50 Hz high precision kinematic GNSS observations for airborne vector gravimetry – First experiences

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Abstract

A *JAVAD JGG100* single frequency receiver has been tested in kinematic observations at a 50 S/s sampling rate in comparison to a linear scale ground truth and compared to a *Leica520*. The study in the framework of an airborne gravimetry project was motivated because high resolution GPS-positioning is a key problem for the computation of kinematic accelerations. In the test, different receiver parameters were applied and the effects studied, resulting in some recommendations for adequate settings for aircraft applications. Because of the influence of the tropospere etc., the ambitious accuracy specifications of the manufacturer could not really be tested. It became clear, however, that one advantage in high sampling rates is the capability to filter out high frequency troposperic effects.

1 Introduction

In the past few decades, airborne gravimetry has emerged as a valuable tool for high resolution gravity field recovery. Current status is scalar (vertical component) airborne gravimetry with a resolution of a few kilometres at the level of a few mGal ($10^{-5} ms^{-2}$). The fundamental equation of gravimetry on moving platforms like shipborne or airborne gravimetry is $\vec{g} = \vec{f} - \vec{b}$, where g is gravity (vector or vertical component), f denotes total specific force observed and b kinematic acceleration. For an overview of the current state of the art see e.g. Schwarz 2001. The determination of the kinematic position as such with GPS is feasible with sufficient accuracy. A key problem for improvements, however, is the determination of the kinematic acceleration b. One problem is taking the second derivative – acceleration – from discrete noisy position data at 1 … 10 S/s in the moving environment of a (light) aircraft, because this includes noise amplification. Sometimes, the first derivative of Doppler counts is preferred instead. Another important problem is ionospheric delay. We studied these issues in a preceding publication last year, where we focussed on the use of reference station networks, see Boedecker et al. 2002. One result was the desire for a receiver capable of higher sampling rates and higher accuracies. Consequently, we acquired *a Javad JGG100*. First results of tests are presented in this paper. Of particular interest was the dynamic perfermance at a 50 S/s sampling rate.

2 Javad GPS Receiver *JGG100*

In January 2003 *Javad Navigation Systems* introduced a new generation of high precision high sampling rate GNSS boards. The manufacturer advertises the *JGG100* single frequency receiver (Figure 1), able to provide raw data 100 times per second without interpolation and a precision of 0.1 mm for the carrier phase measurements.
The receiver board has the dimension of merely 88x57x15 mm and, depending on various options, it is capable of including GLONASS, WAAS and other information over a total of 50 channels. The options of our receiver permit a sampling rate of 50 S/s and GPS evaluation only. For communication and data logging the *JGG100* can be connected directly to a computer using two RS232 standard serial ports.

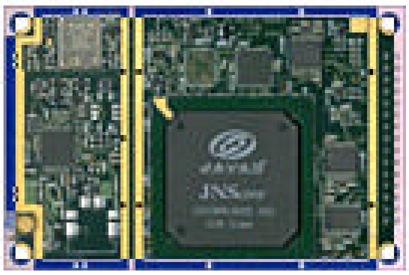

Figure 1: JGG100 receiver

A *Matlab* program was developed and used to send GRIL (GPS Receiver Interface Language [of *Javad*]) commands to one of the receiver ports for accessing all his capabilitys and functions. This manual control enables the user to select observation types, change PLL and DLL loop parameters and opens the possibility for individual receiver configuration adapted to the dynamic situation. The second serial port can transfer 115.2 Kbps or more of data including raw measurement in binary JPS Format to a PC's hard disk in real time. *A Matlab* programme was used also for parsing the receiver's message stream.

