The new ISO standard 17123-8 for checking GNSS field measuring systems

Hans 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 these measuring systems. ISO / TC172 / SC6 has already elaborated for different surveying instruments standards for determining the precision of the equipment in use by suitable field procedures. Recently the new standard ISO 17123 part 8 was published to propose methods for checking satellite positioning systems: GNSS field measurements systems in real-time kinematic (RTK). The paper will introduce the new standard and additional recommendations to stimulate the use of these checking procedures.

ZUSAMMENFASSUNG

GNSS bzw. GPS Vermessungssysteme gehören heute zur Standardausrüstung für unterschiedliche Anwendungen im Vermessungswesen und der Geodäsie. Deshalb sind standardisierte Verfahren, insbesondere mit einem Qualitätsmanagementsystem gemäß ISO 9000, für die Überprüfung und eventuell auch Kalibrierung dringend notwendig. ISO /TC172 /SC 6 hat bereits für verschiedene Vermessungssysteme Standards zur Bestimmung der Messunsicherheit durch geeignete Feldverfahren veröffentlicht. Vor kurzem wurde die neue Norm ISO 12123 Teil 8 zur Überprüfung von GNSS Messsystemen veröffentlicht: GNSS field measurement systems in real time kinematic (RTK). Die Präsentation wird zum einen die standardisierten Verfahren zur quantitativen Genauigkeitsbestimmun erläutern zum anderen aber auch Hinweise auf zusätzliche sinnvolle Prüfverfahren geben.

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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 as well by random as 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 - 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). Additional the introduction of the procedures for evaluating "uncertainty in measurement" is initiated quite recently.

Regarding the special sensor technology treated here, the question, which is the preferred test procedure, can not clearly 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, for the geodetic practice only remains the system testing. In doing so, it should not be excluded to examine thereby individual influence parameters.

In the last year finally the new standard ISO 17123 part 8 "GNSS field measurement systems in real time kinematic (RTK)" was published. Though GPS was already introduced appr. 15 years ago as a geodetic positioning technique it lasted until today to make with this standard a first move in the right direction.

Apart from the general necessity to work out such testing methods 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 the new standard is given; further on other useful testing methods and recommendations for checking GNSS devices are discussed. For a deepened view of checking / testing / calibrating of GPS real time systems is referred to the references at the end of this paper.

Outline

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

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General Remarks

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Checking and testing of geodetic instruments:

Four – phases – model (FIG):

	Objectives / Operations	GNSS
• Phase 1 Simple functional check:	Evaluation of operability, visual inspection, short intervals before and after measuring, in the field.	J ü
• Phase 2 Extended functional check:	Simple quantitative checking of significant deviations of specified thresholds in regular intervals or event dependant.	K (ü)

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General Remarks

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Checking and testing of geodetic instruments:

Four – phase – model (FIG):

• Phase 3	Objectives / Operations	GPS
Calibration:	Nominal /actual value comparison of the defined measurands. Measuring reference (standard), special calibration facilities, traceability, certificate, fixed intervals, expenses	? L
• Phase 4 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 / firmware, event dependant, manufacturers certificate.	? ? ? L

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General Remarks

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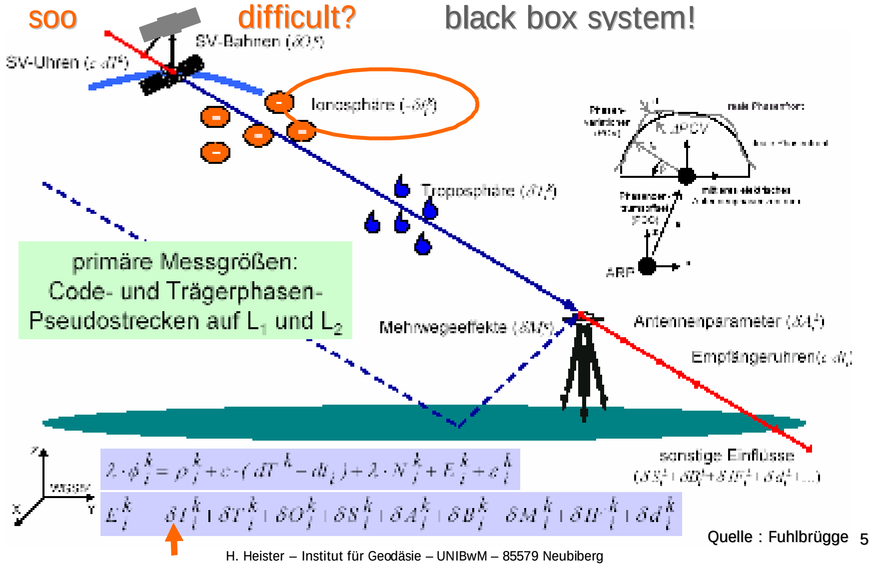
What makes checking of GNSS – measuring systems soo difficult? black box system!



