Benefits of State Space Modeling in GNSS Multi-Station Adjustment

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Content

- Introduction
- State Space Model
  - Examples
- State Space Representation

Network RTK: Network Tasks

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- 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

    -> State Space Model

- secondary task
  - represent network information to be used by rovers
    - distance dependent errors
    - reference station dependent errors

    -> State Space Representation
    -> Observation Space Representation

State Space Model

State Space Model

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- Idea: model ERROR SOURCES instead of ERROR INFLUENCE
  - Error Influence: observation space
  - Error sources: state space

- all error sources build up the State Space Model (SSM) of current status of all GNSS error sources

- State Space Model consists of
  - model algorithms
  - model parameters

- Model Parameters consist of
  - state vector of unknown parameters
  - complete variance/covariance matrix

State Space Model: Advantages

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- better representation of real physics
- separation of error sources with similar influence
  - ionosphere <-> L1/L2 group delay
  - troposphere <-> orbit
  - station multipath <-> antenna PCV
  - etc.
- redundancy
  - all stations contribute to error state
- prediction in time
  - low elevation ambiguity fixing
    -> increased availability
- prediction in space
  - sparse networks
    -> reduced costs
  - extrapolation
- special tasks
  - monitoring of moving reference stations

GNSMART: Redundancy

- Networks with large number of observing stations
  - make use of high redundancy through rigorous multi-station adjustment
- ==> Benefits
  - increase inter-station distance: Sparse RTK Networks
  - determine/reduce site dependent errors (Multipath)
  - improve accuracy of state information
  - improve reliability of state information
  - improve availability of state information
    - Lower elevation mask for ambiguity fixing for rising satellites

GNSMART: Network Size

- Networks with increased network size
  - better de-correlation of state parameters
    - orbits, troposphere, clocks
    - ionosphere, signal delays
  - Benefits
    - state space representation (Standards ?)
    - state parameter exchange
    - wide range coverage
    - use of wide range communication media

