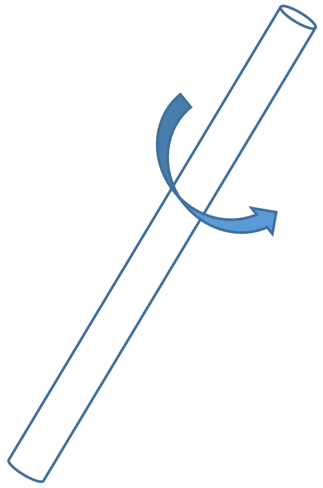
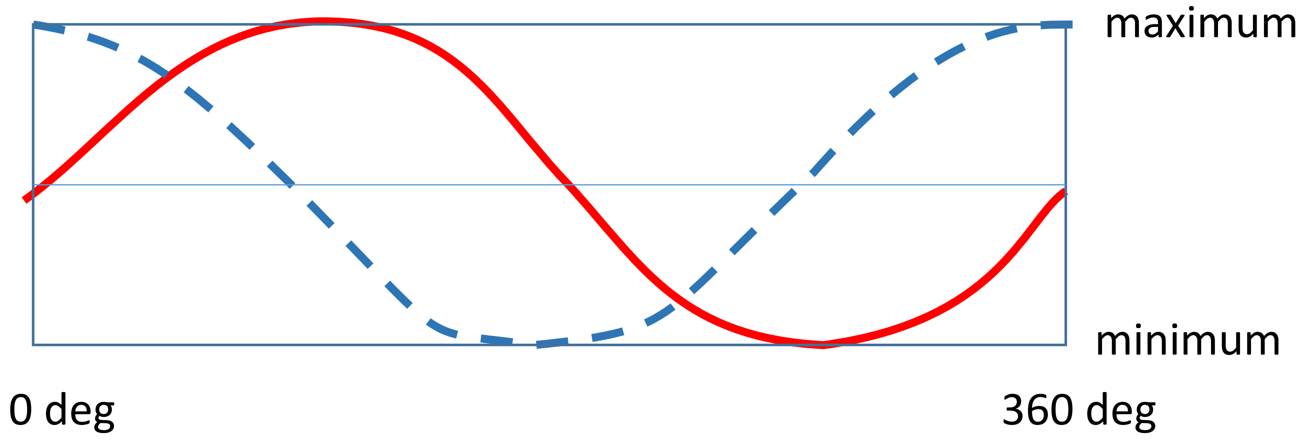
Rotation

This tutorial is about rotation of SAAs in their 27 mm ID PVC conduits. This can arise from external mechanical inputs, residual joint twist that slowly relaxes after installation, or from blasting (really another external mechanical input).

The tutorial assumes you are aware of the Corrections Tab in the VIEW window of SAAView software application (available from Measurand SAASuite Software), and the Antirotation Diagnostics function in the Corrections Tab. This tutorial is aimed at helping to diagnose rotation and decide whether or not to apply this very useful correction.



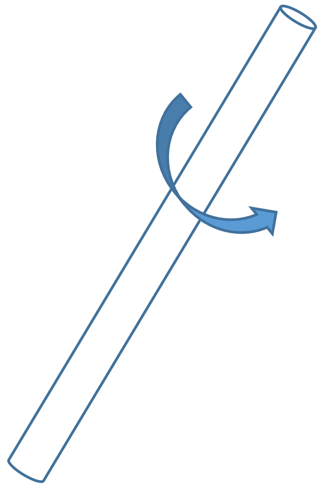


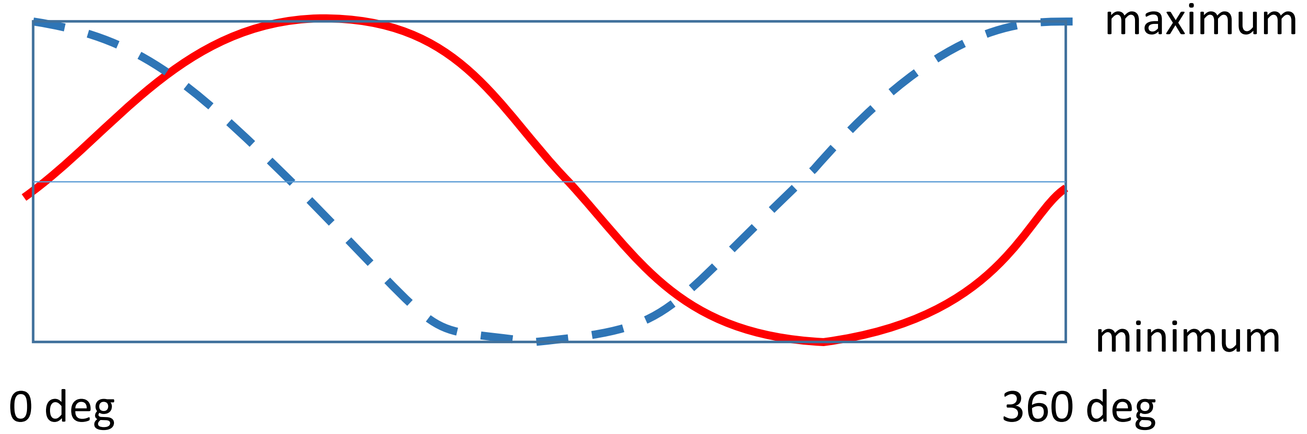
Rotation

Rotation of an SAA involves rolling of many segments about their long axes, as shown here for a single segment. The “roll” geometry is the same for a traversing inclinometer travelling down a casing with “spiral” (really helical) groove error.

