EMPIR EURAMET

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GeoMetre

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Determination of Local Tie Vectors

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Table of Content

Global Geodetic Reference Frames

- Aimed accuracy goal of 1 mm in position on a global scale
- Combination of several space-geodetic techniques
  - Global Navigation Satellite System (GNSS)
  - Doppler Orbitography and Radiopositioning Integrated by Satellite (DORIS)
  - Satellite Laser Ranging (SLR)
  - Very Long Baseline Interferometry (VLBI)
- Largely independent techniques
  - Pure combination yields unreliable results (weak physical connection)
  - Tying information is of crucial importance

Global Geodetic Reference Frames

- Global tying types
  - Tying via common Earth-orientation parameters (EOP) → Global ties
  - Tying via multi-technique satellites → Space ties

- Local tying types
  - Tying via geometric conditions → Local ties
  - Tying via common atmospheric parameters → Atmospheric ties
  - Tying via common clocks → Clock ties
  - Require multi-technique station operating at least two geodetic techniques

Local ties

- Observable at multi-technique station via terrestrial measurement instruments
  - Polar instruments (total station, laser tracker, …)
  - Precise distance measurement instruments (DistriMetre, TeleYAG, …)
  - Spirit levelling
  - Photogrammetric systems
  - GNSS
  - …

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Local ties

- Defined between invariant reference points of space-geodetic techniques
- Provided via SINEX file
- Consists of reference points and related fully populated dispersion matrix
- Relates to Global Geodetic Reference Frame

- Accuracy requirement < 1 mm
- Traceable to SI unit
- In-process determination approaches required to reduce telescope downtime
- Reference point determination approaches should be frame-independent

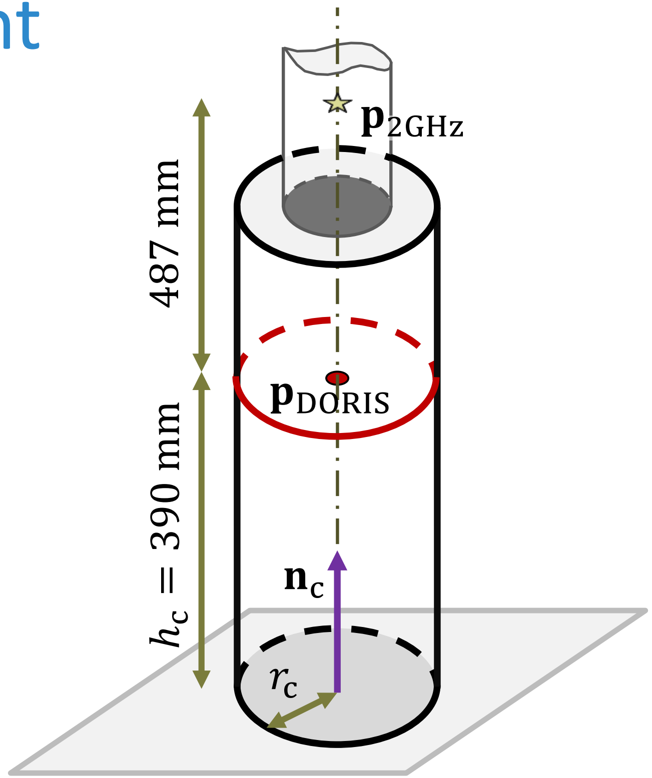
DORIS – Invariant Reference Point

- Reference point $\mathbf{p}_{\mathrm{DORIS}}$ defined at beacon's main-axis
- 390 mm above reference plane
- Combination of cylinder and plane

$$\|(\mathbf{p} - \mathbf{p}_{\mathrm{DORIS}}) \times \mathbf{n}_{\mathrm{c}}\|_2 = r_{\mathrm{c}}$$
$$\mathbf{n}_{\mathrm{c}}^{\mathrm{T}}\mathbf{p} = d_{\mathrm{c}}$$

with the restrictions

$$\mathbf{n}_{\mathrm{c}}^{\mathrm{T}}\mathbf{p}_{\mathrm{DORIS}} - d_{\mathrm{c}} = h_{\mathrm{c}}$$
$$\|\mathbf{n}_{\mathrm{c}}\|_2 = 1$$



