On GNSS In-Situ Station Calibration of Near-Field Multipath

Gerhard Wübbena, Martin Schmitz, Norbert Matzke

Geo++® GmbH
30827 Garbsen
Germany
www.geopp.com

Overview

- Motivation
- Near-Field Multipath
  - Cause and Impact
  - Robot Calibration
- Station Dependent Errors
  - Separation of Near-Field and Far-Field Multipath
  - Different Treatments
- In-Situ Station Calibration
  - Basic Principle, Near-Field Free Station
  - Experiment Setup, Analysis
  - Determing and Applying In-Situ Station Correction/Weighting
- Summary/Outlook

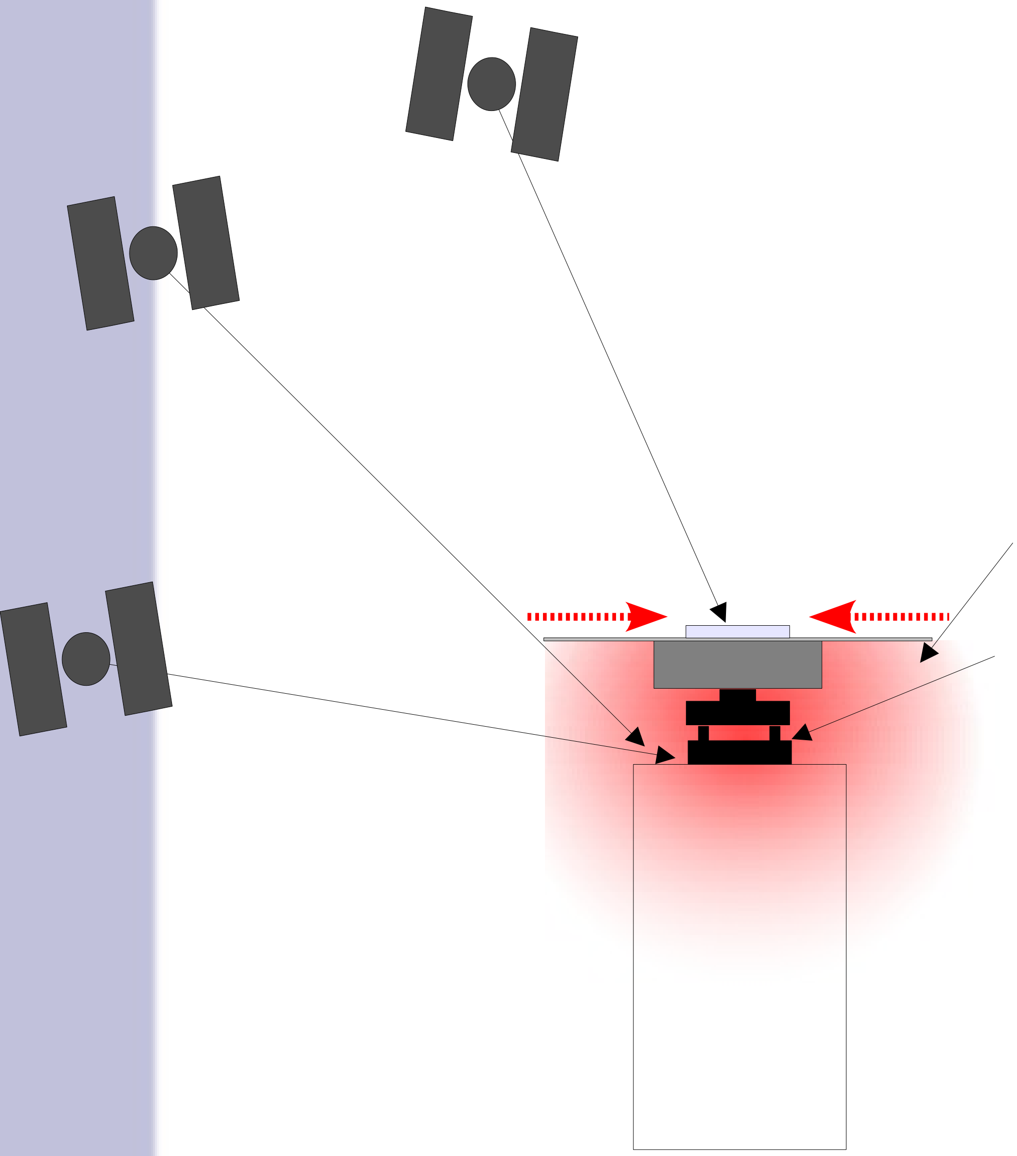
Motivation

- **near-field issue** increasingly of importance and interest in GNSS applications
- **more and more problems** due to near-field issue, therefore
  - investigations are necessary
  - strategies for determination are required
  - approaches for handling are required
- goal is **improvement of accuracy and reliability of GNSS applications** for
  - permanent reference stations
  - height determination using GNSS methods
  - in-situ calibration of kinematic platforms
  - ...

Motivation

- first **theoretical** discussion of near-field effects in **1995**
- **experimental** verification of near-field effects by **Geo++ in 2003**
- numerous experiences regarding near-field issues from
  - antenna calibration with robot
  - RTK Networks
  - coordinate changes after antenna change
  - attitude determination with GNSS
  - ...

