A Fresh Look at the Huygens Radar Altimeter Problem: New Results and Science Opportunities

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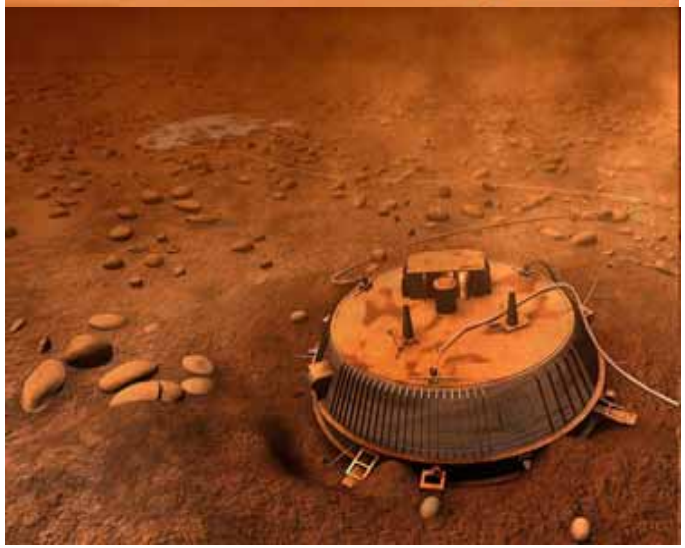
Presentation Overview

- The Mission and Descent Profile of the Huygens Probe
- The Altitude Problem
- The Huygens Altimeter Principle, Design, Interfaces, Signal Processing
- Investigation of Potential Error Sources
- Environmental Tests and their Results
- Interpretation & Discussion
- Conclusions & Future Science Opportunities

Mission and Descent Profile of the Huygens Probe



Huygens Mission & Descent Highlights

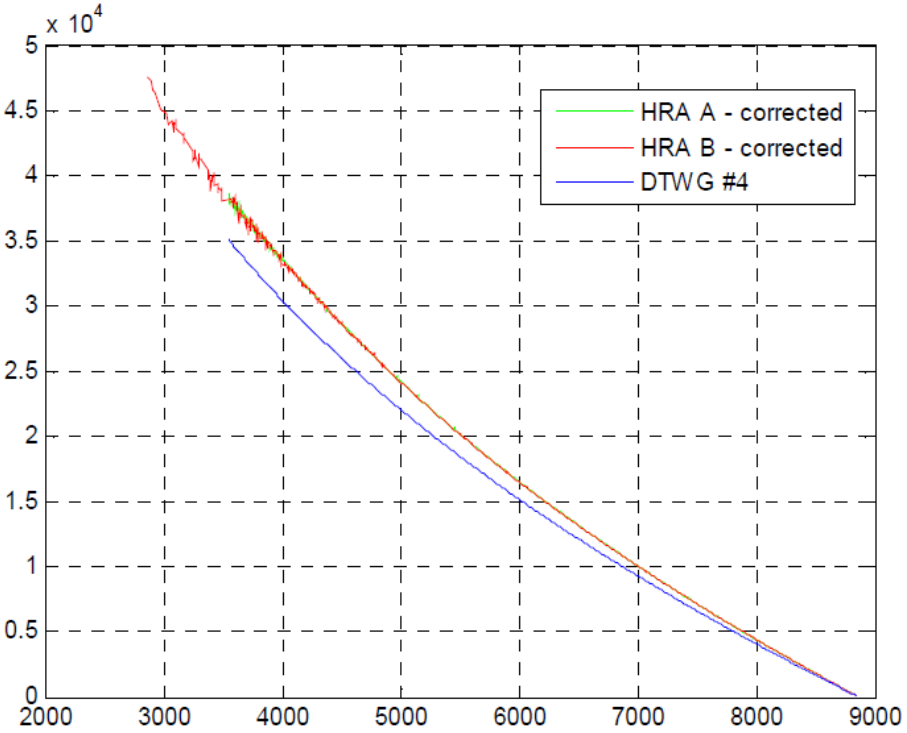
- 2004-Dec-25 02:00 UTC: Huygens separation
- 2005-Jan-14 09:06 UTC: Atmospheric entry (T0)
- HASI activation (T, p, acceleration measurements)
- HRA activation ~ T0 + 1916 sec
- HRA A first lock at ~ T0 + 3549 sec
- HRA B first lock at ~ T0 + 2863 sec
- Huygens impact at ~ T0 + 8870 sec

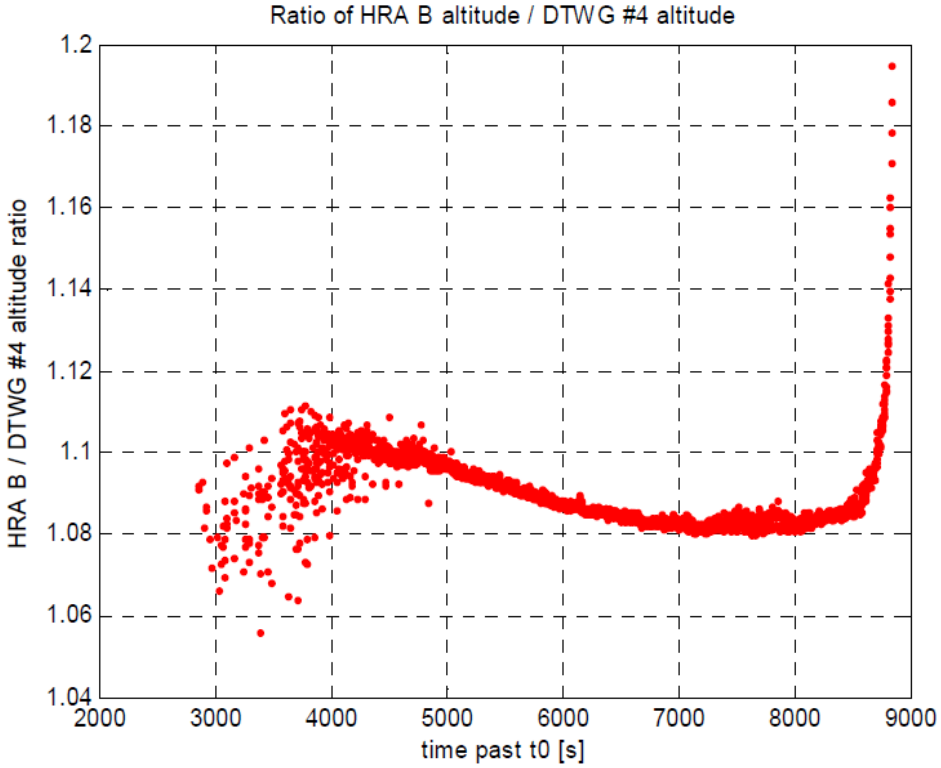
Data collected:

HASI: acceleration, temperature, pressure, HRA B blanking signals, HRA B IF spectra

