[GC]Using Volumetric Calculators for Better Accuracy*

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General Statement

Interpreters routinely use horizon slices and stratal (or proportional) slices to interpret seismic attributes. While some attributes such as dip magnitude and dip azimuth can be computed from a picked surface, most attributes are computed volumetrically on a 3-D grid of voxels whose vertical size is defined by the time or depth sample increment. In general, picked horizons occur at fractional sample increments, requiring subsequent interpolation.

● For attributes that vary smoothly, such as the original seismic amplitude, simple linear, quadratic and sine function interpolation provide excellent results.

● For attributes such as envelope and spectral magnitude components, the results are almost always acceptable, but can be less accurate as the values approach zero.

● For attributes that are cyclical, such as phase, azimuth and strike, such interpolation gives erroneous results.

We present a simple workflow that allows an interpreter to more accurately extract such attributes using the volumetric calculators available in most commercial interpretation software packages.

Method

Many attributes of interest have a cyclical behavior, including instantaneous phase, spectral phase components, dip azimuth and strike of azimuthal anisotropy and curvature. While human interpreters perceive these attributes to be continuous, computer software does not and

injects a numerical discontinuity in phase and azimuth between -180 degrees and +180 degrees (or depending on the software package between 0 degrees and 360 degrees).

Similar discontinuities appear in strike between -90 degrees and +90 degrees. Such discontinuities do not pose a problem if we only wish to look at the data at discrete voxels – but if the number of pixels used on the computer screen is larger than the number of voxels being displayed, the data need to be either replicated or interpolated.

The most common implementation is to interpolate the data, linearly, bilinearly or with a spline. Such interpolation between samples works very well for seismic amplitude and envelope, but fails for cyclic (to a computer, discontinuous) attributes like phase (Figure 1a). Many commercial software packages use splines to interpolate along the vertical axis, which for phase results in erroneous values beyond ±180 degrees. The simplest way to avoid such artifacts is to disable the interpolation. This can almost always be done when displaying vertical or horizontal slices through the data volume.

Examples

Examining Figure 2, we note that the vertical slices through the seismic amplitude and instantaneous envelope display nicely, but the same slice through the instantaneous phase in Figure 2c looks "green." Using Figure 1a as a guide, we realize that much of the green is an artifact of inaccurate interpolation wrapped around values of the phase. Disabling interpolation and instead replicating the nearest pixel provides the lower resolution but acceptable image in Figure 2d. This artifact becomes particularly ugly when we wish to extract cyclical attributes along a picked horizon. Horizon picks rarely fall on an integer sample value such that the data need to be interpolated.

In Figure 3 we show a time-structure map and amplitude extraction where the base Oligocene corresponds to a trough. The initial phase extraction is totally erroneous (Figure 3c). A more accurate means of interpolating the phase is to compute the original data and its quadrature (the "real" and "imaginary" components of a complex trace), using the envelope, as shown in Figure 1a.

Be careful to compute the angle using "ATAN2" (the same one as in Excel) to obtain values of phase range between -180 degrees and +180 degrees. By doing so we obtain the geologically reasonable image (phase close to ±180 degrees, appearing as magenta), consistent with our picked trough. Interpolation of other vector components, such as dip azimuth and dip magnitude, are similar to the technique shown in Figure 1b. In contrast, interpolation of attributes that are defined by a strike require a slight variation.

For azimuthal anisotropy, the "azimuth" is really a strike and also varies between -90 degrees and +90 degrees, while the azimuthal intensity, ε, is a strictly positive number. Here, be careful to use "ATAN" rather than "ATAN2" to obtain strikes between -90 degrees and +90 degrees.

Conclusions

This workflow works well in many, but not all software packages. Figure 4, for example, illustrates a limitation faced in the one that we use. We wish to extract and display volumetric dip azimuth along the same horizon shown in the previous image. Using Figure 1b eliminates some of the artifacts. However, while the software allows us to disable interpolation on vertical and horizontal slices, it does not allow us to disable it on horizon slices.

