Analysis on the track unevenness and alidade temperature behavior of TM65m antenna

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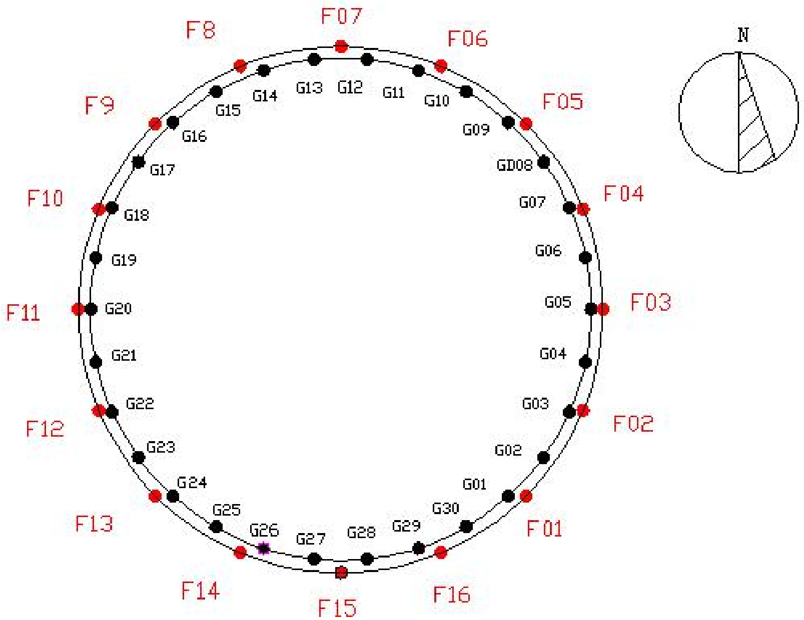
Outline

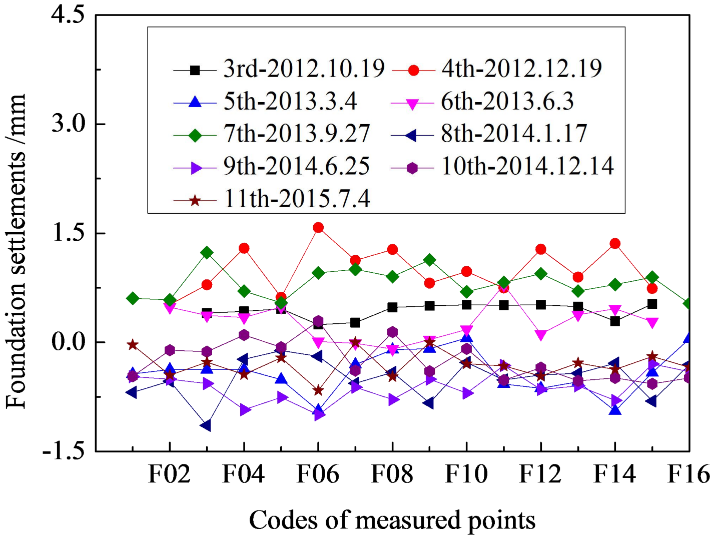
- **The track unevenness and its effects**
  - The foundation settlement and track unevenness
  - The effect of track unevenness on antenna pointing
    - FEM
    - Inclinometer measurement
- **The alidade temperature behavior**
  - Temperature acquisition system
  - The distribution of temperature field
  - The effect of thermal deformation on antenna pointing
- **Further work**
  - The temperature behavior of backup structure
  - The effect of wind on the antenna

The foundation settlement and track unevenness

- Leica DNA03 electronic level, invar leveling staff.
- Accuracy: ±0.3mm/km
- Method: closed level route

