The current state of ground surveys

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Brief background to IERS Working Group

- International Earth Rotation and Reference Systems Service (IERS) consists of
  - International Laser Ranging Service ILRS
  - International GNSS Service IGS
  - International VLBI Service for Geodesy and Astrometry IVS
  - international DORIS Service IDS

WHO

- The combination of space geodetic solutions relies on **local tie vectors**: relations between reference points **in a common reference frame (i.e. ITRF).**

WHAT

- Tie vectors effectively enter the combination as a fifth technique and are necessary for
  - **rigorous terrestrial reference frame realization**
  - to highlight the **presence of technique- and/or site-specific biases**.

WHY

GGOS ambitions require full system reevaluation

- Discrepancies between observed local ties and analytic results continues to exist in ITRF2014
- Previously neglected uncertainty sources need to be accounted for
- Service POC:s

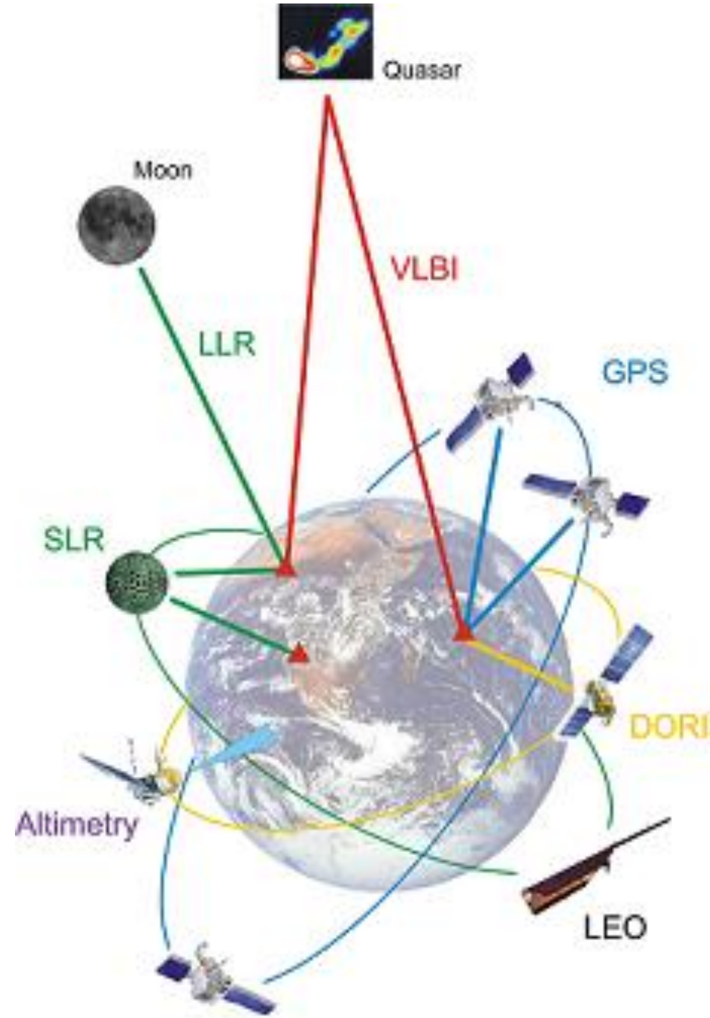
  ILRS - Erricos C. Pavlis, UMBC

  IVS - Rüdiger Haas, Chalmers

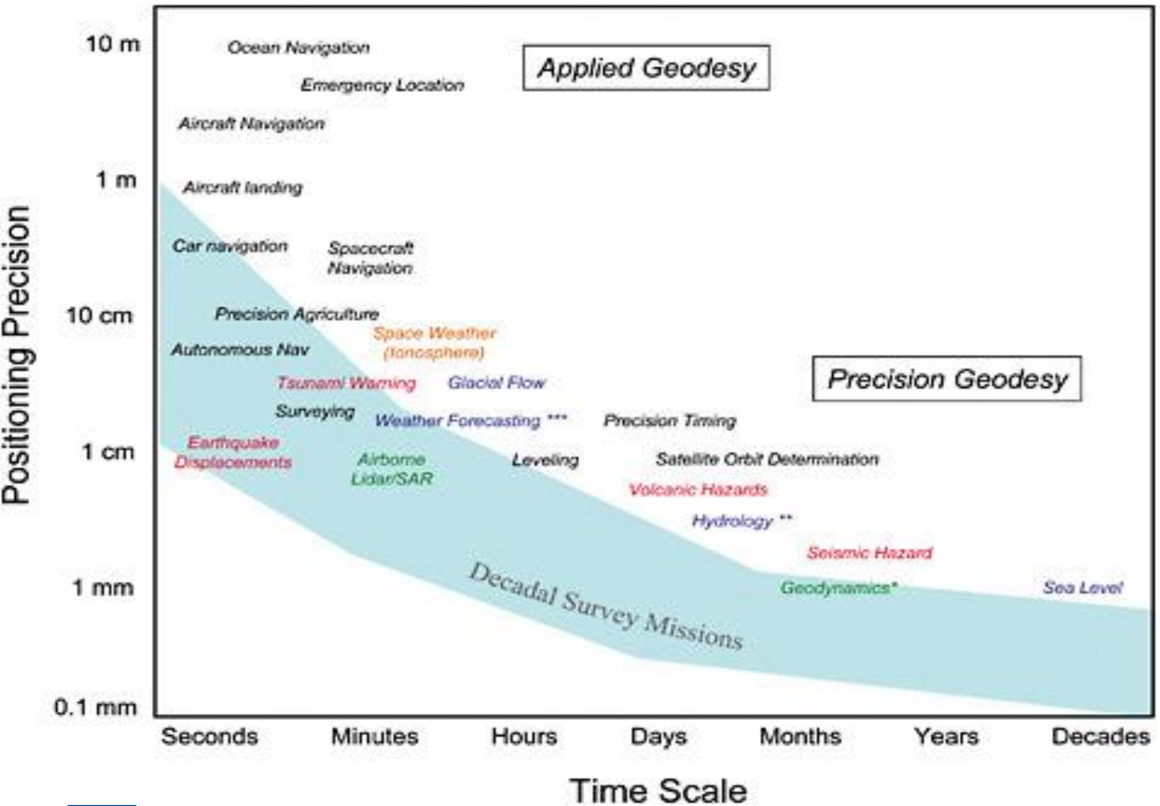
  IDS - Jerome Saunier, IGN

  IGS - Ralf Schmid, TUM

  SGP - Jim Long, NASA



IAG grand challenge GGOS



- GGOS overall *system* requirement for the most challenging applications:
  - 1 mm
  - 0.1 mm/yr on decadal scales
- Local ties should not be a dominant part → uncertainty < 1 mm
- Consistency requires mindset change from ”research to production”

Courtesy of Bernard Minster http://www.nap.edu/read/12954/chapter/5#38

The bigger picture

No.	Parameter	VLBI	GNSS	DORIS PRARE	SLR	LLR	Alti-metry
1	Quasar Coordinates	X					
2	Nutation	X	(X)		(X)	X	
3	Polar Motion	X	X	X	X	X	
4	UT	X					
5	Length of Day		X	X	X	X	
6	Coordinates and Velocities	X	X	X	X	X	(X)
7	Geocenter		X	X	X		X
8	Gravity Field		X	X	X	(X)	X
9	Orbit		X	X	X	X	X
10	LEO		X	X	X		X
