

# **Standards for Checking GNSS Surveying Systems – The Actual Status**

**Hansbert HEISTER, Germany**

**Key words:** GNSS, ISO Standard 17123-8, Calibration, Checking GPS

## **SUMMARY**

GNSS positioning systems are nowadays standard equipment for versatile applications in surveying and geodesy. Therefore it is urgently necessary to have in conjunction with a quality management system standardised procedures for checking and calibrating of these measuring systems. ISO / TC172 / SC6 has already elaborated for different surveying instruments standards for determining the precision by suitable field procedures. Recently a new draft was prepared to propose methods for checking satellite positioning systems: GNSS field measurements systems in real-time kinematics (RTK). The paper will introduce these and additional recommendations to present on the one hand the actual status to stimulate on the other hand the discussion in this field of all involved practitioners.

## **ZUSAMMENFASSUNG**

GNSS bzw. GPS Vermessungssysteme gehören heute zur Standardausrüstung für unterschiedliche Anwendungen im Vermessungswesen und in der Geodäsie. Deshalb sind standardisierte Verfahren, insbesondere in Zusammenhang mit Qualitätsmanagementsystemen gemäß ISO 9000, für die Überprüfung und eventuell auch Kalibrierung dringend notwendig. ISO / TC172 / SC6 ist z.Zt. dabei, eine entsprechende Norm auszuarbeiten. Der Stand der Diskussion um diese Norm 17123, Teil 8 „GNSS field measurement systems in real-time kinematic (GNSS RTK)“ ist Gegenstand der Präsentation. Zusätzlich werden andere Verfahren vorgestellt, um den Dialog für eine für die Praxis zweckmäßige Prüfanweisung zu stimulieren.

# Standards for Checking GNSS Surveying Systems – The Actual Status

Hansbert HEISTER, Germany

## 1. INTRODUCTION

Checking and calibration of measuring devices are traditional tasks of all metrological oriented engineers. The necessity for this is justified in the fact that all measuring processes are influenced by random, but also by systematic errors. Also surveyors have the task and duty to report reliable measurement results and reasonable accuracy data. In the past years, however, new technologies and an increasing complexity of the measuring equipment, and this applies in special to GNSS(GPS)-measuring systems, complicated the introduction of new testing methods and made it even impossible in some areas. The associated discussion about the proven procedures for testing individual components in comparison to the comprehensive system check / calibration is in full course (Hennes, Ingensand, 2000, Rüeger, Brunner, 2000, Heister, H., u.a., 2005). Regarding the special sensor technology treated here, the question, which is the preferred procedure, can not clearly to be answered. Nevertheless, the antenna calibration is a testing method already practised since longer (Wübbena u.a., 2000, Rothacher, 2001, Wanninger, 2002), which gained importance in particular in connection with the reference station networks. However, for these procedures special calibration facilities and high expertise are necessary. Since the functionality of the individual components both of hard and software is not known in detail anymore to the normal GPS user only the system testing remains for the geodetic practice. In doing so, it should not be excluded to examine thereby individual influence parameters.

Unfortunately until today no standardized procedures for field testing / checking were finally worked out, although GPS was already introduced for approx. 15 years as a geodetic positioning technique. Apart from the general necessity to make such testing methods available for practice a modern quality management system (ISO 9000) additionally requires also a confirmation system for measuring devices. This usually contains among testing of the functionality also still the traceability of the measurand. In the following presentation a review of testing methods is given, partly still suggestions in discussion, partly already established testing procedures. For a deepened view of checking / testing / calibrating of GPS real time systems is referred to Fuhlbruegge, 2004.

