

# Automated reference point determination at radio telescopes

**A contribution to the Global Geodetic Observing System**

**Laboratory for Industrial Metrology**

# Agenda

1. Introduction
2. Reference point determination with HEIMDALL
3. Uncertainty budgeting
4. Results of reference point determination during CONT14
5. Outlook

# 1. Introduction

## Global Geodetic Observing System (GGOS)

- Geodetic infrastructure for monitoring of the shape, the gravity field and the rotational model of the Earth
- Combination of different geodetic techniques, different models and different approaches to ensure long-term, precise monitoring of the geodetic observables
- Providing a stable and accurate global reference frame

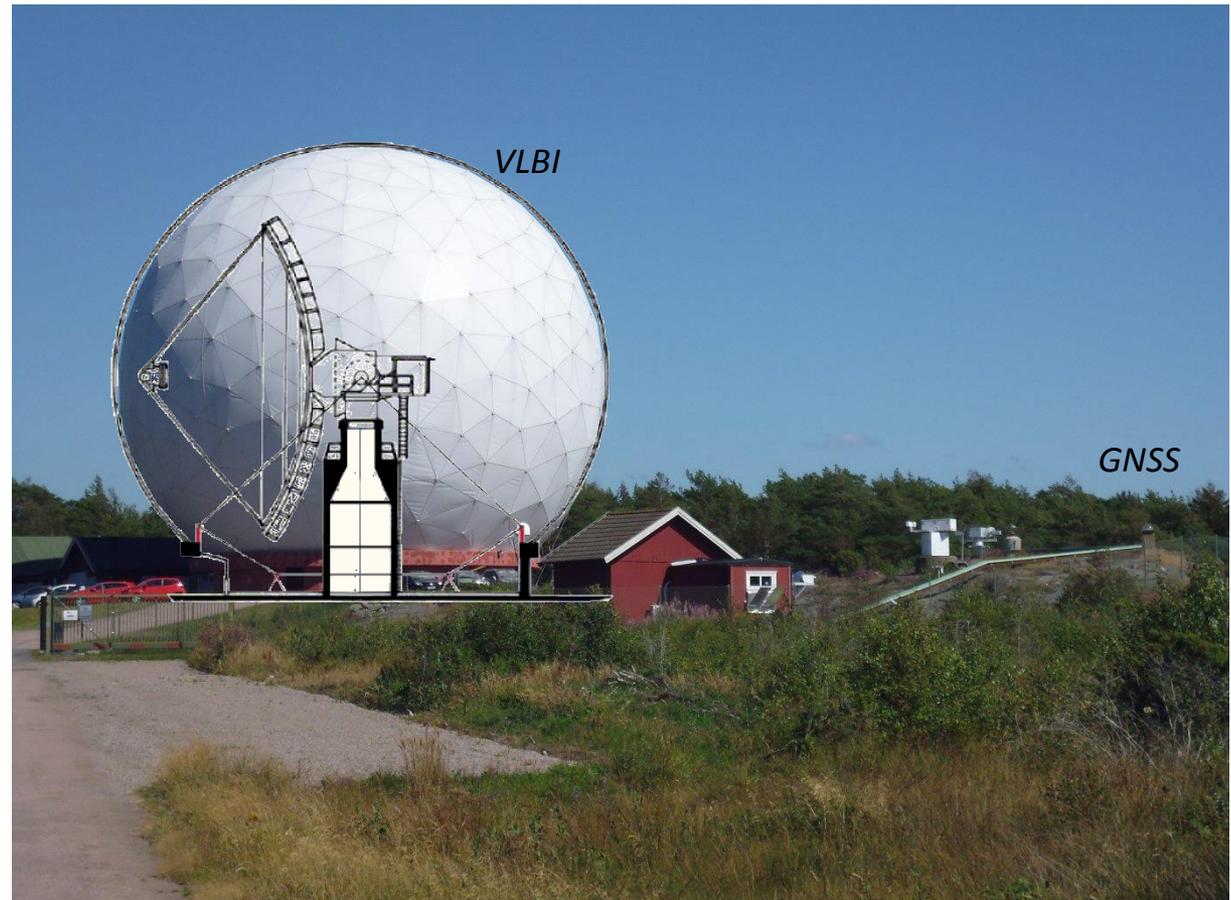
United Nations resolution on the importance of a global terrestrial reference frame for sustainable development