11	Ionosphere	X	X	X			X
12	Troposphere	X	X	X			X
13	Time/Frequency	(X)	X		(X)		

- The different services and techniques are complementary
- Each technique have their own reference frame that are merged into the ITRF
- Local ties and Polar motion are common to all techniques

The GGOS book Chapter 9Courtesy of Rothacher et al.

Site plan

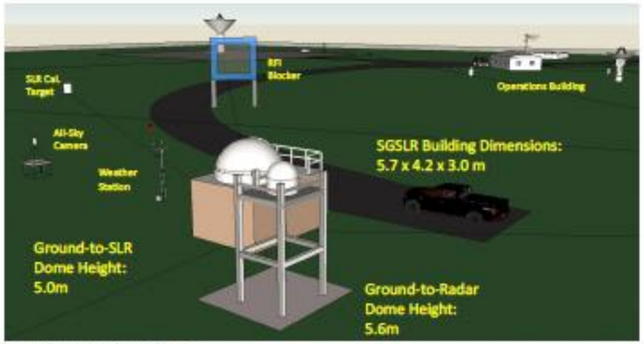


Figure 3a. Idealized site layout showing Site RF Blocker between SLR and VLBI (Provided by Jaime Esper/NASA)

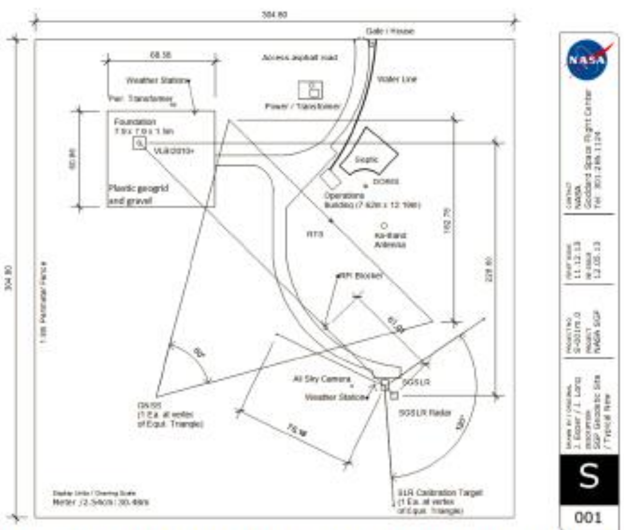


Figure 3b. Notional Site Layout in the NASA Space Geodesy Project Plan highlighting the RF Site Blocking Scheme (Provided by Jaime Esper/NASA)

- Incorporate local tie aspects when planning a new site
- A network of surveying pillars for GNSS as well as robotic theodolites/total stations
- Secure lines of sight
- Multiple surveying positions around each station
- Three GNSS monuments to provide orientation in the global frame is a minimum

Reasonably recent larger gatherings of WG

IERS 2013 Paris workshop

- Representation by Analysts, Surveyors and operators from four services
- Local Tie surveying requires detailed technical knowledge of each contributing technique
- Terminology and applications slightly confused
- Unifying resolution presented by Axel Nothnagel

- No immediate action

REFAG2014

- Resolution scrutinized and reworked
  - One common terminology
  - Should be general and include other services/techniques too (gravity, sea level etc)
- Lesson learned: Working group probably too large to be efficient in previous form
  - Still open Working Group
  - Service appointed Points of Contact

IVS: Rüdiger Haas, Chalmers

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NASA SGP: Jim Long

Resolution on the nomenclature of space geodetic reference points and local tie measurements

The essentials as submitted to REFAG2014 proceedings:

