Sparse RTK Networks with Geo++®-GNSMART

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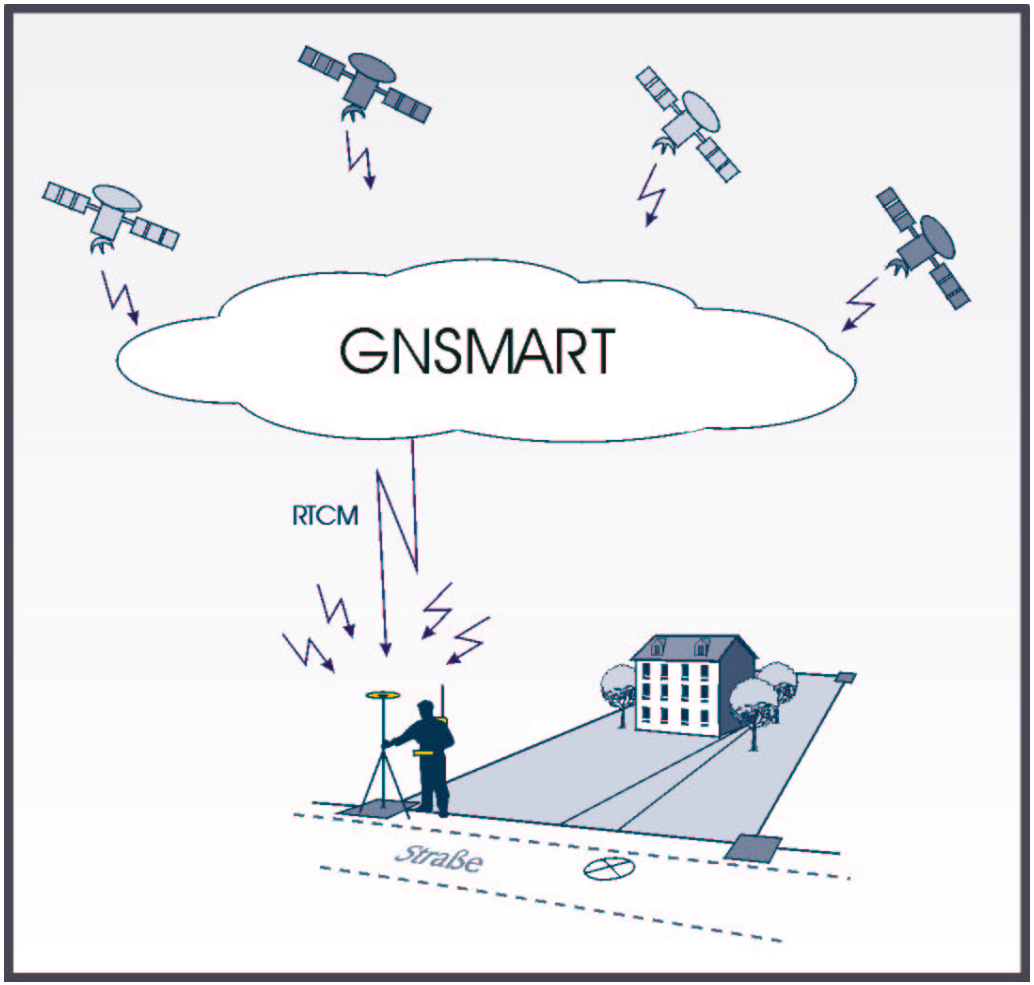
Introduction

Geo++®-GNSMART: A GNSS-SMART System

- **GNSS**: **G**lobal **N**avigation **S**atellite **S**ystem
- **SMART**: **S**tate **M**onitoring **A**nd **R**epresentation **T**echnique
- GNSMART: Implementation of GNSS-SMART system
  - network of reference stations
  - provide RTK service
  - with **homogeneous availability**, **reliability** and **accuracy** covering service area

GNSMART: User View

- user in the field
  - one way communication link
  - receive all necessary correction/reference data
  - determine absolute RTK position
  - anytime/anywhere
- 1 cm accuracy



Sparse Networks

- Ideal Solution:
  - satellite system provides absolute state information with RTK accuracy (< +/- 1cm) in real time
    - Problems:
      - model accuracy (no global ambiguity fixing yet)
      - information density (atmosphere)
      - GNSS system design
        - ground segment
        - data communication to satellites (RT upload)
- Practical Solution
  - regional GNSS SMART networks of reference/monitor stations with optimized (sufficient) density and size
    - Investment, Operation and Maintainance costs

General RTK Operation

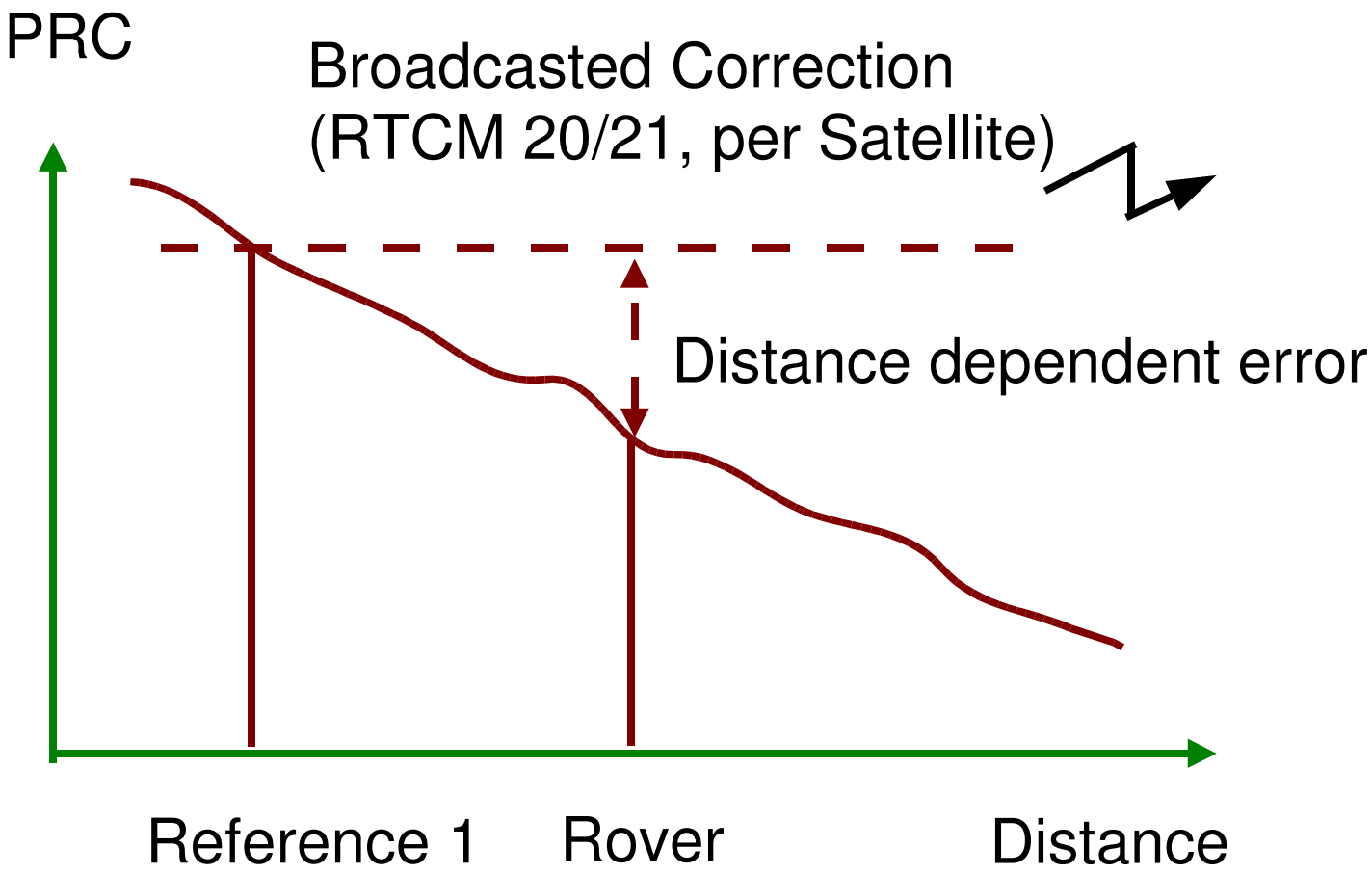
- solve carrier phase ambiguities
  - relative ambiguities to one reference station
- derive carrier phase pseudoranges
- compute position from carrier phase pseudoranges
  - differential position to reference station
- limiting effects
  - site dependent errors on reference station
  - distance dependent errors
  - site dependent errors on rover station

General RTK Requirements

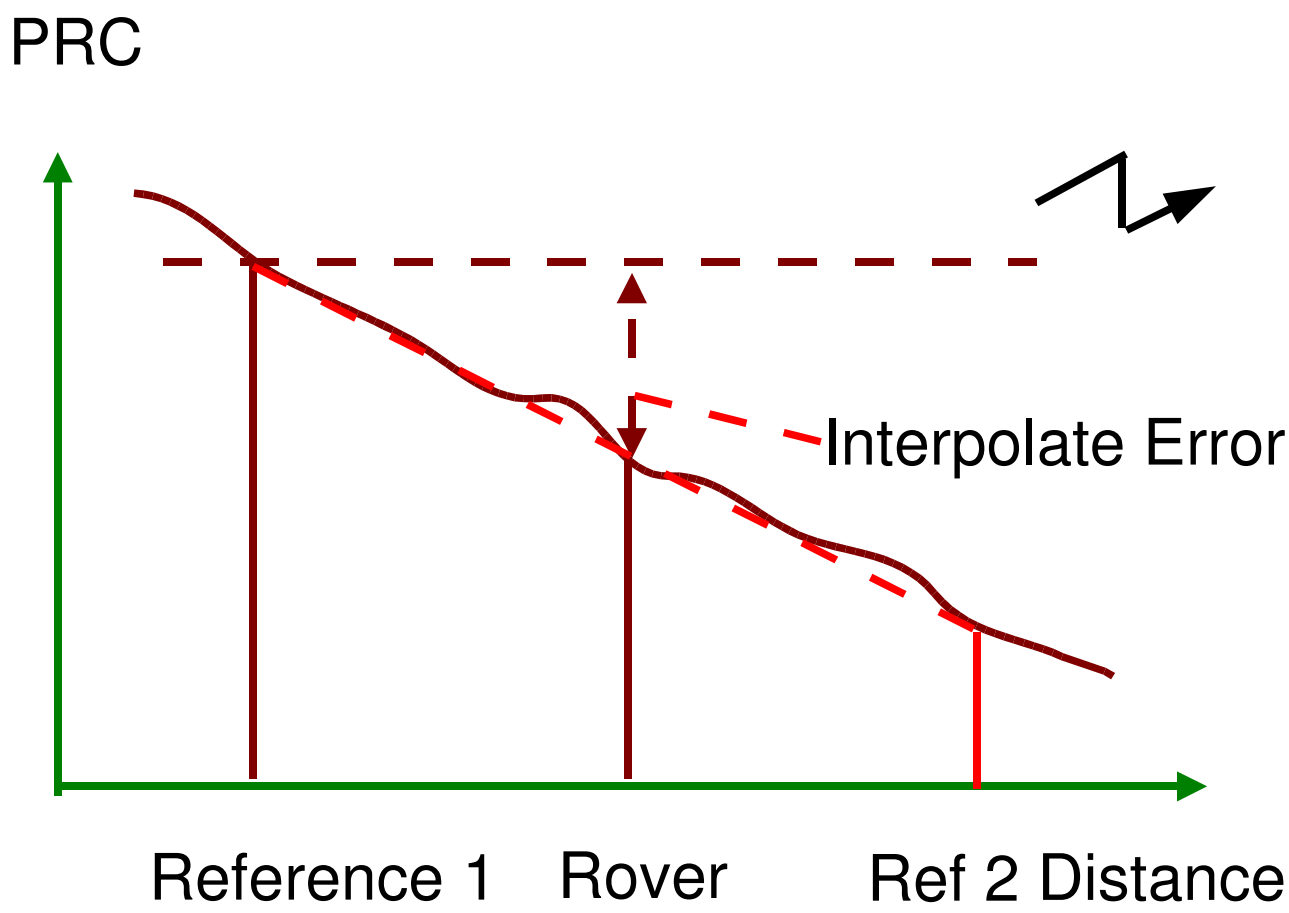
Performance concerned with

- availability
  - TTFA - time to fix ambiguities (seconds)
- reliability
  - reliability of ambiguity solution
    - Residual errors effect initialization time and reliability
- accuracy
  - accuracy of position determination
    - Residual error effect position accuracy

