HUYGENS HRA
Digital Altitude Data Calibration

V3.1

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3 Document Change Record

Date	*Version*	*Changes*	*Author*
21.01.2005	V1.0	First version	TR
05.04.2005	V2.0	Improved temp calibration, sensitivity analysis	TR
10.04.2005	V2.2	Detail improvements	TR
19.5.2005	V3.0	New temperature dataset, new calibration performed, corresponding updates	TR
20.5.2005	V3.1	Updated temperature datset, new calibration performed, corresponding updates	TR

4 Introduction

The Huygens Radar Altimeters (HRAs) have provided digital altitude information during the descent of the Huygens probe. While the digital data of both radars has been acquired via the probe telemetry, the additional data acquired by HASI-PWA is only available for channel B due to the loss of the telemetry data on channel A.

The digital data has been affected by a hardware bug, which caused the upper bits of the digital 15-bit altitude word to change their logical state in a seemingly random fashion. In addition, due to the 15-bit limitation of the digital altitude word any radar data above 32767 m is affected by a register overflow. In addition to these digital data errors, the radar has been found to be sensitive to temperature changes, and is affected by systematic errors that depend on the probe altitude. The raw digital altitude data has been processed in order to eliminate these known errors and to calibrate the measured altitude. After a first calibration using initial estimations of the radar temperatures [1,2] a temperature sensitivity analysis and data assessment showed that more accurate estimates of the radar temperature were required. This data has been made available by ALCATEL and ESTEC [3]. The present document provides an updated description of the processing steps and calibration data involved in the correction of systematic errors and in the data calibration, as well as information on the accuracy of the delivered dataset.

The processed, corrected data is made available to the DTWG and to the Huygens Project in the form of ASCII data files.

R. Trautner, May 2005

5 Raw digital interface HRA data

As described in the introduction, the raw digital data is affected by some problems corrupting individual bits of the data, and / or causing a register overflow. The same behaviour was observed on the flight spare units that were flown on a CNRS/CNES balloon flight in Brazil in December 2004. The following figure shows the unprocessed digital HRA data.

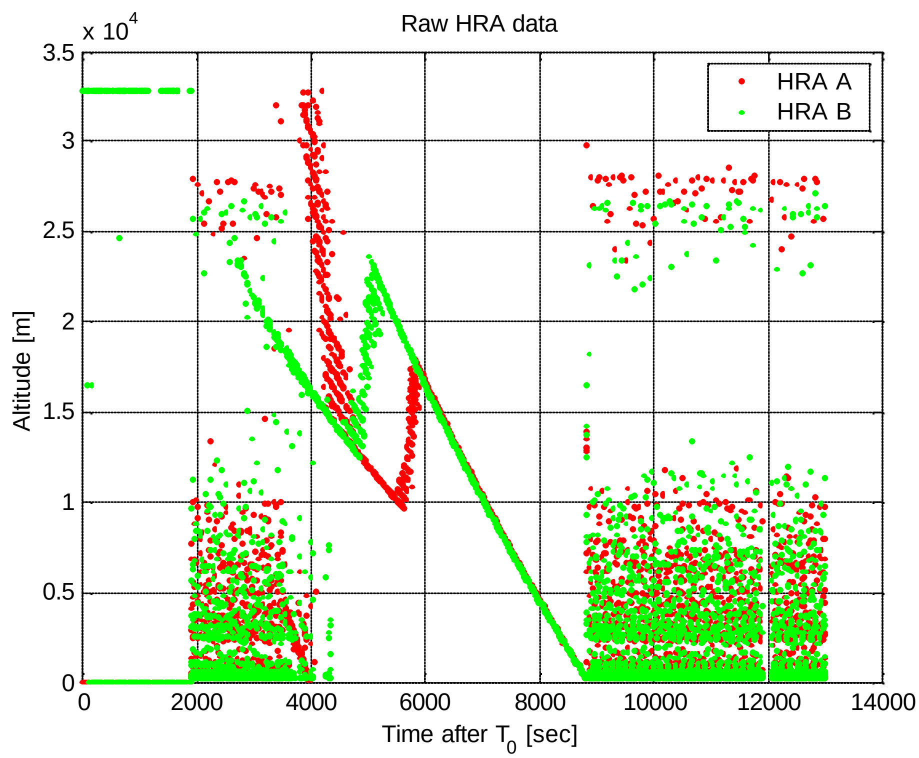


Figure 1: Raw digital interface altitude data

In a first processing step, the bit flip and overflow errors were corrected in order to obtain a consistent digital dataset. This was done using techniques developed for the processing of the data obtained from the December 2004 balloon test flight. Figure 2 shows the corrected dataset (only the data points where the radar was locked).

