Hydrogeophysics: Expectations, limitations and challenges

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Workshop on Hydrogeophysics, Palermo 20

The value of hydrogeophysics

Geophysics has been widely used to support groundwater investigations for many years*. However, much of the earlier approaches concentrated on using geophysics to define lithological boundaries and other subsurface structures.

During the 1990s there was a rapid growth in the use of geophysics to provide *quantitative* information about hydrological properties and processes.

Much of this was driven by the need to gain information of direct value to hydrological models, particularly given the developments of 'data hungry' stochastic hydrology tools.

* For example, Zohdy *et al.* (1974), Application of surface geophysics to ground-water investigations, USGS.

The value of hydrogeophysics

Perhaps more significant is that there is a clear demand by government regulators and agencies for tools and technologies to allow characterisation of groundwater systems, for example linked to the EU Water Framework Directive

Advantages

Geophysics offers advantages over conventional sampling to the hydrologist because of:

High data sampling density

Relative lower cost of measurements – may avoid use of boreholes and/or allow quicker sampling

Minimally invasive – may allow investigations without affecting the hydrology of the system

Larger measurement volume – more consistent with modelling needs

Hydrogeophysical approach

Geophysical imaging

petrophysical model

structure

(e.g. hydraulic conductivity)

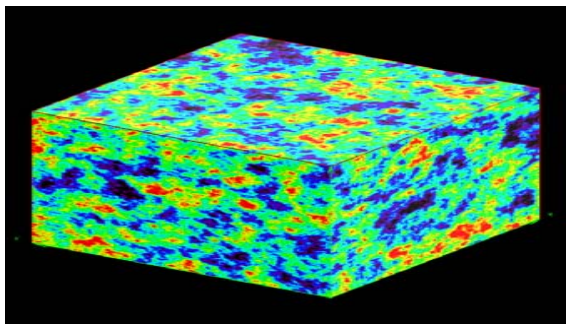
hydrological model

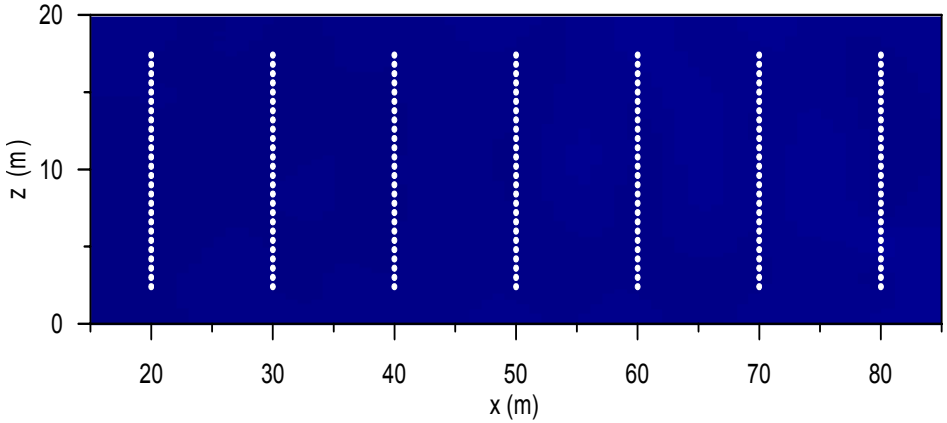
Time-lapse imaging

petrophysical model

process

(e.g. solute transport)