Quelle : Fuhlbrügge 5

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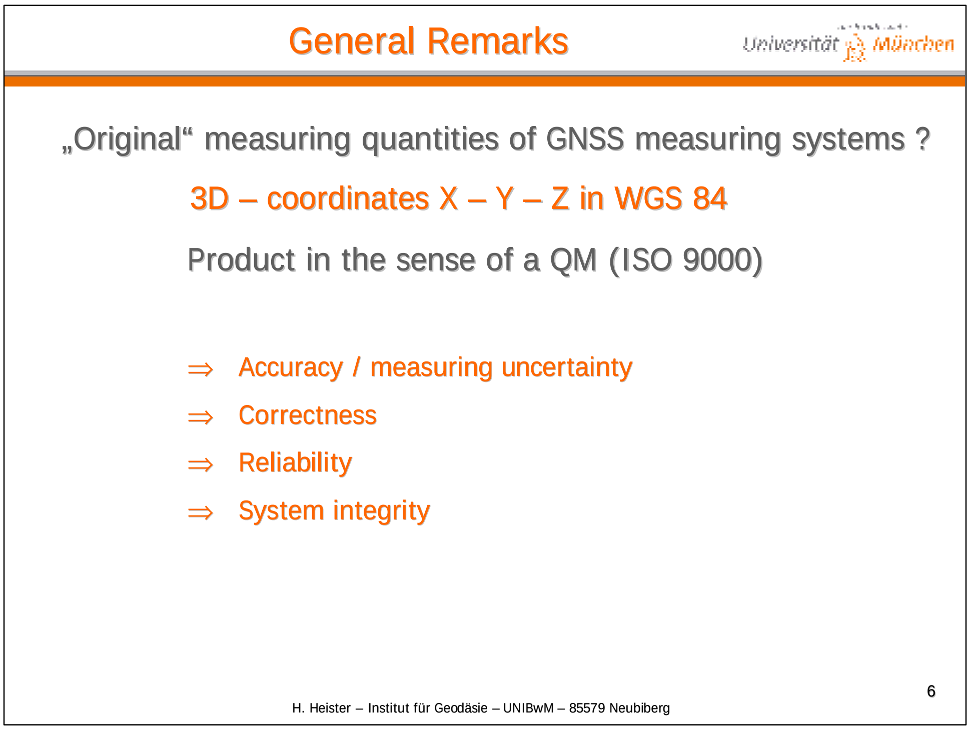
General Remarks
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„Original" measuring quantities of GNSS measuring systems ?
3D – coordinates X – Y – Z in WGS 84
Product in the sense of a QM (ISO 9000)
⇒ Accuracy / measuring uncertainty
⇒ Correctness
⇒ Reliability
⇒ System integrity
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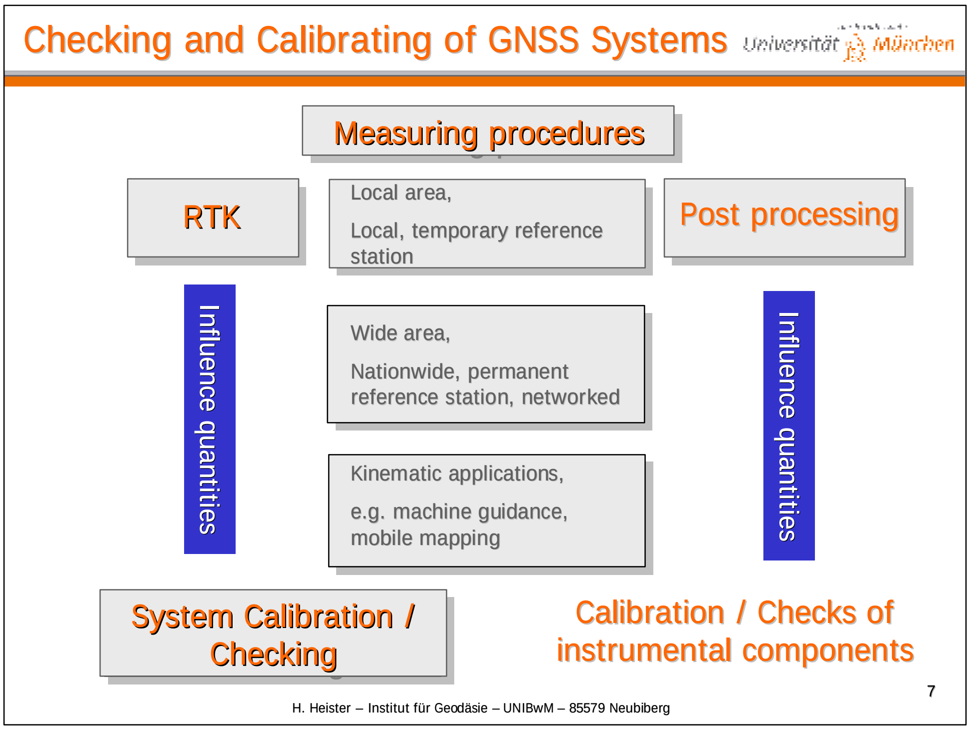
Checking and Calibrating of GNSS Systems
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Measuring procedures
RTK
Local area,
Local, temporary reference station
Post processing
Influence quantities
Wide area,
Nationwide, permanent reference station, networked
Kinematic applications,
e.g. machine guidance, mobile mapping
Influence quantities
System Calibration / Checking
Calibration / Checks of instrumental components
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Series of ISO 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 (current revision status: CD)
- 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 (GNNS RTK)
- Part 9: Terrestrial Laser Scanners (TLS) ??? (Status: Work item study)

