Fachhochschule Frankfurt am Main University of Applied Sciences

Next Generation of Reference Point Determinations

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Motivation

- Geodetic co-location stations
  - Crucial for the International Terrestrial Reference Frame
  - Essential for a meaningful combination of the different space geodetic techniques (➔ local tie vectors)
- Goal
  - Ensuring an utmost level of accuracy of local tie vectors
  - Both in the spatial and temporal domain
  - Reducing time-consuming field work
- Automated reference point determination
  - Agenda VLBI2010
  - Global Geodetic Observation System (GGOS)

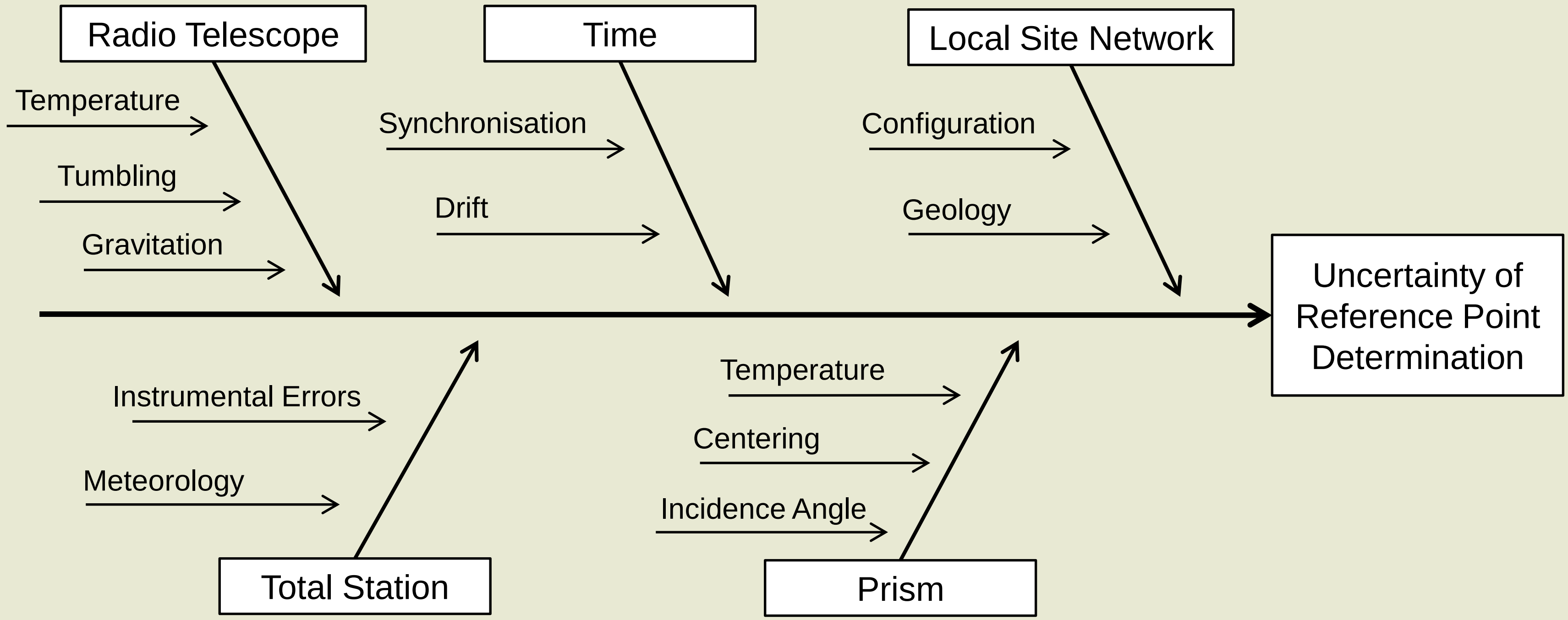
Determination Model

Mathematical model emulates trajectory of the point $\mathbf{P}_{\mathrm{Tel}} = [\mathrm{b\ a\ 0}]^T$ and regards imperfection

$$\mathbf{P}_{\mathrm{Obs}} = \mathbf{P}_{\mathrm{RP}} + \mathbf{R}_{\theta}^{\mathrm{x}} \mathbf{R}_{\phi}^{\mathrm{y}} \mathbf{R}_{\alpha - \mathrm{O}_{\alpha}}^{\mathrm{z}} \mathbf{R}_{\psi}^{\mathrm{y}} \left(\mathbf{E}_{\mathrm{cc}} + \mathbf{R}_{\varepsilon - \mathrm{O}_{\varepsilon}}^{z} \mathbf{P}_{\mathrm{Tel}} \right)$$