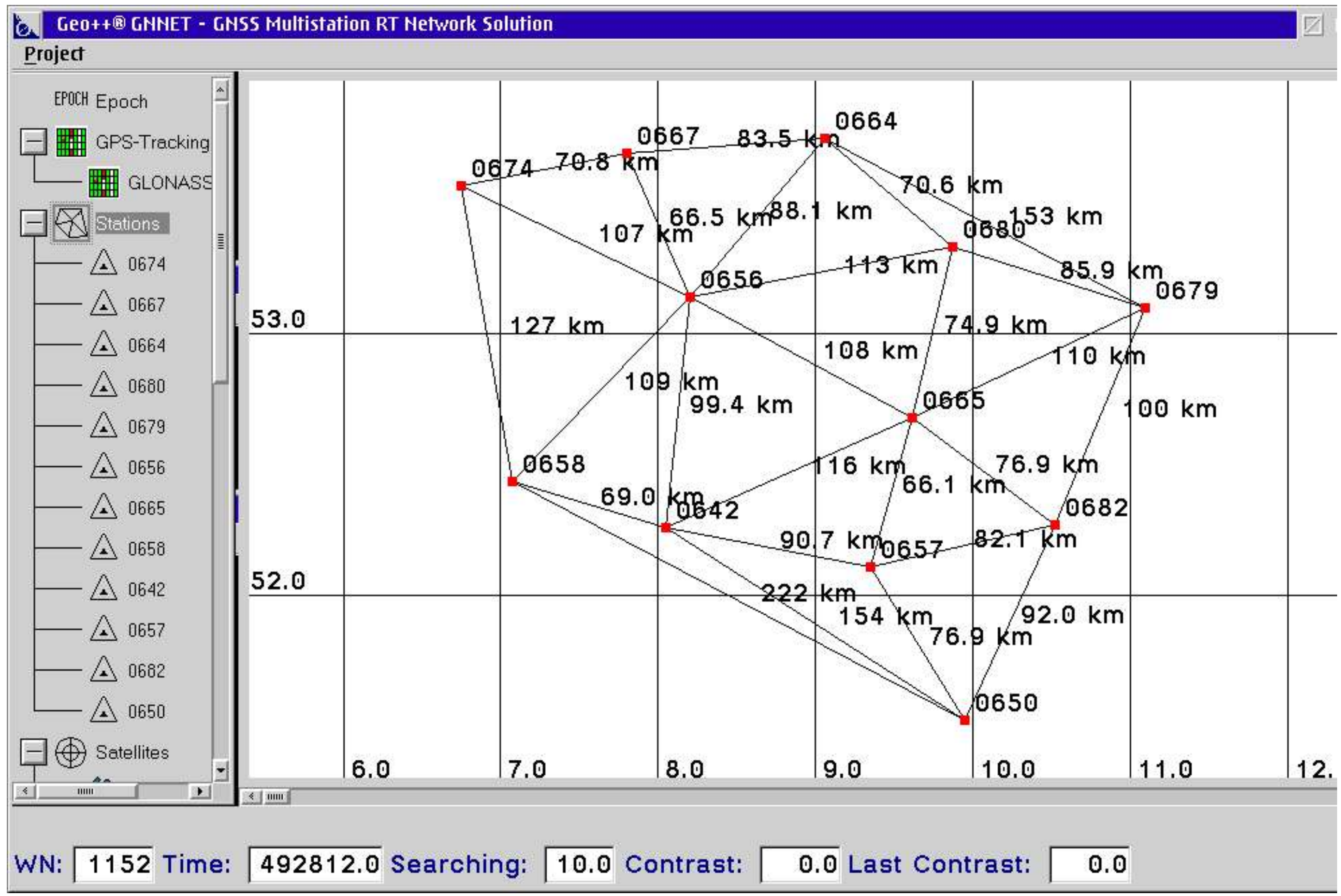
Hierarchical + Cooperating Networks

- Exchange of state parameters including variance/covariance matrixes allows rigorous combination of networks:
  - Hierarchical networks
    - take advantage of better de-correlation of state parameters in large scale networks
    - provide network RTK service from small scale networks with higher density
  - Cooperating networks
    - increase combined network size (state parameter de-correlation)
    - increase network performance through higher redundancy

Examples

Robust from Redundancy

- robust against single reference station
  - failure or
  - errors
- all state parameters can be estimated even if one stations is off
- only small reduction in accuracy and availability (TTFA)