Near-Field Multipath: Cause

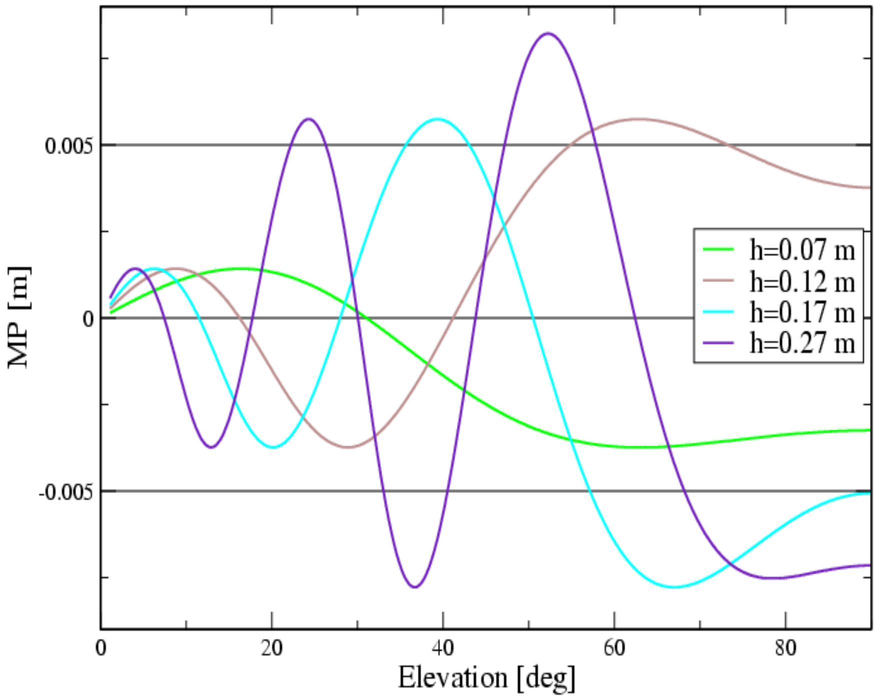


- antenna near-field depends on
  - antenna type
    (plus radome construction, ...)
  - mount/setup
    (tripod, tribrach, adaption, ...)
  - station environment
    (pillar, roof, ...)
  - weather conditions
    (reflecting coefficient, snow, ...)
- effect on signals due to
  - diffraction
  - reflection
  - imaging?
  - electro-magnetic inter-action?

Near-Field Multipath: Theoretical Impact

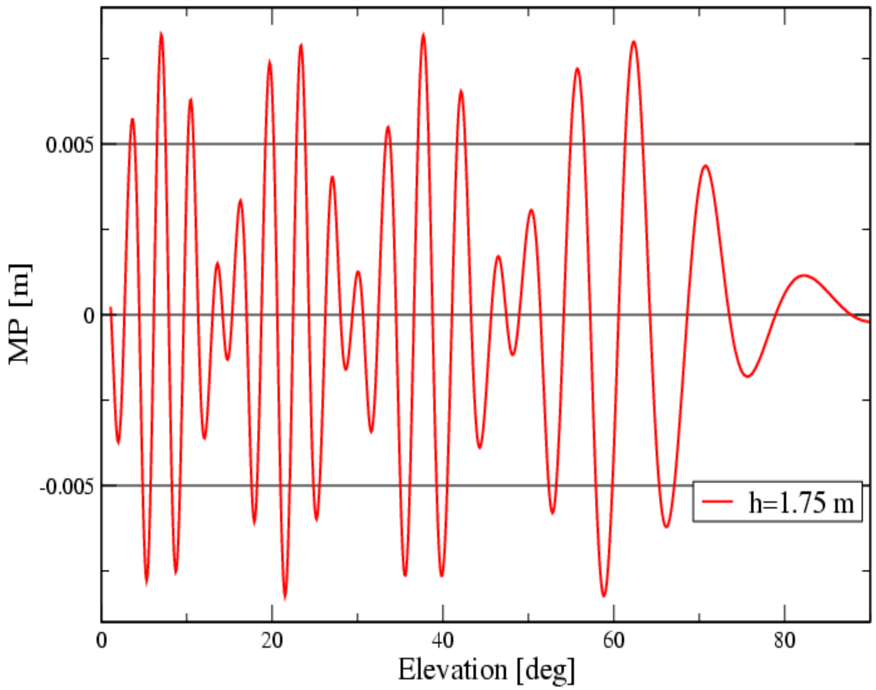
model assumption: horizontal reflector

- pillar/pier setup



- low frequencies
- effect in high elevations
- systematic influence and elevation dependency

- tripod setup



- high frequencies
- „comparable magnitude" over elevations
- effect expected to be „smaller"

Near-Field Multipath: Impact

- characteristics $MP_{near\text{-}field}$
  - constant geometry antenna/near-field
  - **average** of near-field effects is **not zero**
  - **no reduction** through long observation time
  - systematic error in coordinates
  - **amplification in position domain**
  - dependency of near-field effects on
    - linear combination (ionospheric free linear combination)
    - tropospheric modeling
    - satellite constellation
    - elevation mask
  - influence on positioning is time dependent (satellite constellation, ...)

MP multipath

Near-Field Multipath: Robot Calibration

- determination with precise robot calibration
  - standard deviation 0.2 bis 0.4 mm
  - repeatability 1 mm, except close to horizon
- representative near-field environment required
- constant geometric relation antenna/near-field despite movements of antenna
- calibration provides
  PCV + $MP_{near\text{-}field}$
- separation obtained through difference of calibration with/without near-field environment and antenna