CDMU: HRA A and HRA B altitude and AGC data

Corrected & Calibrated Data – and the Problem





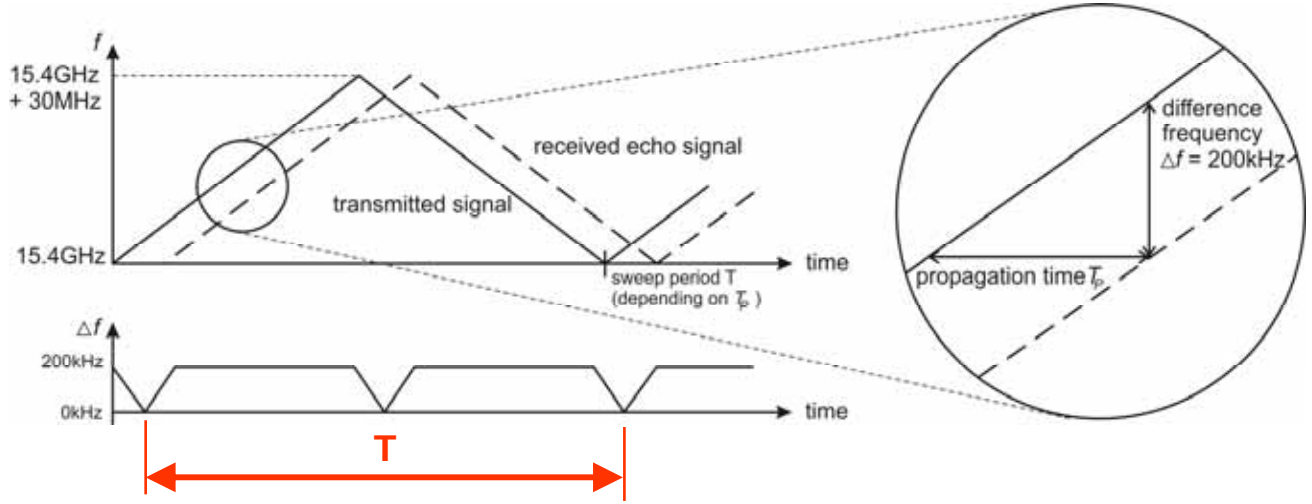
FMCW Radar Principle

FMCW principle

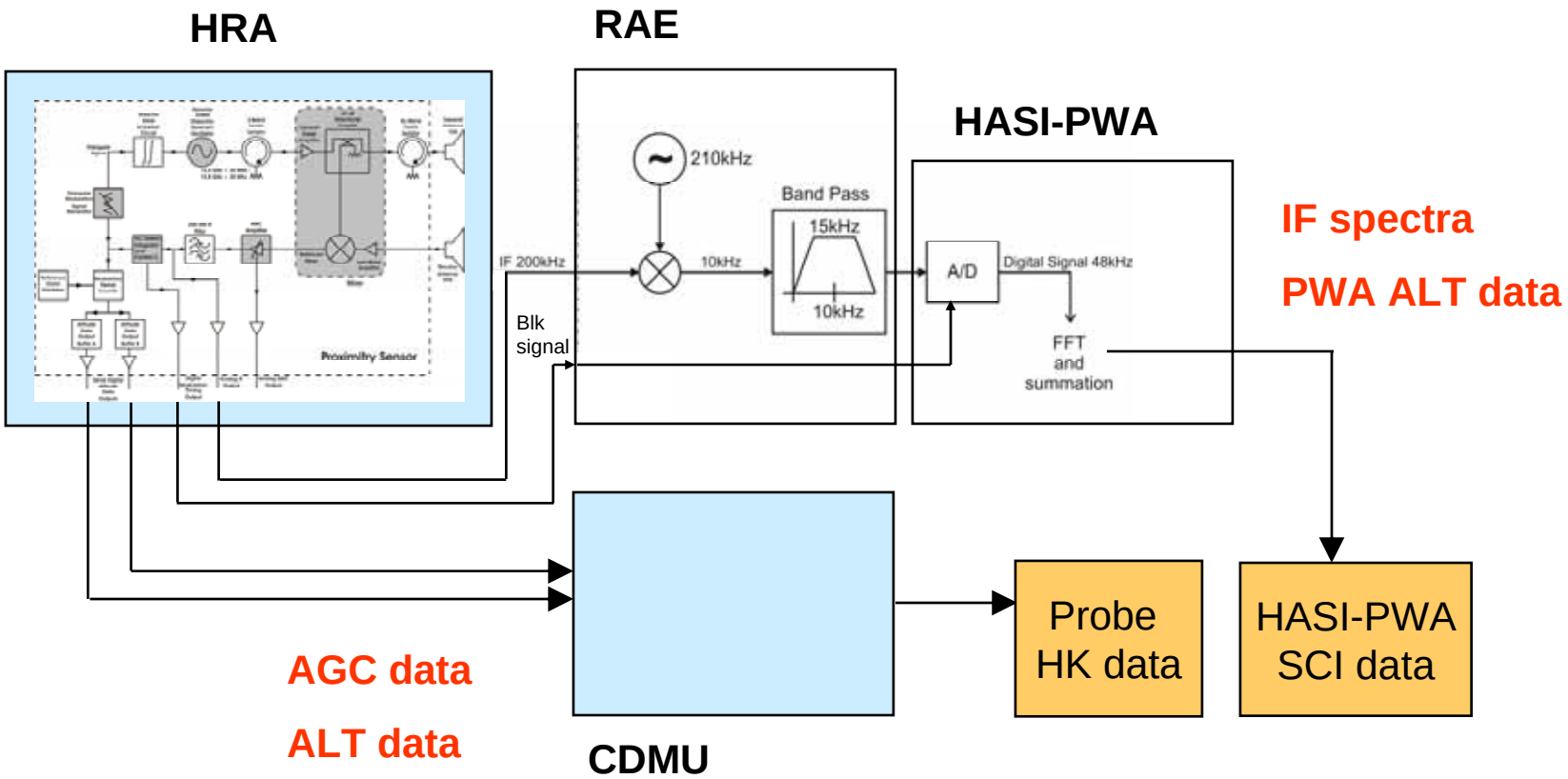
- constant power output, frequency modulated by triangular waveform
- received frequency mixed with transmitted freq
- difference freq is kept constant at defined IF frequency

=> triangular signal frequency proportional to 1/ Alt

=> <u>Altitude measurement done via time measurement of sweep period T</u>

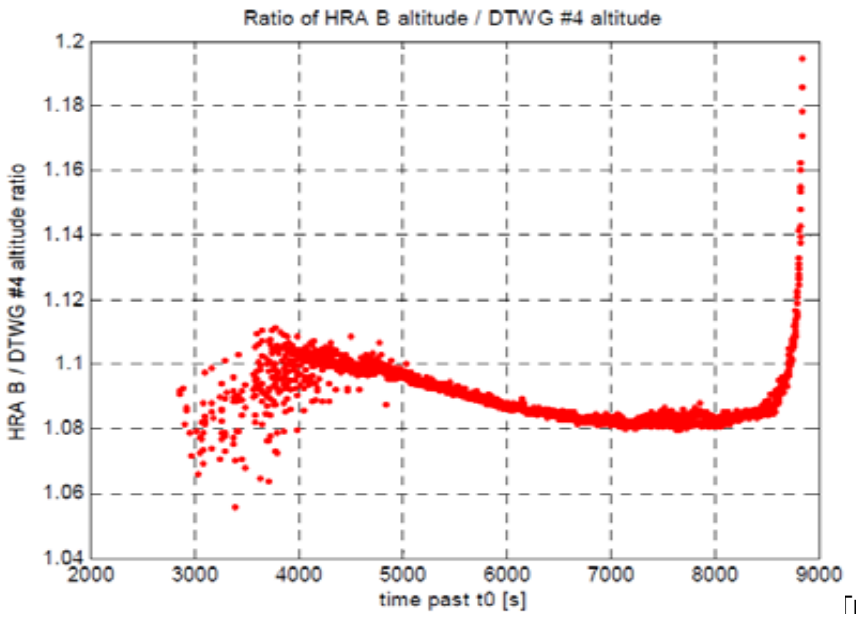


Huygens HRA: Interfaces & Data Processing



Error Characteristics

- Deviation not constant over time / alt (ca 10% => 8% => ca 15%)
- Not restricted to single radar: must be systematic
- Likely a combination of multiple factors
- Different factors may dominate in different descent phases



DTWG Parameter Study (B. Kazeminjad, 2005)

Quick study done to see which errors in DTWG input data could lead to the observed deviations

- The planet radius is increased by 150 km
  Unlikely
- The Titan GM is decreased by –11 %
  Unlikely as Titan's GM is fairly constrained from Cassini OD data.
- The HASI temperature measurements are increased by a constant offset of 10 K
  Unlikely as the HASI-TEM uncertainty is in the range of 0.5 – 2.0 K
- The molecular mass is decreased by a constant offset of 10 % (Study Case D)
  Unlikely as GCMS specifies a relative error of only 1%

But:

=> Combination of individual errors can contribute to oberved deviation

=> Some possibilities such as pressure offset error not evaluated

HRA Possible Error Sources

An assessment of possible altitude measurement error sources was performed in 2005-2006:

- Calibration errors
- Probe attitude
- Doppler effects
- Supply voltage related errors
- Component degradation due to radiation
- Component degradation due to ageing
- Component degradation due to vacuum exposure

Potential HRA Error Sources: Calibration

R. Dutta-Roy, 2006:

ESTEC Contract No. 20672/07/NL/NR

=> Correction for

- **Bitflip errors**
- **Thermal effects**
- **Altitude effects**

is correct.

The standard deviation of the fit described in chapter 3 is $\Delta z/z = 1.3\%$ for HRA-A and 0.6% for HRA-B. The difference between the altitude measured for a specific delay and the calibrated altitude at this delay is generally smaller than 1% apart from a few exceptions, as displayed in Figs. 3.7-3.14.

In the previous calibration, the accuracy of the calibration fit was stated as 2.7%, which included a temperature related relative error of 1.2% for a temperature inaccuracy of ±5°C. The maximum relevant gradient dz/dT obtained from the present analysis is 0.2%/°C. The similarity between FS and FM models is of the order of 1% or better for all models [Trautner, 2005].