$\mathbf{P}_{\mathrm{RP}}$	IVS-definded reference point
$\mathbf{E}_{\mathrm{cc}}$	axis-offset
ψ	inclination angle (azimuth to elevation axis)
θ and ϕ	vertical misalignment (telescope system – local network)
O_{α} and O_{ε}	orientation angles
$\mathbf{R}_{\theta}^{\mathrm{x}}, \mathbf{R}_{\phi}^{\mathrm{y}}$, …	Rotation matrices

Ishikawa diagram to visualise error budgeting



Compensation of Errors

Compensations for each observed position

- Height compensation by recorded invar data
- Thermal expansion of the telescope structure using monument temperature

$$a_{\Delta T_i} = a(1 + \gamma_S \Delta T_i)$$
$$b_{\Delta T_i} = b(1 + \gamma_S \Delta T_i)$$
$$z_{\mathrm{P_{RP}},\Delta T_i} = z_{\mathrm{P_{RP}}} + (\gamma_F h_F + \gamma_S h_S)\Delta T_i$$

- Calibration parameters or 2-face measurements
- Meteorological correction of EDM
- Error of reflector alignment

Effects of Errors of Reflector Alignment

- Optical shift of the prism center
- Causes lateral and radial deviations

- Depending on angle of incidence
- Not correctable by two-face observations

- Test set-up
  - High precision total station TS30
  - Automatic target recognition (ATR)
  - Standard GPR121-type prism (identical in construction with GPH1P)
  - 10°-increments of angle of incidence

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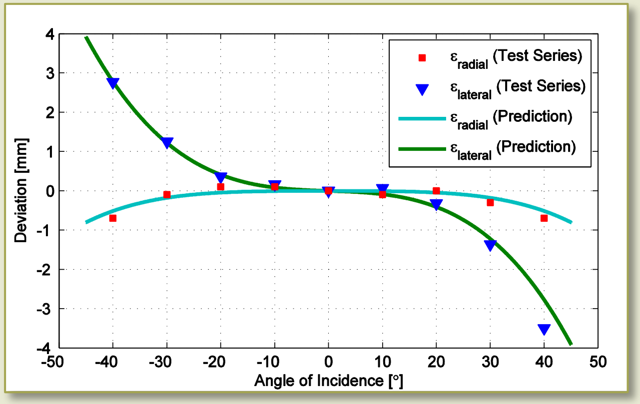
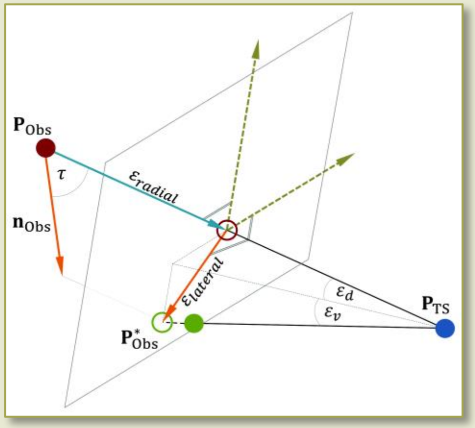
Effects of Errors of Reflector Alignment

- Significant deviations
  - E.g. at angle of incidence of 35°
  → 1.2 mm lateral
  → 0.2 mm radial



- Angle of incidence depends on
  - Alignment of the prism (general)
  - Elevation and azimuth angles (in framework of RP determination)

- Separating into horizontal and vertical correction values



Lösler et al. (2013), JGeod; DOI: 10.1007/s00190-013-0647-y

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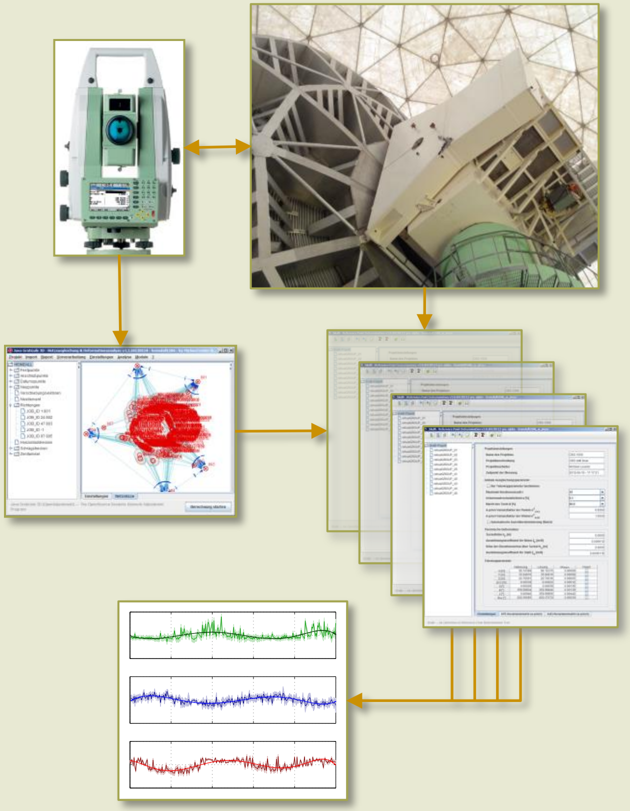
Automated Reference Point Monitoring