**Folie 1**

**Standards for checking GNSS**  
- the actual status -

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**Hans Heister**

Institute for Geodesy  
- Geodetic Metrology -

UniBw München  
D-85577 Neubiberg

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H. Heister – Institut für Geodäsie der UNIBwM – D 85579 Neubiberg      e-mail: h.heister@unibw.de

**Folie 2**

**Outline**

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- General remarks
- Checking and calibrating of GNSS systems
- The ISO series of standards 17123
- The draft of ISO 17123 – part 8
- Other proposals for checking GNSS systems
- Conclusions

H. Heister – Institut für Geodäsie der UNIBwM – D 85579 Neubiberg      e-mail: h.heister@unibw.de

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### General Remarks

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Checking and testing of geodetic instruments:  
**Four – phases – model (FIG):**

Phase	Objectives / operations	GNSS
<ul style="list-style-type: none"> <li>Phase 1</li> </ul> Simple functional check:	Evaluation of operability, visual inspection, short intervals before and after measuring, in the field.	☺ ✓
<ul style="list-style-type: none"> <li>Phase 2</li> </ul> Extended functional check:	Simple quantitative checking of significant deviations of specified thresholds in regular intervals or event dependant.	☹ (✓)

H. Heister – Institut für Geodäsie der UNIBwM – D 85579 Neubiberg      e-mail: h.heister@unibw.de

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### General Remarks

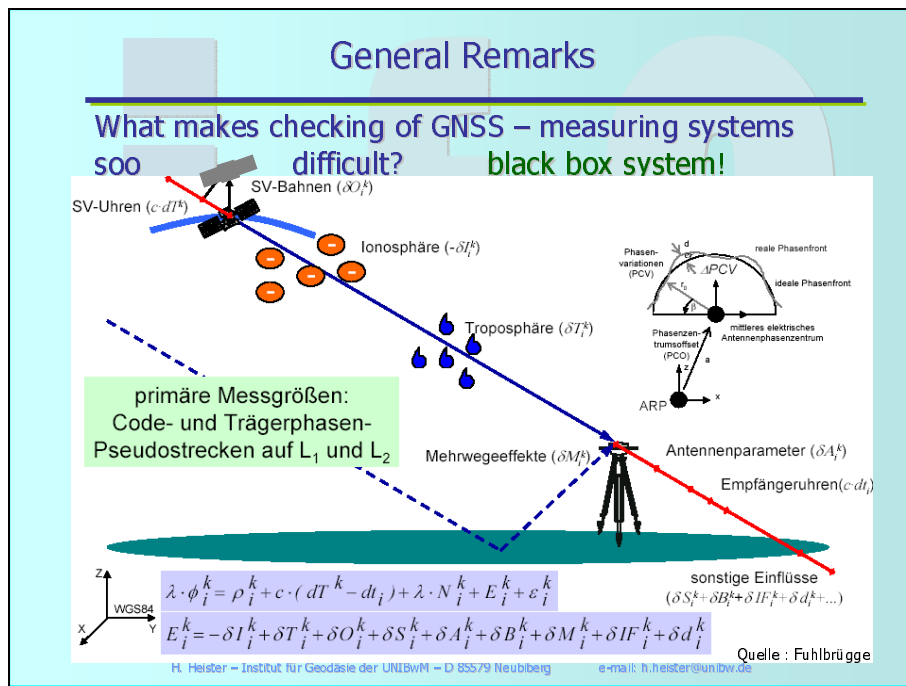
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Checking and testing of geodetic instruments:  
**Four – phase – model (FIG):**