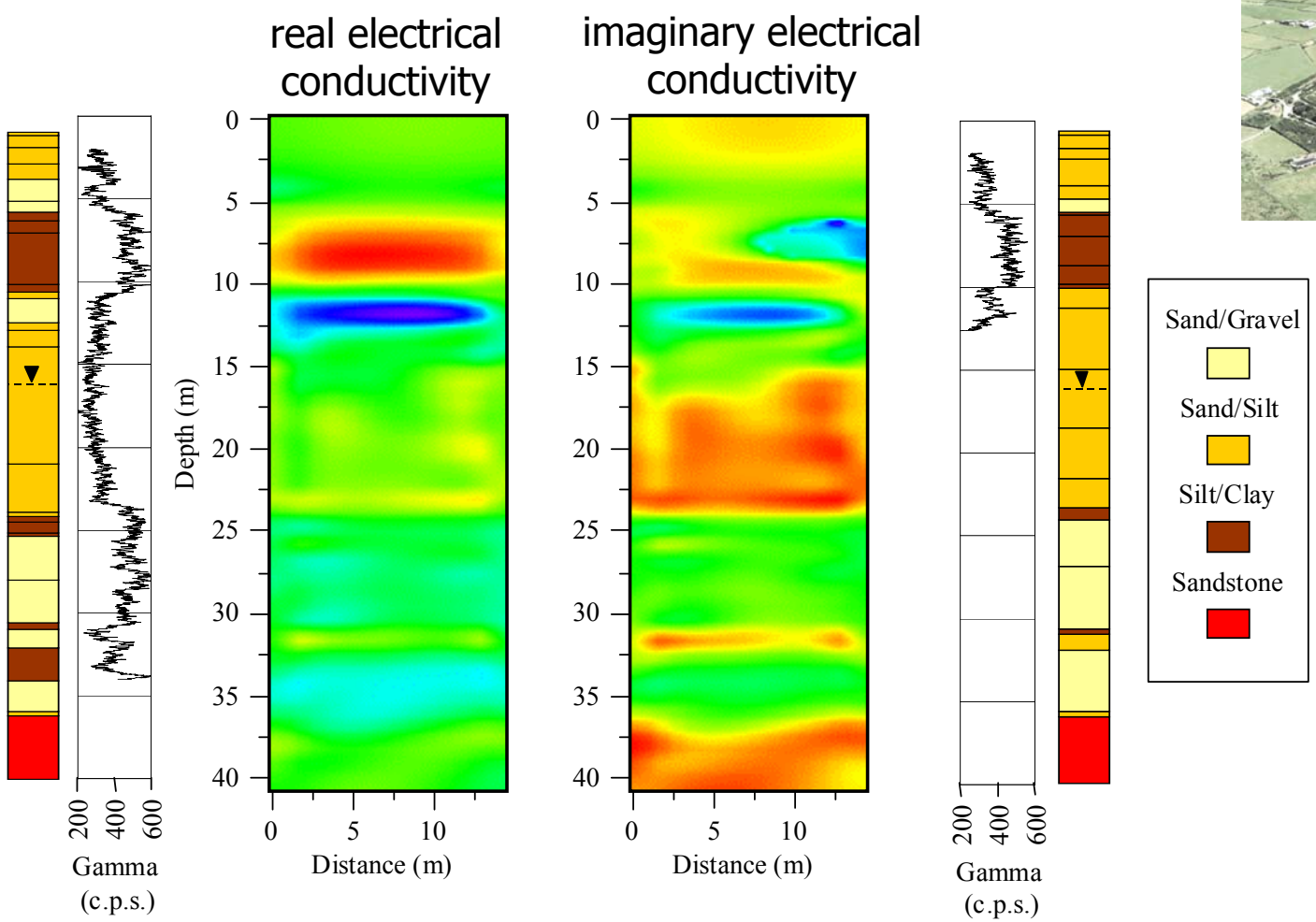




After Kemna (200

Structural characterisation example

Complex resistivity at the Drigg nuclear site, UK

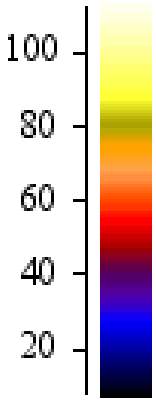


Kemna, Binley and Slater (2003

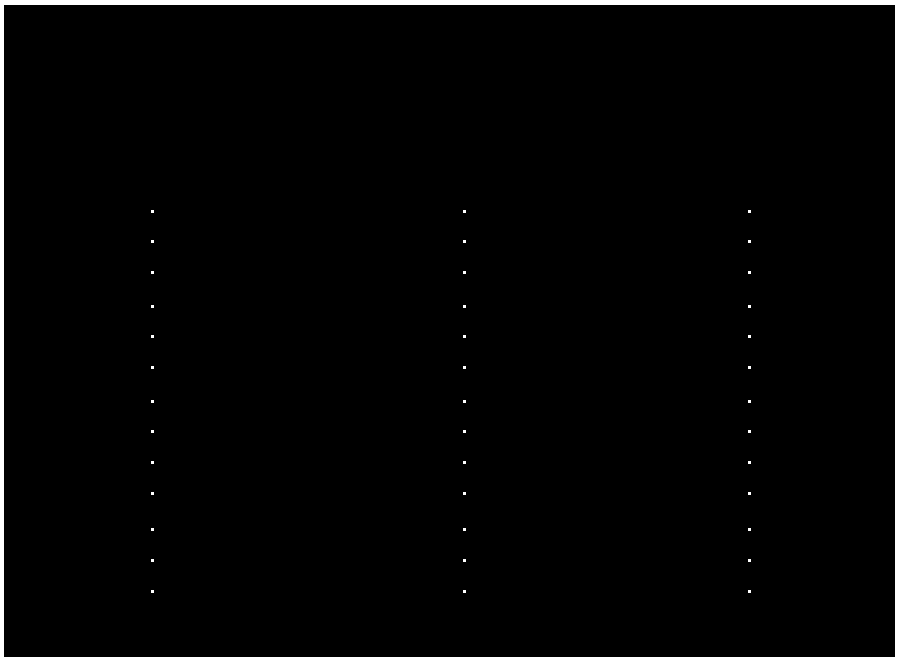
Process characterisation example

Tracer experiment at the Krauthausen test site

day 1



electrical conductivity changes (%)



Kemna, Vanderborght, Kulessa and Vereecken (2002

Expectations

The hydrologist **may expect** the following:

1. Coverage over a large area at high resolution

2. Significant depth penetration

3. To make use of existing infrastructure

4. That the geophysicist will use the most appropriate method available

5. An (error free) image of the hydraulic property that they are interested in

Expectations versus reality

The hydrologist **may get**:

1. Coverage of a small plot of the site of interest

2. Limited depth penetration due to surface cover and conditions

3. Gaps in coverage or anomalies due to steel cased boreholes, for example

4. The geophysicist used the method that he/she is most familiar with

5. An image of a geophysical property (with unquantified uncertainty) that is somehow related to a hydraulic property

Expectations – essential communication

It is important, therefore, to communicate in order to establish:

1. What exactly does the hydrologist want ?

2. Does geophysics offer any solution ? There may be a better solution.

3. What exactly is realistic given the site conditions (geology, access, cover, etc.)

4. How will the geophysical property be related to what the hydrologist wants ? Can this be quantified ?

5. Is it possible to determine some level of uncertainty in the results that are communicated ?

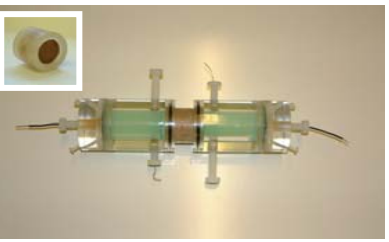
Limitations – hydrogeophysical relationships (1)

For static imaging there must be a contrast in a geophysical property that can be related to hydrological parameters

This may be site specific

Limitations – hydrogeophysical relationships (1)