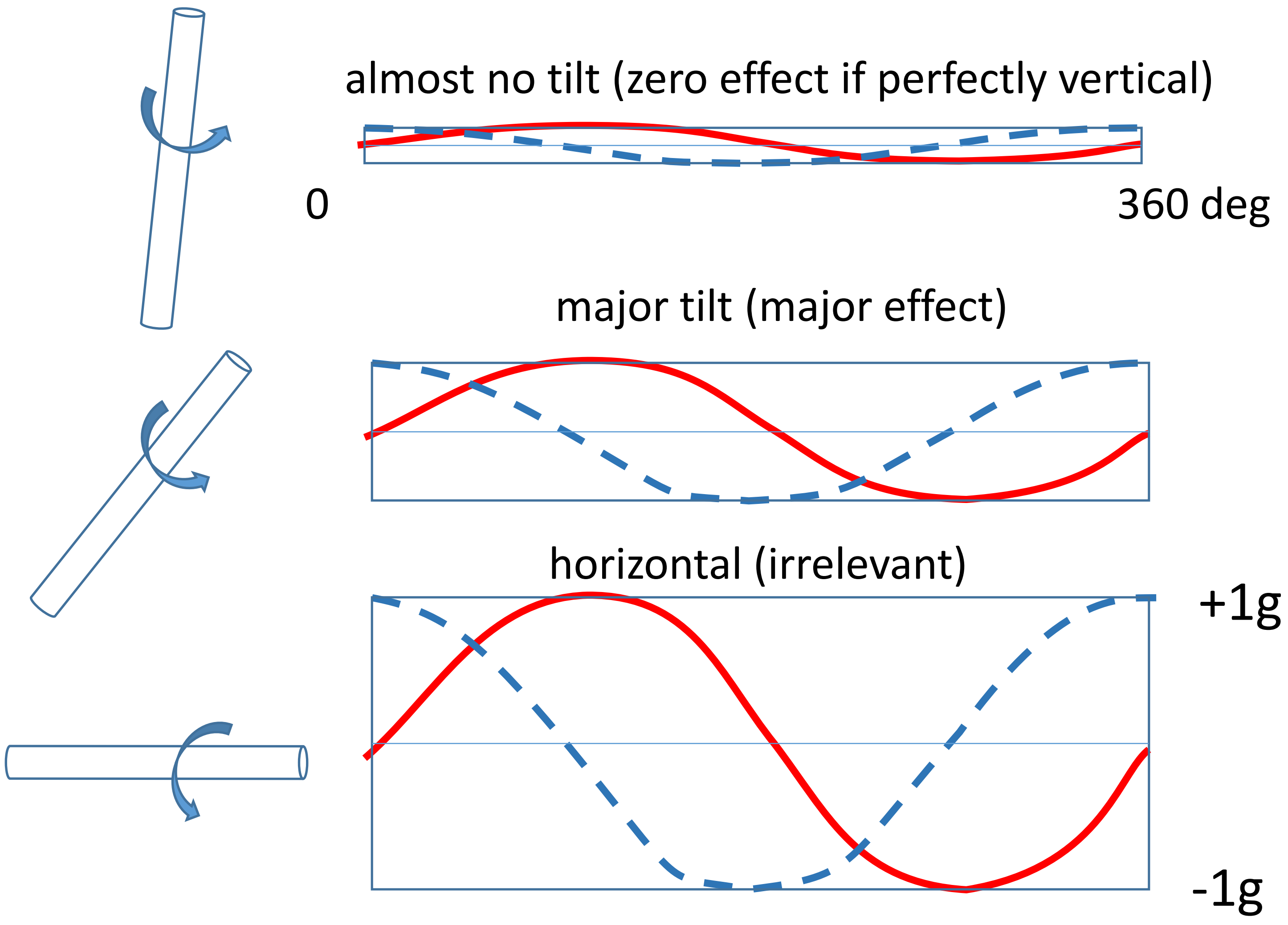
Rotation is not a problem for perfectly vertical casings because of geometry, or for horizontal casings, because roll does not affect the Z sensors used in horizontal installations.

Roll causes the X and Y sensors to sample different components of gravity. A roll from 0 to 360 degrees causes X and Y sensor outputs to vary sinusoidally. X and Y are 90 degrees out of phase.





X and Y sensor outputs for rolls of 0 to 360 degrees, for different tilt angles:



But X and Y outputs are not used for horizontal installations!

Rotation does not affect data when the segments are vertical, except for a very small change in azimuth (usually sub-degree, because rotations are typically very small).

The effects of rotation on X and Y data become larger as the tilt angle deviates from vertical, until the effects reach a maximum effect for a horizontal segment. BUT, when a segment is near-horizontal, only the Z sensors are used. Z sensors are not affected by rotation.

