JR 6/08/99

SOHO Roll Angle Analysis

These notes summarize how the roll angle is controlled and determined on SOHO, and provide some recommendations for improving this in the future as well as reprocessing to improve the attitude history.

Background

The roll angle of SOHO is controlled by uplinking the desired guide star roll position in the SSU field of view, and the control loop then drives the spacecraft roll so that the observed SSU star position matches the uplinked value. In the SSU frame, the roll coordinate is Z and the pitch coordinate is Y. The uplinked value is calculated by FDF so that the SOHO spacecraft body Z-axis will be parallel to the Sun's spin axis. This requires a motion of the Z-body axis with respect to the North Ecliptic pole (NEP) of +/- 7.25 degrees with a period of one year, which is referred to as the roll steering law or roll scanning law (RSL). The RSL roll angle for a period of one year is shown in Figure 1.

In order to proved a measure of the actual roll angle to the user community; the telemetry contains a roll angle, R, calculated on board as

$$R = err + RSL\_roll + roll\_TM\_offset \qquad (1)$$

Where err is the control loop error, RSL_roll is the uplinked SSU Z-coordinate, and roll_TM_offset is a constant ground-commanded offset. This telemetry is processed by CDHF and placed in definitive attitude files with a time resolution 10 min, and in full time resolution (FTR) files with a time resolution of 1sec.

Recently, the scientific community has expressed concern that the telemetered roll indicates that SOHO is not following the RSL to within the requirement of 90 arc-sec. For example, Figure 2 shows the telemetered roll converted to a frame relative to the Sun's north pole for a period of two years – apparent deviations of 0.5 deg or more occur. Figure 3 shows the telemetered roll for a period in April, 1999. The guide star was switched on April 6, 9 and 20, and roll_TM_offset was updated on April 6 and 20. An apparent linear variation with jumps when roll_TM_offset is reset may be seen.

Analysis

Figure 4 shows the RSL roll angle with respect to the NEP (also referred to as the ACF frame) along with some roll solutions during April, 1999 (the time period of Figure 3). The RSL roll angle is that used by FDF to calculate the expected guide star positions for uplink. These solutions were calculated from the raw SSU data in the telemetry and do not depend on the telemetered roll angle. The approximate times of guide star switches shown as well. This suggests that the actual SOHO attitude is smoothly following the RSL as expected. On the other hand, as illustrated in Figure 5, the definitive attitude only agrees with the RSL at the points where roll_TM_offset is reset.

The telemetered roll was simulated by assuming err = 0 in equation (1), and biasing the SSU observed Z-coordinate such that the Z-coordinate is equal to the solution roll angle at the first point following a guide star switch. This is plotted in Figure 6 as residuals from the RSL roll angle. The similarity with the definitive attitude may be seen, and indicates that the problem is not with the actual attitude of SOHO, but rather with its representation in telemetry. This may be understood, qualitatively at least, by noting that the 1 deg/day yaw attitude motion of the spacecraft with respect to inertial moves stars on the positive pitch side of SSU field of view in the direction of the roll motion, and stars on the negative pitch side in the opposite direction (Figure 7). Thus, since the guide star before the switch on April 20 was on the positive side, and the guide star after the switch was on the negative side, we would expect the telemetry roll to change faster than the actual roll prior to the switch, and slower afterwards. This is what was observed.

SOHO Gyroless Updates

As part of the flight software updates to operate SOHO without gyros, Matra has proposed some changes to the implementation of the RSL on board. These changes are designed to simplify operations by making the uplink RSL information independent of a specific guide star, and allowing the option for automatic guide star switches on board.

The basic approach is to uplink a "sliding line", which gives in essence the SSU Z-coordinate of a hypothetical star moving from one side of the FOV to the other. Along with the sliding line are uplinked offsets from the line to several potential guide stars. The control system then uses the sliding line along with the appropriate offset to reconstruct the SSU Z-coordinate for any of the potential guide stars. The difficulty with this approach, as presently understood, is that it does not take into account the pitch motion of the guide stars, and so will have the effect of making the actual attitude look like the current telemetered attitude, i.e., the actual attitude will not follow the RSL. In any case, the present mode of operation can be emulated with the sliding line by making the sliding line correspond to an actual star, and uplinking zero offset for this star.