General RTK
Distance Dependency



Distance Dependent Errors from RTK Network

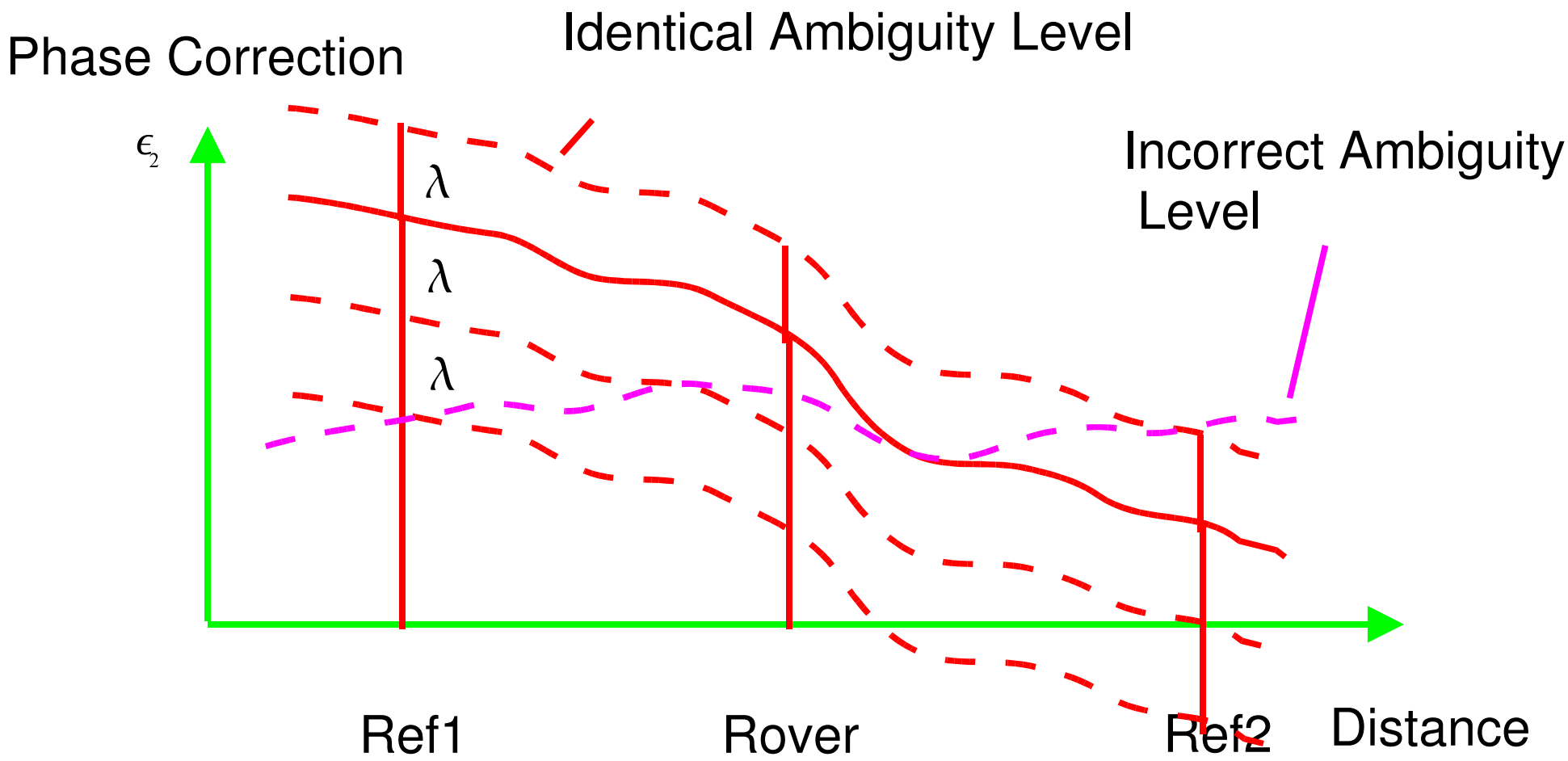


RTK Networks

Network RTK: Network Tasks

- primary task (pre-requisite)
  - carrier phase ambiguity resolution within network through adequate modeling
  - determine distance (and site) dependent errors
    - minimum number (density) of reference stations
    - ambiguity free distance dependent errors required
- secondary task
  - represent network information for user
    - distance dependent errors
    - reference station dependent errors

Ambiguity Level



GNSMART Modeling

GNSMART: State Modeling

- functional models
  - dynamic processes with temporal and/or spatial stochastic characteristics
  - static parameters
- stochastical models
  - stochastic processes with temporal and/or spatial characteristics

GNSMART: Satellite State Parameters

- satellite clock biases
  - dynamic 2nd order polynomial
  - stochastic white noise
- satellite signal delays
  - constant bias
  - integrated white noise
- satellite orbit
  - dynamic tangential, normal, radial offset

GNSMART: Ionospheric State Model

Ionosphere modeled as

- dynamic single layer or multi-layer as 2D polynomial in latitude and longitude/local time
- dynamic satellite dependent vertical delay bias
- stochastic 3D Gauss-Markov process
  - 1 parameter per receiver-satellite pair

GNSMART: Tropospheric State Model

Troposphere modeled as

- dynamic vertical delay biases (dry,wet) per station
- optional: dynamic polynomial in latitude, longitude and height
- optional: azimuth dependent
- optional: stochastic 3D process per station
- optional: meteorological parameters (p,T,e)

Network RTK Definitions 1

- State Space Model (SSM)
  - complete model for GNSS observable describing all (error) states with carrier phase accuracy
    - Multi-station adjustment
    - including ambiguity resolution
    - highest precision for state estimation
- Observation Space Model (OSM)
  - simplified model for GNSS observable not describing all states
  - a non-complete SSM

Network RTK Definitions 2

- State Space Representation (SSR)
  - representation model to transmit state parameters to a user (rover)
- Observation Space Representation (OSR)
  - representation of combined effect of state parameters in observation space (mapping of state space to observation space)

GNSMART Concept
Monitoring

- complete State Space Model (SSM)
  - Multi-station RT network solution
  - undifferenced observables
  - complete (regional) state model with carrier phase accuracy
  - undifferenced ambiguity resolution

GNSMART Concept
Representation

- State Space Representation
  - broadcast transmission
  - today: spatial model through FKP (state transformed to observation space)
  - future: actual state (SV clocks,orbits,iono,tropo)
- Observation Space Representation
  - today: VRS
    - Duplex communication
  - Future: Correction Differences

State Space Approach: Advantages

- satellites and upper atmosphere independent from reference stations
- closer to physical behavior than polynomial models
- models can be aided by external information
- observation space information can be derived from state model easily
- robust against failures of single reference station
- resistance against biases
- utilization of high redundancy in multiple reference station networks

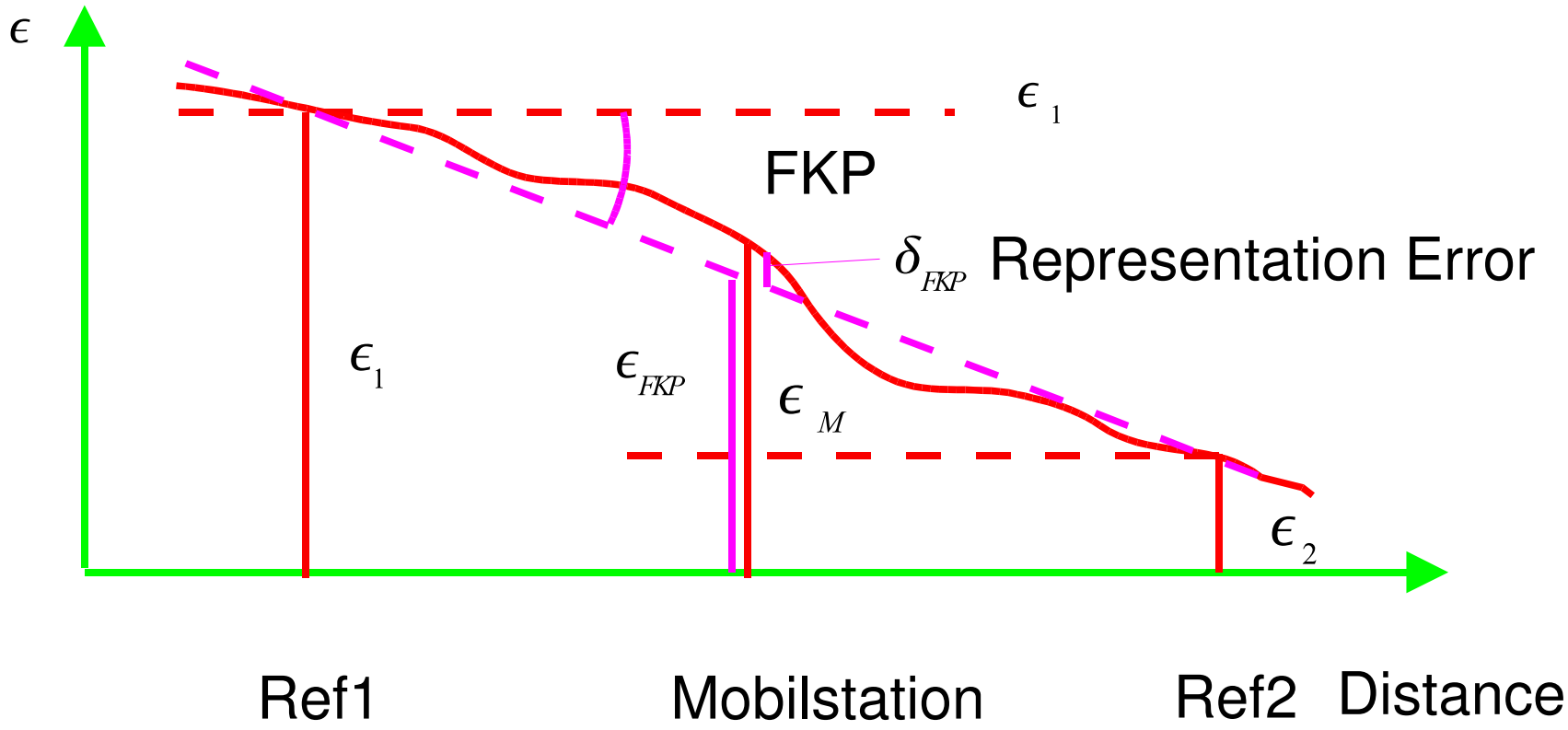
State Space Approach: More Advantages

- longer inter-station distances -> Sparse Networks
- better performance (TTFA and reliability)
- communication link
  - optimum bandwidth with SSR
  - broadcast possible
- monitoring through state space parameters
- determination site dependent errors on reference stations

Representation

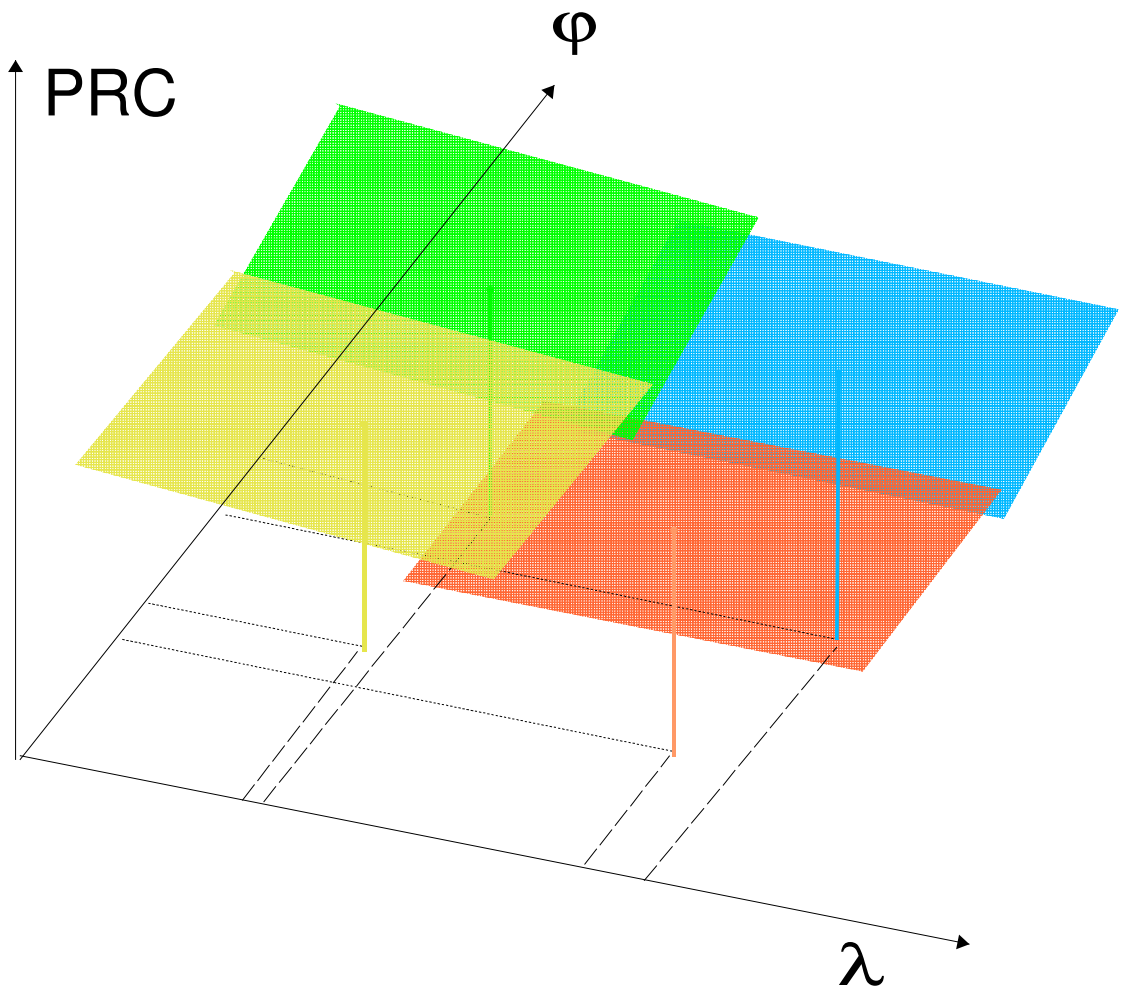
FKP Representation

Phase Correction



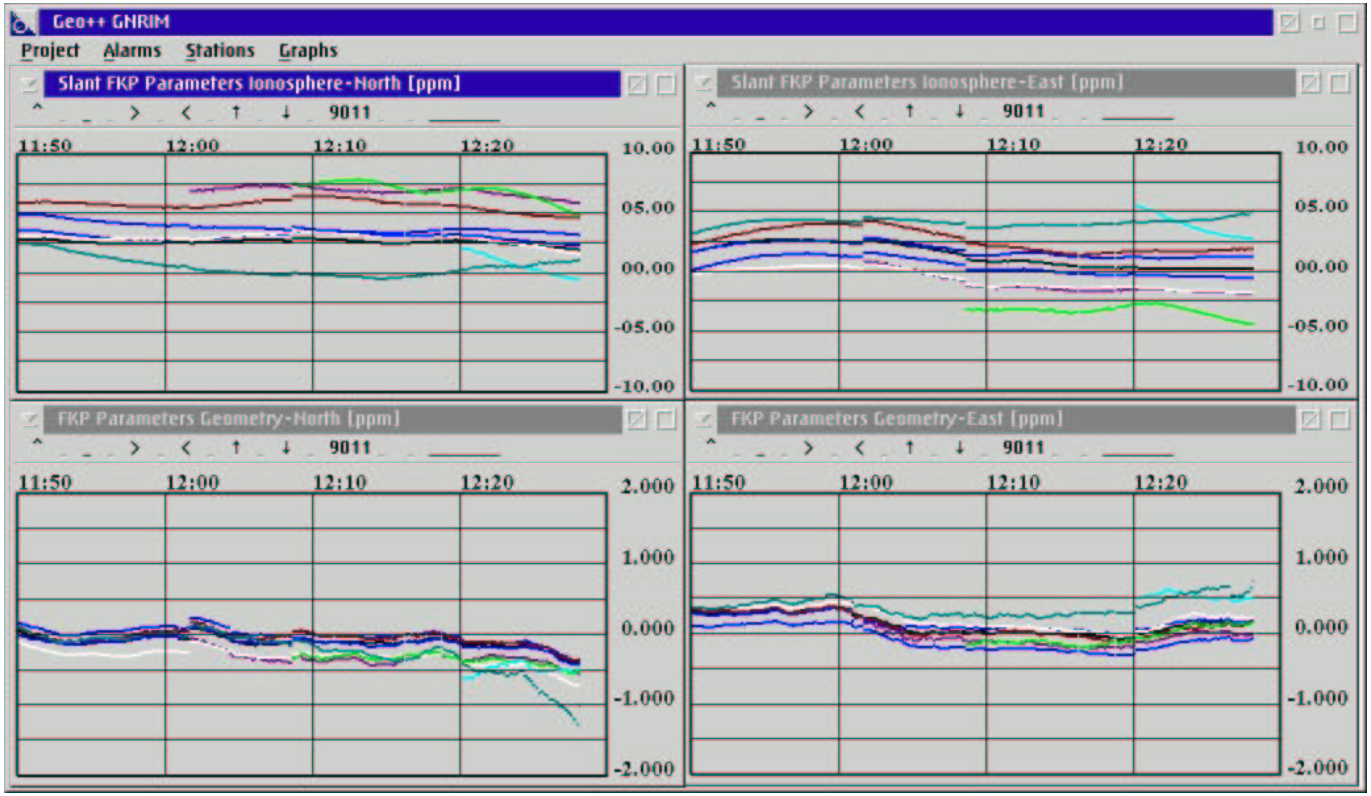
GNSMART: FKP Representation Example

- one linear FKP plane for each
  - reference station
  - signal (L_i, L_0)
  - Satellite
- Optional: higher order polynomials (n > 8)