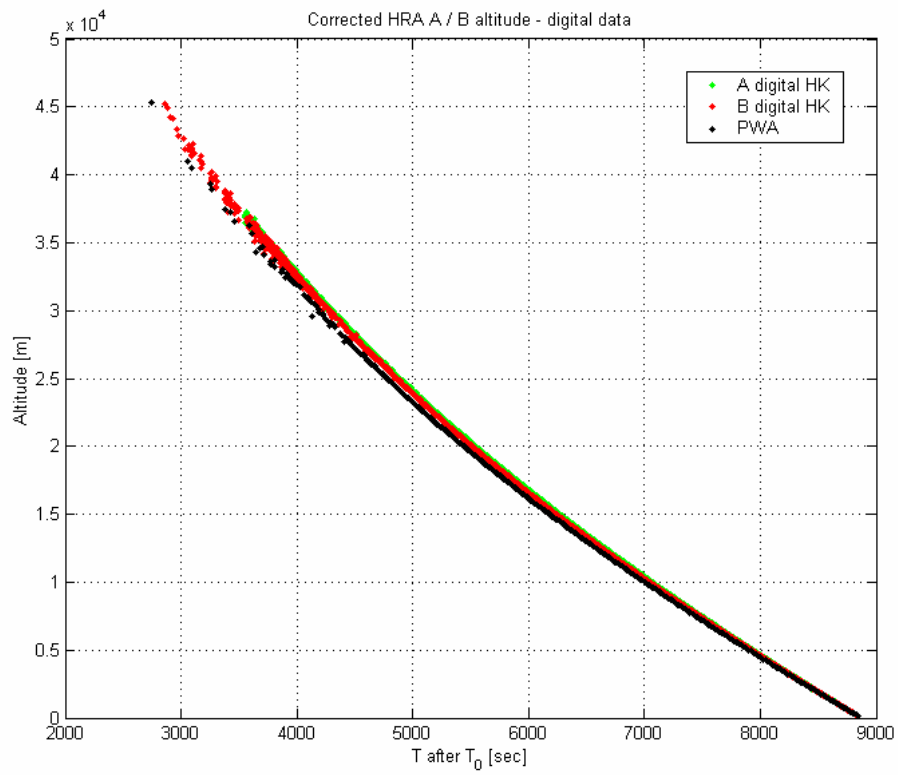


Figure 2: Digital interface altitude data after digital error correction

6 PWA Altitude Data

The digital altitude data provided by the HASI-PWA instrument was generated by measuring the duration of rising and falling edges of the radar ramp signal via the corresponding blanking signal. Although the quartz crystal oscillator on board of PWA would in principle allow a more accurate measurement than the RC oscillator in the radars, the radars have been calibrated using data from their digital outputs. There is no altitude calibration data available for the PWA dataset. The balloon test flight data shows that the PWA altitude data is equally affected by the temperature and altitude related systematic errors of the radar. Therefore it is preferable to use only HRA digital data for further processing.

7 Temperature and Altitude related Errors

7.1 Test data from FS balloon flight in Brazil

One of the main results of the Brazil test flight was that there is a strong impact of the radar temperature on the altitude measurement accuracy. In Brazil, altitude errors as high as -13.5% have been observed for platform temperatures of 47 °C. The temperature and altitude error data obtained for the FS models exhibit a linear relationship, which is similar but not equal for both FS radars. Figure 3 shows the raw (red), true (green) and corrected (blue) altitude data for radar B on the Brazil flight.