3 Investigations

3.1 Aim: Testing JGG100

The aim of our practical investigations was to test the applicability of the *JGG100* single frequency receiver for airborne gravimetry. The magnitude of the effective receiver noise and the operation of the receiver circuits under dynamical conditions are focused in this study.
A convenient method to identify receiver problems independent from external environment like multipath is a zero baseline measurement: Given two receivers constructed in the same way connected to one antenna using a signal splitter, the baseline components should all be zero (Hofmann-Wellenhof 1992). The discrepancies can be interpreted as the double receiver noise. Up to now a second *JGG100* receiver was not available. If the receiver noise for one participant is known, different receiver models may be used for this test. In our case, a combination with a *Leica 520* was tried to have a test at least at 10 S/s. However, the test failed because of impedance mismatch between the two receivers.

A second way to find out something about receiver performance offers the *JGG100* trajectory tracking by an independent positioning device of superior quality by comparison. Because the receiver characteristics under *dynamical* conditions are of particular interest, the test should enable movements similar to a ligtht aircraft. Details are given in the next section.

Figure 2: Vertical lift with antennae

3.2 Lay-out of experiment

For ground truth tracking *a* vertical linear scale (figure 2) with 0.01 mm resolution, made available by the the *GeoForschungsZentrum Potsdam* (GFZ), has been employed. Two aviation antennae were mounted on top of the vertical rail for vertical motion of some 0.6 m. A common plate of some 40x30 cm was installed in order to have a similar environment to the antennae as on the aircraft.

This way, along with the *JGG100*, we also tested a receiver *Leica520* at 10 S/s.
The following significant equipment was used:

- *Mitutoyo* linear scale *AT115* for ground truth height observations at 50 S/s,
- *Javad JGG100* connected to a L1 aviation antenna type *AT575-62 of AeroAntenna*,
- *Leica 520* connected to a L1/L2 aviation antenna type *NovAtel 512*,
- *Leica 520* with a *Leica AT504* choke ring antenna as static reference receiver.

Diverse test series using different settings for the *JGG100* receiver have been carried out on the observation deck of the *Technical University München*.

The antennae were moved up and down by hand and it was tried to apply various frequencies and accelerations up to about 1 g in order to simulate the kinematic load in the aircraft.
Figure 3 shows the acceleration spectrum of one of the aircraft used, figure 4 shows the acceleration exerted by hand on the lift. Because the latter fits sufficiently to the aircraft acceleration spectrum, we can expect some meaningful results. The missing higher frequencies have very low amplitudes and are therfore meaningless. The restriction to purely vertical motion is justified because the results will primarily depend on the control loops in the receivers, i.e. the line-of-sight acceleration is important; a 3D-motion would not be an advantage.

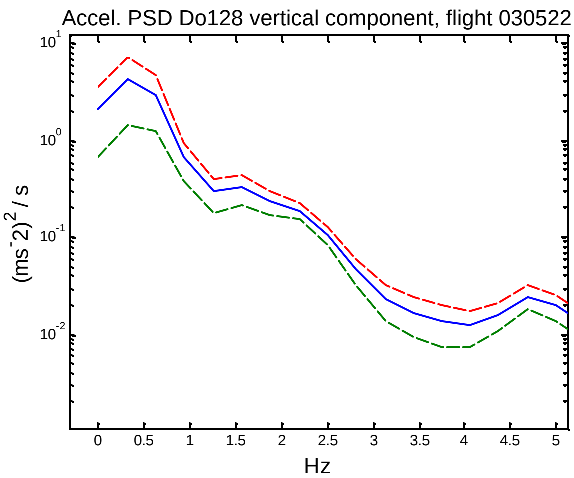

Figure 3: Aircraft vertical acceleration spectr.