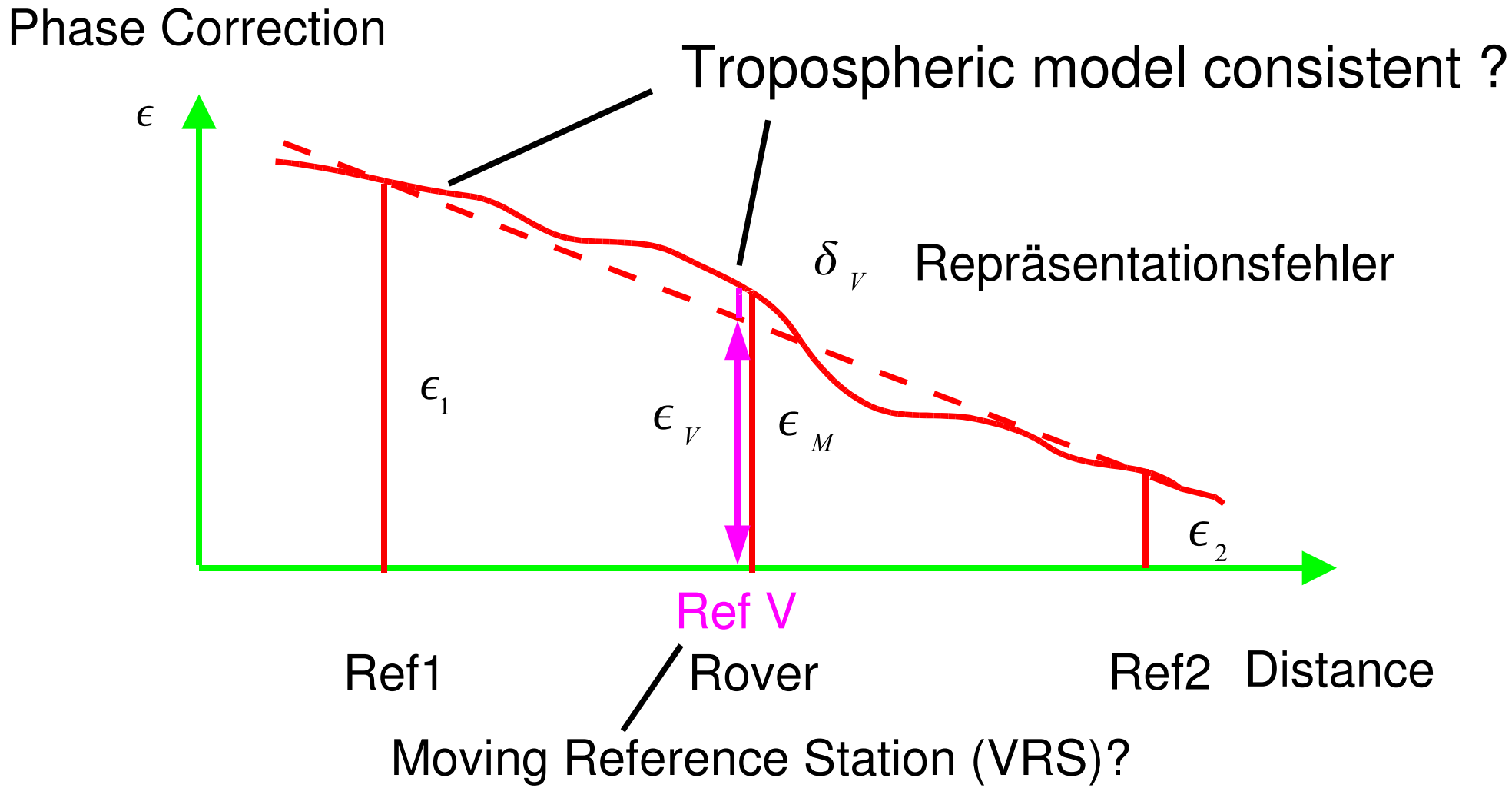


GNSMART: GNRIM FKP Windows

- FKP representation of state vector
  - dispersive/ ionosphere
  - non-dispersive/ troposphere, orbits
  - ionospheric effects

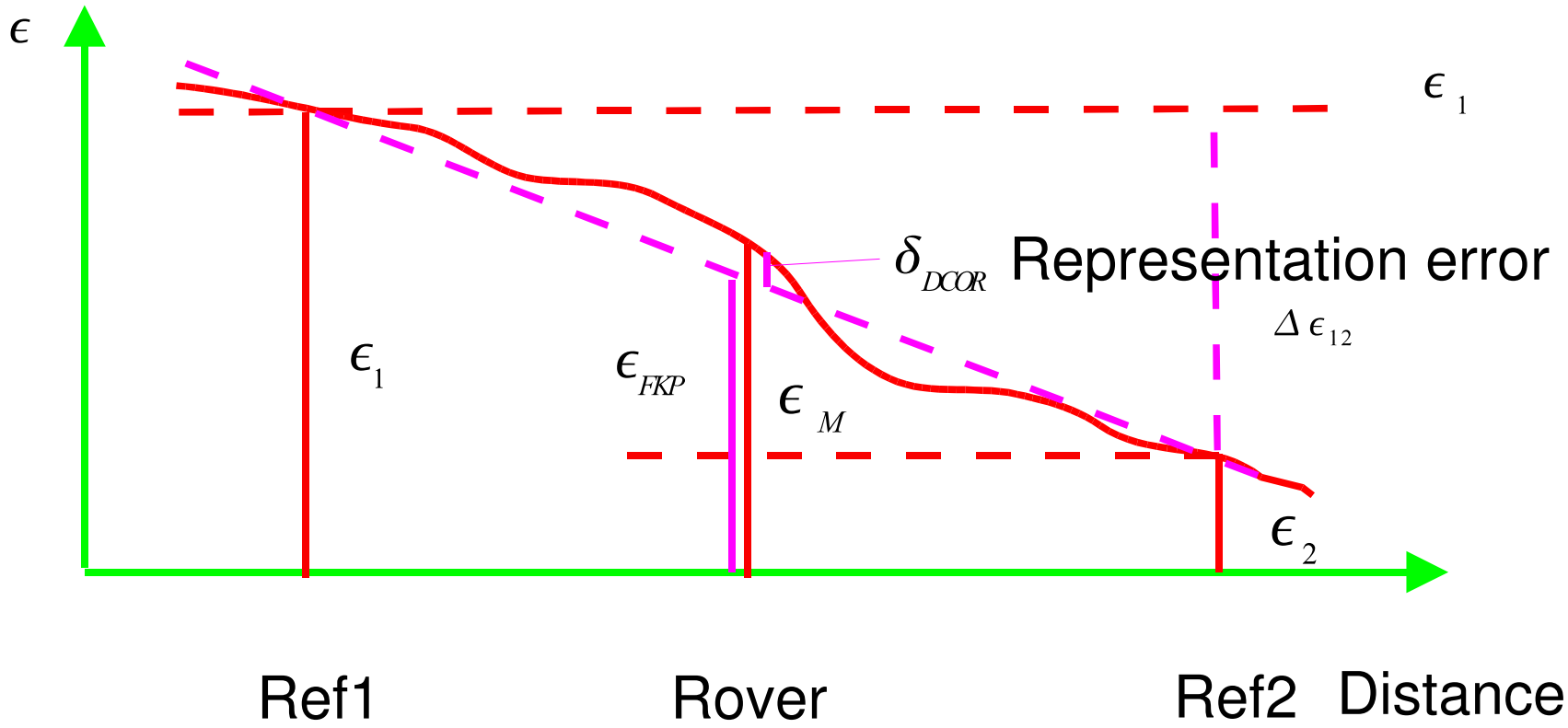


Virtual Reference Station (VRS)



Ambiguity free phase correction differences

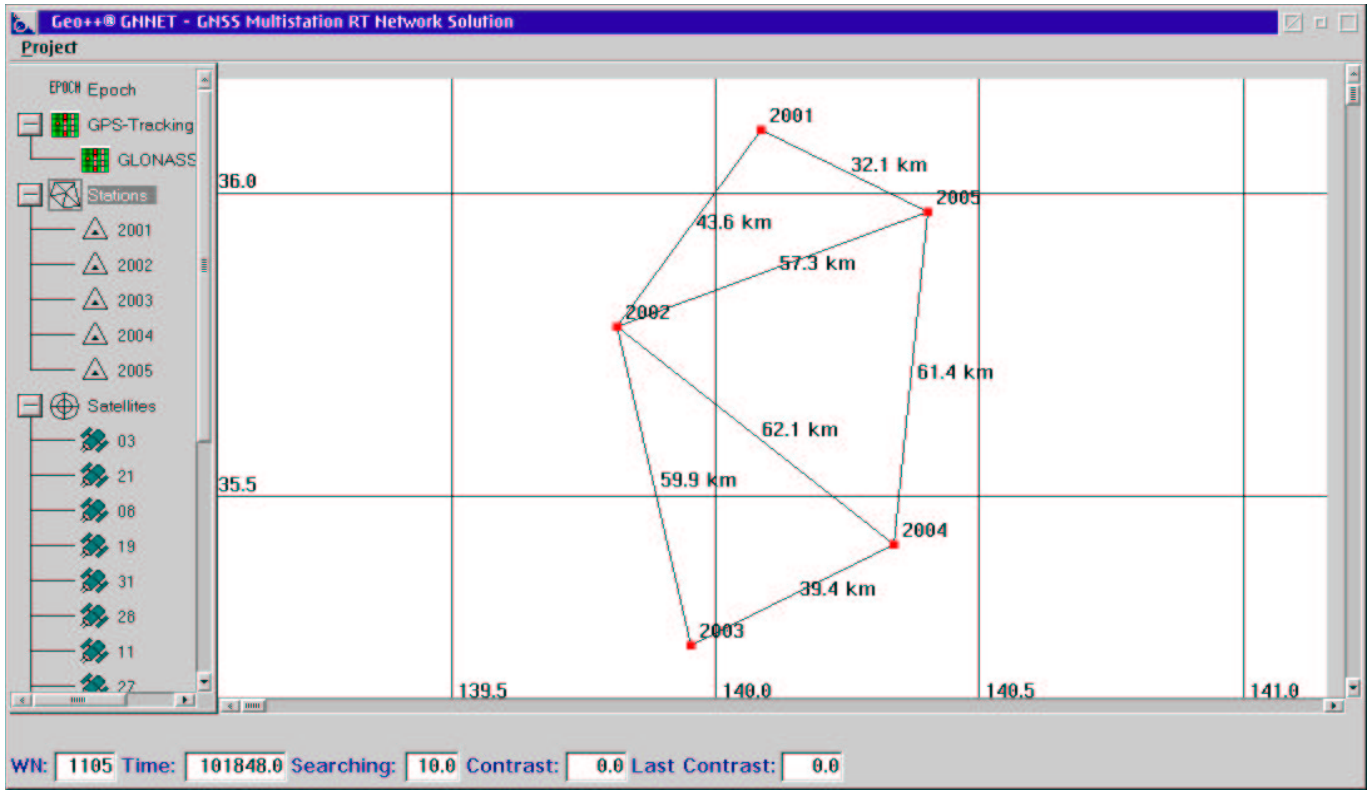
Phase Correction



Network Examples

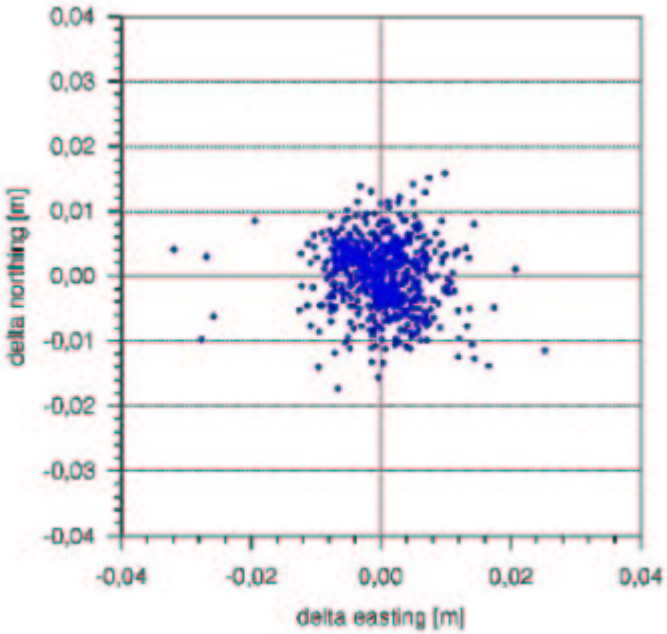
GNSMART: High Ionospheric Activity
GSI Test Japan

