Australian Government
Geoscience Australia

The determination of telescope and antenna IVP

Geoscience Earth Monitoring

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IERS Workshop on site co-location, Matera, Italy, Session 4 "Analysis and SINEX"

Overview

- Theory of Invariant Point (IVP) determination
- Terrestrial observational techniques
- Analysis procedure
- IVP results for the Australian observatories

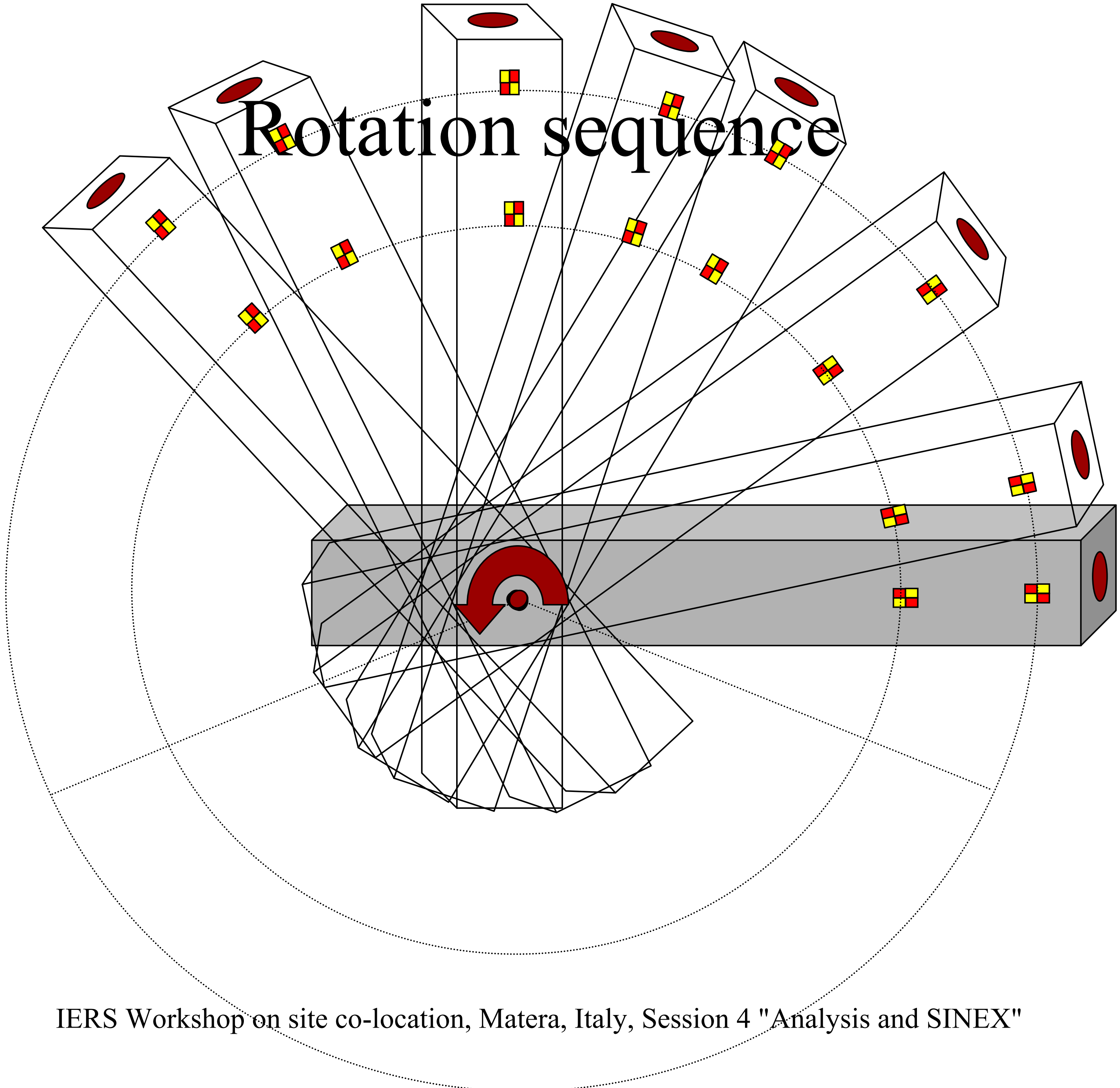
Theory of IVP determination

- IVP determination
  - Generally for both SLR and VLBI the IVP is difficult measure directly
  - IVP can be determined indirectly by observation to targets on system axes during rotational sequences
  - Least squares analysis that utilises all target coordinates and their variance-covariance information to determine the system IVP

