Separation of Near-Field and Far-Field Multipath: New Strategies for Station Calibration

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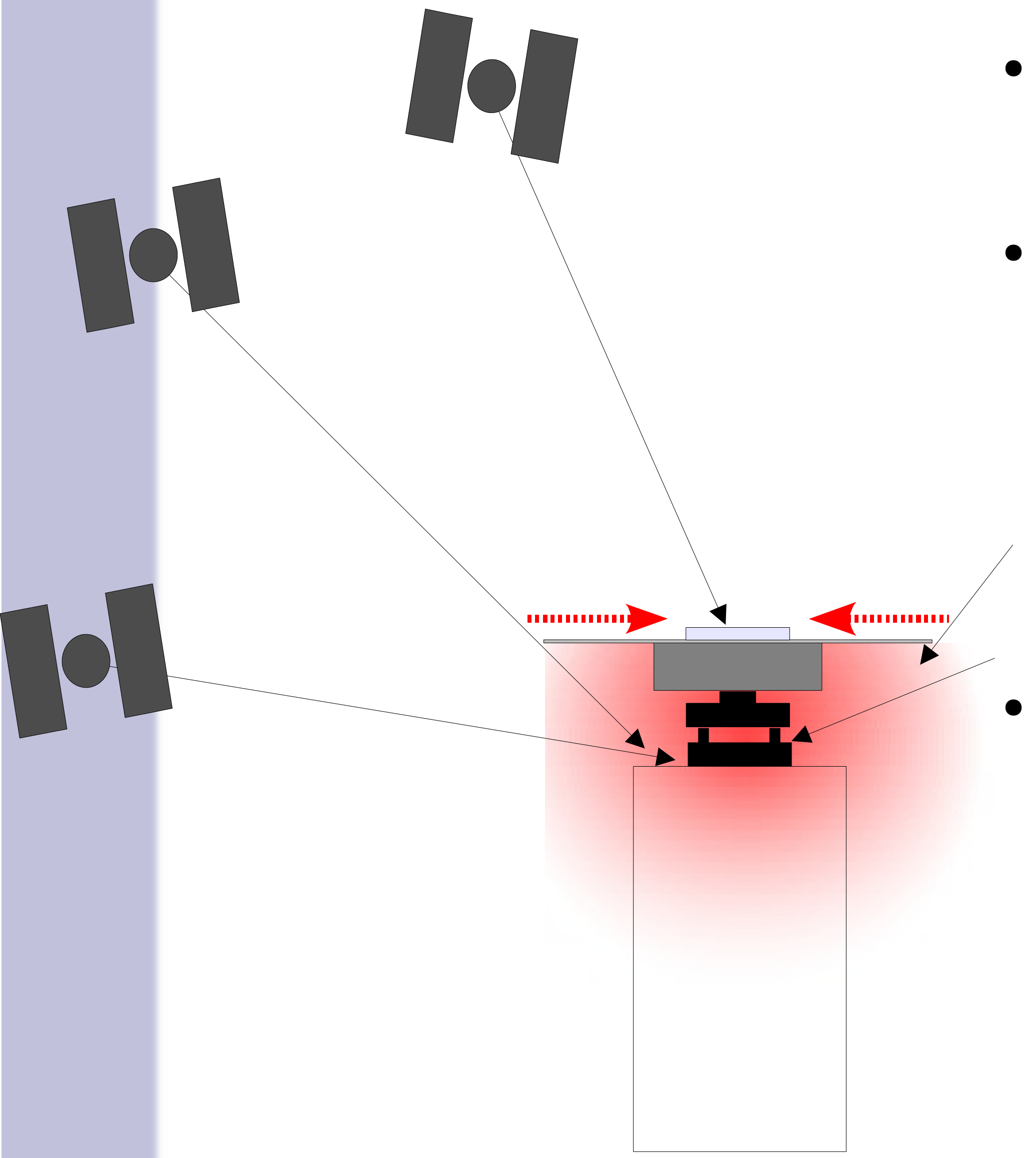
Overview

- Motivation
- Cause and Impact of Near-Field Multipath
- Calibration of Near-Field Multipath
- Real Life Example from RTK Networking
- Separation of Near-Field and Far-Field Multipath
- Determining Near-Field Multipath of a Reference Station
- In-situ Calibration of Kinematic Platforms
- Summary/Outlook

Motivation

- near-field issue addressed by Geo++ at Antenna Workshop 2003, Frankfurt
- numerous experiences regarding near-field issue from
  - antenna calibration with robot
  - RTK Networks
  - coordinate changes after antenna change
  - attitude determination with GNSS
- near-field issue increasingly of importance and interest, therefore
  - investigations are necessary
  - new strategies for determination are required
- goal is improvement of accuracy and reliability of GNSS applications
  - permanent reference stations
  - height determination using GNSS methods
  - ...

Cause of Near-Field Multipath

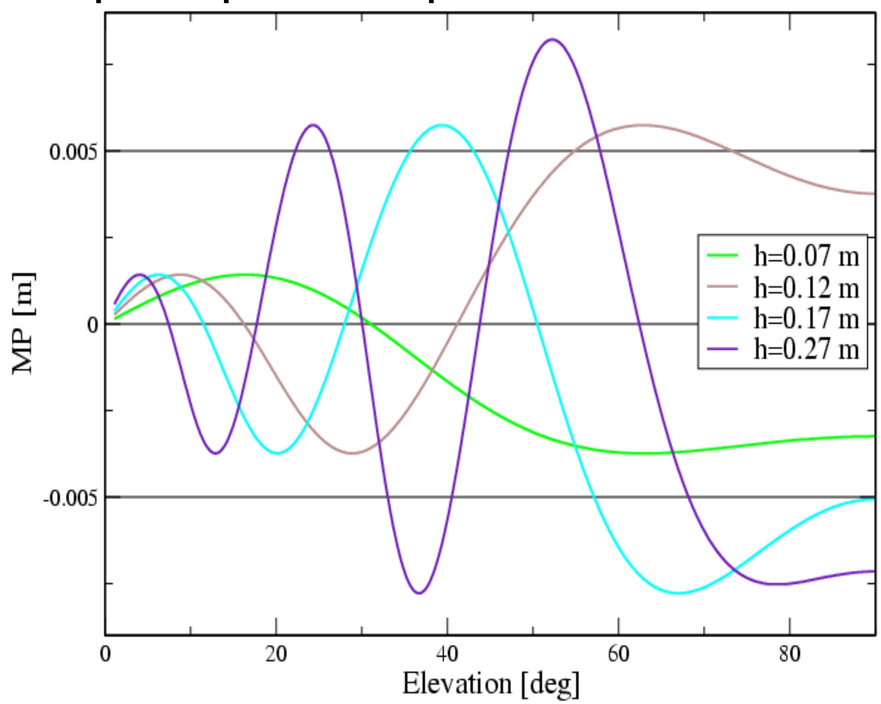


- antenna near-field
  - pillar, tripod, tribrach, adaption, etc.
- effect on signals due to
  - diffraction
  - reflection
  - imaging?
  - electro-magnetic inter-action?
- multipath within near-field
  - constant geometry antenna/near-field
  - systematic effects
  - no averaging over time