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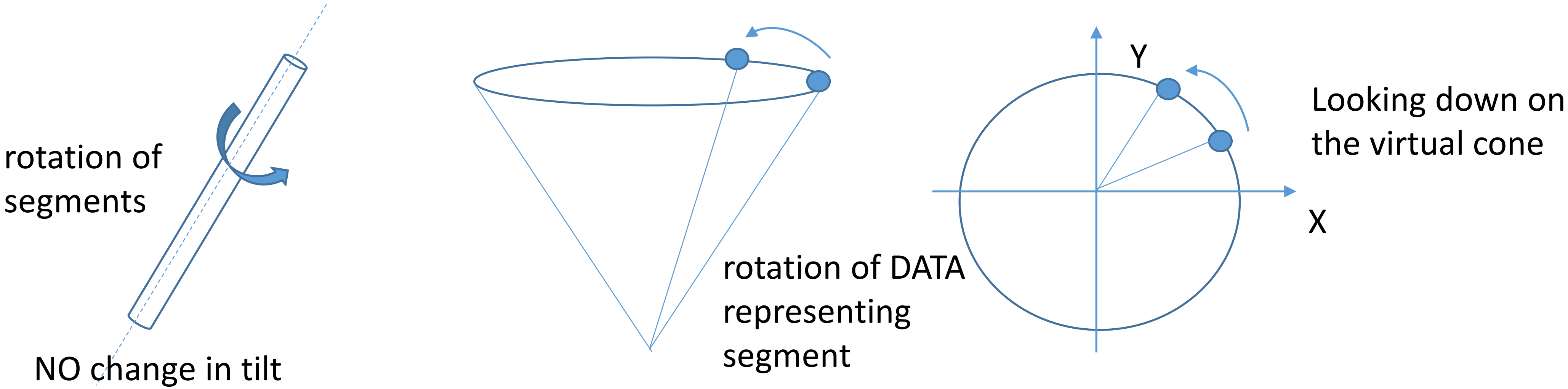
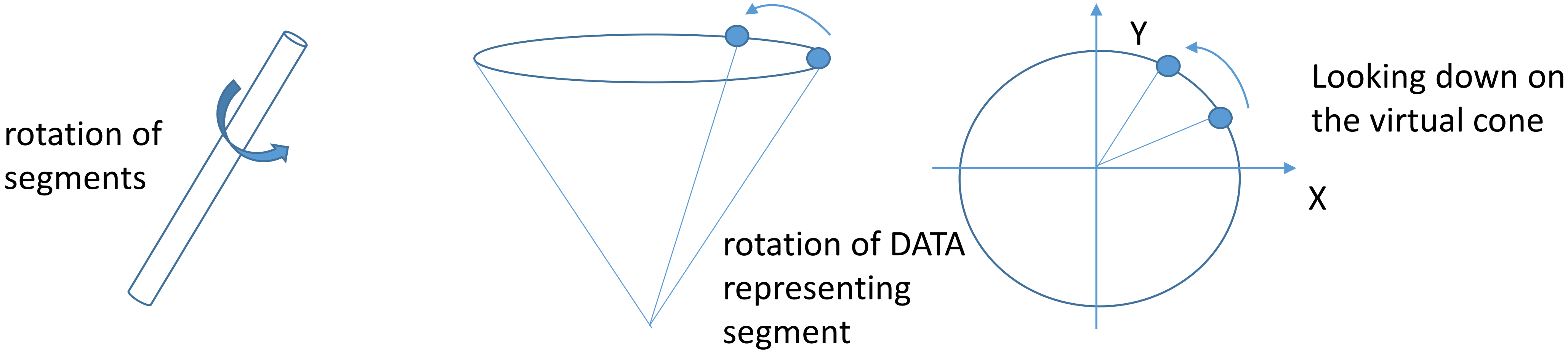


For a segment at a constant tilt angle, a rotation of the segment about its long axis (with no change in tilt <u>and no change in physical end position</u>) will move the incremental displacement <u>data</u> (not the physical segment) associated with the upper end of the segment in a circle in the horizontal plane: the data for the segment describe a cone. The segment <u>data</u> travel around a virtual data cone with a <u>constant tilt magnitude</u>. The cone viewed from above looks like a circle. Note that the cone is a <u>virtual cone</u>. The physical <u>segment only rolls about its axis with no change in tilt or relative positions of the ends</u>.



Rotation angle can be found from atan(Y/X), where X and Y are the tilt outputs of the MEMS sensors. Depending on the proportions of X and Y tilt in the virtual cone at the beginning of rotation, the motion around the virtual cone can be mostly in X, mostly in Y, or a combination. It has nothing to do with actual azimuth of expected deformation, but is determined by the azimuth of tilt of the borehole where the segment is located, and whether the X axis of the segment is oriented down, up, or sideways.

<u>Rotation is not deformation, but effects of rotation can look like deformation</u>. How do we tell the difference?

