# Co-location of VLBI with other techniques in space: a simulation study

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# Reference frame and local ties

- today TRF is defined through not very well-connected networks of SLR, GPS, VLBI and DORIS

  → offsets between different space techniques are measured by ground-based surveys at stations with two or more space techniques

  → accuracy of the TRF is limited by the accuracy of these local ties

  → precise and stable local ties will cause improvements in the realization of the TRF

- Global Geodetic Observing System (GGOS):

  → realization of the terrestrial reference frame (TRF) with 1mm accuracy and 0.1 mm/year stability

# Co-location in space - concept

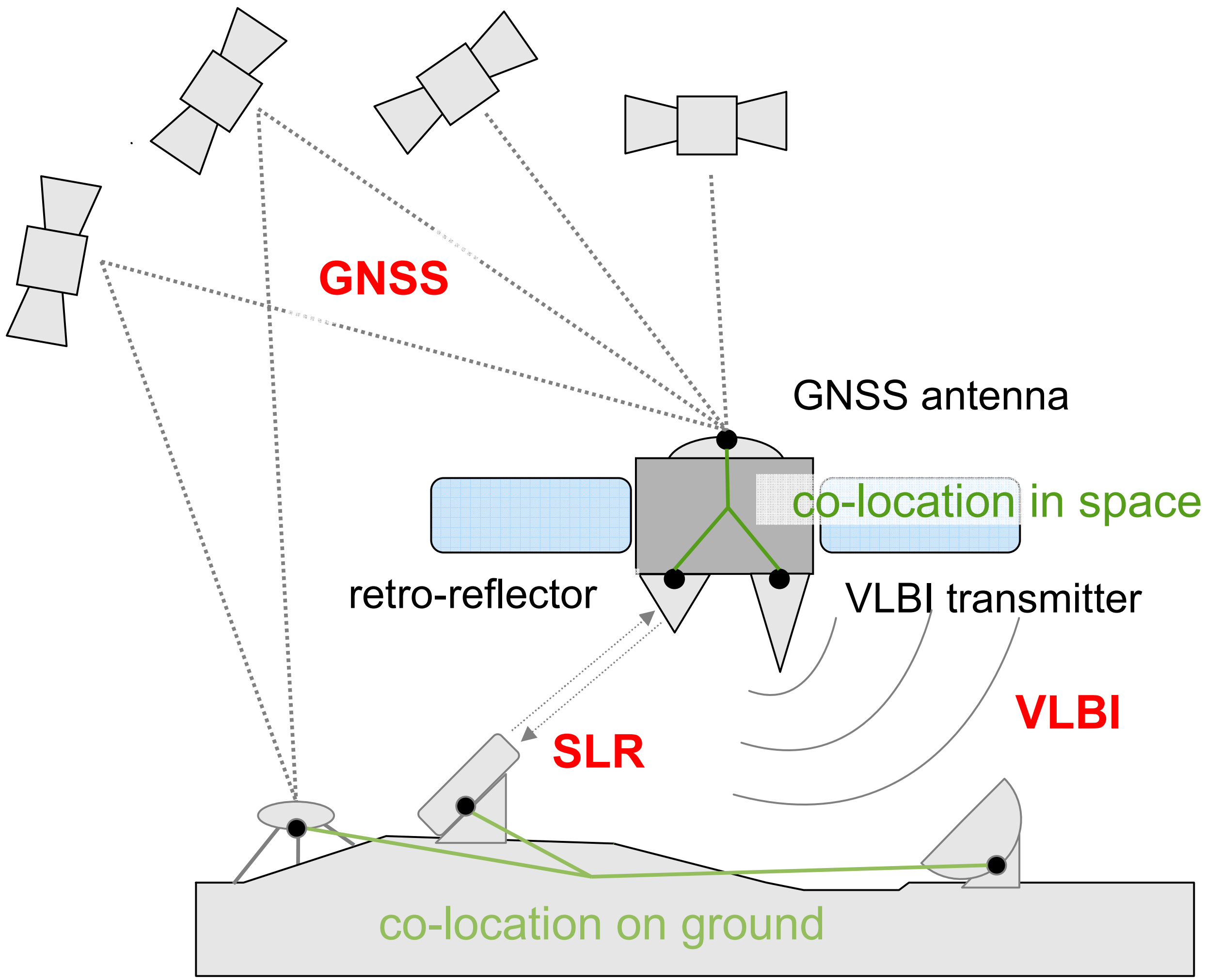
→ improvements in local ties and technique-specific effects

→ e.g. calibration of antennas

→ well-calibrated and designed spacecraft

- baselines between sensors are measured before satellite launch (~1mm accuracy)
- satellite positioning with 1cm accuracy (1mm using a satellite constellation)
- extremely simple spacecraft (no moving parts, no sloshing fuel, stable center of mass)

# Co-location in space - concept



# Co-location in space - satellites

- GPS, GLONASS, Compass/ Beidou and GIOVE/Galileo
- Jason-1, TerraSAR-X, Tandem-X, Envisat, CHAMP, GRACE, GOCE

→ co-location in space is typically used for orbit estimation and validation

**Geodetic Reference Antenna in Space (GRASP)**

- GNSS-antenna,
  SLR retro-reflector, VLBI and DORIS transmitters
- sun-synchronous orbit, altitude 1600 – 2500km
- total mission cost app. 150M$, launch date 2016

*(→ Bar-Sever, 2009)*

**NanoGEM**

- GNSS-antenna, SLR retro-reflector, VLBI transmitter
- sun-synchronous, polar orbit, altitude 700-800km
- nano-satellite → total mission cost a fraction of GRASP and possibility/goal to build up a small constellation

# VLBI transmitter onboard a satellite

- curved wave front

  → delay model for curved wave front: *Sovers et. al. (1998), Sekido and Fukushima (2006)*