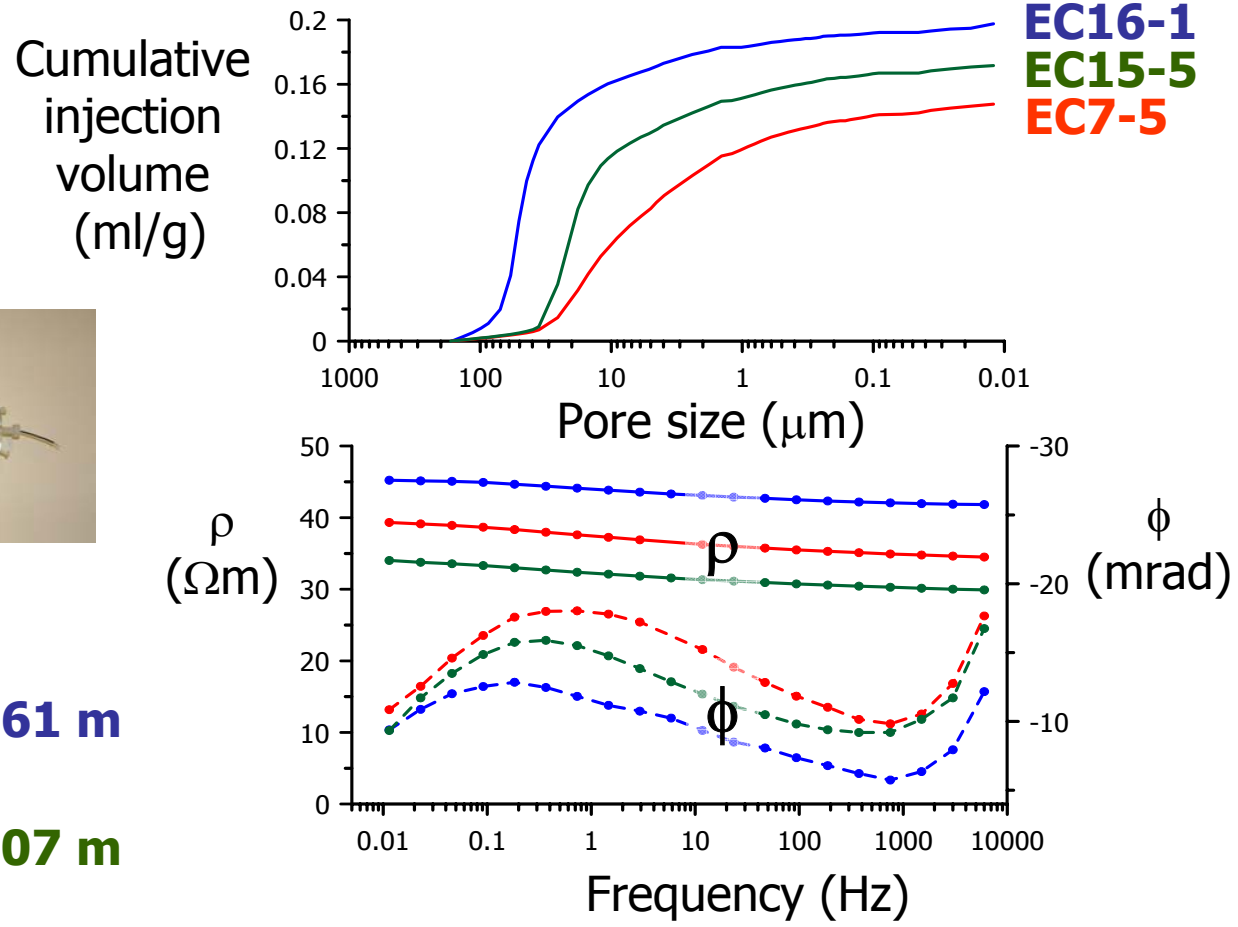
Spectral induced polarisation of Triassic Sandstone



VEC16-1
depth = 17.61 m

VEC15-5
depth = 16.07 m

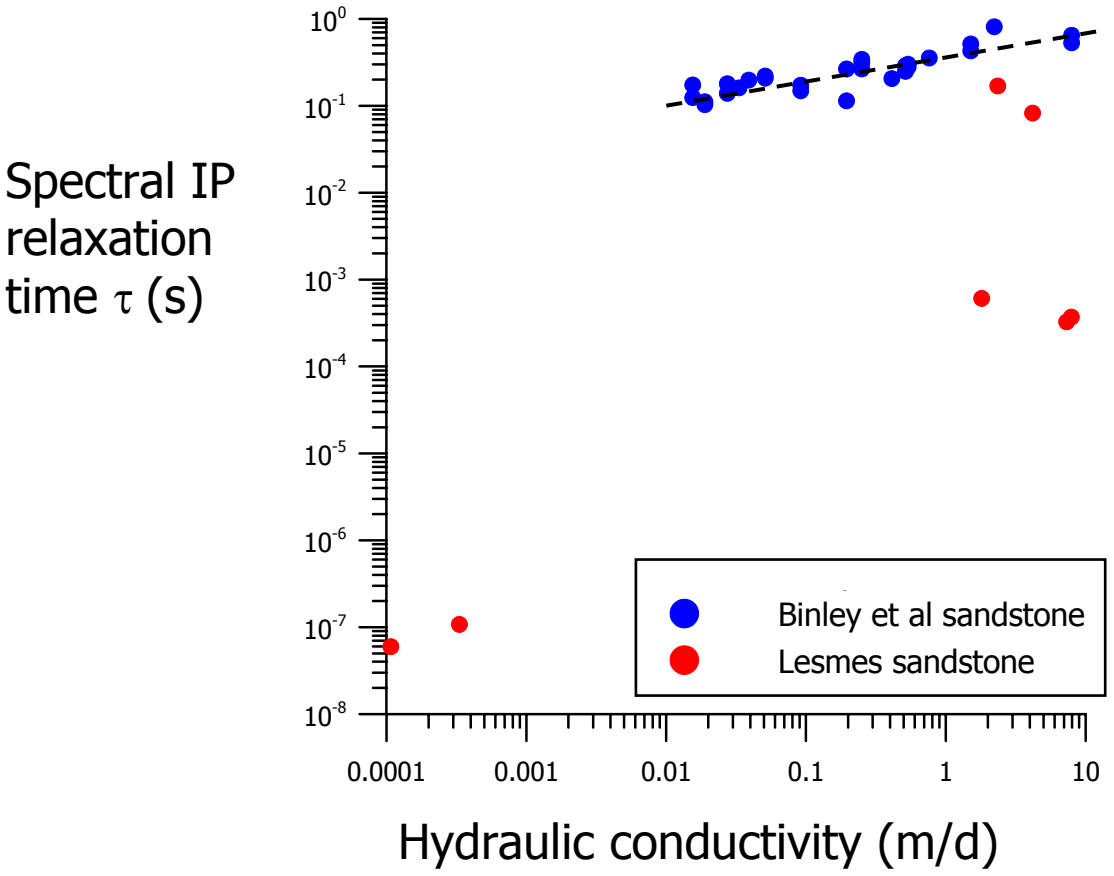
VEC7-5
depth = 8.22 m



Binley, Slater, Fukes and Cassiani (2005

Limitations – hydrogeophysical relationships (1)

Is there a universal relationship ? Should there be one ?