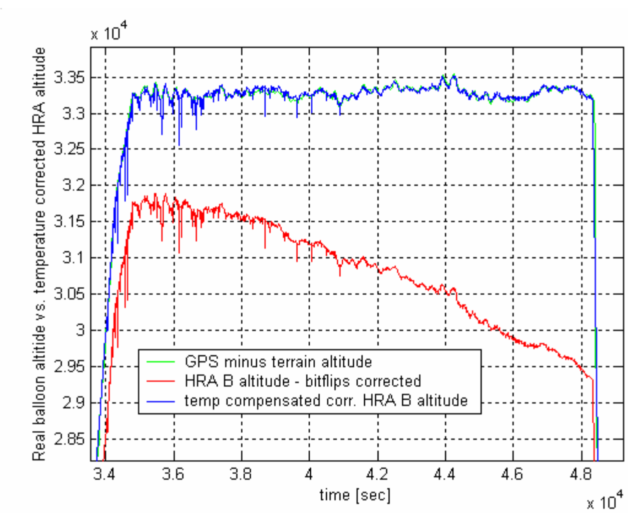


Figure 3: FS B temperature related altitude error (PEASMA/Brazil)

During the Brazil test flight, the balloon remained at an altitude of ~ 33km most of the time. Therefore the temperature calibration information from the Brazil test is valid for that altitude. The temperature sensor was accommodated on the aluminium sheet of the payload platform, which was a good thermal conductor. Although the sensor was not very close to the radars it is assumed that the aluminium sheet provided a sufficient thermal bridge to use the sensor data for the radar temperature. The test data shows a relative altitude error, which is decreasing with decreasing altitude, indicating that in addition there is also an altitude dependent error. The following plot shows the relative altitude error at ~ 33.3 km altitude vs. temperature as observed in Brazil (FS radar).

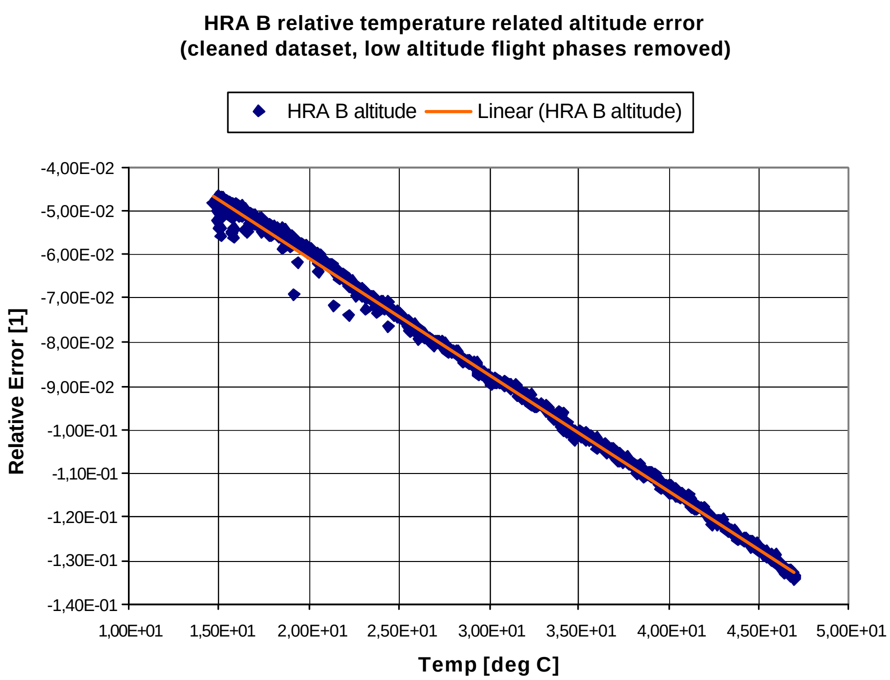


Figure 4: FS B temperature related relative altitude error at 33.3 km

It appears that for constant altitude the temperature error can be described by a linear relationship with good accuracy.

7.2 Tests performed on FM and FS models (HRA ADP data)

An investigation of the FS and FM test data acquired during the flight unit qualification confirmed the observed temperature and altitude effects. During the qualification tests, the FM and FS models were connected to the return signal simulators (RSS), which were used to simulate a range of altitudes from 150 m up to 10 km. The simulators are based on up/down modulators and delay lines. Their altitude / delay accuracy is estimated to be in the order of 1% or better at simulated altitudes of 1000m or higher.

The temperature of the radars was varied in a range of –40 deg C to +20 deg C, and the digital interface altitude reading was recorded for all available RSS altitude settings. Furthermore, the supply voltage was varied in order to allow assessing the impact of power supply changes on the accuracy.