GNSS – Invariant Reference Point

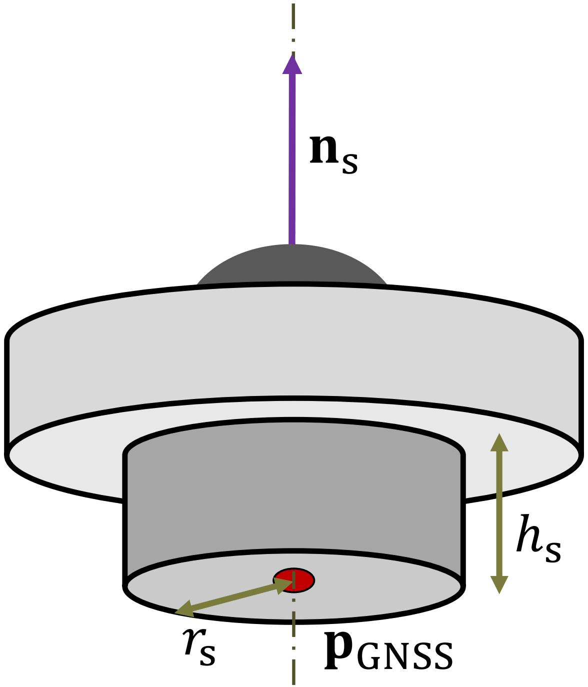
- Reference point $\mathbf{p}_{\text{GNSS}}$ defined at antenna's main-axis at bottom of pre-amplifier
- Combination of sphere and plane

$$\|(\mathbf{p} - \mathbf{p}_{\text{GNSS}})\|_2 = r_\text{s}$$
$$\mathbf{n}_s^\text{T}\mathbf{p} = d_\text{s}$$

with the restrictions

$$\mathbf{n}_s^\text{T}\mathbf{p}_{\text{GNSS}} - d_\text{s} = -h_\text{s}$$

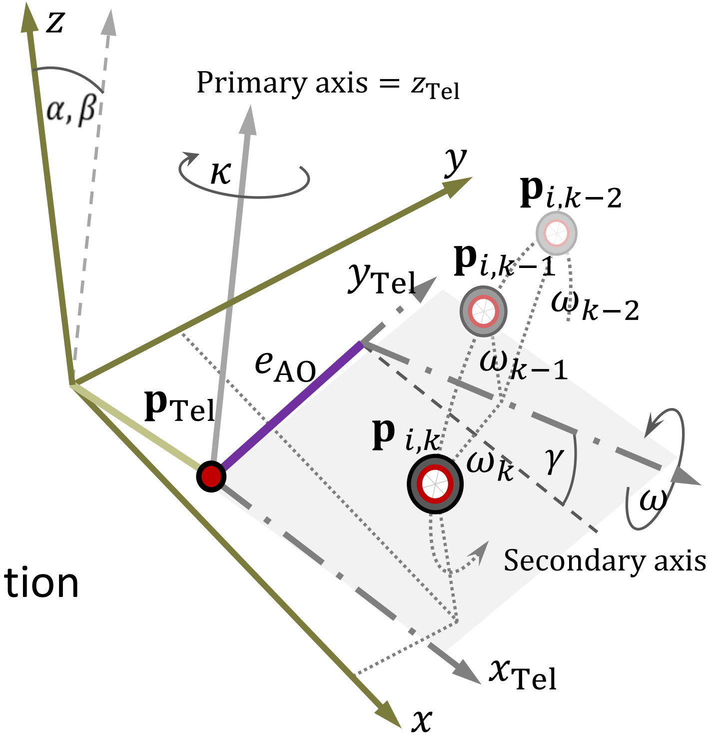
$$\|\mathbf{n}_s\|_2 = 1$$



SLR/VLBI – Invariant Reference Point

- Reference point $\mathbf{p}_{\mathrm{Tel}}$ defined as orthogonal projection of secondary axis onto primary axis
- Transformation between telescope-fixed frame and Earth-fixed frame via

$$\mathbf{p}_{i,k} = \mathbf{p}_{\mathrm{Tel}} + \mathbf{R}_{\mathrm{x}}(\beta)\mathbf{R}_{\mathrm{y}}(\alpha)\mathbf{R}_{\mathrm{z}}^{\mathrm{T}}(\kappa_k^*)\mathbf{R}_{\mathrm{y}}(\gamma)(\mathbf{e}_{\mathrm{AO}} + \mathbf{R}_{\mathrm{x}}(\omega_k)\mathbf{q}_i)$$