# 1. Introduction

## Global Geodetic Reference Frame

- Combining results from different space geodetic techniques
  - Very Long Baseline Interferometry (VLBI)
  - Global Navigation Satellite System (GNSS)
  - Doppler Orbitography and Radiopositioning Integrated by Satellite (DORIS)
  - Satellite Laser Ranging (SLR) / Lunar Laser Ranging (LLR)
- Co-location stations as connection
  - Local-tie vectors between the reference points of the space geodetic techniques
- Requirements for the local-tie vector
  - High accuracy of about 1 mm
  - Continuously determined to investigate time-stability
  - Automations in measurement and determination process

## 2. Reference Point Determination

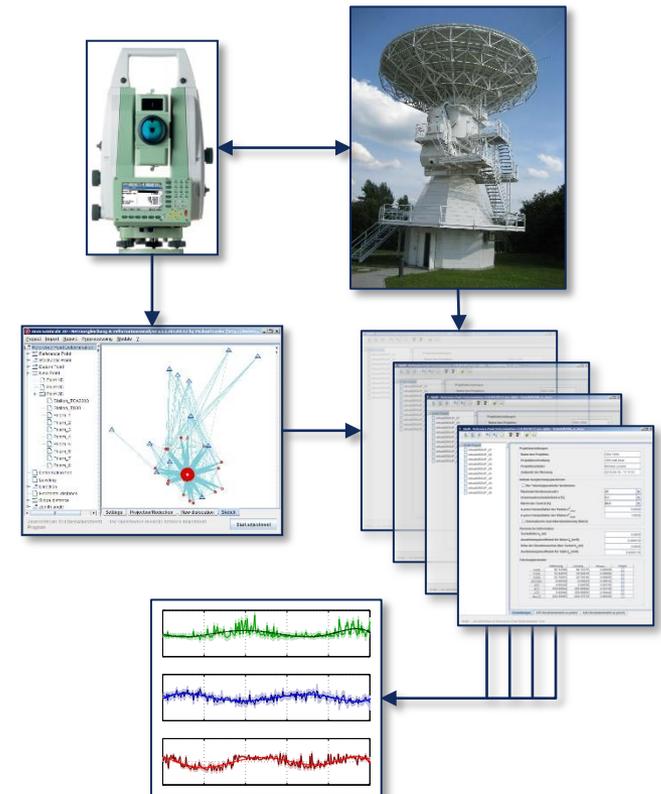


*Radome hosting the  
IVS radio telescope (20 m)  
at the Onsala Space  
Observatory (Sweden)*

## 2. Reference Point Determination

### HEIMDALL

- OpenSource Software implemented in Java
- HyperSQL for central data storage
- Components
  - Sensor communication
  - Observation schedule based on VLBI-schedule
  - Coordinate-based bundle adjustment
  - IVS-reference point determination
  - Analysis of time series / filter