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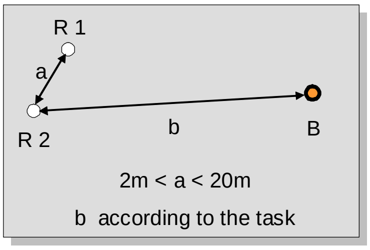
„GNSS field measurement systems in real-time kinematic (RTK)“

Concept of the test procedures



- Horizontal distances and height differences determined by tacheometry, $s_d < 3$ mm

ð Nominal values D*, h*

- Observables, measurements: Coordinates x, y
  ellipsoidal height h (WGS 84)
  ð D, ?h

Comparison D* 6 D and h* 6 ?h

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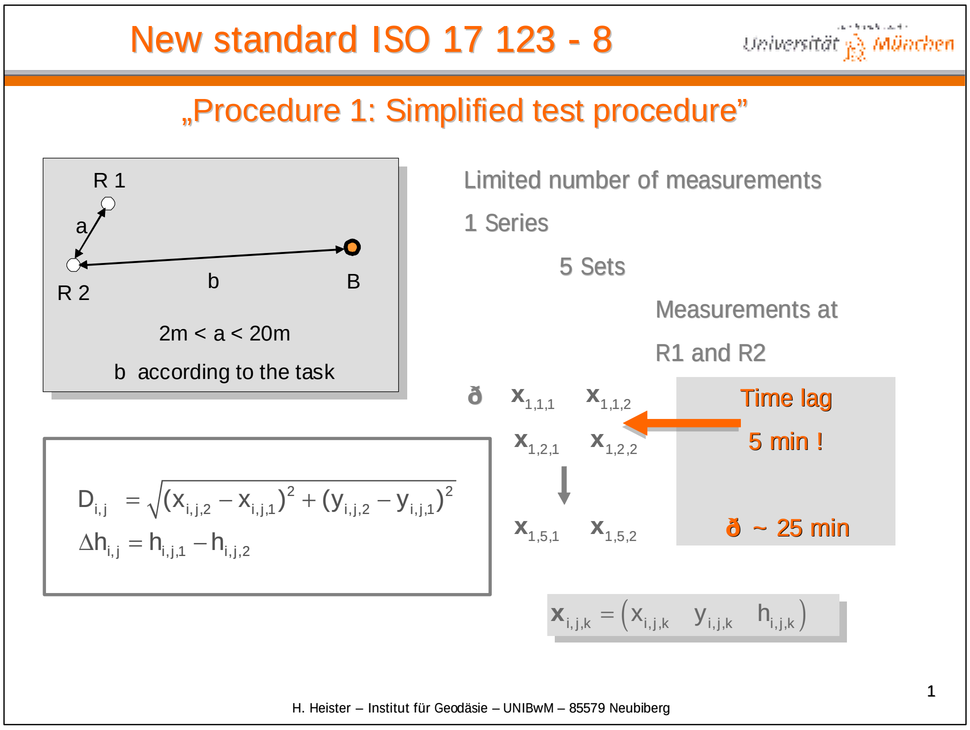
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„Procedure 1: Simplified test procedure”
R 1
a
R 2
b
B
2m < a < 20m
b according to the task
Limited number of measurements
1 Series
5 Sets
Measurements at
R1 and R2
$x_{1,1,1}$ $x_{1,1,2}$
$x_{1,2,1}$ $x_{1,2,2}$
$x_{1,5,1}$ $x_{1,5,2}$
Time lag
5 min !
~ 25 min
$D_{i,j} = \sqrt{(x_{i,j,2} - x_{i,j,1})^2 + (y_{i,j,2} - y_{i,j,1})^2}$