- Each station/instrument has a

UNIQUE GEOMETRIC REFERENCE POINT

- Each site should be represented by a

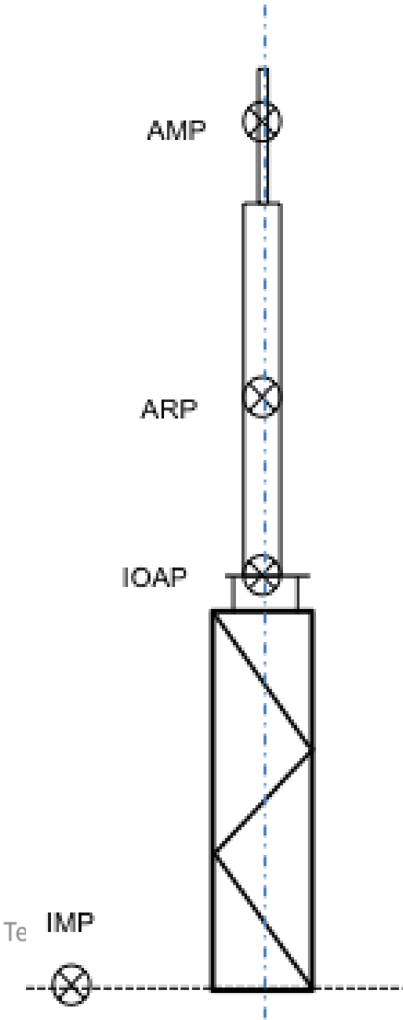
PHYSICAL SITE MARKER

- Relations between lithosphere, site markers, reference points and actual observations – e.g. CCD centers – are described by

MODELS or **MEASUREMENTS**

- The term ”REFERENCE point” is reserved
- Reference point definitions are determined by the individual services

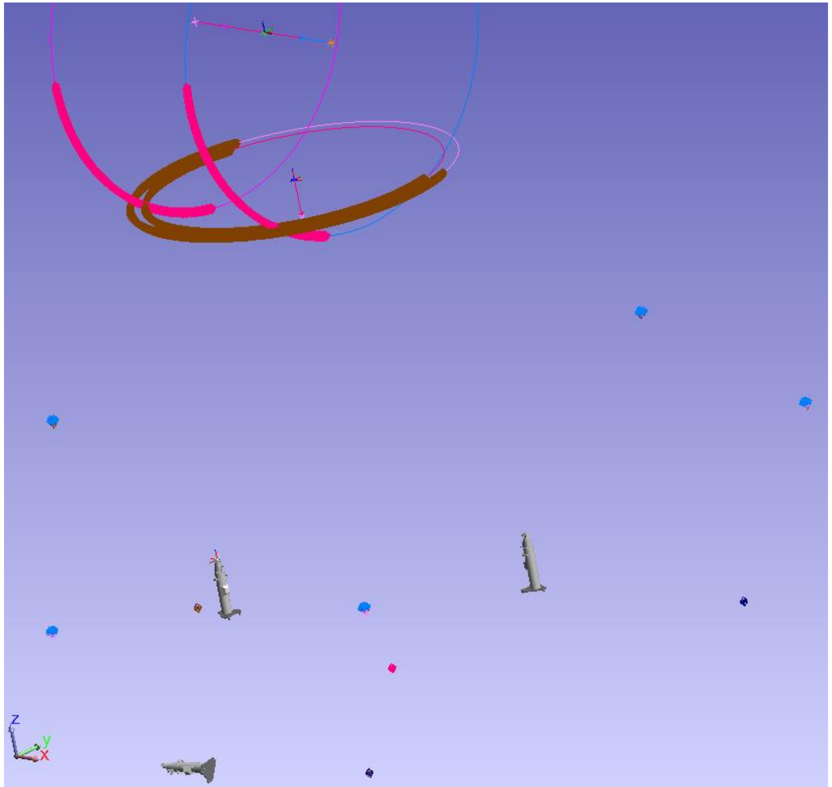
Activities in the different services



- IDS
  - Changed to new antenna types
  - Identified points according to resolution
  - Surveying procedures and relations clarified
    - AMP is the Antenna measuring point (phase center)
    - ARP is the traditional reference point (center of a painted ring)
    - IOAP Observable Antenna Point (surveying CCR)
    - IMP Instrument measuring point (ground marker)

- IGS
  - Going through co-located station status and antenna calibration. Status January 2016:
    - absolute robot calibration: 83.0 %
    - converted field calibration: 6.5 %
    - unmodeled radome/other severe issues: 10.5 %