- 5 reference stations
- up to 62 km
- State Space Model (SSM) VKS mode

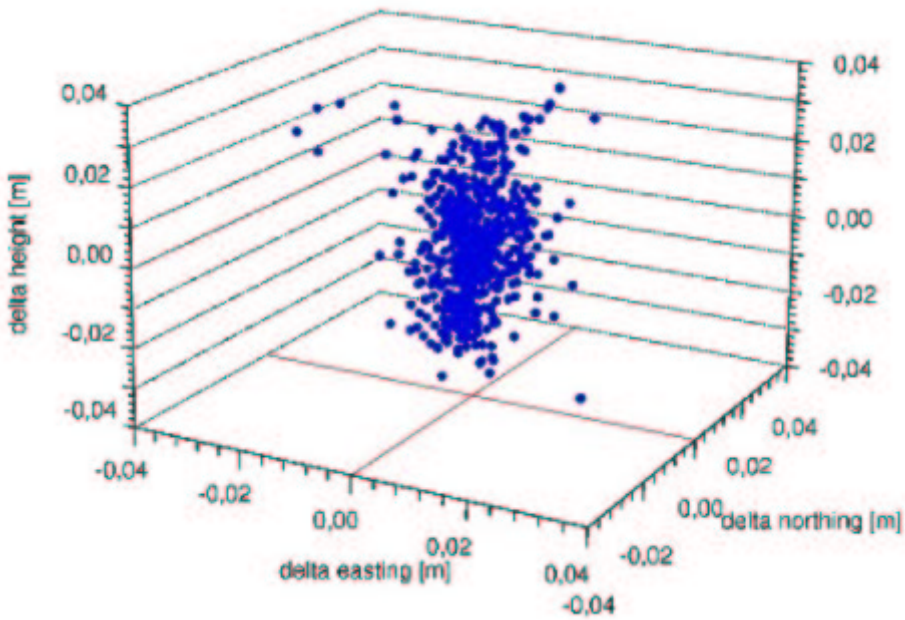


– only minimum number of reference stations

GNSMART: High Ionospheric Activity
GSI Test Japan

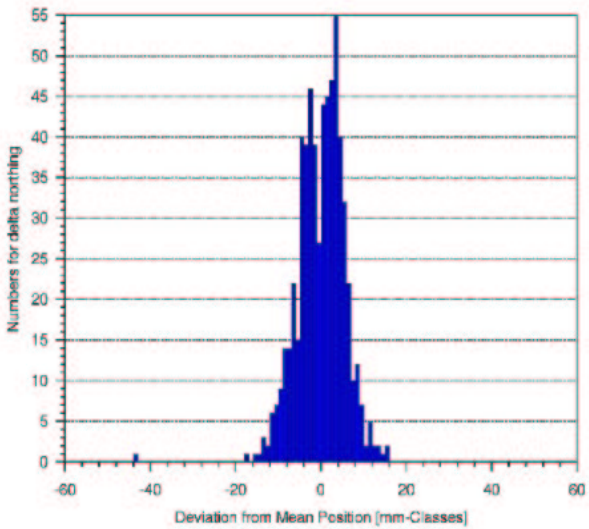


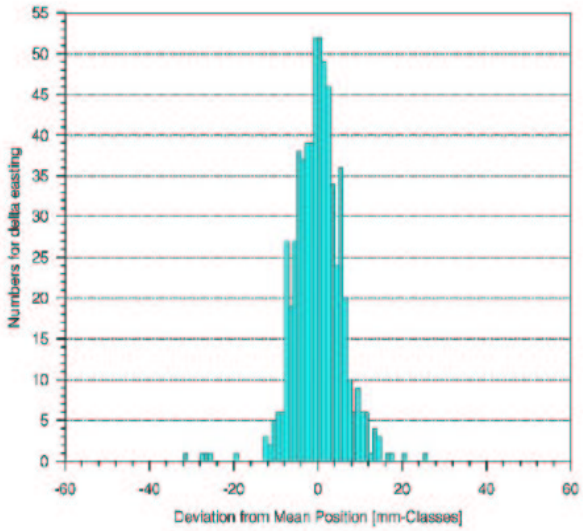
2D Scatter Plot +/- 7.9 mm

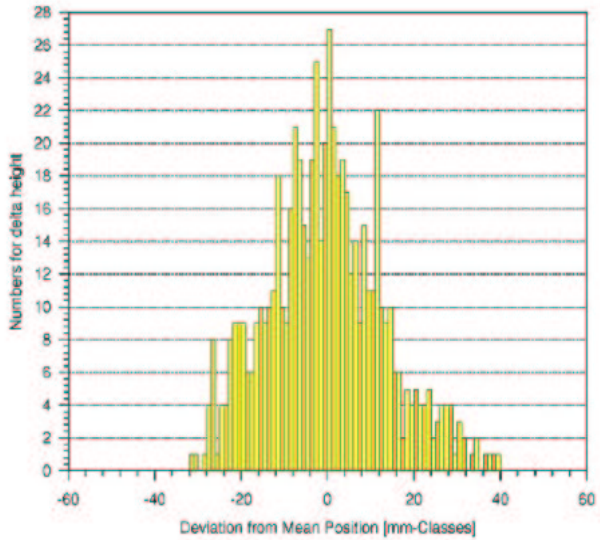


3D Scatter Plot +/- 15.6 mm

GNSMART: High Ionospheric Activity
GSI Test Japan



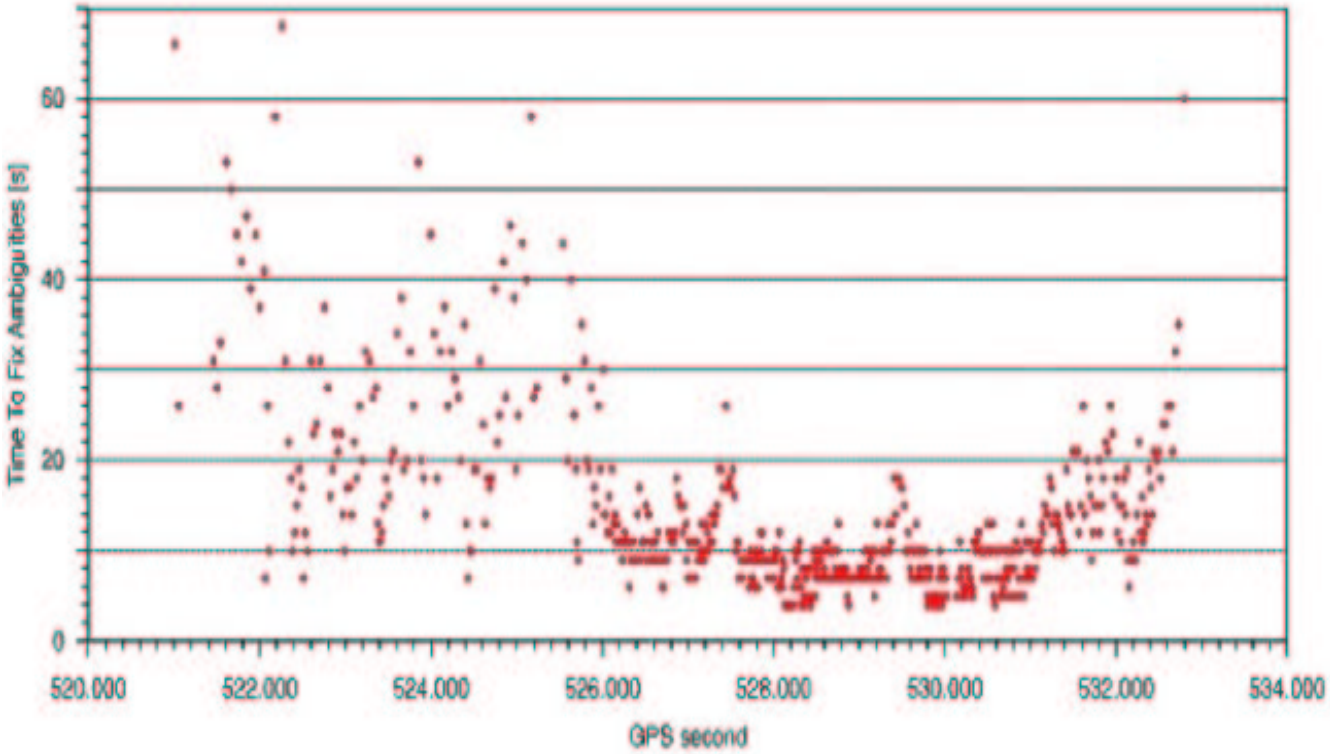




Northing: +/- 5.5 mm Easting: +/- 5.7mm Height: +/- 13.5 mm

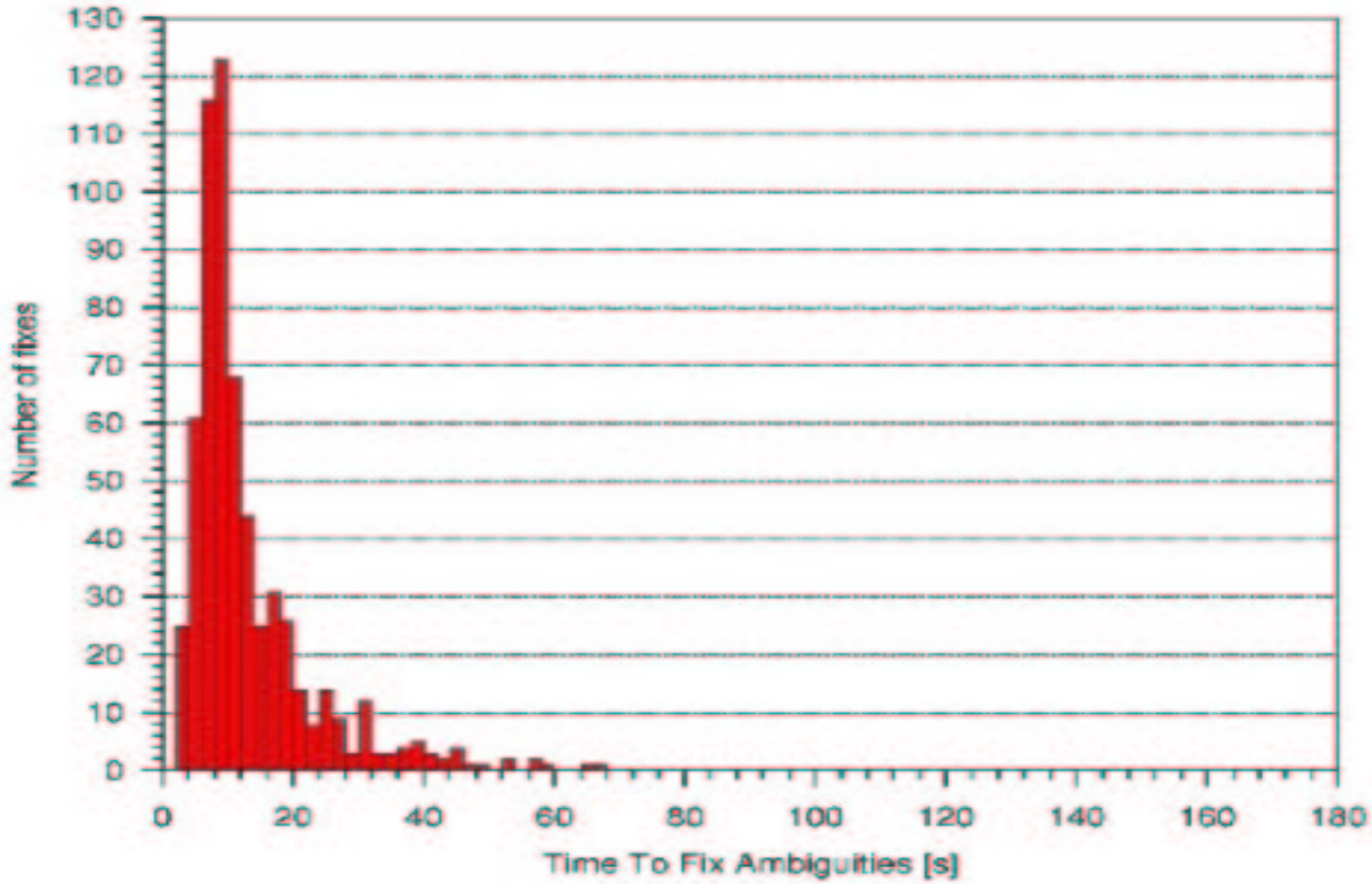
GNSMART: High Ionospheric Activity
GSI Test Japan

- TTFA (time to fix ambiguity)
- 615 fixes
- 3 h
- mean 14 s



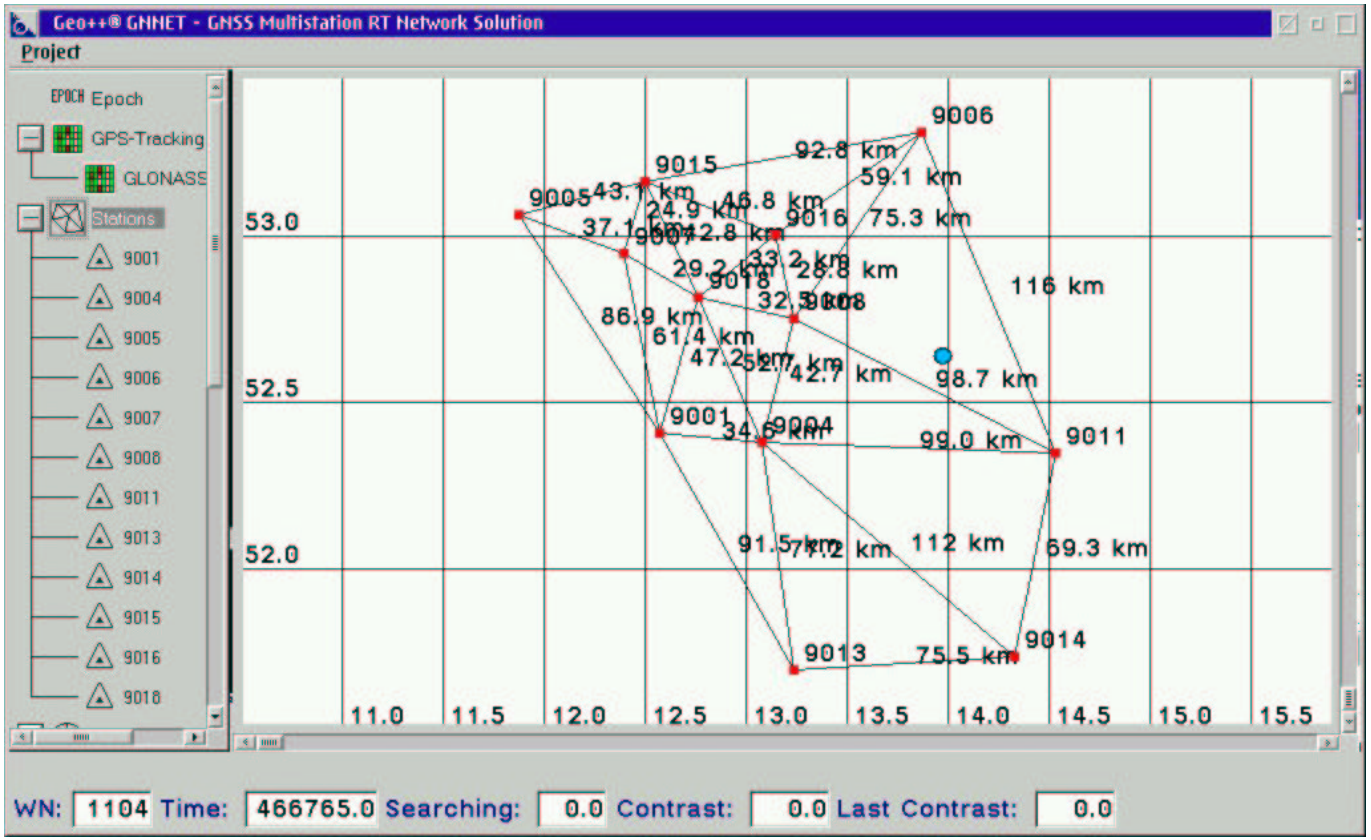
GNSMART: High Ionospheric Activity
GSI Test Japan