$\Delta h_{i,j} = h_{i,j,1} - h_{i,j,2}$
$x_{i,j,k} = (x_{i,j,k} \quad y_{i,j,k} \quad h_{i,j,k})$
1
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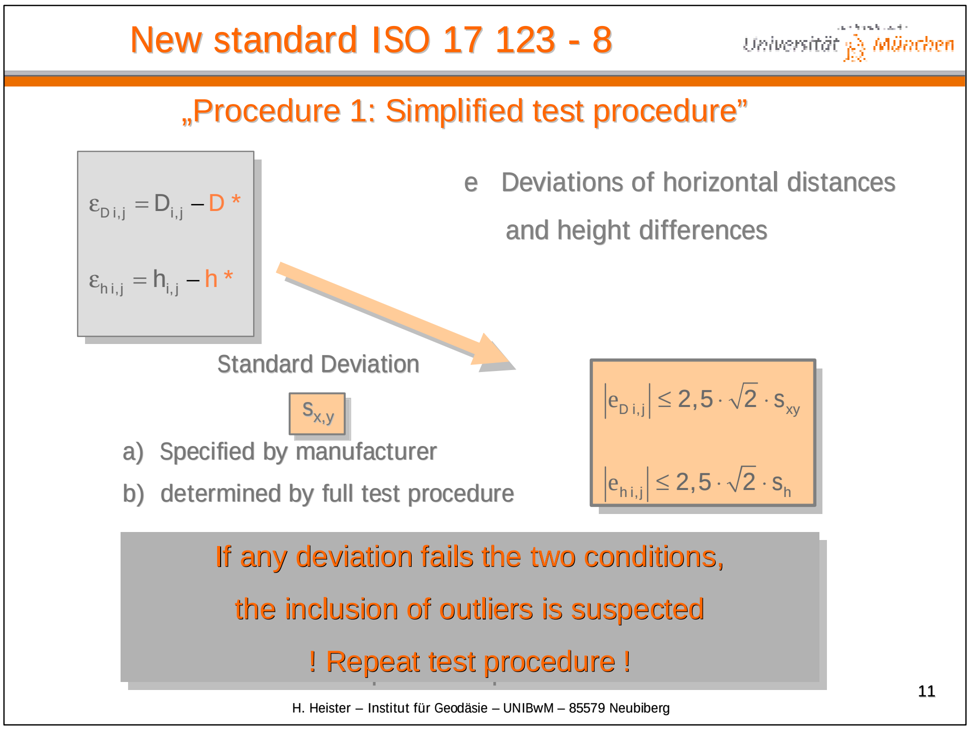
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„Procedure 1: Simplified test procedure”
$\varepsilon_{D\,i,j} = D_{i,j} - D^*$
$\varepsilon_{h\,i,j} = h_{i,j} - h^*$
Deviations of horizontal distances
and height differences
Standard Deviation
$s_{x,y}$
a) Specified by manufacturer
b) determined by full test procedure
$|e_{D\,i,j}| \leq 2{,}5 \cdot \sqrt{2} \cdot s_{xy}$
$|e_{h\,i,j}| \leq 2{,}5 \cdot \sqrt{2} \cdot s_{h}$
If any deviation fails the two conditions,
the inclusion of outliers is suspected
! Repeat test procedure !
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„Procedure 1: Simplified test 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)