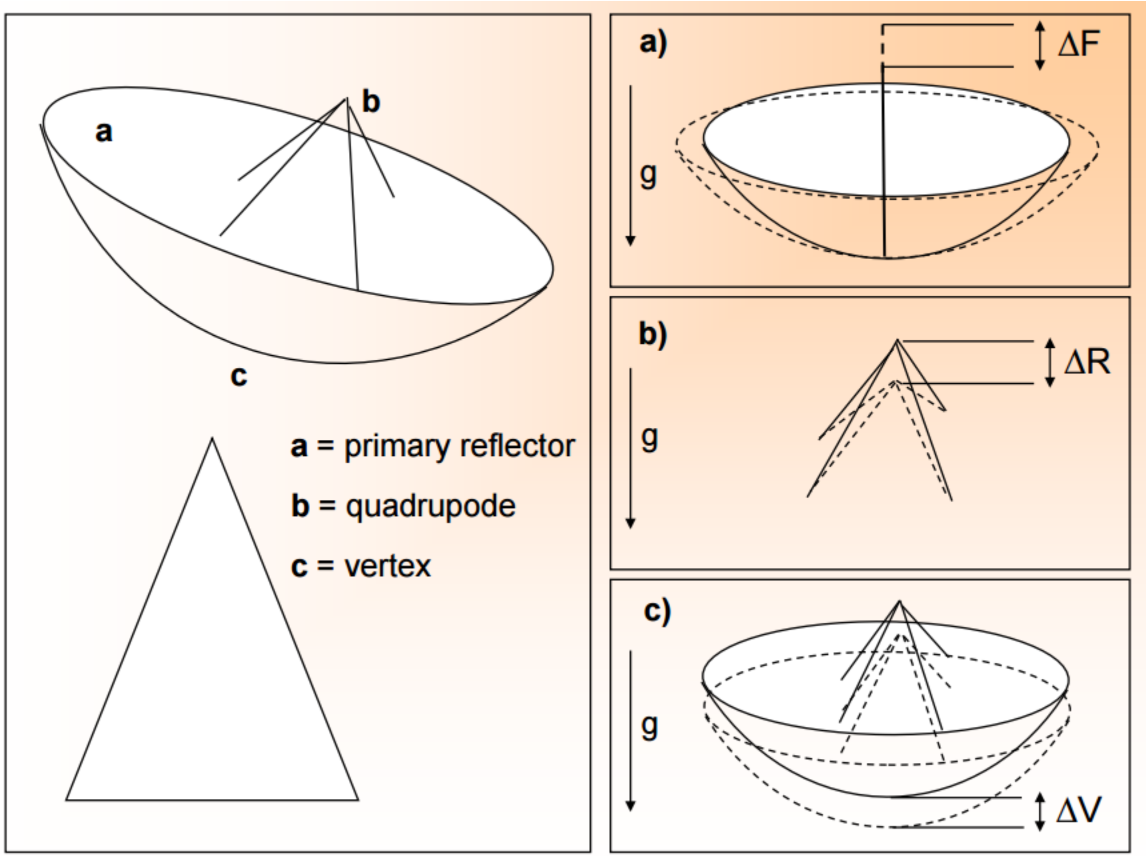
Determining the IVS reference point



- Definition: Projection of secondary axis onto primary axis
- Most often not physically available
- Wisely chosen targets (retroreflectors) on the telescope's moving parts ideally perform circular trajectories
- E.g. elevation axis rarely exceeds quarter of a circle – secondary axis is not ideally constrained
- Feed-horn offsets are handled by pointing models
- GNSS coordinates used for orientation

Gravitational dependent telescope deformation

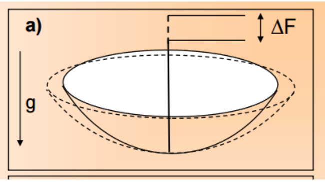
$$\Delta L(\varepsilon) = \alpha_F \Delta F(\varepsilon) + \alpha_V \Delta V(\varepsilon) + \gamma \alpha_R \Delta R(\varepsilon)$$

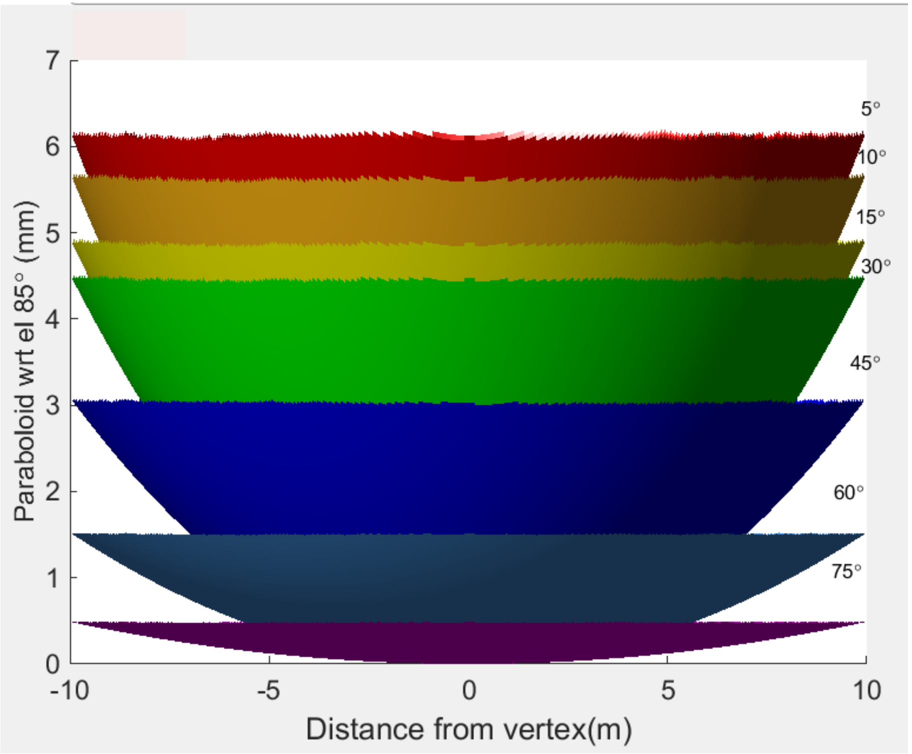


- Sub-mm is a challenging metrological task on any large structure
- General models are not sufficient
- Moving parts complicate matters further
- Analysis of results include Kalman filtering