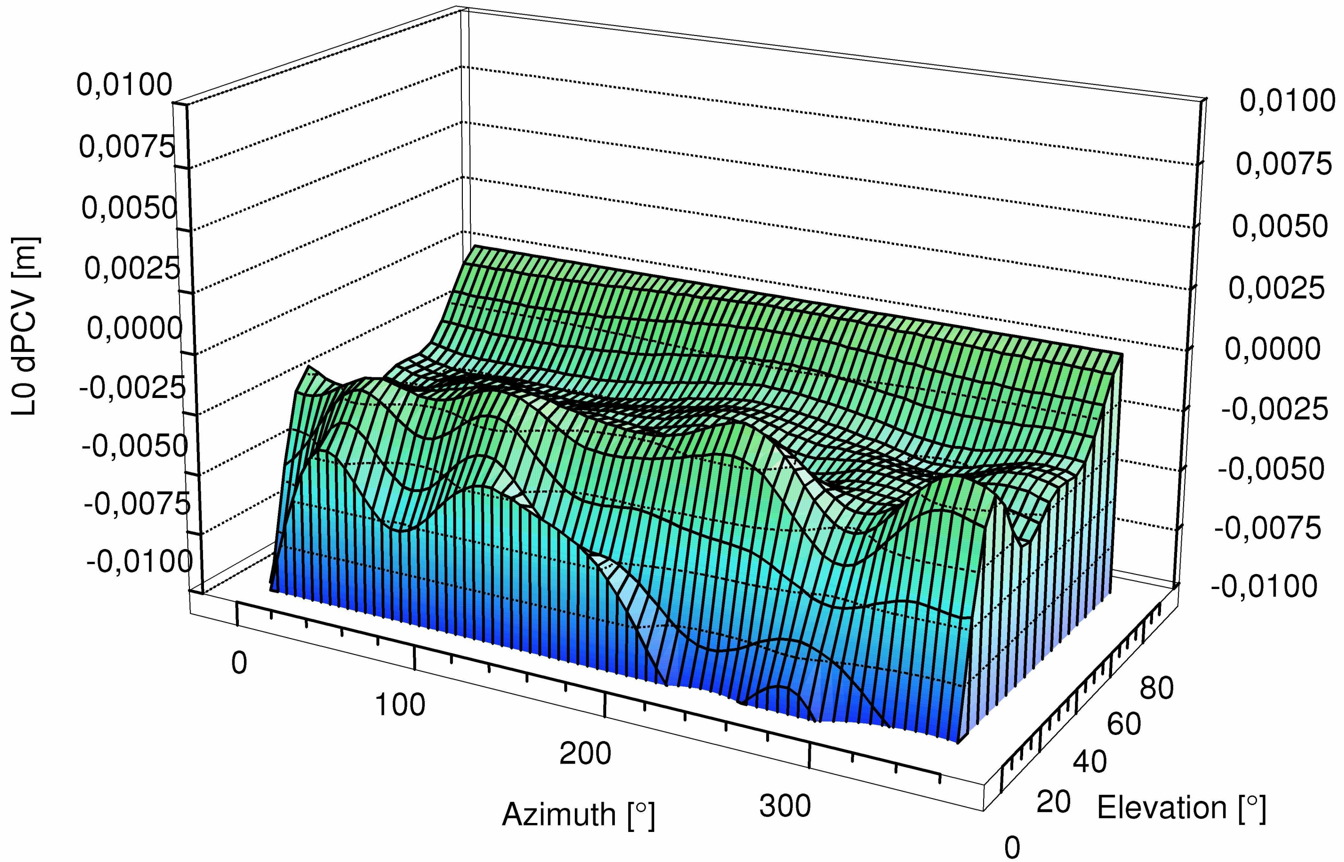
PCV phase center offsets and variations
MP multipath

Near-Field Multipath: eg Impact on DM-Type Chokering Antenna

- ASH700936D_M
- reconstruction head of pillar/tribrach
- ∅ 19cm/Δ Zeiss
- difference L0 PCV against regular calibration
  - 10-30° elevation

    mean ca. 2 mm
    maximum 7 mm
  - 40-70° elevation

    mean ca. 2 mm
    maximum 3 mm
  - impact in range domain!