The result is the appearance of blue "rings" (corresponding to north, or 0 degrees) circling anomalies that wrap around between SSW and SSE (±180 degrees) azimuths. Presented with such an image, the only recourse is to realize that they are artifacts and not geology!
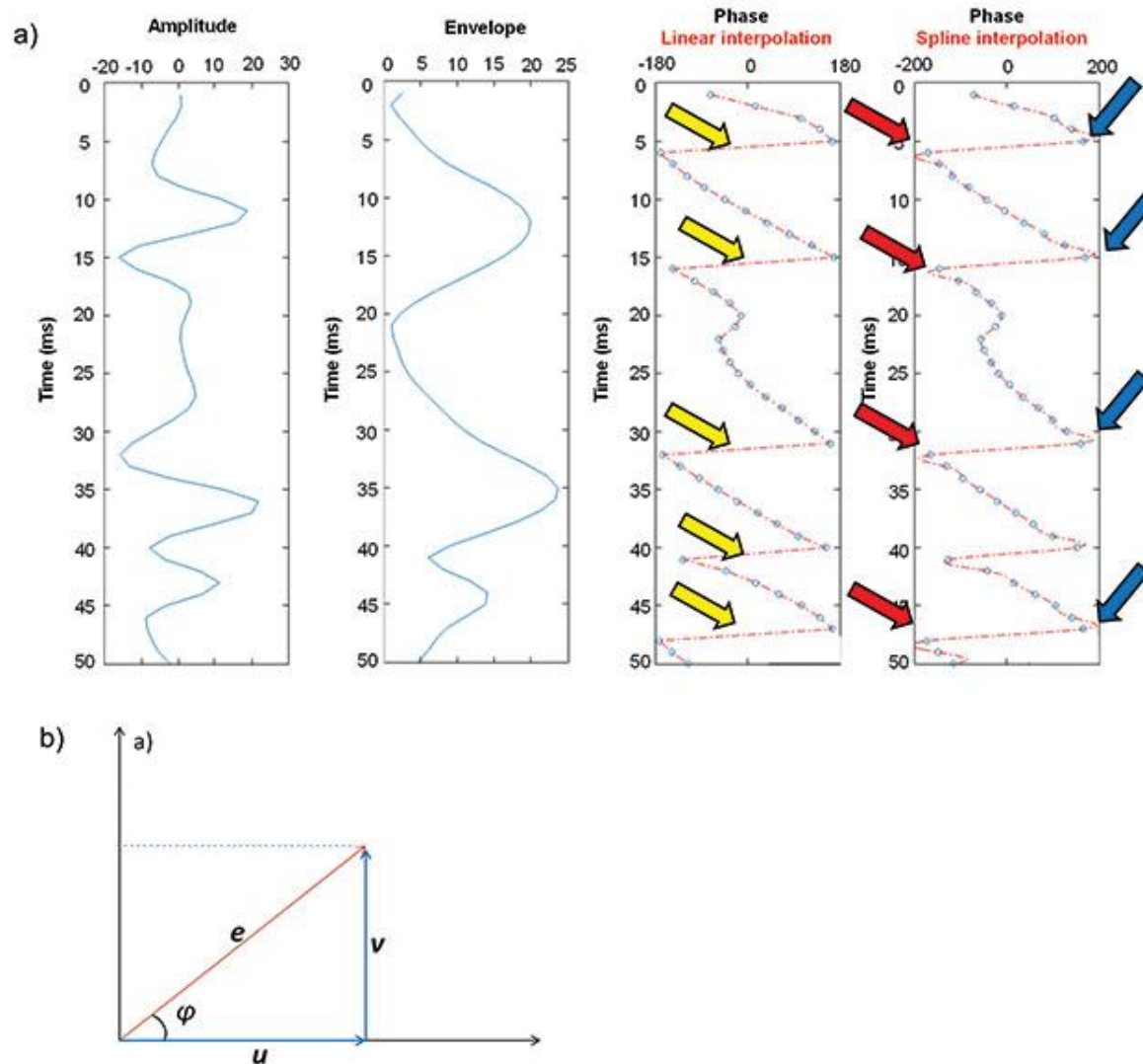
Figure 1. (a) Seismic amplitude, and its corresponding instantaneous envelope and phase. The envelope is linearly interpolated and exhibits no strong intersample errors. In contrast, the linearly interpolated phase generates inaccurate estimates between samples (yellow arrows) when the phase "wraps" around the circle. The spline-interpolated phase (used in many commercial software implementations) exhibits the same artifacts, but also overshoots (blue arrows) and undershoots (red arrows) values beyond ±180 degrees. (b) A cartoon showing the relationship between the original amplitude, u, its quadrature component, v, instantaneous