Theoretical Multipath Influence

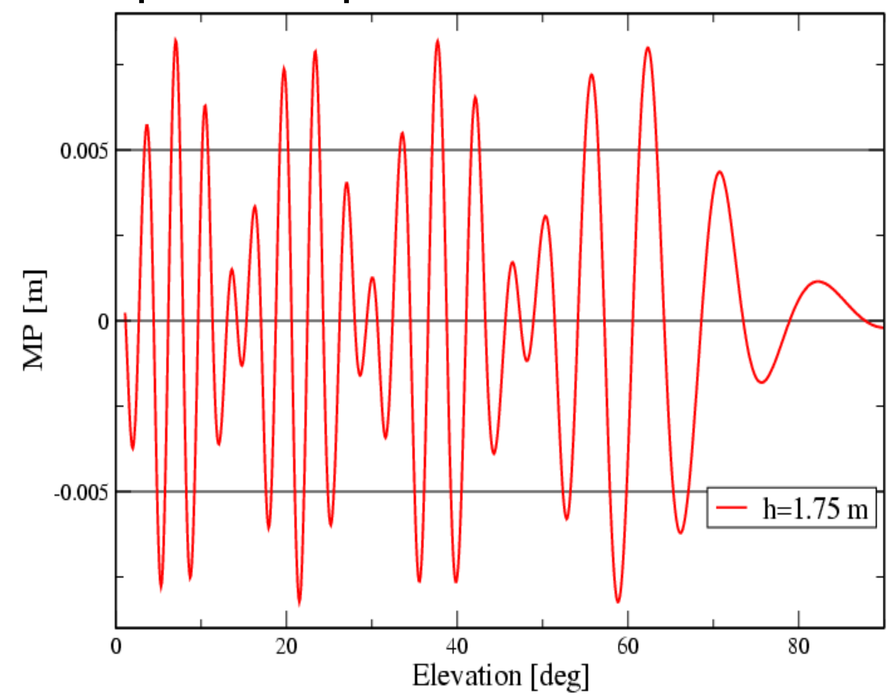
model assumption: horizontal reflector

- 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“

Impact of Near-Field Multipath

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

Calibration of Near-Field Multipath

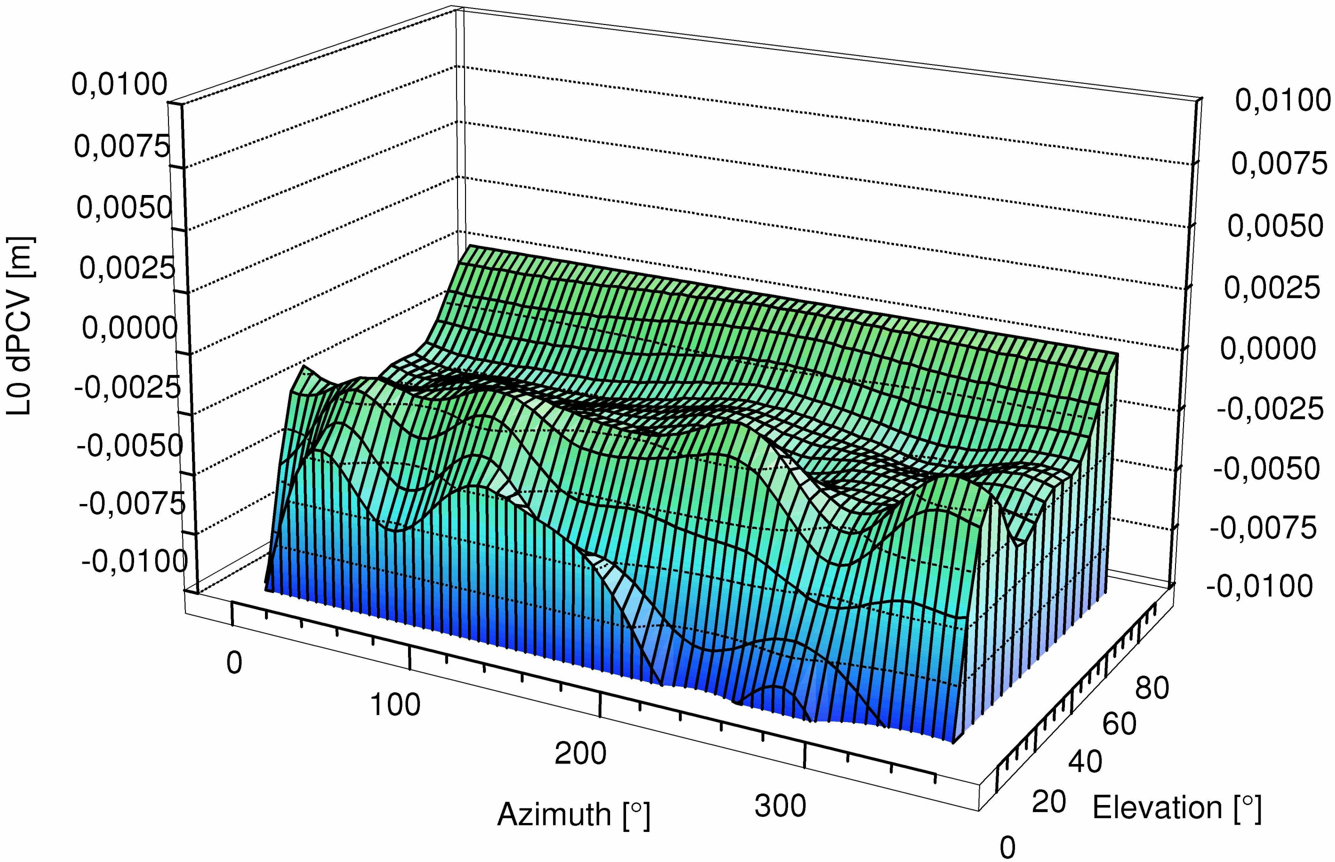
- precise robot calibration
  - standard deviation 0.2 bis 0.4 mm
  - repeatability 1 mm, except close to horizon
- representative near-field environment required
- constant geometric relation antenna/near-field despite movements of antenna
- calibration provides PCV + $MP_{near\text{-}field}$
- separation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