Figure 5 shows the altitude correction factor for FS B for simulated altitudes of 3005, 6018 and 10020m as a function of temperature. The data obtained during the Brazil flight (true altitude 33300m) is added in the temperature range 10 to 25 deg C. The Brazil data as well as the high temperature part of the ADP data show a linear relationship with temperature. This linear relationship is also expected for the FMs in the 10 deg C to 25 deg C temperature range which is relevant for Huygens data.

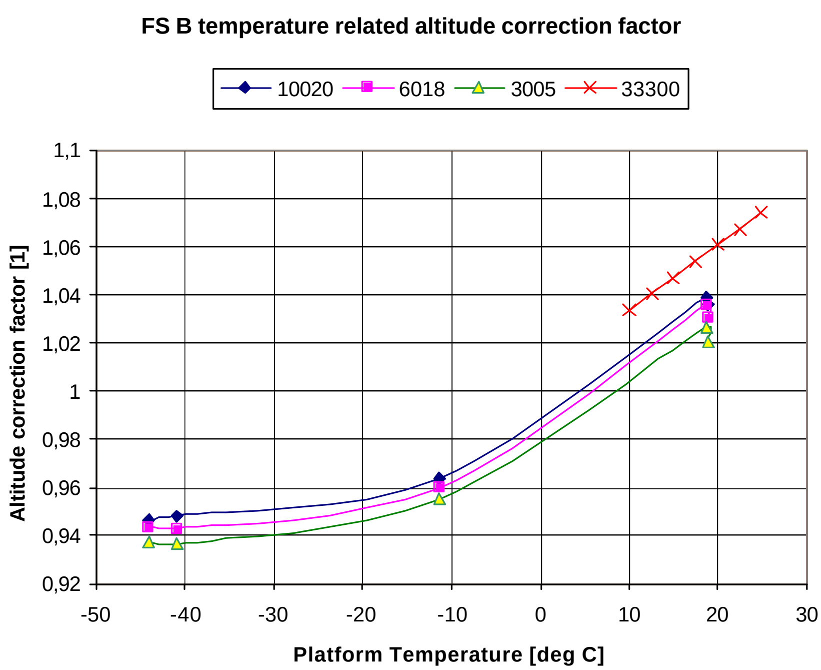


Figure 5: FS B temperature related altitude correction factor (parameter: altitude)

The data available in the ADP also allows assessing the relative altitude error vs. altitude at constant temperature. Figure 6 shows the FS B altitude correction factor for 2 temperatures (-11,3 and 18,85 deg C). One data point from Brazil test flight data is added for the +18.85 deg C temperature curve.

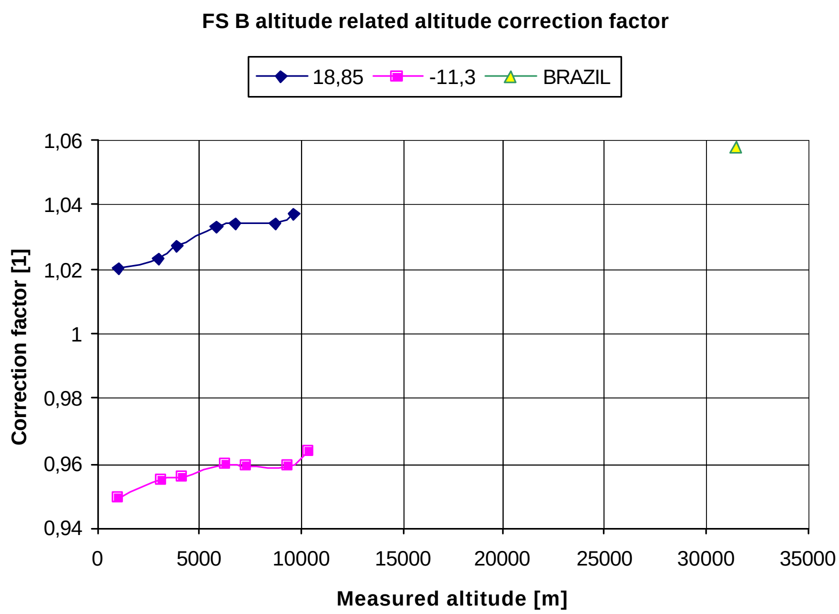


Figure 6: FS B relative altitude error vs. altitude (parameter: temperature)

Just like the temperature related error, the altitude related relative altitude error shows a tendency which can be described by a linear relationship with reasonable accuracy.