- Central data management
  - HEIMDALL system
  - Interfaces for data transfer
  - SQL-based DBMS

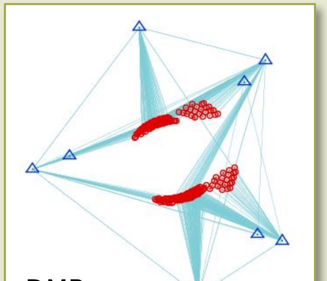
- Monitoring modules
  - Communication with peripheral devices
  - Observation plan (based on VLBI-schedule)
  - Spatial network adjustment
  - Reference point determination
  - Time series analysis

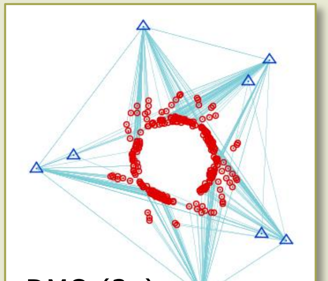


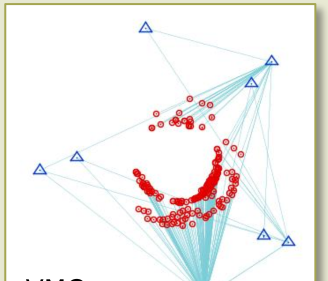
Automated Reference Point Monitoring

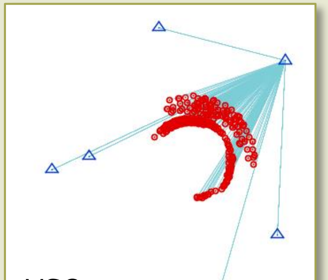
- Field experiments at Onsala, testing different observation configurations

Approaches/Experiments	I	II	III	IV	V
Dedicated survey/Real **V**LBI schedule	D	D	V	D	V
Single/**M**ultiple survey stand point(s)	M	M	M	M	S
Target was observed **O**nce/**R**edundantly	R	O	O	O	O


DMR


DMO (2x)


VMO


VSO

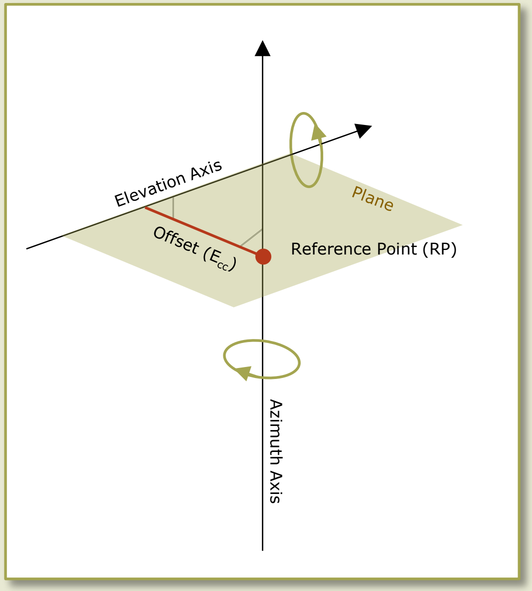
Results of Reference Point Monitoring

- Considering each single solution as an independent realisation of a random experiment
- Recursive parameter estimation
  - Combination incorporates information of prior results
  - Using full variance-covariance-matrix of single solution
  - Regarding timeliness of data via additional variance matrix of the process noise
  - Model expansion is possible (e.g. for seasonal variation)
- $\hat{\mathbf{x}}_j = \hat{\mathbf{x}}_{j-1} + \mathbf{K}_{j-1,j}\left(\mathbf{x}_j - \hat{\mathbf{x}}_{j-1}\right)$ and
  $\mathbf{Q}_{\hat{\mathrm{x}}_j\hat{\mathrm{x}}_j} = \mathbf{Q}_{\hat{\mathrm{x}}_{j-1}\hat{\mathrm{x}}_{j-1}} - \mathbf{K}_{j-1,j}\mathbf{Q}_{\hat{\mathrm{x}}_{j-1}\hat{\mathrm{x}}_{j-1}}$
  where $\mathbf{K}_{j-1,j} = \mathbf{Q}_{\hat{\mathrm{x}}_{j-1}\hat{\mathrm{x}}_{j-1}}\left(\mathbf{Q}^{\Delta t}_{\mathrm{x}_j\mathrm{x}_j} + \mathbf{Q}_{\hat{\mathrm{x}}_{j-1}\hat{\mathrm{x}}_{j-1}}\right)^{-1}$
  $\mathbf{Q}^{\Delta t}_{\mathrm{x}_j\mathrm{x}_j} = \mathbf{Q}_{\mathrm{x}_j\mathrm{x}_j} + \mathbf{B}\mathbf{C}_{\mathrm{nn}}\mathbf{B}^{\mathrm{T}}$