Near-Field-Influence 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

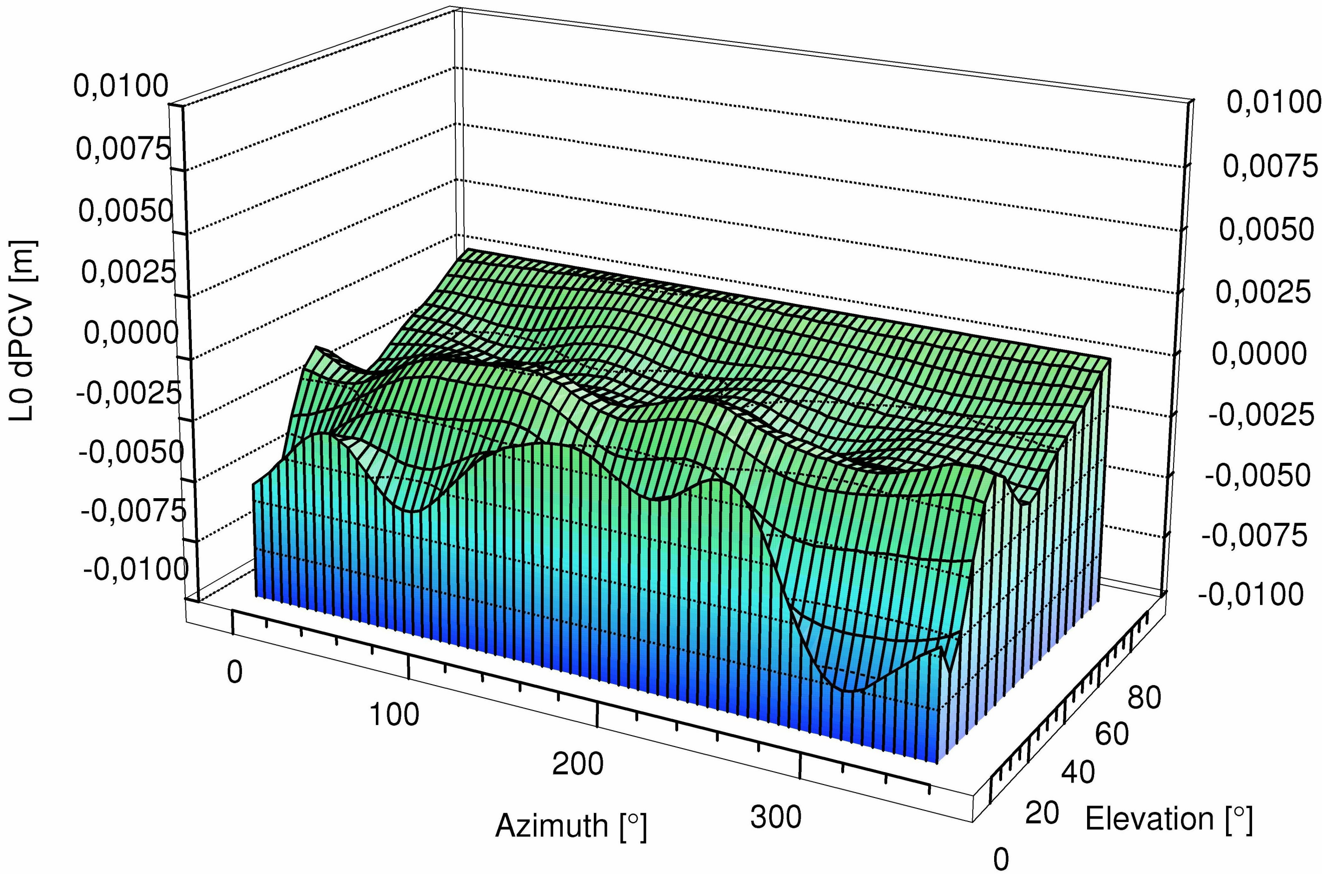


Near-Field-Influence on DM-Type Chokering Antenna

- ASH700936D_M
- reconstruction head of pillar/tribrach
- 30x30 cm/Δ 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

