Remove RTM Artifacts Using Delayed Imaging Time Gathers

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Summary

In RTM imaging, double top salt (DTS) is frequently seen but difficult to remove by conventional post-RTM processing. This paper analyzes the DTS characteristics and demonstrates that the reason for DTS is shallower than true top of salt (TOS) placement or higher than true supra salt velocity or both present in the migration model. By introducing delayed imaging time (DIT) scan and DIT gathers, DTS events can be easily recognized and removed. Several field examples have shown the effectiveness of this method with greatly improved TOS images.

Introduction

Reverse time migration (Baysal 1983, Whitemore, 1983, McMechan 1986) has become the de-facto workhorse in depth imaging, especially for regions with complex geological structure. While RTM's principles are simple and the produced image is accurate, it is notorious for creating low frequency artifacts. Yoon et al (2004) applied the Poynting vector in the imaging condition to remove artifacts. Shan et al (2008) discussed the velocity sensitivity of different migration methods. By comparing one-way WEM and RTM, he concluded that RTM can generate spurious reflections and mirror images with apparently strong focusing if major impedance contrasts are mis-placed in migration models. Fletcher et al (2005) discussed damping wave equation to reduce artifacts at strong reflectors. Guitton et.al (2006) proposed least-square attenuation to reduce artifacts. Kaelin and Guitton (2006), investigated the artifacts created by applying different imaging conditions. Sava and Fomel (2006) proposed a shifted-time imaging condition (we refer it as delayed imaging time or DIT in this paper). Since then, there have been DIT applications for subsalt velocity update (Wang et at, 2008, Wang et at, 2009, Ma 2011) and assisting salt interpretation (Whiteside et al, 2011). More recently, Kaelin and Carvajal (2011) applied time-shift imaging condition on Sigsbee and BP-2004 synthetic data/model to remove artifacts.

Among of the various RTM artifacts, one of them is the double top salt referred as DTS in this paper. The DTS is often seen as a "fat" top salt, sometimes as two salt surfaces that are slightly separated. The DTS can also be extended to the interface that has strong velocity/impedance contrast such as slow sandstone to carbonate, etc. The following section explains the fact that DTS is due to the shallower than true TOS or higher supra salt velocity. Since the current depth imaging methodology is an iterative process of model building/updating and migration, it is not uncommon that the top of salt position or the supra salt velocity is inaccurate.

DTS and DIT Scan

In RTM migration, we forward propagate the source wavefield and backward propagate the receiver wavefield and apply cross-correlation (or other imaging conditions) to the two wavefields to form the image. If the migration model is correct, the image position will be properly placed. However, if the top of salt is slightly shallower than the true TOS (assuming the velocity above TOS is accurate), then the RTM wavefields (both source and receiver) will reflect from the TOS earlier than the true imaging time. Part of the energy will be propagated/reflected back to form a "mirror" DTS image slightly above the misplaced TOS. The penetrated energy will be imaged in the position slightly deeper than the true TOS position under the condition that salt velocity is higher than the velocity above TOS. It is also predictable that if the velocity above TOS is higher than the true value, the propagated wave fields reach TOS earlier and a similar imaging effect will occur. The shallower the TOS misplacement relative to the true TOS (or the higher the supra salt velocity relative to its true value), the larger the vertical distance between the two imaging points.

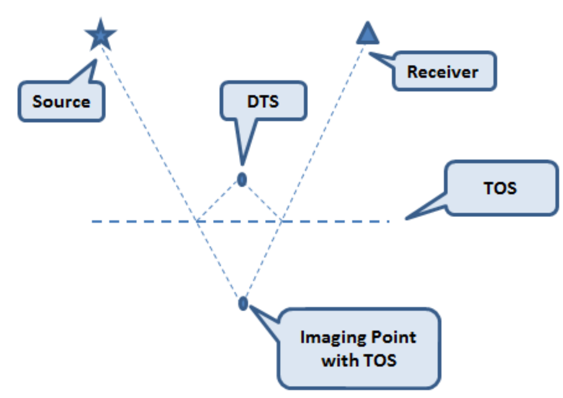

Figure 1: RTM stack, there is a hidden DTS close to top salt, so the top salt looks "fat"

Assuming a flat TOS and zero source and receiver offset, a simple formula (Eq. 1) can be formed to estimate the distance between the two image points,

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$$d = d_{vel} \cdot (1 + \frac{V_{salt}}{V_{sed}}) \quad \text{(Eq. 1)}$$

where d_{vel} is the vertical distance between misplaced TOS to true TOS, V_{salt} and V_{sed} are velocities of salt and supra TOS, respectively. Consider a case that d_{vel}=25m (misplaced by one migration velocity grid), V_{salt}=4500m/s and V_{sed}=2250m/s, then the distance between the two image points are 75m, which is approximately the level of one wavelength of general case of RTM migration. Therefore, the two images are usually not separable when the model/TOS is only slightly away from its true value/position, resulting in a "fat" TOS image. Even though they are separated, it is not easy to remove the artifact because of the similar wavelet characteristics of the other signals/events. That is why conventional methods such as low-cut filter, Laplacian filter and top-salt mute, etc, have difficulty in removing DTS. In fact, at the model building stage, this can lead to incorrect picking which could be more damaging than the unsuccessfully removed multiples because it can be a strong, coherent event that is very similar and indistinguishable from the true events in terms of velocity discrimination.