- TTFA (time to fix ambiguity)-hist ogram
- 615 fixes
- mean 14 s



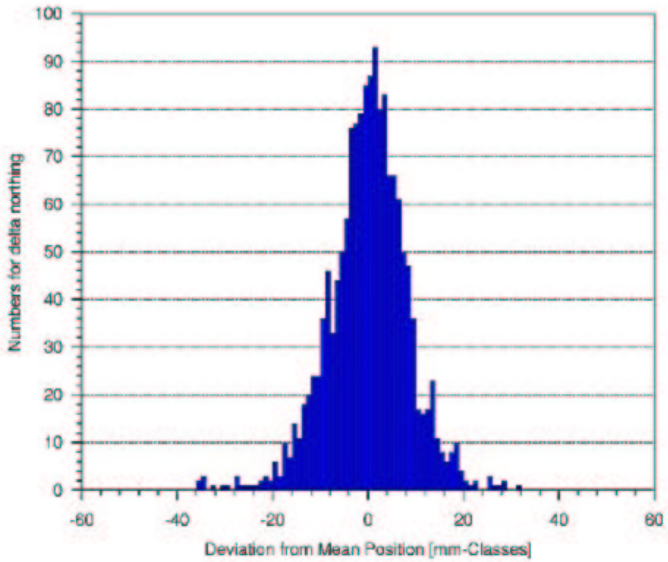
GNSMART: Sparse RTK Network (100 km)
SAPOS Brandenburg

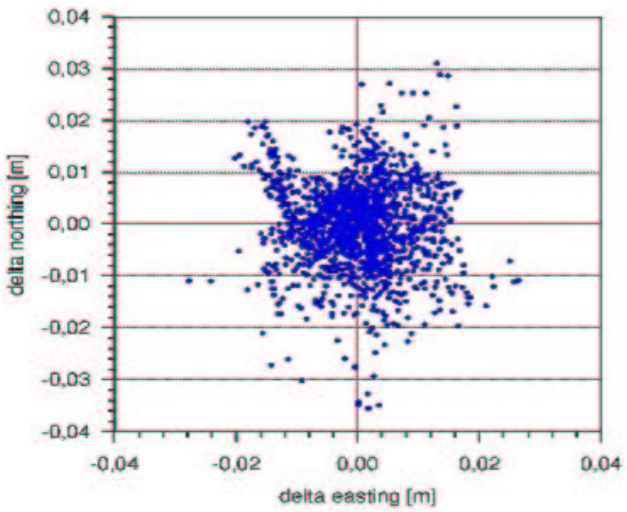
- northwest part
- 12 reference stations
- up to 116 km
- State Space Model (SSM) FKP mode
  - rover position

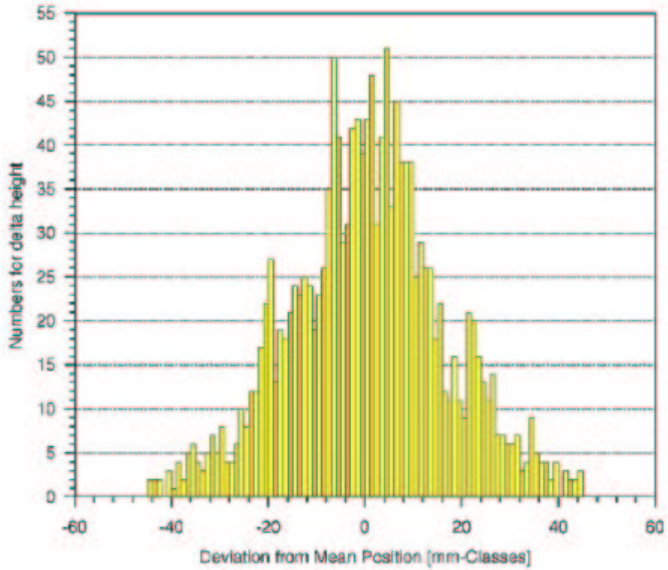


GNSMART: Sparse RTK Network (100 km) SAPOS Brandenburg

- 1544 fixes over 12 hours
- 47 to 58 km distance to closest reference stations





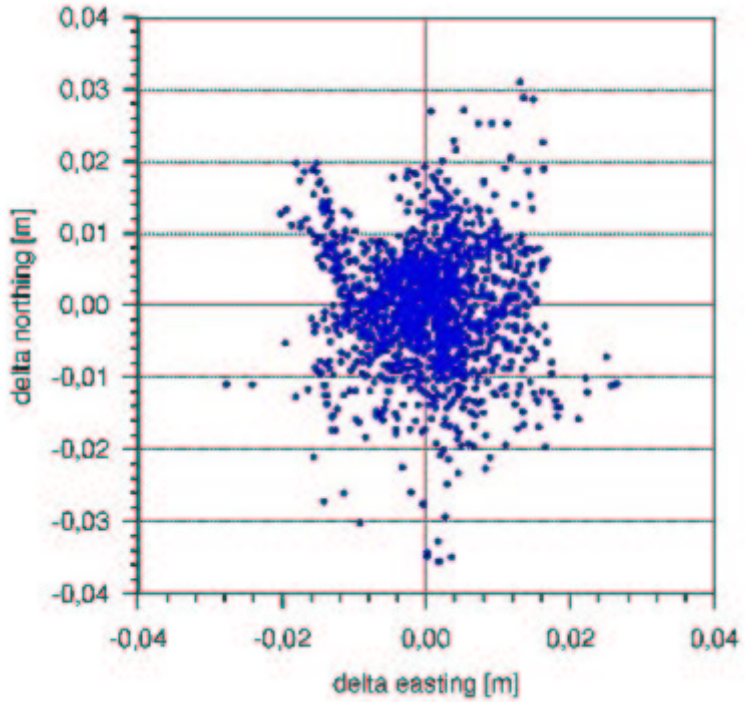


Northing +/- 8.3 mm Easting +/- 7.4 mm Height +/- 17.0 mm

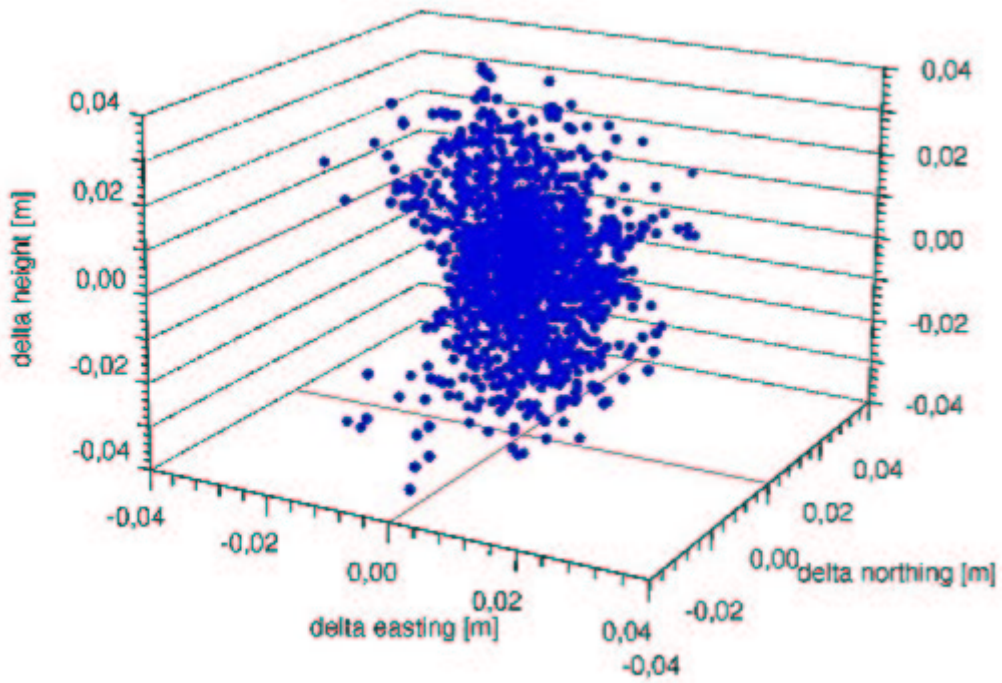
GNSMART: Sparse RTK Network (100 km)