The ideal way to accomplish these goals (if sufficient computing resources exist on board) is to make the RSL uplink be the actual roll angle. The inertial positions of the potential guide stars would also be uplinked, and the SSU Z-coordinate calculated on board for the selected guide star. This has also the advantage that the downlink telemetry (computed in the same way as before) is now a good representation of the actual attitude, which will follow the RSL closely.

Another potential impact is the new CRP mode, which uses ratios of the transverse momentum components to provide a roll reference. In the event of extended operation in this mode without the SSU, an absolute roll angle will be periodically provided by the MDI experiment. Incorporation of this measurement into the onboard and definitive attitude needs to be considered.

Roll Attitude Solution Options

The next issue to be considered is how to obtain an accurate representation of the roll angle for use by the scientific community. This problem has two parts, first obtaining the correct roll angle in the future, and second, obtaining the correct roll angle in the past for data already processed by CDHF (going back in fact to the start of science operations in 1995 or 1996).

In terms of future operations, both short term and long term may be considered. In the short term we need a solution that does not require any software updates (either on board on the ground). Two possibilities have already been proposed:

- Update roll_TM_offset frequently enough to keep the telemetered roll within some constraint the actual roll (3 arc-min has been proposed, leading to roll_TM_offset update once/day)
- Ask the users to just ignore the definitive attitude files when the RSL is active, and assume that the attitude is zero with respect to the Sun's north pole. If the RSL is not active, the existing telemetry will provide a reasonable representation of the attitude.

The first not only generates additional work for the FOT and FDF, but induces an artificial variation in the roll angle solution with a period of 24 hours (in a sense, one problem is replaced with another). The second option is probably best and is essentially the current default. In the case of the FTR files the high frequency variation of the roll angle with respect to the Sun's north pole may be obtained by experimenters if they simply detrend the FTR roll data (as discussed below).

In the long term, a combination of ground and/or flight software changes may be considered. If it were possible to adopt the approach to implementation of the RSL mentioned in the previous section, the downlink telemetry could simply be used as it is now by CDHF. Thus, in this scenario all changes are encapsulated on board and are transparent to CDHF.

One can also envision solutions with only changes to the ground system. One approach would be to calculate the attitude from the SSU data, potentially either in FDF or CDHF, and use this as a basis for the definitive files. This will entail a considerable amount of processing, especially for the FTR files.

Another approach is suggested by the observation that the actual attitude of SOHO follows the RSL quite well. We also note that the control loop error is a measure of the instantaneous error in the attitude, and is approximately the same in both the Sun and ACF frames. Thus, the roll telemetry can be detrended (in 24 hour blocks as currently processed by CDHF) to remove the constant and low frequency terms that are in error. The detrended data are then added to the nominal RSL roll attitude to obtain a reasonable approximation to the actual attitude. If the 24 hour block includes a roll_TM_offset update or period when the RSL is not active, then the block would have to be segmented and the segments processed separately. This approach is illustrated in Figure 8 on a short segment of data (this example was generated from an FTR file rather than directly from the telemetry, but the effect is the same). The top plot shows the original data, the middle plot after detrending, and the bottom plot after adding to the nominal RSL.

If the RSL is not active, then the roll telemetry should be used as is. Since roll_TM_offset may not be updated immediately when the RSL is disabled, CDHF may need to do some backfilling.

Operationally things would remain much the same – the roll_TM_offset should be updated every time the guide star is switched or the RSL is not active.

Reprocessing of Old Data

The project scientists would like to have available a compete and accurate attitude history for the mission, allowing future generations of scientists to process the science data with some confidence that the attitude data necessary to interpret their results is correct. Since the on board system cannot be modified for old data, a ground solution is necessary. Indeed, the best thing is to make the ground system-only updates discussed in the previous section and then just reprocess all of the old telemetry.