GNSMART: Sparse RTK Network

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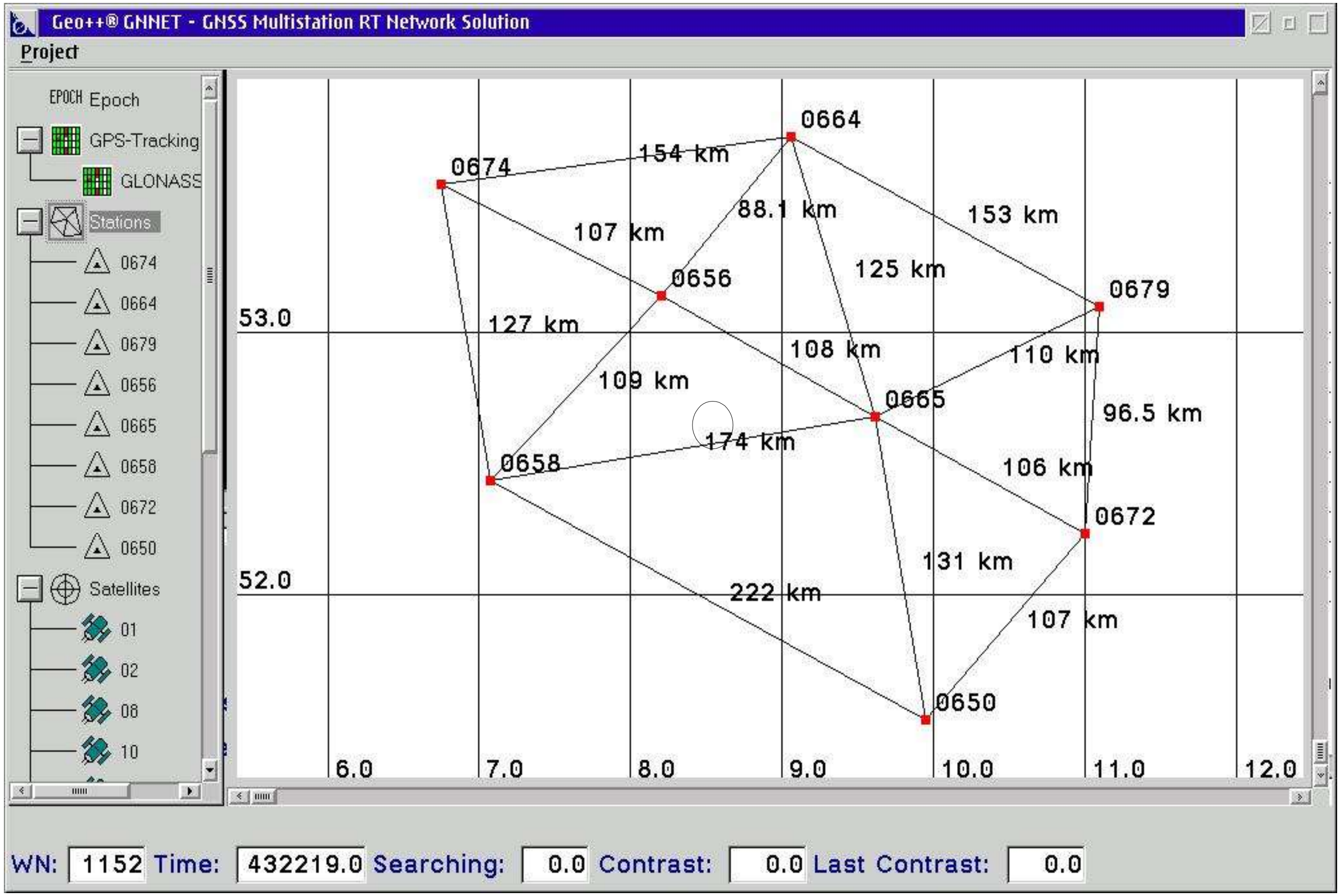
Example: SAPOS Niedersachsen

- complete area 300 x 400 km
- normally:
  45 reference stations
  40 to 70 km
- reduced to:
  8 reference stations
  96 to 222 km
- State Space Model (SSM) FKP mode



-> no problem for GNSMART network

GNSMART: Sparse RTK Network
SAPOS Lower Saxony (8 Stations)