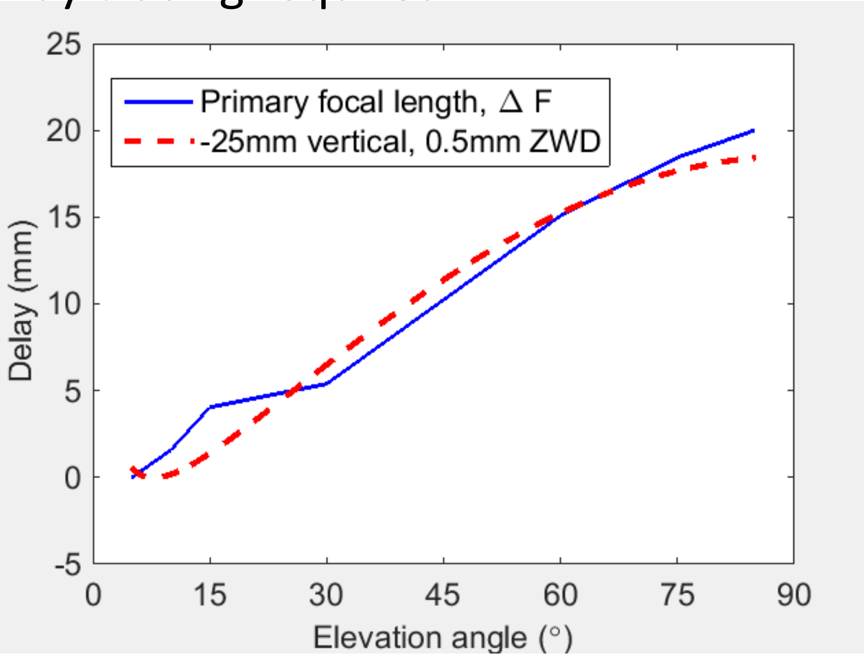
Courtesy Sarti after Clarke and Thomsen

Paraboloid deformation, ΔF





- ΔF computed from best fit paraboloid
- ΔF shifts more than 2Δd, rays intercepted by subreflector
- Net effect: distance + defocus?
- Ray tracing required



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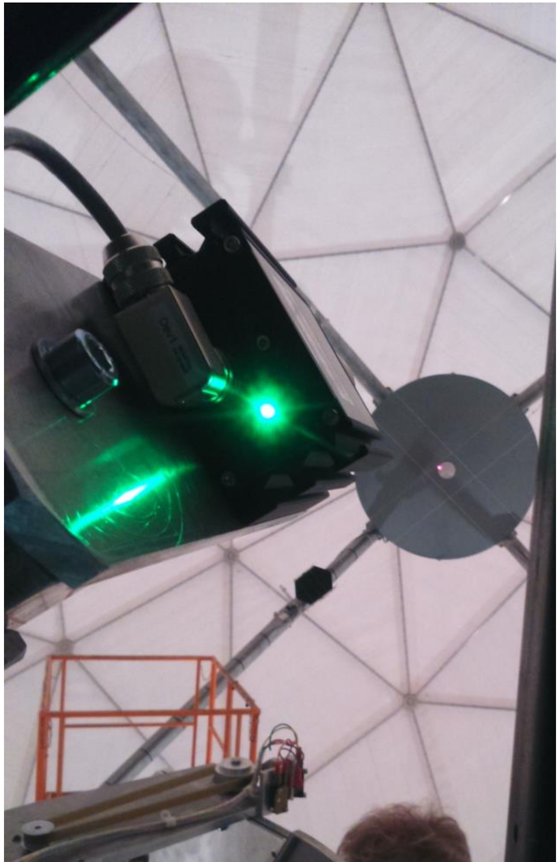
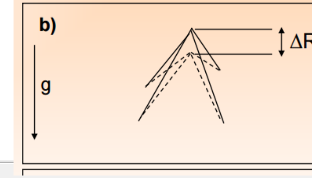
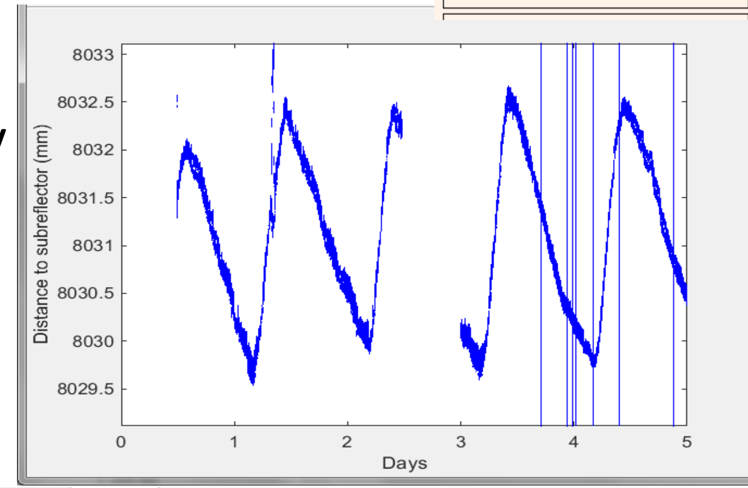
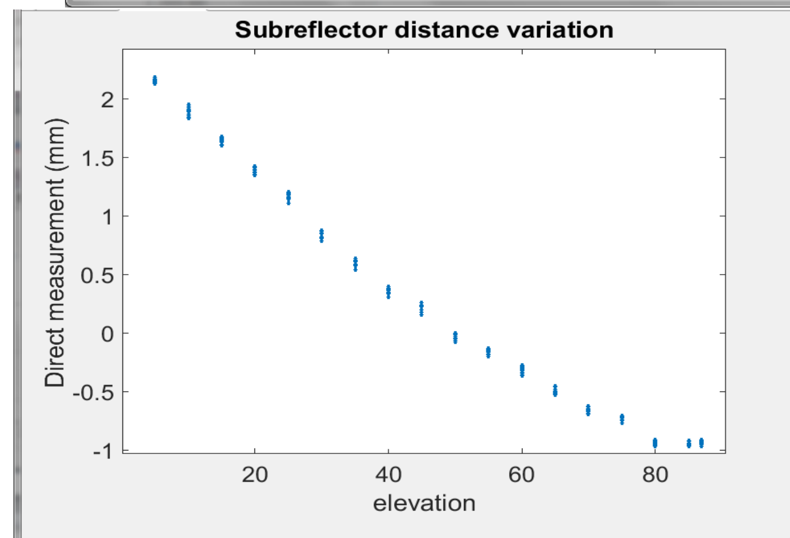
Distance to subreflector, ΔR