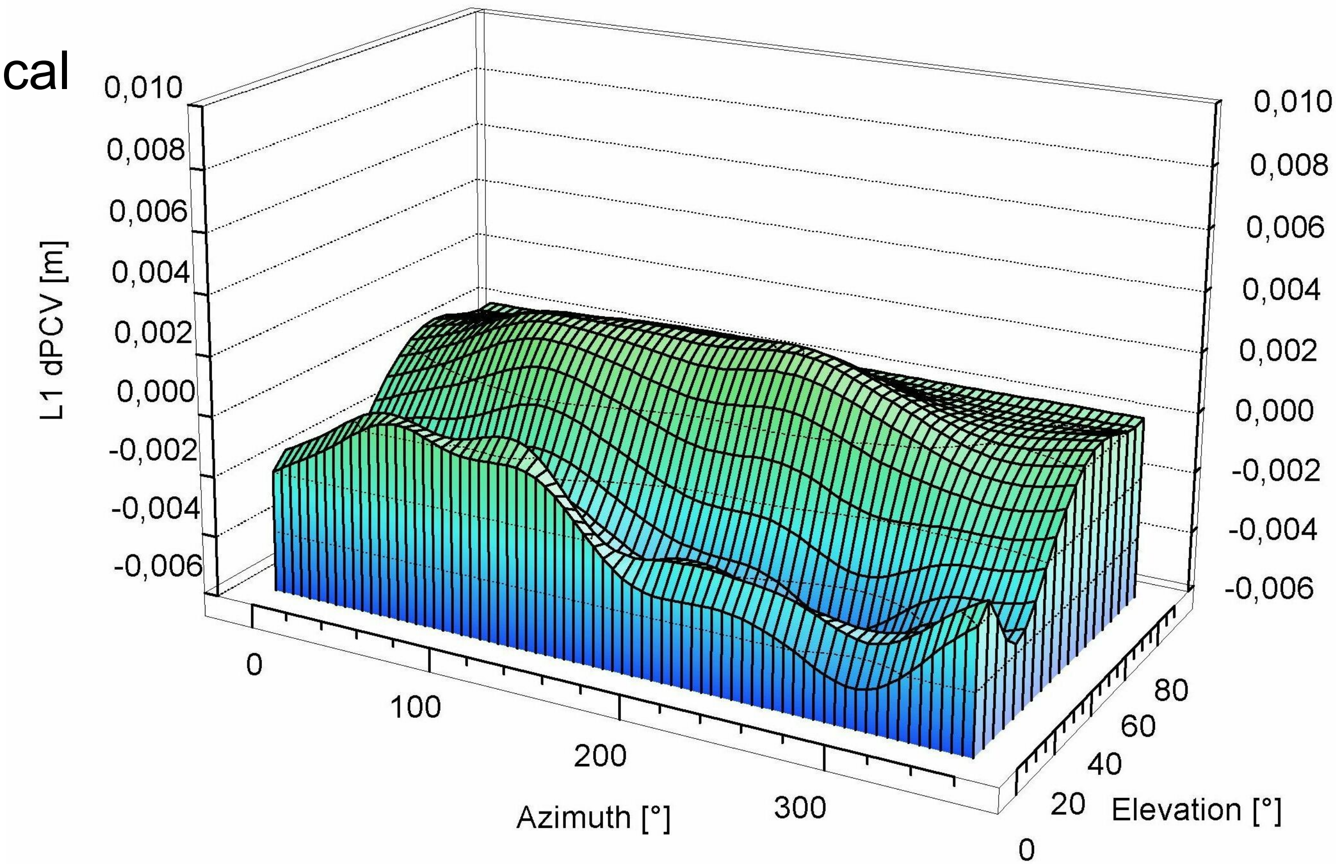


Real Life Example from RTK Networking

- TPSPG_A1 GNSS antenna
- 10 cm prism spacer and special construction with two ground planes ca. ∅ 14 cm
- target device for classical surveying
- L1 PCV difference against regular calibration
  - 10-30° elevation

    mean ca. 3 mm
    maximum 6 mm
  - 40-70° elevation

    mean ca. 1 mm
    maximum 2 mm

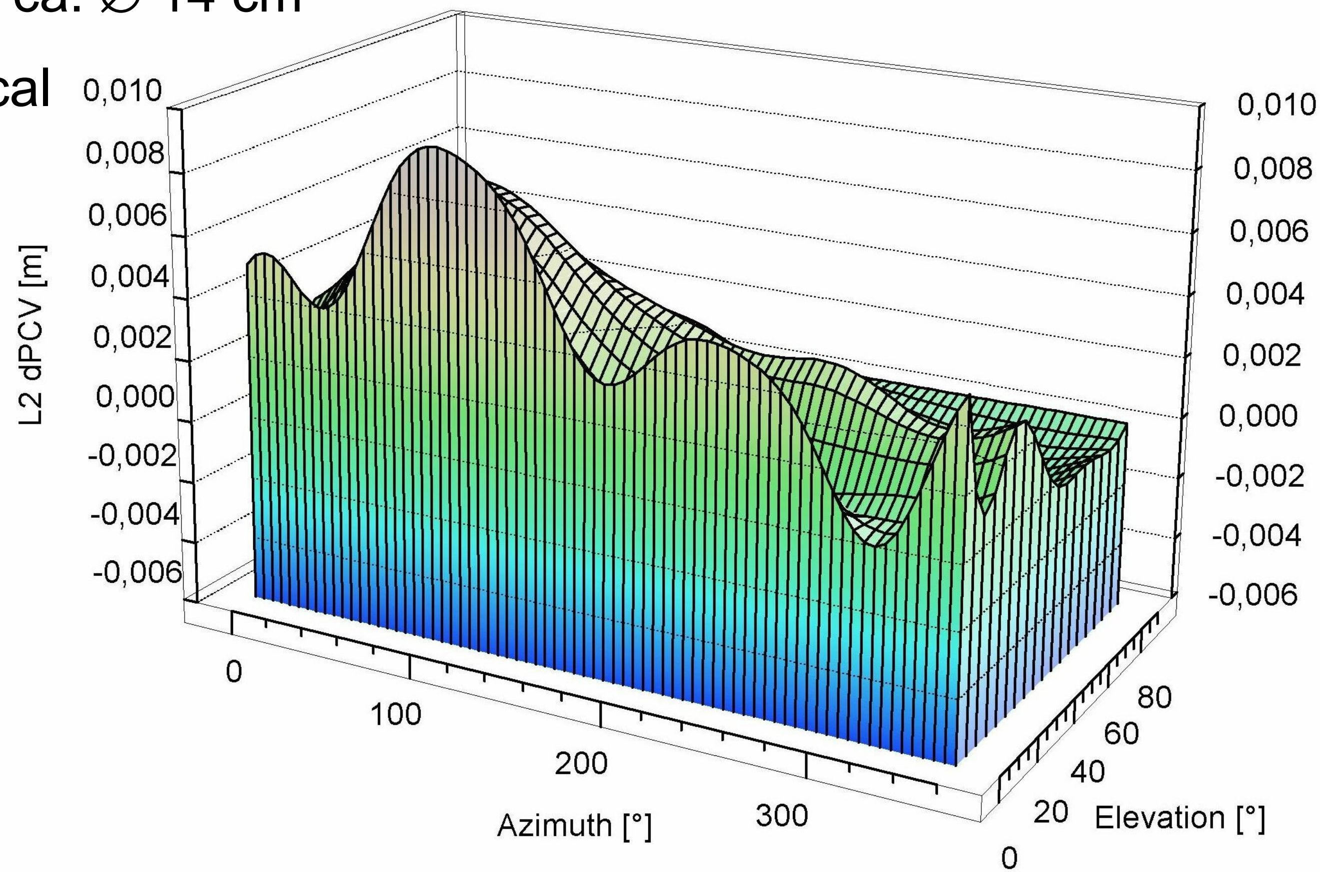


Real Life Example from RTK Networking

- TPSPG_A1 GNSS antenna
- 10 cm prism spacer and special construction with two ground planes ca. ∅ 14 cm
- target device for classical surveying
- L2 PCV difference against regular calibration
  - 10-30° elevation