Recommendations

1. Once the gyroless updates to the flight software are in place, ESA/Matra should consider the rigorous treatment of the RSL on board. No changes are required to CDHF for future processing, and the operation is streamlined.
2. The ground solution based on detrending data should be implemented in CDHF for processing past and future data.

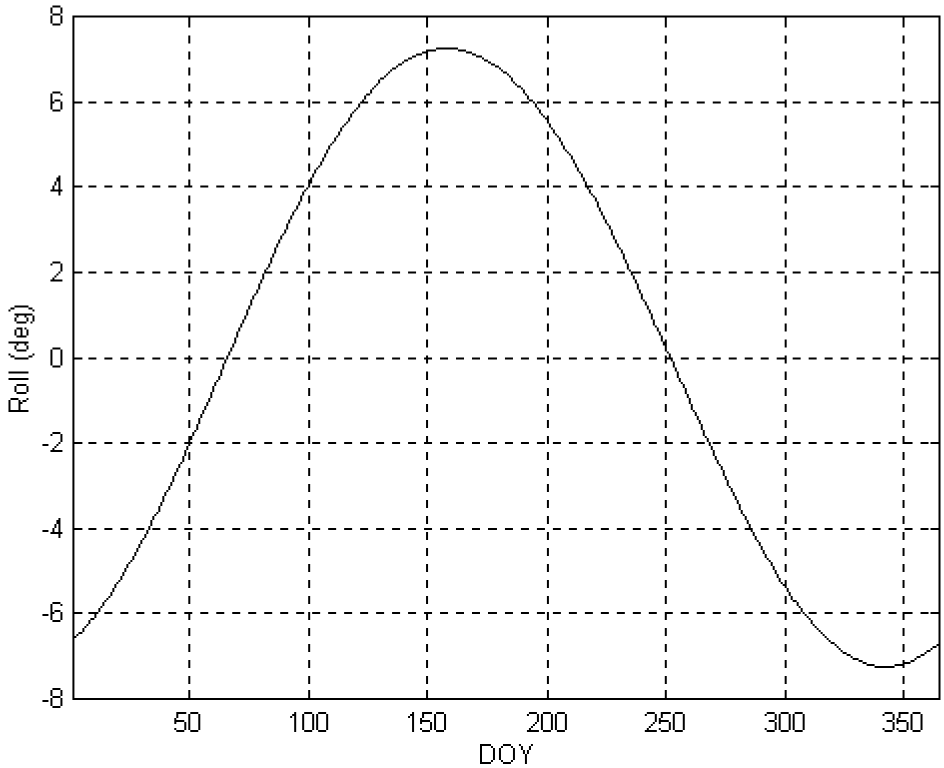


Figure 1.

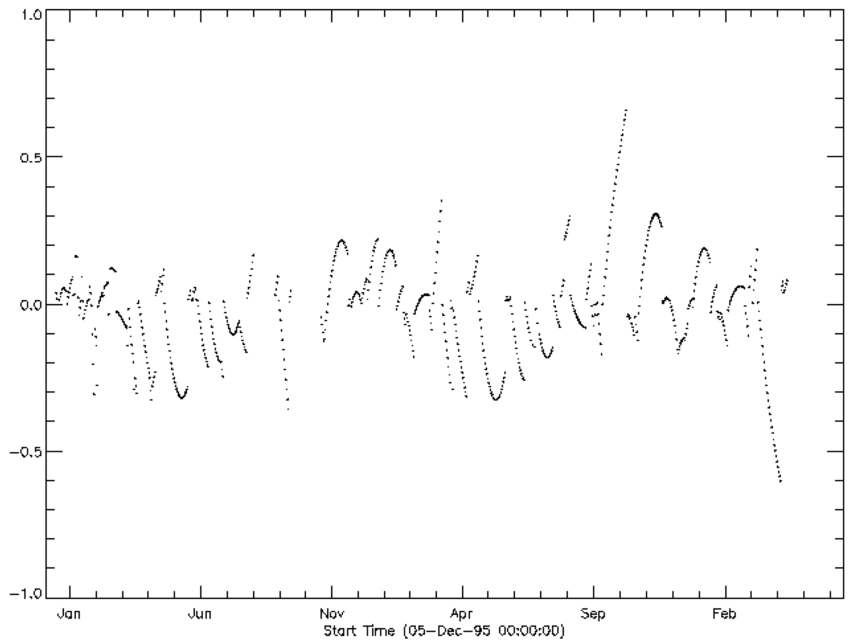

1.0
0.5
0.0
-0.5
-1.0
Jan
Jun
Nov
Apr
Sep
Feb
Start Time (05-Dec-95 00:00:00)

Figure 2.