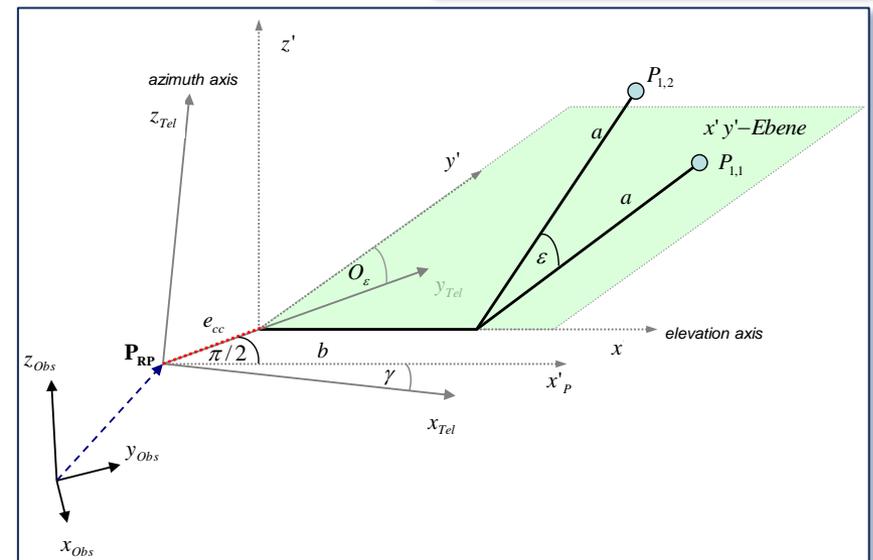
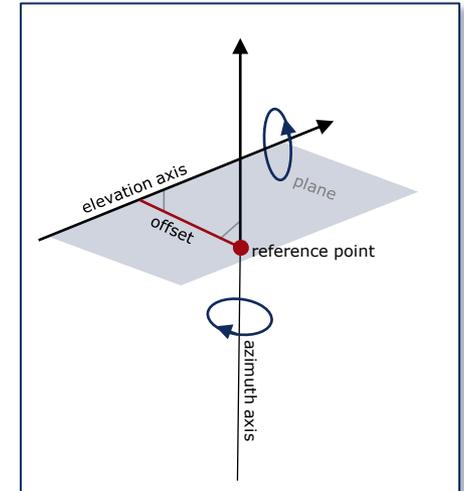
## 2. Reference Point Determination

### Calculation model

- IVS-RP definition: orthogonal projection of the secondary axis onto the primary axis
- Real-time capable model

$\mathbf{P}_{RP}$  estimated from  $\mathbf{P}_{Obs}$ -trajectory

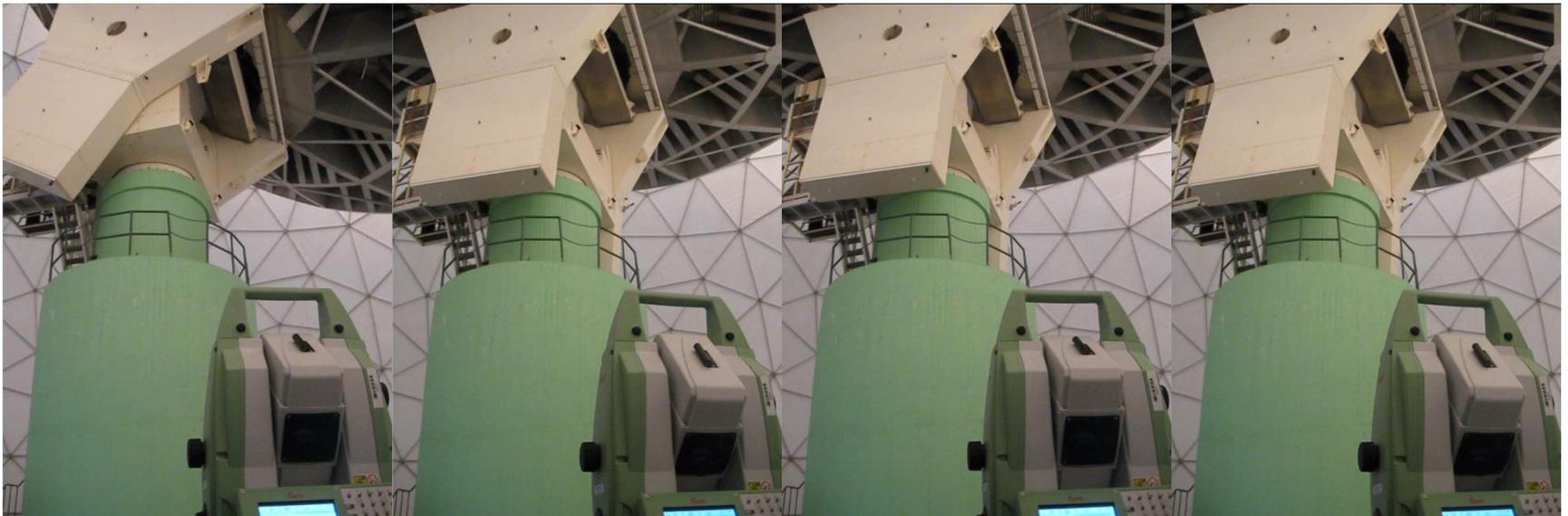
$\mathbf{P}_{RP}$	IVS-reference point
$\mathbf{E}_{CC}$	axis offset
$\gamma$	non-orthogonality
$\theta$ and $\phi$	axis tilting
$O_\alpha$ and $O_\varepsilon$	orientation angle