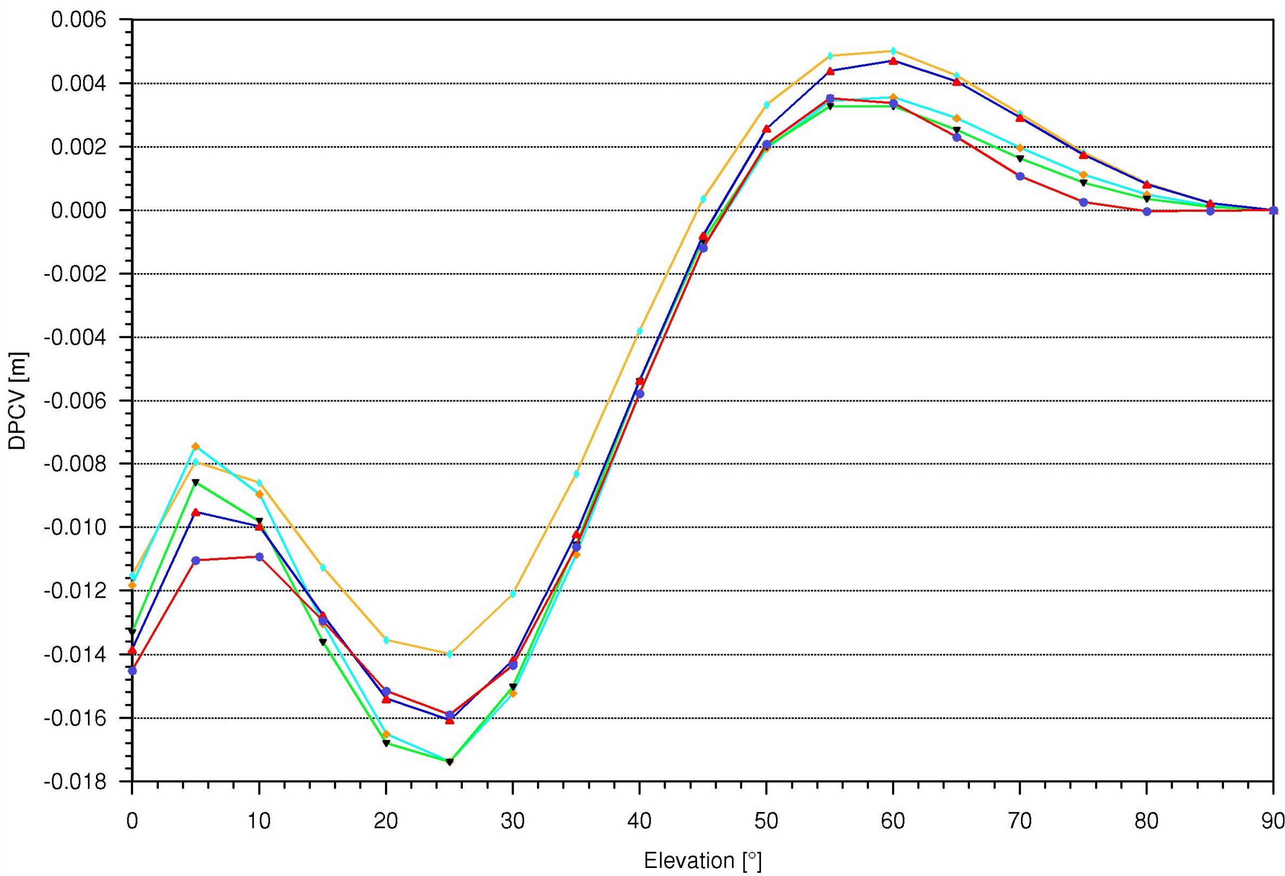
    mean ca. 4 mm
    maximum 8 mm
  - 40-70° Elevation