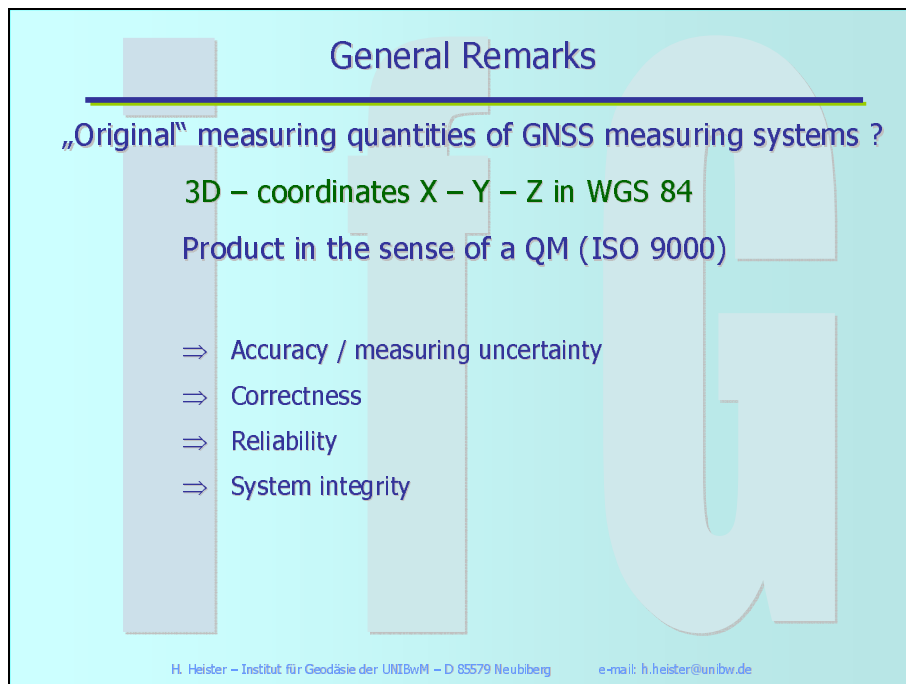
Phase	Objectives / operations	GPS
<ul style="list-style-type: none"> <li>Phase 3</li> </ul> Calibration:	Nominal /actual value comparison of the defined measurands. Measuring reference (standard), special calibration facilities, traceability, certificate, fixed intervals, expenses	? ☹
<ul style="list-style-type: none"> <li>Phase 4</li> </ul> Specification test, type testing:	Checking of the technical specifications in conjunction with QM, independent testing of new instruments or prototypes, components and / or measuring systems, knowledge of measuring principles and software / firm ware, event dependant, manufacturers certificate.	? ? ? ☹