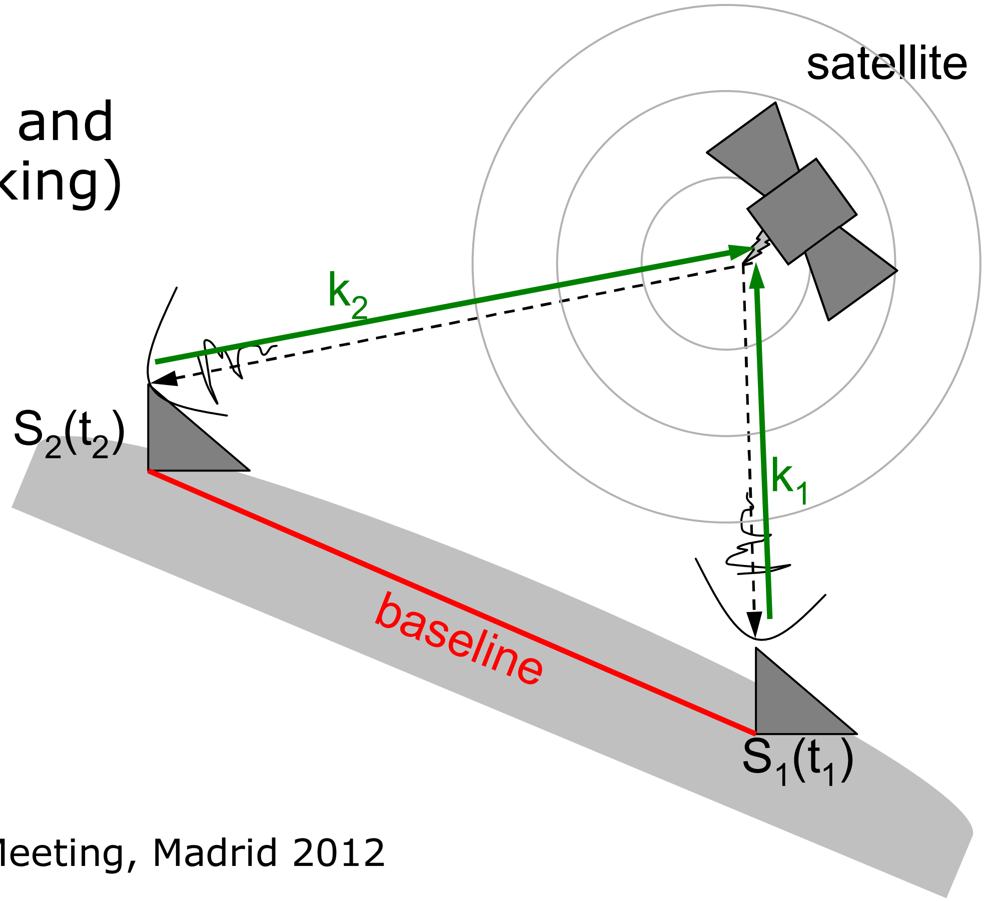
  → implemented in Bernese GPS Software based on the VLBI-version by Ralf Schmid

- known (a-priori) satellite position and fast moving source (satellite tracking)

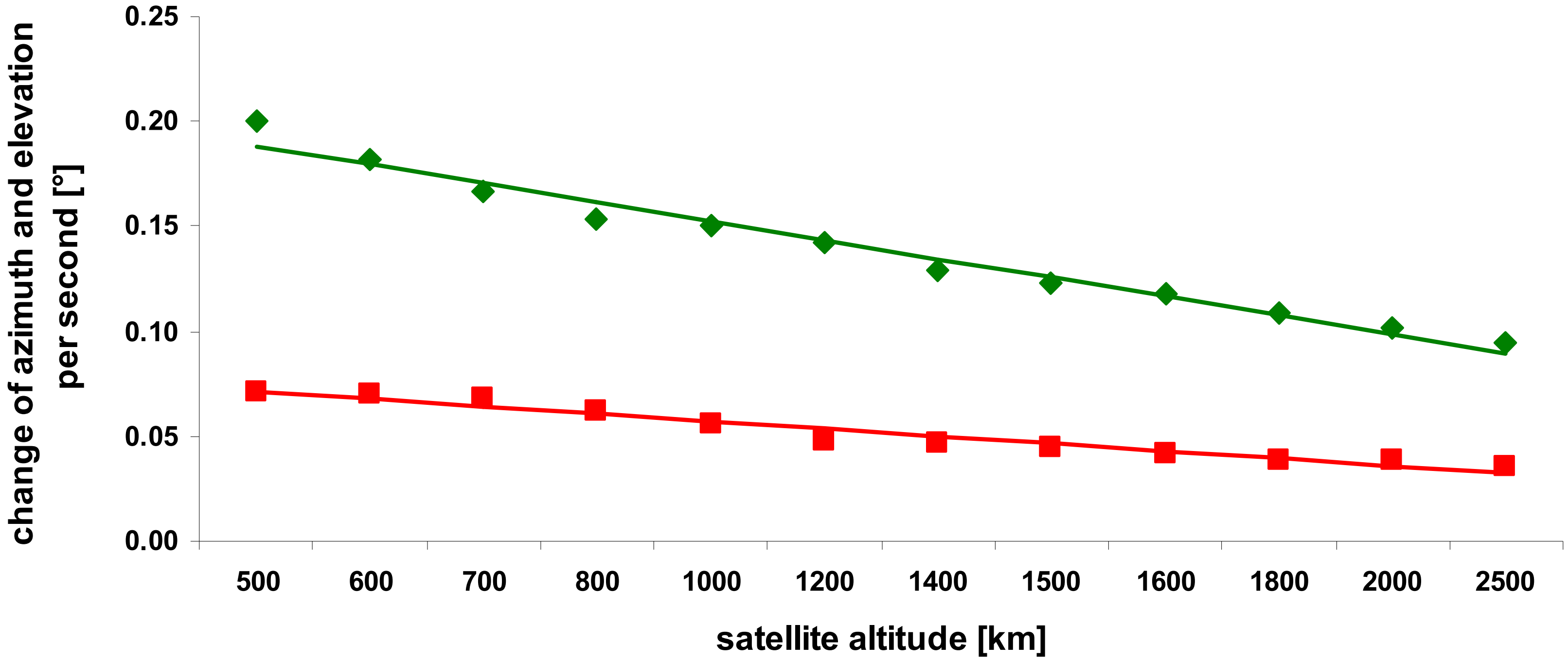
- maximal length of baselines and observation time interval is defined by the orbital design