„Procedure 2: Full test procedure”

- Objective: Extended functional check, quantitative investigations of significant deviations of specified thresholds (statistical evaluation) in regular intervals or event dependant (FIG phase 2).

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„Procedure 2: Full test procedure”

Objective:

Best achievable measure of precision

- experimental standard deviation for a single position, height

Higher measuring effort

3 Series

5 Sets

Measurements at R1 and R2

$\mathbf{x}_{1,1,1}$ $\mathbf{x}_{1,1,2}$ $\mathbf{x}_{2,1,1}$ $\mathbf{x}_{2,1,2}$ $\mathbf{x}_{3,1,1}$ $\mathbf{x}_{3,1,2}$

$\mathbf{x}_{1,2,1}$ $\mathbf{x}_{1,2,2}$ $\mathbf{x}_{2,2,1}$ $\mathbf{x}_{2,2,2}$ $\mathbf{x}_{3,2,1}$ $\mathbf{x}_{3,2,2}$

$\mathbf{x}_{1,5,1}$ $\mathbf{x}_{1,5,2}$ $\mathbf{x}_{2,5,1}$ $\mathbf{x}_{2,5,2}$ $\mathbf{x}_{3,5,1}$ $\mathbf{x}_{3,5,2}$

Time lag

> 90 min !

ð ~ > 3 h 15 min

$$\mathbf{x}_{i,j,k} = \left(x_{i,j,k} \quad y_{i,j,k} \quad h_{i,j,k}\right)$$

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1. Step:

Individual measurements are compared with the nominal values.

ð Same evaluation as described in the simplified test procedure

Objective: Detection of gross errors

2. Step: Statistical evaluation

- Estimates x, y, h of R1 and R2

$$\bar{x}_k = \frac{1}{15}\sum_{i=1}^{3}\sum_{j=1}^{5} x_{i,j,k} \quad ð \quad \bar{y}_k\ ,\ \bar{h}_k$$

- Residuals for all measurements

$$r_{x\ i,j,k} = \bar{x}_k - x_{i,j,k} \quad ð \quad r_{y\ i,j,k}\ ,\ r_{h\ i,j,k}$$

- Degree of freedom

$$\nu_x = \nu_y = \nu_h = (3 \cdot 5 - 1) \cdot 2 = 28$$

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2. Step: Statistical evaluation

- Standard deviation of a single measurement

$$s_x = \sqrt{\frac{\sum r_x^2}{\nu_x}} = \sqrt{\frac{\sum r_x^2}{28}} \qquad s_y = \sqrt{\frac{\sum r_y^2}{28}} \qquad s_h = \sqrt{\frac{\sum r_h^2}{28}}$$

Experimental standard deviation for a single position (x,y)

$$s_{\text{ISO-GNSS RTK xy}} = \sqrt{s_x^2 + s_y^2}$$

Experimental standard deviation for a single height (h)

$$s_{\text{ISO-GNSS RTK xy}} = s_h$$

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- Influence quantities: For the full test procedure
  - GPS (GNSS) Constellation (minimized)
  - Orbit deviations of satellites (minimized
  - Ionospheric and tropospheric conditions (eliminated)
  - Environmental conditions of the receiver (multipath) (minimized)
  - Precision of GNSS receiver

  - GPS (GNSS) reference station (permanent, temporarily) ?!
  - Calculation of corrective data (FKP, VRS) ?!

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Step 3: Statistical tests

- Is the calculated $s_{\text{ISO-GNSS RTK }xy}$ smaller or equal than the value s_{xy} stated by the manufacturer?

$$s_{\text{ISO-GNSS RTK }xy} \leq \sigma_{xy}\sqrt{\frac{\chi^2_{0,95}(\nu_x + \nu_y)}{\nu_x + \nu_y}} \qquad \chi^2_{0,95}(56) = 74,47$$

$s_{\text{ISO-GNSS RTK }xy} = s_{xy} ?\, 1,15$

- Is the calculated $s_{\text{ISO-GNSS RTK }h}$ smaller or equal than the value s_h stated by the manufacturer?