Taking these characteristics into account and adopting the assumption from Trautner [2005] that the mean temperature inaccuracy is ±5°C, we obtain a mean fit accuracy of approximately 3%. This limit has been plotted in Figs. 8.1 and 8.2. From these figures, it is clear that the present recalibration cannot improve the previous calibration performed by Trautner [2005]. Both calibrations are consistent within their accuracy limits.

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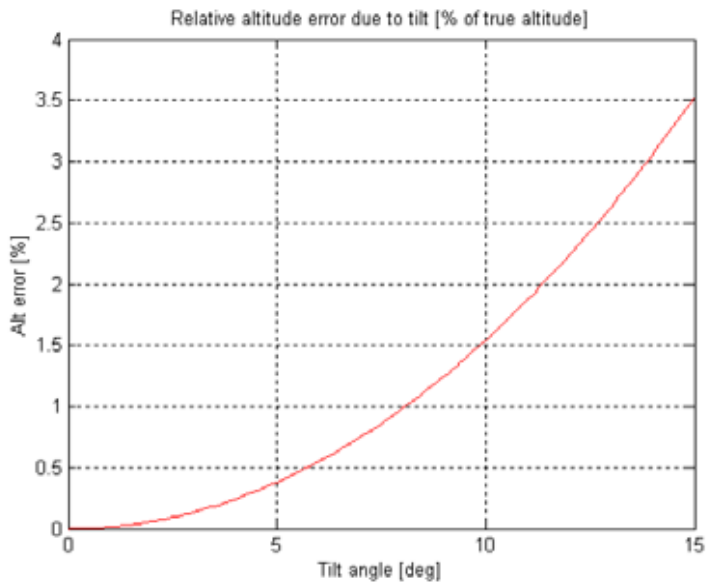
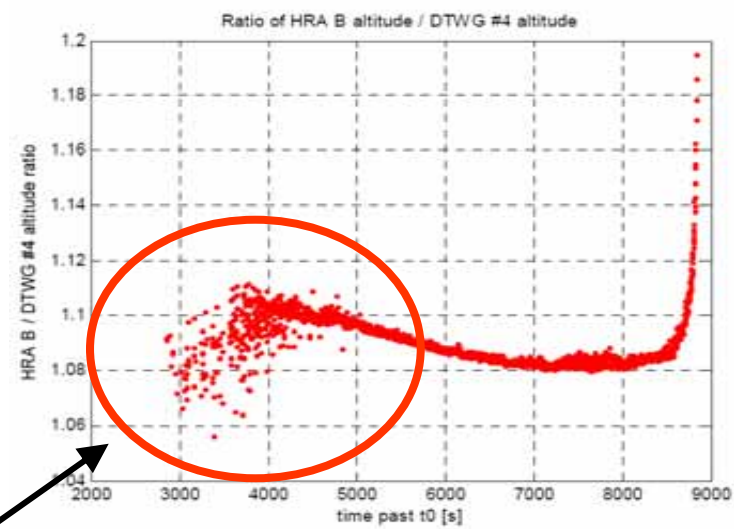
Potential HRA Error Sources: Probe Attitude

Effects: longer propagation path due to tilt => higher altitude reading
slight reduction of effect due to non-isotropic surface reflectivity



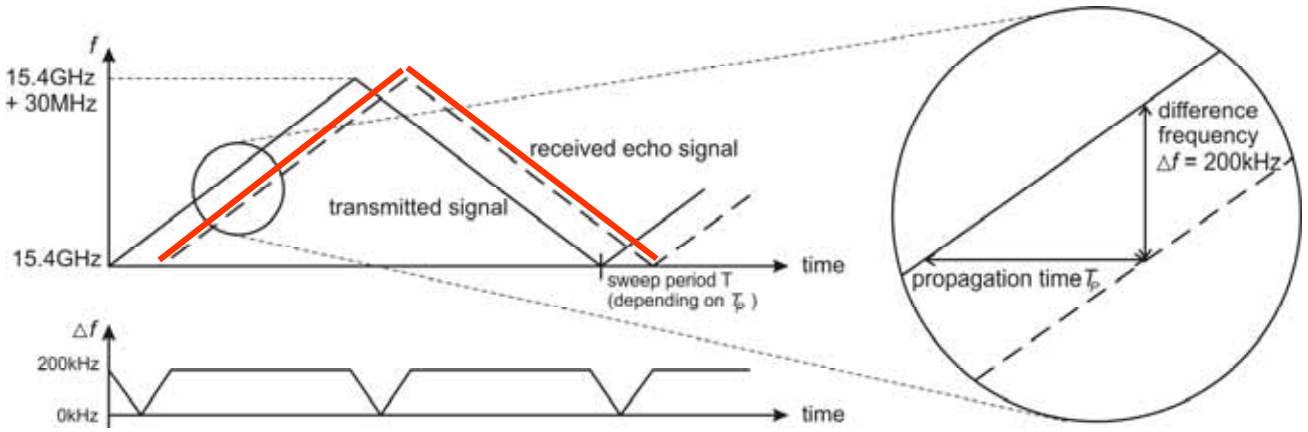


⇒ Minor contribution expected at high altitude

⇒ Reduced / no effect at low altitudes

Potential HRA Error Sources
Doppler effects

Doppler effect causes change of up-ramp / down-ramp times:

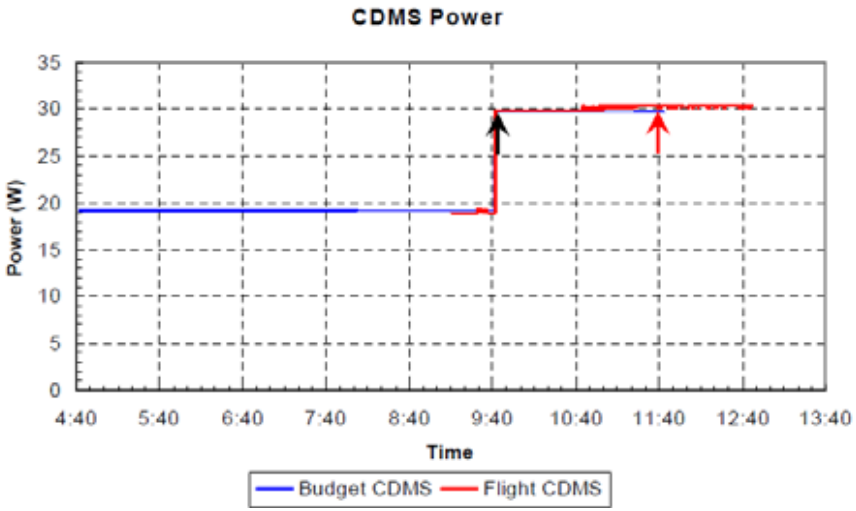


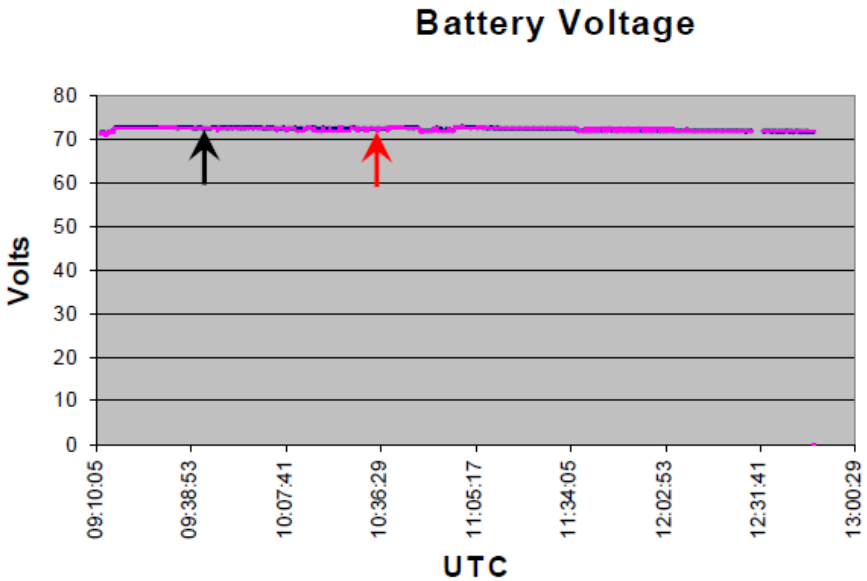
- Effects on up-ramp and down-ramp cancel each other
- Negligible effect on altitude measurement that is based on time measurement of both ramps

=> Not an issue for observed altitude deviation

Potential HRA Error Sources
Supply Voltage

Supply voltage for radars: Calibration showed small (known and characterized) effect on accuracy from changes of the supply voltage.