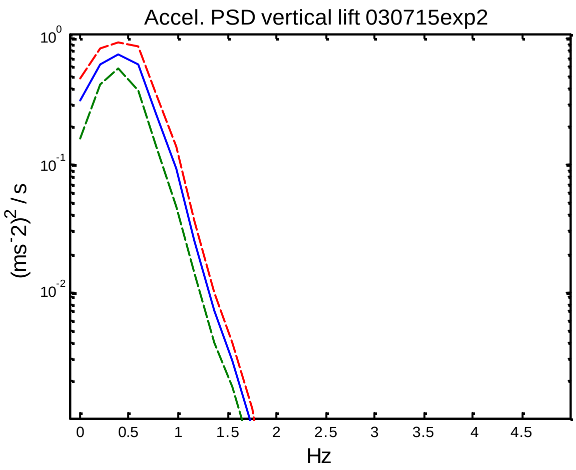

Figure 4: Lift vertical acceleration spectrum

3.3 Evaluation

The collected ground truth height observations have been scaled to the heights derived from GPS measurements. To compute the *JGG100* trajectory at 50 S/s we used *Trimble Total Control* software. Because this is based on double differences, the original *Leica520* reference observations at 10 S/s have been interpolated to 50 S/s. This means, numerical results based on 50Hz *JGG100* positions are affected by reference position quality and interpolation effects. All GPS data were processed using precise orbits and carrier phase OTF procedure.

4 Observational results

4.1 JGG100 raw observations

We desire to study the raw observations of the JGG100 at 50 S/s in order to be free of any hypotheses or other instrumentation that may affect the JGG100 observations. On the other hand, this is meaningful only if we are able to eliminate some of the constituents of the observational signal. As a result, we applied a (low) high pass filter to the observations and studied the high frequency band 5..25 Hertz under various receiver parameter settings. Because of preceding experiences with spectral domain filter design we preferred for this study a polynomial time domain filter design for illustration of signal behaviour. For spectral decomposition, we applied standard Fourier transformation methods.

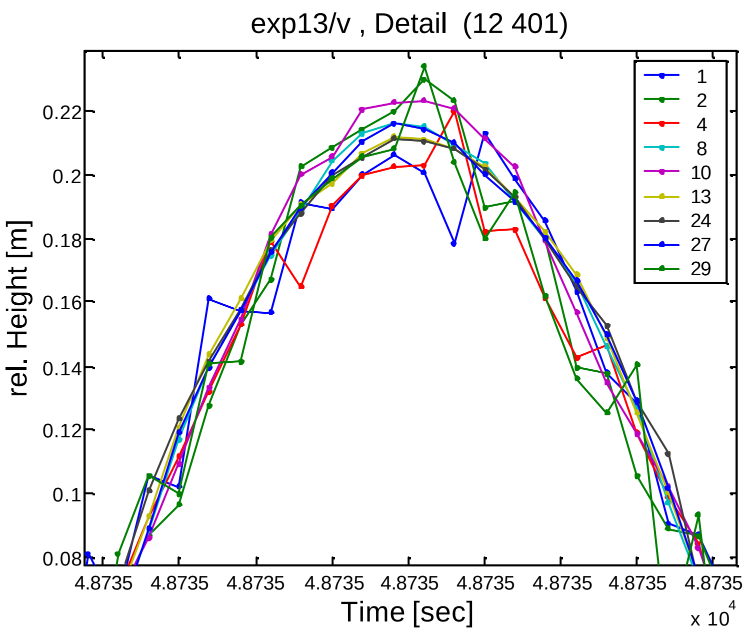

Figure 5: Detail of motion phase tracking by 9 satellites over some 0.5 sec, transformed to vertical

Starting with *carrier phase*, figure 5 depicts the carrier phase observations for about 0.5 sec during motion, transformed to the vertical in order to make the phase variations to the various satellites comparable. Consulting the elevation angles of the satellites during this experiment, see figure 6, we recognize that the variability of the