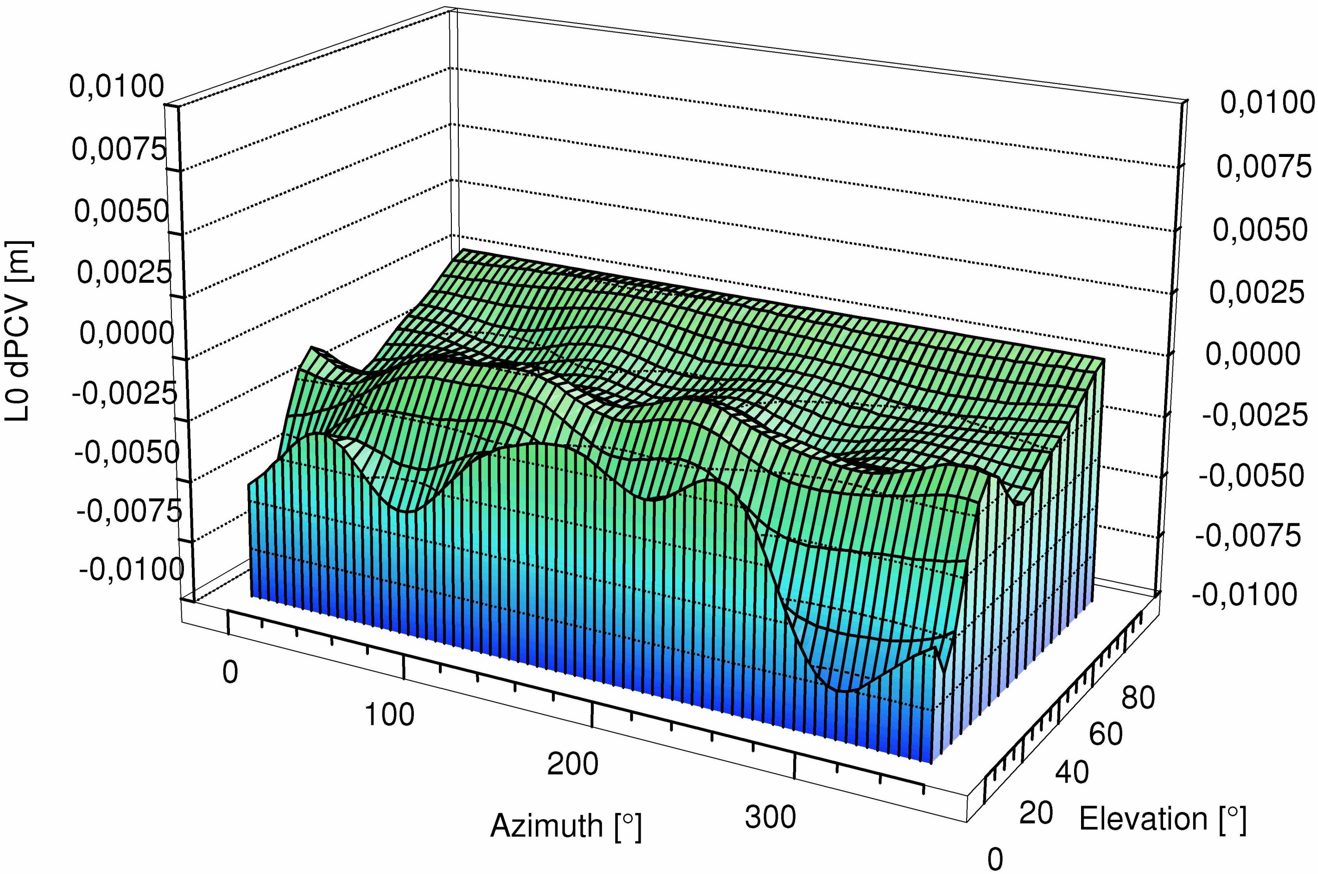
L0 ionospheric free linear combination

Near-Field Multipath:
eg Impact on DM-Type Chokering Antenna

- ASH700936D_M
- reconstruction head of pillar/tribrach
- 30x30 cm/∆ Zeiss
- difference L0 PCV against regular calibration
  - 10-30° elevation

    mean ca. 2 mm
    maximum 6 mm
  - 40-70° elevation

    mean ca. 4 mm
    maximum 5 mm
  - impact in range domain!



Station Dependent Errors

- Geo++ philosophy: separation of individual error components
- PCV and multipath are most important station dependent errors

  dS = PCV + MP

  - PCV => absolute GNSS antenna calibration
  - multipath => ?

- Strategy: separation of near-field and far-field multipath

  $dS = PCV + \mathbf{MP}_{near\text{-}field} + \mathbf{MP}_{far\text{-}field}$

- but, complexity demands for

  In-Situ Station Calibration

Station Dependent Errors: Different Treatments

	Error	*Characteristic*	*Treatment*
Antenna	PCV	elevation and azimuth dependent PCV	calibration of PCV using robot
Multipath	$MP_{near\text{-}field}$	long-periodic, systematic effect, bias	calibration of near-field effects using robot/ in-situ station calibration
	$MP_{far\text{-}field}$	short-periodic, systematic effect	averaging over time, absolute station calibration or weighting (CN0)
Station Uncertainty		stable unterground, setup, monumentation	analysis of time series

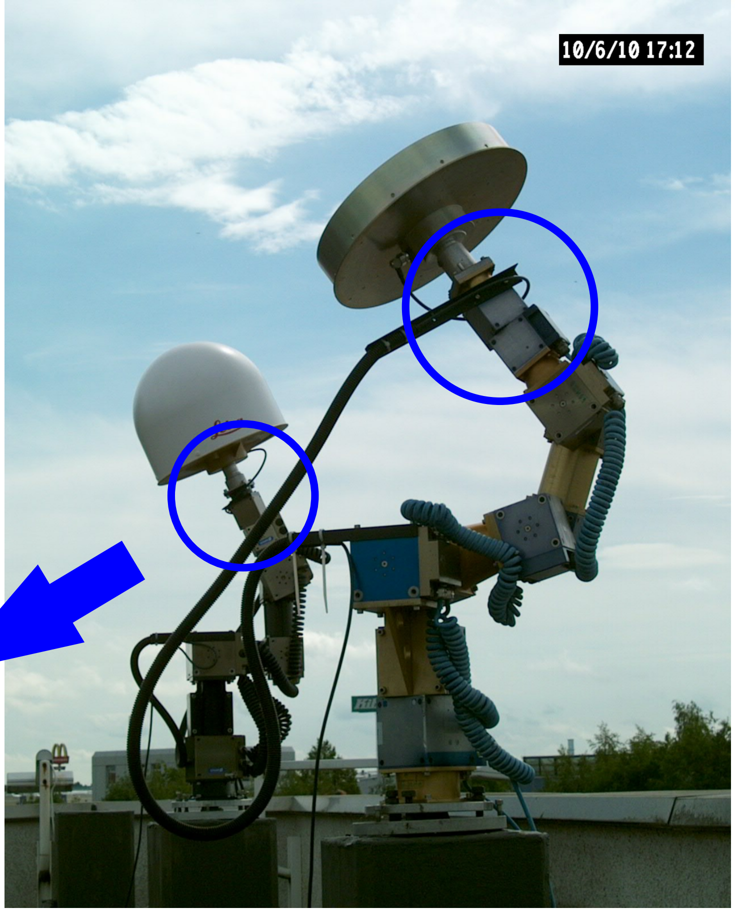
CN0 carrier-to-noise

In-Situ Station Calibration: Basic Principle

- Geo++ In-Situ Calibration Approach
- combination of methods
  - robot calibration gives calibrated, **near-field free GNSS equipment**
  - **in-situ GNSS observation** to account for site dependencies
- goal for a GNSS reference station is
  - analysis of $MP_{\text{near-field}}$
  - determination of $MP_{\text{near-field}}$
  - for GNSS application derive $\mathbf{MP_{\text{near-field}}}$
    - **correction**
    - **weighting**
    - or both