One additional item worth noting is that the RTM migration result shows that the DTS is more significant at shallower TOS than the deeper TOS, because the impedance contrast is larger and the main frequency is higher at the shallower TOS boundary.

Now we have concluded that DTS is generated due to shallower misplacement of TOS or slightly higher velocity over TOS or both. Under these circumstances, the RTM wavefields need shorter than normal imaging time to image at TOS. If we can alter the imaging time, we can change the DTS position and the change is approximately linear with respect to the change of the imaging time.

Sava and Fomel (2006) proposed an extended imaging condition with both space-shift and time-shift.

$$I(x,h,\tau) = \sum_{shot} \int S(t-\tau, x-h) R(t+\tau, x+h) dt$$

We will refer to the time-shift only imaging condition as delayed imaging time or DIT imaging condition,

$$I_{DIT}(x,\tau) = \sum_{shot} \int S(t-\tau, x) R(t+\tau, x) dt \quad \text{(Eq. 2)}$$

DIT can be used for velocity updating in which the picked delayed imaging times can be converted into a velocity update analogous to the way that curvature picks in space are used in conventional velocity updating (or tomography). One advantage of DIT scan is it needs only one migration run with a DIT output option. Running RTM with a DIT option only adds (in our practice) an extra 20% to the total migration time. We have been using RTM with DIT output for velocity updating and for assisting salt interpretation. Since DIT scan can shift imaging time, it becomes an ideal tool to study DTS.

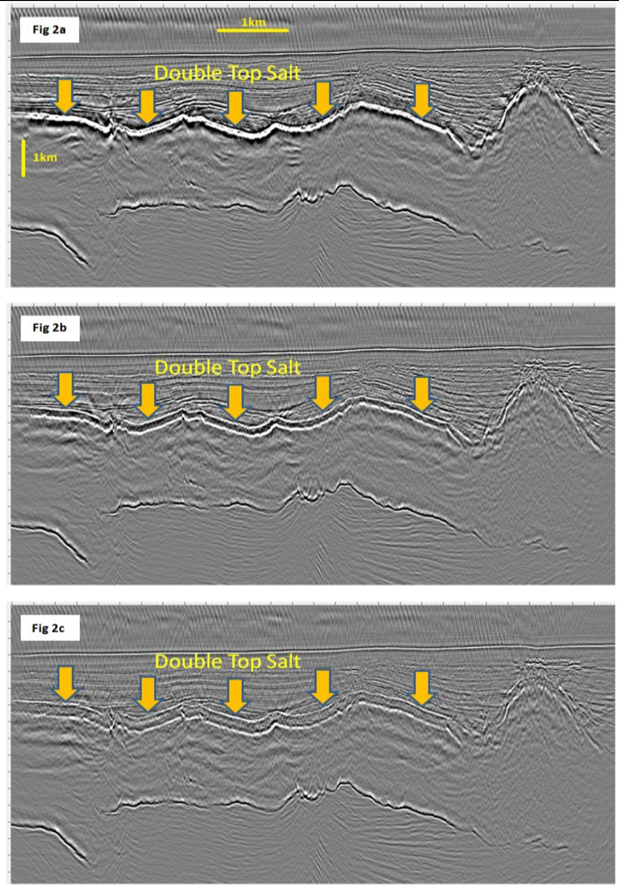

Figure 2: DIT stack panels to simulate "ghost-out" DTS. 2a is zero-lag panel (DIT=0), then each following panel DIT increased by 48 ms from its previous panel.

DIT can simulate the DTS event. Positive DITs generate DTS because the wavefield imaging time at TOS is less than the normal imaging time. Figure 2 is an example RTM migration with DIT volumes output for a 3D project in the Gulf of Mexico region. The DIT scan generated 41 volumes with DIT values from -240ms to 240ms. Three DIT panels (for one line) are displayed in Figure 2. Panels from top down are stacks with 0, 48ms and 96ms DIT. It

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can be seen a DTS image gradually "ghost" out from the zero-lag (DIT=0) panel to the positive DIT panels.

