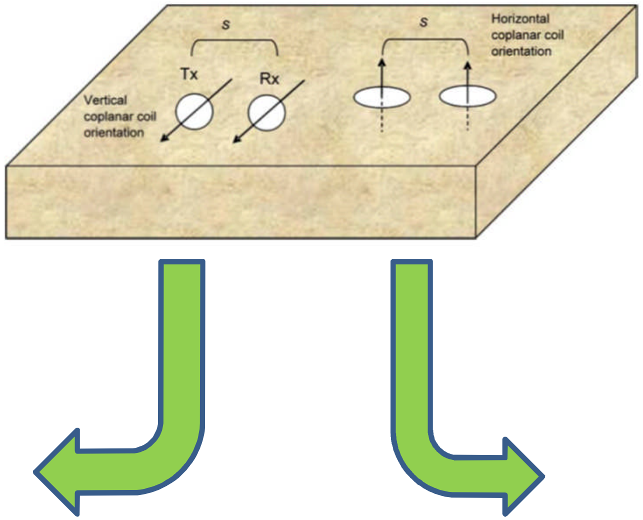
New instrumentation provides multiple coil separations – giving multiple depths at one location.

For example, the GF Instruments CMD Mini Explorer has coils at 1.18m, 0.71m and 0.32m in one instrument.

Electromagnetic Induction (EMI)

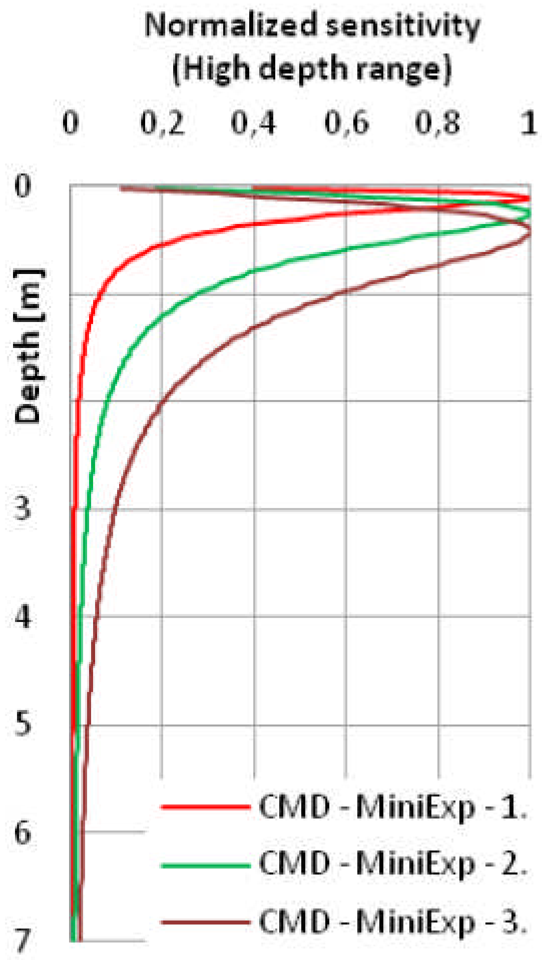
This gives us 6 possible depths of investigation