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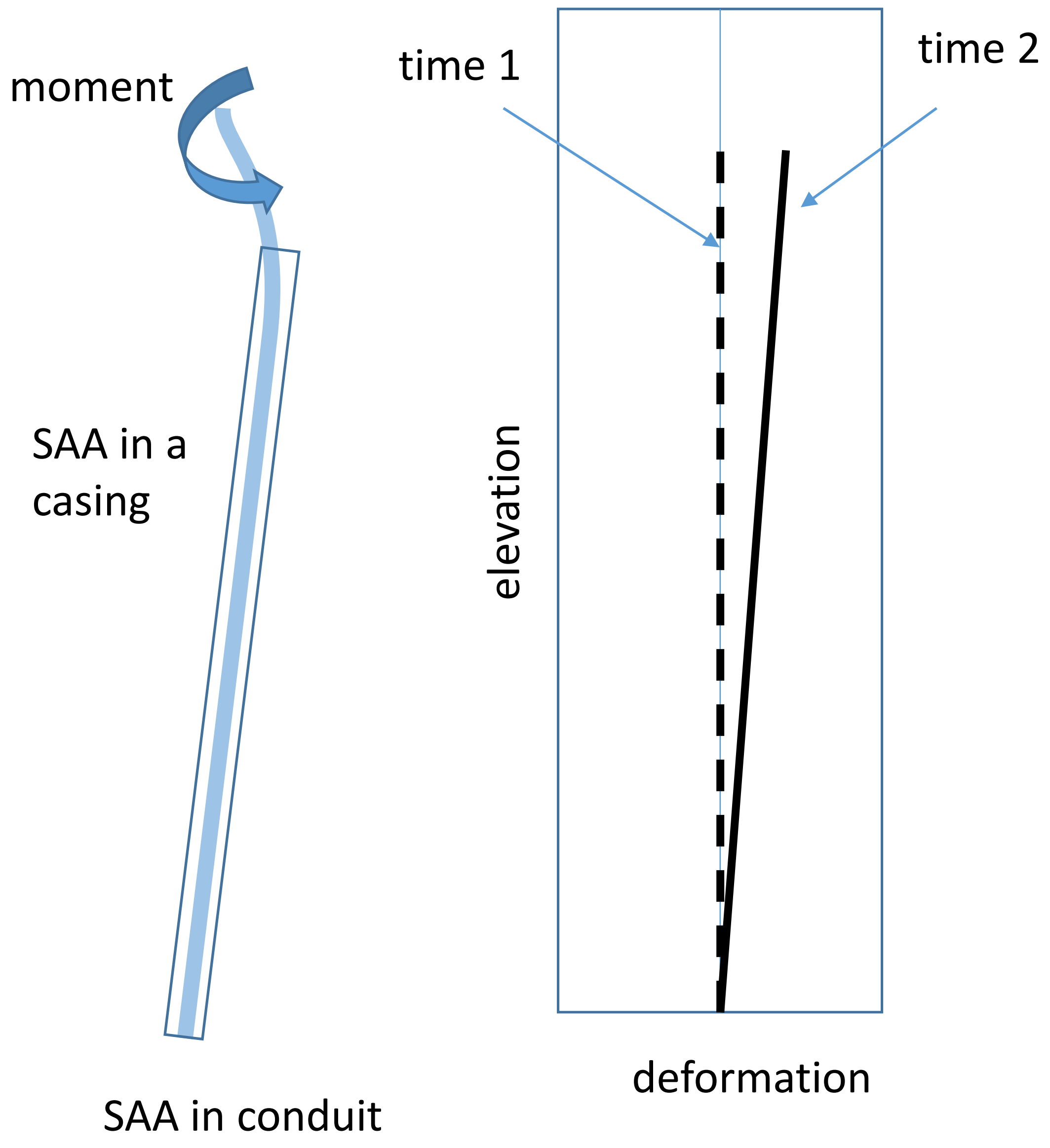
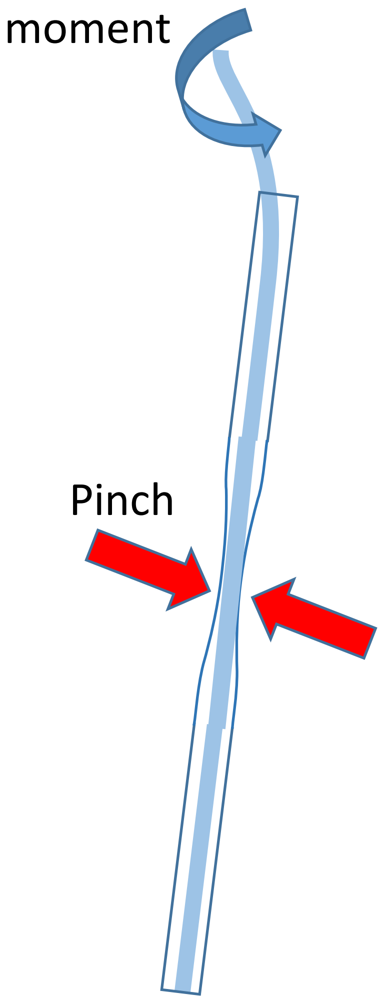
Rotation involves <u>MANY SEGMENTS of an SAA rotating together</u> in the same direction (i.e. all clockwise or all counterclockwise). This follows from the segments being connected by twist-resistant joints. Imagine an SAA in its casing smoothly rotating from top to bottom because of a moment (force acting through a distance) applied at the top. Unless the segments encounter a pinch point, they will all rotate. Friction or an obstruction may taper off the rotation or stop it abruptly at some elevation.

For uniform rotation, the X or Y deformation plot will look like the sketch to the right. Whether it is in X or Y depends on the remarks made in the previous slide. A deformation that looks like it represents data from a wall falling over is probably not the entire SAA leaning, but rather is a rotation error.