Arrows show radar activation and touchdown

No significant voltage changes / power consumption changes observed

=> No evidence for supply voltage induced errors

Potential HRA Error Sources: Environment

Huygens was exposed to Space for ca 7 years between calibration and descent on Titan. Environmental effects include:

- Component degradation due to radiation
- Component degradation due to ageing
- Component degradation due to vacuum exposure

⇒ Can <u>not be ruled out</u>

⇒ Can be <u>investigated by tests with FS models</u>

⇒ Can <u>cause errors in DTWG source data</u> as well

Potential HRA Error Sources: Components

HRA electronics components studied in search for possible error mechanisms:

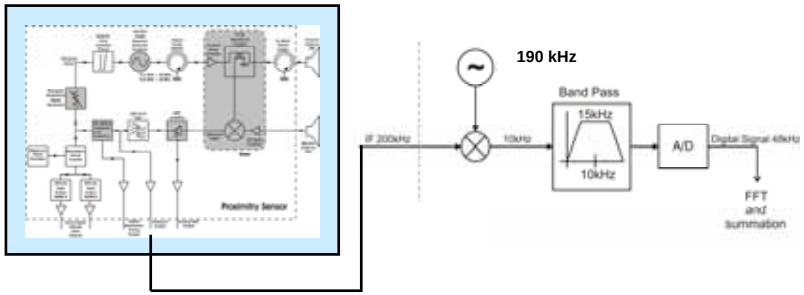
- LF VCO circuit: sensitive to supply voltage change (20% change required for 10% change in alt reading). No evidence.
- RF ramp linearizer circuits and dielectric resonator: compensated internally via defined IF. No evidence.

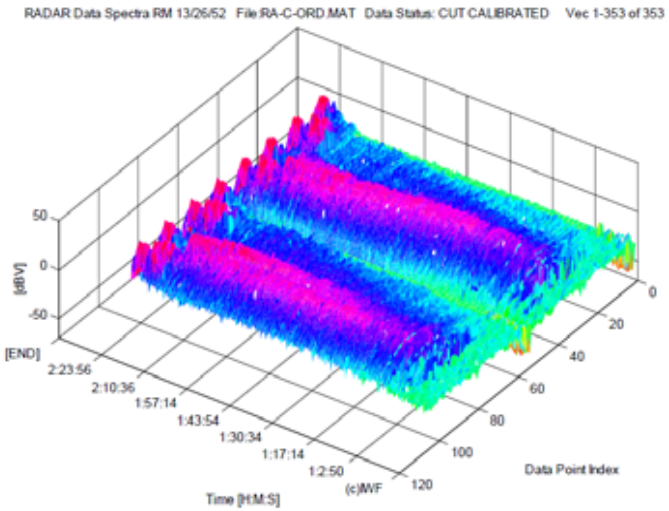
- IF filter: defines 200 kHz IF. Mixed to 10 kHz in RAE => stability can be verified via HASI PWA data analysis
- Altitude counter RC oscillator: => can be verified via HASI PWA data, pre-launch & during mission

IF Filter Stability

HRA IF filter frequency stability:

- IF filter defines 200 kHz IF which directly affects altitude reading
- IF mixed to 10 kHz in RAE via quartz-derived 190 kHz signal





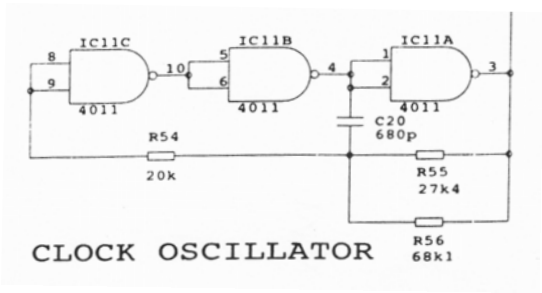
=> IF peak center stays close to 10 kHz center frequency

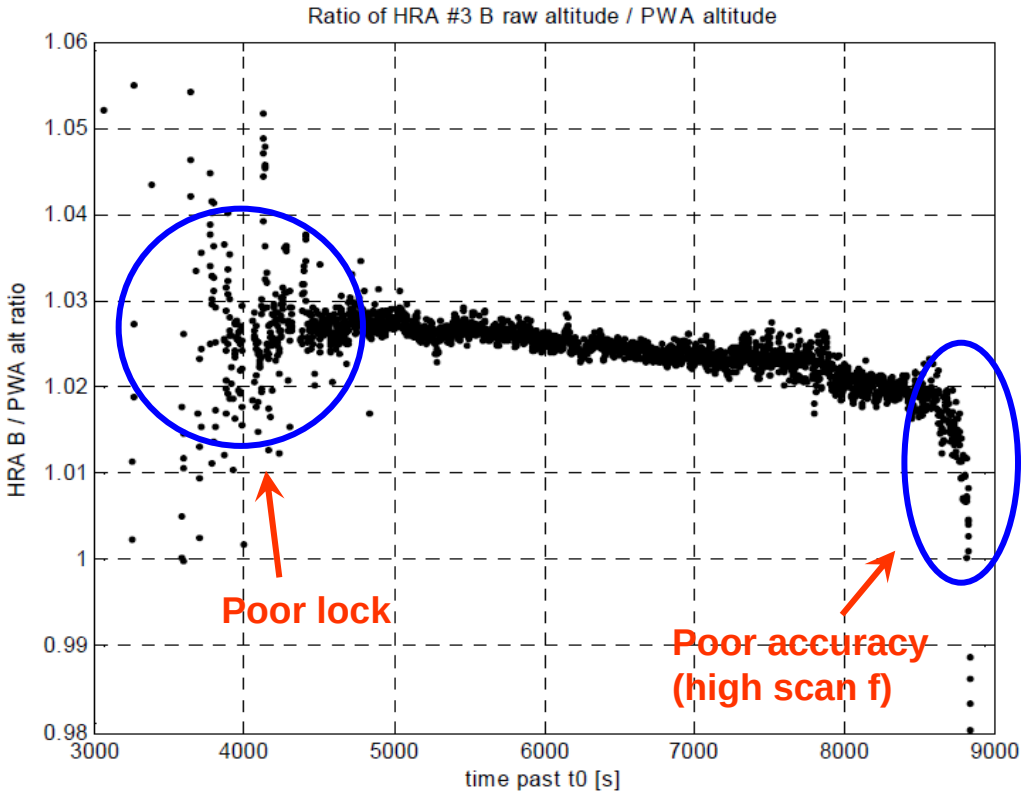
=> No Evidence for deviations.

Altitude Counter RC Oscillator

- Ratio of HRA B altitude / PWA measured altitude:
  ~ 1.028 @ +2°C (To+4500 sec)
  ~ 1.02 @ -11°C (To+8500 sec)
  on Titan

- Pre-launch test data available from radar tests during SFTs / ISTs (both HASI and HRA activated).





=> Degradation of the counter -> difference between flight and GND test data
=> GND test data available on de-commissioned (!) MTP machines

Recovery of Huygens MTP data, or: A visit to the Museum

- **2006:** contract established to re-activate MTP @ ESTEC, retrieve and process data
- **2007:** contract failed, MTPs fragile, unreliable, data carriers unreadable / optical drives failing. Cryptic SW & OS.
- **2008:** months wasted reactivating optical drives (failed, disks mostly unreadable)
- **Late 2009:** backup tapes discovered. Transfer of several Gbyte to MTP processor (1 month). Processing of data using old ADA software. Transfer of output data to ftp-capable machine.
- **2010: data processed !**