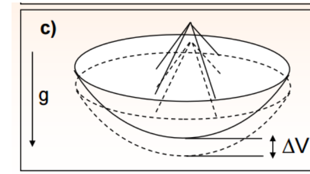
- Temperature dependence 3 mm/day (clock)
- Elevation dependence 3 mm (atmosphere)

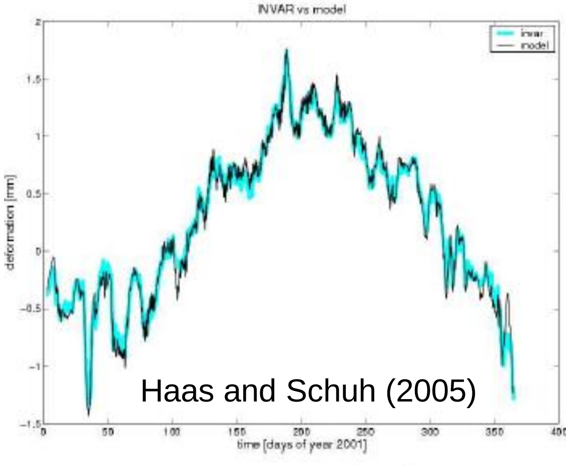






Thermal deformation measured by Invar rods

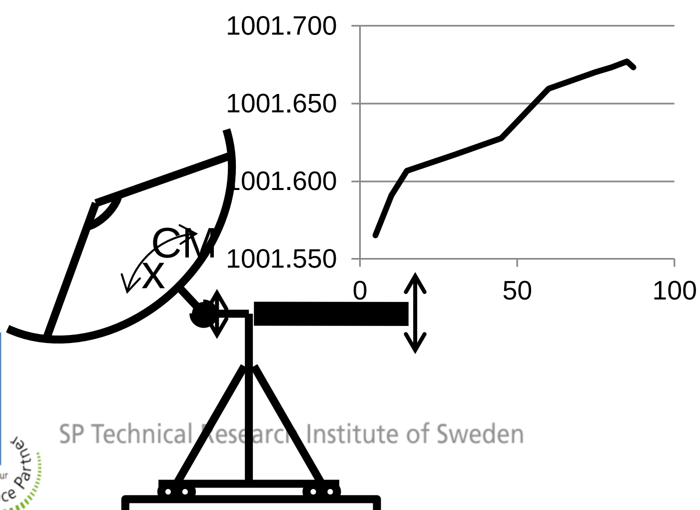


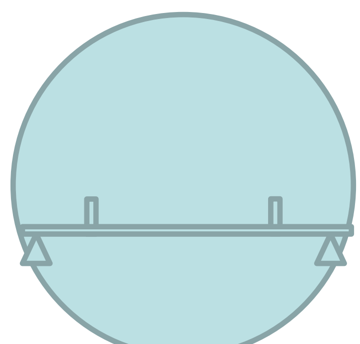


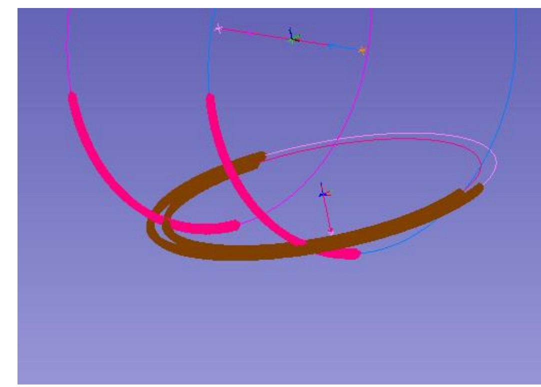
- Direct measurements of monument height

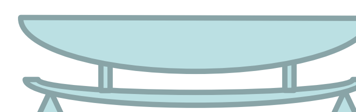
$$\Delta L = L\alpha\Delta T \text{ (3 mm annually)}$$

- Support nod (0.1 mm)
- Support deformation (0.1 mm)

