

**KMS Technologies – KJT Enterprises, Inc.**

**Feasibility study of surface-to-borehole  
CSEM for oil-water fluid substitution in  
Ghawar field**

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Saudi Arabia, Geo 2010, poster





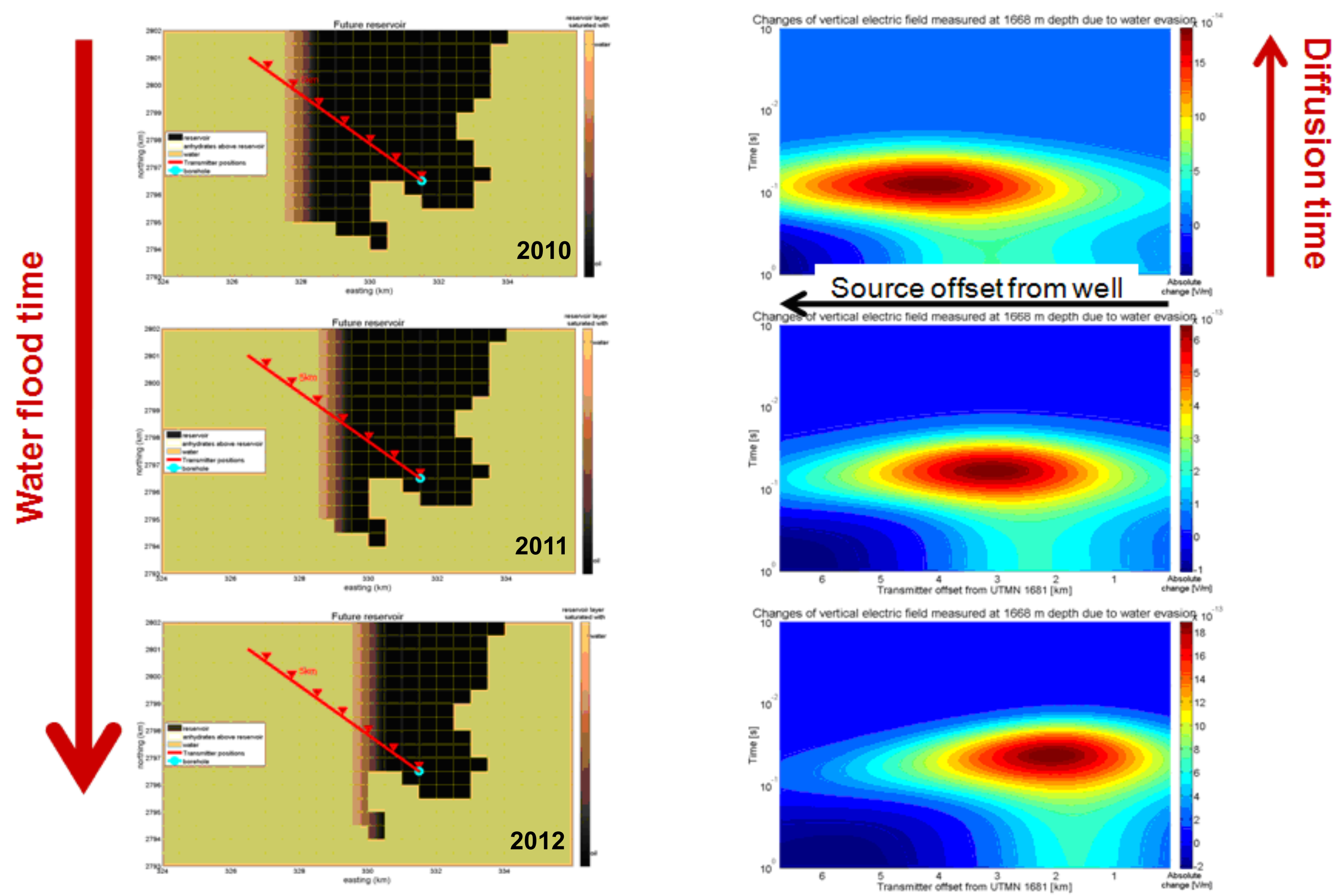


Figure 3. For a predicted reservoir depletion from the West (shown in the left panel), the measured vertical electric field changes due to an electric dipole source excitation at the surface are on the right. As the water front moves to the west, the maximum tracks it. The horizontal axis denotes the source offset from the monitoring borehole and the vertical axis denotes transient. The transmitter are deployed along the profile in red.