Bilbo & Frodo – Digital VAXstations (90'ies)
VAX-VMS V5.5-2H4

ATG optcal disks
(1 Gbyte)
`

Tapes

Altitude Counter
RC Oscillator Errors

- **MTP data results: HRA/PWA alt ratio (HRA B)**

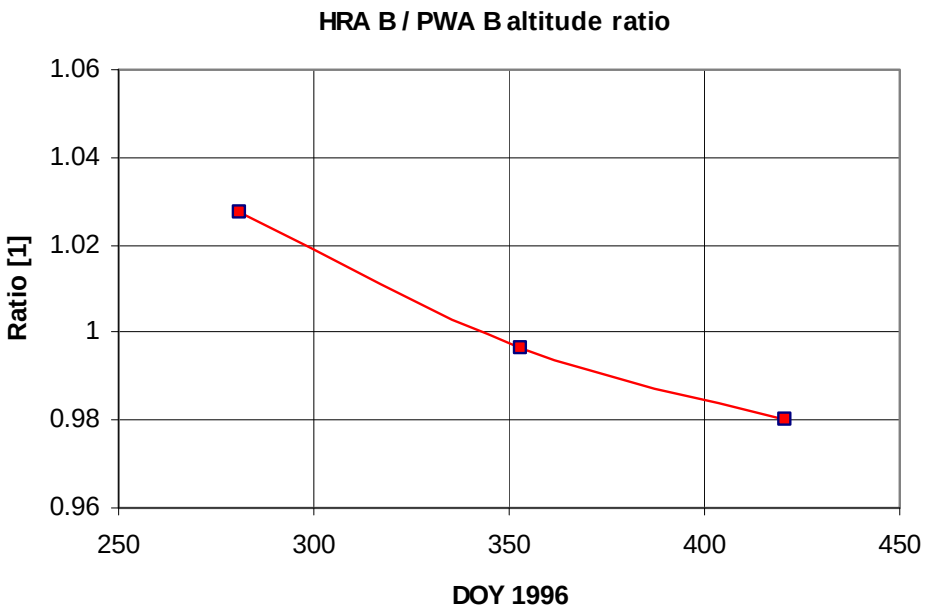
OCT-7-96-SFT3-NM-1 TEST ratio:	**1.0273 @ 34°C => CDMU was 2.73% higher than PWA**
DEC-18-96-EMC-RAU-1 TEST ratio:	**0.9966 @ 36°C => PWA 0.34% higher than CDMU**
FEB-24-97-NM-1 TEST ratio:	**0.9799 @ 34°C => PWA indicated 2.05% higher altitude**

Measurement equipment:

- **RSS: delay lines (mechanical)**
- **PWA: DSP & quartz based**

⇒ Something strange went on in the oscillators …

⇒ So we went to do some testing !

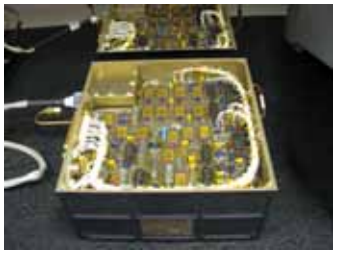


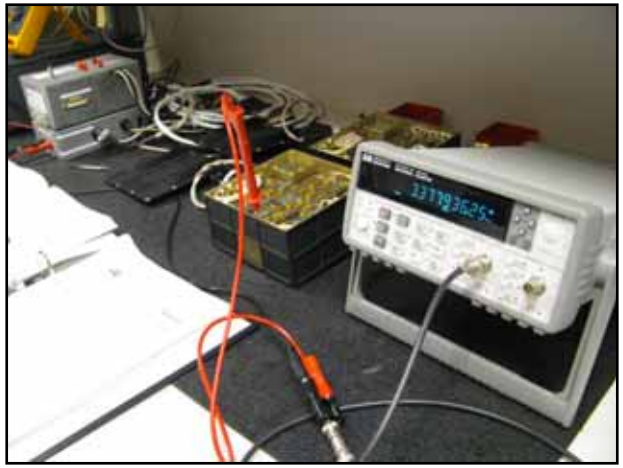
RC Oscillator Frequency Tests Radiation & Vacuum (1)

FS HAR A and FS HRA B were set up for lab bench tests

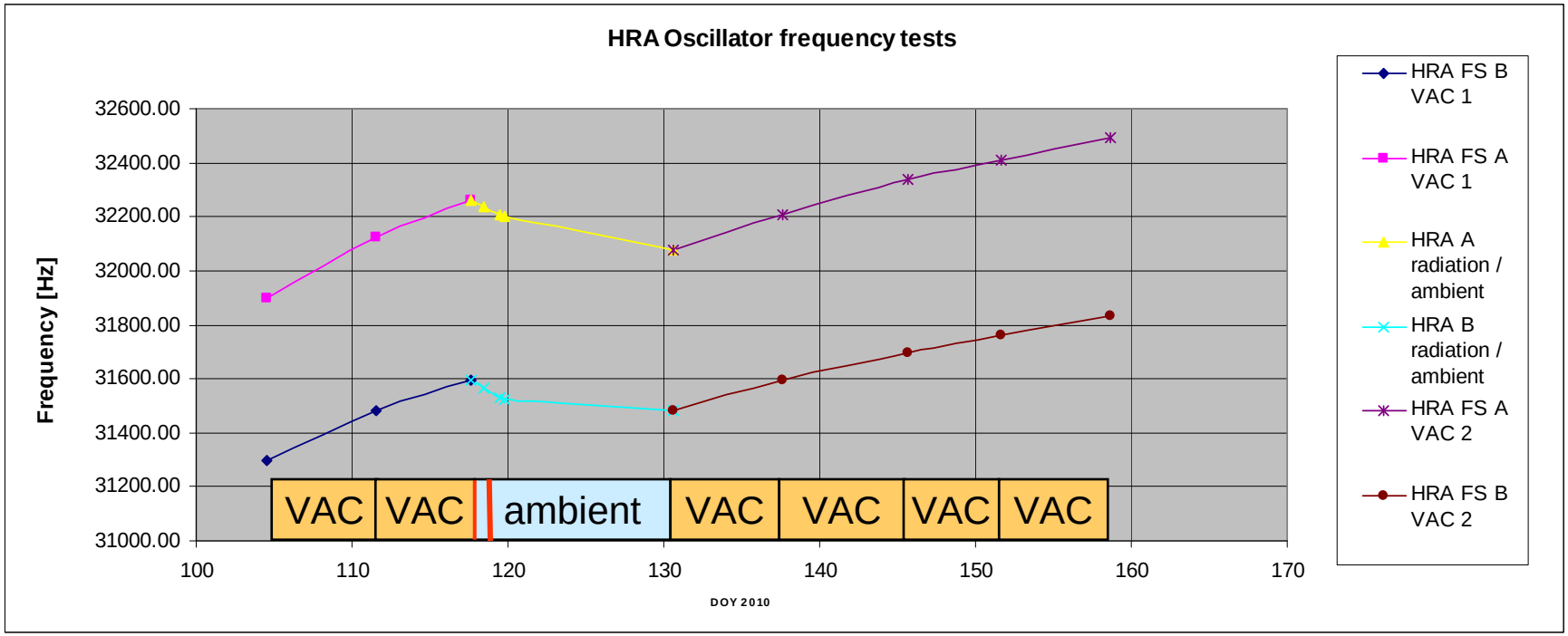
Oscillator frequency measured via buffer

- **Several weeks of vacuum exposure**
- **Intermediate measurements at ambient conditions (20 deg C)**
- **Two radiation exposures (1.14 krad and 1.35 krad Si) 27/28 04 2010**
- **Intermediate 'relaxation' period**





HRA FS Oscillator Test Campaign



What did we learn ? or Summary of Lab Test Results

HRA FS models show significant impact of Vacuum exposure

- **Oscillator frequency increase in vacuum, relaxation in ambient conditions**
- **In low quality vacuum, ~1.05% and 1.22% was observed in ~2 weeks and 4 weeks**
- **In ambient, ~0.47% relaxation was observed in ~2 weeks; relaxation during Huygens descent time (2.5 hours) very small if not negligible**