Theory of IVP determination

- Geodetic system types in Australia
  - Azimuth/elevation (fixed vertical axis)
  - X/Y (fixed horizontal axis)

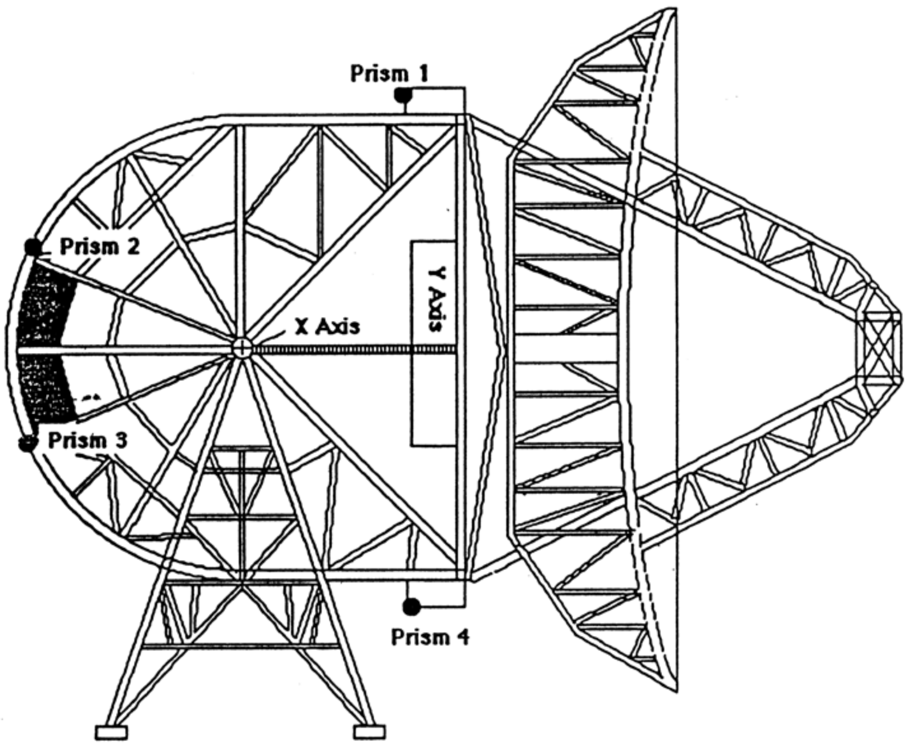
Rotation sequence

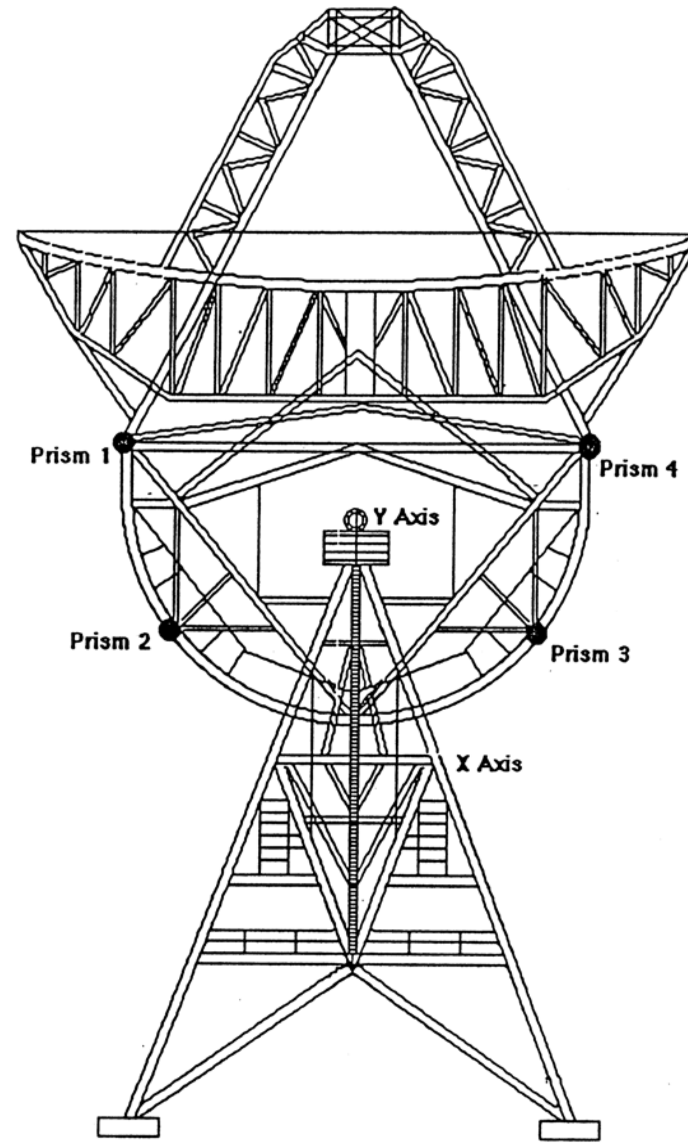


Theory of IVP determination

- System Issues
  - X/Y system fixed (primary) axis and the secondary axis do not intersect (generally many metres apart)
  - Structural design can constrain observations
    - Generally observing up onto structures
    - Domes limit visibility
    - Limited rotational freedom