H. Heister – Institut für Geodäsie der UNIBwM – D 85579 Neubiberg      e-mail: h.heister@unibw.de

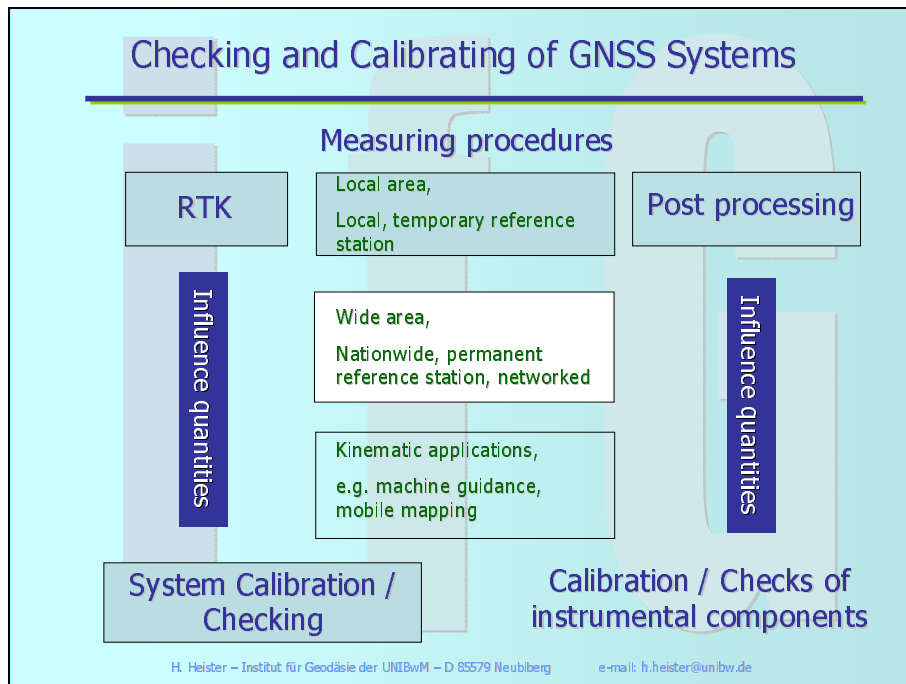
Folie 5



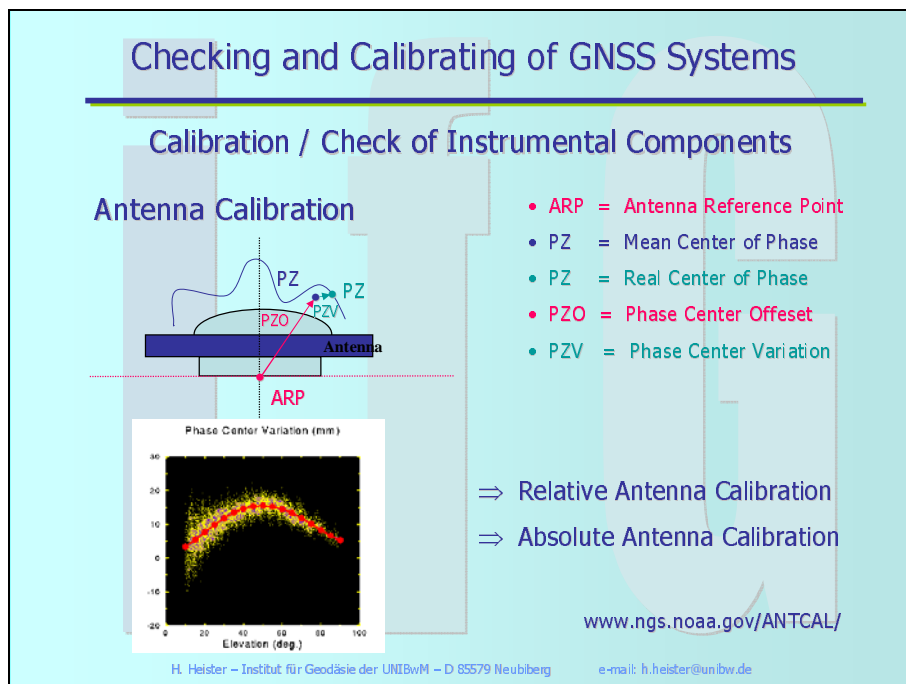
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Folie 7



Folie 8



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## Checking and Calibrating of GNSS Systems

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### Calibration / Check of Instrumental Components

**Zero – Baseline - Test**

**Compensated errors / influences**

- Orbit deviations of satellites
- Ionospheric influences
- Tropospheric influences
- Multipath effects
- Antenna offsets

**Remaining errors / influences**

- Receiver errors  
(Synchronisation of receiver clocks, calibration of the different channels)

H. Heister – Institut für Geodäsie der UNIBwM – D 85579 Neuburg      e-mail: h.heister@unibw.de

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## ISO Series of Standards 17123

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### ISO TC 172 „Optics and photonics“

#### SC 6 „Geodetic and Surveying Instruments“

ISO 17 123 „Field procedures for testing geodetic and surveying instruments

- Part 1: Theory
- Part 2: Levels
- Part 3: Theodolites
- Part 4: EDM instruments
- Part 5: Electronic tacheometers
- Part 6: Rotating Lasers
- Part 7: Optical plumbing devices
- Part 8: GNSS field measurement systems in real-time kinematic (GNSS RTK) (WD)

H. Heister – Institut für Geodäsie der UNIBwM – D 85579 Neuburg      e-mail: h.heister@unibw.de

**ISO 17 123 - 8 „GNSS field measurement systems in real-time kinematic (GNSS RTK)“**

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Working draft in discussion – there is not yet a coordinated proposal (CD)

**Simplified Method: Antenna swapping procedure**

- Objective: Determination of the operational reliability of the GNSS-equipment and a simple quantitative check carried out under minimal exterior influences and minimal effort (FIG phase 1 / 2)
- Observables: Coordinates x, y und ellipsoidal height h (WGS 84)
- Influence quantities:
  - GPS (GNSS) Constellation (eliminated)
  - Ionospheric and tropospheric conditions (eliminated)
  - Environmental conditions of the receiver (multipath) (eliminated)
  - Precision of GNSS receiver
  - GPS (GNSS) reference station (permanent, temporarily) ?!
  - Calculation of corrective data (FKP, VRS) ?!