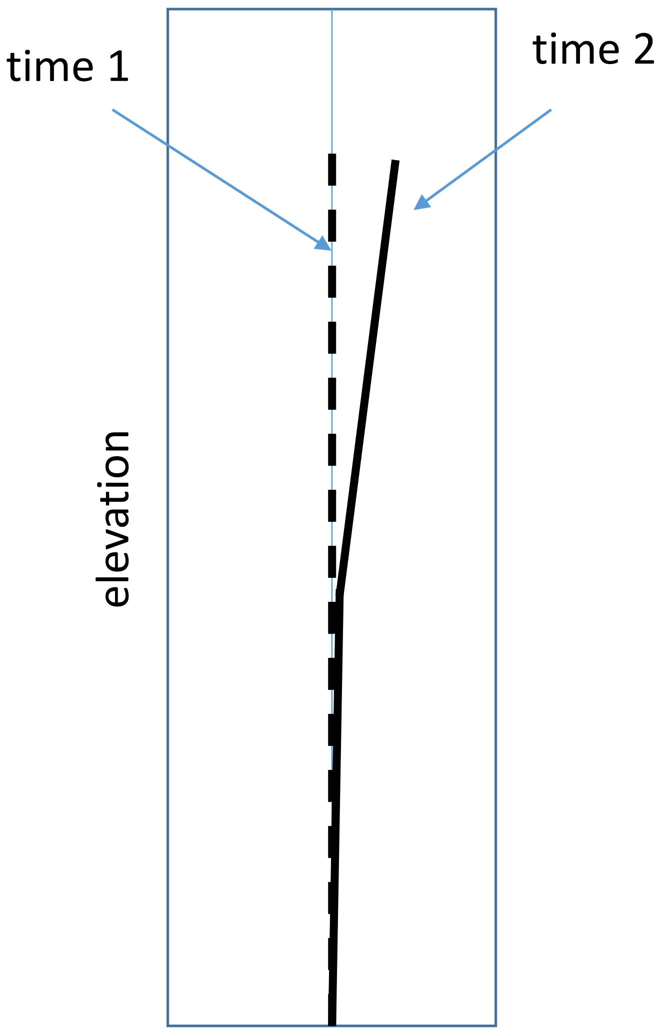


If there is a blockage (e.g. abrupt change of course of the casing, ovalization, or impinging rock) half way up the borehole, then the "falling-over wall" <u>apparent</u> deformation will begin half way up the elevation axis if the SAA cannot rotate below that elevation.

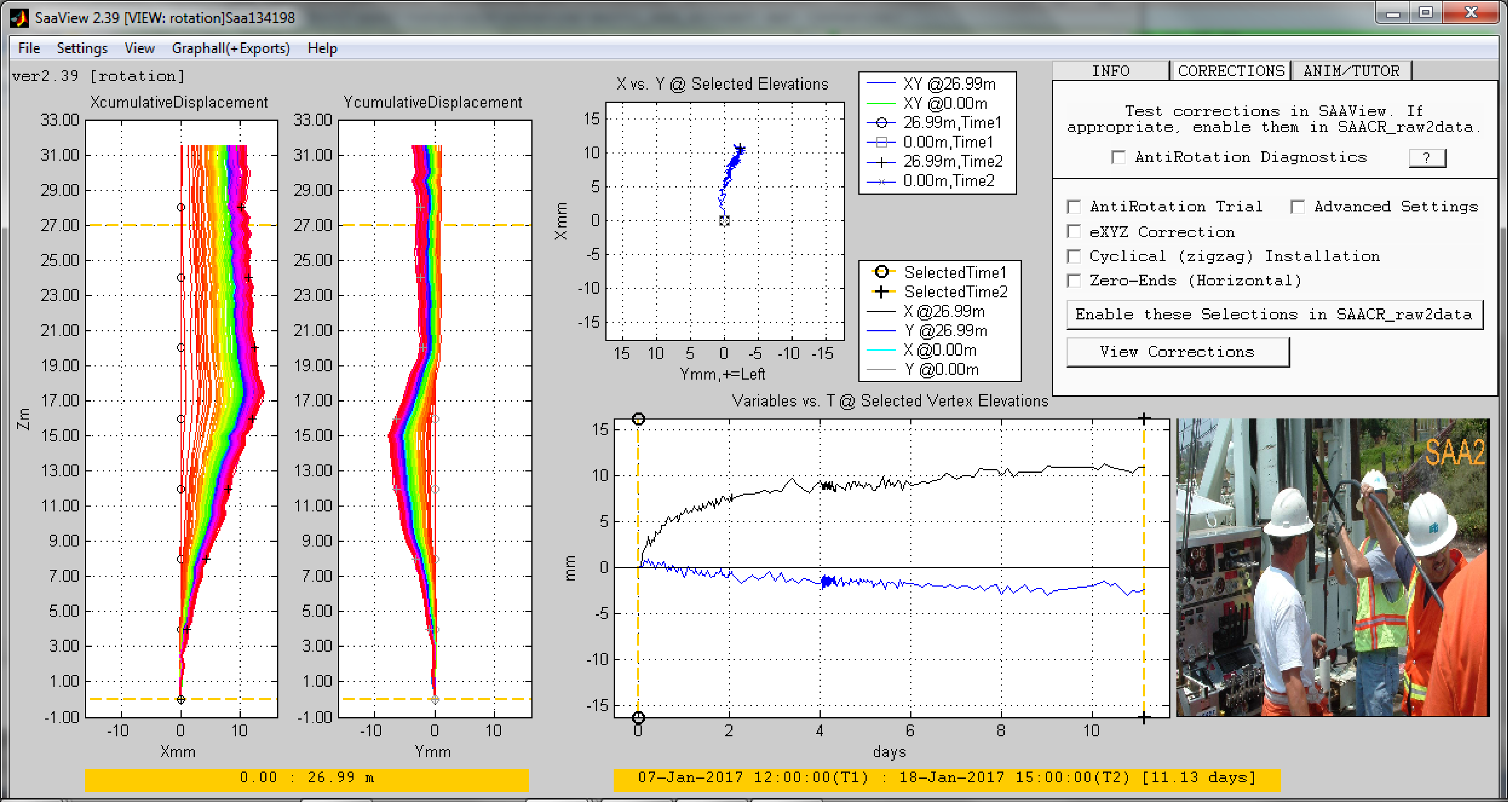
When rotation effects are seen, they are often erroneously called "drift". Electrical drift is not seen in Measurand MEMS SAAs. Even if the sensors did drift, there is no way such drifts could make it through the 3D math to look like a "falling-over wall".



SAA in conduit



deformation



These data are from a near-vertical installation of SAA. Note the telltale signs of rotation. In this case the “falling-over wall” is near the bottom, and the upper part of the SAA is relatively unaffected.