HRA FS models show temperature effect on alt counter oscillators

- **~ 0.0049 % per °C observed**

No or negligible effect of radiation exposure

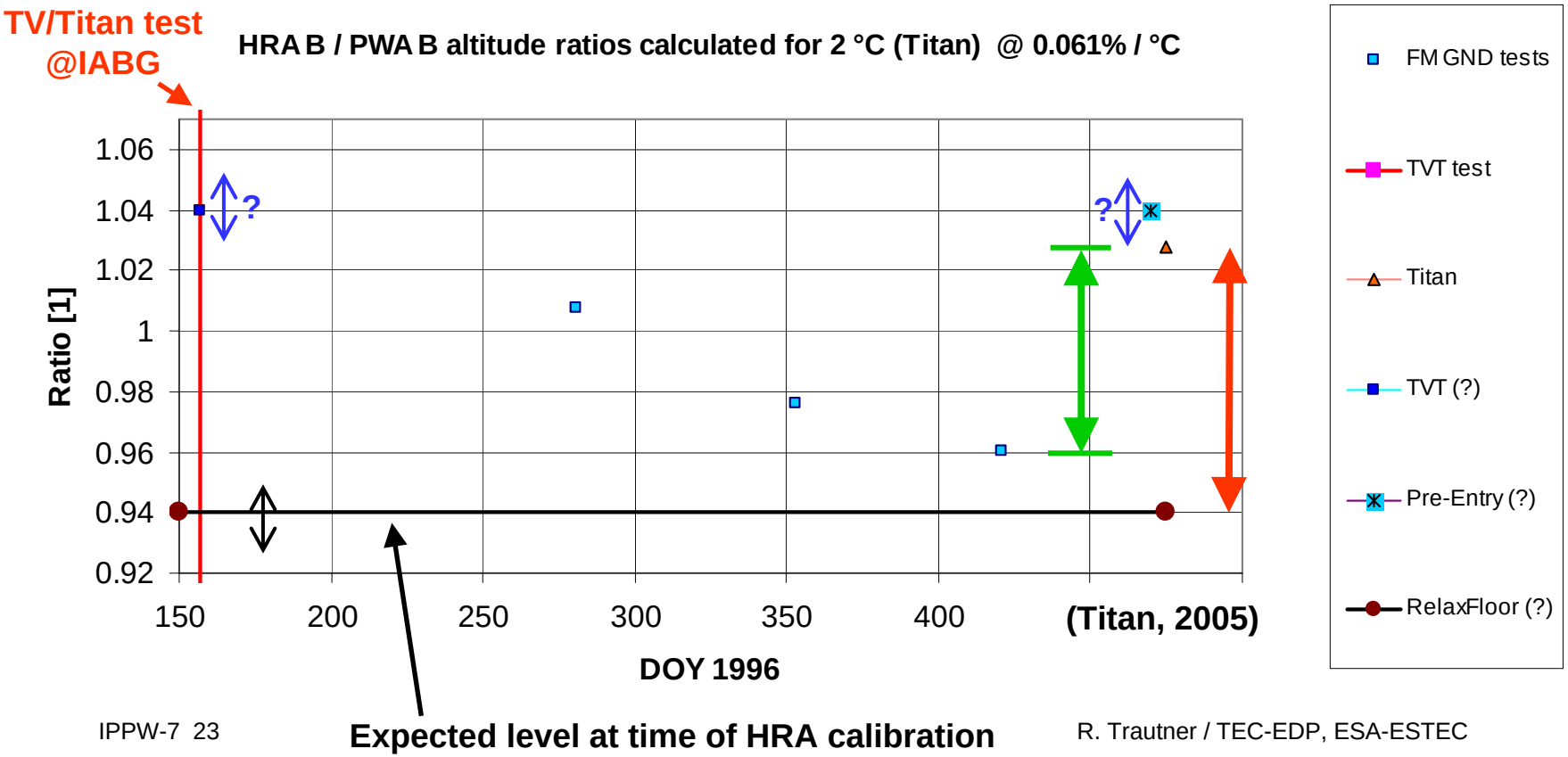
- **ca. 2.5 krad (Si) showed no identifiable effects**
- **Thermal and vacuum / relaxation related effects dominant**

FM data: what we know, what we think, and what we don't know (yet)

HRA and PWA ratios normalized to 2 deg C (Temp on Titan @ To + 4500 sec)

Green arrow: minimum correction factor for Oscillator Vacuum Degradation (~6.8%)

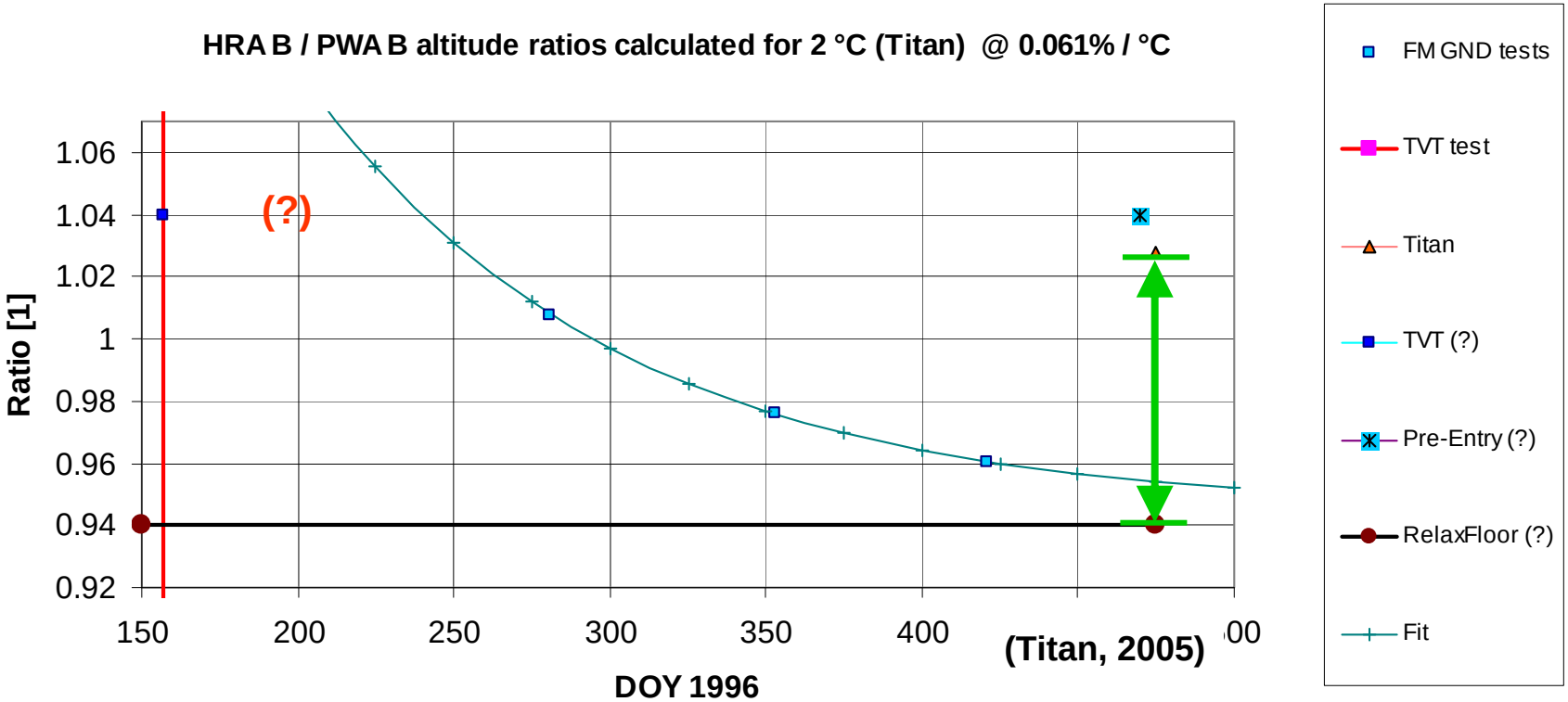
Red arrow: expected correction factor for Oscillator Vacuum Degradation