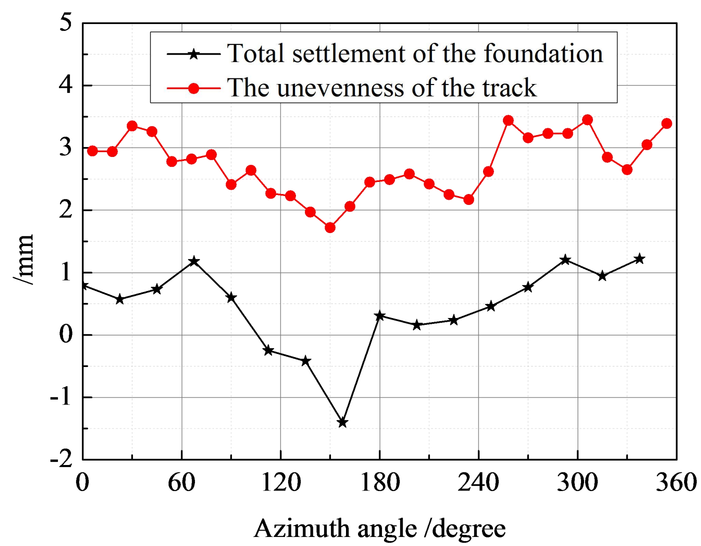


The foundation settlement and track unevenness



The foundation settlement :

- Jul. 2012~Jul. 2015, 11times
- The foundation tends to even settlement
- The reasons of the settlements are positive:
  - The variation of groundwater level
  - The settlement of reference point larger than base



The foundation settlement and track unevenness on 4 July, 2015:

- There are relevant between foundation settlements and track heights with variation of the azimuth angle.
- The track unevenness (RMS): 0.47mm