envelope, e, and instantaneous phase, φ. Then first define u=ecos φ and v= ecos φ before interpolation. After interpolation of u and v, compute φ=ATAN2(v,u). We will use this relationship to improve our interpolation.
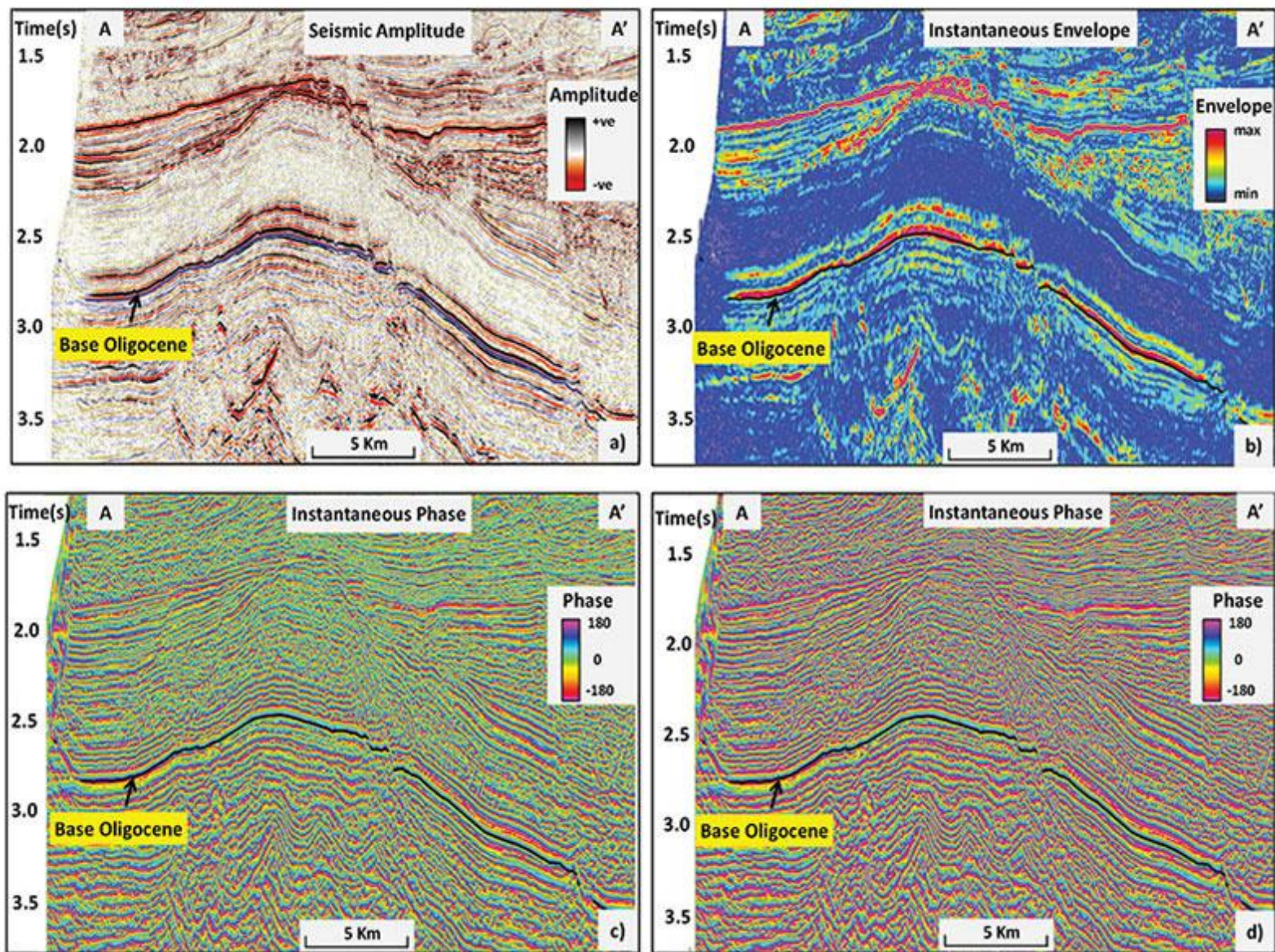
Figure 2. A representative vertical time slices through (a) seismic amplitude, (b) instantaneous envelope, e, (c) instantaneous phase, φ, displayed with pixel interpolation turned on, and (d) instantaneous phase with pixel interpolation turned off. Since the software does not know that instantaneous phase is cyclical, it incorrectly linearly interpolates values that fall between purple values near -180 degrees and purple values near +180 degrees to generate green values near 0 degrees. Turning interpolation off removes these display artifacts. The blue pick indicates the base of the Oligocene section corresponding to a trough. (Data courtesy of NZPM)