  → crucial orbital elements:

  - satellite altitude
  - inclination



# Changing rate of elevation and azimuth




**GPS satellites: ~0.01°/s** *(Tornatore, 2010)*

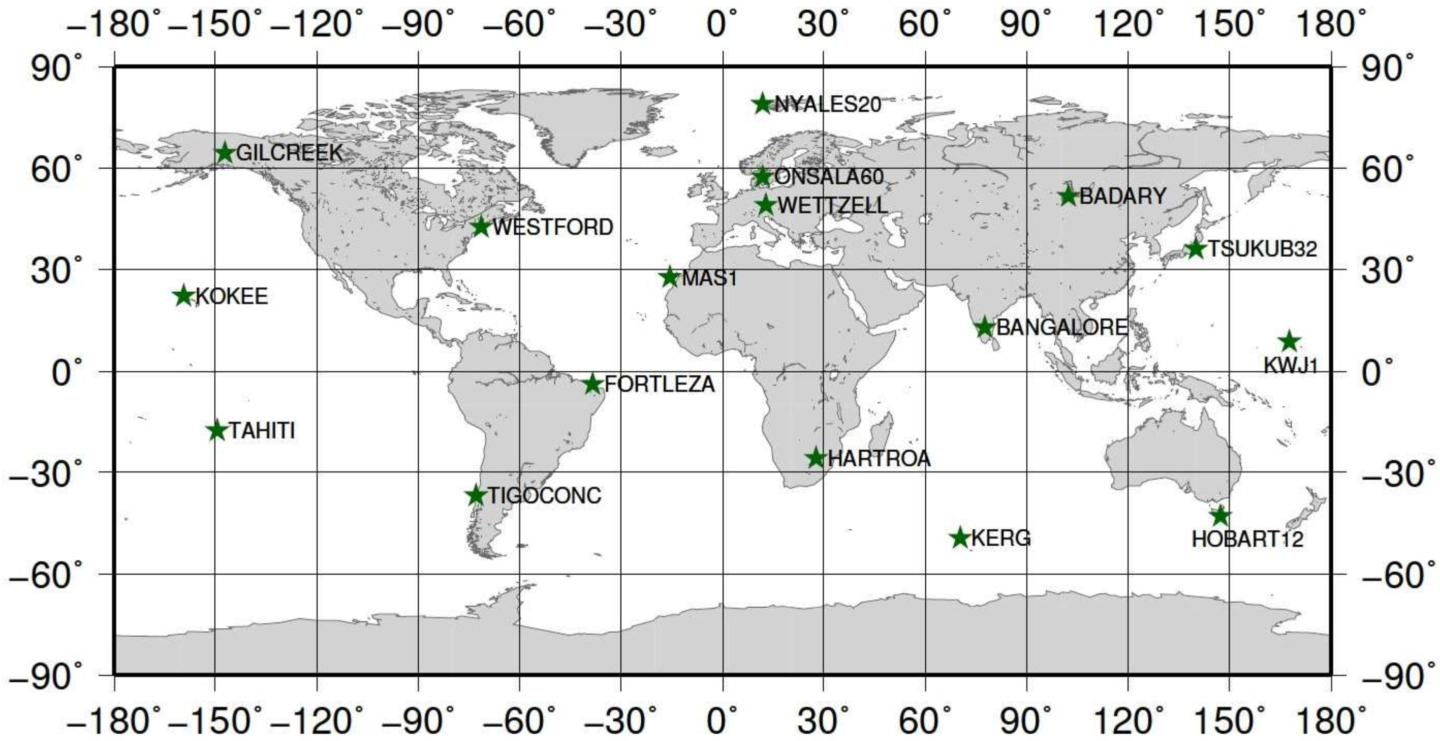
| **slew rates** | azimuth | elevation |
|---|---|---|
| Today | 1.5-12°/s | 0.7-3.1°/s |
| VLBI2010 | >6.0°/s | >2.1°/s |