The effect of track unevenness on pointing——FEM

The track unevenness based on the electronic level

↓

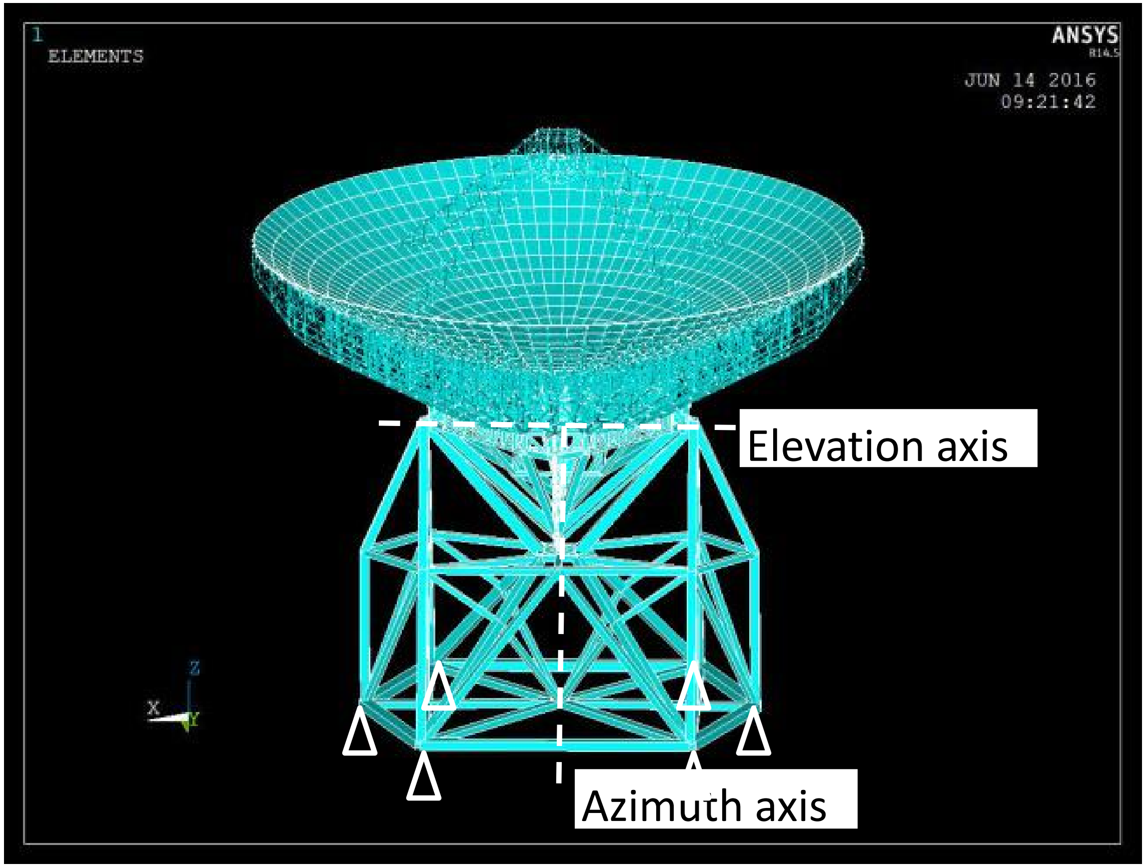
Linear interpolation

↓

Extracting the heights of some 6 supporting points of azimuth wheels

↓

Obtaining the $P_4\cos(az)$and $P_5\sin(az)$ by FEA



$$\Delta az = \frac{\Delta Xel}{\cos(el)} = \frac{P_1 + P_2\cos(el) + P_3\sin(el)}{\cos(el)} + \frac{P_4\cos(az)\sin(el) + P_5\sin(az)\sin(el)}{\cos(el)}$$

P_4——inclination of azimuth axis (toward west); P_5 ——inclination of azimuth axis (toward north)[1]

[1] Juan P, Ute L, Rainer M. Pointing with the IRAM 30m Telescope. SPIE, 2000.

Inclinometer measurement system

- Leica Nivel220 electronic inclinometer：
  - Range：A:±311 ＂， B: ±518 ＂, C: ±619 ＂;
  - Resolution：1 μ rad=0.2 ＂; Accuracy：A: ±1.3 ＂, B: ±3.9 ＂, C: ±9.7 ＂;
  - Zero stability： ＜0.97 ＂/°C; Sample speed：minimum 300ms ;
  - RS323 or RS485 interface; two-axis sensor