7.3 Altitude Error Correction Method

The observed effects show that digital interface altitude data from Huygens needs to be corrected for both temperature and altitude related errors. The available data indicate that linear relationships of error vs. altitude / temperature can be used. The observed linear relations of correction factors and temperature / altitude are applied using the following equations:

$$\mathbf{A_{corr\_T} = A_{meas} * k\_T} \textbf{ for a given altitude a,}$$

And

$$A_{corr\_A} = A_{meas} * k\_At \qquad \textbf{for a given temperature T}$$

These need to be combined into a single expression, which takes into account the corrections for both altitude and temperature:

$$A_{corr} = A_{meas} * (k0 + k\_T*T + k\_A*A_{meas})$$

The factors K_A and K_B are given by

$$K\_A = A_{corrA} / d A$$
$$K\_T = A_{corrT} / d t .$$

From the FS Brazil test data we obtain

$$A_{corrT\_A} = 1{,}012240 + T * 0{,}00194 \qquad \text{(FS A, at 33300m)}$$
$$A_{corrT\_B} = 1{,}007106 + T * 0{,}00267 \qquad \text{(FS B, at 33300m)}$$

Averaging these relations yields

AcorrT = 1,009673 + T * 0,002305 (FS A + B, at 33300m true altitude)

From ADP test data on the FS models (+12V / -8V supply voltages) we obtain

$$A_{corrA\_A} = 1{,}0233 + A * 8{,}5260E\text{-}07 \qquad \text{(FS A, 18,90 deg C)}$$
$$A_{corrA\_B} = 1{,}0235 + A * 1{,}1406E\text{-}06 \qquad \text{(FS B, 18,85 deg C)}$$

Again, averaging these equations yields

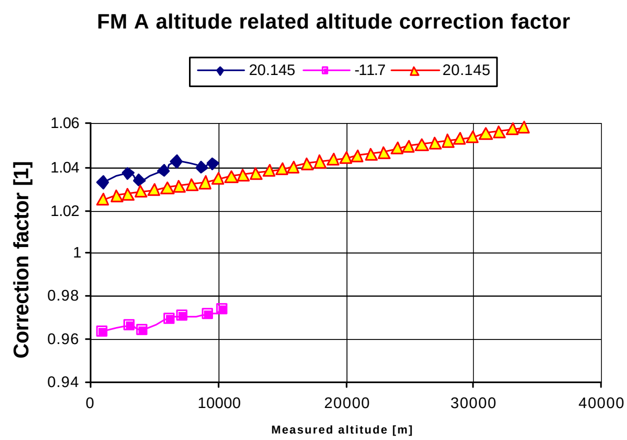
AcorrA = 1,0234 + A * 9.966E-07 (FS A + B, at 18,88 deg C)

The test data from Brazil provides the overall correction factor Acorr for the true altitude of 33300m (measured altitude 31618m) and a temperature of 18,88 deg C.

This allows the calculation of **k0** and the completion of the overall correction formula:

$$\mathbf{A_{corr} = A_{meas} * (0{,}97788 + 0{,}002305 * T + 9{,}966E\text{-}07 * A_{meas})}$$

While this correction method is based on the FS data (which is the most complete calibration dataset), it is also applicable for the FM models due to the similarity of the individual models. A comparison of the correction formula results and the FM test data in the ADP shows that the deviation in the [+20 ºC .. –10 ºC] temperature interval are in the order of 1%. Figure 7 shows the measured and calculated altitude correction factor for radars FM A and FM B at room temperature. The calculated factor is in good agreement with the average of the measured factors for A and B.