# Simulation of a global network

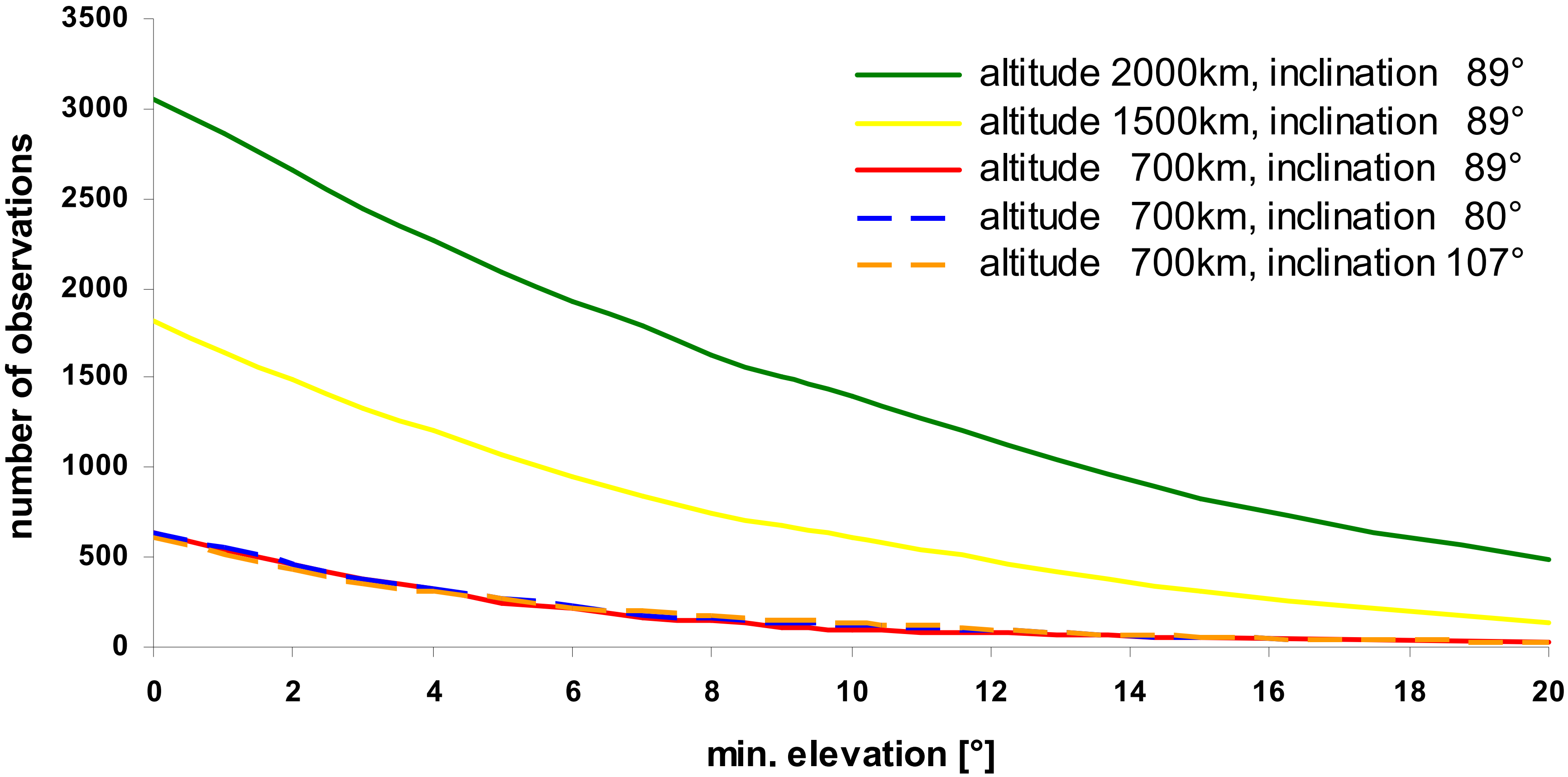
- simulation using different orbital elements
    - satellite altitude (700, 1500 and 2000km)
    - inclination (80°, 89° and 107°)
- global observing network with 17 existing or maybe future stations (*Wresnik et. al. 2009*)

- parameter estimation during data processing
    - troposphere zenith delay and gradients and
    - station coordinates
    - orbital elements