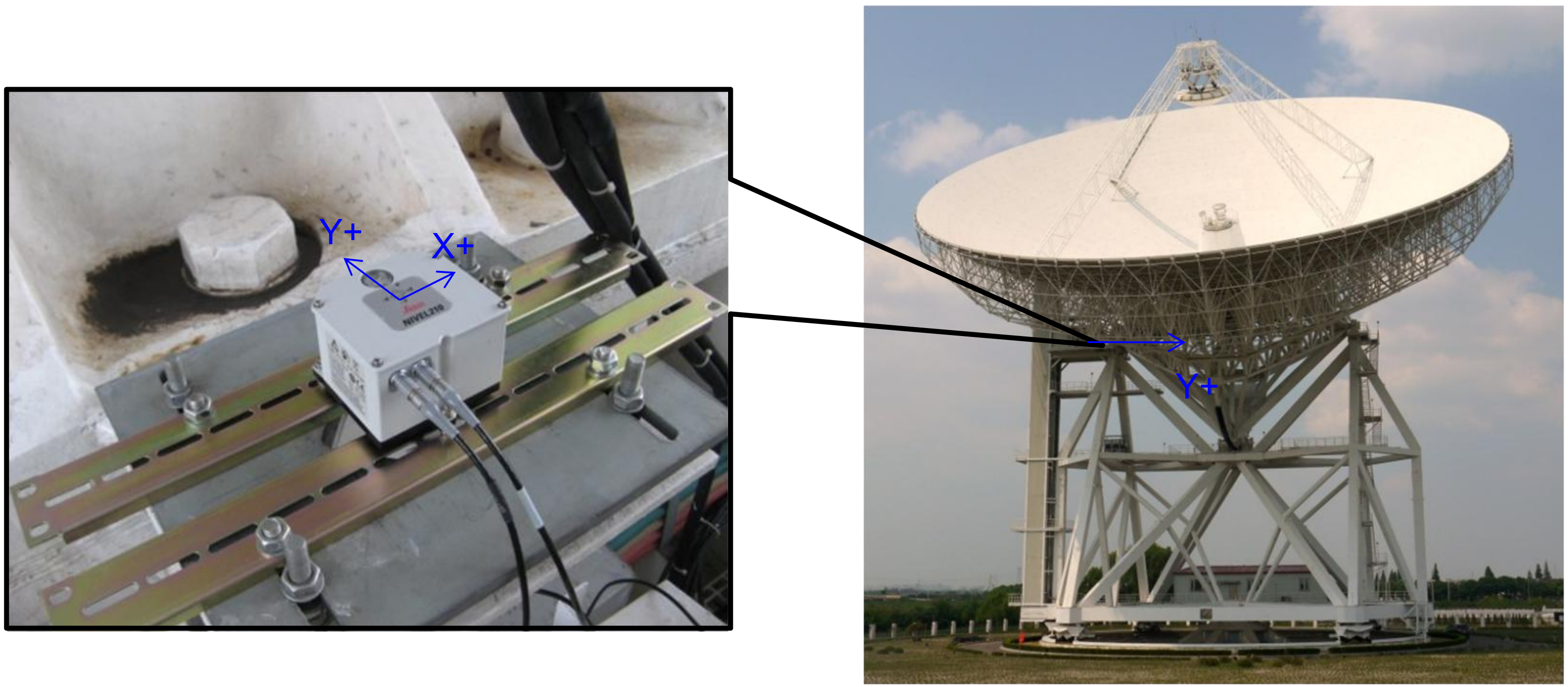


Fig. The antenna structure of TM65m on the right; a zoom of the inclinometer located on the upper part of the alidade on the left.

The format of data measured by inclinometer

- We compiled data acquisition software to record the inclinometer data and the format is shown as Table 1.
- The elevation tilt (y-tilt), cross-elevation tilt (x-tilt), azimuth and elevation angle, rotation velocity and so on were recorded simultaneously, which will be convenient to analyze data and modify pointing model.

Table 1. The format of data measured by inclinometer.

DATE	TIME	X-TILT (mrad)	Y-TILT (mrad)	TEMP (℃)	AZ (°)	Vaz (°/s)	EL (°)	Vel (°/s)
2015-7-29	10:34:01	0.029	-0.015	34.5	153.9993	0	87.9995	0
2015-7-29	10:34:02	0.03	-0.012	34.5	153.9993	0	87.9995	0
2015-7-29	10:34:03	0.037	-0.021	34.5	153.9993	0	87.9995	0
2015-7-29	10:34:04	0.042	-0.012	34.5	153.9993	0	87.9995	0
2015-7-29	10:34:05	0.038	-0.018	34.5	153.9993	0	87.9995	0
2015-7-29	10:34:06	0.035	-0.019	34.5	153.9993	0	87.9995	0
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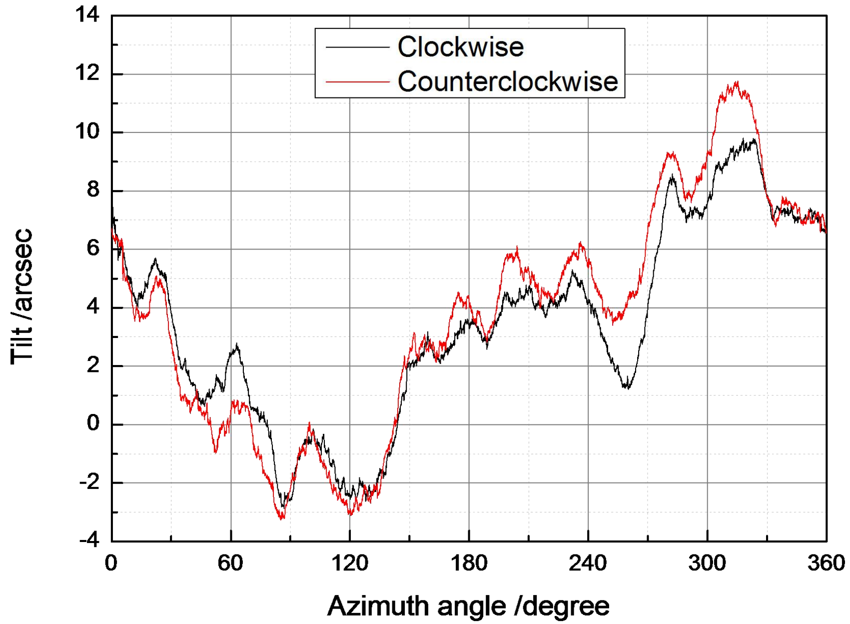
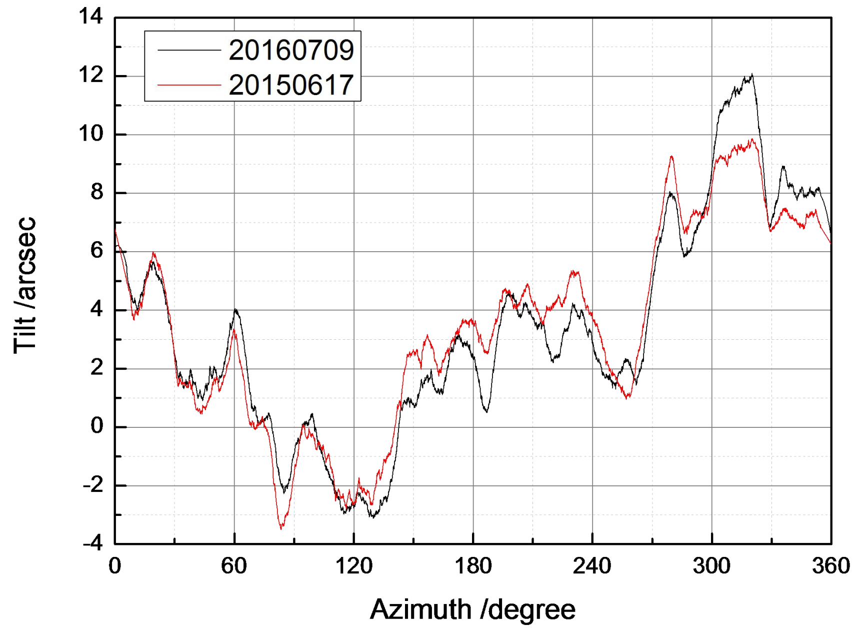
The track unevenness measured by inclinometer