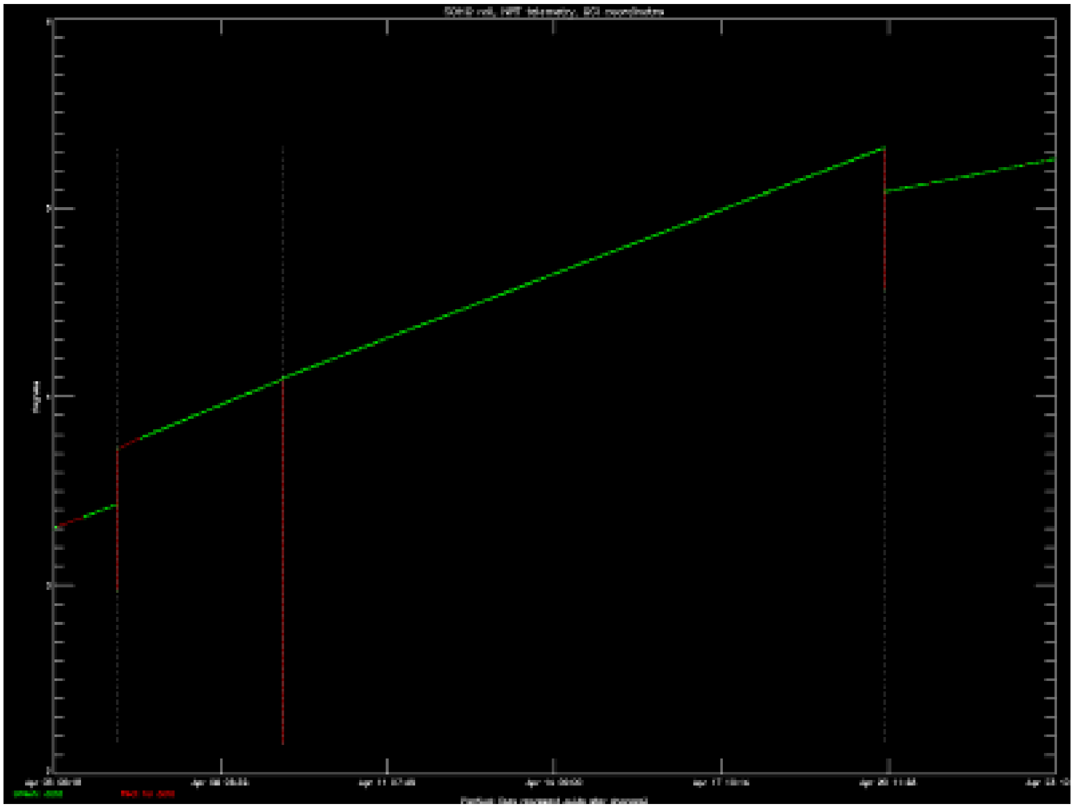


Figure 3.

Figure 4.