# Simulation of a global network



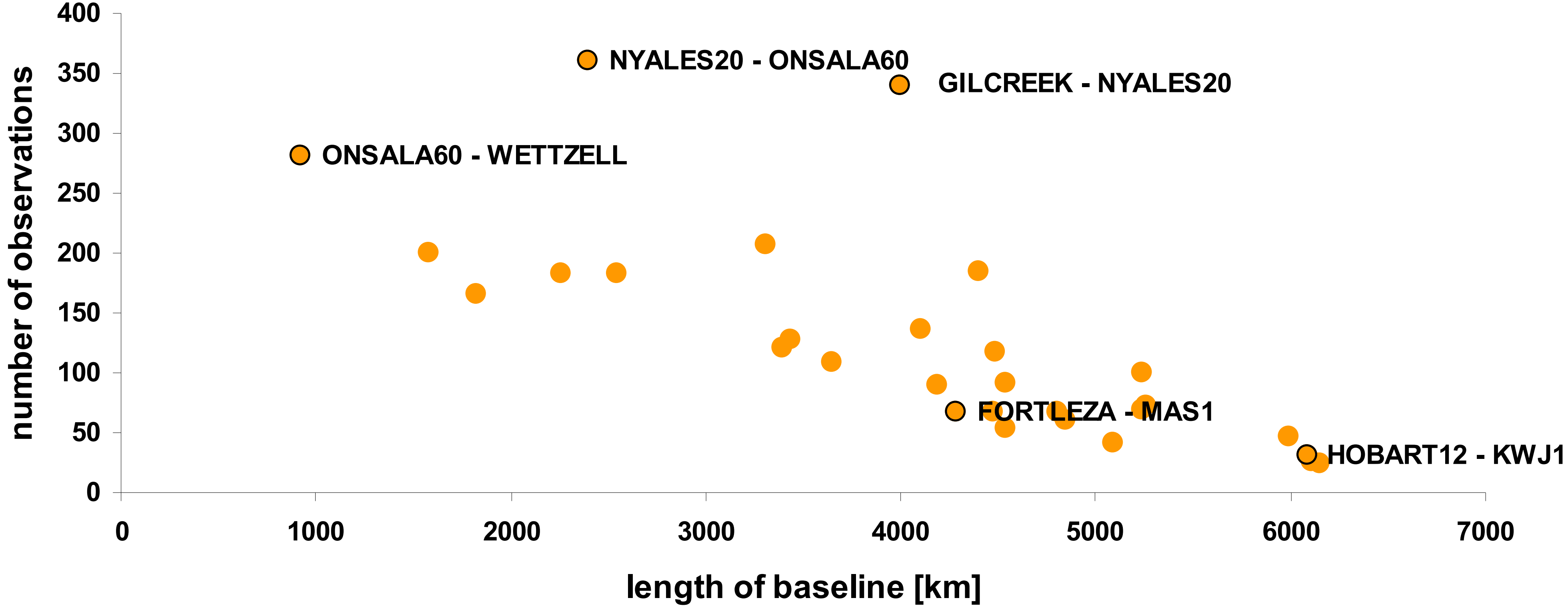
# Number of observations




→ one day of observations,
integration time per observation 30 seconds

# Number of observations

- min. elevation angle set to 5°
- satellite altitude 2000 km

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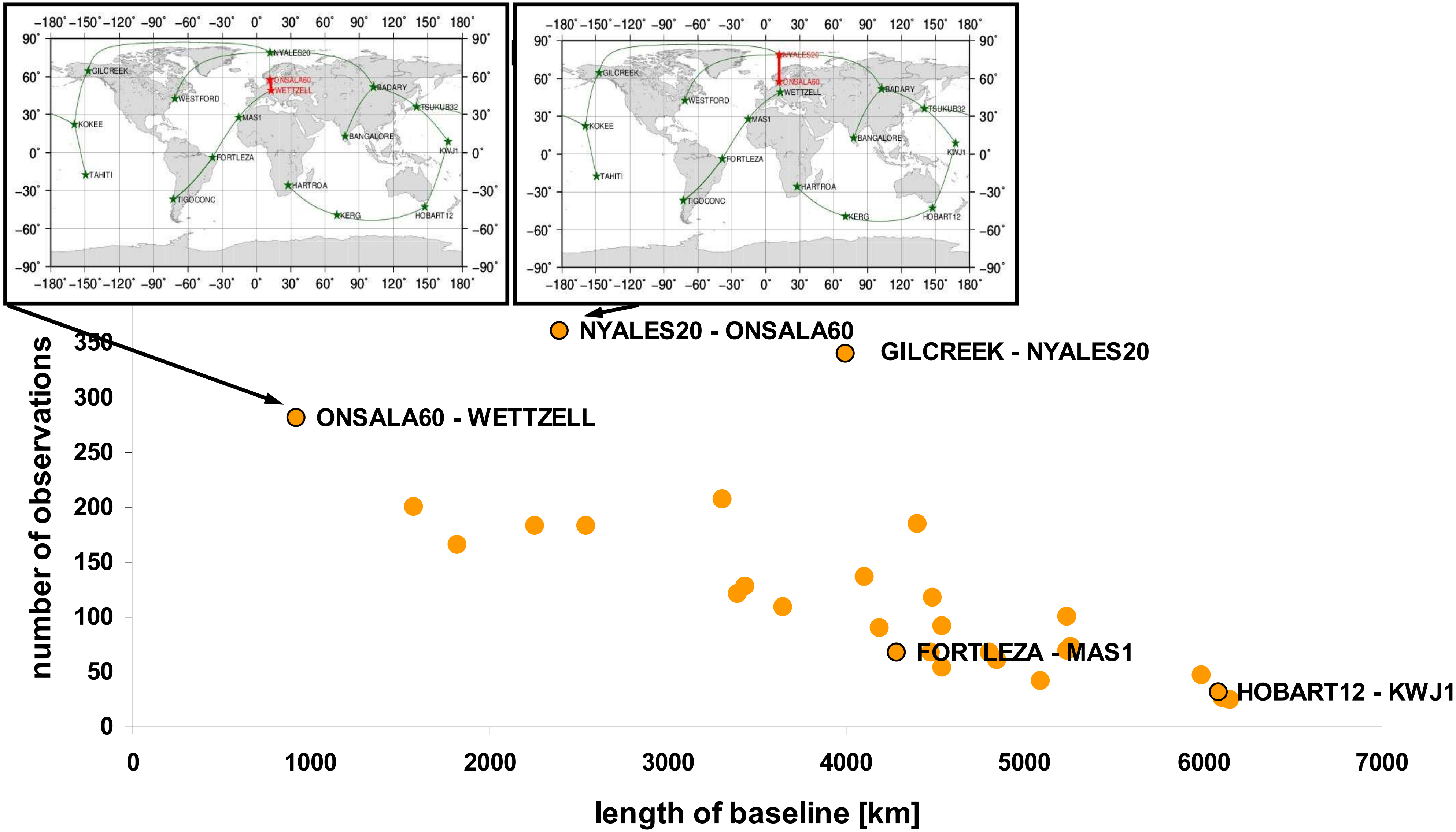
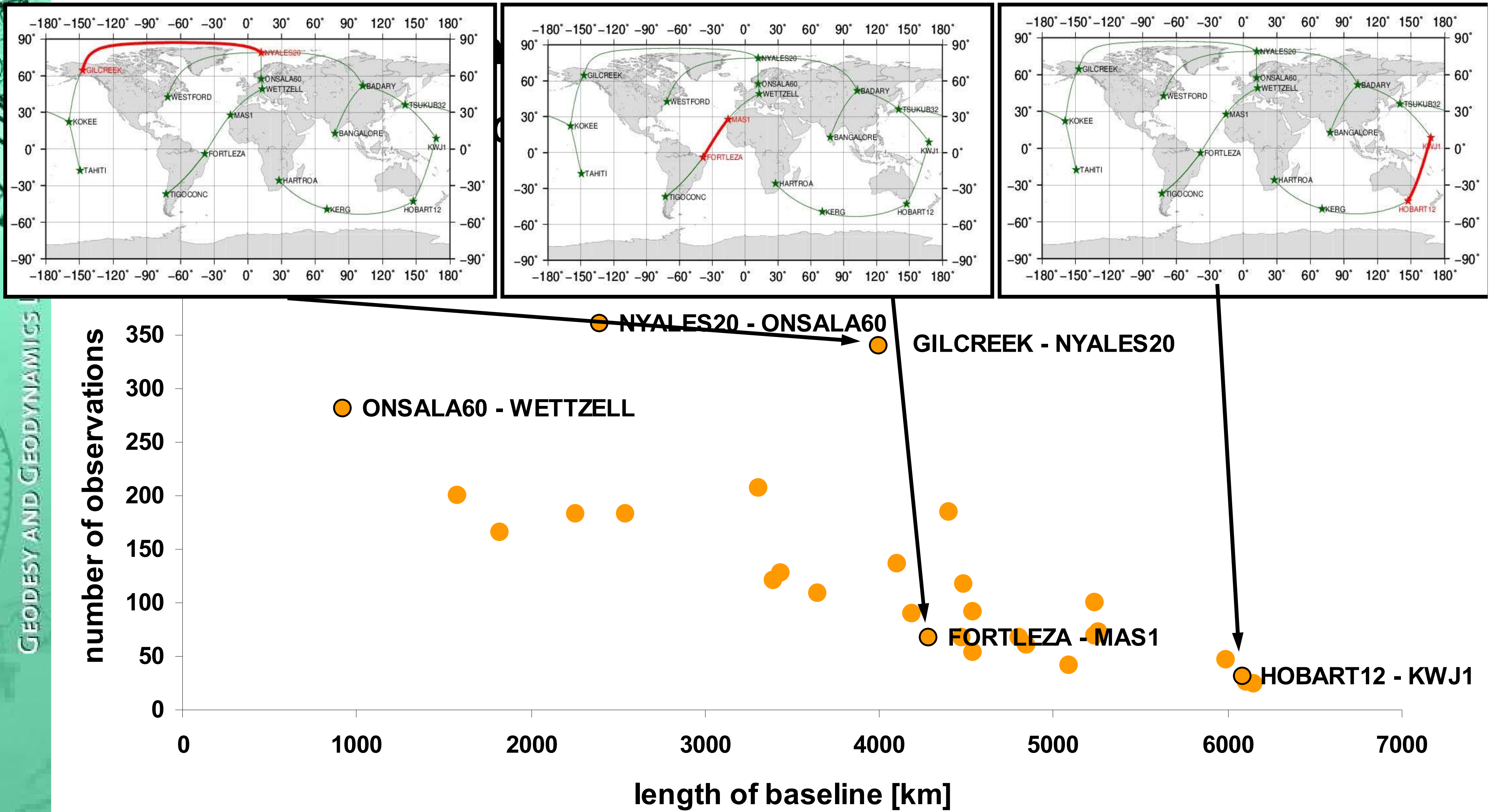
# Number of observations