    mean ca. 1 mm
    maximum 4 mm

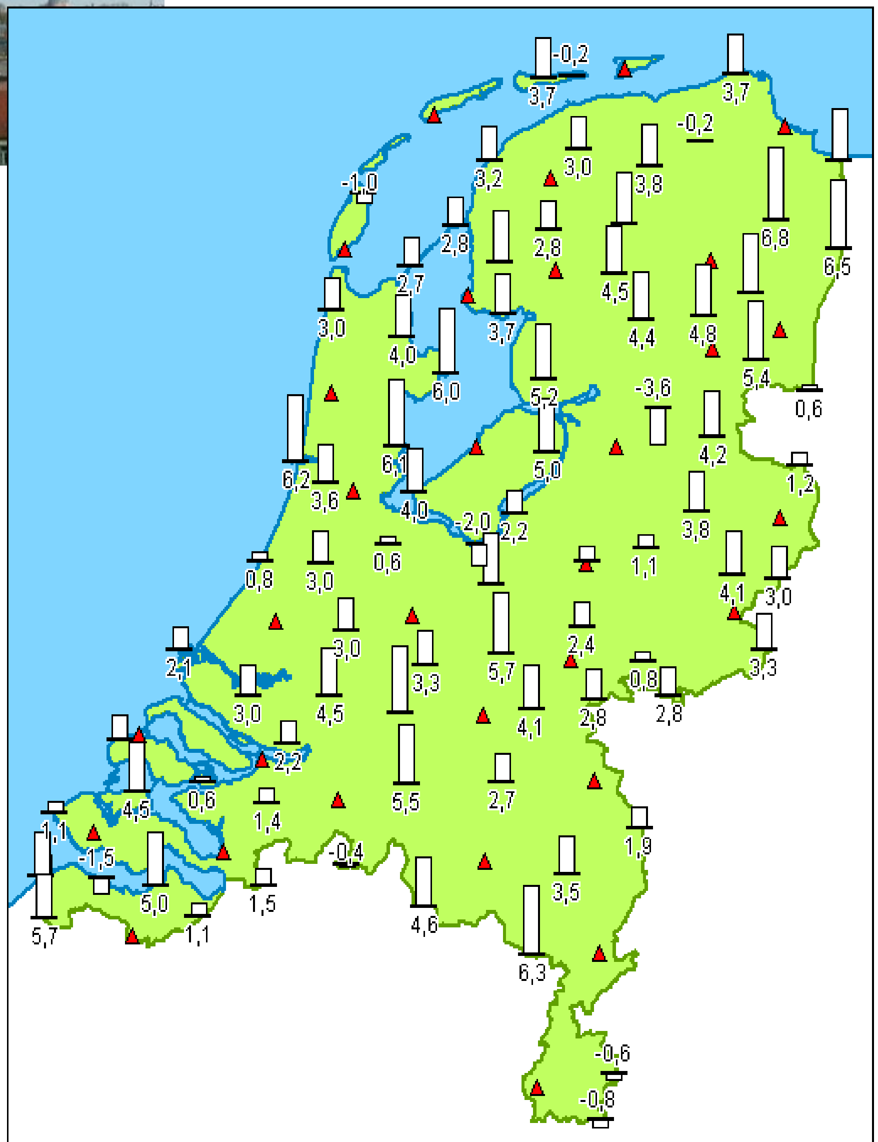


Real Life Example from RTK Networking

- amplification for L0 PCV
- L0 PCV differences against
  - 10-30° elevation maximum -18 mm
  - 40-70° elevation maximum +5mm
- repeatability of five antenna constructions ca. 4 mm
- also individual PCV and near-field components of antennas present



Real Life Example from RTK Networking



- Kadaster, The Netherlands
- NETPOS RTK Network (31 stations)
- 81 control points of Dutch network
- 10 RTK measurements with 10 initializations each time
- without near-field correction
  - time and spatial dependent height errors
  - mean of systematic height error is 31 mm (81points)
- with near-field correction
  - free of systematic errors mean height difference is -2 mm (49 points)

results and graphic have been kindly provided by Kadaster, The Netherlands

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

  $dS = PCV + MP_{near\text{-}field} + MP_{far\text{-}field}$

- advantages:
  - $MP_{near\text{-}field}$ absolute determinable
  - different treatment of MP components
  - differently affected through conditions of actual environment

Treatment of Station Dependent Errors

	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 and reconstruction of antenna setup
	$MP_{far\text{-}field}$	short-periodic, systematic effect	averaging over time, absolute stations calibration or weighting (CN0)
Station Uncertainty		stable untergound, setup, monumentation	analysis of time series

Determining $MP_{near\text{-}field}$ of a Reference Station

- basic principle:
  - noisifying of multipath through spatial variations
  - high number of variations of importance
  - variation over time (e.g. station calibration with robot)
  - variation in space (e.g. long observations with different antenna setups, stations, etc.)
- goal: absolute $MP_{near\text{-}field}$ determination of a reference station

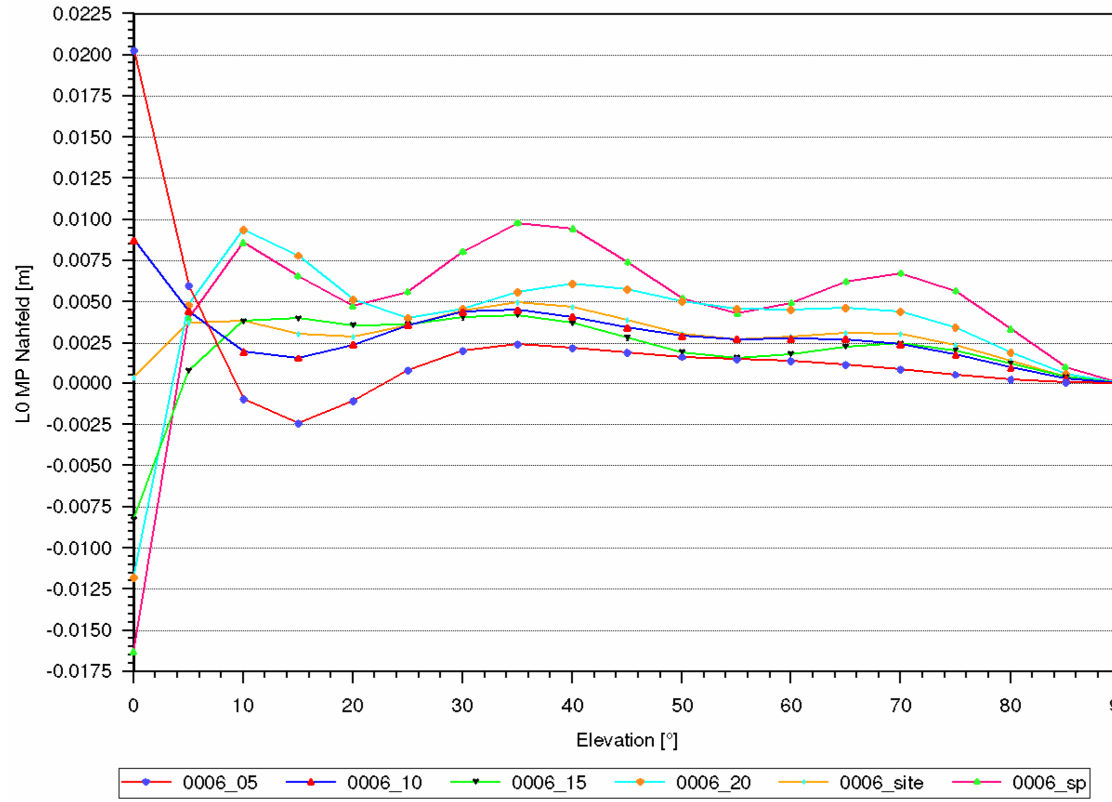
Approach	***Method***
explicit determination	robot calibration
noisifying multipath	station calibration using robot
	multiple station setup
combination of approaches	calibrated equipment

Investigations of Multiple Station Setup

- extensive measurements
- analysis of six pillars
- at least 24 h data in every case
- variations of antenna setups
  - permutation of adaption:
    ca. 5, 10, 15, 20 cm height, tripod over pillar
- variations regarding
  - tribrach, chokering antenna and receiver
- varying obstructions
- varying weather conditions over one month duration of measurements
- unchanged setup of reference station 1000
- goal: analysis and if applicable determination of $MP_{near\text{-}field}$