X/Y Systems


Prism 1
Prism 2
X Axis
Y Axis
Prism 3
Prism 4


Prism 1
Prism 4
Y Axis
Prism 2
Prism 3
X Axis

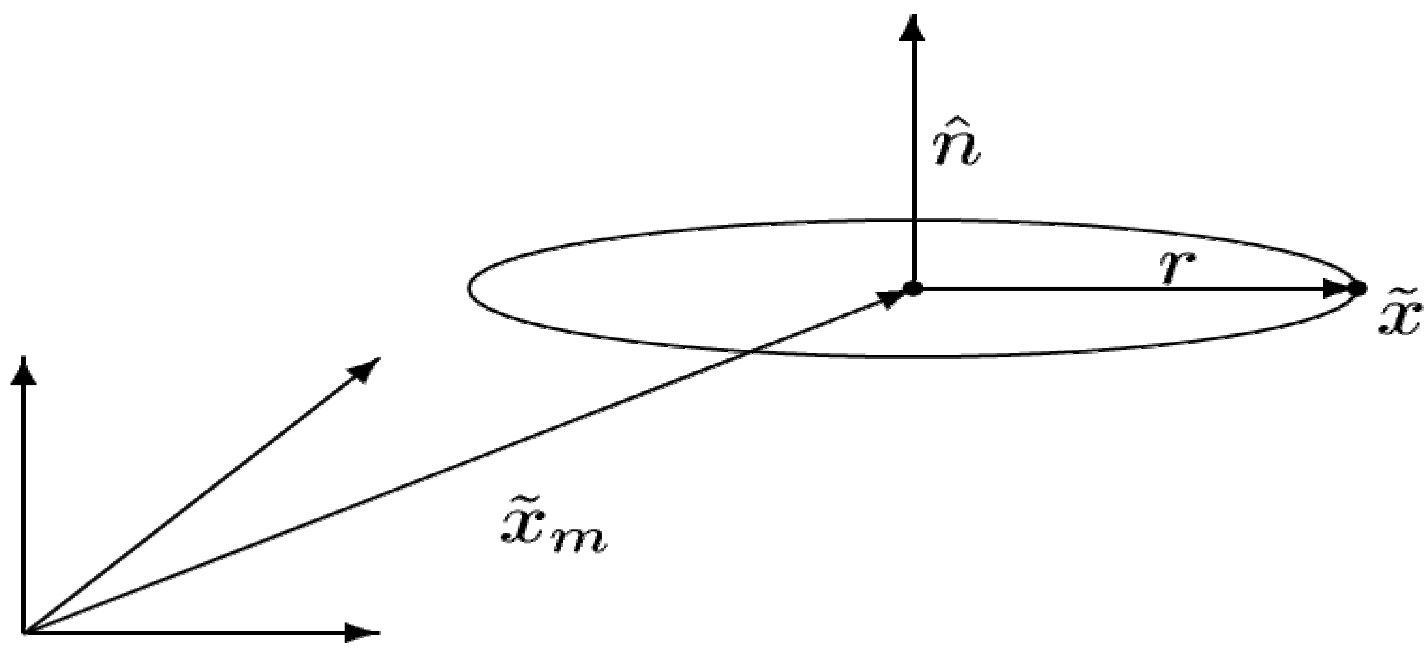
Theory of IVP determination

- Accuracy
  - Should match/better the space geodetic techniques
  - 1 mm and less is generally achievable

Theory of IVP determination

- Assumptions
  - During rotational sequence target paths scribe a perfect circular arc in 3D space
    - No deformation of targeted structure during rotational sequence
    - No axis wobble
    - Axes are true (linear)
  - Primary axis can be held fixed during rotational sequence of secondary axis