The normalized field strength is around 0.3 nV/m. For this the field changes from flood movement are around 0.6 pV/m. For a practical scenario with realistic sources and sensors, the vertical voltage is in the range of 120  $\mu$ V. The water flooding will cause signal variation in the order of 240 nV. If the systems can achieve noise levels below 120 nV, we can track signal changes from water flooding better than 2:1.

Vertical electric field changes are different for different transmitters. This behavior will be used in the inversion to decompose water flood front movement from different directions and at various offsets. With the surface transmitter sites shown in Figure 4, we can measure vertical electric field water flood front changes during production.

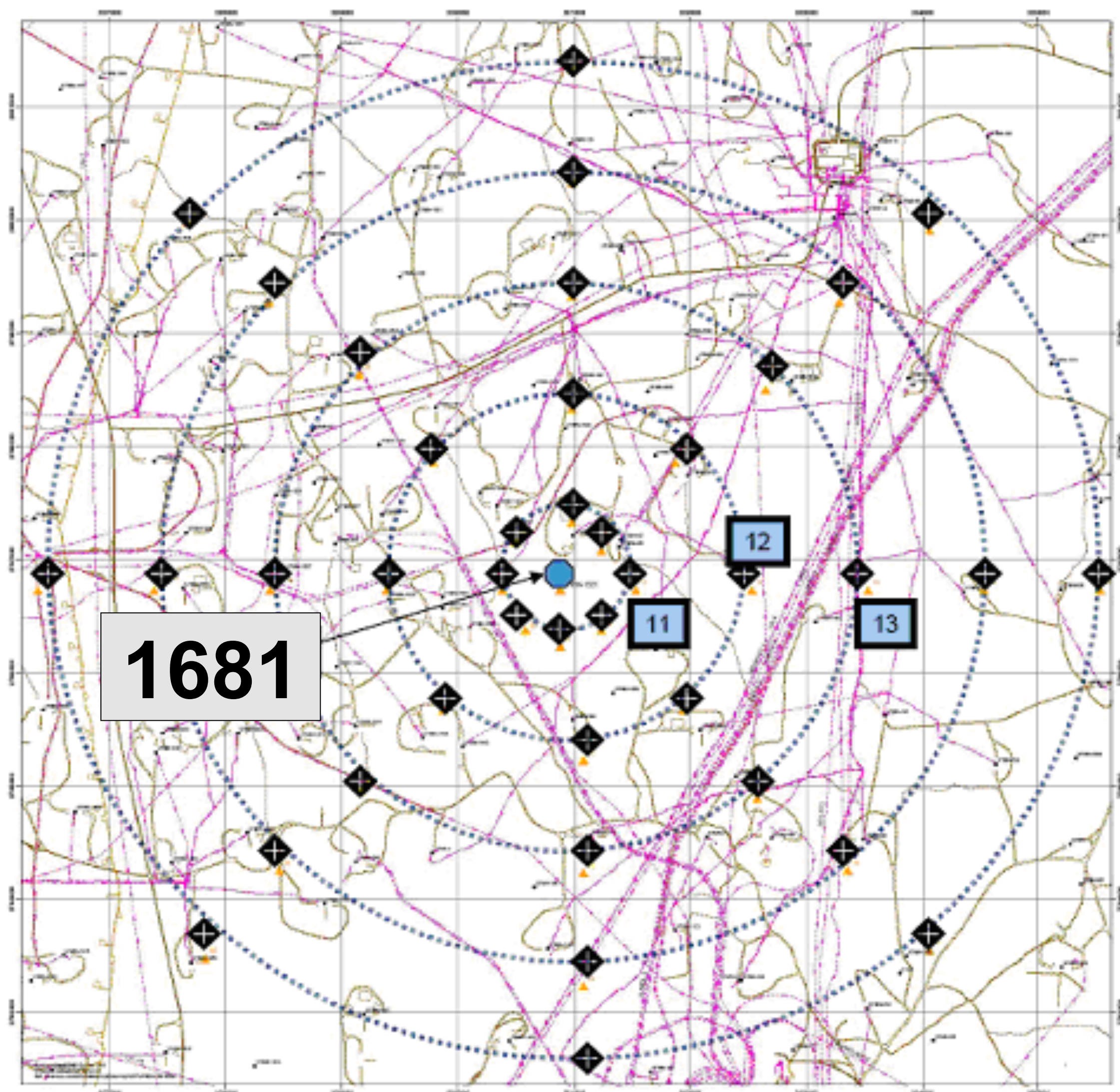


Figure 4. Planned of transmitter positions around test well. Each diamond represents an electric dipoles position..

For near borehole water coning, the caustic response is independent of the transmitter azimuth. The water coning effects can be removed using this independency (Figure 5).

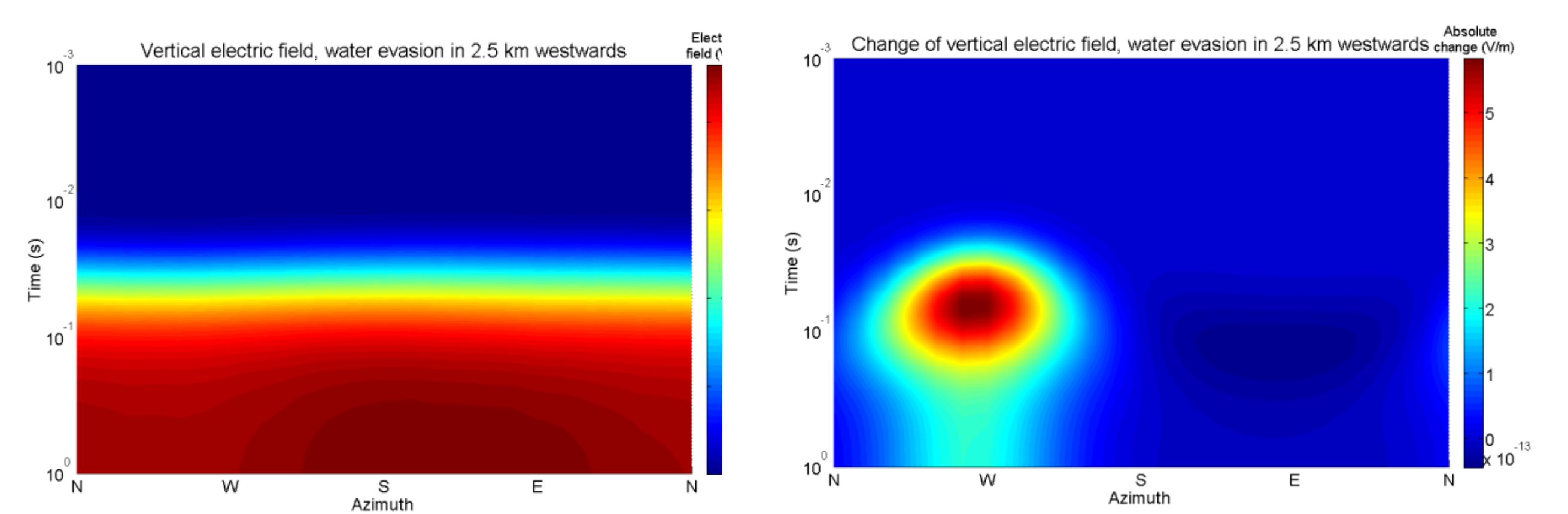


Figure 5. Vertical electric field and its changes as a function of source azimuth. When source and invasion direction align, maximum change occurs.