In-Situ Calibration: Near-Field Free Station

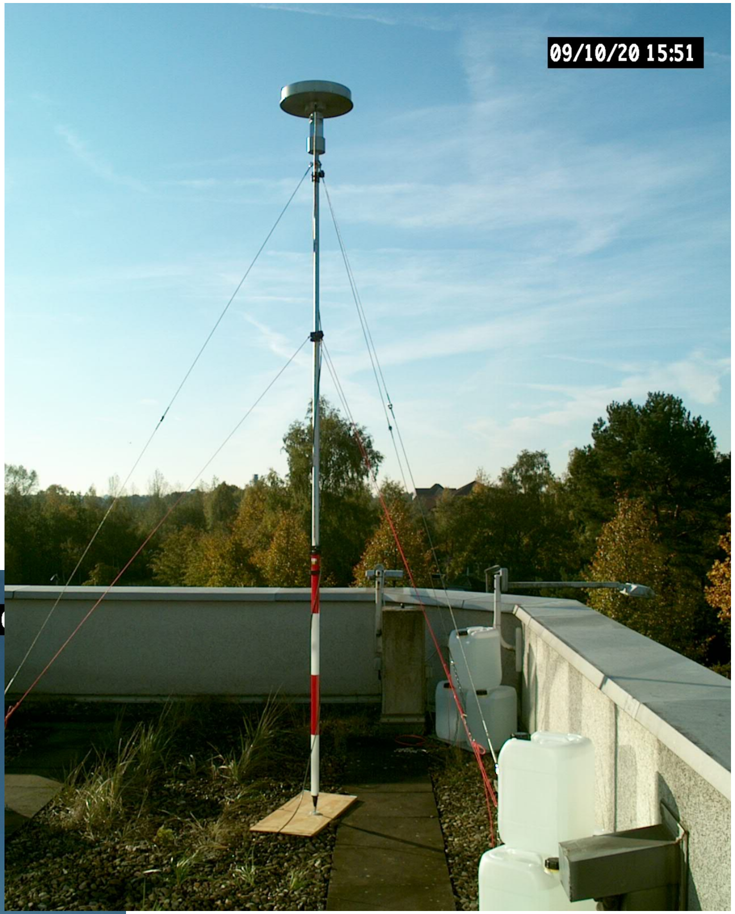
- individual absolute GNSS antenna calibration
- optimal control of near-field effect required
  - mock-up of top robot and mount
  - best approximation of all errors (near-field and PCV of antenna)



top of robot with mount

In-Situ Calibration: Near-Field Free Station

- mock-up of antenna's robot calibration
  - no near-field multipath
- high and slight setup on a pole (~ 3 m)
  - reducing far-field multipath
- short distances
  - no impact from atmospheric or orbit errors
- setup and system design
  - transportable
  - flexible
  - scalable
  - easy to use
  - ...



In-Situ Station Calibration: Setup

- near-field free stations
- redundant setup with three stations (or more)
- stations must cover GNSS visibility of reference stations
- sophisticated GNSS receivers with optional coupled clock

