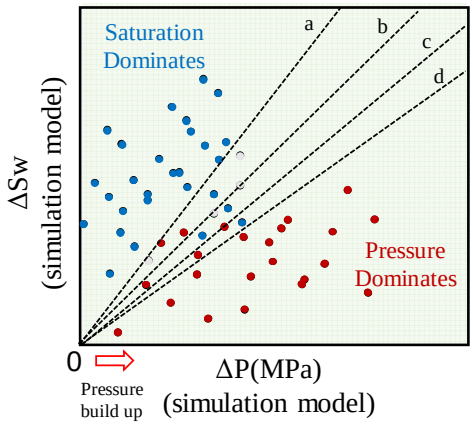

Figure 1 *Schematic plot of ΔSw versus ΔP from the simulation model, colour coded based on the polarity of the 4D response and with a selection of PEMs "a" to "d" overlain as straight lines. A red point corresponds to pressure increase, whilst blue is for water saturation increase.*

Synthetic Example

The cross-plot is firstly applied to a synthetic 4D seismic dataset generated from a North Sea field model. The ΔP-ΔS_w points are colour coded using the P-wave impedance, and are shown in Figure 2. Figure 2(a) gives the results for synthetic seismic calculated using a previously field-calibrated PEM A, and the boundary line relates to this model. Figure 2(b) gives the corresponding results for another model, PEM B. Both plots show a clear distinction and consistency between the two polarity groups.

Figure 2 *Example of ΔSw versus ΔP cross-plot, using P-wave impedances calculated from two different PEMS: (a) using the results from PEM A; (b) using the results from PEM B.*

Observed Data Examples

The cross-plot is applied to two fields in the UKCS and Norwegian Sea with distinctly different geological settings. First of all, the ratio C_P/C_S for both fields are calculated using four different log calibrated deterministic PEMs (A, B, C and D) at baseline and monitor times following the work of Briceño et al. (2016). The ΔP-ΔS_w cross-plot points are then colour-coded using the mapped 4D seismic amplitudes for both fields. For the UKCS field the seismic attribute chosen is sum of negative amplitudes (SNA), and for the Norwegian Sea field is root mean square (RMS). On top of our plots, we display the four different boundaries C_P/C_S obtained from the deterministic PEMs since they give a range of variability, and set the limits that represent softening and hardening of the reservoir.

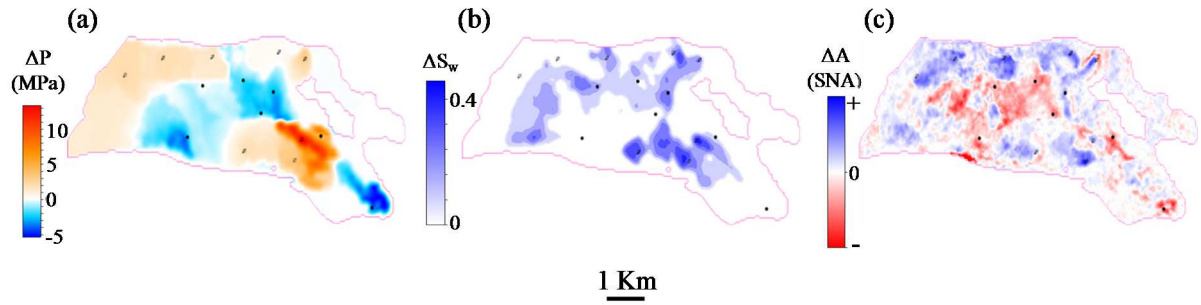

Figure 3 *(a) Change in pore pressure map for 2004 minus baseline for our UKCS field. (b) Change in water saturation map. (c) 4D map using sum of negative amplitude attribute.*

The plot for the UKCS field (Figure 4a) shows incorrect polarities (or wrong position) at the right top corner, meaning that decisions to update the model must be taken if the seismic data are accepted to be correct. Updating of the simulation model is performed by altering the transmissibility multipliers between geobodies in the areas of the model relating to the incorrect clusters of data. These effectively reduce the pressure change for that specific area. This updating is qualitative but can be guided carefully with the understanding PEM and seismic uncertainties in the cross-plot. Different scenarios for the simulation model are run, and here we show our most optimal model which provides the best all round agreement (Figure 4b).