H. Heister – Institut für Geodäsie der UNIBwM – D 85579 Neubiberg e-mail: h.heister@unibw.de

**ISO 17 123 - 8 „GNSS field measurement systems in real-time kinematic (GNSS RTK)“**

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**1. Configuration of the test field:**

- 2 marked points, a few meters apart from each other
- Measuring distance with tape or electronic tacheometer
- Free satellite visibility (elevation >15°)
- Minimal multipath influence
- Set up of identical receivers respectively antennas on both points

**2. Measurements**

- Static measurements of 30 min. (2 x 15 min.) in two sessions A + B
- PDOP < 4 and 15 sec. sampling interval
- After each session antennas shall be swapped
- Session B under same conditions

H. Heister – Institut für Geodäsie der UNIBwM – D 85579 Neubiberg e-mail: h.heister@unibw.de



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**Antenna swapping: position (northing, easting)**

$$\Delta e = de(A) + fe + fe$$

$$\Delta e = de(B) - fe - fe$$

$$\Delta e = \frac{1}{2} (de(A) + de(B))$$

$$\Delta n = \frac{1}{2} (dn(A) + dn(B))$$

$$\Delta n = dn(A) + fn + fn$$

$$\Delta n = dn(B) - fn - fn$$

H. Heister – Institut für Geodäsie der UNIBwM – D 85579 Neubiberg      e-mail: h.heister@unibw.de

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**Antenna swapping: height**

$$\Delta h = \frac{1}{2} (dh(A) + dh(B))$$

$$\Delta h = dh(A) - fh + fh$$

$$\Delta h = dh(B) + fh - fh$$

H. Heister – Institut für Geodäsie der UNIBwM – D 85579 Neubiberg      e-mail: h.heister@unibw.de

### ISO 17 123 - 8 „GNSS field measurement systems in real-time kinematic (GNSS RTK)“

**3. Calculations**

- Transformation
 
$$\begin{bmatrix} dn_{s,f} \\ de_{s,f} \\ dh_{s,f} \end{bmatrix} = \begin{bmatrix} -\sin\phi\cos\lambda & -\sin\phi\sin\lambda & \cos\phi \\ -\sin\lambda & \cos\lambda & 0 \\ \cos\phi\cos\lambda & \cos\phi\sin\lambda & \sin\phi \end{bmatrix} \begin{bmatrix} dX_{s,f} \\ dY_{s,f} \\ dZ_{s,f} \end{bmatrix}$$

S = Session A, B                      f= L1, L2
- Evaluation
 
$$s_{M,f} = \sqrt{dn_{M,f}^2 + de_{M,f}^2 + dh_{M,f}^2}$$

$$dn_{M,f} = \frac{1}{2}(dn_{A,f} + dn_{B,f})$$

$$de_{M,f} = \frac{1}{2}(de_{A,f} + de_{B,f})$$

$$dh_{M,f} = \frac{1}{2}(dh_{A,f} + dh_{B,f})$$

$|s_T - s_{M,f}| \leq \epsilon_s \quad (f=1,2)$   
 $|dn_{A,f} - dn_{M,f}| = Fn \leq \epsilon_H \quad (f=1,2)$   
 $|de_{A,f} - de_{M,f}| = Fe \leq \epsilon_H \quad (f=1,2)$   
 $|dh_{A,f} - dh_{M,f}| = Fh \leq \epsilon_V \quad (f=1,2)$

H. Heister – Institut für Geodäsie der UNIBwM – D 85579 Neuburg                      e-mail: h.heister@unibw.de

### ISO 17 123 - 8 „GNSS field measurement systems in real-time kinematic (GNSS RTK)“

Herein is:

- $s_T$ : Baseline length, measured by tape or tacheometer ( $u < 2\text{mm}$ )
- $\epsilon_s$ : Allowable difference for the baseline length test
- $\epsilon_H$ : Allowable difference for the horizontal antenna offset test
- $\epsilon_V$ : Allowable difference for the vertical antenna offset test