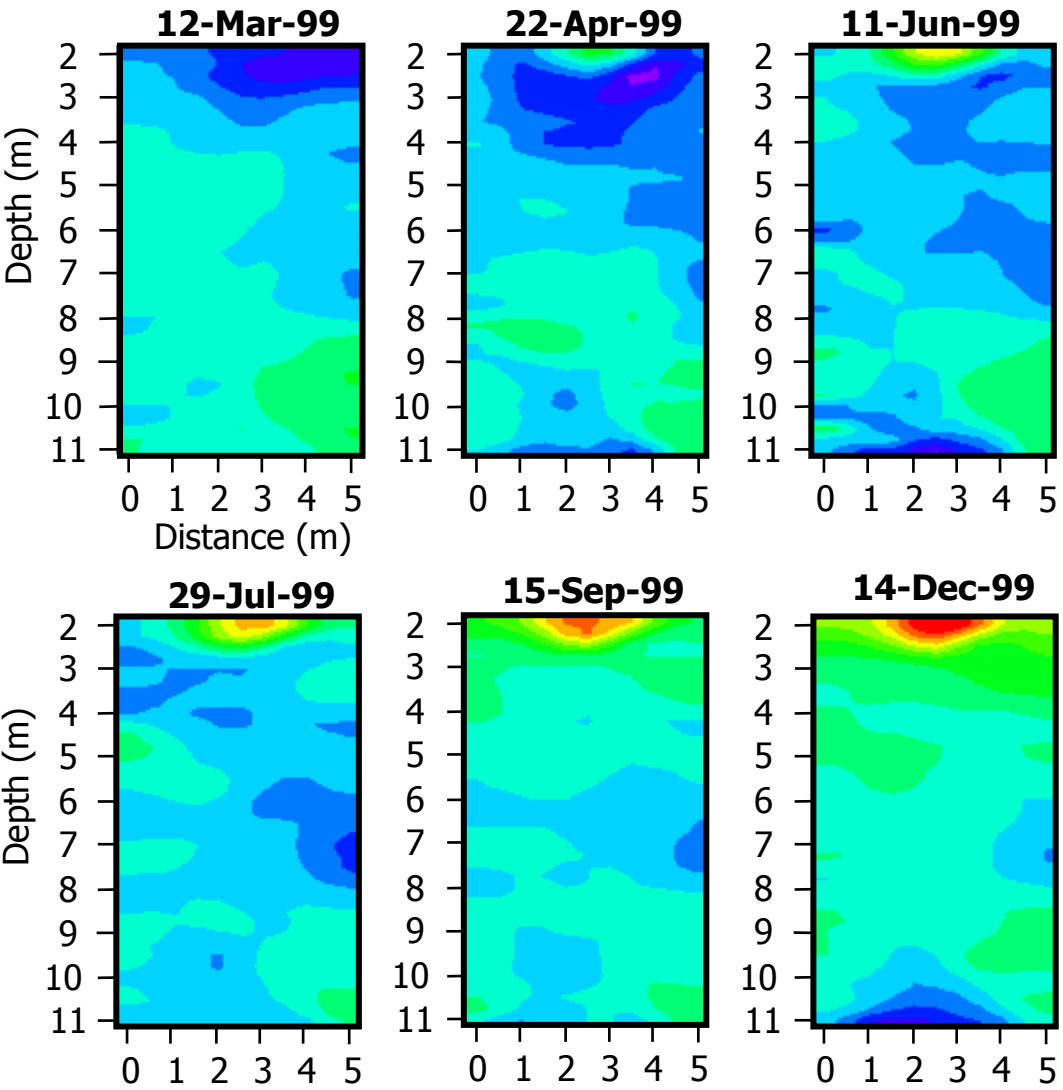


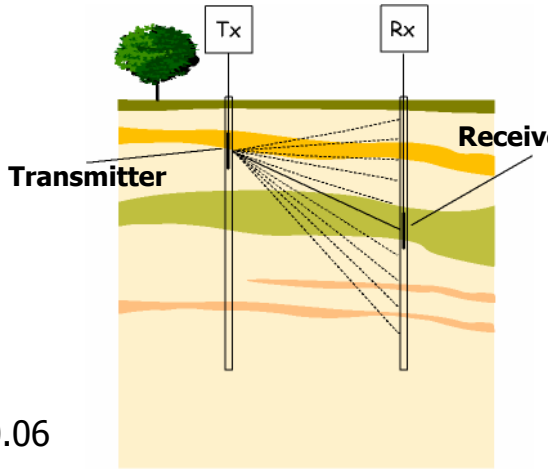
Limitations – hydrogeophysical relationships (2)

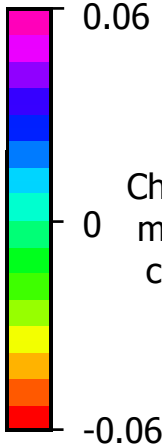
Time-lapse measurements may be easier to interpret in order to study processes but appropriate petrophysical relationships are needed

Limitations – hydrogeophysical relationships (2)