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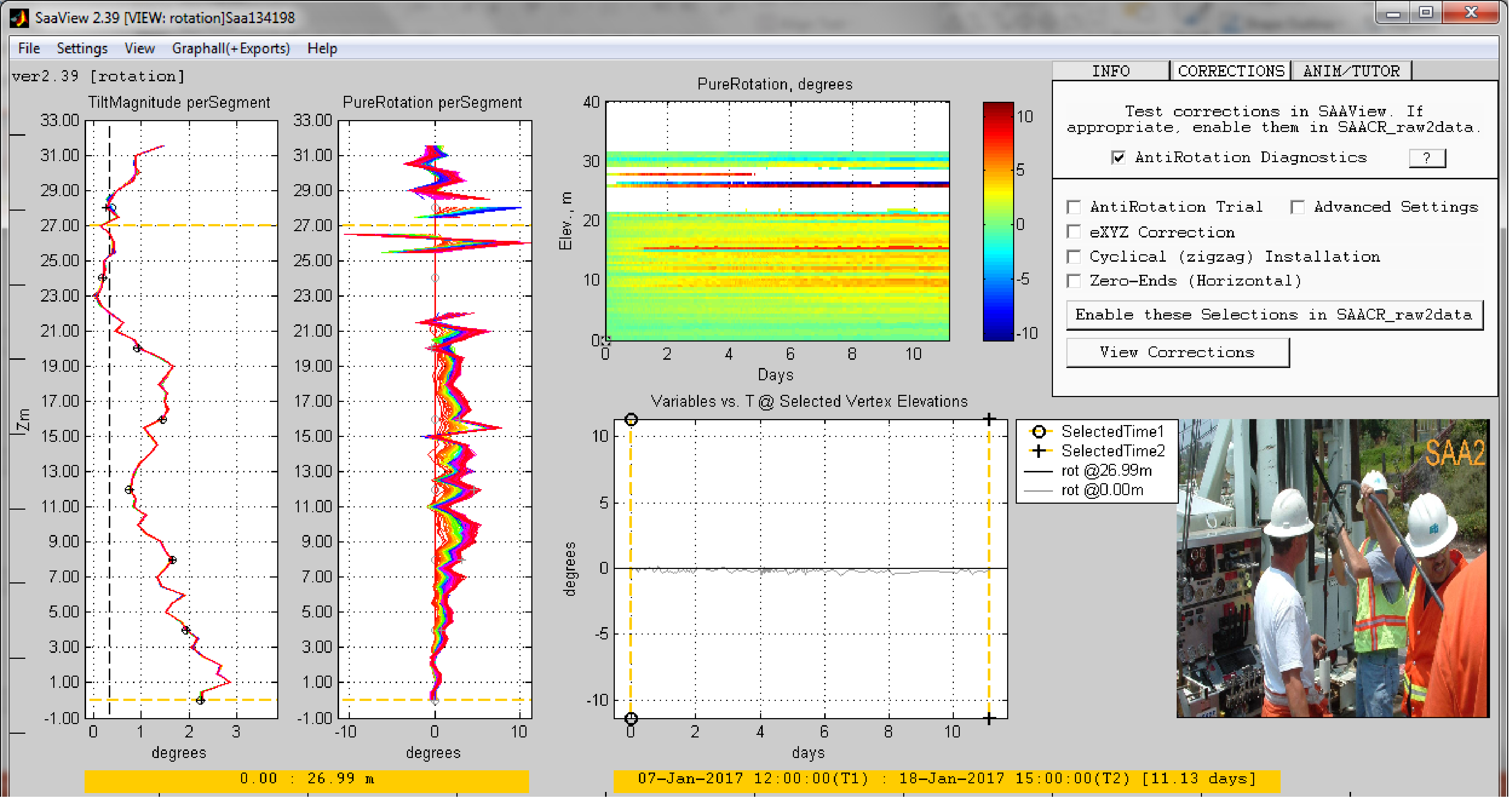