H. Heister – Institut für Geodäsie der UNIBwM – D 85579 Neuburg                      e-mail: h.heister@unibw.de

## ISO 17 123 - 8 „GNSS field measurement systems in real-time kinematic (GNSS RTK)“

Working draft in discussion – there is not yet a coordinated proposal (CD)

**Full test procedure:**

Precondition: GPS (GNSS) equipment passed through simplified method

- Objective: Determination of the experimental standard deviation for position and height including statistical tests.
- Observables: Coordinates x, y und ellipsoidal height h (WGS 84)
- Influence quantities (to minimize):
  - GPS (GNSS) Constellation
  - Ionospheric and tropospheric conditions
  - Environmental conditions of the receiver (multipath)
  - Precision of GNSS receiver
  - GPS (GNSS) reference station (permanent, temporarily) ?!
  - Calculation of corrective data (FKP, VRS) ?!

H. Heister – Institut für Geodäsie der UNIBwM – D 85579 Neubiberg      e-mail: h.heister@unibw.de

## ISO 17 123 - 8 „GNSS field measurement systems in real-time kinematic (GNSS RTK)“

**1. Configuration of the test field:**

- Fixing of the reference station, some 100 m apart from
- 3 marked points (rover), each some meters spaced of each other
- Measuring distances between the rover points by tape or EDM
- Free satellite visibility (elevation >15°)
- Minimal multipath influence
- Set up of identical receivers respectively antennas on all points

H. Heister – Institut für Geodäsie der UNIBwM – D 85579 Neubiberg      e-mail: h.heister@unibw.de

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ISO 17 123 - 8 „GNSS field measurement systems in real-time kinematic (GNSS RTK)“

2. Measurements

- Static measurements of 10 sessions à 10 epochs (mean values) on all stations R1, R2, R3 (rotating)
- PDOP < 3 and 15 sec. sampling interval
- After each session follows a change of station

3. Possible Calculations / Evaluations

- Mean of coordinates and height
- Residuals and experimental standard deviations
- Mean standard deviation of coordinates
- Chi<sup>2</sup>-test

H. Heister – Institut für Geodäsie der UNIBwM – D 85579 Neubiberg e-mail: h.heister@unibw.de

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ISO 17 123 - 8 „GNSS field measurement systems in real-time kinematic (GNSS RTK)“

3. Possible Calculations / Evaluations

- ... ..
- Calculation of the slope distances  $s_i$  by the original coordinates X,Y,Z
- Comparison of the distances
- Statistical test of significant deviations

H. Heister – Institut für Geodäsie der UNIBwM – D 85579 Neubiberg e-mail: h.heister@unibw.de

### ISO 17 123 - 8 „GNSS field measurement systems in real-time kinematic (GNSS RTK)“

4. Questions to be discussed

- Time need of one or two hours reasonable?
- Number of series of measurements sufficient?
- Fixing of allowable thresholds?
- Disadvantages of the procedures?
- Appliance of the tests on RTK using reference station networks possible?
- Is the indication of the uncertainty of measurement strong enough for characterizing "quality " of the investigated measuring equipment?

H. Heister – Institut für Geodäsie der UNIBwM – D 85579 Neubiberg      e-mail: h.heister@unibw.de

### GPS test procedure of the legal survey (Sachsen-Anhalt)

**Basic principle:**  
GPS software and hardware have to be checked on accuracy and reliability:

➤ Checking GPS software

Test data set in RINEX format

- Different measurement set ups according given instructions
- Different measurement periods
- Given reference stations
- Consideration of phase center offsets
- Fixed evaluation procedures