Moisture content changes due to natural inputs



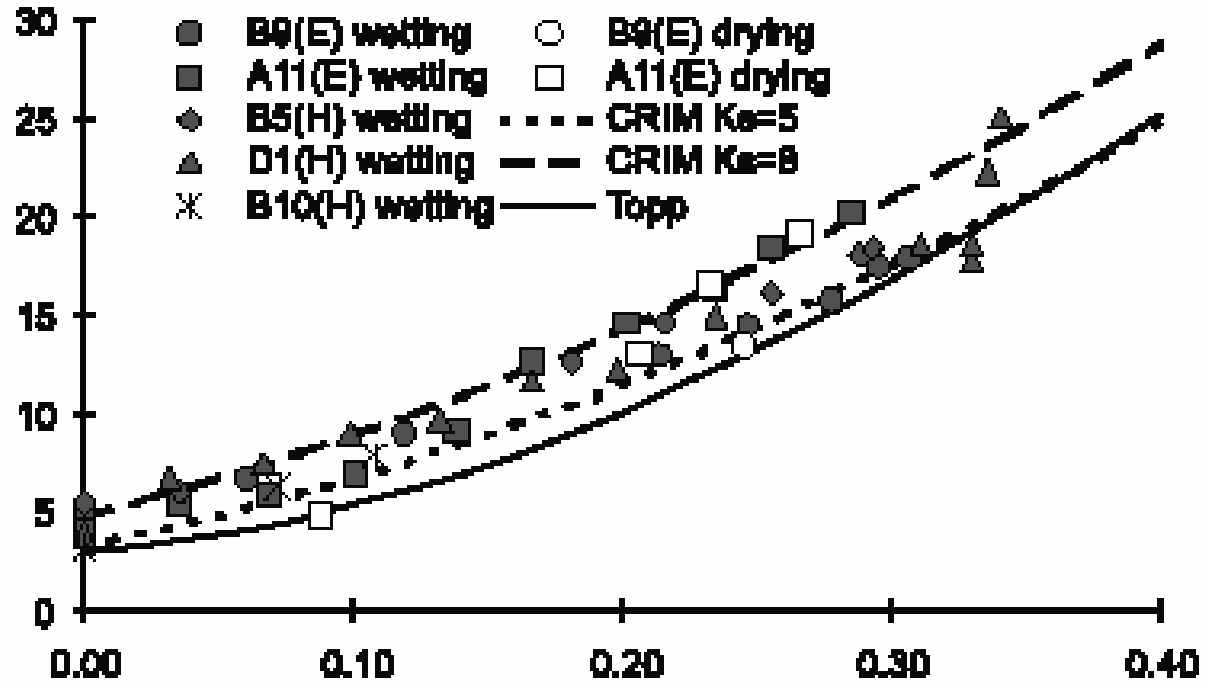




Binley, Winship, Middleton, Pokar and West (200

Limitations – hydrogeophysical relationships (2)

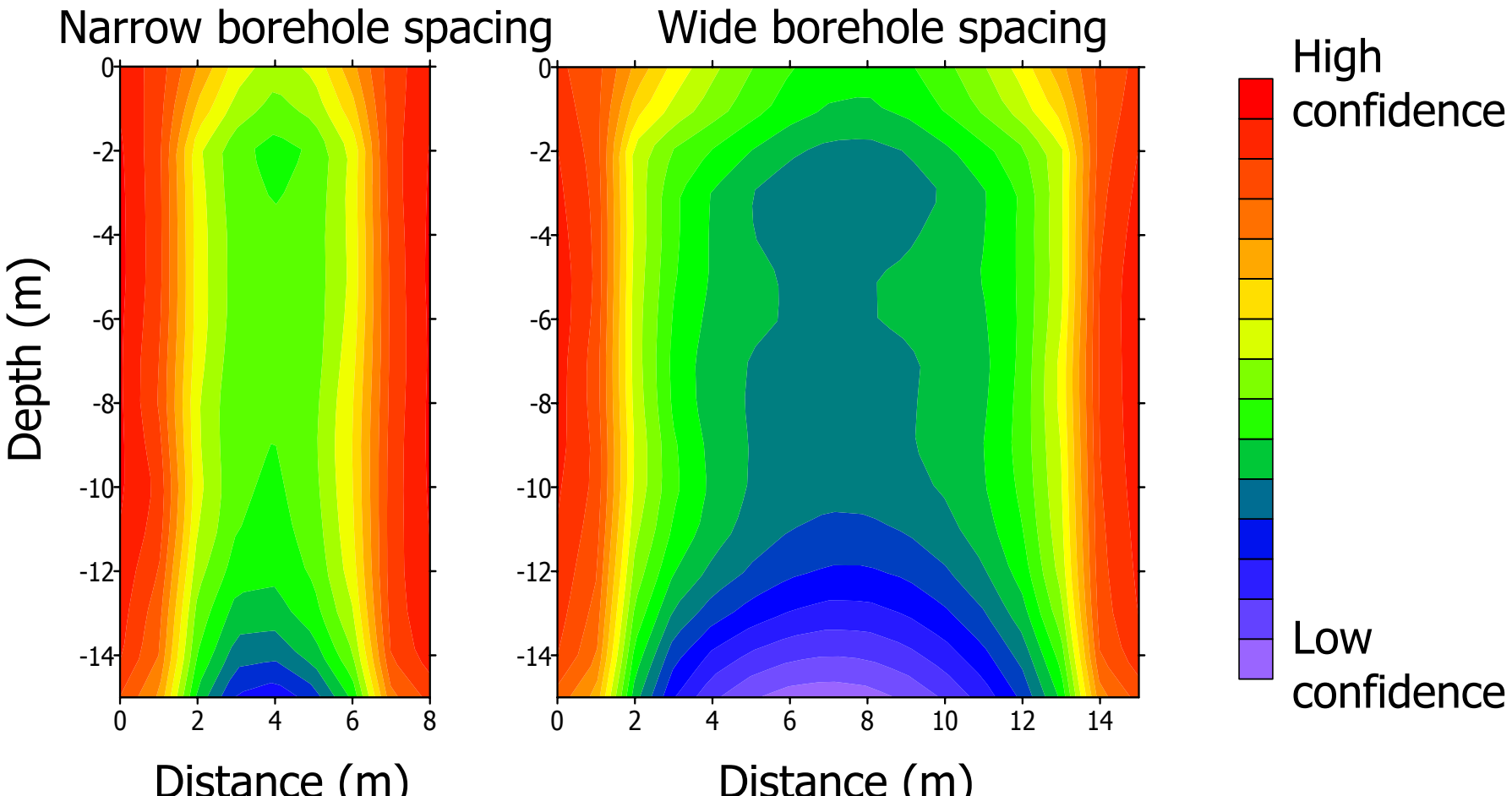
Petrophysical relationships may be site specific and also highly uncertain