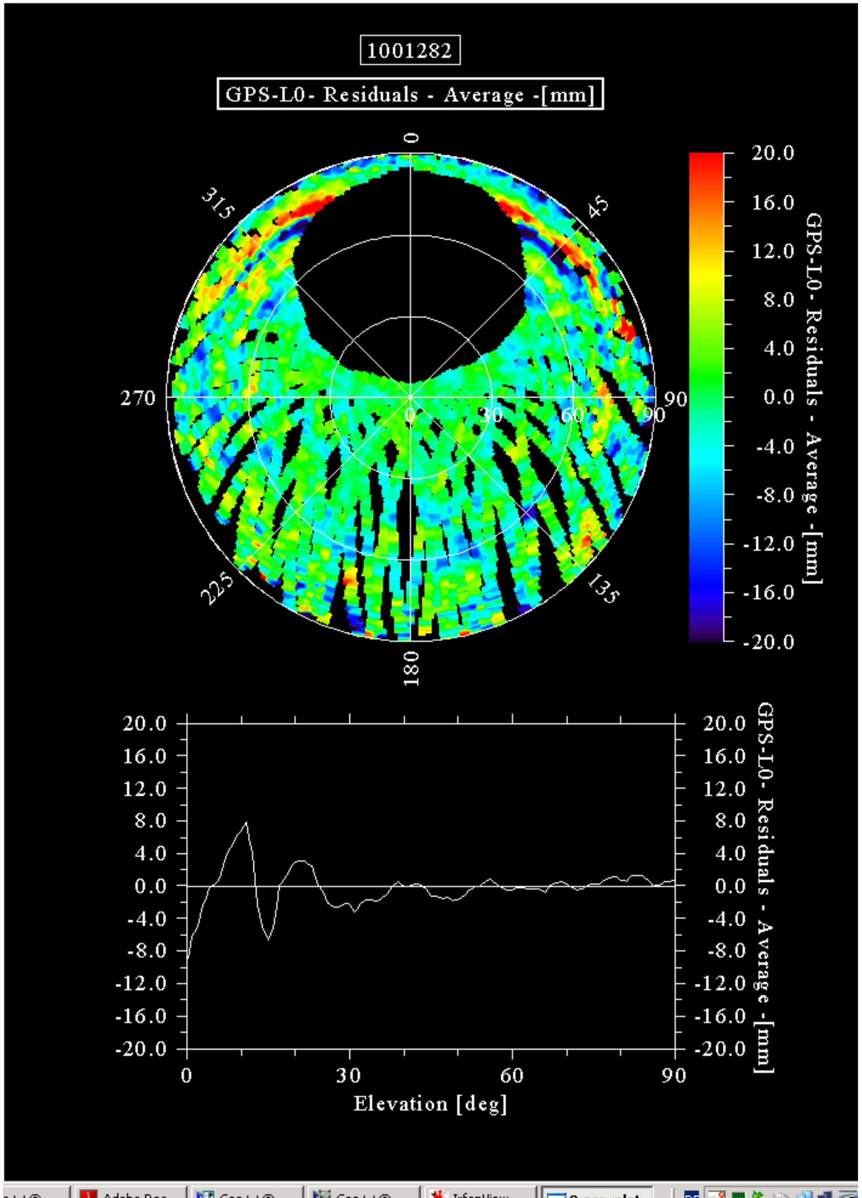
In-Situ Calibration: Setup

- reference stations to be calibrated
- original receiver substituted through in-situ calibration system receiver using antenna splitter
- optional coupled clock
- 1 Hz data rate
- 0° cut-off
- at least 24 h data

In-Situ Calibration: Experiment: Reference Stations

- experiment on Geo++ roof
- reference station on roof top (1000/1001)
  - close objects
  - flat reflectors
  - remote reflectors
- reference station on pillar (0007)
  - standard setup
  - pillar top is reflector
  - remote reflectors

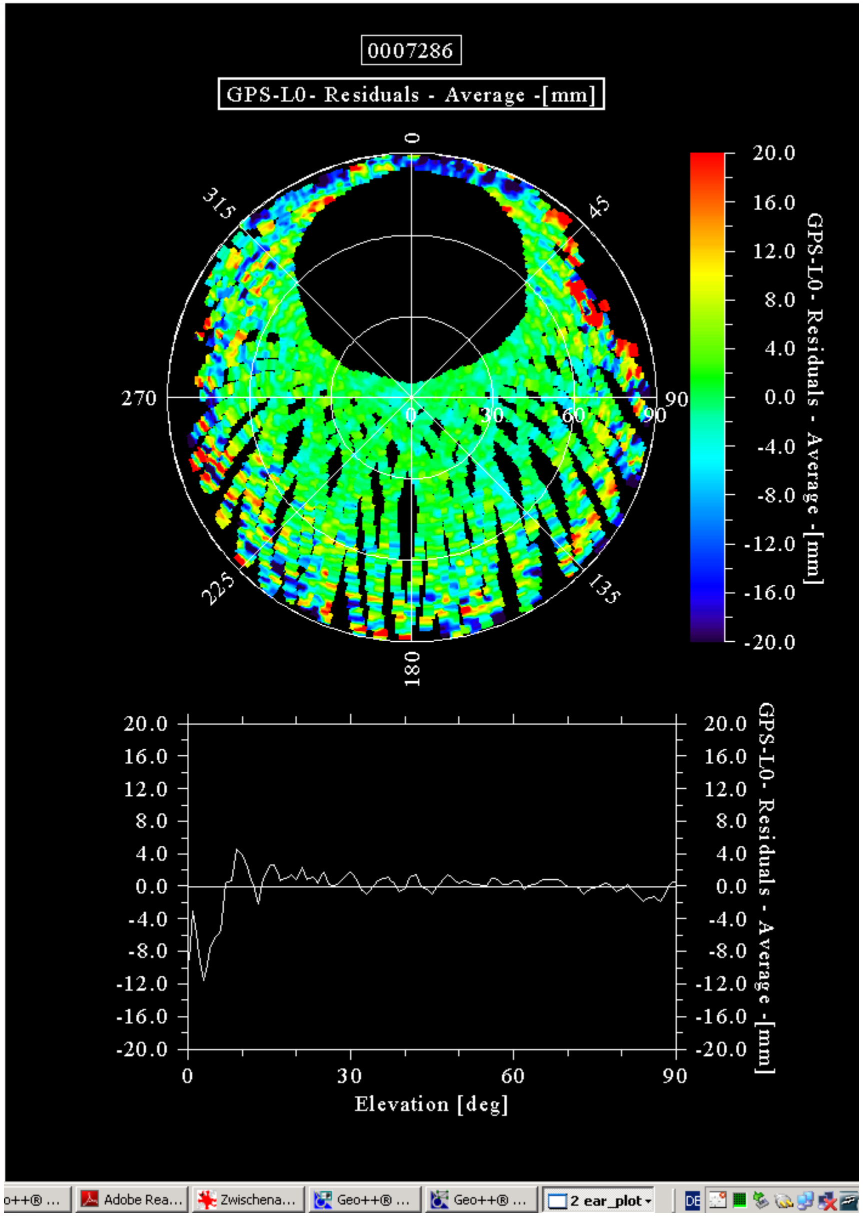
In-Situ Calibration: Residual Analysis



- 24h doy 282-283, 2009 reference station (roof top, 1000/1001)
- GPS L0 residuals shown
- basically no obstructions
- prominent band in N (280°-80°) up to ~10°-15° elevation
- up to 4 cm residual changes over small elevation range