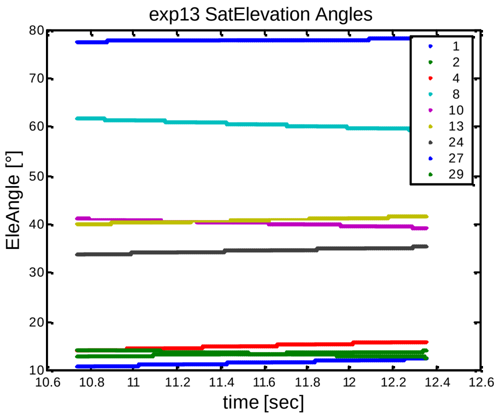

Figure 6: Satellites elevation angles for experiment of fig. 5

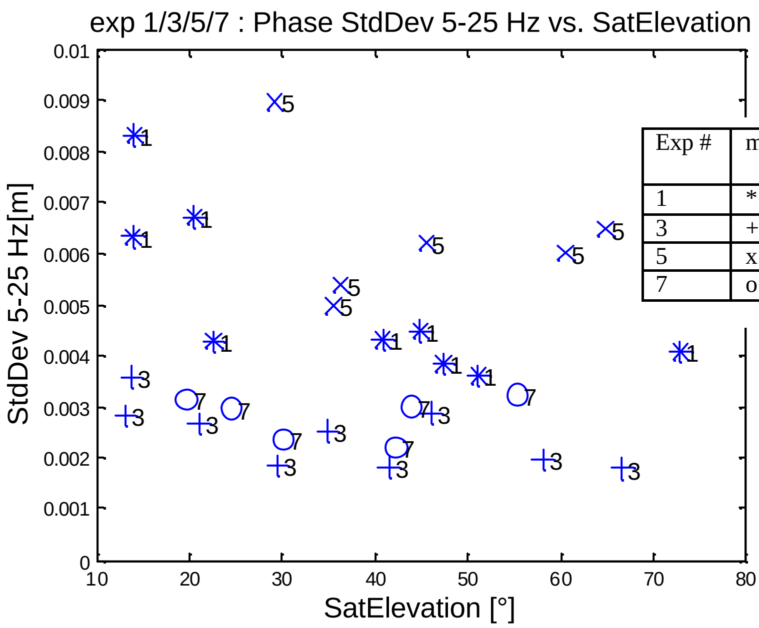

Figure 7: Phase STD in frequency band 5-25 Hz under various receiver PLL-settings. Further explanation see text

carrier phase data is increasing with decreasing elevation angle for two reasons: The tropospheric and quick multipath noise inevitably included in the data is bigger for low elevation angles; additionally, the projection to the vertical component amplifies this noise depending on the elevation angle. Please compare e.g. sat #1 – blue line with sat #4 – red line.

The receiver parameter settings affect the ability to adapt to various dynamic environments: The PLL bandwidth and PLL order may be adjusted accordingly. The results are shown in figure 7: Four experiments with static and dynamic intervals were selected, each over a few minutes. Explanations are given in the table. The high frequency carrier phase noise in the 5..25 Hz band confirms that a major contribution comes from the troposphere / high frequency multipath. Smaller bandwidth reduces the noise considerably. In general, a small bandwidth bears the risk of loss of lock. In our dynamic scenario, we did not observe a loss of lock, i.e. only at higher dynamics this may happen. Setting the PLL order from 2 to 3 did not improve results. So far, we have not studied possible phase delays. Summarising the current status, we would recommend a lower Pll bandwidth and a PLL order 2. However, this is based only on inspection of high frequency raw observation noise. After looking at the position estimate, this judgement has to be adjusted, see section 4.3.

Exp #	marker	PLL bandwidth	PLL order	Comment
1	*	25	2	default
3	+	10	2	
5	x	50	2	
7	o	10	3	

Next, we looked at the *code observations* in various experiments, each with a static and a dynamic part. A selection is explained in the adjacent table and the results are depicted in figure 8: Again, the noise depends on the satellite elevation angle. Depending on the DLL bandwidth set, 5..25 Hz STD varies drastically.