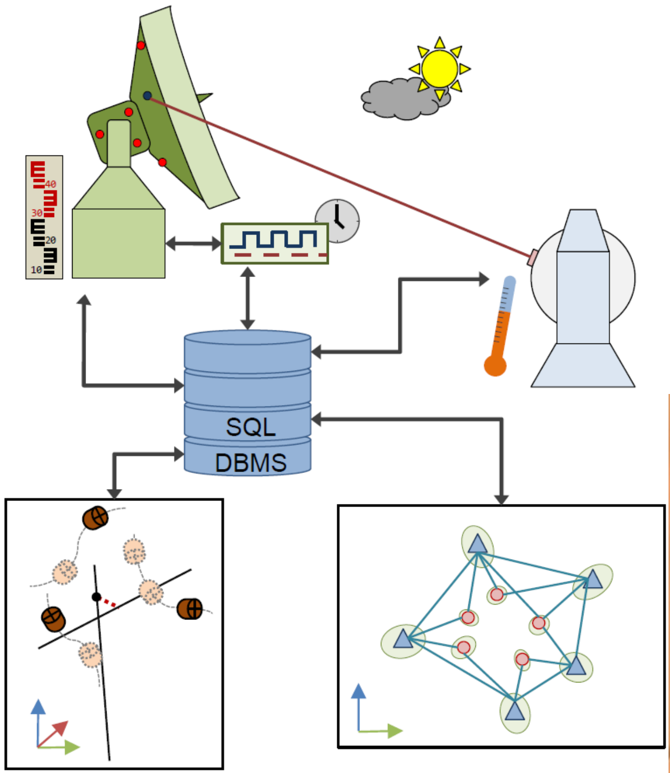


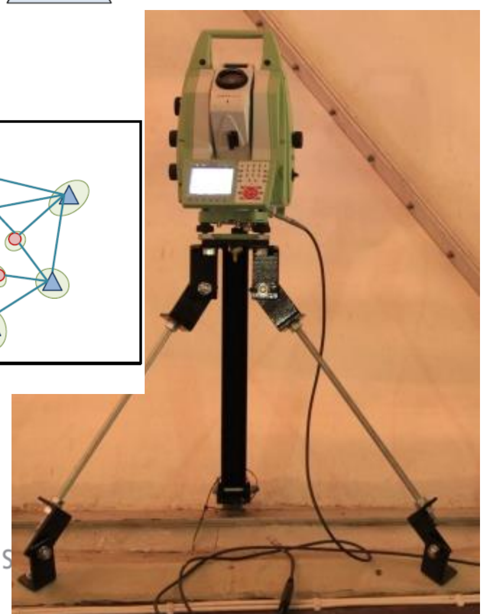






Activity in the working group



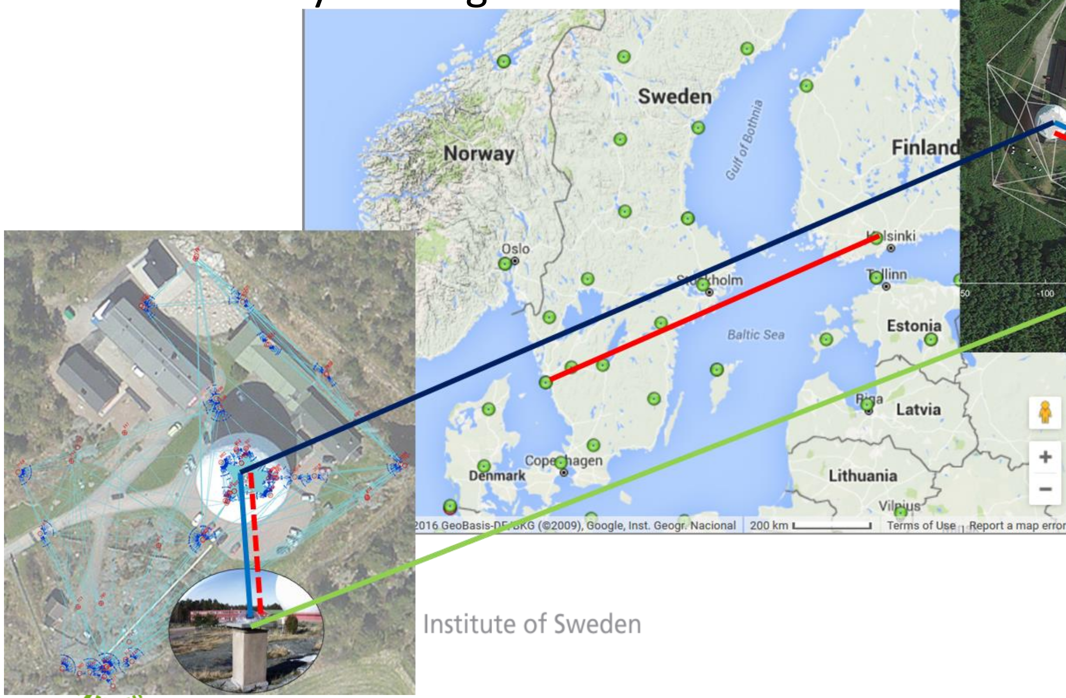


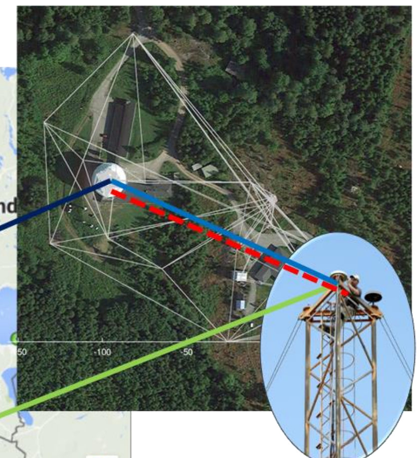
- VLBI-schedule adapted robotic tachymeter system HEIMDALL operative
  (Michael Lösler, FRA-UAS)

- Automated and continuous monitoring of the reference points of space geodetic techniques in line with GGOS requirements
- Currently VLBI.
- Operating at Metsähovi VLBI telescope since 2015
- Adaptable to SLR

Comparison of IVS and IGS baseline with terrestrial and GNSS-based local ties

- Tachymeters have excellent repeatability but need external orientation to fit into ITRF
- GNSS observations have comparatively poor repeatability, but observations are made directly in the global reference frame





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- Terrestrial measurements HEIMDALL operated
- Hinge-mounted GNSS antennas on each side of VLBI reflector

Summary

- It is imperative to GGOS that local 3D vectors are robust and accurate
- Baseline lengths are not enough:
  3D ITRF coordinates at each site are required
- GNSS to provide coordinates for transformation between topocentric and global frames
- A common terminology for local ties has been established between the IERS services, and surveying operations are now better defined.
- An automated terrestrial monitoring system is operative for VLBI schedules.