H. Heister – Institut für Geodäsie der UNIBwM – D 85579 Neubiberg      e-mail: h.heister@unibw.de

### GPS test procedure of the legal survey (Sachsen-Anhalt)

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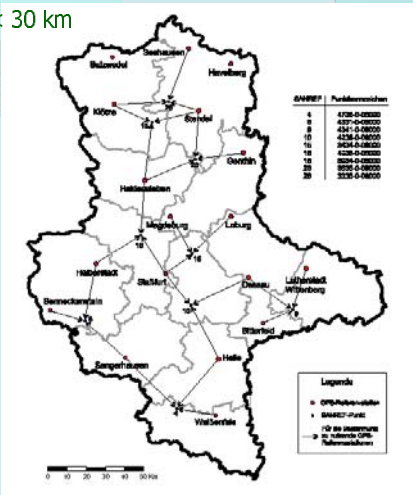
- **Checking of GPS-Software**  
Proof of calculations (QM)
  - Baseline evaluation
  - Multi station evaluation
  - Position coordinates and standard deviations
  - Nominal / actual value comparison
  
- **Checking of GPS hardware**  
Measurement set up
  - Selected legal stations of the reference network (SANREF)
  - Five independent series of measurement à 2 sessions (official instructions)

H. Heister – Institut für Geodäsie der UNIBwM – D 85579 Neuburg      e-mail: h.heister@unibw.de

### GPS test procedure of the legal survey (Sachsen-Anhalt)

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- SANREF - stations > 12 km to ref.station < 30 km
- Optimal measuring conditions,
- Measurements at different dates and different satellite constellations  
 4, 5 and > 5 satellites  
 elevation > 15°
- Evaluation of all GPS measurements equivalent to software test



SANREF Punktnummern	
1	4708 0-02000
2	4807 0-02000
3	4241 0-02000
4	4258 0-02000
5	3424 0-02000
6	4126 0-02000
7	3224 0-02000
8	4126 0-02000
9	3224 0-02000
10	3224 0-02000
11	3224 0-02000
12	3224 0-02000
13	3224 0-02000
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H. Heister – Institut für Geodäsie der UNIBwM – D 85579 Neuburg      e-mail: h.heister@unibw.de

### GPS test procedure of the legal survey (Sachsen-Anhalt)

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- **Checking of GPS hardware**
  - Confirmation of all checks
  - Complete measurement reports
  - All results of the individual sessions
  - Indication of all excluded reference stations and satellites
  - Description of the calculation mode
  - Adjustment of all coordinates and determination standard deviations
  - Nominal / actual comparison of coordinates
- Compilation of Differences:

Maximum allowable deviations:

<b>Criteria for valuating accuracy and reliability!</b>	position	≤ 7 mm (for 66% of all measurements)
		≤ 10 mm (for 100% of all measurements)
	height	≤ 30 mm (for 100% of all measurements)

H. Heister – Institut für Geodäsie der UNIBwM – D 85579 Neubiberg      e-mail: h.heister@unibw.de

### Conclusions

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- The GNSS measuring system as a non autonomous and black-box system is for the practitioners hard to understand.
- Periodical checks or tests for GNSS systems in terms of a recent quality management system are unavoidable.
- Applicable standardized field checks – RTK -, not calibration, are at the time being in discussion (e.g. ISO).
- Antenna checks / calibration demand further discussions (specifications, manufacturers information).
- New methods techniques (kinematc!) und instrumental developments e.g. GPS-tacheometer, frequencies, etc. permit improved / extended test approaches.

H. Heister – Institut für Geodäsie der UNIBwM – D 85579 Neubiberg      e-mail: h.heister@unibw.de

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## BIOGRAPHICAL NOTES

Prof. Dr.-Ing.habil. **Hansbert Heister**

Education in Surveying and Geodesy at the University Bonn, Germany, Dipl.Ing.. Research work in optimization techniques and engineering surveys at the Technical University Munich, Dr.-Ing.. Prof for Geodetic Metrology at the University of the Bundeswehr Munich, Involvement in undergraduate and graduate teaching, many professional activities abroad, numerous lectures at Universities and Congresses.

## CONTACTS

Prof. Dr.-Ing.habil. Hansbert Heister  
University of the Bundeswehr Munich (UniBwM)  
Werner-Heisenberg-Weg 39  
85577 Neubiberg  
GERMANY  
Tel. +49 89 6004 3433  
Fax +49 89 6004 3904  
Email: h.heister@unibw.de