Exp #	marker	DLL bandwidth	Smoot hing	Comment
1	*	1	0	default
10	+	0.1	0	
13	x	30	0	

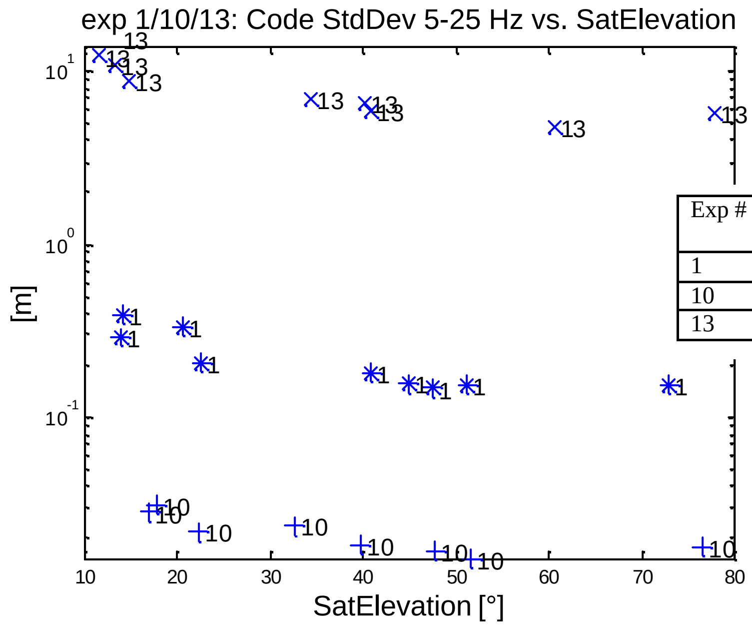

Figure 8: Code STD in frequency band 5..25 Hz under various receiver DLL-settings. Further explanation see adjacent table and text

4.2 Position intercomparisons – heights

Here ground truth values were observed by a linear vertical scale, see section 3.2. Because the linear scale relies on its own time scale, we did a least squares match to GPS time by the observations.
Firstly we tested both receivers, *Leica 520* and *JGG100* with default settings under different dynamic intensities, see figures 9 a and b.

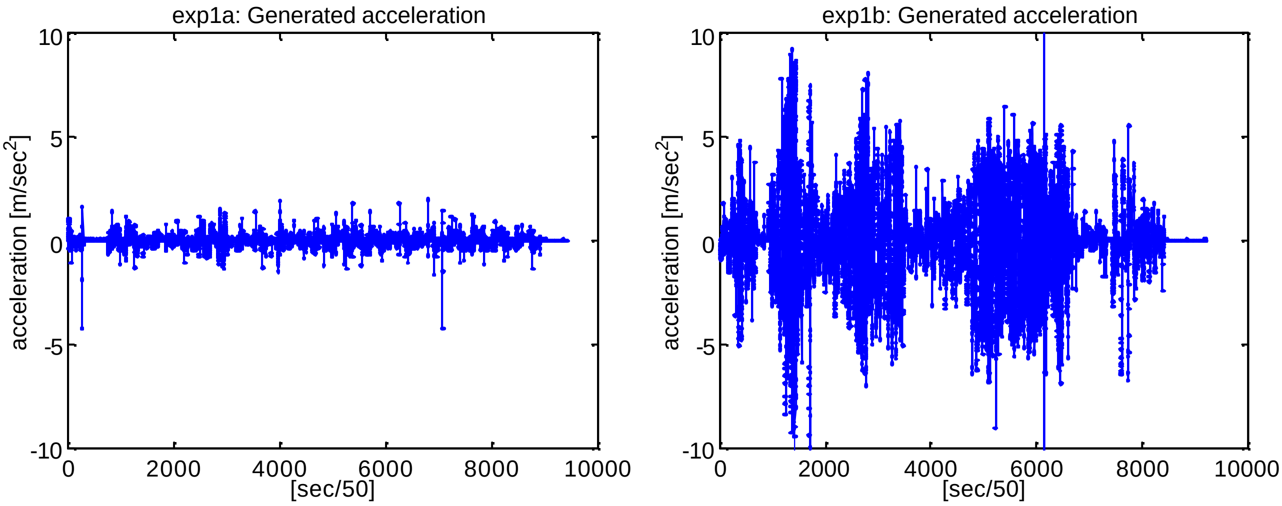

Figure 9a,b: Acceleration in low and high dynamics

The ground truth agreement is the same for both receivers and quite good in the range of millimeters, see figure 10.