# Number of observations

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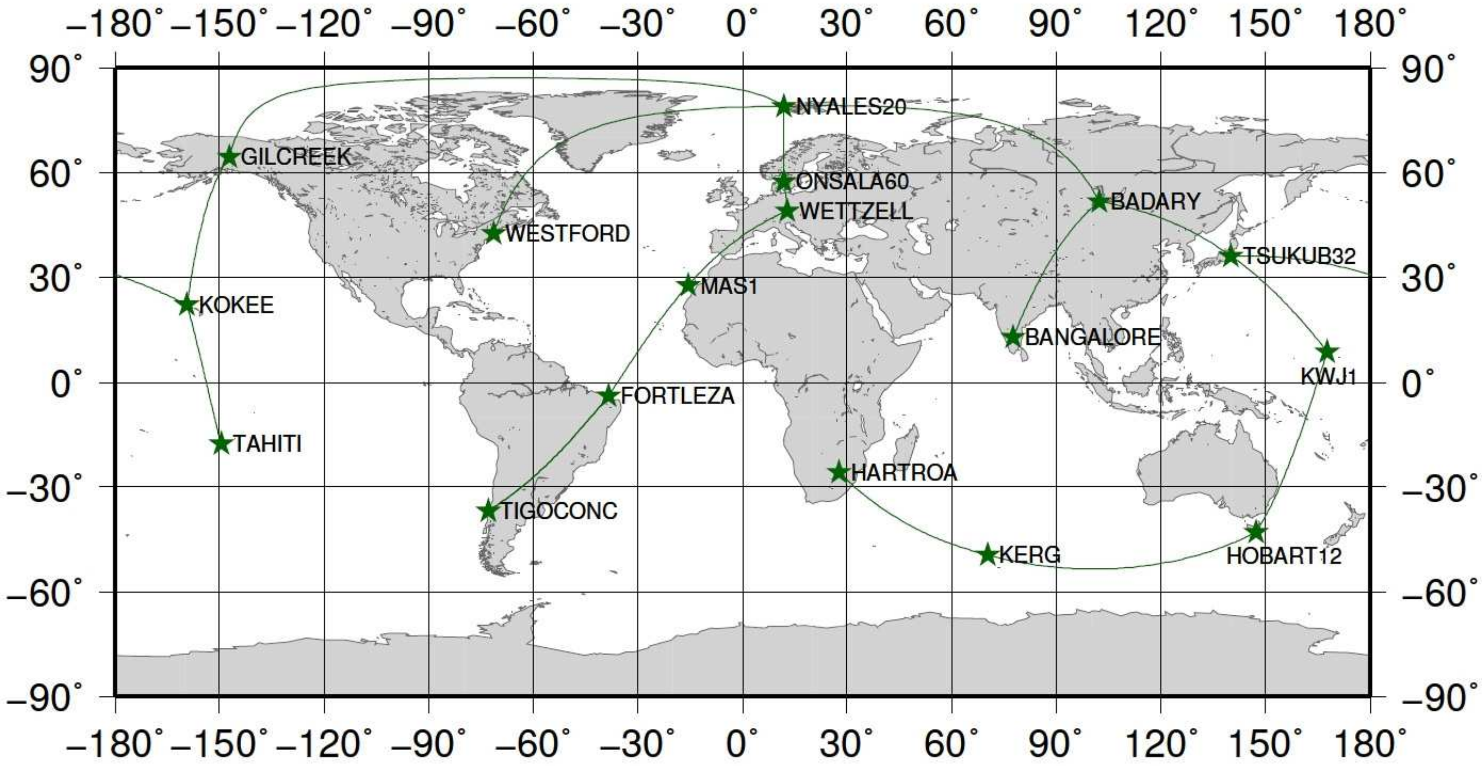
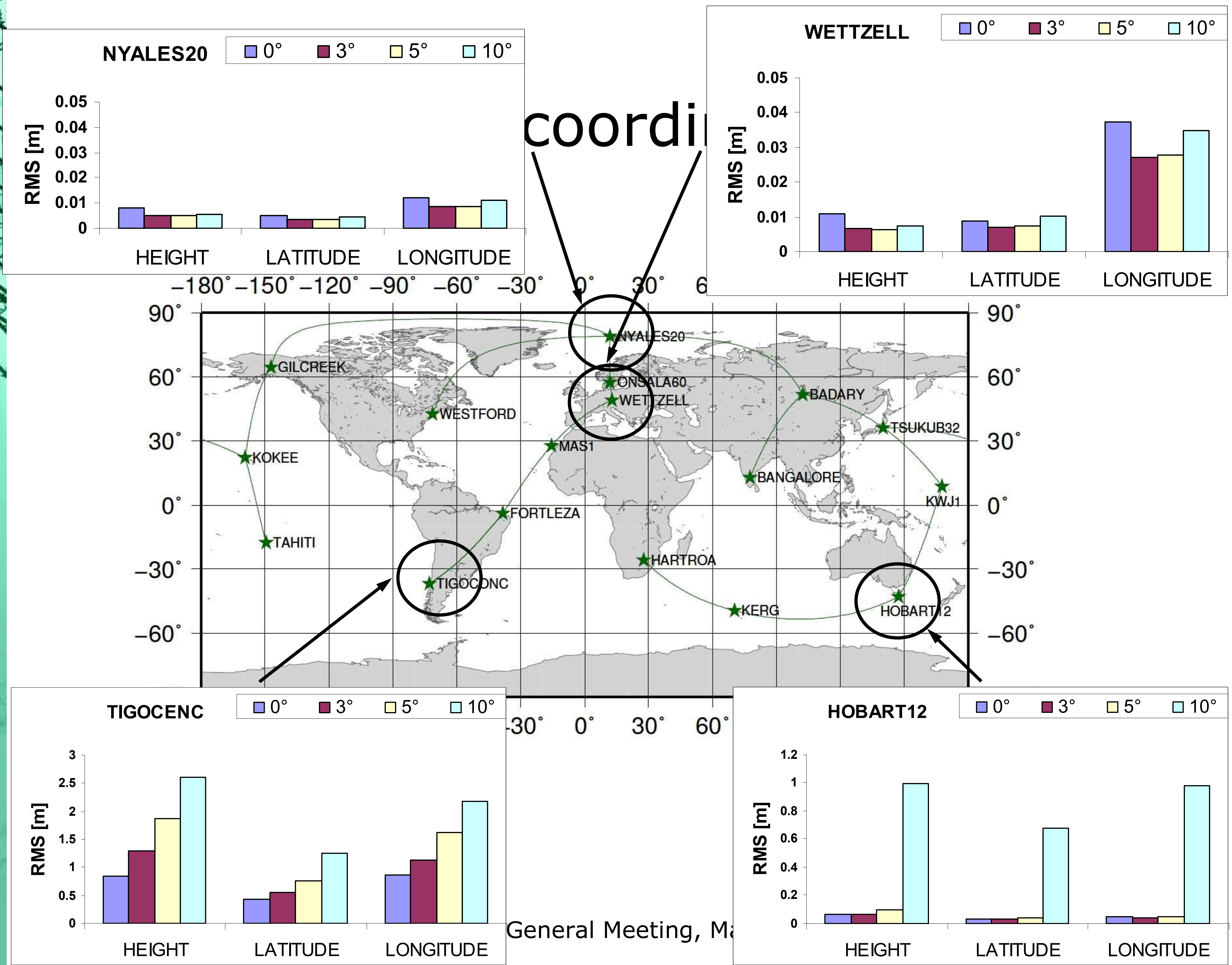
# RMS of station coordinates