Conclusions

- Telescope surveying is required to meet GGOS/VGOS requirement of 1 mm accuracy
- Geometric telescope variations are accountable for biases in VLBI observations.
- The GNSS based orientation is a limiting case for accurate site surveying in 3D
- Establish a robust method for Local Tie orientation, e.g. by advocating for Customized Core station GNSS antennas.

- The geometric reference point is defined to be able to tie the station to the surroundings of the site
- *The reference point is likely not representative from an observational technique point of view*

THANKS FOR THE ATTENTION!

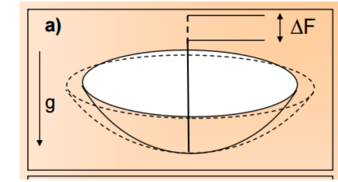
QUESTION TIME

Questions for the SLR society on an 0.1 mm ITRF 3D level

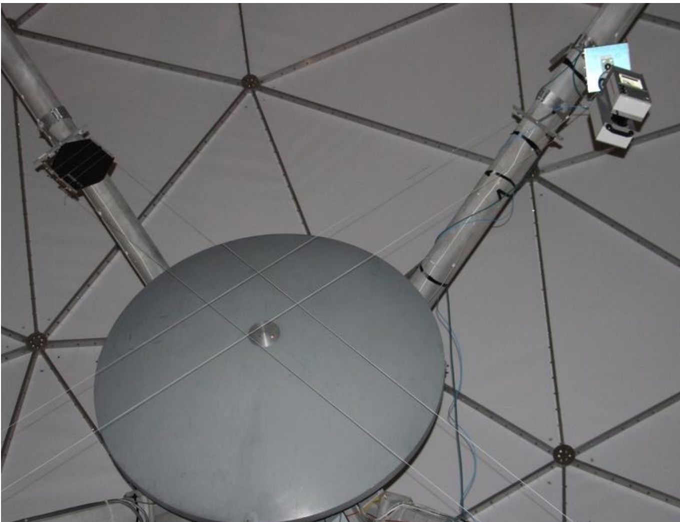
- The geometric reference point is defined to be able to tie the station to the surroundings of the site.
- **However, *the reference point is likely not representative from an SLR point of view***

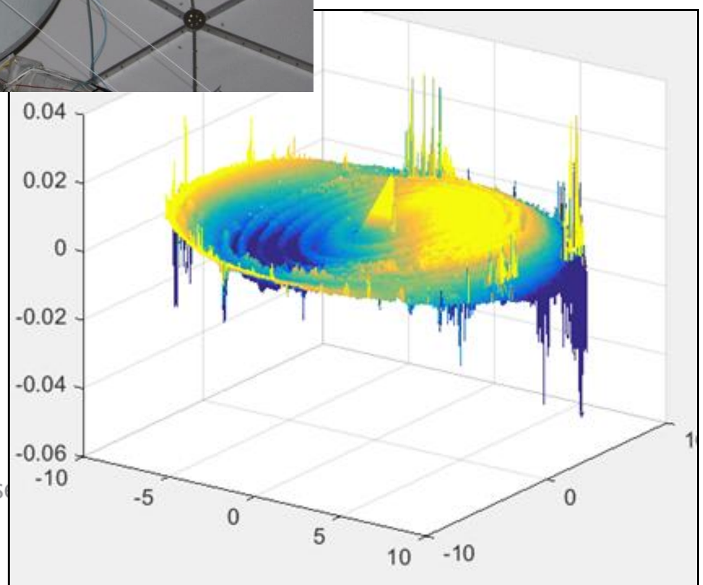
- Are the definitions absolutely clear?
- Are there neglected terms?
- Are the geometric/optic relationships of the satellites agreed on?
- Are observations really made at the reference point?
- What is the relationship between the reference point and the recording unit?
- Are the thermal properties of the telescopes accounted for (varying telescope height, internal ray path, etc)
- How well is the reference point determined in the topocentric frame?
- How well is the topocentric frame oriented with respect to the global frame?
- Are the GNSS antennas calibrated?

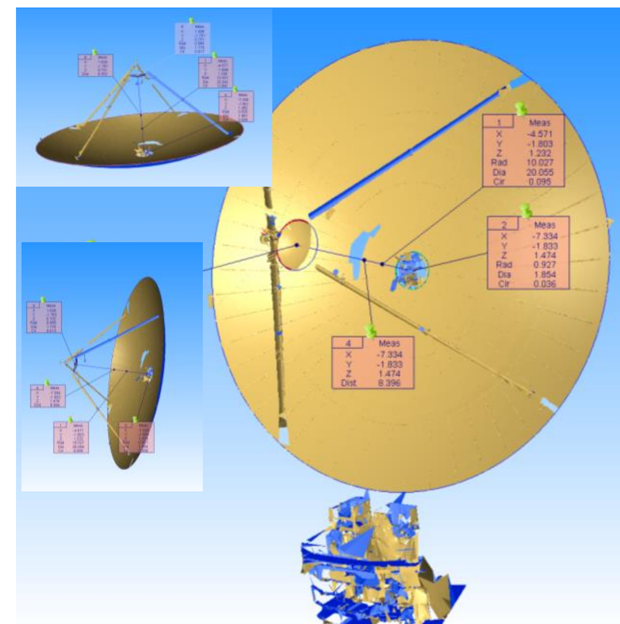
Scanning the primary reflector, ΔF



- Direct surface measurement (approx. 1 pt/cm^2)
- Customized setup
- 15-30 min/per full scan
- 15 kg added weight







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