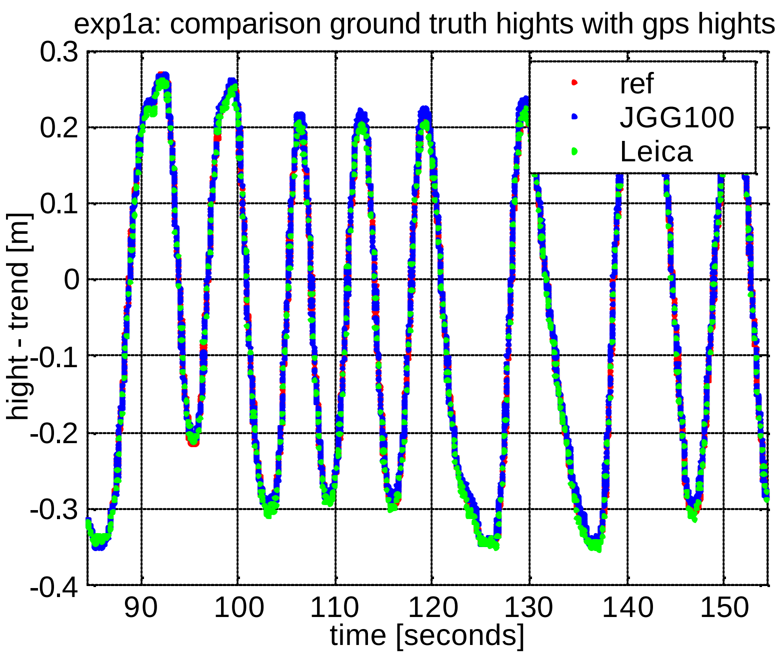

Figure 10: Agreement of JGG100, Leica 520 with ground truth, detail

Increasing dynamics as in figure 9 a > b results in an increasing standard deviation from 6 mm to 9 mm, see also figure 11 a, b.
It must be pointed out, that the comparison of *Leica520* and ground truth is based on 10 Hz update rate from the Leica receiver.

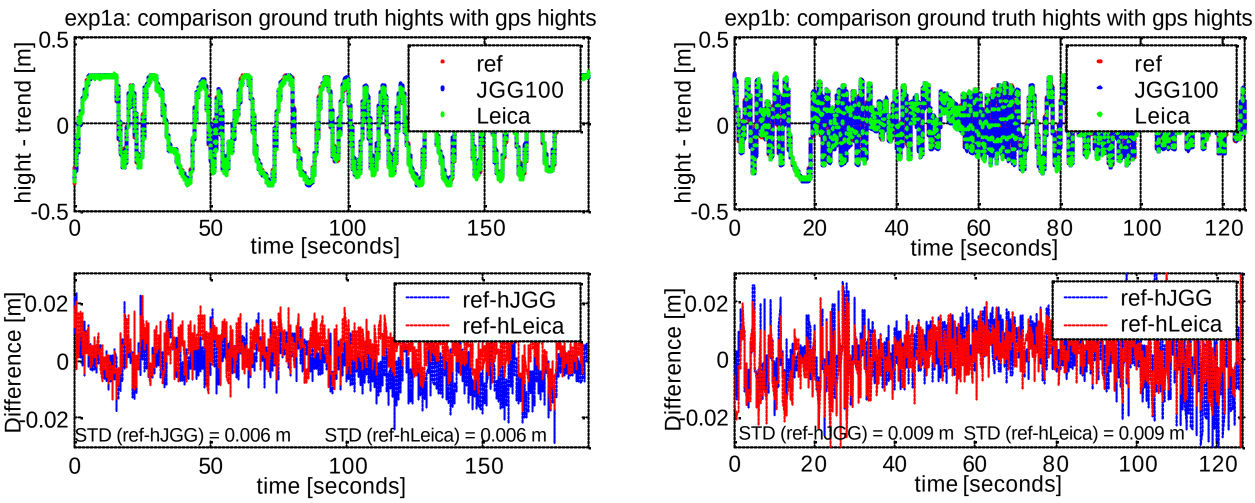

Figure 11 a, b: Intercomparisons at low and high dynamics, see figure 9 a,b: Resulting differences and their standard deviations

Some test series with the *JGG100* were carried out using different loop parameters. PLL-bandwidth and -order as also DLL-bandwidth may be changed. Quality assessment is done on the basis of standard deviations of differences of the individual solution to ground truth by the linear scale.