SAPOS Brandenburg

- 1544 fixes over 12 hours
- 47 to 58 km distance to closest reference stations



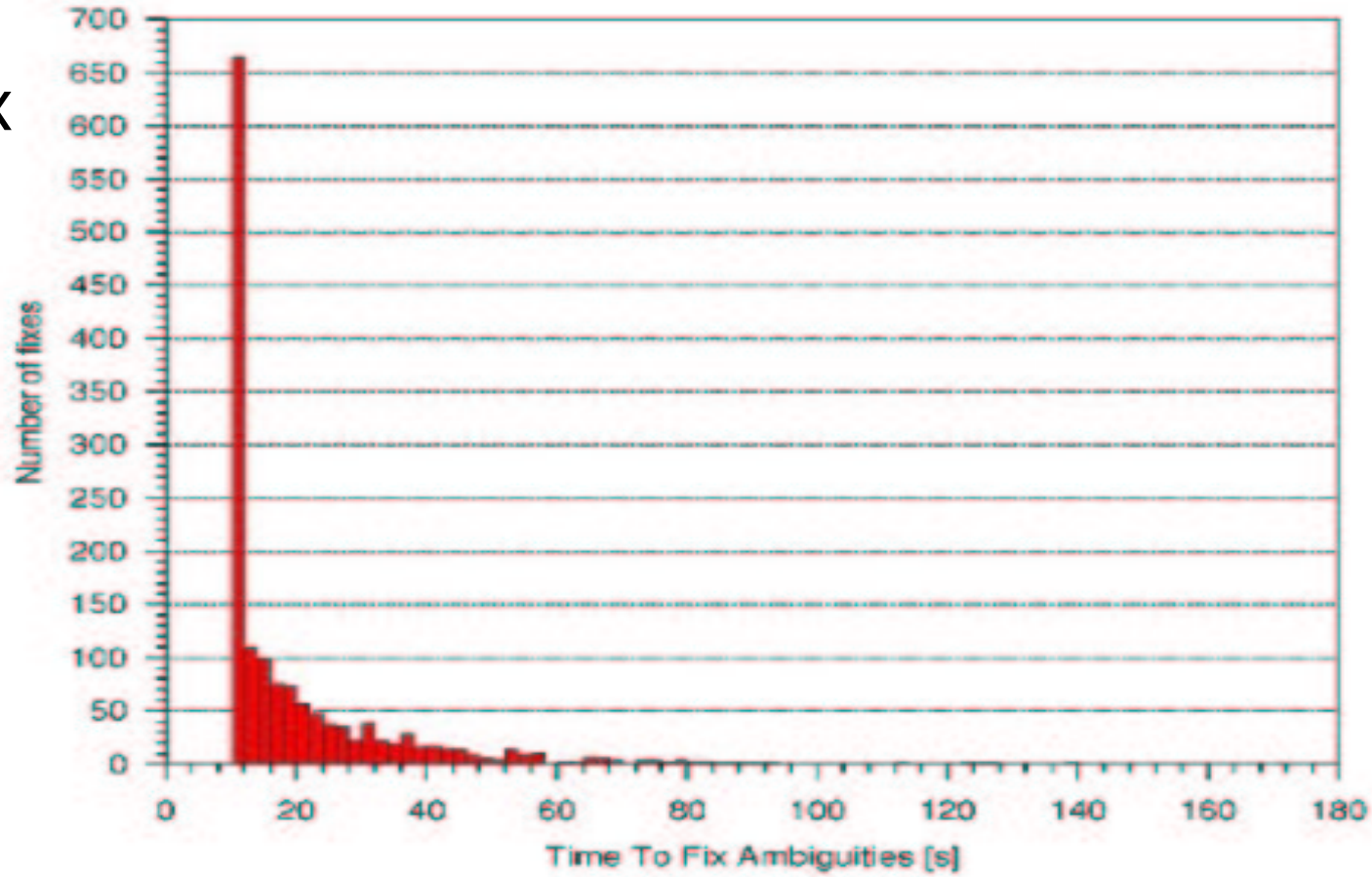
2D Scatter Plot +/- 11 mm



3D Scatter Plot +/- 21 mm

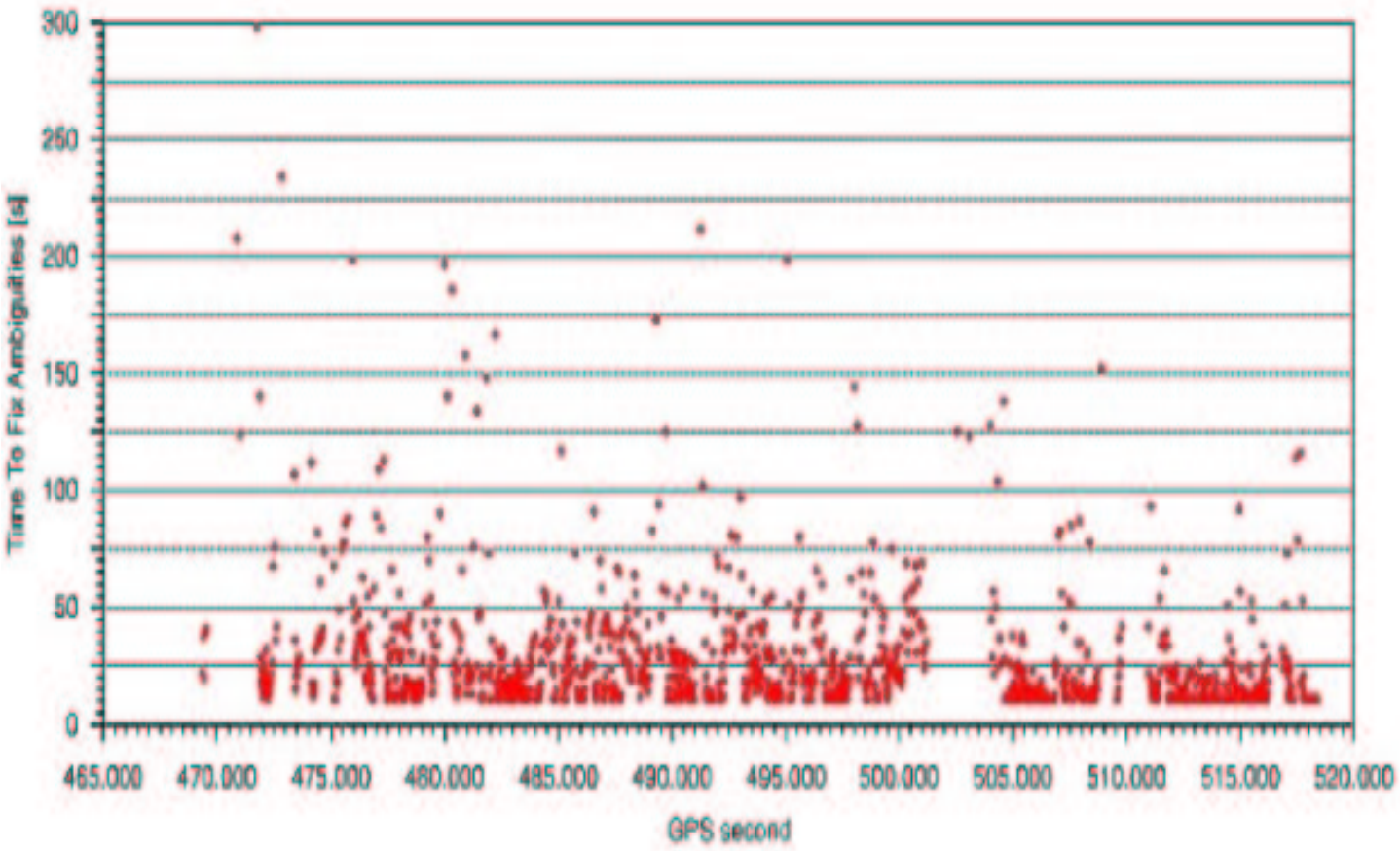
GNSMART: Sparse RTK Network (100 km) SAPOS Brandenburg

- TTFA (time to fix ambiguity)-histo gram
- 1544 fixes
- mean 12 s



GNSMART: Sparse RTK Network (100 km) SAPOS Brandenburg

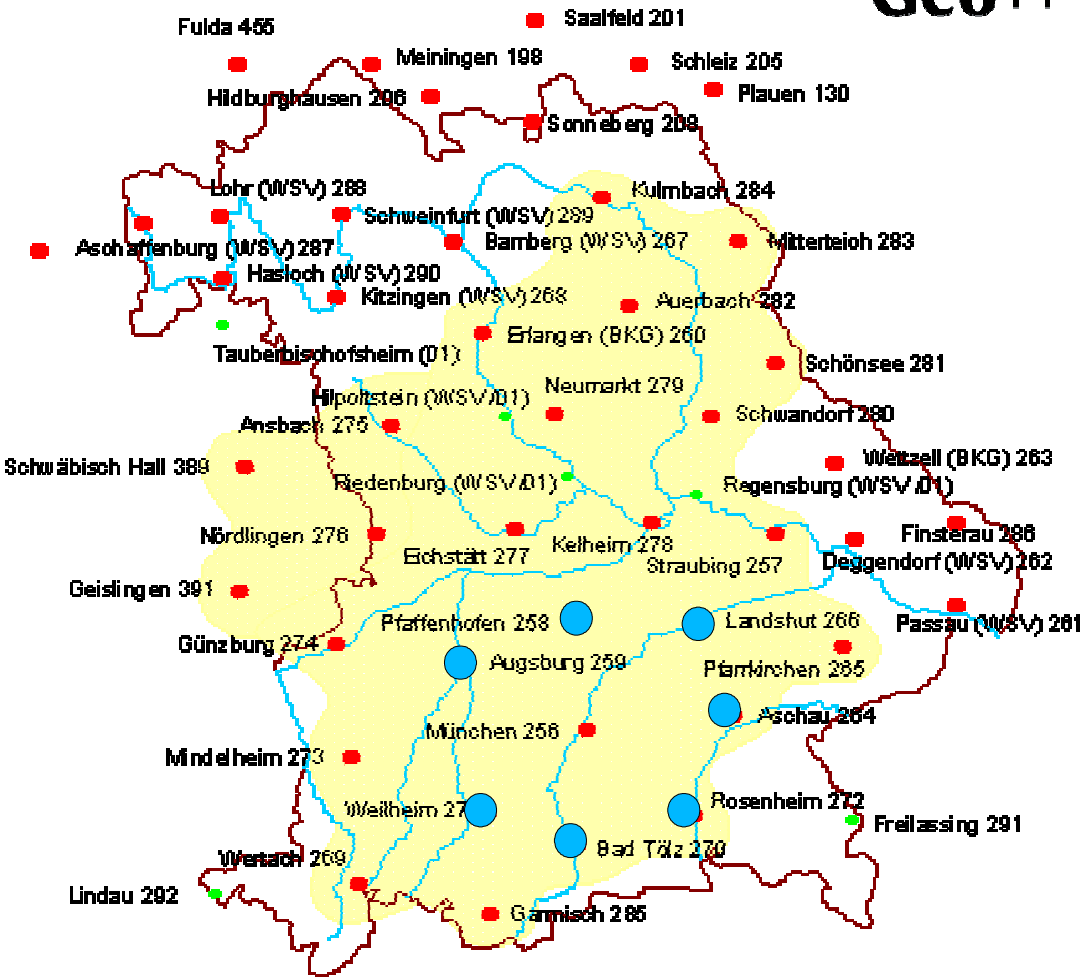
- TTFA (time to fix ambiguity)
- 12 hours
- mean 12 s



GNSMART: Sparse RTK Network (100 km)

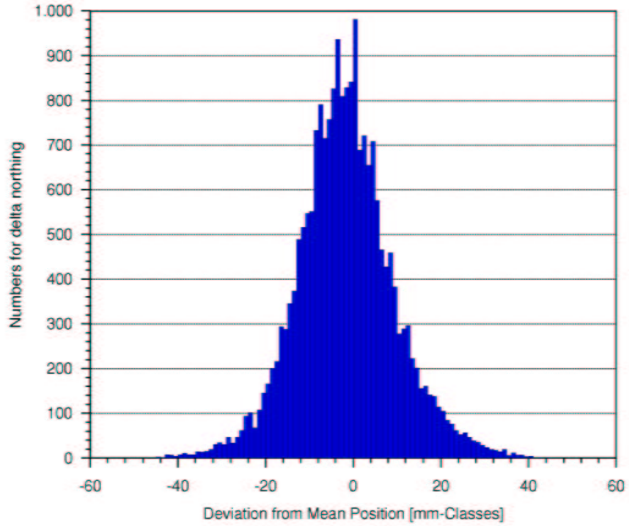
Bavaria/Rover Munich

- 7 reference stations
- 33 to 110 km
- State Space Model (SSM) FKP mode

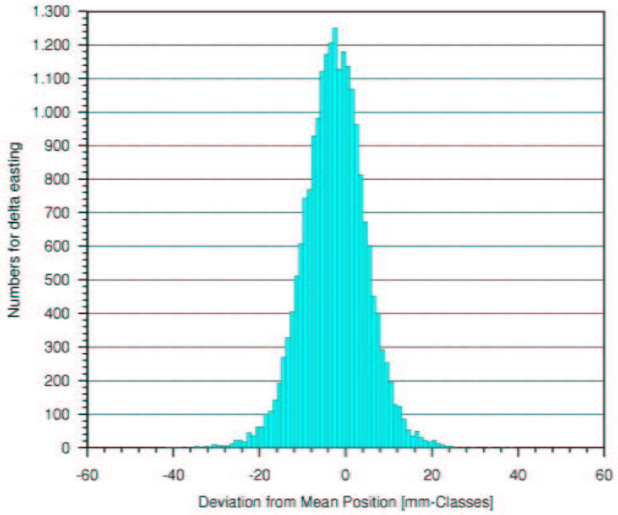


GNSMART: Sparse RTK Network (100 km) Bavaria/Rover Munich

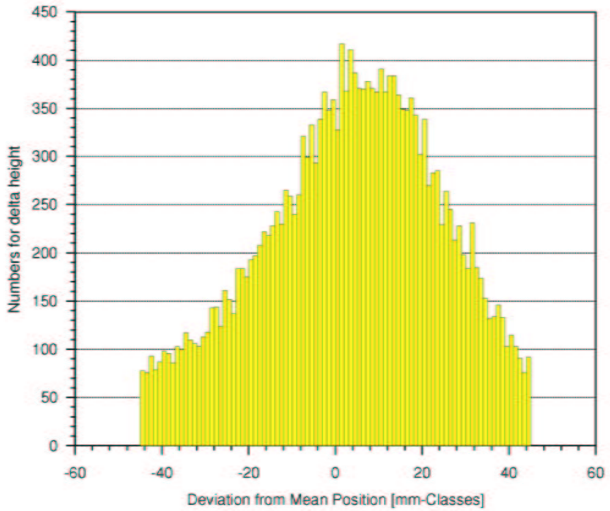
- 20978 fixes over 3 weeks in 2001
- 42 to 61 km distance to reference stations