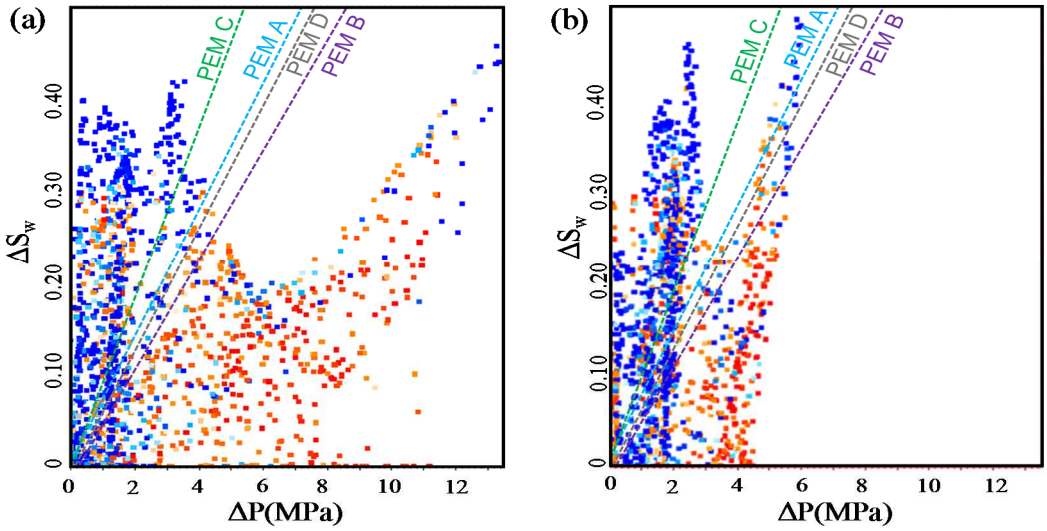

Figure 4 *(a) ΔSw versus ΔP cross-plot using the original simulation model for the UKCS field and colour-coded with the polarities of observed 4D seismic response. (b) as in (a) but the points correspond to a more optimal simulation model after updates are performed.*

The same approach is applied to the Norwegian Sea field, the ΔS_w versus ΔP plot (Figure 5a) shows clusters of points where there is a disagreement between the pressure and saturation regions. For this field, the updating of the simulation model is performed by altering fault transmissibility multipliers. Figure 5b shows our new cross-plot, this time using the updated simulation model, where the data points display a better position and agreement with the lines of C_P/C_S representing the boundary between the pressure and saturation domains.

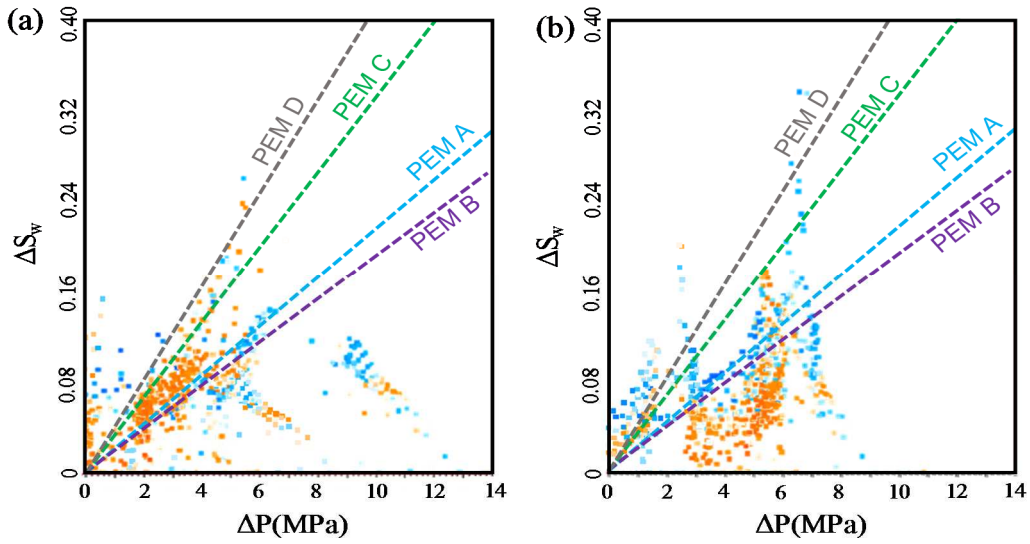

Figure 5 *(a) ΔSw versus ΔP cross-plot using the original simulation model for the Norwegian Sea field and colour-coded with the polarities of the observed 4D seismic response. (b) as in (a) but the points correspond to the best simulation model after updates are performed.*

Conclusions

The Δ*Sw*-*ΔP* cross-plot is found to be a simple yet effective tool to simultaneously visualize the uncertainties associated with three different domains: the simulation model, the seismic data and the PEM. The plot allows us to discriminate between regions in the reservoir that are dominated by pressure or saturation change using a straight-line boundary corresponding to the selected PEM. A synthetic example has verified the usefulness of this approach, and the sensitivities to both data and the model. Application to two field datasets has confirmed the utility of the cross-plot as a way of guiding updating of the simulation model to agree with the observed seismic data. This interactive method is useful as a step prior to a full quantitative seismic history matching.

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