## 2. Reference Point Determination

### Observation schedule

- Misalignment of reflectors
- Synchronisation of total station and radio telescope operation system
- Environmental parameters



## 2. Reference Point Determination

### Coordinate-based bundle adjustment

- Conversion of polar measurements to Cartesian spatial coordinates of each stand point
- Conformance spatial parameters coordinate transformation
- Valid for stand points that are unrelated to the plumb line
- Independent of reference frame

All calculations in the global reference frame

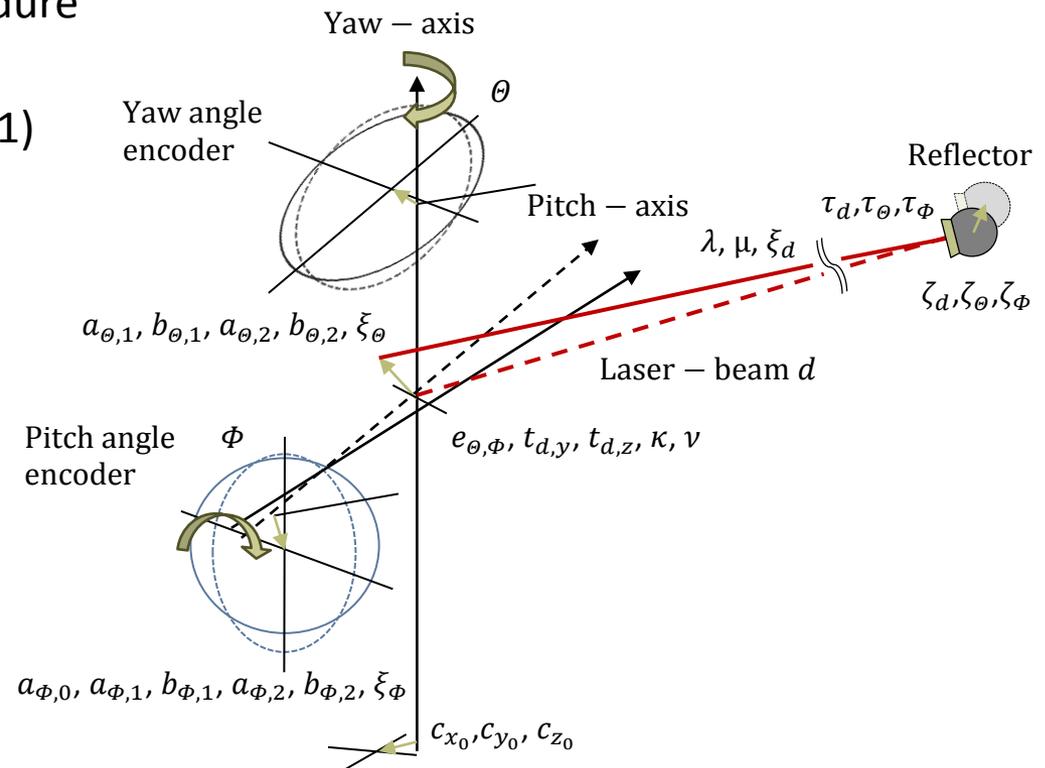
# 3. Uncertainty budgeting

## Stochastic model for a polar measurement system

- Manufacture's calibration procedure
- Geometric compensation model suggested by Hughes et. al. (2011)
- Compensation model for the measurement process