Here we discuss only the effect of PLL parameter variation on heights. Default values are a bandwidth of 25 Hz and an order of 2. Some kind of factors prevent from further narrowing PLL bandwidth: The internal oscillator noise often does not allow the use of bandwidths less then 5 Hz. Another critical factor is the ionosphere fluctuation and quick multipath. In our measurement environment these guesses were confirmed: An evaluation of the raw data with *Trimble Total Control* was feasible only at 10 Hz bandwidth and more. The resulting standard deviation at 10 Hz is not better than 2.8 cm. A bandwith increase up to 50 Hz causes an improvement of the standard deviation. Hence, it appears an advantage to set the receiver to a higher PLL bandwidth to adapt to higher dynamics.
Looking at the results based on a PLL-bandwidth of 50 Hz and varying loop orders in figures 12 a,b, we recognize the dependency of the accuracies on loop order.

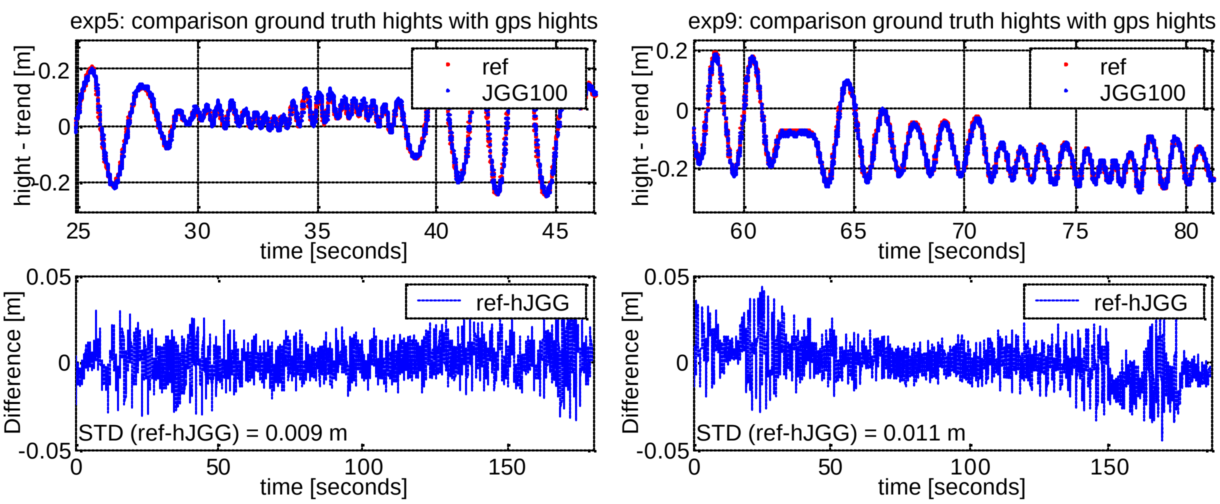

Figure 12 a, b: Intercomparison of the effect of different loop orders at identical bandwidth (50 Hz): Resulting differences and their standard deviations for loop orders 2 (fig. 12a) and 3 (fig. 12b).

Searching for an explanation, we zoom in figure 12b, see figure 13a and b. We identify two phenomena: In figure 13a we detect some overshooting in the case of real movement, in figure 13b we see noise misinterpreted as motion while the antenna is at rest. It seems, that the 3rd order is appropriate only for high dynamics clearly beyond noise. However, the bandwidth has to be set in accordance.