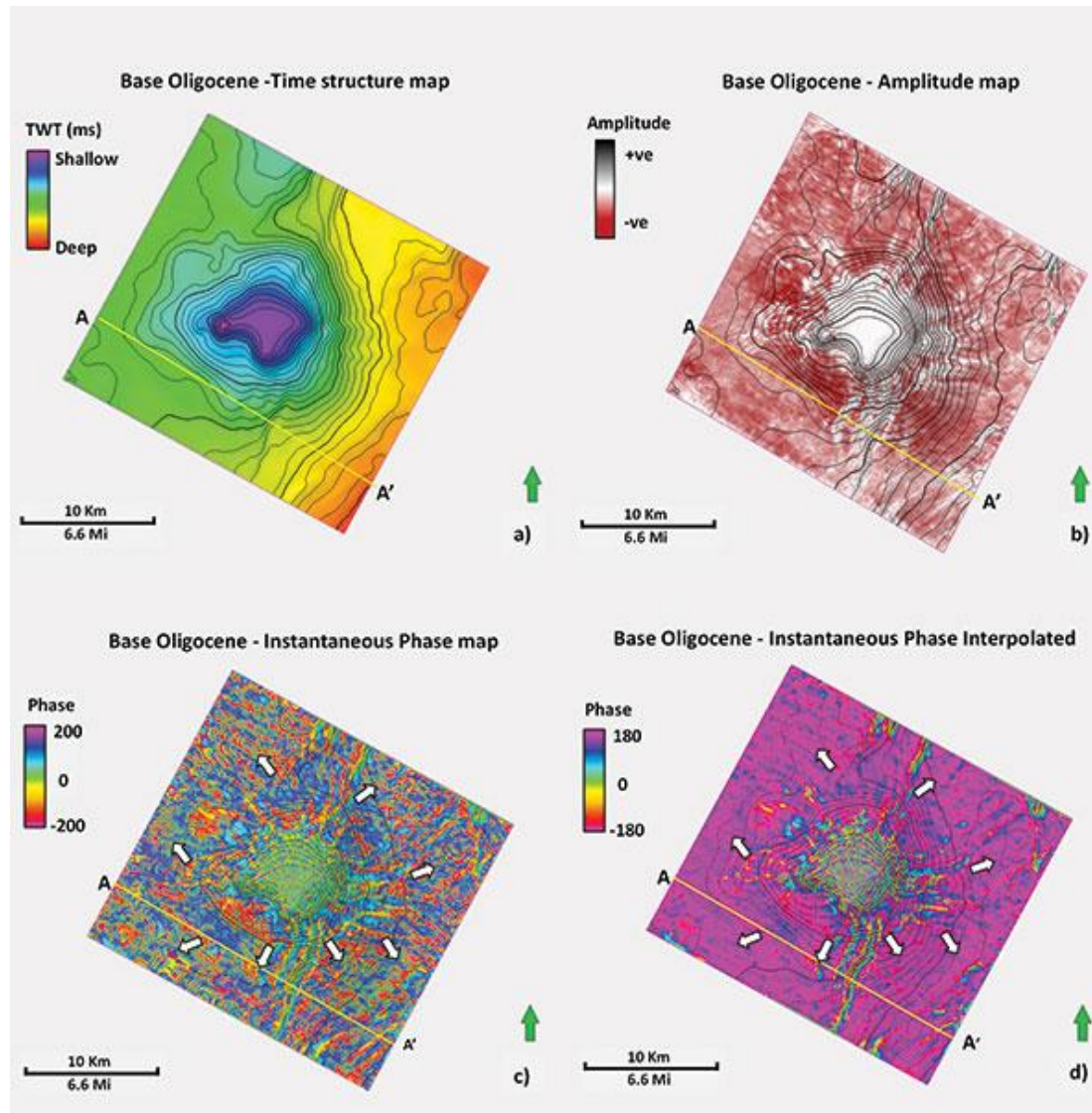
Figure 3. (a) Time structure map of the base Oligocene corresponding to the blue pick in Figure 2. These picks corresponded to a trough. (b) Horizon slice through seismic amplitude, where the values are mostly negative, consistent with the trough pick. (c) Horizon slice through instantaneous phase without vector interpolation. Since we picked a trough corresponding to $\varphi = \pm180$ degrees, the interpolation is highly inaccurate, resulting in a useless image. Notice how the interpolation creates erroneous values beyond ±200 degrees. (d) Horizon slice through instantaneous phase using the vector interpolation algorithm described by equation 2. Here, the phase appears to be purple, corresponding to $\varphi = \pm180$ degrees. The anomalous phase values correspond to radial faults associated with the volcanic plug. There are very few artifacts in linearly interpolating the phase about a peak. Note the white arrows show improvement of artifacts.