Results of Reference Point Monitoring

- Filtered combination of single experiments

	I+II	I+II+III	I+…+IV	I+…+V
X_{RP} [m]	90.1236 ±0.0002	90.1236 ±0.0001	90.1236 ±0.0001	90.1236 ±0.0001
Y_{RP} [m]	35.9493 ±0.0002	35.9492 ±0.0002	35.9492 ±0.0001	35.9492 ±0.0001
Z_{RP} [m]	22.7592 ±0.0002	22.7592 ±0.0002	22.7593 ±0.0002	22.7592 ±0.0002
E_{CC} [m]	-0.0061 ±0.0002	-0.0061 ±0.0002	-0.0061 ±0.0001	-0.0060 ±0.0001



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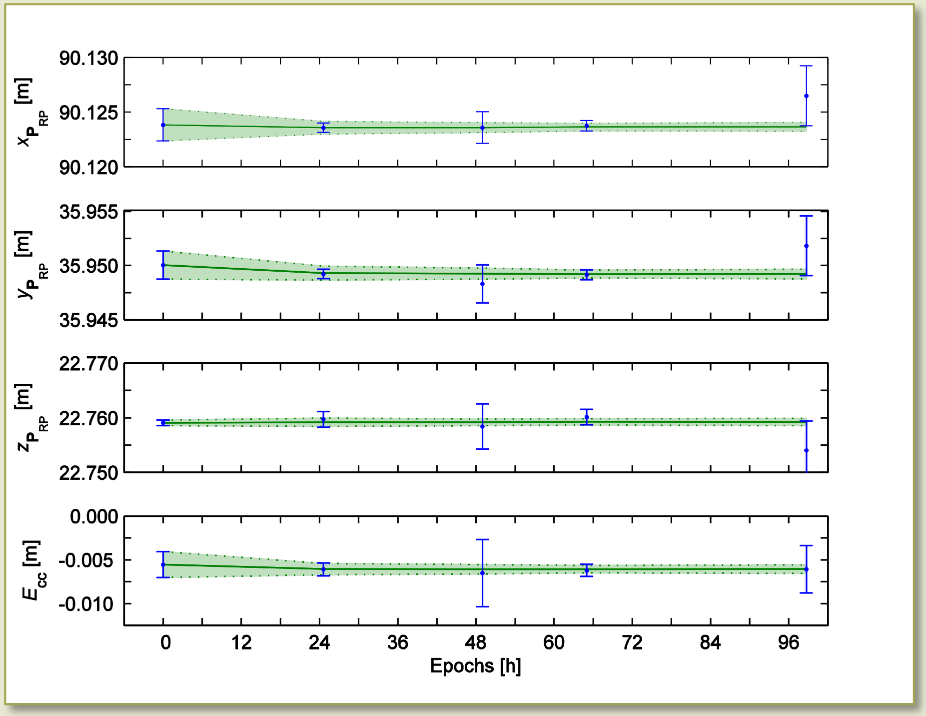

- Single solution with 3σ error bars (blue)
- Combined solution with 3σ error band (green)

Conclusion and Outlook

- General
  - Neglecting the reflector alignment error yields significant systematic errors
  - Temperature compensation for each observed point

- At Onsala: Five reference point determinations campaigns in **one** week
  - Dedicated reference point determinations
  - Collateral reference point determination during regular VLBI schedule

  → No station downtime during local survey
  → Achieved sub-mm accuracy for reference point and eccentricity offset

Conclusion and Outlook

- Automated monitoring system HEIMDALL fulfills the extended requirements of VLBI2010 and GGOS

- Recursive parameter estimation
  - Combination incorporates information of prior results
  - Increasing reliability

- Outlook
  - Plan to implement the automated monitoring system for the Onsala Twin Telescope project
  - Extension to further co-located equipment to achieve complete automated local-tie surveys

Thank you for your attention!