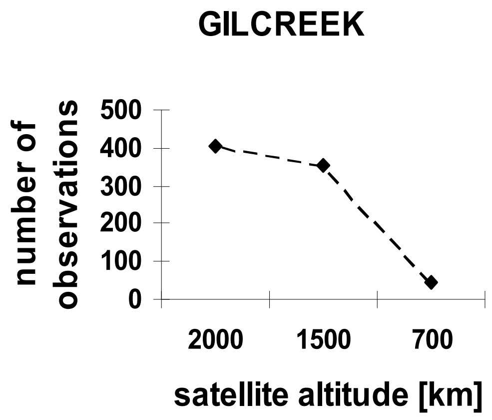


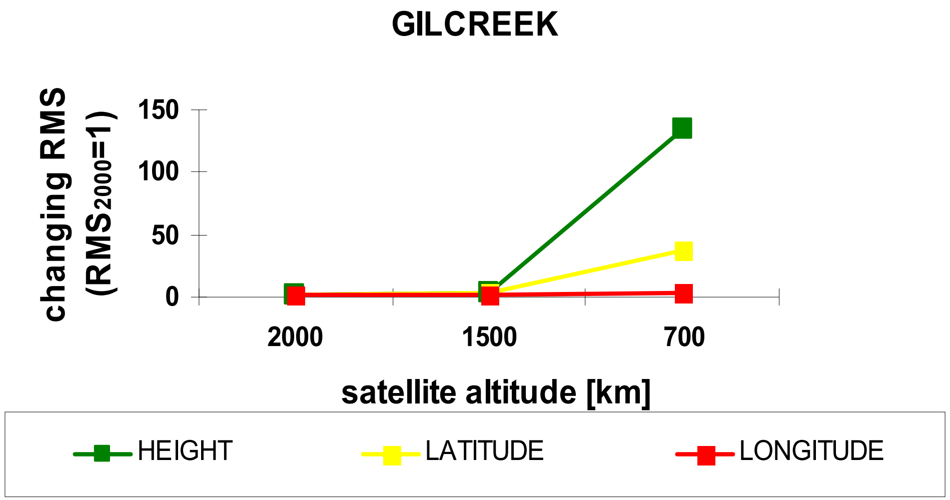
# coordi

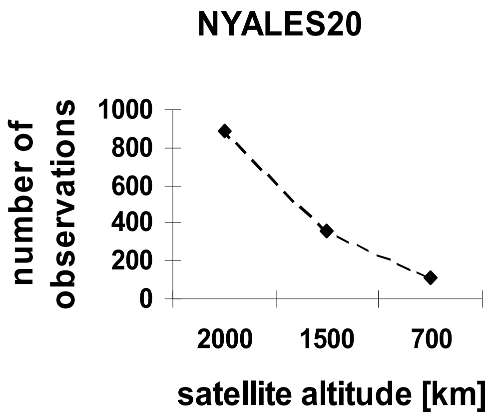

NYALES20
WETTZELL
TIGOCENC
HOBART12
0° 3° 5° 10°
RMS [m]
HEIGHT
LATITUDE
LONGITUDE
GILCREEK
WESTFORD
KOKEE
TAHITI
FORTLEZA
TIGOCONC
MAS1
NYALES20
ONSALA60
WETTZELL
HARTROA
KERG
BADARY
TSUKUB32
BANGALORE
KWJ1
HOBART12
−180° −150° −120° −90° −60° −30° 0° 30° 60°
90° 60° 30° 0° −30° −60°