### 28 uncertainty parameters

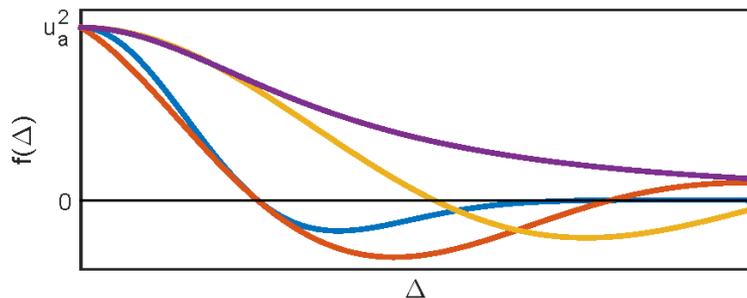
- 16 for instrument geometry
- 12 for measurement process



# 3. Uncertainty budgeting

## Time-dependent stochastic model

- Statistical temporal dependencies
- Persistence of a series expressed by auto-covariance function

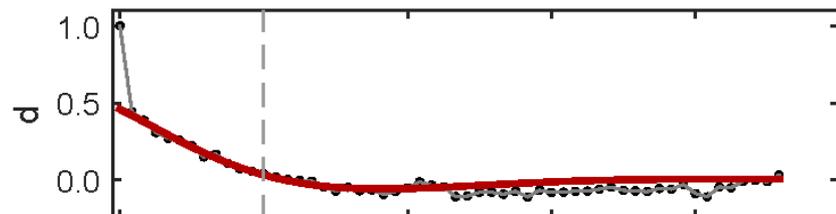
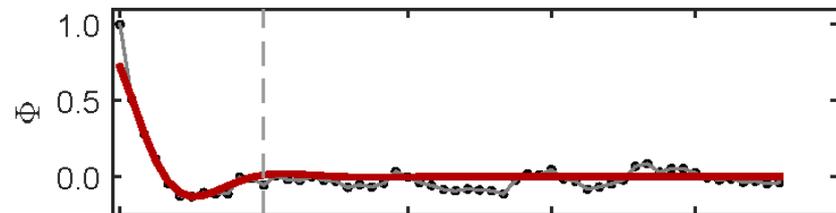
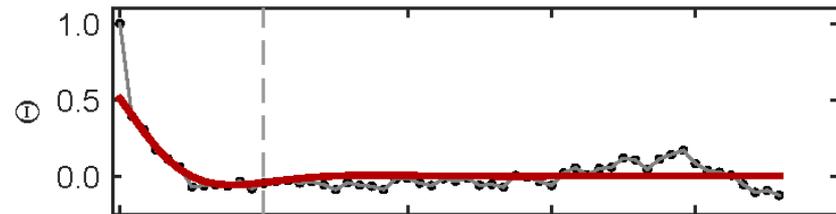