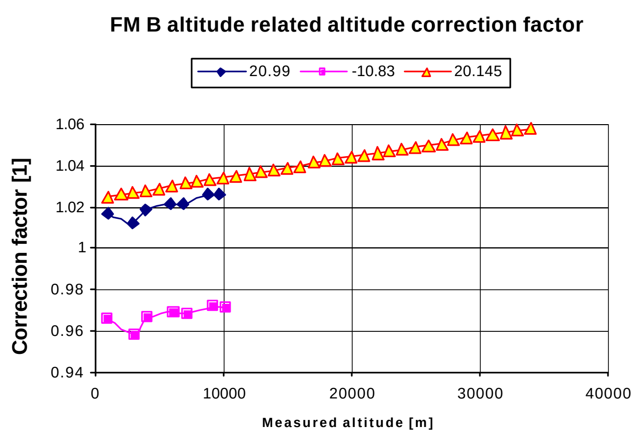


Figure 7: Calculated (red) and measured (blue/pink) altitude correction factor

7.4 Huygens Platform Temperature

The Huygens payload platform remained in a comfortable temperature range during the whole mission. However, the platform temperature changed significantly during the descent. The Figure 8 shows the temperature of sensors D5017T – D5020T which were accommodated on the Huygens platform (HRA side). The sensor positions are indicated in the sketch below. Data from sensors closer to the radars (D5005T, D5007T) is not available due to the loss of telemetry chain A. Therefore the temperatures of the radars have been estimated using thermal models [3]. The simulation results indicate temperatures which are much lower than the measured platform temperatures. The results are shown in **Error! Reference source not found.**. For the calibration of HRA altitude data the temperature data from these simulations is used.

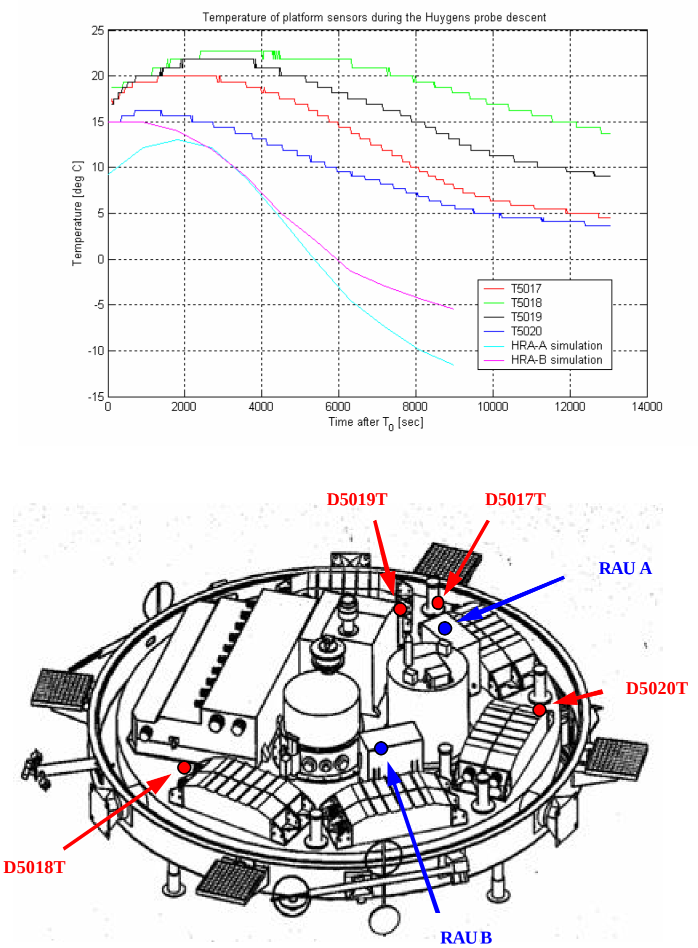


Figure 8: Huygens platform temperatures and sensor locations

8 Probe Attitude and related HRA Measurement Error

It is understood that the attitude of the Huygens probe has an impact on the accuracy of the HRA altitude data. A deviation from the nadir position leads to an altitude reading, which is higher than the true altitude. However, due to the beam width of the HRA antennas (~8 degrees) only deviations exceeding several degrees would lead to significant measurement errors. The following figure shows the relative altitude measurement error as a function of the probe tilt angle for a perfectly focused beam. Even under these worst-case conditions, the altitude error does not exceed 1% for tilt angles of 8 degrees or below.

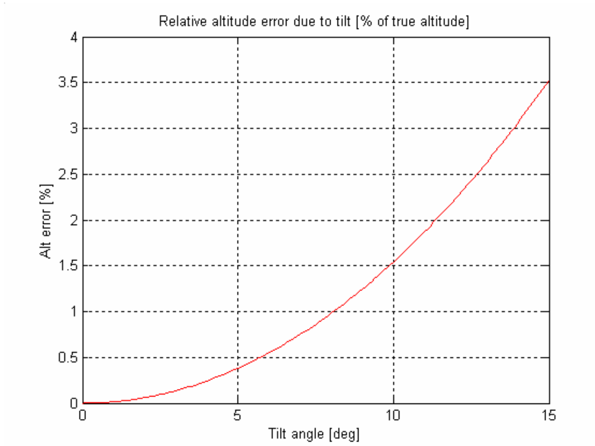


Figure 9: Relative altitude measurement error vs. probe tilt angle

Therefore the altitude and temperature related errors will be the dominant effects for HRA altitude data. Attitude deviations can be taken into account as soon as attitude data becomes available.