3D circle in space



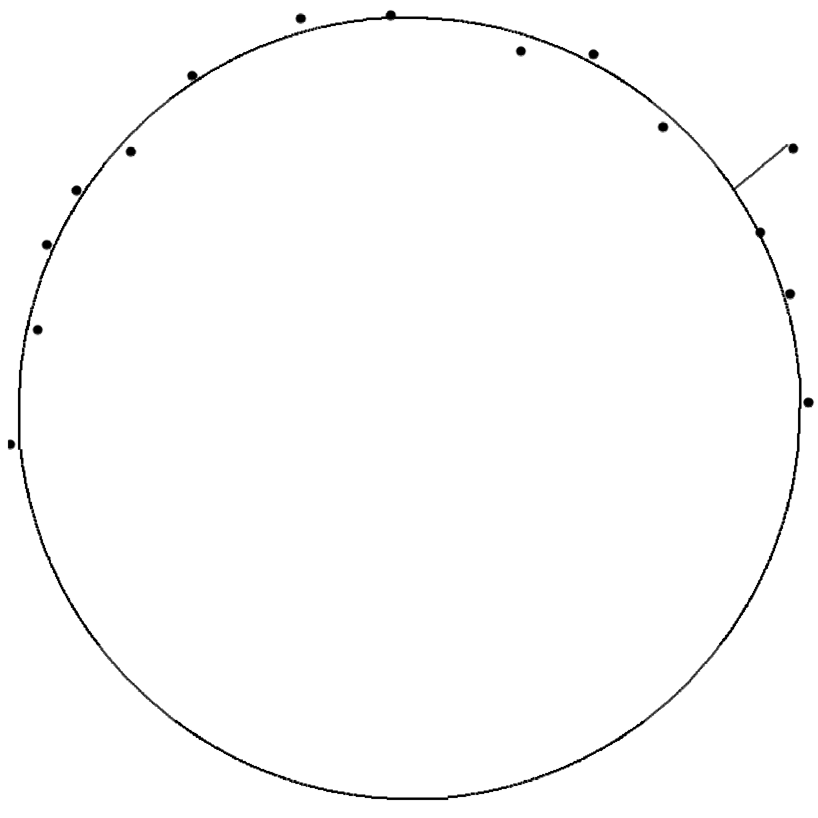
Circle fitting equations

(1) $$\hat{n}.(\tilde{x_m} - \tilde{x}) = 0$$

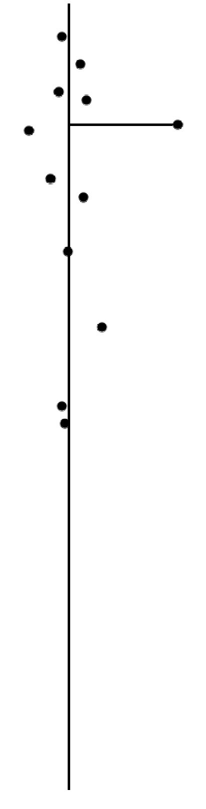
(2) $$\mid (\tilde{x_m} - \tilde{x}) \mid = r$$