—  $f_1(\Delta) = u_a^2 e^{-(u_b \Delta)^2} \cos(u_c \Delta)$

—  $f_2(\Delta) = u_a^2 e^{-u_b |\Delta|} \cos(u_c \Delta)$

—  $f_3(\Delta) = u_a^2 \frac{\sin(u_b \Delta)}{u_b \Delta}$

—  $f_4(\Delta) = u_a \frac{u_b^2}{u_b^2 + \Delta^2}$



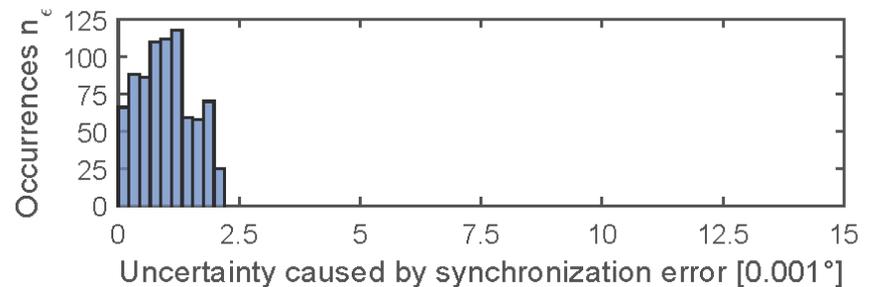
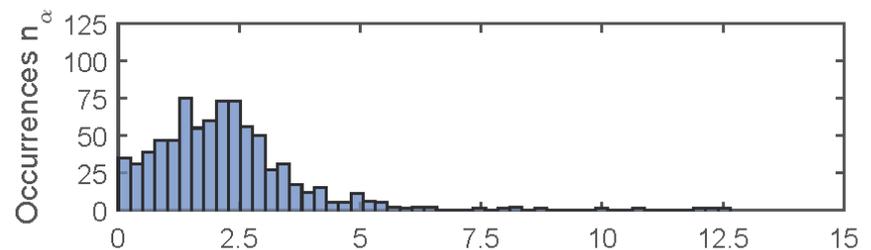
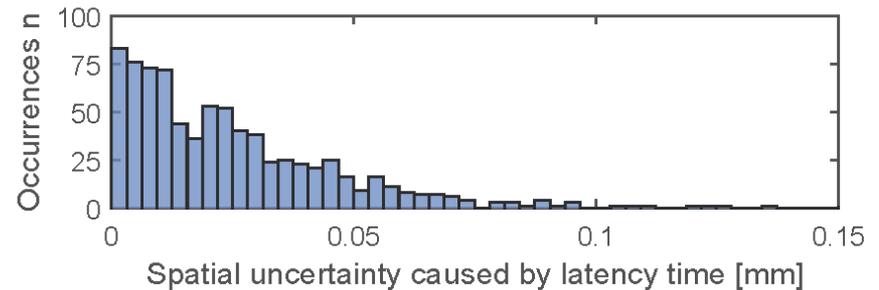
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# 3. Uncertainty budgeting

## Synchronizing

- Latency time of polar observations: time lag between angle and distance measurement of the total station
- Synchronization error between total station and radio telescope

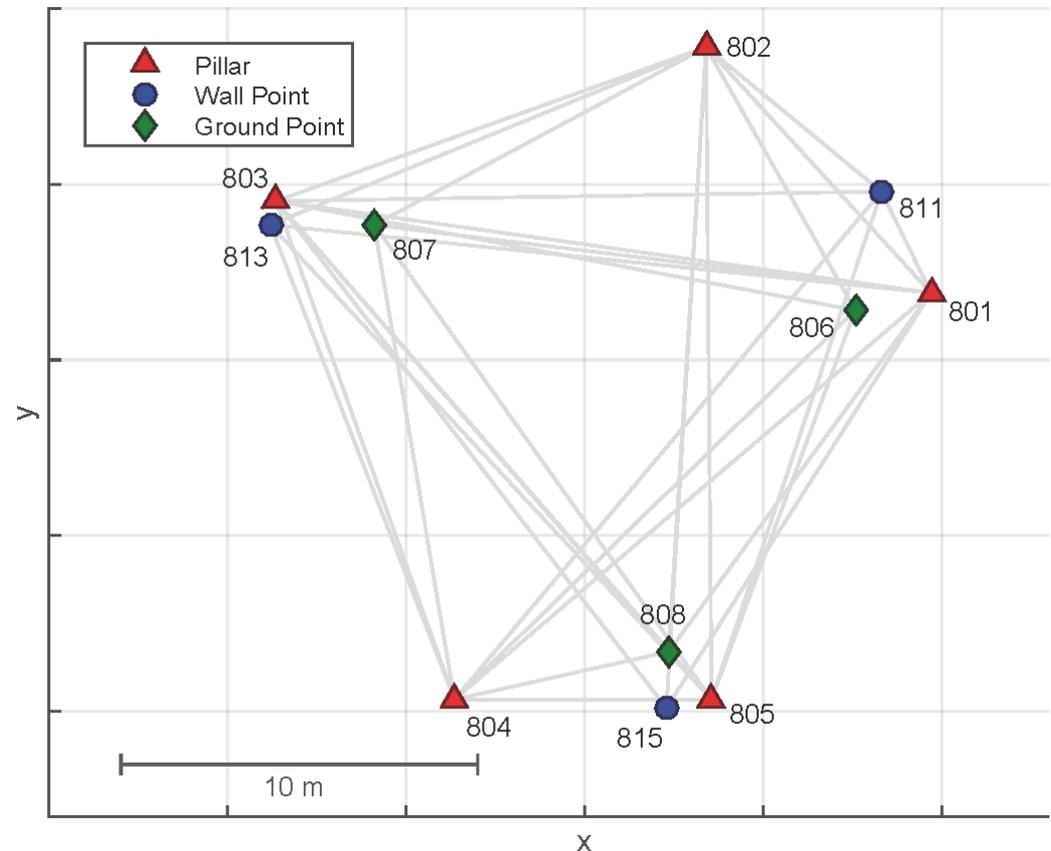
Influence included by using Monte Carlo simulation