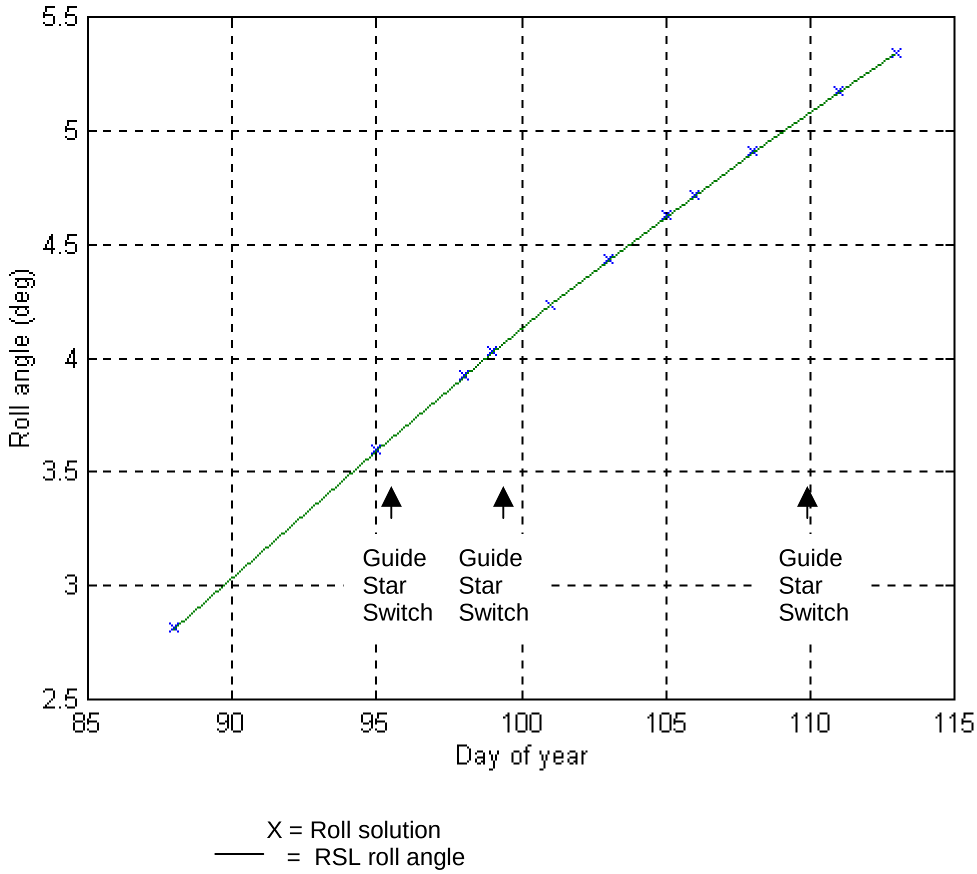
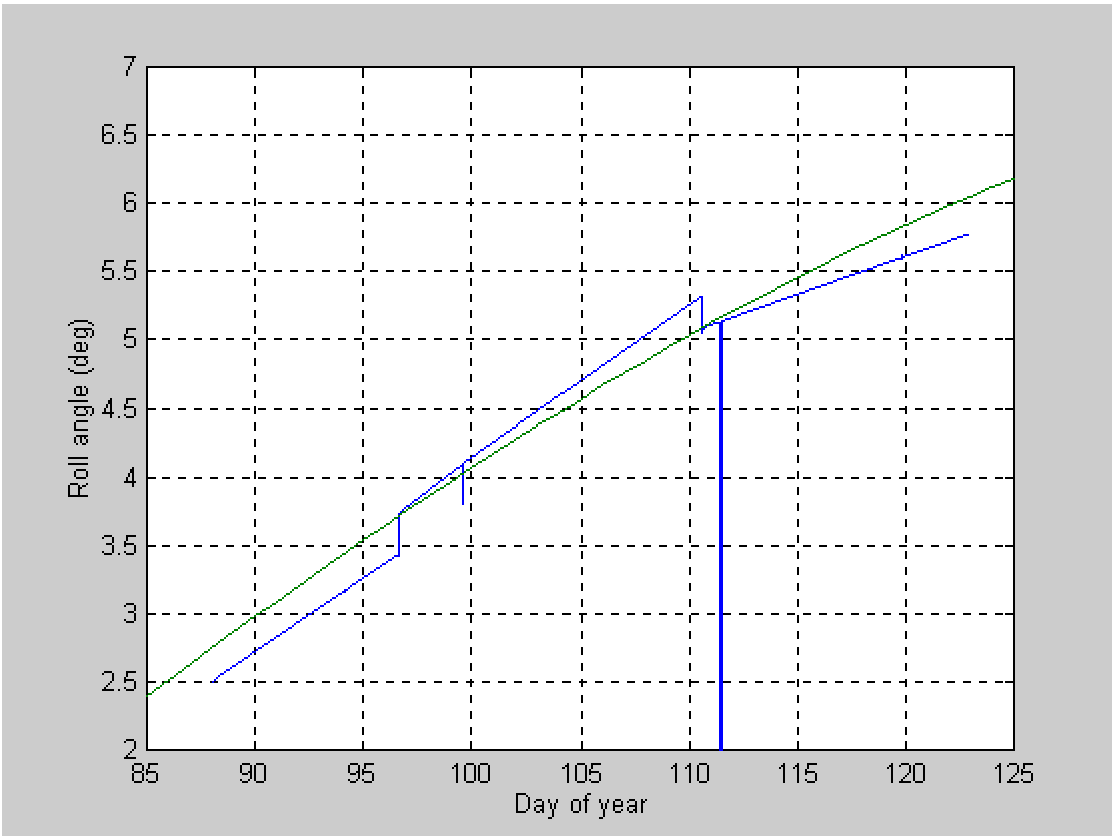