- Allows for in-process reference point determination
- Downtime reduction

SAR – Invariant Reference Point

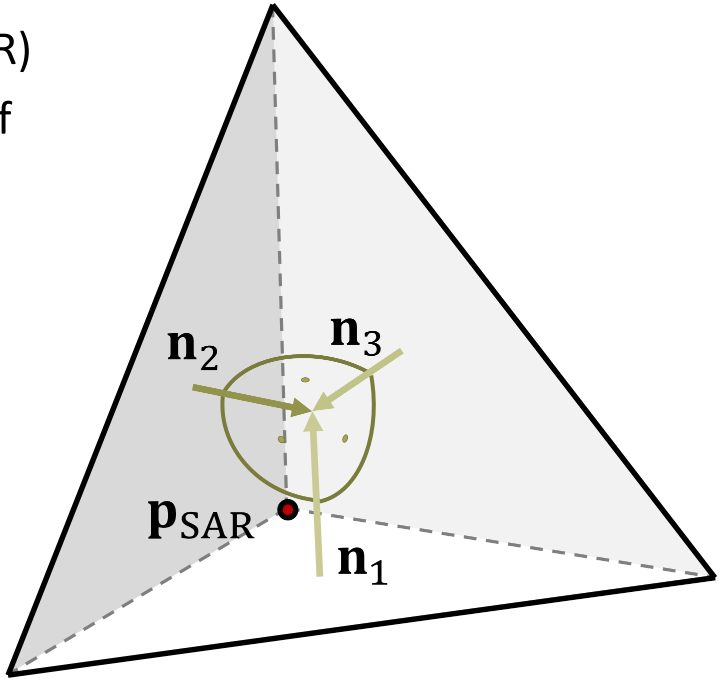
- Increasing use of Synthetic Aperture Radar (SAR)
- Reference point $\mathbf{p}_{\mathrm{SAR}}$ defined as intersection of three materialized planes (inner corner)

$$\mathbf{n}_j^{\mathrm{T}} \mathbf{p} = d_j \;\; \forall \;\; j = \{1,2,3\}$$

with the restrictions

$$\mathbf{n}_j^{\mathrm{T}} \mathbf{p}_{\mathrm{SAR}} = d_{\mathrm{j}}$$
$$\left\| \mathbf{n}_j \right\|_2 = 1$$

$$\mathbf{n}_j^{\mathrm{T}} \mathbf{n}_k = 0$$

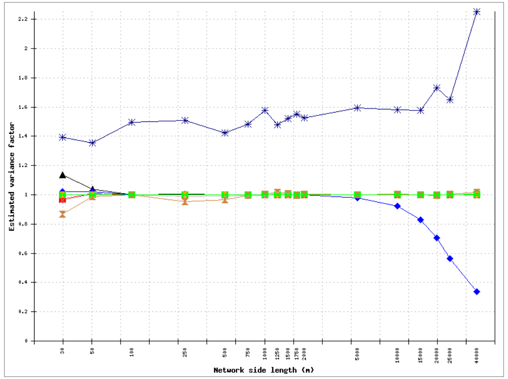


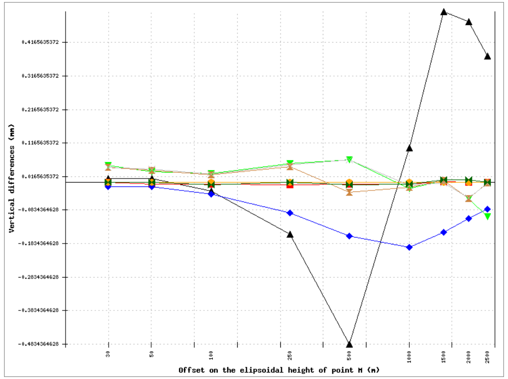
Network Adjustment

- Evaluation as spatial network is strongly recommended
  - Datum relates to Global Geodetic Reference Frame
    - Results refer directly to target frame
    - Implicit transformation of local side network to global frame
    - Analysis difficult and results hard to interpret
  - Datum relates to local (topocentric) frame
    - Results refer to an arbitrarily defined frame
    - Explicit transformation of local side network to global frame
    - Analysis is clear and results are easy to interpret
- Both procedures yield identical results

Network Adjustment

- Round robin test
  - Differences in implementation
    - Functional model
    - Stochastic model
    - Handling of auxiliary parameters
  - Operator software impact
- Adjustment results
  - Differences in parameters
  - Differences in dispersion matrix