## 4. Results of reference point determination

### CONT14

- 15-day-long VLBI campagne in May 2014 yielded in 15 collateral reference point determinations
- 20 m radio telescope at the Onsala Space Observatory covered by a radome
- Network realization consisting of eleven fixed points inside the radome and several stand points outside the radome for connection the IGS reference point

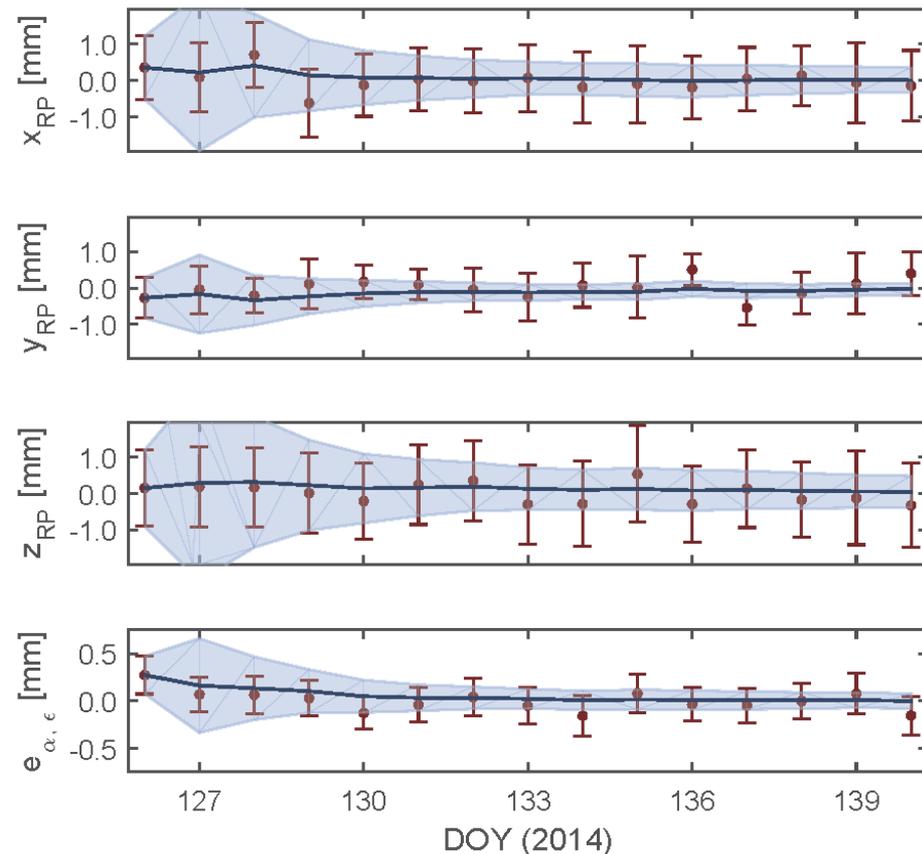


## 4. Results of reference point determination

### CONT14

- Recursive parameter estimation
  - Stability check
  - Time series includes prior information
- Maximum uncertainty of the hyper confidence ellipsoid of the reference point  
 $u_{\max, 95\%} = 0.5 \text{ mm}$

Reliable results fulfill requirements  $< 1 \text{ mm}$



## 5. Outlook

### Local-tie measurement

- Reference point determination of IVS radio telescope
- Connection to the local network
- Determination of reference points of several other techniques

CONT14 local-tie vector (VLBI-GNSS) at ONSALA better than 1 mm

# Thank you for your attention

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