In-Situ Calibration: Residual Analysis

N



- 24h doy 286-287, 2009 reference station (pillar, 0007)
- GPS L0 residuals shown
- obstructions in W (building) and NE (45°-90°, tree)
- alternating pattern reaching 30° elevation over complete azimuth range
- up to 2 ... 4 cm over small elevation range

In-Situ Station Calibration: Residual Analysis

- residual analysis for reference station
- input GNSS data is
  - original **phase** observable
    (not limited to ionospheric free signal L0)
  - original **code** observable
  - carrier-to-noise observable (**CN0**)
  - GPS and GLONASS, all future signals and GNSS systems
- residuals f (azimuth, elevation)
- sophisticated analysis software derives
  - **corrections** of **observable**
  - **weighting** scheme for **observable**
  - depending on azimuth and elevation
  - iterative approach possible

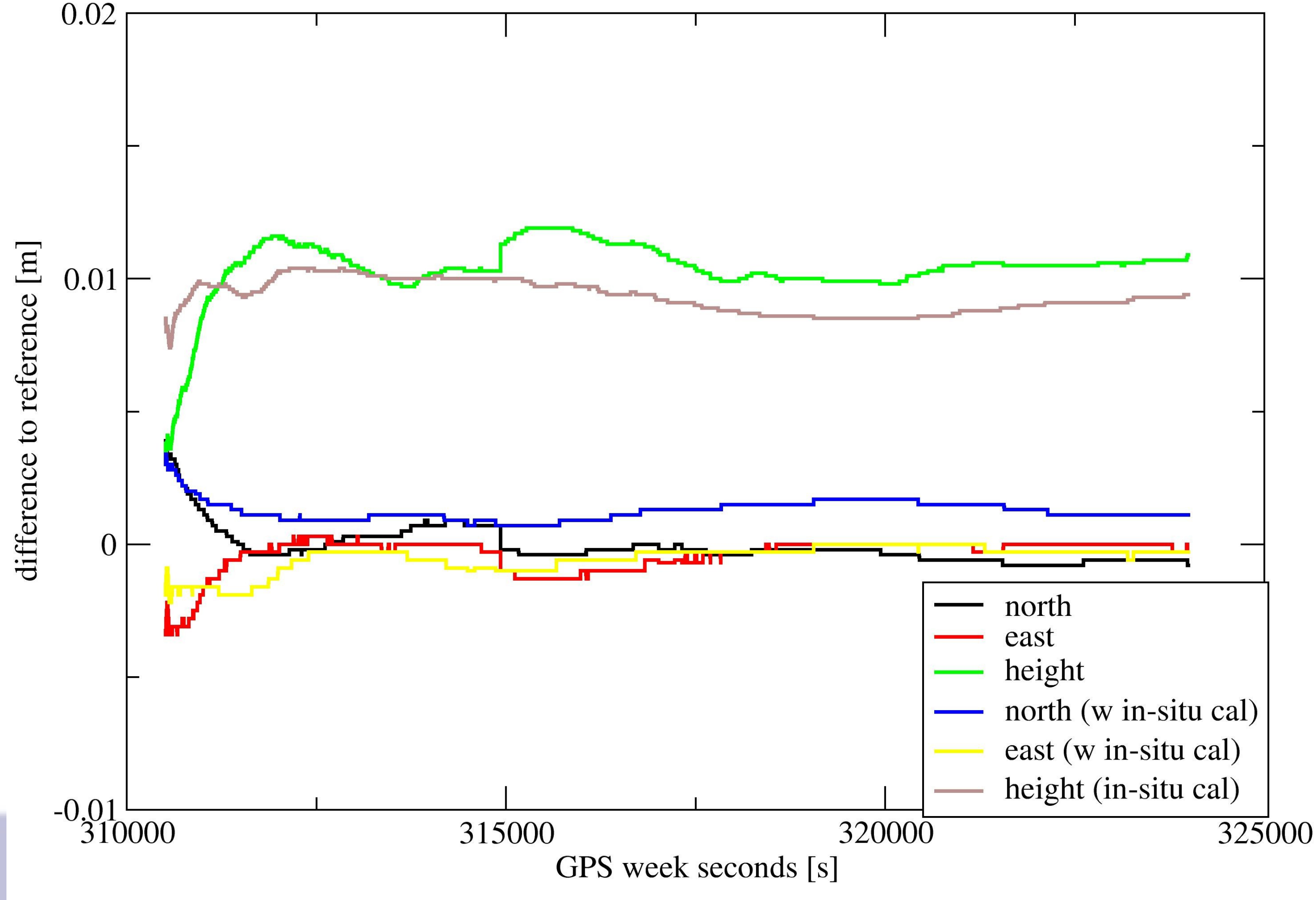
In-Situ Calibration: Applying Correction/Weighting

- different data set used
- applying correction/weighting in GPS processing
  - doy 287, 2009
    (different time period compared to in-situ station calibration data)
  - **static baseline** processing
    (between calibrated station 1000-0007)
  - arbitrary 4 h data set
  - 1 Hz data rate, 5° cut-off angle
  - **ionospheric free linear combination** L0
  - ionospheric free linear combination L0
    with troposphere estimation

in-situ station calibration of reference station
- 24h doy 282-283, 2009 (roof top, 1000/1001)
- 24h doy 286-287, 2009 (pillar, 0007)