Network Adjustment

- Handling of deflection of the vertical
  - Introducing as known (fixed) parameters (4DOF)
  - Treading as parameters to be estimated (6DOF)
- Adjustment results depend on realization of datum
- Misspecified datum yields network tilt and bending
- Risk of weak form increases for long stretched or large networks
- Network adjustment yields
  - Spatial coordinates of observed points collected in vector $\mathbf{y}$
  - Fully populated dispersion matrix $\mathbf{\Sigma}_{\mathbf{yy}}$

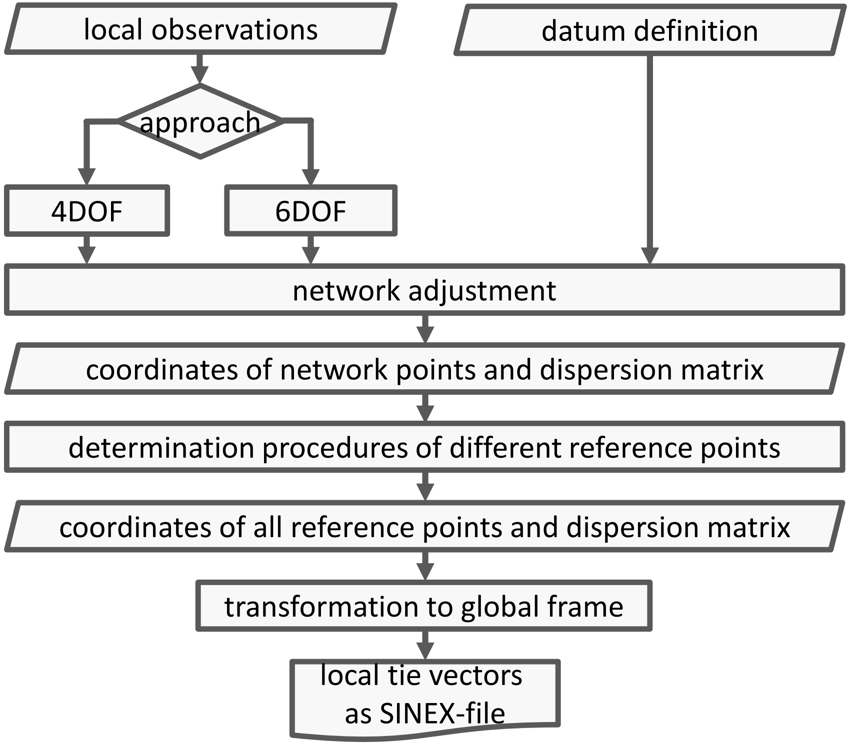
Sequential Reference Point Determinations

- Estimate reference point $\mathbf{x}$ using technique-specific observed points $\mathbf{y}_*$
- Remove technique-specific observed points $\mathbf{y}_*$ from $\mathbf{y}$
  $\bar{\mathbf{y}} \leftarrow \mathbf{E}\mathbf{y}$
- Join coordinates of reference point $\mathbf{x}$ and (remaining) network points $\bar{\mathbf{y}}$
  $\mathbf{y}^{\mathrm{T}} \leftarrow [\mathbf{x}^{\mathrm{T}} \quad \bar{\mathbf{y}}^{\mathrm{T}}]$
- Obtain fully populated dispersion matrix $\mathbf{\Sigma}_{\mathbf{yy}}$ of $\mathbf{x}$ and $\bar{\mathbf{y}}$
  $$\mathbf{\Sigma}_{\mathbf{yy}} \leftarrow \begin{bmatrix} \mathbf{\Sigma}_{\mathbf{xx}} & \mathbf{\Sigma}_{\mathbf{x}\bar{\mathbf{y}}} \\ \mathbf{\Sigma}_{\bar{\mathbf{y}}\mathbf{x}} & \mathbf{\Sigma}_{\bar{\mathbf{y}}\bar{\mathbf{y}}} \end{bmatrix}$$
- Repeat procedure until all reference points are determined
- In final step $\mathbf{y}$ contains all reference points and $\mathbf{\Sigma}_{\mathbf{yy}}$ is fully populated

Conclusion

- Precise datum definition
- Reliable measurements
- Uncertainty budgeting
- Network adjustment
- Reference point determination
- Rigorous uncertainty propagation

→ Local tie determination is challenging metrological task



Thank you for your attention!

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