(3) $$\mid \hat{n} \mid = 1$$

Circle fitting residual analysis

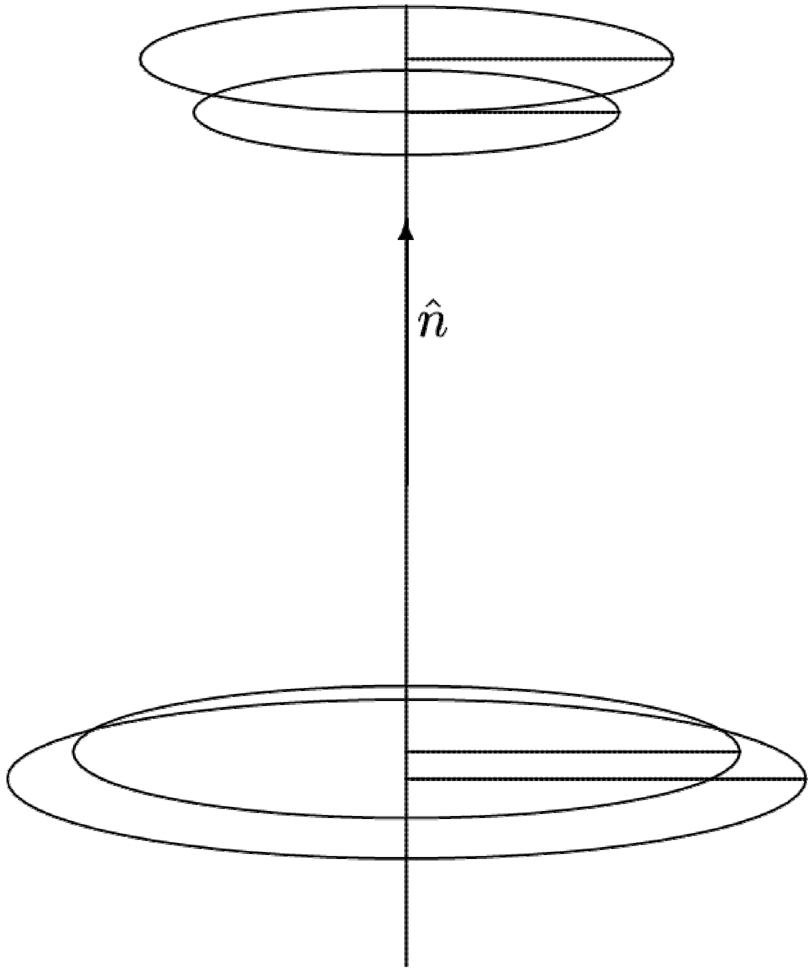


in-plane residuals

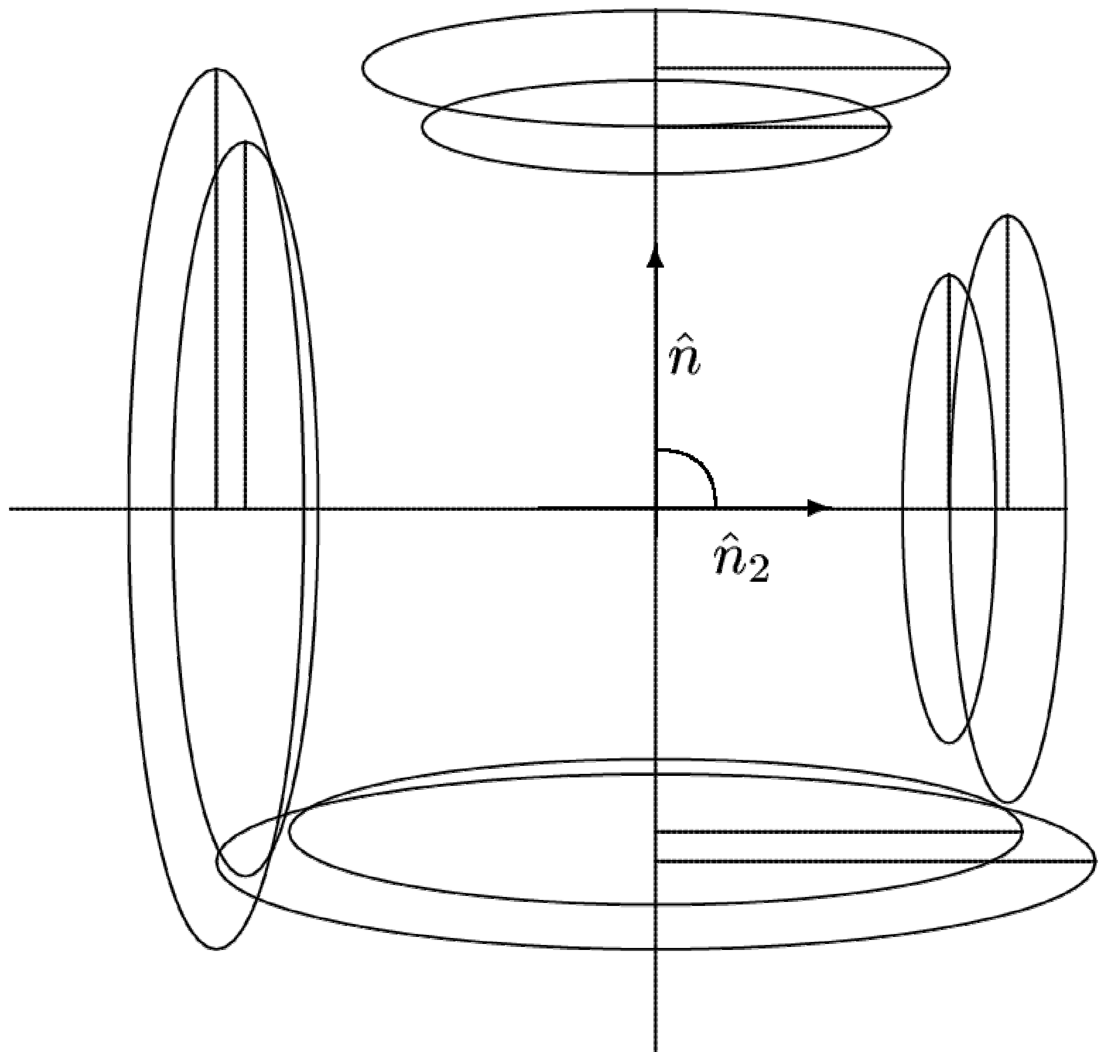


out-of-plane residuals

Constraining the unit normal vector



Constraining radius parameters



Analysis procedure

- Axis determination
  - In-house developed least squares analysis software
  - Input of coordinate values and variance-covariance matrix from the geodetic adjustment
  - Estimation of 3D circle parameters
    - Constraining circle parameters where appropriate
    - Residual analysis and outlier detection
  - Output of axis parameters
    - Multiple axis parameters and their associated variance-covariance matrix