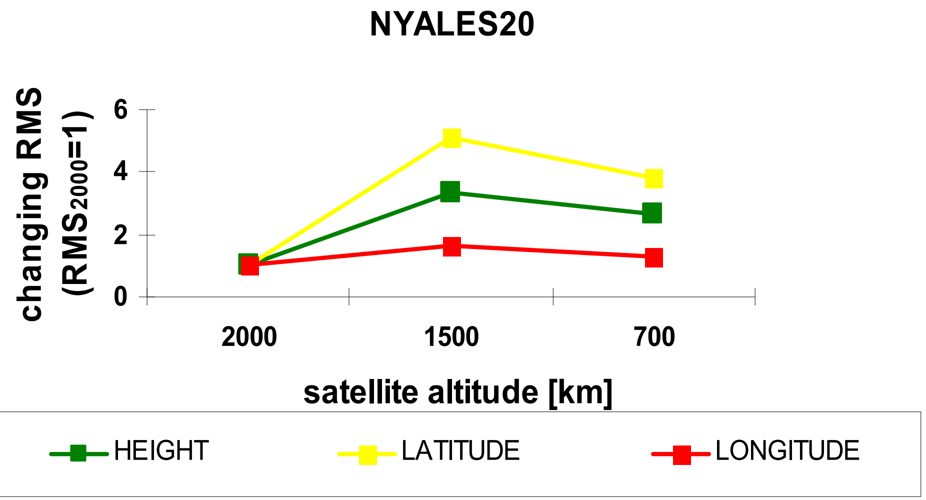
# RMS of station coordinates

- scaled to RMS obtained by the simulation using the orbit with 2000 km altitude



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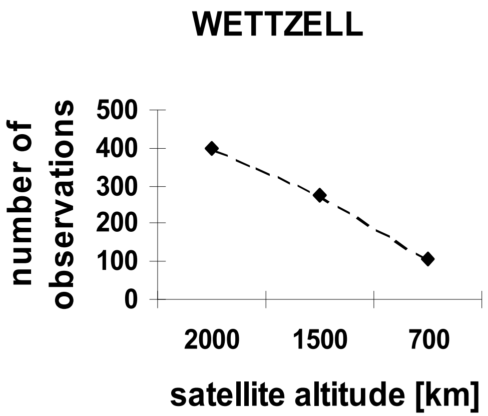


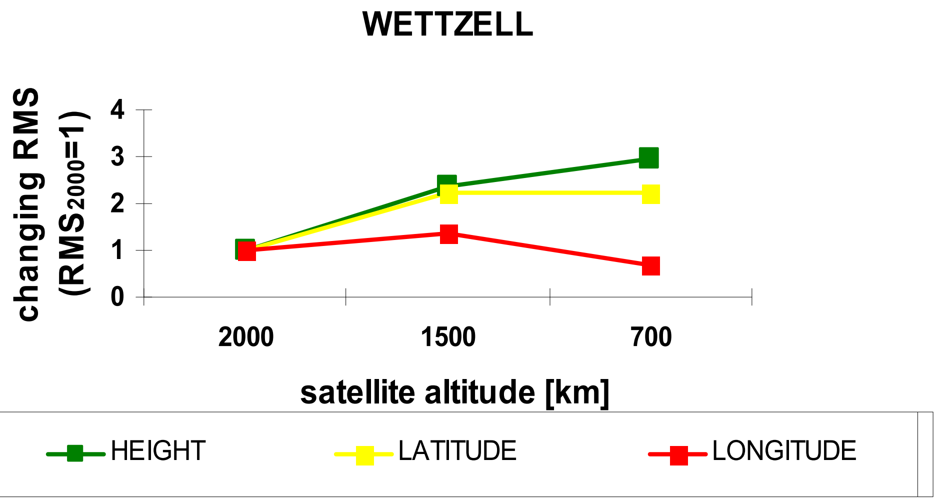


→ slow increase (or decrease) of RMS for stations with shorter baselines → regional networks are a good option for observing satellites with lower altitude

# Consequences and outlook

- co-location in space allows the estimation of local ties and will improve the realization of the TRF
- VLBI observations
  - fast moving satellites -> high antenna slew rates necessary
  - the satellite altitude is crucial for the number of observations, but also baseline length and station latitude is important
  - to estimate the local ties with 1mm accuracy we recommend the use of baselines shorter then 2000km
- next steps
  - combination of GPS, SLR and VLBI → some further simulations and maybe once using real satellite transmitted VLBI data to improve the local ties

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# Thank You for listening

## References:

Y. Bar-Sever et. al. (2009) The Geodetic Reference Antenna in Space (GRASP) Mission Concept. EGU meeting in Vienna 2009

M. Sekido and T. Fukushima (2006): A VLBI delay model for radio sources at a finite distance, J. Geod, 80:137-149

O. Sovers et. al. (1998): Astronometry and geodesy with radio interferometry: experiments, models, results, Review of Modern Physics, 70:1393

V. Tornatore (2010): Planning of an Experiment for VLBI Tracking of GNSS Satellites, IVS 2010 General Meeting Proceedings, p. 70-74

J. Wresnik et. al. (2009): VLBI2010 simulations at IGG Vienna, Proceedings of the 19th European VLBI for Geodesy and Astronometry Working Meeting