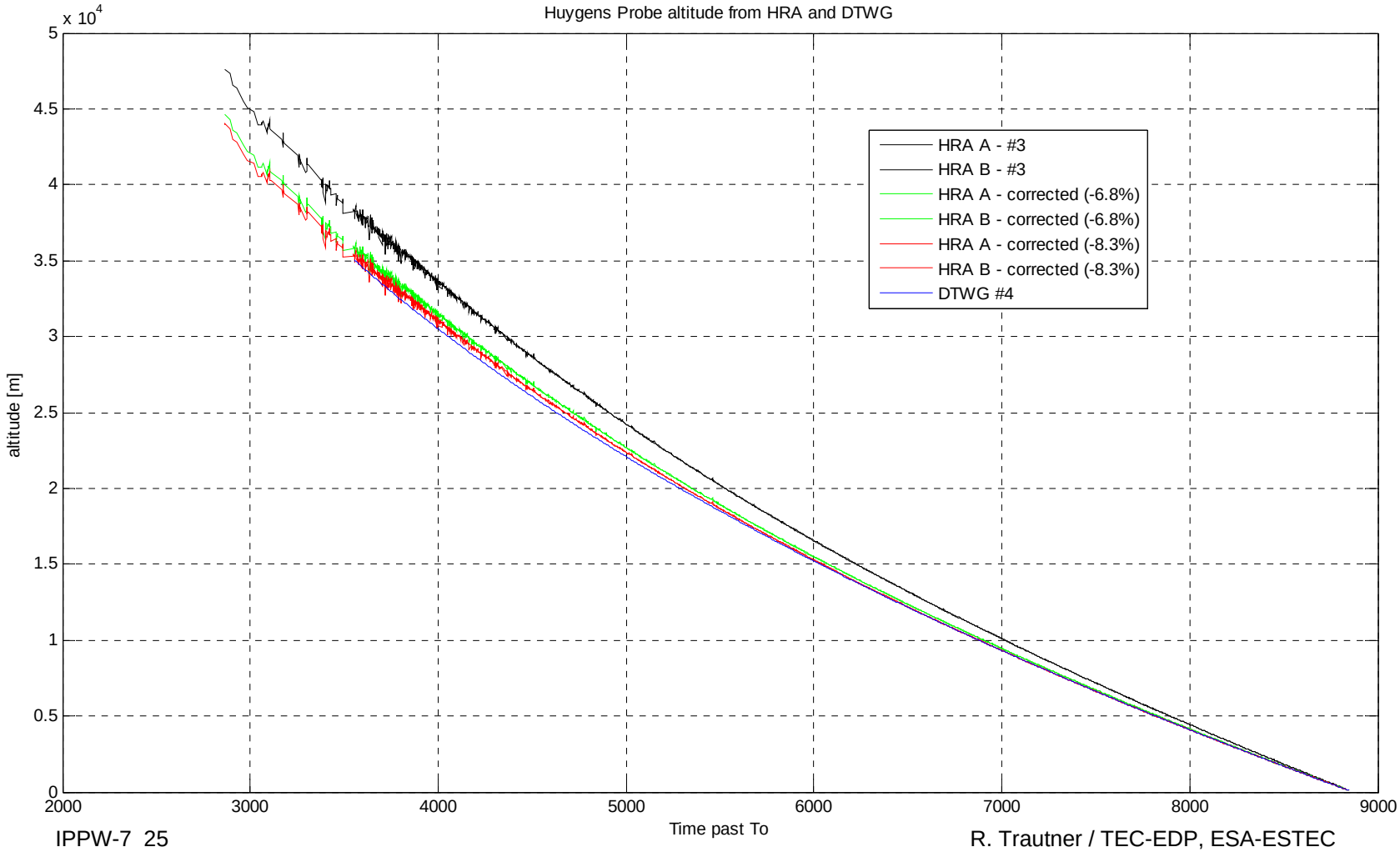
FM data: estimation of pre-vacuum exposure HRA / PWA alt ratio

HRA and PWA alt measurements, normalized to 2 deg C (Temp on Titan @ To + 4500 sec)

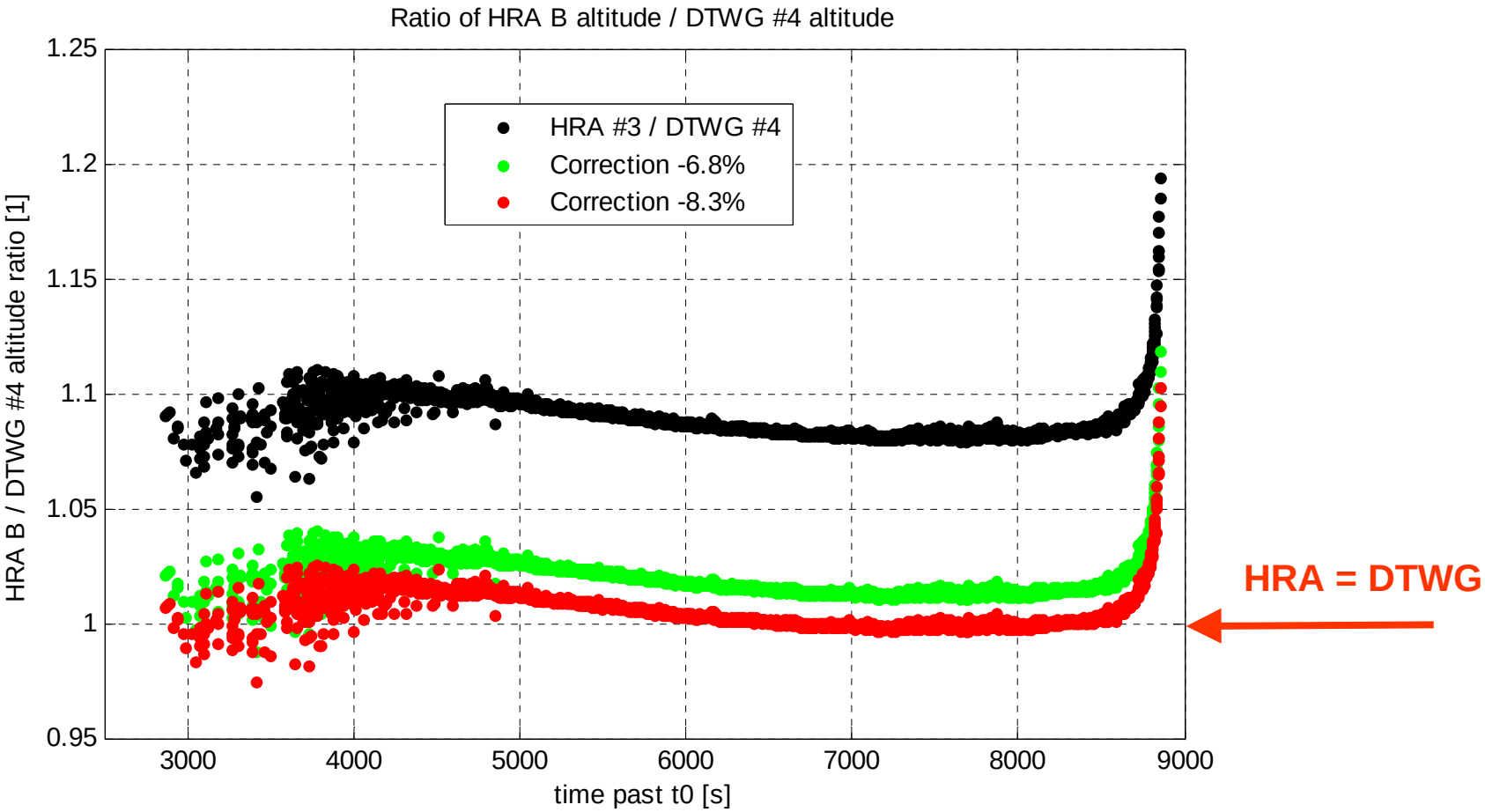
Exponential LSQ fit: Y = C + A*exp(- (t-T)/tau) => Estimated correction = ~ 8.3%



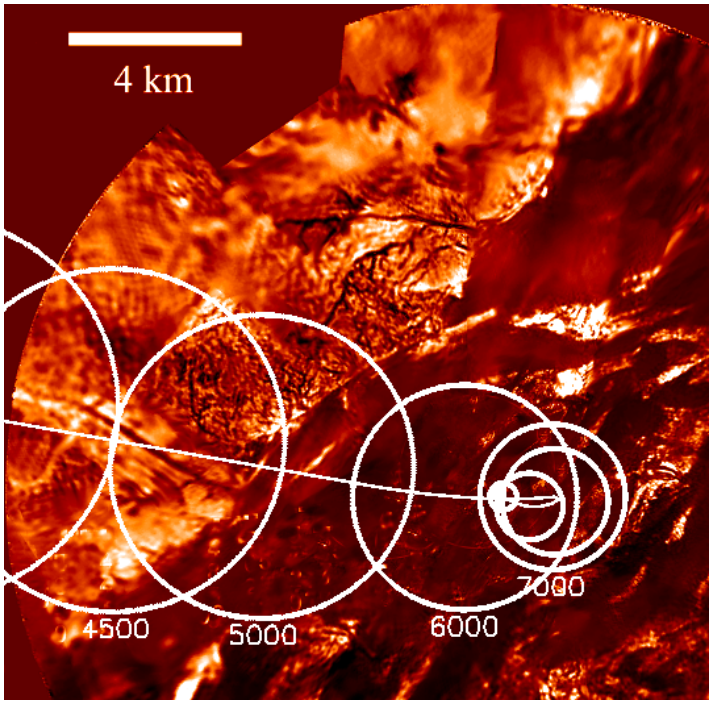
DTWG and updated HRA altitude profile (-6.8% / -8.3%)