Multiple Station Setup: Variation of Antenna Setups

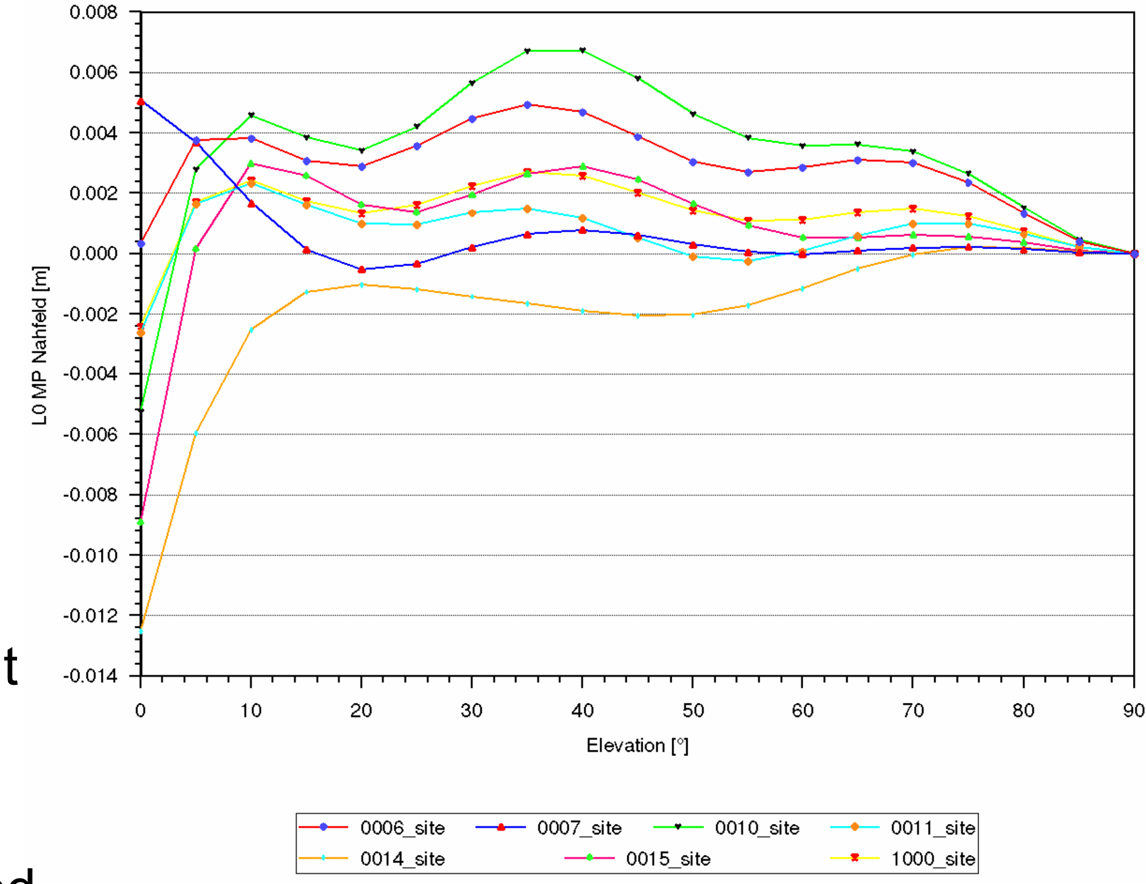
- PCV corrected in processing
- estimation of MPnear-field using spherical harmonic expansion
  - for every antenna setup
  - for every station
- „relative“ $MP_{near\text{-}field}$
- discussion
  - known $MP_{near\text{-}field}$
  - different frequencies
  - band width of 10 mm
  - largest at horizon



05:	height ca. 5cm
10:	height ca. 10 cm
15:	height ca. 15 cm
20:	height ca. 20 cm
sp:	tripod over pillar
site:	combination for station

Multiple Station Setup: Variation of Stations

- combining all MPnear-field data using weighted adjustment
- is result MPnear-field of reference station 1000 ?
- discussion
  - different near-field effects of setups obvious
  - no absolute leveling without any absolute MPnear-field reference
  - strategy allows no controlled MPnear-field determination



*_site: combination for station

An Almost Philosophical Question ...

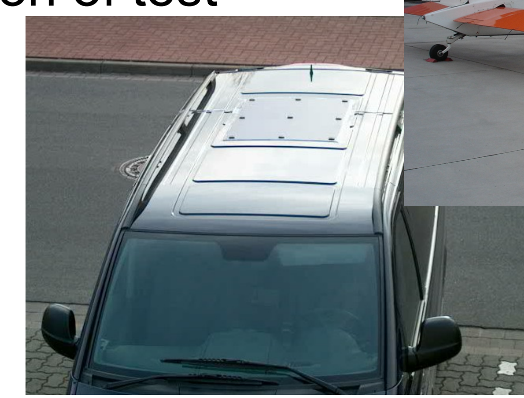
- obviously there are systematic errors through $MP_{near\text{-}field}$

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 $MP_{near\text{-}field}$

In-situ Calibration of Kinematic Platforms

- GPS attitude determination
  - antenna mounting causes large and complex near-field impact
  - loss of accuracy in the application
  - calibration required
  - reconstruction of environment is difficult (robot limited in weight and dimension of test antenna)