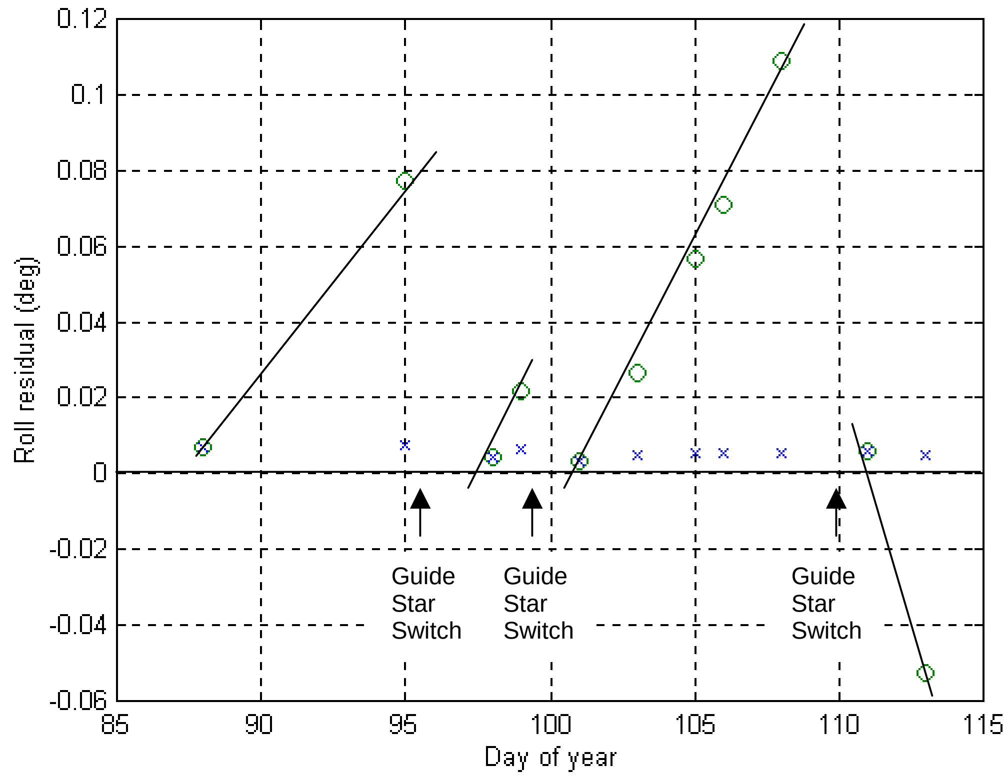