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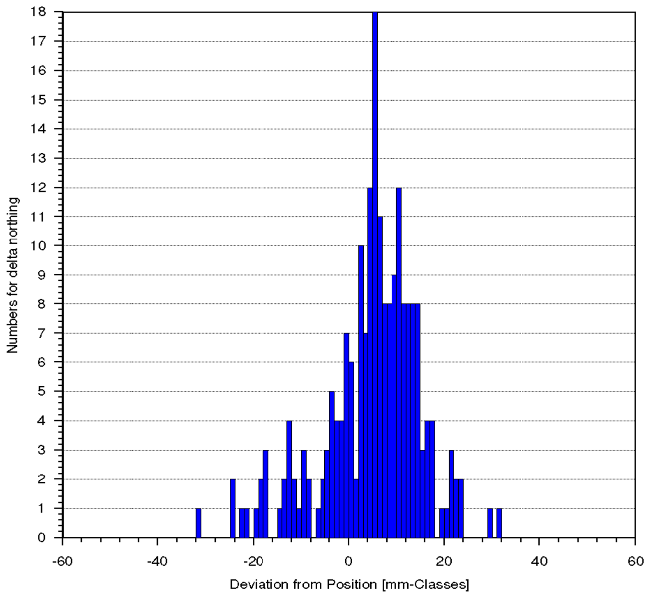
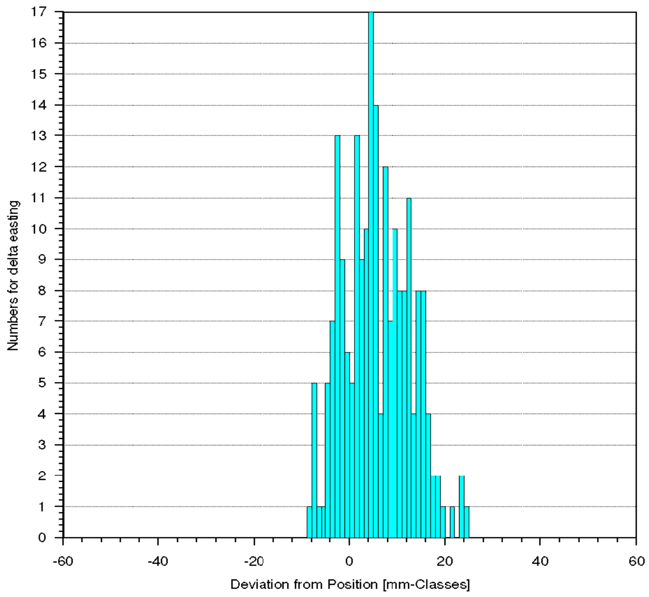
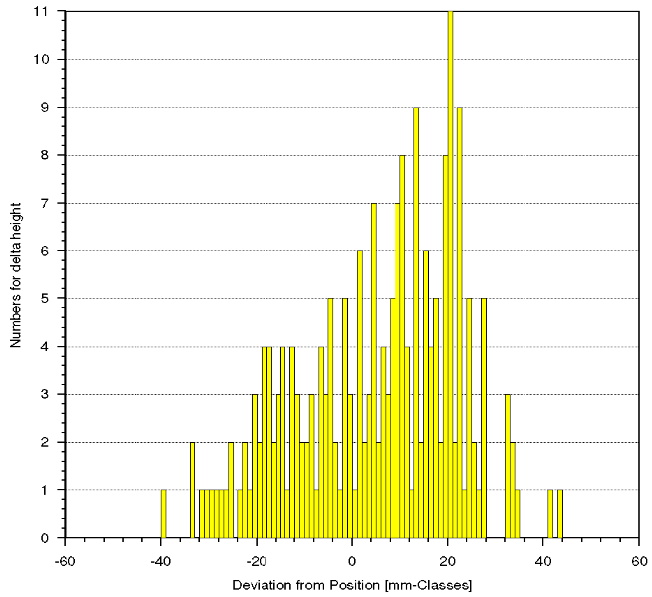
- Rover 0654, 354 fixes over 12 h with stochastic trop.
- 65.4 km distance to closest reference station