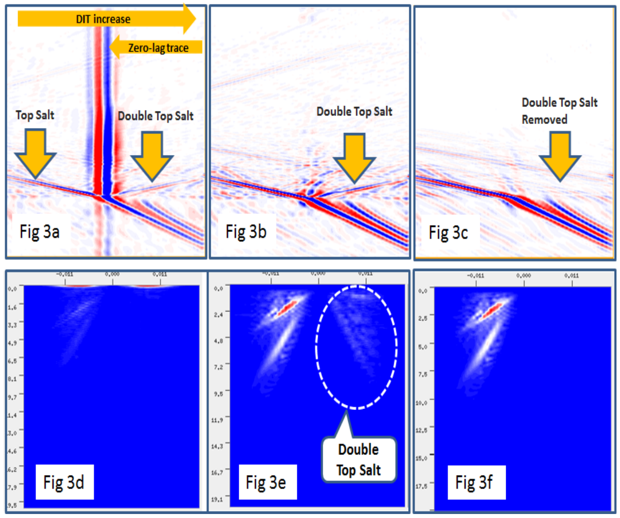

Figure 3: From left to right the DIT time increases from -240 ms to 240ms with increment of 12ms, total of 41 traces. In RTM stack (zero-lag DIT volume), there is a hidden DTS. 3a, 3b, 3c are DIT gather, DIT with low-cut filter and DIT with 2D filter. 3d, 3d, 3f are their respective 2D FFT spectrum.

By sorting the DIT volumes by Line/CDP and DIT time, one can form DIT gathers similar to offset gathers, but the offset axis is replaced by DIT time. Figure 3 is an example DIT gather and filtered results. From Figure 3a the DTS signal is clearly shown as the coherent event with positive slope. DTS "mirror"s about the center DIT trace (zero-lag) to those traces with negative slope on the left side, which are images of TOS. Figure 3b applies a simple low-cut filter, one can see that the strong low frequency component is removed, but the DTS is not removed from the signal. Figure 3c applies 2D filter and the unwanted DTS is removed. Figures 3d to 3f are the corresponding 2D spectrums of Figures 3a to 3c. Compared to the conventional low-cut filter, DIT gathering adds an additional DIT dimension. In a DIT gather, the DTS appears as a coherent event "mirroring" the TOS event, therefore it can be easily recognized and removed by a 2D FFT filter. Figure 4 shows the zero DIT time stacks before and after DIT filtering. The DTS is removed and the TOS image is clearer, and appears to have higher resolution

In practice, the depth DIT gather can be converted to a time DIT gather, then each trace is shifted-down by its corresponding DIT value. The DTS event is then approximately flattened in the time DIT gather, so that in the 2D spectral domain the DTS will appear as a vertical event that is more easily recognized and can be filtered out. One can also perform a similar operation to flatten the TOS (by shifting-up the DIT traces by their DIT values) to make it more easily captured. Figure 5 shows the depth DIT (left) and time corrected DIT gather (right) where the TOS event is approximately flattened and it becomes vertical in the 2D spectrum. The DTS (part of the "dim cloud" on the right side of the spectrum) is also easier to distinguish. After 2D filtering, the time DIT gather (or just zero-lag DIT trace) can be converted back to depth.

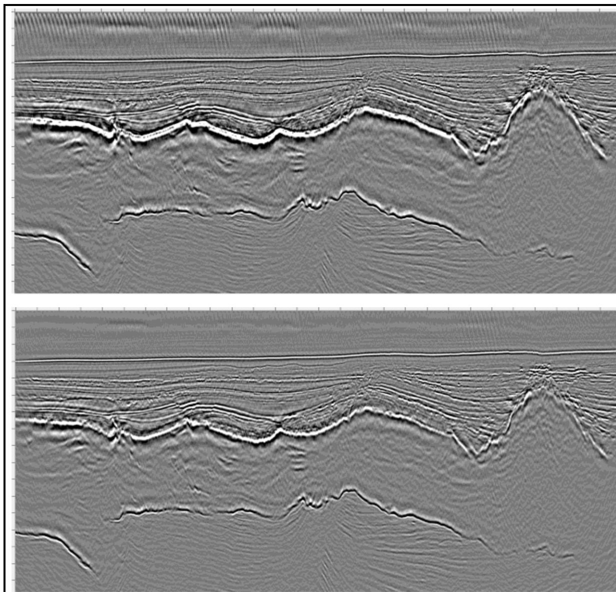

Figure 4, a) RTM stack before DIT filter (w/ low-cut only)
b) RTM stack after DIT filter. Compared with Fig 4a the DTS is removed and TOS looks "thinner"

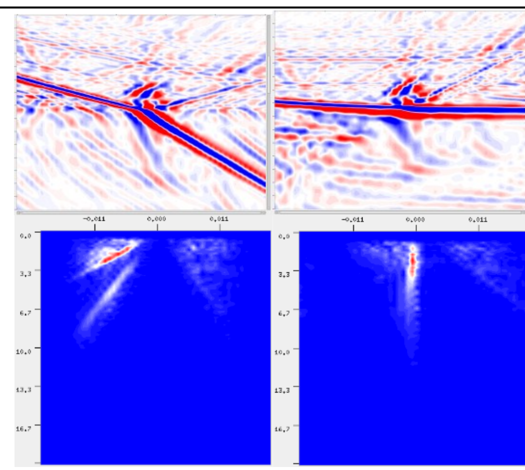

Figure 5, Depth/Time corrected DIT gather makes a specific event easier to be distinguished.