$s_{\text{ISO-GNSS RTK }h} = s_h ?\, 1,22$

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Step 3: Statistical tests

- In the case of two samples, the Fisher test indicates whether two experimental standard deviations e.g. $s_{\text{ISO-GNSS RTK xy}}$ and $\bar{s}_{\text{ISO-GNSS RTK xy}}$ belong to the same population?

$$\frac{1}{F_{1-\frac{\alpha}{2}(\tilde{\nu}_x+\tilde{\nu}_y+\nu_x+\nu_y)}} \leq \frac{s^2_{\text{ISO GNSS RTK-xy}}}{\bar{s}^2_{\text{ISO GNSS RTK-xy}}} \leq F_{1-\frac{\alpha}{2}(\tilde{\nu}_x+\tilde{\nu}_y+\nu_x+\nu_y)} \qquad F_{0,975}(56,56)=1,70$$

$$0,59 \leq \frac{s^2_{\text{ISO GNSS RTK-xy}}}{\bar{s}^2_{\text{ISO GNSS RTK-xy}}} \leq 1,70$$

$$0,47 \leq \frac{s^2_{\text{ISO GNSS RTK-h}}}{\bar{s}^2_{\text{ISO GNSS RTK-h}}} \leq 2,13$$

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We can state:

- measure of precision of equipment under given conditions (short term and long term influences)

  ð statistical test: chi²

- measure of precision of equipment used in different periods of time under different conditions (multiple samples, same equipment)

  ð statistical test: Fisher

- measure of the capability of comparison between different precision of equipment achievable under similar conditions (different equipment)

  ð statistical test Fisher

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Questions to be discussed

- Time need of 3 ... 4 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 experimental standard deviation strong enough for characterizing “quality “ of the investigated measuring equipment?

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Additional proposals for checking GNSS systems

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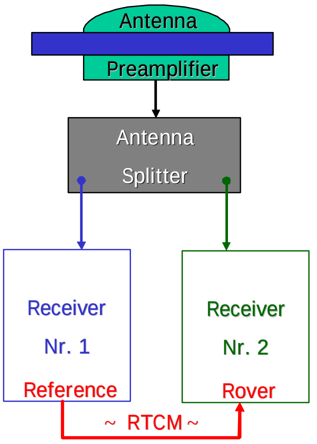
Check of Instrumental Components

Zero – Baseline - Test



Compensated errors / influences

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

Remaining errors / influences

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

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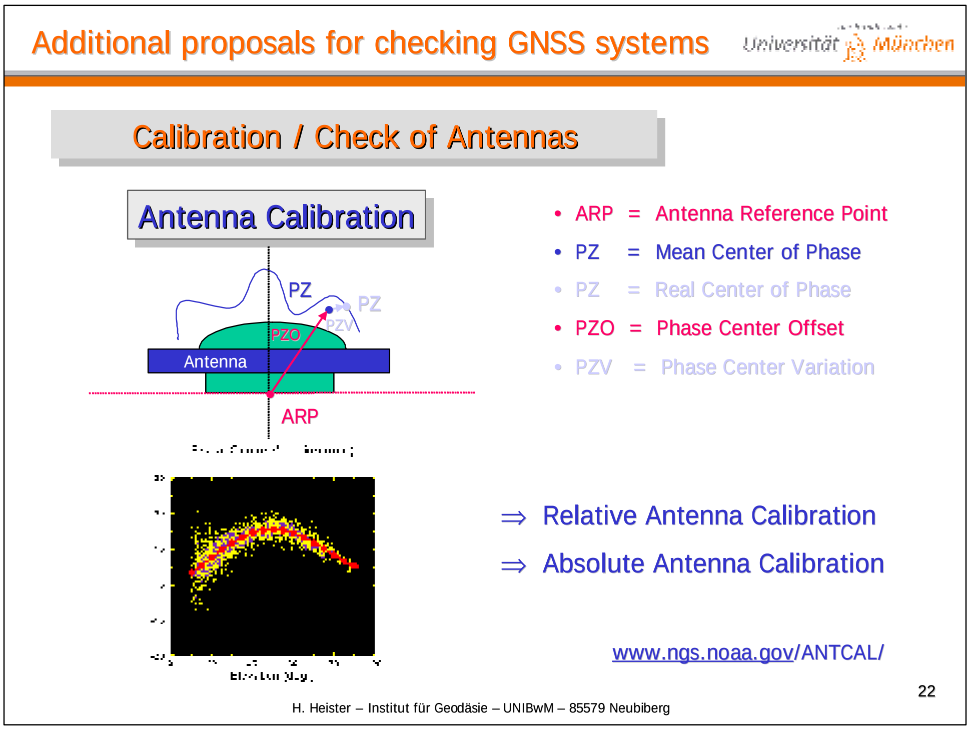