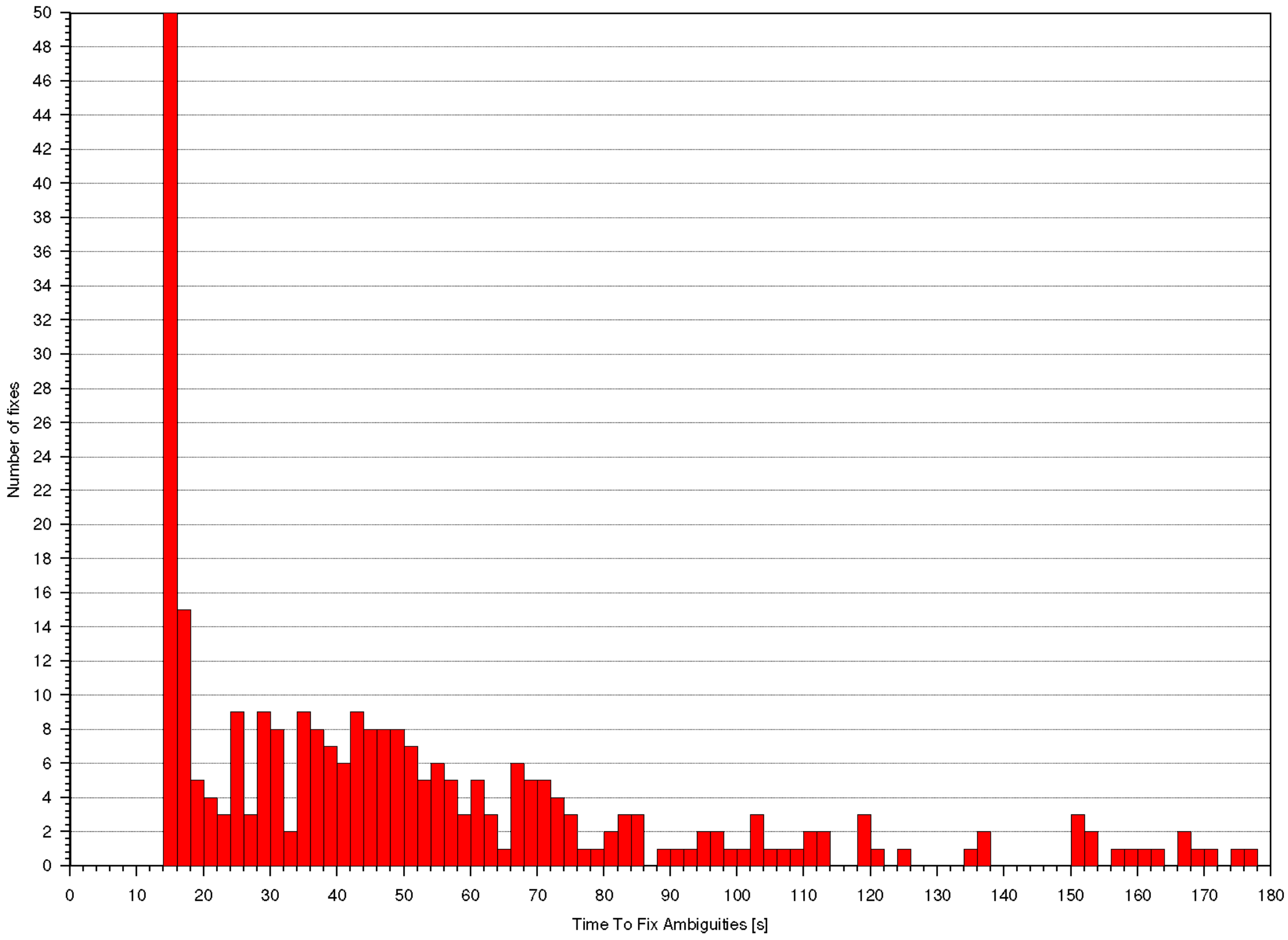


Northing +/- 13,0 mm Easting +/- 8,6 mm Height +/- 18,9 mm

-> still good accuracy for 2D, height acceptable

GNSMART: Sparse RTK Network SAPOS Lower Saxony (8 Stations)

- TTFA (time to fix ambiguity)-histogram
- 583 fixes
- Mean 43 s
- rover with stochastic troposphere