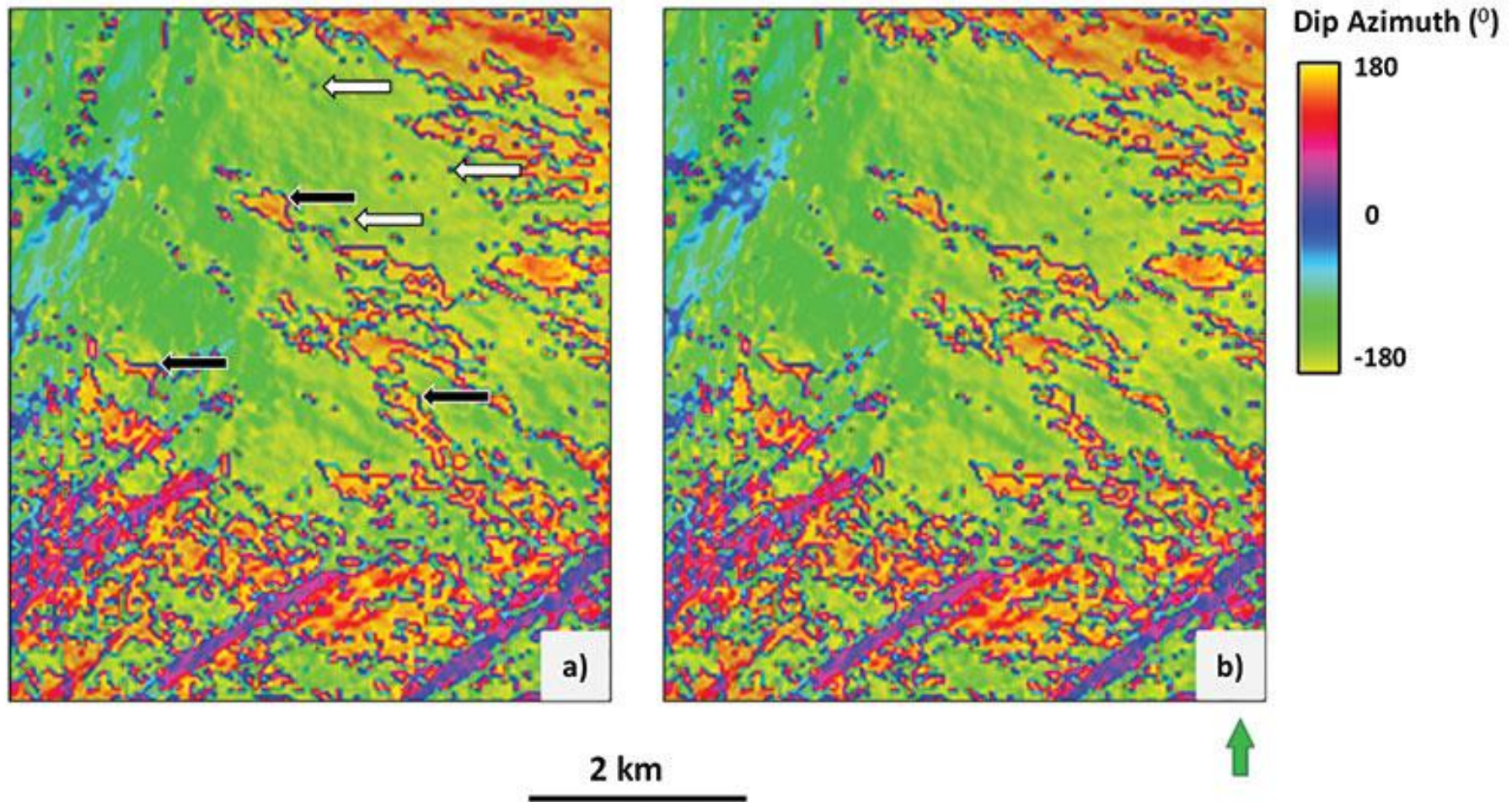
Figure 4. A zoomed image of horizon slice through volumetric dip-azimuth along the picked horizon shown in the previous image about an area of predominantly south (ψ = 180 degrees) dip (a) without and (b) with vector interpolated defined in equation 1c. Careful examination of small artifacts indicated by the white arrows are eliminated when using vector interpolation. However, the major overprint here is the pixel interpolation artifacts introduced by the surface rendering software. In the software we use, there is no way to turn off pixel to pixel interpolation between seismic data points, giving rise to (typically blue, ψ~0 degrees) linear (vs. cyclical) interpolation between yellow values near -180 degrees and yellow values near +180 degrees. For this reason, the extra steps involved in vector interpolation is not worth the trouble.