Additional proposals for checking GNSS systems
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Calibration / Check of Antennas
Antenna Calibration
PZ
PZ
PZO
PZV
Antenna
ARP
• ARP = Antenna Reference Point
• PZ = Mean Center of Phase
• PZ = Real Center of Phase
• PZO = Phase Center Offset
• PZV = Phase Center Variation
⇒ Relative Antenna Calibration
⇒ Absolute Antenna Calibration
www.ngs.noaa.gov/ANTCAL/
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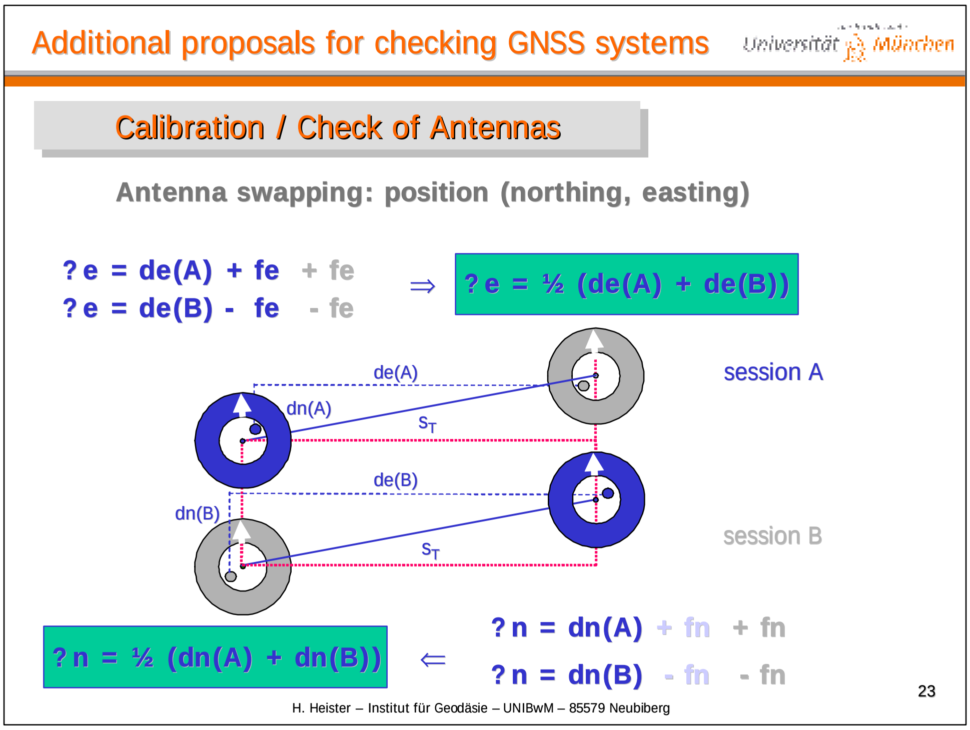