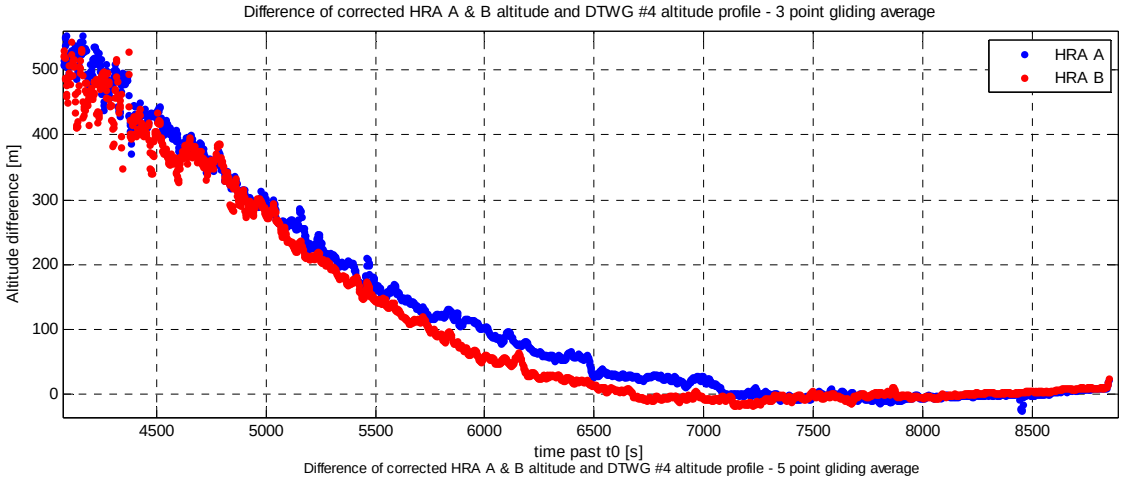


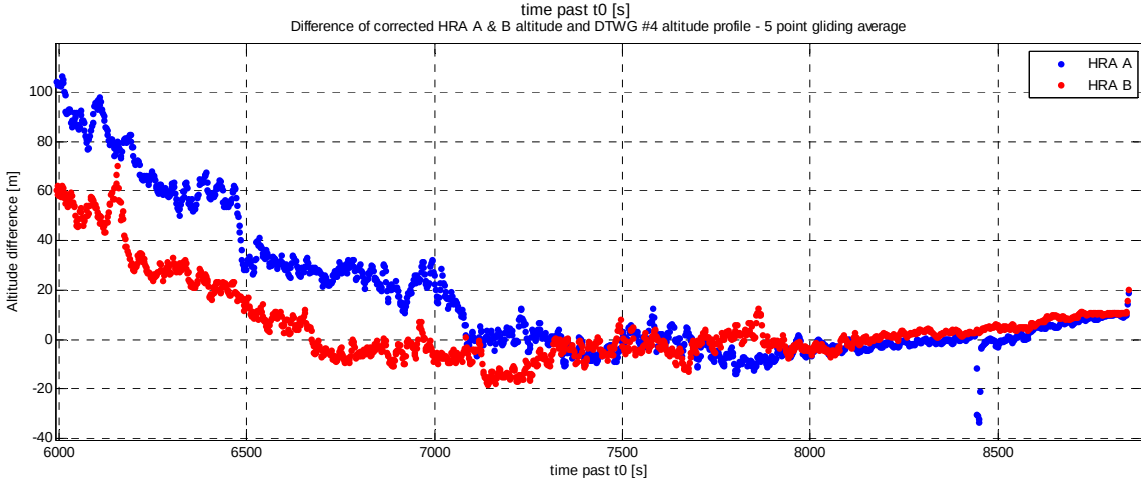
HRA / DTWG deviation after correction (-6.8% / -8.3%)



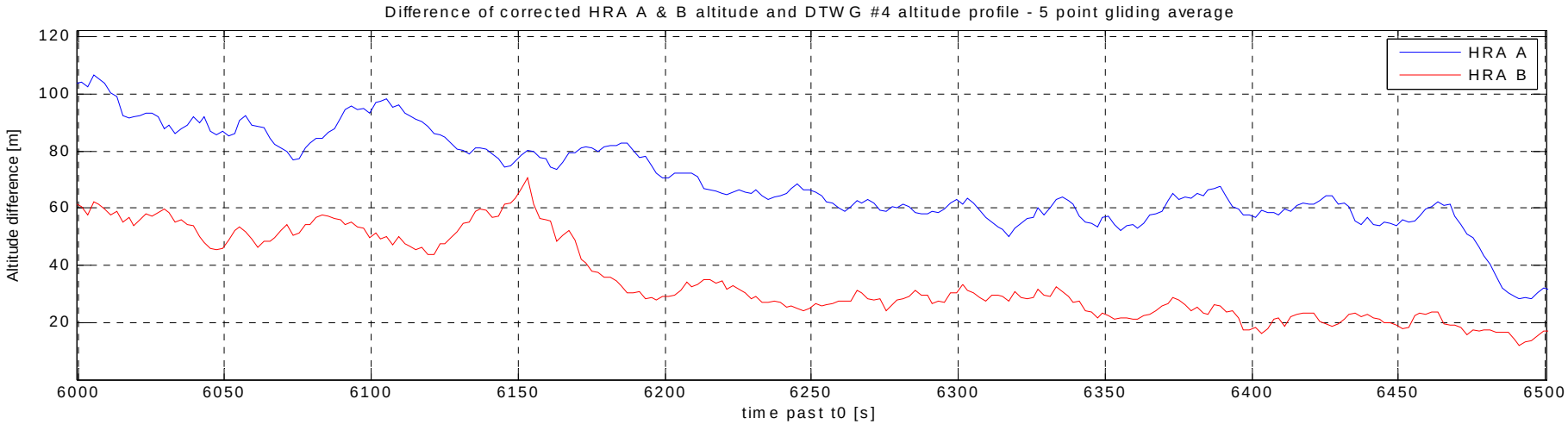
Error- and terrain related features in HRA – DTWG difference (1)

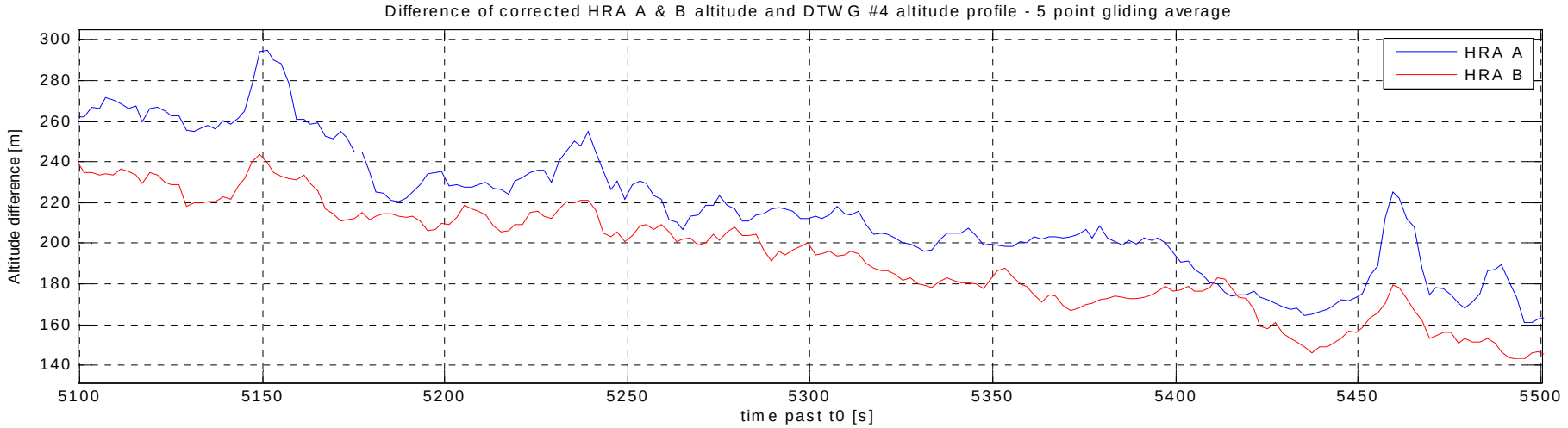






Terrain related features in HRA – DTWG difference (2)





Conclusions

HRA altitude measurements performed on Titan

- **Alt counter oscillator has been identified as dominant error source**
- **Test and FM data indicate that vacuum related effects are responsible for errors**
- **Estimated error (min 6.8%, likely 8.3%) consistent with observed deviation (~ 8%+)**
- **Preliminary updated HRA altitude profile close to DTWG#4 profile**

=> For final HRA alt profile attitude data, refined thermal data, and more tests needed
=> A fresh look at the DTWG input data may be useful

Science opportunities based on HRA data

- **Very little has been published based on HRA data**
- **Altitude profile and HASI PWA spectra contain lots of unexploited information**
- **Once updated & corrected HRA altitude dataset is available there should be material for a number of nice papers**

Acknowledgements

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- Steve Esson and Andrea Toni, VAX experts, ESTEC
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- Nicolas Hughes, former HRA radar designer @ Ylinen
- D-TEC radiation lab staff and management, ESTEC
- D-SRE laboratory staff and management, ESTEC