-> significantly increased TTFA on rover

Mixed distances in Network

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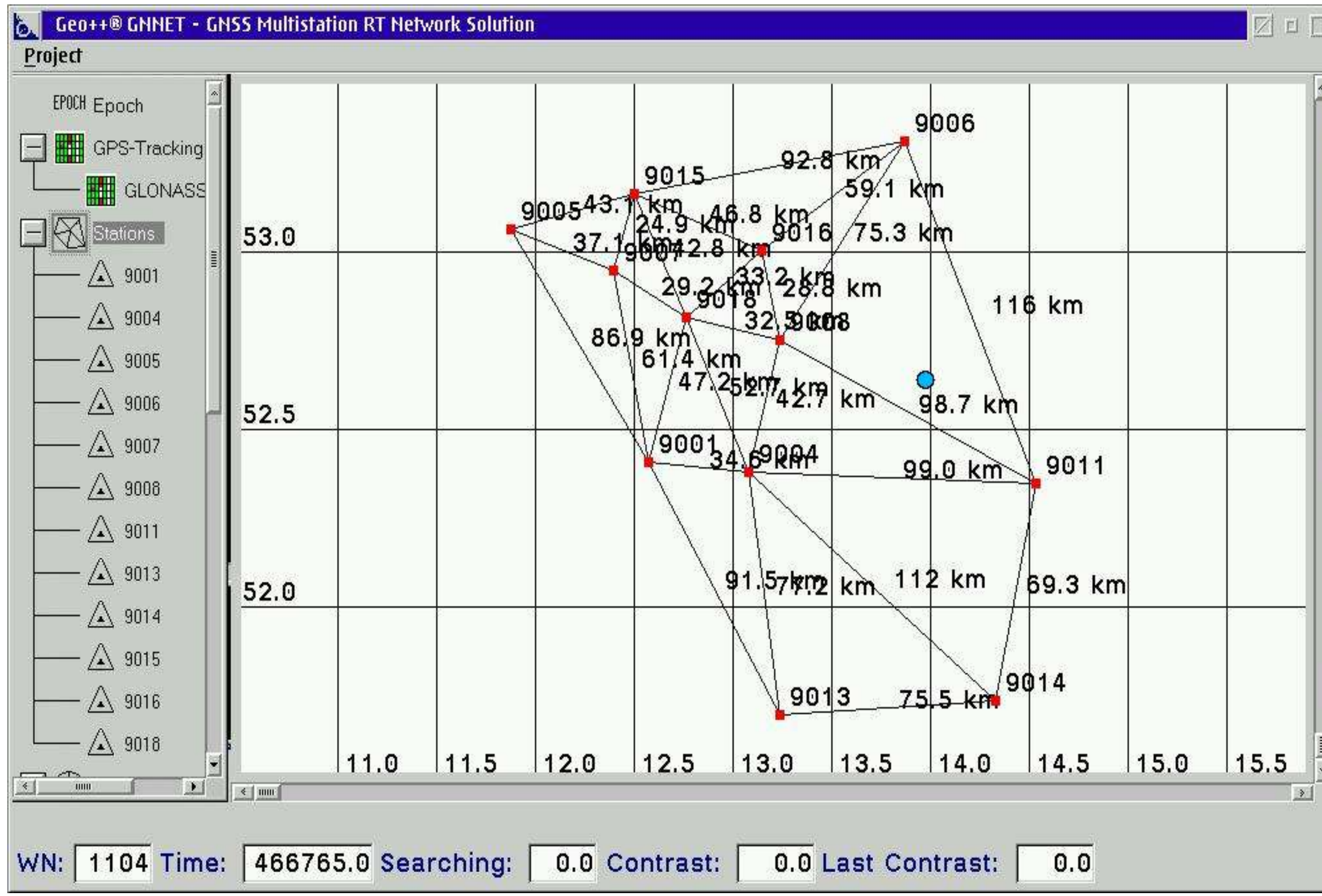
- combination of different reference station distances in one network
- small distances in developed areas
- long distances in desert areas