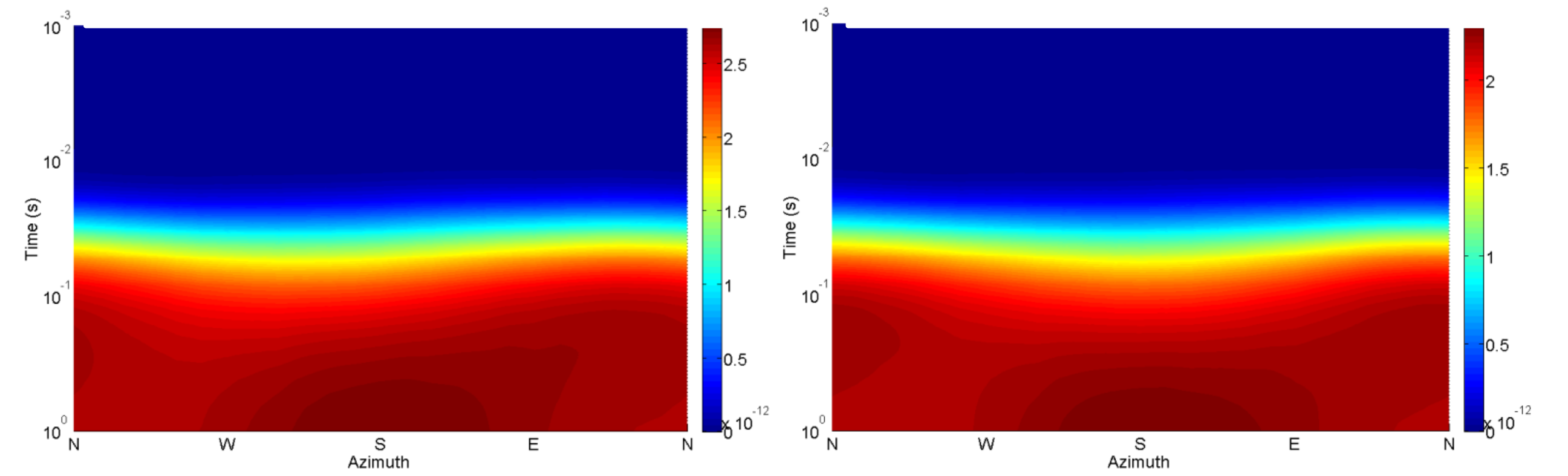


Figure 6. Downhole electric field response from transmitters on a circle for the flat reservoir model (left panel) and response for a coning model (right panel). The transmitter circle center is at the monitoring well with 2,000 m radius. The coning response (right) is different from water flooding (Figure 5 right). It has low azimuth dependence and shows at later times.

**NOTE:** Figure 5 and 6 can be combined together. The purpose here is to show that the water invasion has an azimuth dependence that can be used to map the invasion direction whilst coning has no azimuth dependence (i.e. it is not affecting the prediction far from the well).

I would envisage a figure showing the normalized change of  $E_z$  due to water invasion from West (Figure 5 – right) compared to an equivalent figure showing the non-azimuth dependence of normalized  $E_z$  due to coning at the well.

## Next steps

Electrical anisotropy --- show examples of cumulative conductance and cumulative resistance for  $R_h$  &  $R_v$  (i.e. show how the total conductance or transverse resistance change if  $R_h$  or  $R_v$  are used).

Anything else?.. I am ok with this as next steps

## Conclusions

Water flood front movement during hydrocarbon production generates measurable electromagnetic (EM) response for all source and receiver type combinations. Among source and receiver combinations, the surface electric current dipole source and downhole vertical electric field measurements have strongest coupling to water flood front changes. Other source and receiver combinations provide also operational advantages. Best monitoring results are expected using all combinations of sources and receiver.

## Bibliography

1. Wilt, M.J., and Alumbaugh, D.L., (1998) "Electromagnetic Methods for Development and Production: State of the Art," *The Leading Edge* (1998), 17, 4, 450-548.
2. Strack, K.-M., 2004, Surface and borehole integrated electromagnetic apparatus to determine reservoir fluid properties, US patent 6,739,165,





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