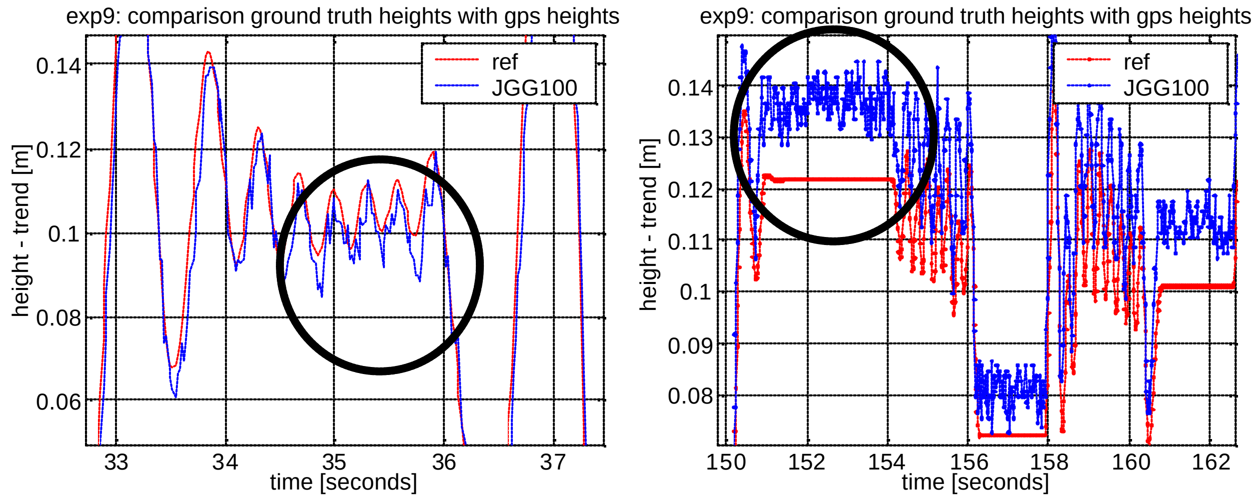

Figure 13 a,b: Effects of loop order set too high with respect to process dynamics and bandwidth:
a.: Overshooting at real movement; b.: Hypersensisitivity to noise during zero movement

The influence of choosen DLL bandwith to PLL function and derived heights is subject of further investigations.

4.3 Effects of receiver parameters

The raw data analysis results of section 4.1 agree with the positioning studies in 4.2 when taking into account that in 4.1 only the high frequency part was studied.
As to the PLL bandwidth and order selection, we would confirm the default values recommended by the manufacturer.

5 Summary, outlook

- We managed to handle this new type of receiver in a rather short time. Communication and parsing software has been developed.
- In the tests, we tried to simulate aircraft dynamic environment. The ground truth was of superior geometric quality with the slight drawback of a separate clock.
- The agreement with either Leica520 as also with ground truth is quite good in the range of millimeter. The variation of standard deviation depending on receiver parameter settings is plausible.
- It is not possible to test the ambitious specifications (0.1 mm) for *JGG100* without an adequate environment; for this purpose a special laboratory would be required; otherwise, utmost care must be exercised to exclude any disturbing effects. A zero baseline test with a second identical receiver would be useful.
- Various receiver loop settings have been tested under various dynamic levels. The recommended default values seem to be appropriate initial set. Fine tuning will be pursued for our demands in a light aircraft.

6 Acknowledgements

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7 References

Boedecker, G.; V. Böder; C. Völksen, 2002. Wanninger, W. Wende: Precise GPS-Positioning and -Acceleration for Airborne Gravimetry: A Case Study.
Proceedings, IGGC Meeting Thessaloniki

Hofmann-Wellhof, B.; H. Lichtenegger, J. Collins, 1992: GPS Theory and Practice. Springer

JAVAD 2003: http://www.javad.com/

Schwarz, K.P., 2001. The impossible dream – Thoughts on the development of airborne gravimetry. In: Festschrift Torge. Wiss.Arb.Vermwes.UniHannover Nr. 241

Seeber, G., 2003: Satellite Geodesy, 2nd ed., de Gruyter