9 Digital Altitude Data Error Correction

9.1 Assumptions

The correction of systematic HRA measurement errors is based on the following assumptions:

- The mechanism of the digital altitude data corruption is understood
- The FM and FS models radars are using the same design, and are built using identical components, and therefore show similar systematic errors
- The average attitude deviation from nadir does not exceed few degrees

These assumptions are confirmed by the following observations: The digital data corruption is the same observed in the test data obtained during the PEASMA stratospheric balloon flight. Correction algorithms have been developed and tested for the Brazil flight, and are applied to the Huygens data. The identity of the FS and FM design has been confirmed by the manufacturer. The similarity of FM and FS radars has been confirmed by the analysis of the data available in the ADP documents. All flight and flight spare radars show the same behaviour, which is a negative relative altitude error, which increases both with altitude and temperature.

9.2 Results

After correcting the digital bit errors and the temperature and altitude related altitude error we obtain a dataset which indicates the probe with improved accuracy. The following figures show the corrected altitude data as a whole and in detail.

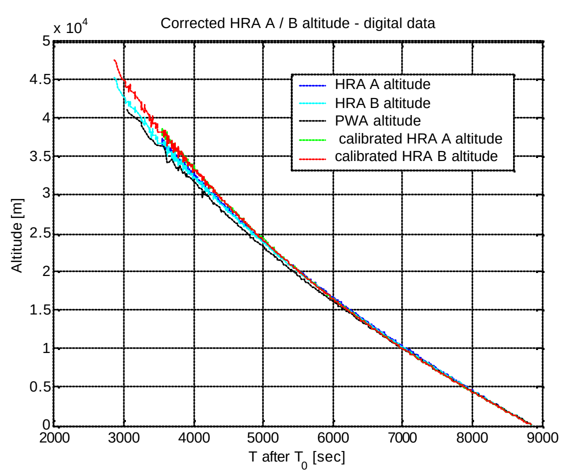


Figure 10: Uncorrected and corrected digital HRA data

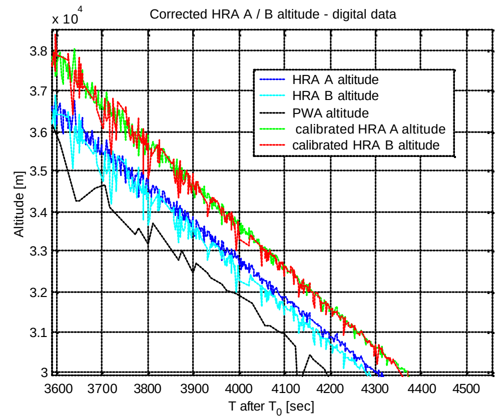


Figure 11: Uncorrected and corrected digital HRA data – detail 1

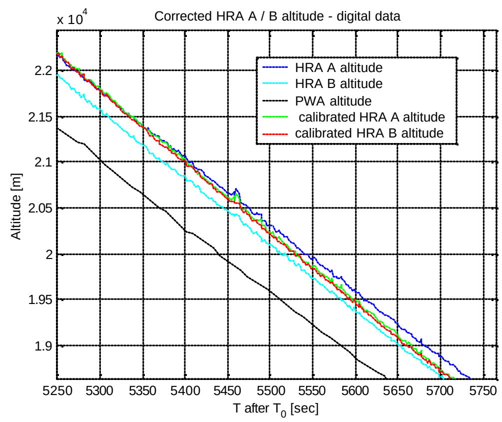


Figure 12: Uncorrected and corrected digital HRA data – detail 2

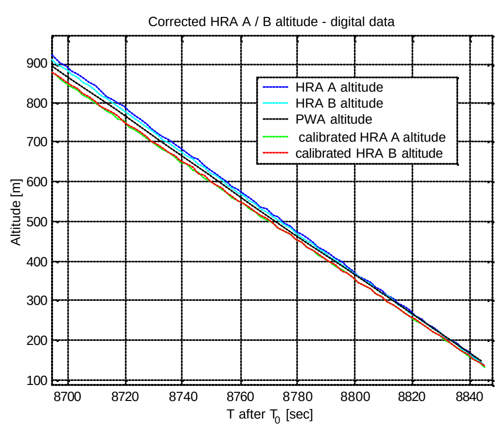


Figure 13: Uncorrected and corrected digital HRA data – detail 3

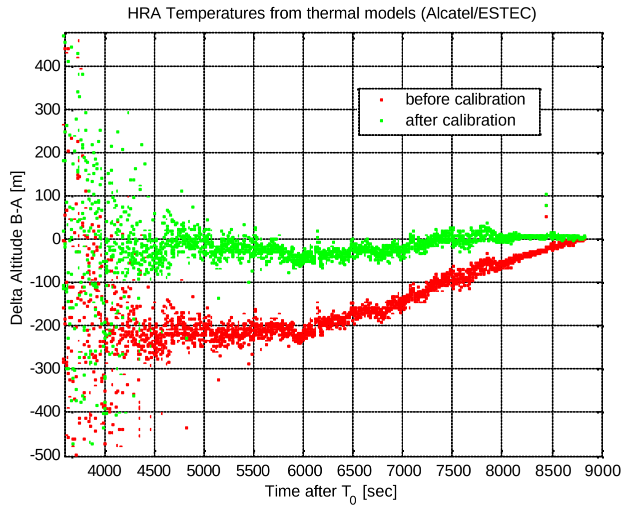


Figure 14: Difference HRA A / HRA B before and after calibration

In general, the calculated altitude is increased with respect to the uncalibrated data during the first part of the descent. After ~ T0+5500 seconds the calculated altitude is lower. The difference of radar A and B altitudes is decreased significantly especially during the last part of the descent, providing evidence that the calibration actually improves the dataset.

10 Conclusion