West, Handley, Huang and Pokar (200

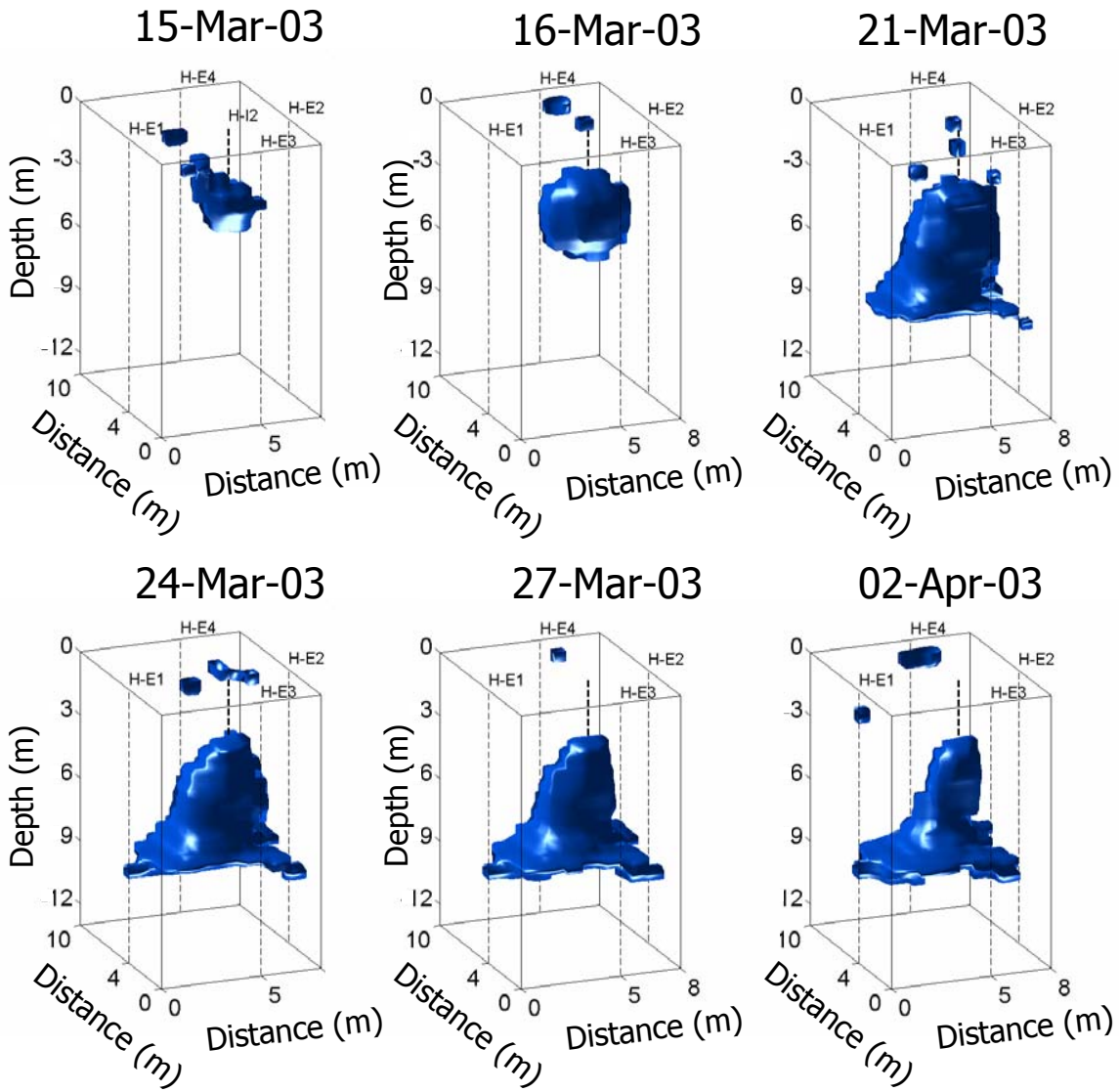
Limitations – variability of sensitivity in an image

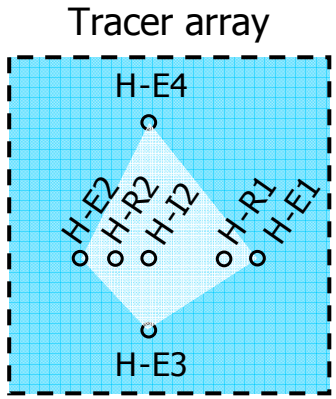
The sensitivity of the imaging varies within the image – in some areas uncertainty in the geophysical property is high – will lead to mass balance errors in tracer studies