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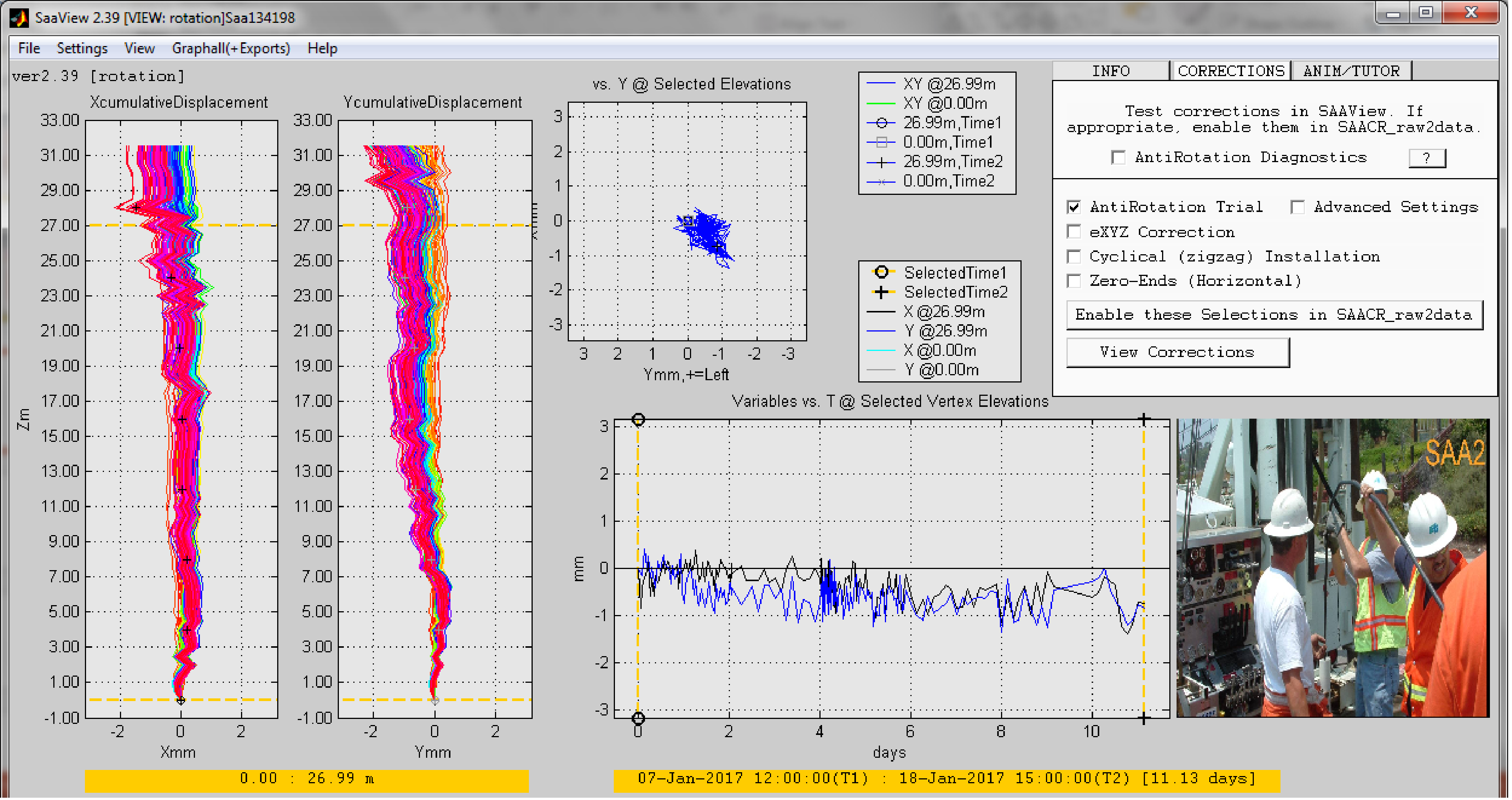
The rotation diagnostic shows the SAA to be nearly vertical near the top, so roll angles cannot be read with any accuracy, and are not shown in the upper middle color plot. A couple of segments show large total rotations in the upper region, but these are artifacts due to near-vertical data. The PureRotation values below 22 m are consistently of the same sign (positive in this case) and demonstrate many segments rotating together in concert.



The antirotation correction works on this data to reduce what were almost 15 mm apparent deformations to a background of negligible deformation below 2 mm.

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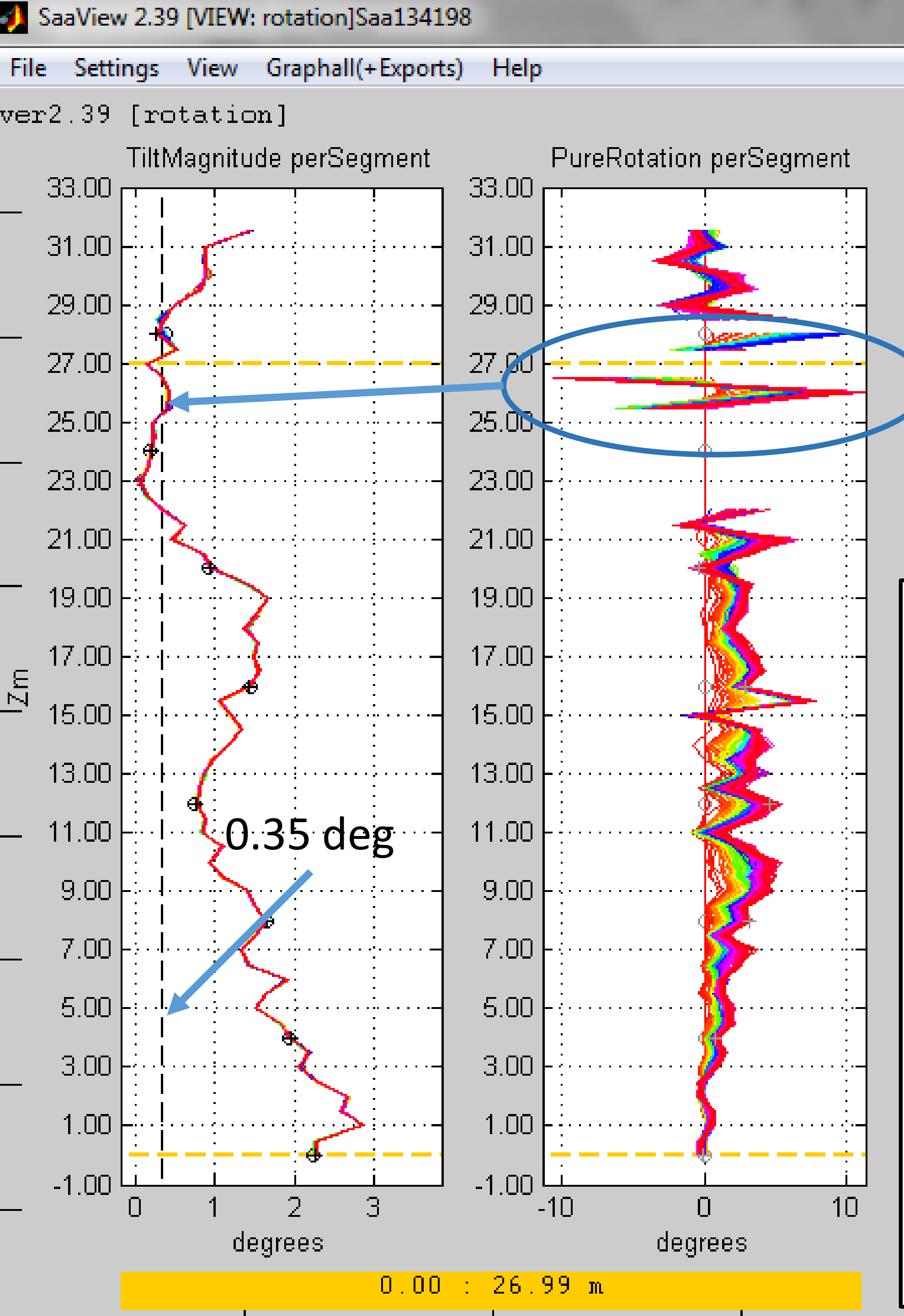