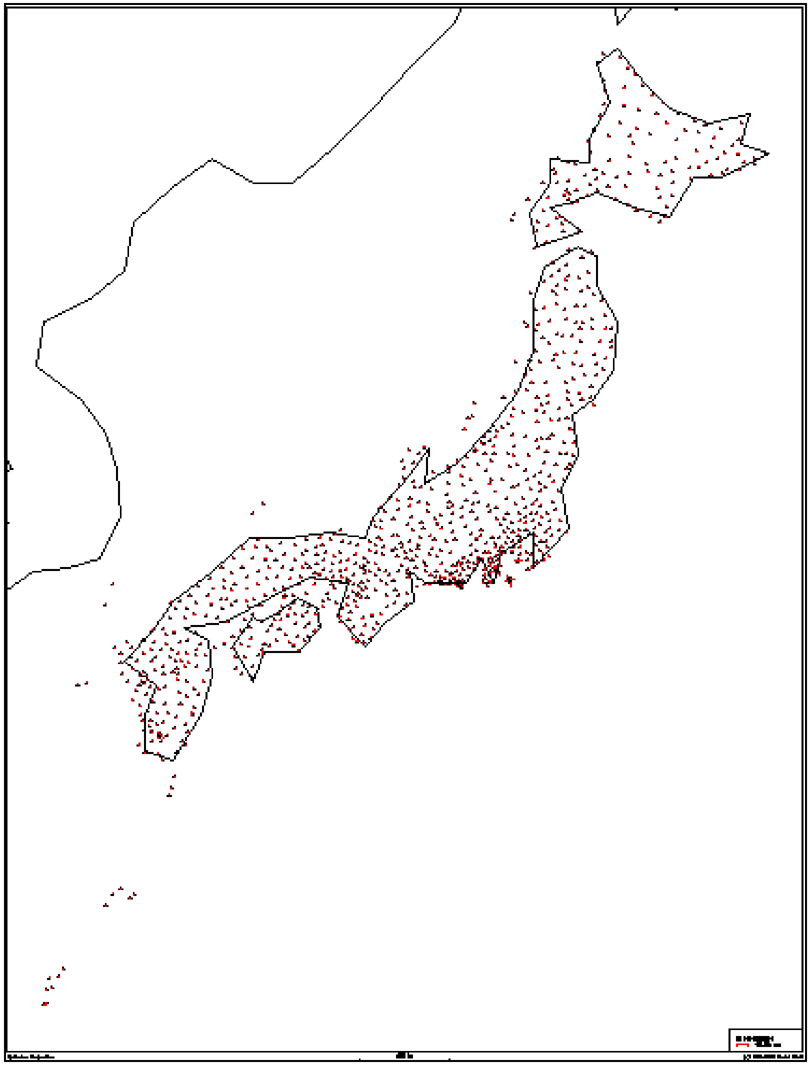
- Example: Brandenburg/Germany



Large Networks

- nation-wide networks
- 1200 GSI stations
- 300-350 in reference network
- co-operating sub-networks
- homogenous network
  from user-view

- Example:
  PAS network (Mitsubishi/Japan)
  - Dynamic Datum included



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State Space Representation of Network-RTK Information

GNSMART: State Space Representation

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- Advantages of State Space Representation (SSR) vs Observation Space Representation (OSR)
  - Broadcast Operation
  - Optimized Bandwidth
    - 200-300 bps (SSR)
    - >=2400 bps (OSR-RTCM)
  - Information exchange between networks

- Disadvantages of SSR vs OSR
  - More complicated standardization due to necessity of consistent modeling

- Requirement: State parameters must maintain integer nature of carrier phase ambiguities

GNSMART: State Space Representation

- Transmission rates and validity

– Satellite clock	few seconds	global
– Satellite Orbit	10-30 minutes	global
– Ionosphere		
•	minutes	global
•	minutes	regional
– Troposhere	minutes	regional

- Higher transmission rates often useful
  - only for practical reasons (minimized acquisition time)

- ToDo: standardization of models

Conclusions

- GNSMART is based on State Space Model which allows
  - best robustness
  - high performance
  - mixed distances in networks
  - very large networks
  - sparse networks
  - co-operating networks
  - hiearchical networks
- GNSMART State Space Model is required for State Space Representation
  - prepared for future representation techniqes

Further Information

For **general information** on GNSMART State Space Model please refer to the Geo++ home page:

http://www.geopp.com/gnsmart

For **background publications** refer directly to the Geo++ Publications page:

http://www.geopp.com/publications/english/lit_e.htm