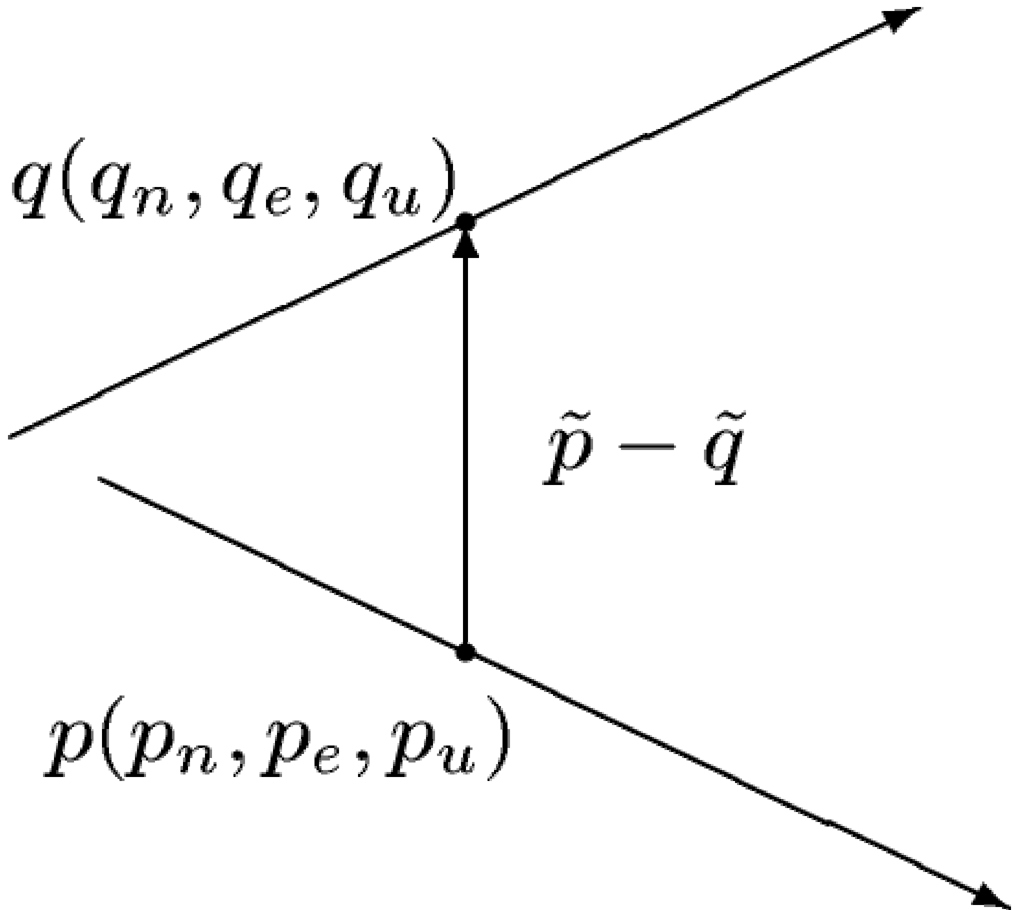
Analysis procedure

- Intersecting systems i.e. Yarragadee SLR
  - Intersection tested both experimentally and from Engineering data
  - Least square analysis of intersecting vectors
  - variance-covariance information from circle fitting
  - Axis vertical/horizontal-ness, orthogonality and intersection are useful data for station operators
  - IVP output in geodetic adjustment format

Analysis procedure

- Non-intersecting systems i.e. Hobart VLBI
  - Least squares analysis of common perpendicular of axes and IVP coordinate estimation
  - variance-covariance information of axis parameters from circle fitting software
  - IVP output in geodetic adjustment format

Common perpendicular



Common perpendicular equations

(1)
$$\tilde{p} = \tilde{c}_p + t\tilde{n}_p$$
$$\tilde{q} = \tilde{c}_q + s\tilde{n}_p$$