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Calibration / Check of Antennas
Antenna swapping: position (northing, easting)
? e = de(A) + fe + fe
? e = de(B) - fe - fe
⇒ ? e = ½ (de(A) + de(B))
de(A)
dn(A)
sT
session A
de(B)
dn(B)
sT
session B
? n = ½ (dn(A) + dn(B))
⇐
? n = dn(A) + fn + fn
? n = dn(B) - fn - fn
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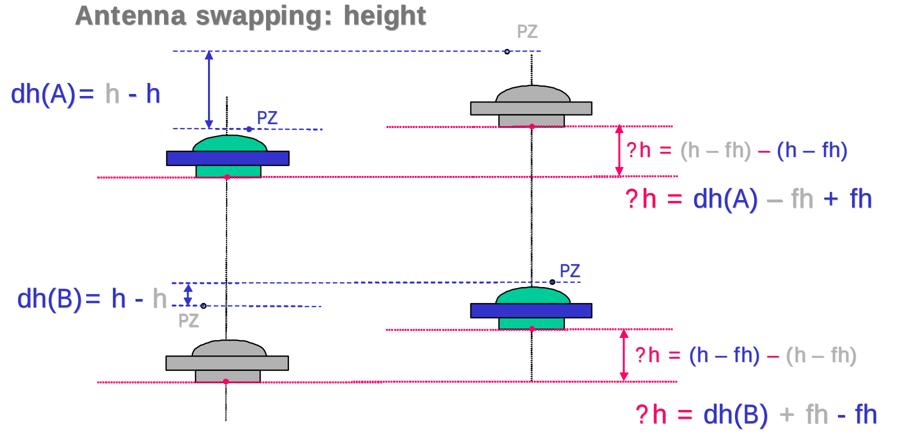
Calibration / Check of Antennas

Antenna swapping: height



?h = ½ (dh(A) + dh(B))

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Additional proposals for checking GNSS systems

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GPS test procedure of the legal survey (Germany

Basic principle: Check of GPS software *and* hardware

- Ø Checking GPS software
  - Test data set in RINEX format
  - \- Given reference stations
  - \- Consideration of phase center offsets
  - \- Fixed evaluation procedures
- Ø Checking Hardware
  - Defined Measurement set up
  - \- Selected legal stations of the reference network
  - \- Fixed evaluation procedures
  - \- Compilation of differences, given thresholds for position, height

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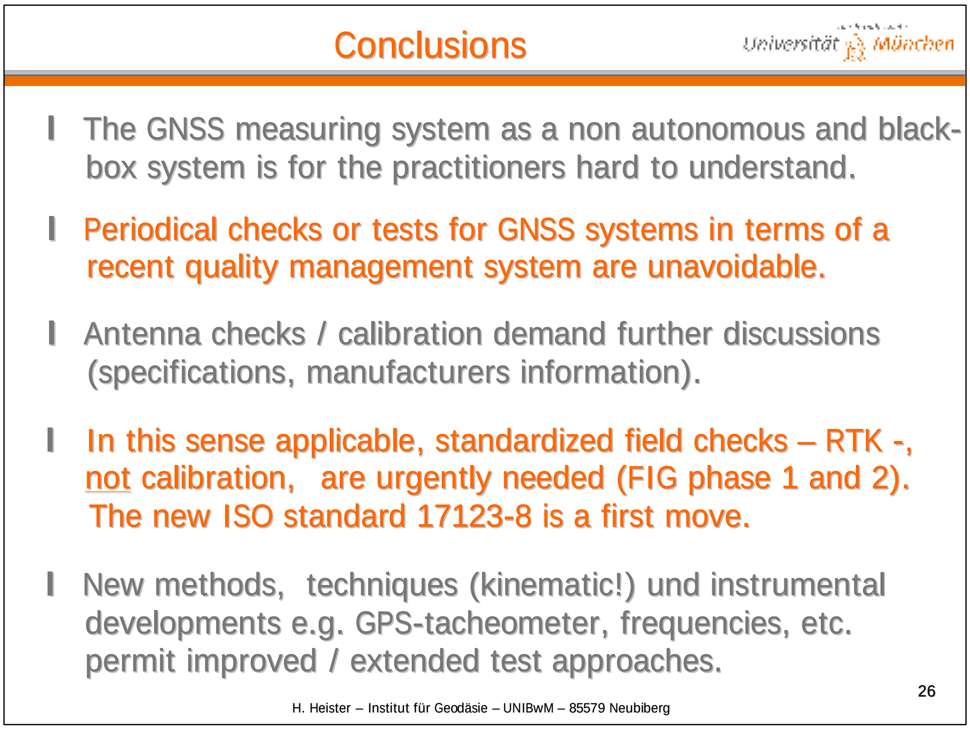

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BIOGRAPHICAL NOTES

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