Northing +/- 11.1 mm



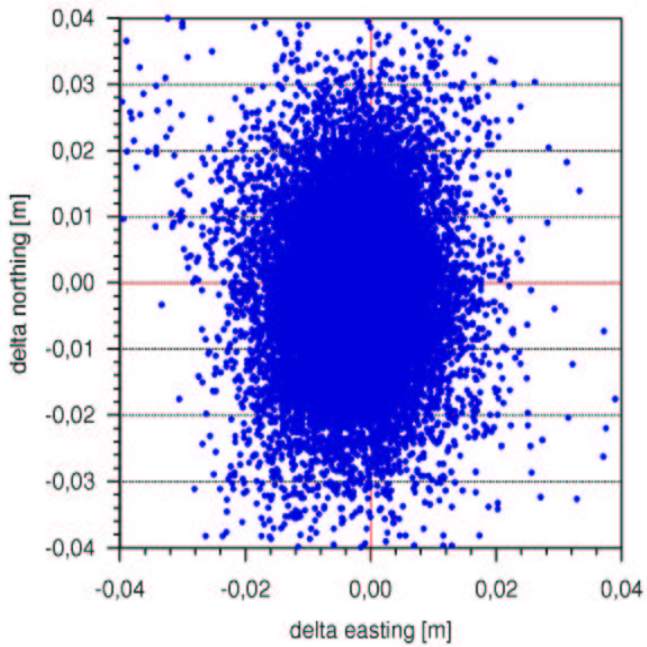
Easting +/- 7.3 mm



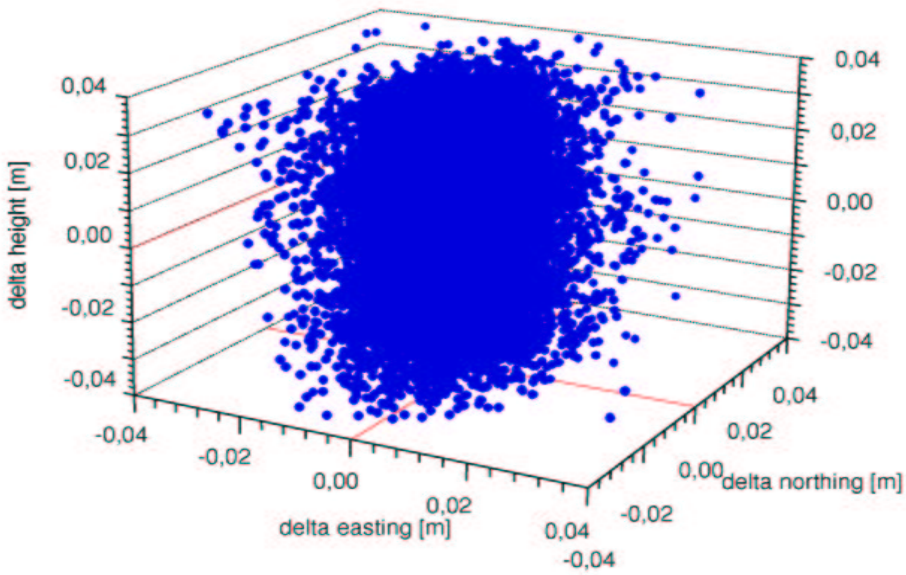
Height +/- 21.7 mm

GNSMART: Sparse RTK Network (100 km) Bavaria/Rover Munich

- 20978 fixes over 3 weeks
- 42 to 61 km distance to reference stations



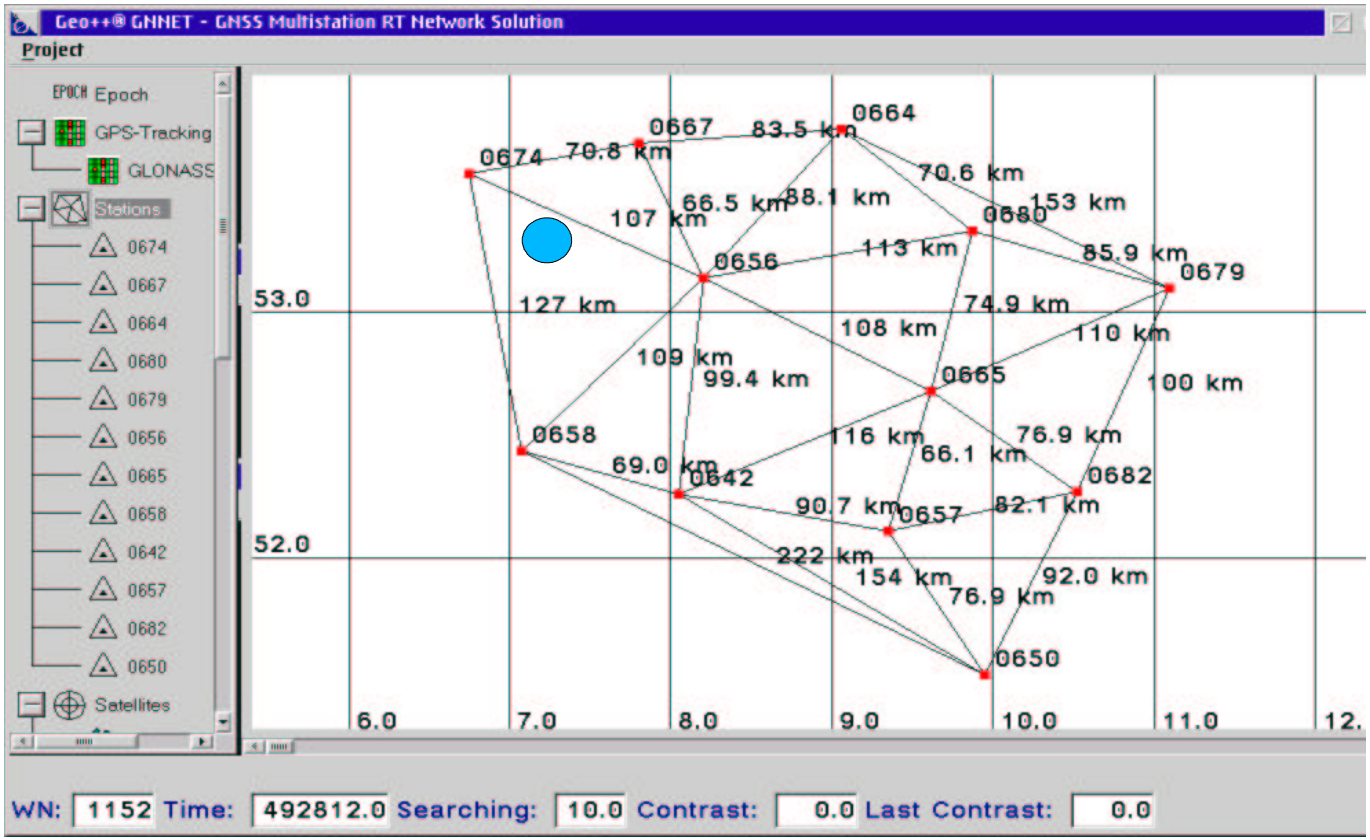
2D Scatter Plot +/- 13 mm



3D Scatter Plot +/- 25 mm

GNSMART: Sparse RTK Network
SAPOS Niedersachsen (12 Stations)

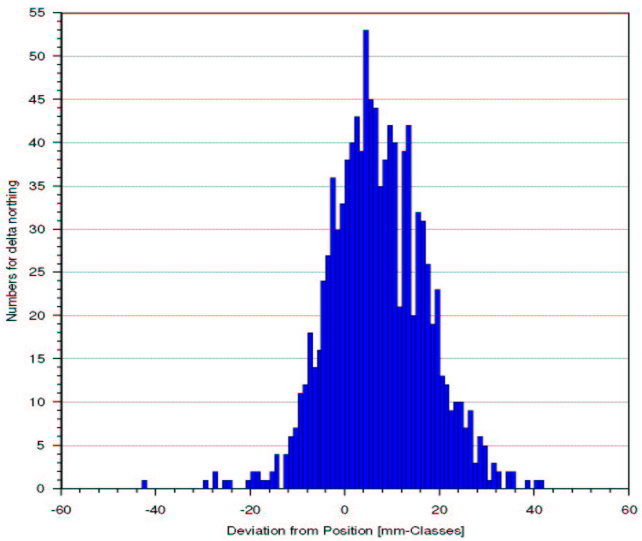
- Complete area 300 x 400 km
- 12 reference stations
- 66 to 107 km
- State Space Model (SSM) FKP mode

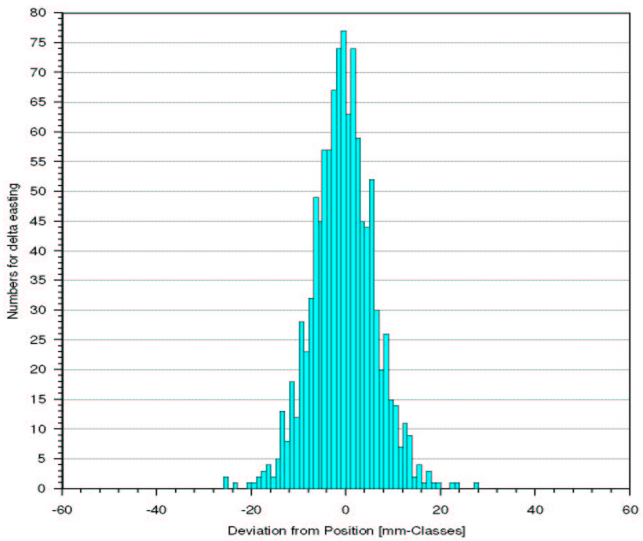


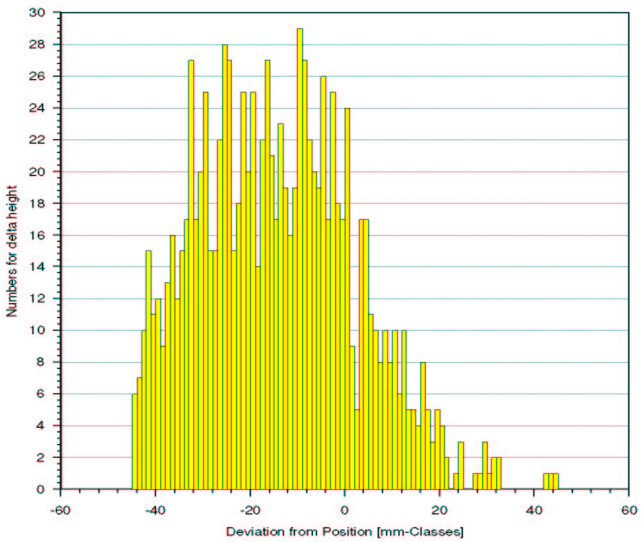
- rover 0645 position

GNSMART: Sparse RTK Network
SAPOS Niedersachsen (12 Stations)

- Rover 0645, 1065 fixes over 24 h
- 51.5 km distance to closest reference station



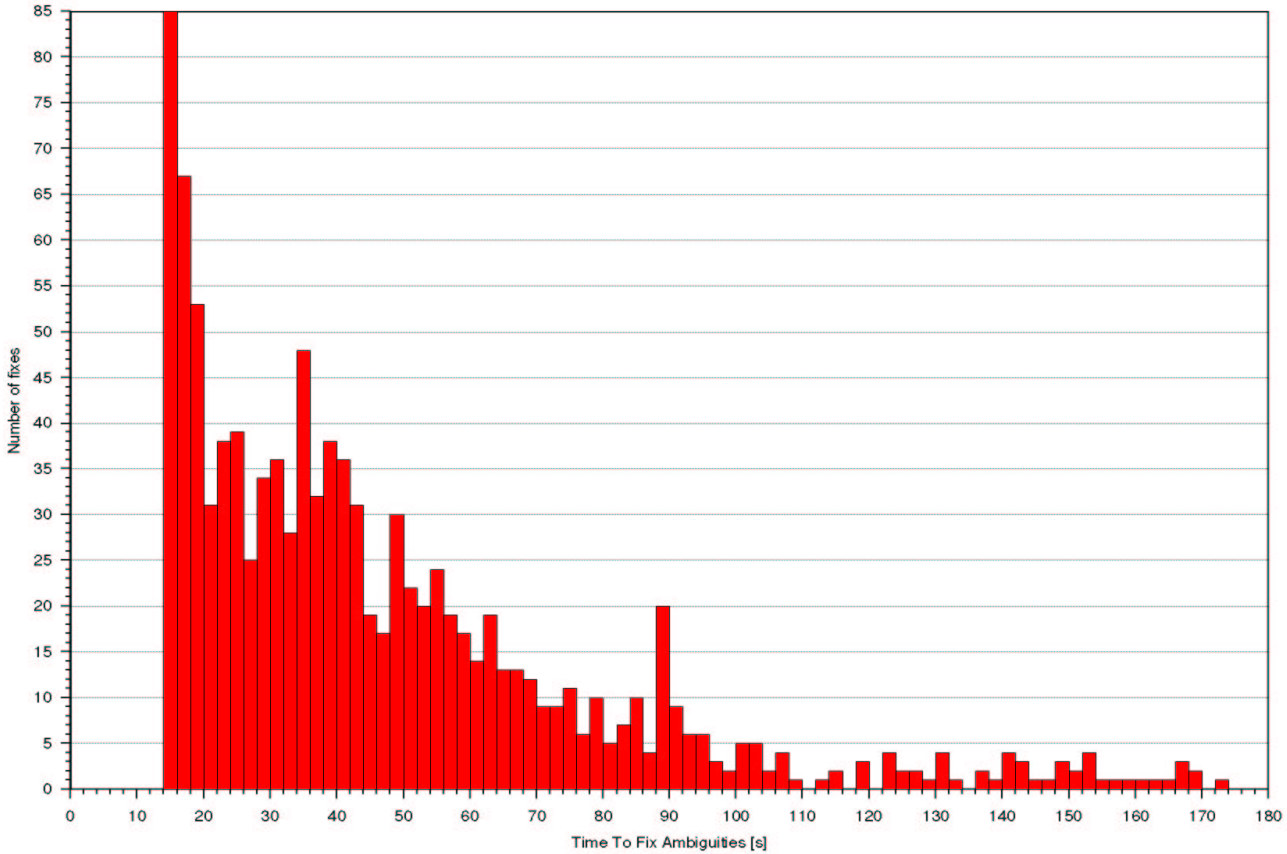




Northing +/- 12.3 mm Easting +/- 6.6 mm Height +/- 22.7 mm

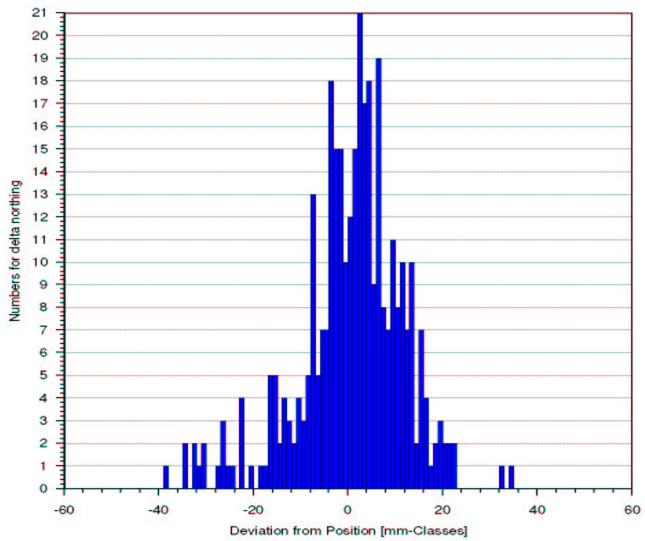
GNSMART: Sparse RTK Network
SAPOS Niedersachsen (12 Stations)

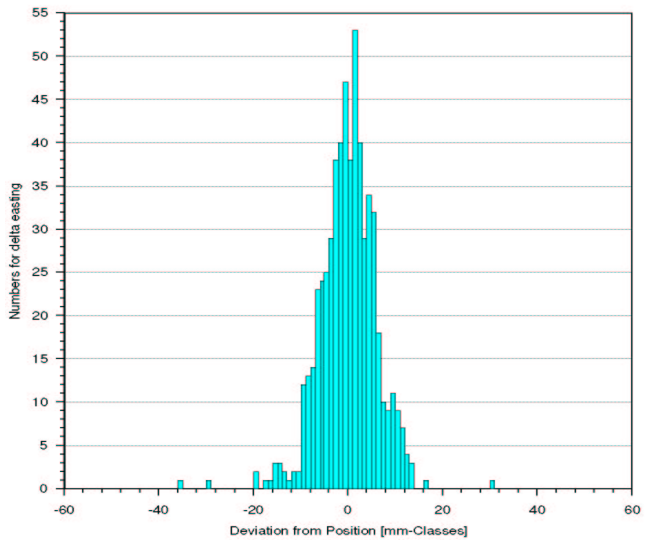
- TTFA (time to fix ambiguity)-histo gram
- Rover 0645
- 1065 Fixes
- Mean 51 s

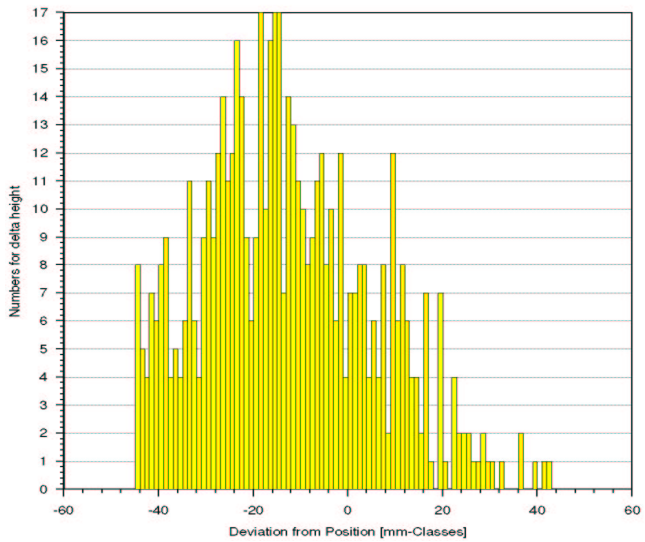


GNSMART: Sparse RTK Network
SAPOS Niedersachsen (12 Stations)

- Rover 0645, 583 fixes over 12 h with stochastic troposphere
- 51.5 km distance to closest reference station