Limitations – variability of sensitivity in an image

Vadose zone tracer experiment Hatfield, UK – ERT results



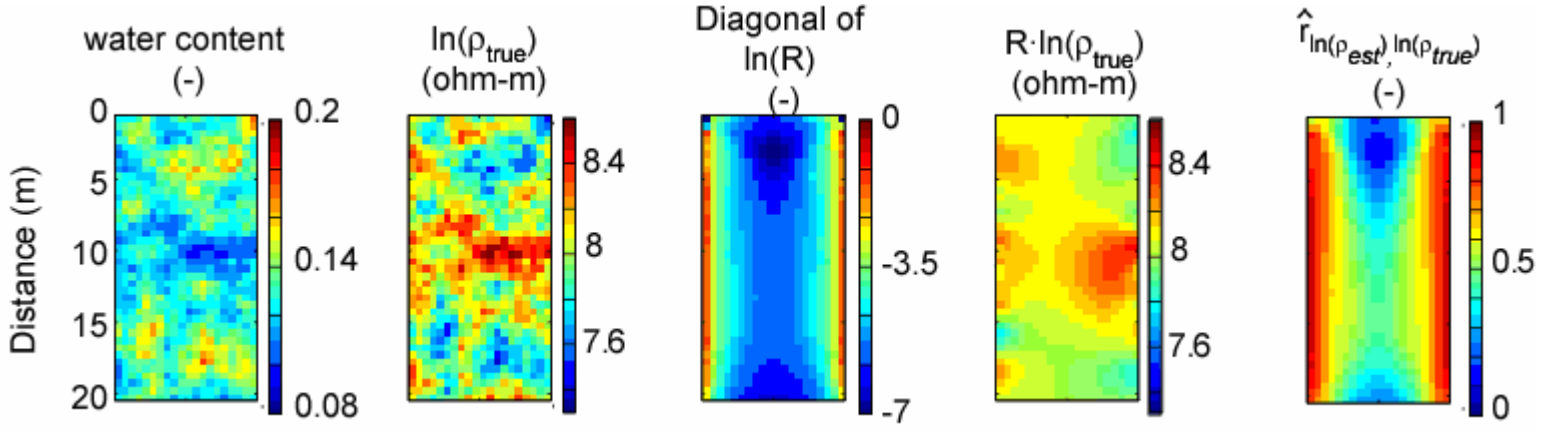


Binley, Winship and Gomez (2005)

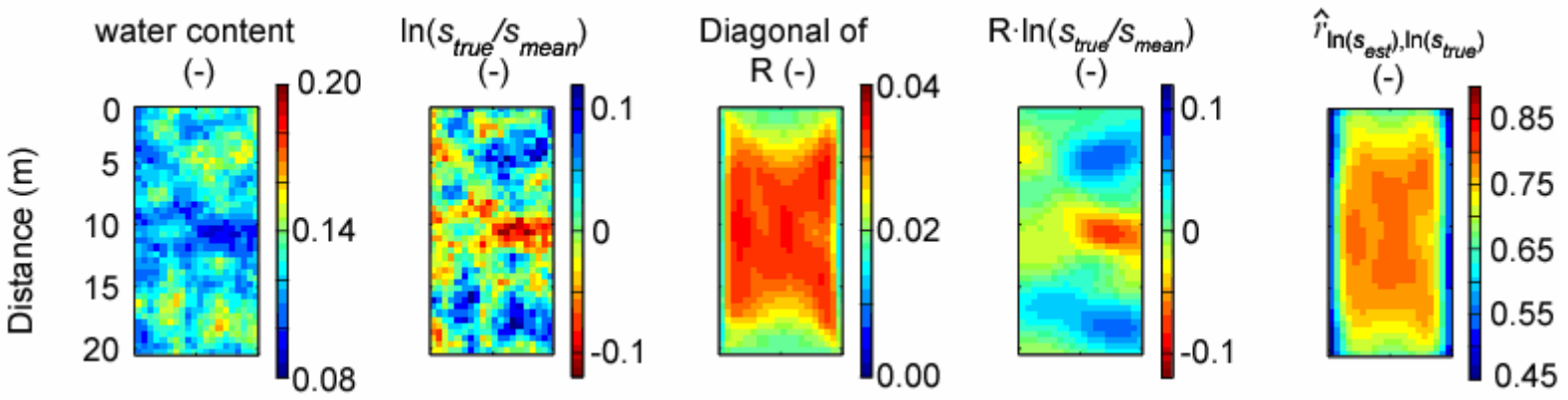
Limitations – variability of sensitivity in an image

The sensitivity of the imaging varies within the image and is dependent on the technique and may be a function of the geophysical parameter

ERT



Radar

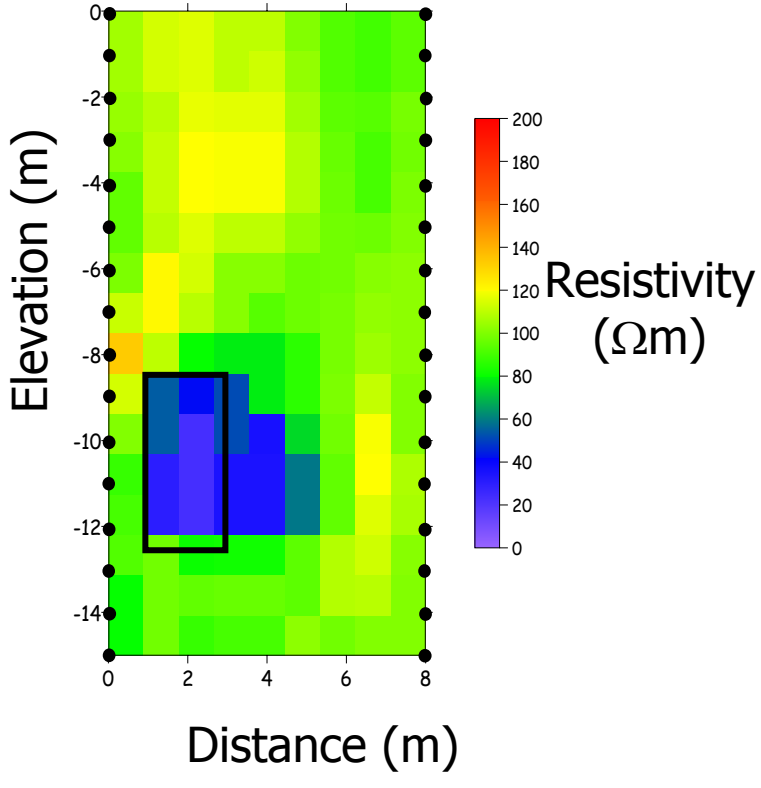


Day-Lewis, Singha and Binley (200

Limitations – imaging artefacts

Data inversions can be strongly affected by regularisation (needed to get stable solutions)

This may lead to hydrologically meaningless results or may give the false impression of something hydrologically meaningful