(2)
$$(\tilde{c}_p + t\tilde{n}_p - \tilde{c}_q - s\tilde{n}_q).\tilde{n}_p = 0$$
$$(\tilde{c}_p + t\tilde{n}_p - \tilde{c}_q - s\tilde{n}_q).\tilde{n}_q = 0$$

(3)
$$(\tilde{n}_p.\tilde{n}_p - \tilde{n}_q.\tilde{n}_p)t - (\tilde{c}_q.\tilde{n}_p - \tilde{c}_p.\tilde{n}_p) = 0$$
$$(\tilde{n}_p.\tilde{n}_q - \tilde{n}_q.\tilde{n}_q)s - (\tilde{c}_q.\tilde{n}_q - \tilde{c}_p.\tilde{n}_q) = 0$$

Terrestrial observational techniques

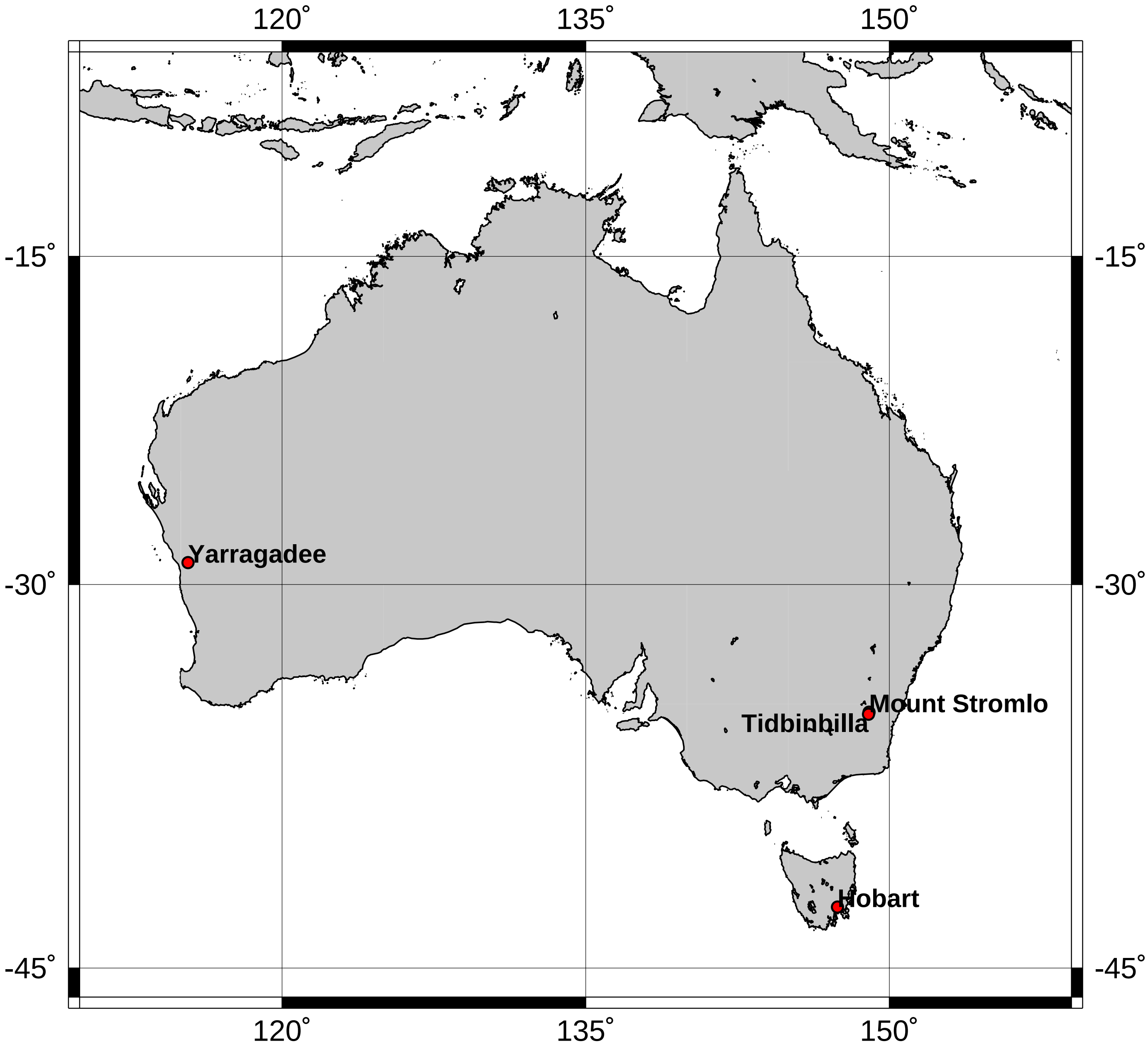
- Geodetic observations
  - Slope distance and vertical/horizontal angles
  - Precise differential levelling
    - Transfer of height
    - Precise height of instrument determination
  - Multiple instrument standpoints
    - depending on system design
  - Observation made from within highly over-determined local geodetic network