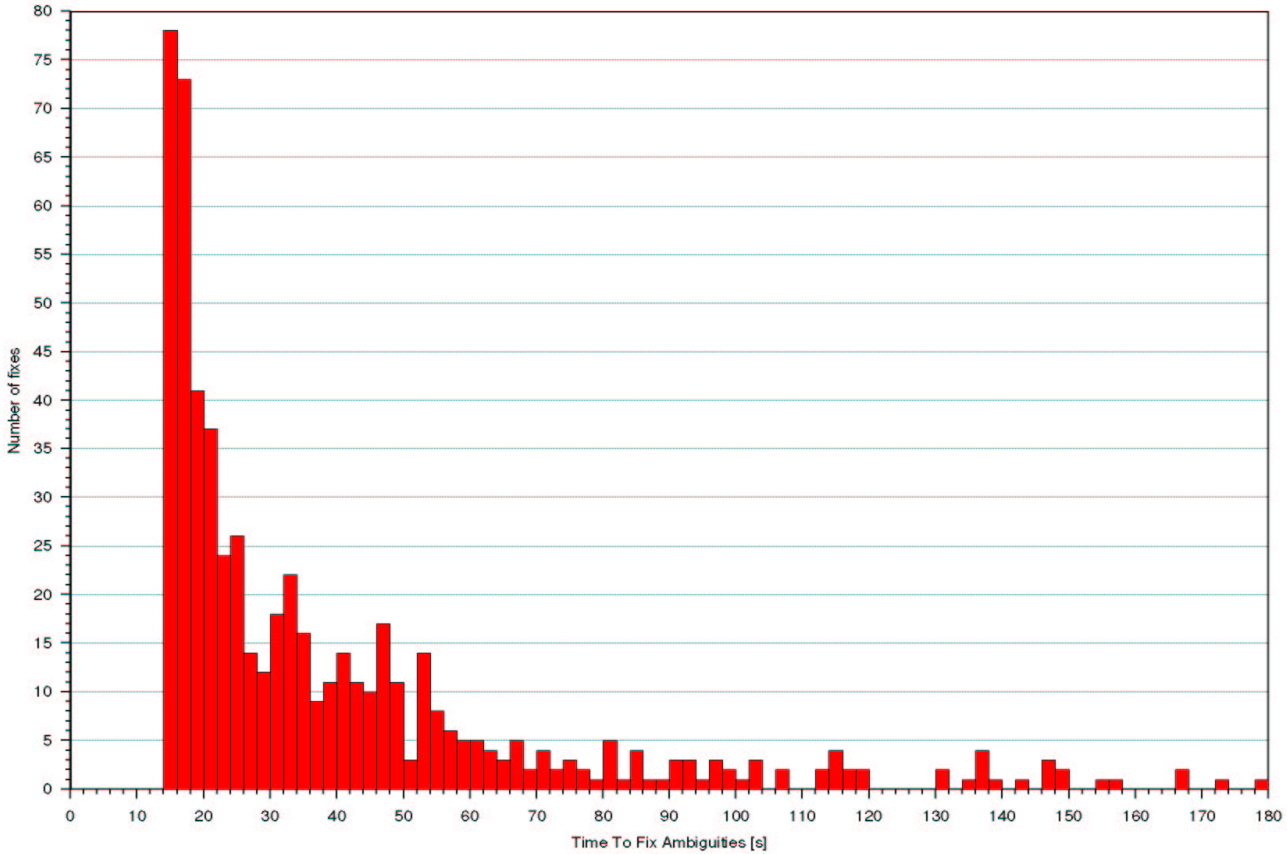




Northing +/- 12.1 mm Easting +/-6.0 mm Height +/- 23.2 mm

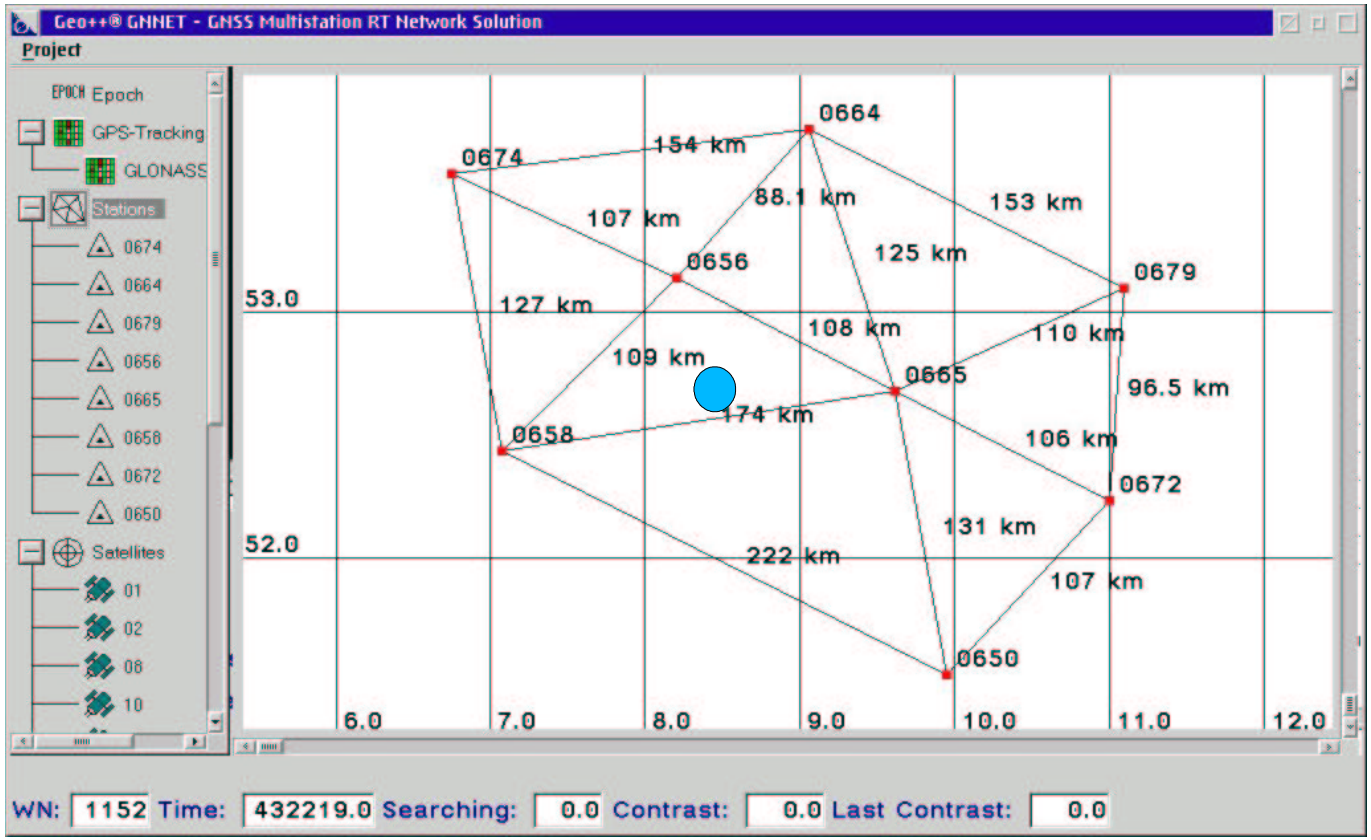
GNSMART: Sparse RTK Network
SAPOS Niedersachsen (12 Stations)

- TTFA (time to fix ambiguity)-histo gram
- rover 0645
- 583 fixes
- Mean 43 s
- with stochastic Troposphere



GNSMART: Sparse RTK Network
SAPOS Niedersachsen (8 Stations)

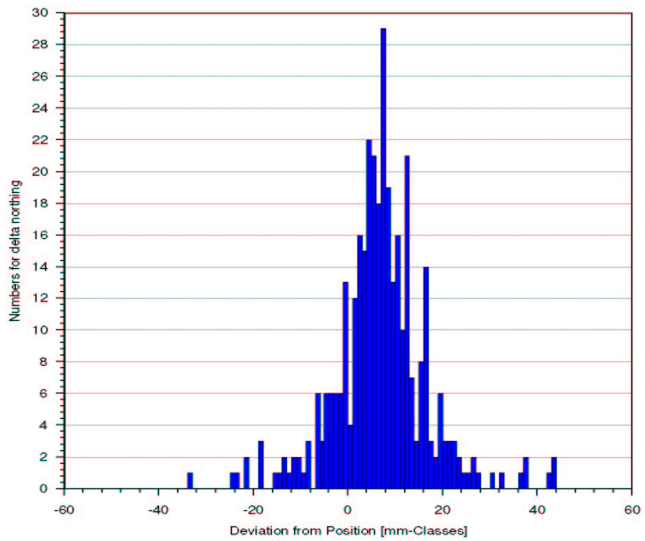
- complete area 300 x 400 km
- 12 reference stations
- 96 to 222 km
- State Space Model (SSM) FKP mode

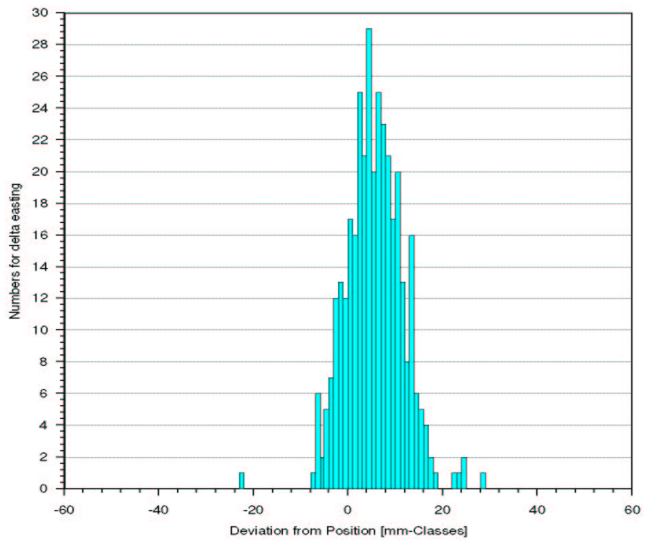


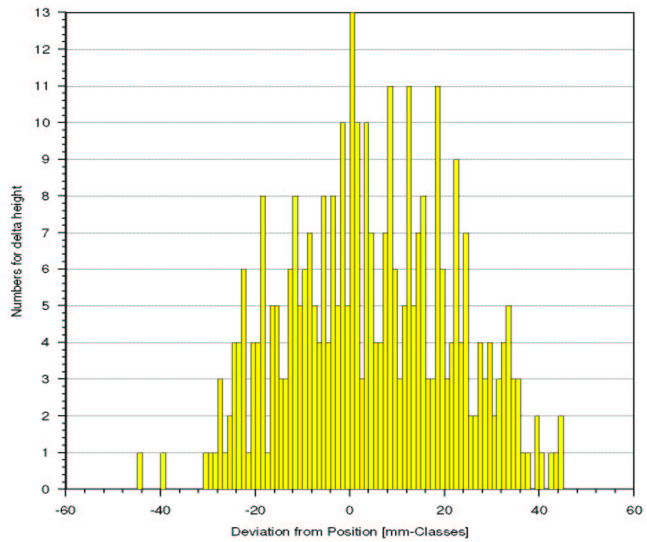
- rover 0654 position

GNSMART: Sparse RTK Network
SAPOS Niedersachsen (8 Stations)

- Rover 0654, 354 fixes over 12 h with stochastic trop.
- 65.4 km distance to closest reference station



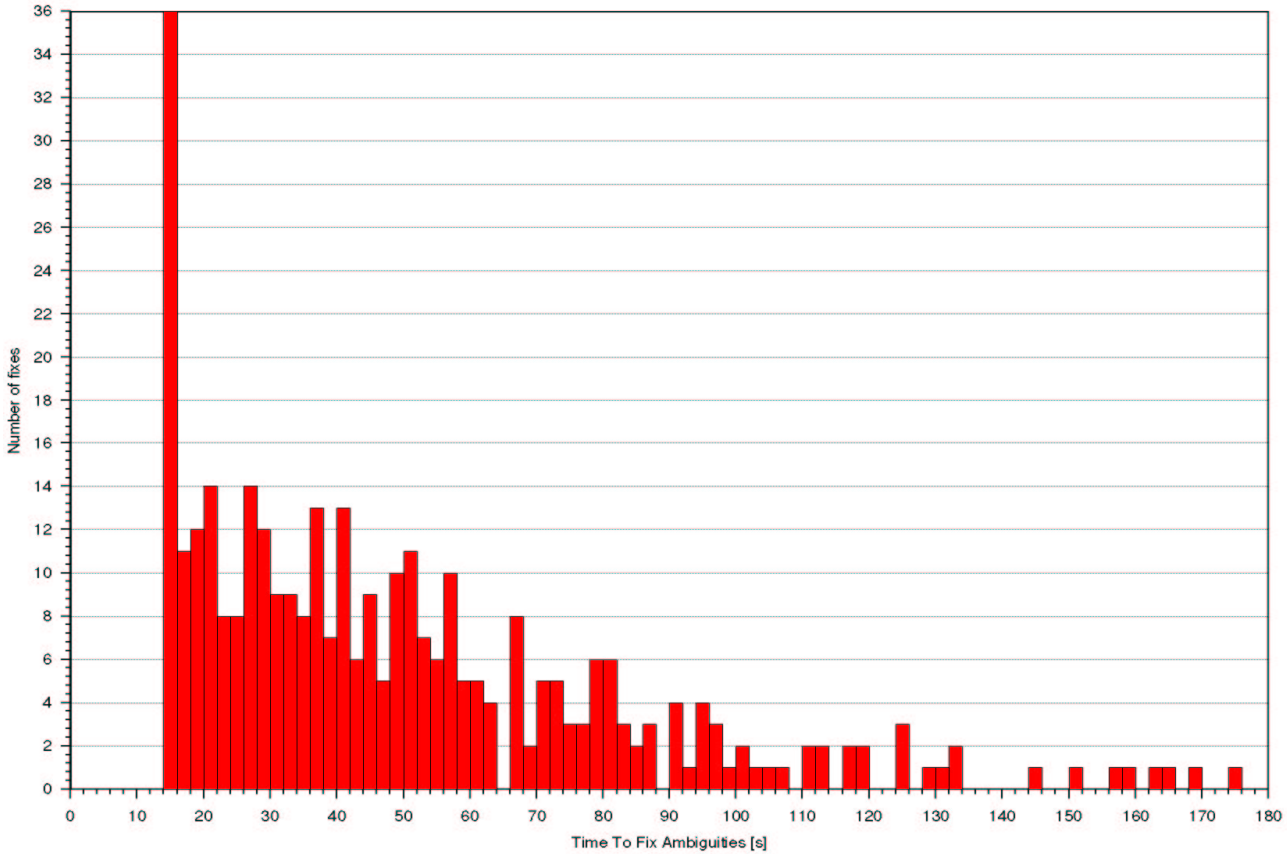




Northing +/- 13,0 mm Easting +/- 8,6 mm Height +/- 18,9 mm

GNSMART: Sparse RTK Network
SAPOS Niedersachsen (8 Stations)

- TTFA (time to fix ambiguity)-histogram
- rover 0654
- 354 fixes
- Mean 58 s
- with stochastic Troposphere



Geo++® GNSMART


thank you for your attention
... artist view of Geo++® building in Garbsen