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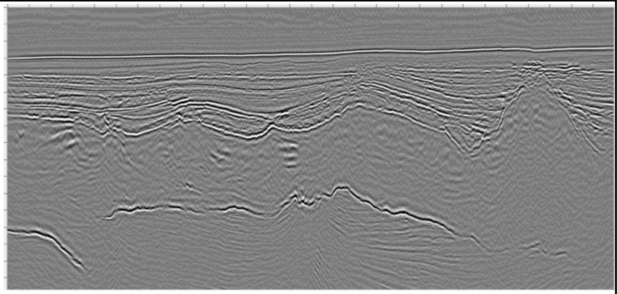
Figure 6, RTM stack with DIT filter and salt-shrinking

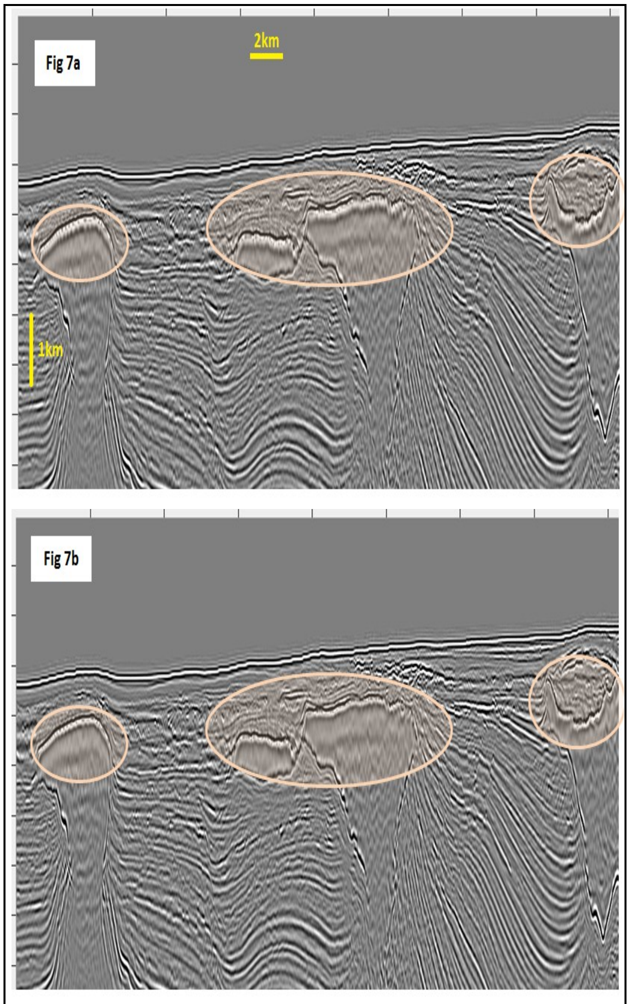

Figure 7, An example of a 3D project at GOM
a) before TOS enhancement
b) after TOS enhancement

This paper mainly discussed DIT scan for DTS removal. Other than DIT filtering, there are other methods such as salt-shrinking and surface-coherent filtering that can also improve the TOS image. For example, salt-shrinking has long been used in migration and is a standard industry practice. It has the merit of supra salt flooding in velocity model building and aims to increase the resolution of TOS, However, due to the change in the velocity model, the subsalt migration image will be incorrect. We have adapted the salt-shrinking concept to the post-migration processing. Therefore there will be no distortion to the image beneath the salt. Figure 6 is the result of DIT filtering and salt-shrinking. The TOS image has been significantly improved.

Figure 7 is another example of a 3D project in Gulf of Mexico region. The TOS was processed with the combination of DIT filtering and salt-shrinking. It can be seen that TOS images were greatly improved.

Conclusions

We have analyzed the double top salt (DTS) in RTM migration and demonstrated that the shallower misplacement of top salt or slightly higher than true supra salt velocity can cause the DTS. RTM with DIT output can simulate the distinguishable and coherent DTS events in DIT gathers, thus making it easy to recognize and remove the DTS artifact. Field examples have shown the effectiveness of this method with great improvements appearing in the TOS images.

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EDITED REFERENCES

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