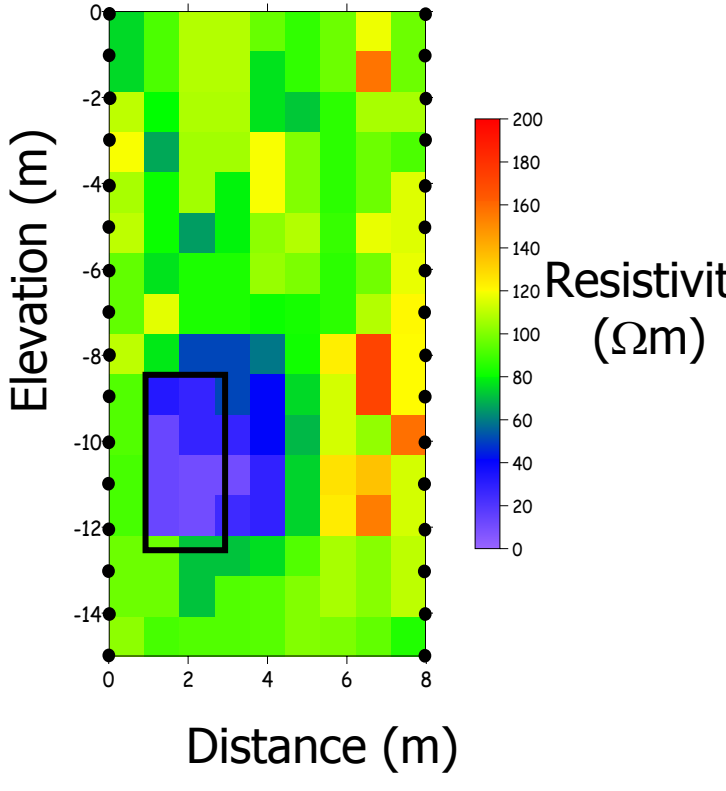


Limitations – impact of noise on images

Data inversions are strongly affected by data and modelling noise levels and these must be characterised for accurate assessment of geophysical properties

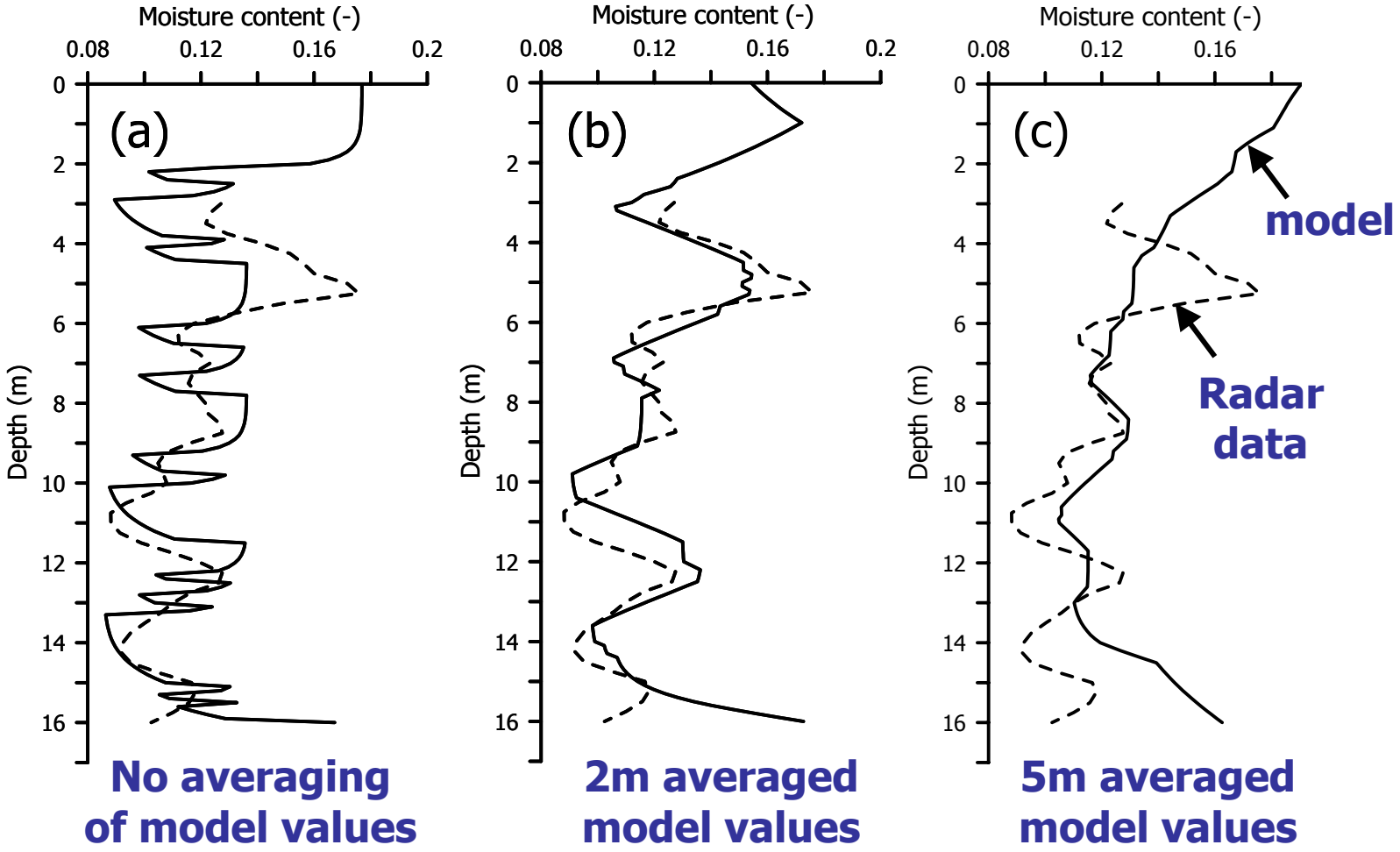
We can ignore this for 'anomaly hunting' but not if we want to get quantitative information from the images

Inversion of synthetic data with 5% error added but 2% error assumed



Limitations – measurement scale

We need to ensure that measurement and model scales are comparable



Cassiani and Binley (200

Challenges

This workshop will allow us to assess the challenges we face but here are a few to start with:

1. Better understanding of the processes that lead to some geophysical signals (e.g. IP, SP)

2. Development of multi-geophysics and hydro-geophysics data fusion techniques

3. Improved assessment of uncertainty in geophysical and hydrogeophysical results

4. Advances in techniques for large area coverage (in complex terrains) to allow better watershed characterisation