The data obtained by the Huygens Radar Altimeters has been processed and improved by correcting the digital errors and by applying a temperature and altitude error compensation based on data from the FM ADP and FS model tests on the PEASMA balloon flight. The similarity of FS and FM models in terms of error characteristics has been confirmed and the deviation of the error model and ADP measurement data is in the order of 1% or better for all models. The estimated accuracy of the temperature data is 5 °C, corresponding to an altitude error of ~1.15 %. In the absence of attitude data, an additional altitude measurement error of 0.5% is assumed. Based on these assumptions, an analysis of the overall error of the calibrated altitude data indicated a relative error of 2.7%. This error corresponds to the accuracy of the derived altitude over terrain; for the reconstruction of the Huygens descent trajectory, the possible effect of varying terrain elevation needs to be taken into account.

The calibrated data shows an altitude, which is increased by 5 % with respect to the original unprocessed data at T0+3000 sec. The deviation then decreases with decreasing altitude and reaches a minimum around T0+5500 sec. During the later part of the Huygens descent, the calibrated altitude is up to 4% lower than the uncalibrated one. The agreement of radar A and radar B data has significantly improved in all parts of the descent.

Further improvements of the dataset may be possible if the following data is made available:

- Data on the probe attitude during the descent
- Additional measurements of the altitude related error using available hardware (RSS and FS models)
- More accurate estimations of the radar temperatures during the descent

The corrected altitude dataset is made available in the following ASCII files:
HK_CDMS_RADAR_A_CORRECTED.TAB
HK_CDMS_RADAR_B_CORRECTED.TAB

Acronyms

Acronym	*Meaning / Description*
ADP	Acceptance Data Package (HRA documentation)
ALT	Altitude
ASCII	American standard code for information interchange
FM	Flight Model
FS	Flight Spare Model
HASI	Huygens atmospheric structure instrument
HRA	Huygens radar altimeter
PWA	Permittivity, wave and altimetry experiment
PEASMA	Name of the stratospheric balloon campaign performed in 12 2004
RA	Radar
RSS	Radar Return Signal Simulators

11 References

[1] R. Trautner, Huygens HRA Altitude Data Calibration V1, ESA/ESTEC 02 2005

[2] R. Trautner, Huygens HRA Altitude Data Calibration V2, ESA/ESTEC 04 2005

[3] G. Cluzet, ALCATEL; T. Blancquaert, ESA/ESTEC, personal communication.