In-Situ Calibration: Applying Correction/Weighting

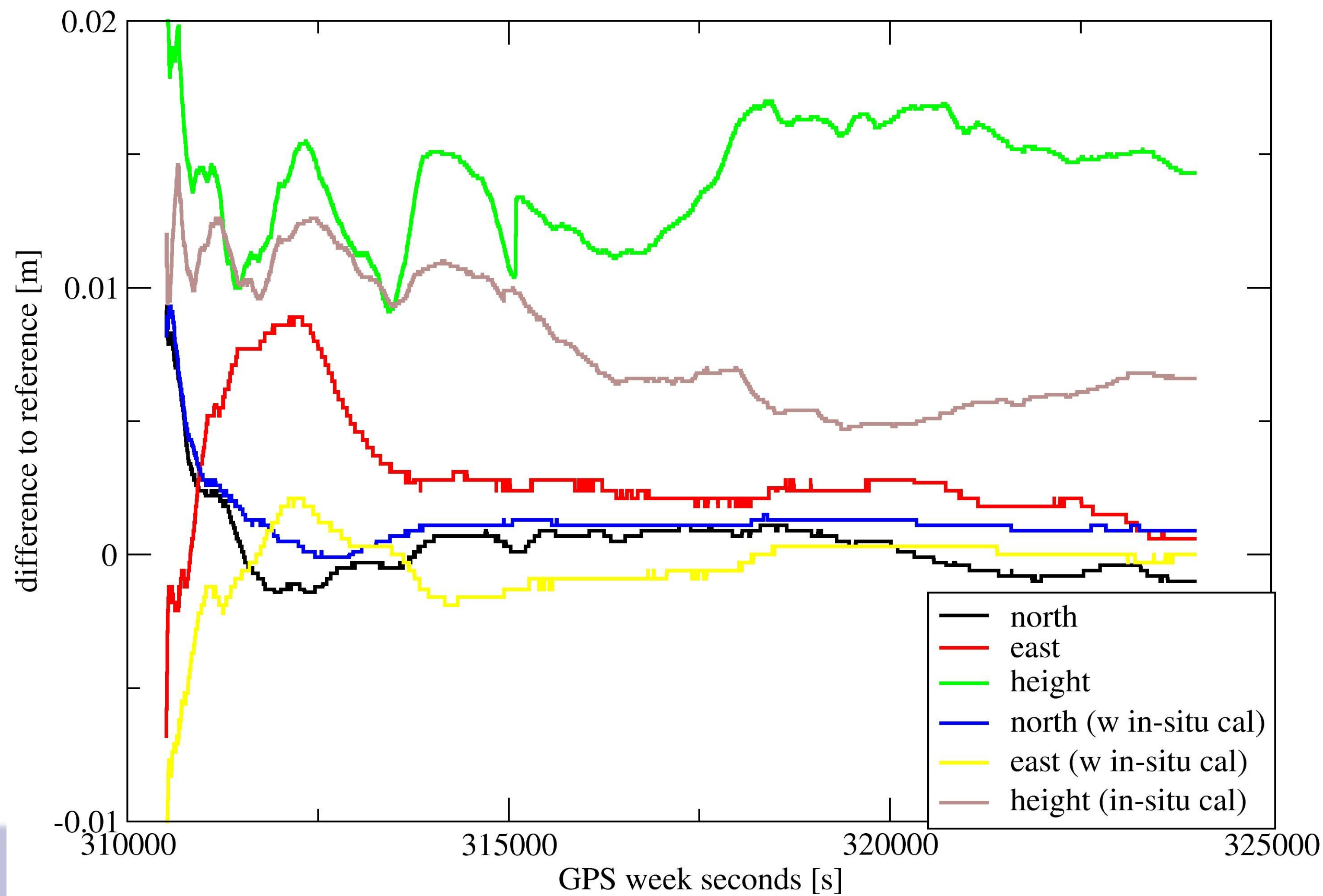
- static GPS **L0 processing**
- **standard** approach and **with in-situ correction/weighting** applied
- difference to reference coordinates (horizontal GNSS, leveled height*)



* to be checked!

In-Situ Calibration: Applying Correction/Weighting

- static GPS **L0 processing with troposphere estimation**
- **standard** approach and **with in-situ correction/weighting** applied
- difference to reference coordinates (horizontal GNSS, leveled height*)



* to be checked!

In-Situ Station Calibration: Results

- obvious systematic errors through $MP_{near\text{-}field}$
  - residual analysis
- **applying correction/weighting** from in-situ station calibration
  - small coordinate changes in plane coordinates (2 … 3 mm)
  - **changes in height** component (up to 1 cm)
  - **improvement** in **coordinates**
    and also **performance** (jumps)
- further analysis
  - actual reference stations/RTK networking
  - absolute height (comparison with leveling)
  - coupled clock
  - GLONASS correction/weighting
  - ...

Summary/Outlook

- **$MP_{near\text{-}field}$** impact has significant importance
- **in-situ station calibration** has been developed
  - combined approach using
    - calibrated, near-field free equipment
    - in-situ GNSS observations within short distances
  - **correction/weighting of $MP_{near\text{-}field}$** derived
- very promising results from applying correction/weighting
- further analysis and assessment of in-situ station calibration to determine $MP_{near\text{-}field}$ are necessary
- will be further developed into a complete in-situ station calibration equipment and analysis software

IGS Warning

BRFT

Thank You

for mounting your antennas away from reflecting surfaces!

from: Ray, J. (2008). Systematic Errors in GPS Position Estimates. IGS Workshop, May 11, Darmstadt, Germany.

thank you for your attention

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An Almost Philosophical Question ...

- obviously there are systematic errors through $MP_{near\text{-}field}$

Is it possible to determine GNSS heights without any systematic error?

- no, without considering $MP_{near\text{-}field}$
- yes, with taking $MP_{near\text{-}field}$ into account
  - with absolute $MP_{near\text{-}field}$ correction heights are free of systematic errors
- recommendation
  - analysis and assessment of additional strategies
  - avoiding $MP_{near\text{-}field}$