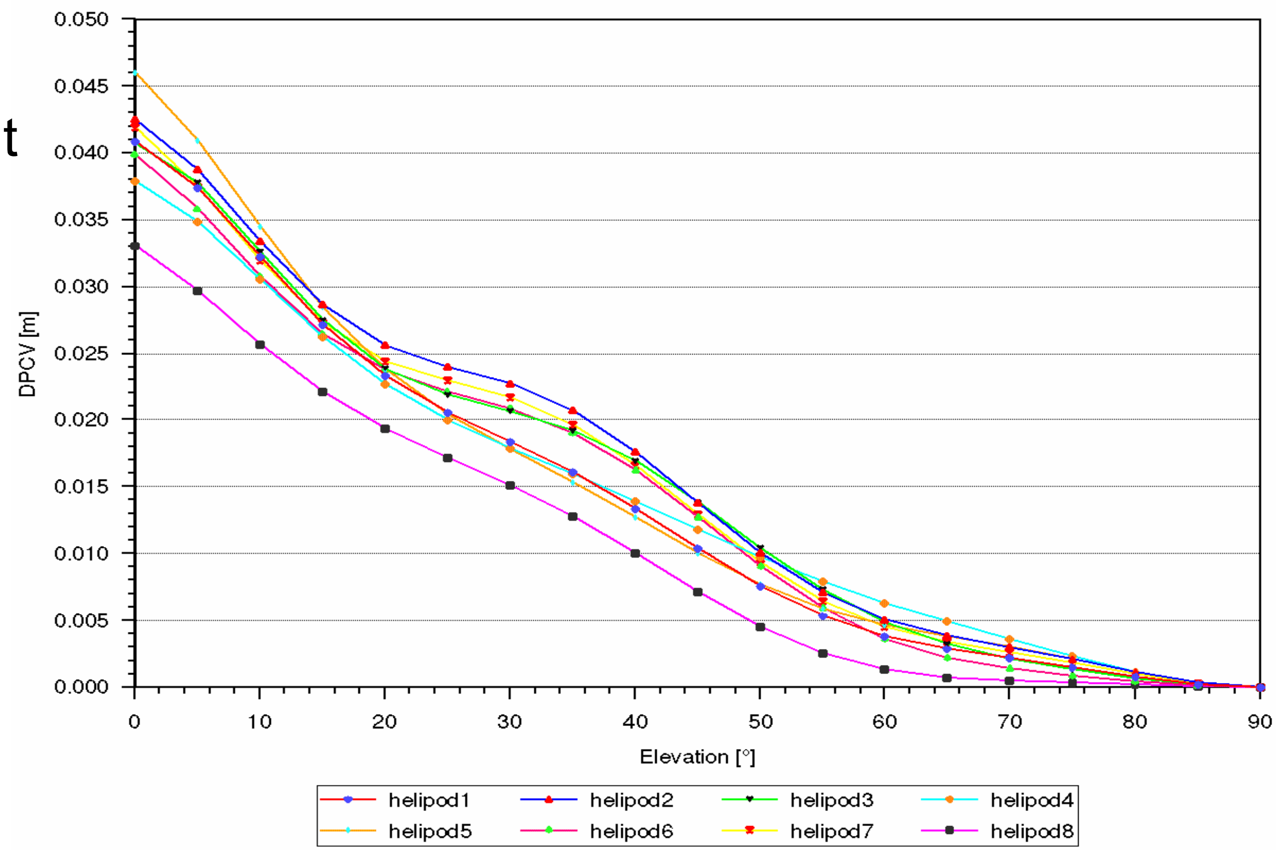
In-situ Calibration of Kinematic Platforms

example

- "Helipod" ILR Braunschweig
- eight TRM41555.00 „Bullet" L1-only antennas
- spatial variations: through movements with different tilts and inclination (executed with a car)
- several hours of observation
- determination of combined PCV and MP$_{near\text{-}field}$ effect in post-processing
- remark: attitude application requires only relative MPnear-field corrections

In-situ Calibration of Kinematic Platforms

- TRM41555.00 „Bullet"
- pure elevation dependent comparison against regular calibration
- PCV + $MP_{near\text{-}field}$
- systematic effect
- differences between antennas due to individual PCV and individual $MP_{near\text{-}field}$ impact

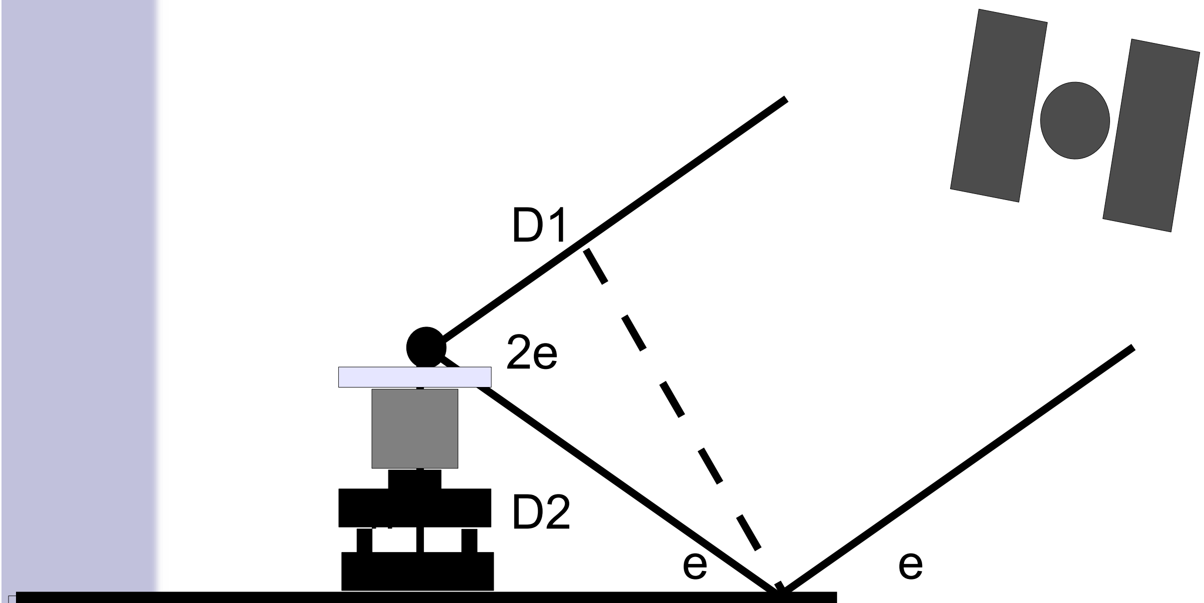


Summary/Outlook

- $MP_{near\text{-}field}$ impact is becoming of significant importance
- proposed strategy:
  separation of multipath into $MP_{near\text{-}field}$ and $MP_{far\text{-}field}$
  - correction of $MP_{near\text{-}field}$ demonstrated
  - enables different treatment of the two multipath components
- analysis and assessment of strategies to determine $MP_{near\text{-}field}$ are necessary
- in-situ calibration of kinematic platforms
  - $MP_{near\text{-}field}$ has impact on GPS attitude systems
  - determination of $MP_{near\text{-}field}$ using the moving platform


thank you for your attention

Multipath Caused by Horizontal Reflector



- isotropic (point like) antenna
- unlimited horizontal reflector
- effect is function of
  - elevation of satellite
  - path length and height
  - reflection coefficient
  - frequency