Geodetic least squares analysis

- Geodetic Adjustment
  - Observation reduction
    - Formatting
  - Observation correction
    - Theodolite error, Atmospheric, Prism offsets, Geoid
  - Geodetic adjustment
    - Least Squares Analysis (GEOLAB 2.4d)

Analysis procedure

- SINEX production
  - IVP determined coordinate and its associated variance-covariance information input into geodetic adjustment software
  - Local network re-processed including new observations to IVP
  - Geodetic adjustment output translated into SINEX format



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Target-shots per survey

Observatory (date)	Target-shots
Mount Stromlo (1999)	373
Mount Stromlo (2001)	224
Yaragadee (1998)	285
Yaragadee (2001)	243
Tidbinbilla DSS45 - 34m (1995)	101
Hobart - 26m (1995)	91
Hobart - 26m (2002)	298

Circle residuals (primary axis)

Observatory (date)	System Type	RMS in-plane residual (mm)	RMS out-of-plane residual (mm)
Mount Stromlo (1999)	AZ/EL	1.1 (AZ)	0.7 (AZ)
Mount Stromlo (2001)	AZ/EL	0.5 (AZ)	0.7 (AZ)
Yarragadee (1998)	AZ/EL	0.6 (AZ)	0.4 (AZ)
Yarragadee (2001)	AZ/EL	0.5 (AZ)	0.4 (AZ)
Tidbinbilla (1995)	AZ/EL	0.8 (AZ)	8.9 (AZ)
Hobart (1995)	X/Y	0.2 (X)	4.0 (X)
Hobart (2002)	X/Y	0.3 (X)	7.9 (X)

Circle residuals (secondary axis)

Observatory (date)	System Type	RMS in-plane residual (mm)	RMS out-of-plane residual (mm)
Mount Stromlo (1999)	AZ/EL	1.8 (EL)	0.7 (EL)
Mount Stromlo (2001)	AZ/EL	0.6 (EL)	0.7 (EL)
Yarragadee (1998)	AZ/EL	0.2 (EL)	0.2 (EL)
Yarragadee (2001)	AZ/EL	0.7 (EL)	0.2 (EL)
Tidbinbilla (1995)	AZ/EL	0.1 (EL)	2.6 (EL)
Hobart (1995)	X/Y	0.7 (Y)	3.4 (Y)
Hobart (2002)	X/Y	0.5 (Y)	6.4 (Y)

Impact of targets? - Hobart (VLBI)

IVP to individual axes distance

Observatory (date)	System Type	RMS IVP to axis distance (mm)	Primary axis to Secondary axis distance (mm)
Mount Stromlo (1999)	AZ/EL	3.6	1.9
Mount Stromlo (2001)	AZ/EL	1.6	0.8
Yaragadee (1998)	AZ/EL	0.6	0.3
Yaragadee (2001)	AZ/EL	1.2	0.4
Tidbinbilla (1995)	AZ/EL	7.0	7.6
Hobart (1995)	X/Y	-	8193.2
Hobart (2002)	X/Y	-	8193.0

IVP from individual axes sets

Observatory (date)	North RMS IVP (mm)	East RMS IVP (mm)	Up RMS IVP (mm)
Mount Stromlo (1999)	0.1	0.3	2.1
Mount Stromlo (2001)	0.9	1.0	0.9
Yaragadee (1998)	0.4	0.3	0.4
Yaragadee (2001)	0.4	0.2	0.9
Tidbinbilla (1995)	2.3	4.1	0.9
Hobart (1995)	0.7	1.6	0.8
Hobart (2002)	0.4	1.6	0.4

Local Tie Repeat Surveys

Observatory	East IVP to reference mark (mm)	North IVP to reference mark (mm)	Up IVP to reference mark (mm)
Mt Stromlo (1999-2001)	**-0.3**	**-0.4**	**0.4**
Yarragadee (1998-2001) **(from GPS YAR1)**	**0.0** **(-0.8)**	**1.9** **(1.5)**	**-1.3** **(-4.2)**
Hobart (1995-2002)	**-1.2**	**-0.3**	**-0.4**

Final Comments

- Errors
  - Retro-targets a potential issue
  - refraction
- When should new local tie survey results be released?
- Survey reports located at www.ga.gov.au
- SINEX format results files located at ftp.ga.gov.au/sgac/sinex/ties