5.5
5
4.5
4
3.5
3
2.5
85
90
95
100
105
110
115
Roll angle (deg)
Day of year
Guide Star Switch
Guide Star Switch
Guide Star Switch
X = Roll solution
= RSL roll angle

Figure 5.



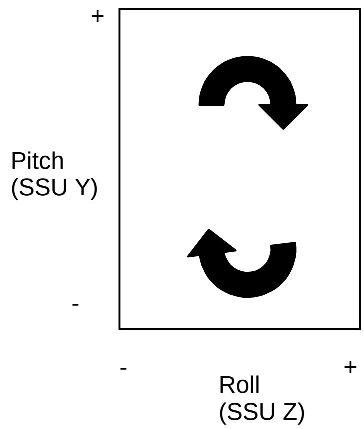
7
6.5
6
5.5
5
4.5
4
3.5
3
2.5
2
Roll angle (deg)
85
90
95
100
105
110
115
120
125
Day of year

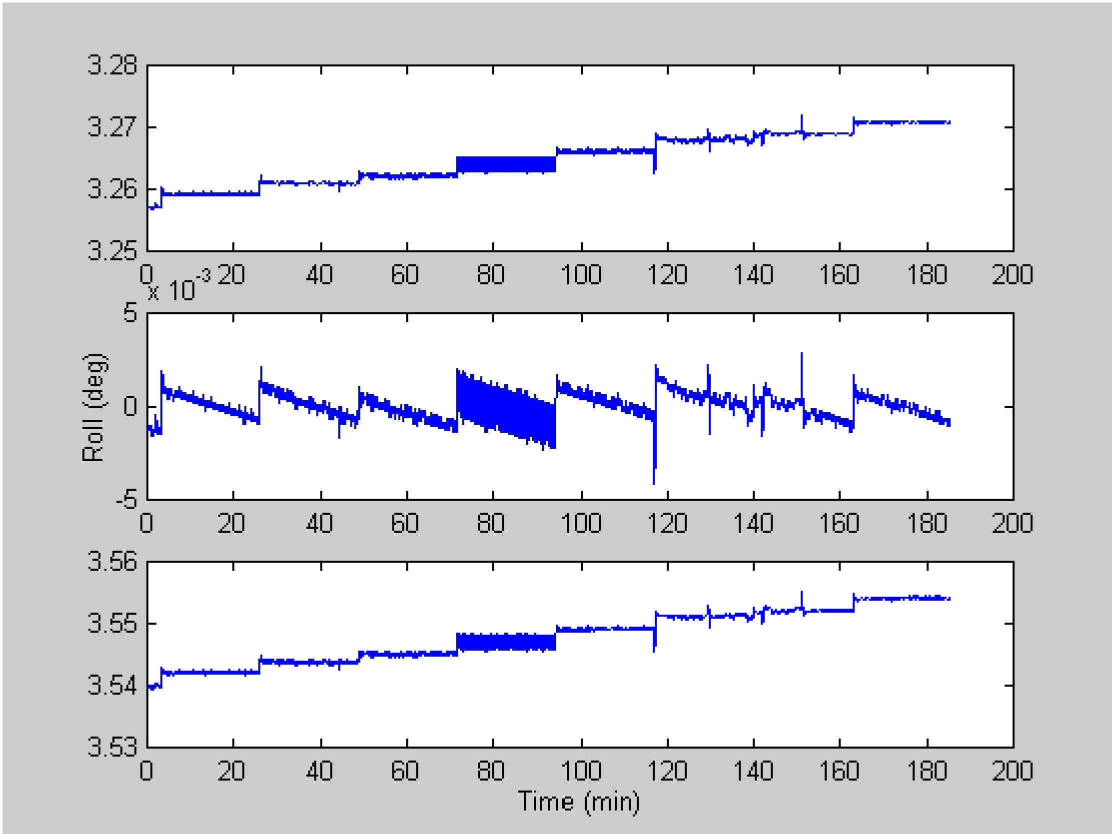
Figure 6.



X = Roll solution
O = SSU Z-component (biased so Z = Roll at 1st point)

Figure 7.





3.28
3.27
3.26
3.25
0 20 40 60 80 100 120 140 160 180 200
x 10^-3
5
0
-5
Roll (deg)
0 20 40 60 80 100 120 140 160 180 200
3.56
3.55
3.54
3.53
0 20 40 60 80 100 120 140 160 180 200
Time (min)

Figure 8.