0.25m
0.5m
0.9m

0.5m
1.0m
1.8m

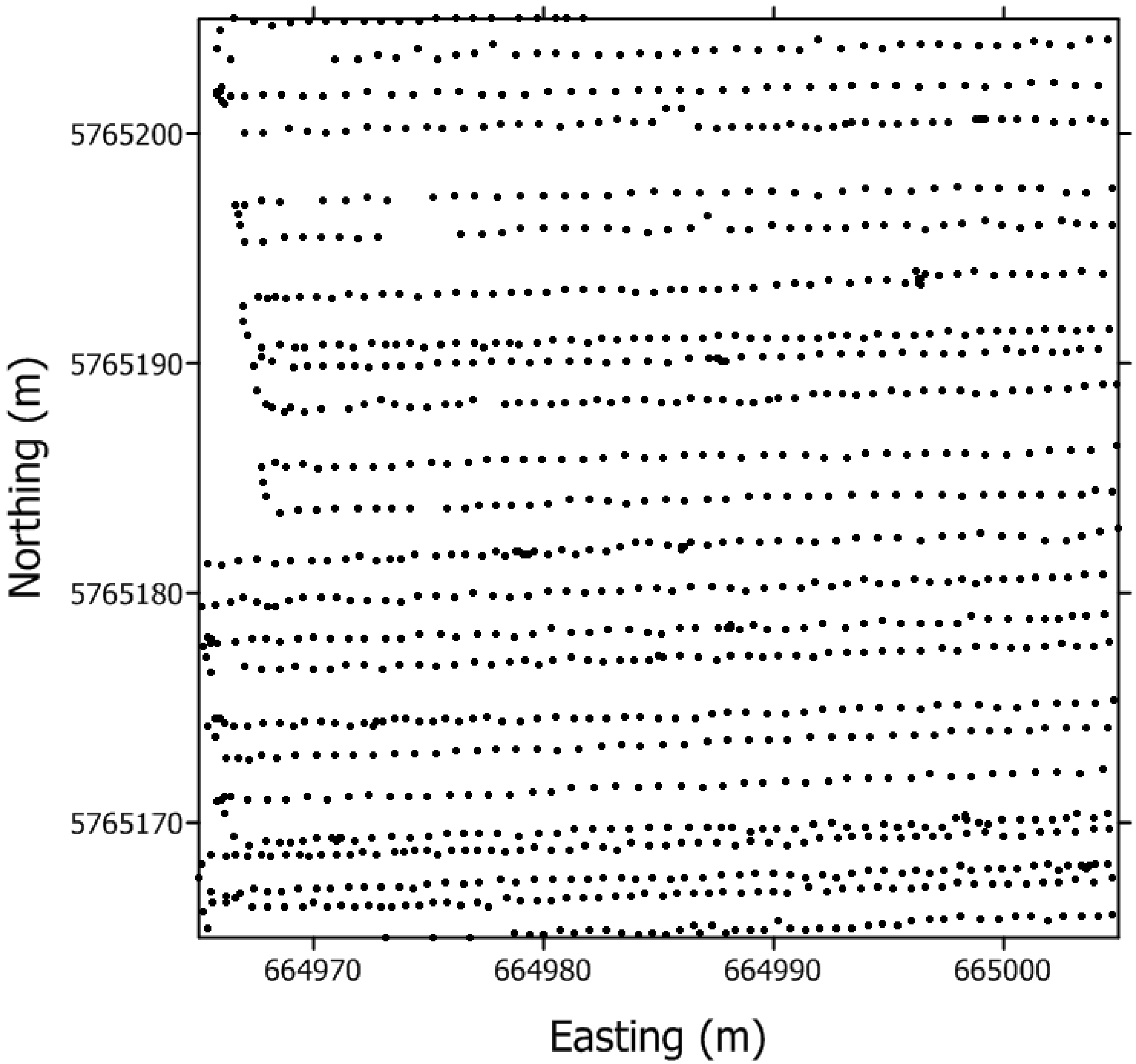


Example results

EMI at the Woburn site - Initial trials June 2012

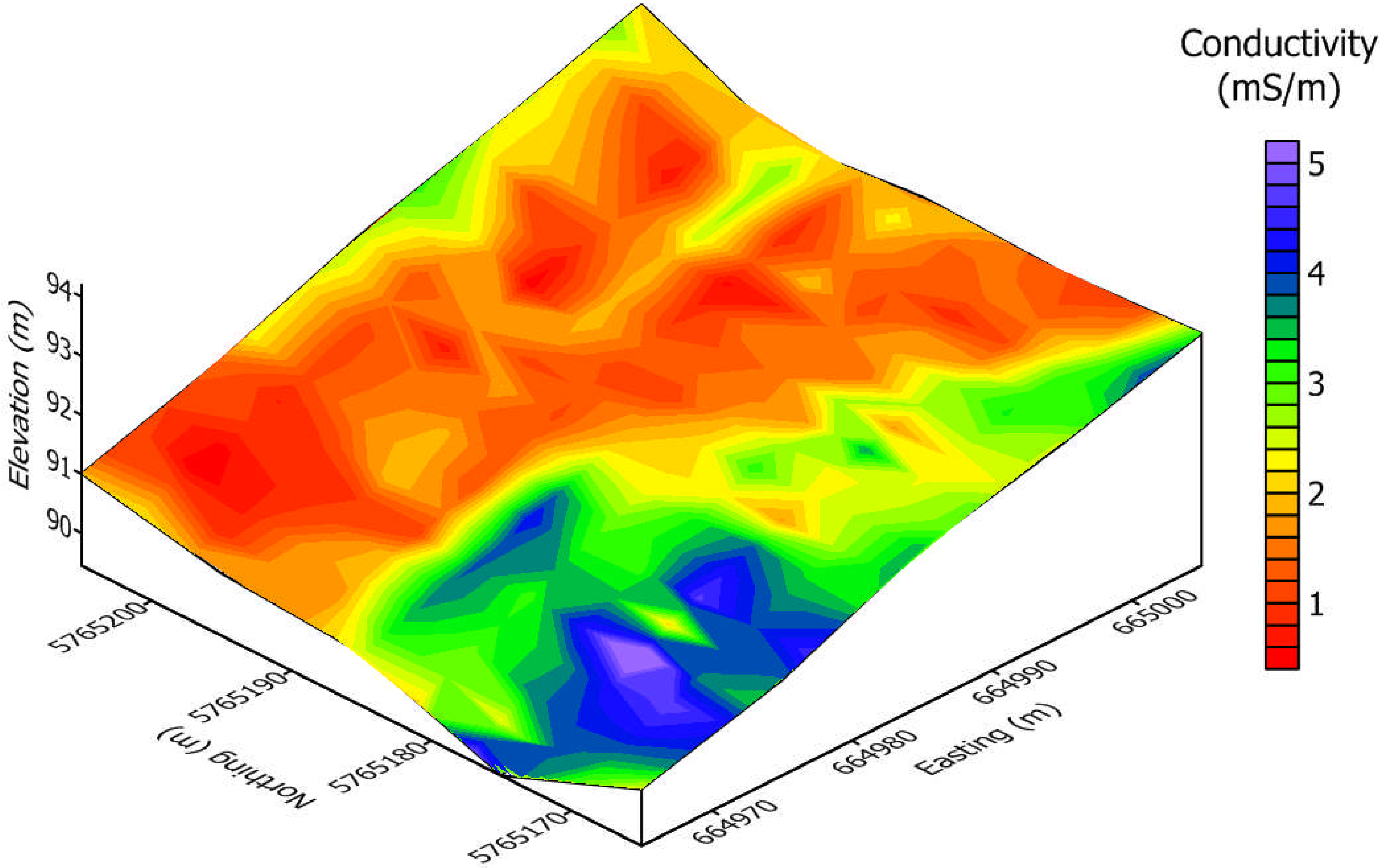
Example results

EMI at the Woburn site - Initial trials June 2012



Example results

EMI at the Woburn site – conductivity over 50cm depth



Finally: Future Project

We aim to develop a new methods of measuring root function that is rapid, non-destructive and accurate

- EMI and ERT data will be compared with data from buried soil moisture meters, soil sampling at various depths, root depth measurement with transparent rhizotrons and the emerging qPCR approach to measuring root DNA concentration in soil.
- Data from these invasive approaches will be used to validate and refine as necessary the EMI protocol.

Part of project funded by BBSRC, CRIC project: Phenotyping root function in wheat