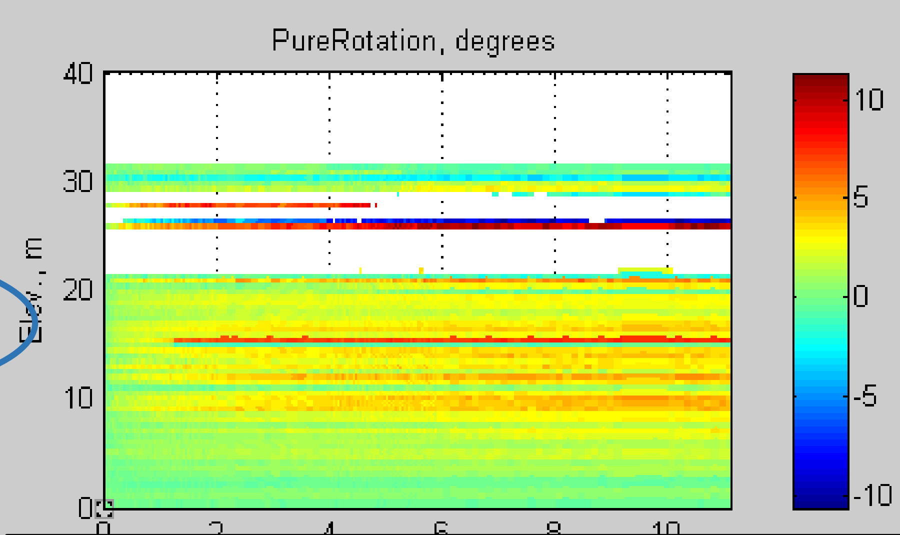

Let’s go back to the isolated large rotations. They come from segments with tilt barely over 0.35 degrees (the vertical dashed line). In this region there can be large errors in determining rotation angle from atan(Y/X), because X is very small.

But near 0.35 degrees, rotation has almost no effect anyway. These false rotations are distinctive in that they occur generally in equal and opposite pairs and the pairs tend to be isolated (NOT concerted rotation of many segments).

If isolated rotation pairs are the only features evident, the antirotation correction is not needed or advisable.

What does the antirotation correction do?

The antirotation algorithm acts as follows:

- Tilt magnitude of each segment is measured. This is sqrt(X^2+Y^2), where X and Y are the incremental displacements of an individual segment unrelated to any other segment.
- Rotation of each segment is measured using atan(Y/X), which was introduced earlier in this document.
- If the tilt magnitude (sqrt(X^2+Y^2)) does not change appreciably from frame to frame, and the tilt is large enough to get a decent reading of roll angle, then the measured roll is used to correct the azimuth of the segment (basically, the segment is "unrolled" mathematically).
- No change is made to any tilt. Corrections involve only the azimuth.

What are some features of the antirotation algorithm?

- If a segment is very nearly vertical, its rotation can not be corrected, but rotations tend to be very small, so the only error is a small change in azimuth (usually sub-degree).
- By nearly vertical, we mean 0.35 degrees or less, unless advanced settings are used (not recommended without a lot of consultation).
- Correcting rotation involves automatically reading the rotation angle and un-rotating by that amount. This is very accurate and is applied to each segment individually.
- It is best to apply antirotation correction to a reasonably uniform set of data without uneven gaps in time. The correction is done from one frame to the next, and does not "look forward" or "look back" in time.
- Antirotation corrections cannot be added to an automated SAACR_raw2data process until the user has examined the data (and hopefully has read and understood this tutorial).
- The algorithm never changes the magnitude of tilt. The only change is a (usually very slight) correction of azimuth.
- The apparent deformation due to rotation error can move along any azimuth. It is <u>apparent</u>, and <u>not related to the underlying deformation.</u>
- Antirotation correction is not needed or allowed for horizontal installations. Horizontal data comes from Z sensors with axes aligned to the long axis of a segment. Z sensors are little affected by rotation, but optimally responsive to tilt away from horizontal.

What to do about a rotation problem?

- If possible, correct the mechanical issue. Installations should have a Measurand Installation Kit with two blunt screws holding the SAA within the 27 mm ID PVC. Remove sources of moments near the top. A run of conduit that looks like a big wrench, IS a big wrench. Avoid twisting an SAA during handling or insertion.
- Examine the data in Measurand SAAView. Try eXYZ correction first. If it improves the data, then leave it on. Use the Antirotation Diagnostic in the Corrections Tab. Turn antirotation trial on and off. Consult with Measurand if in doubt about results.
- If convinced that an antirotation correction is needed, then enable it for that particular SAA in the Corrections Tab. Then set up SAACR_raw2data to apply all enabled corrections.
- If uncertain that antirotation is needed, revisit the data in (for instance) a month.
- If applying antirotation, ensure that all data are reconverted with the correction.
- Generally, antirotation does no harm and is safe to leave on. BUT:
    - ❑ Don’t correct if the “rotation” is really a few isolated pairs of segments that have large rotation angles moving in opposite directions.
    - ❑ Don’t correct if the data are from an experiment where only a few frames of data are generated, representing very different shapes of an SAA.