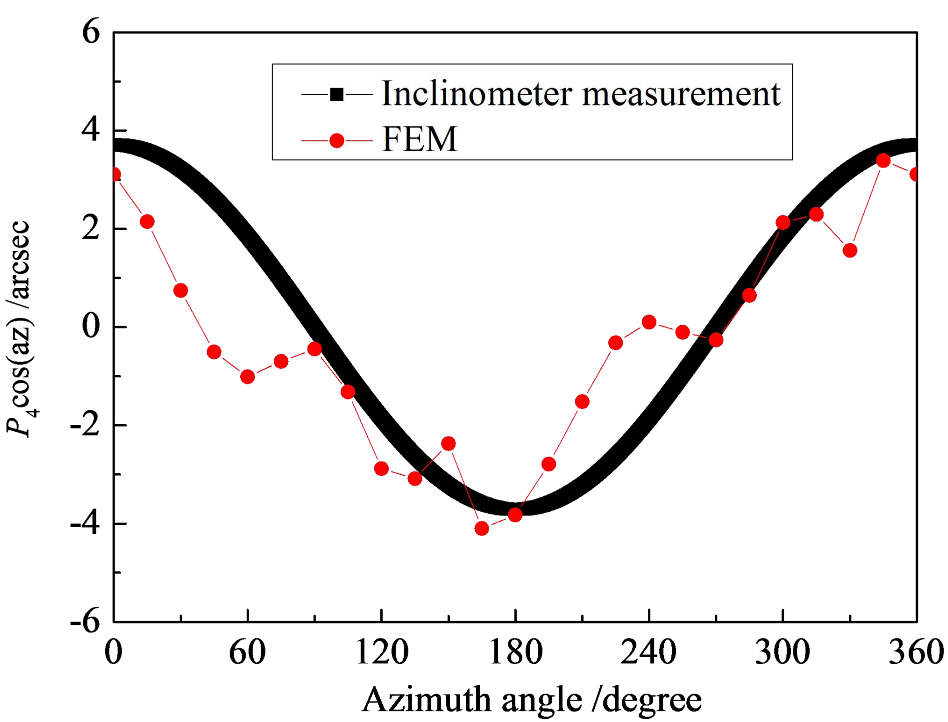
- Date: June 17, 2015
- The black line: the azimuth rotation in clockwise direction.
- The red line: the azimuth rotation in counterclockwise direction.

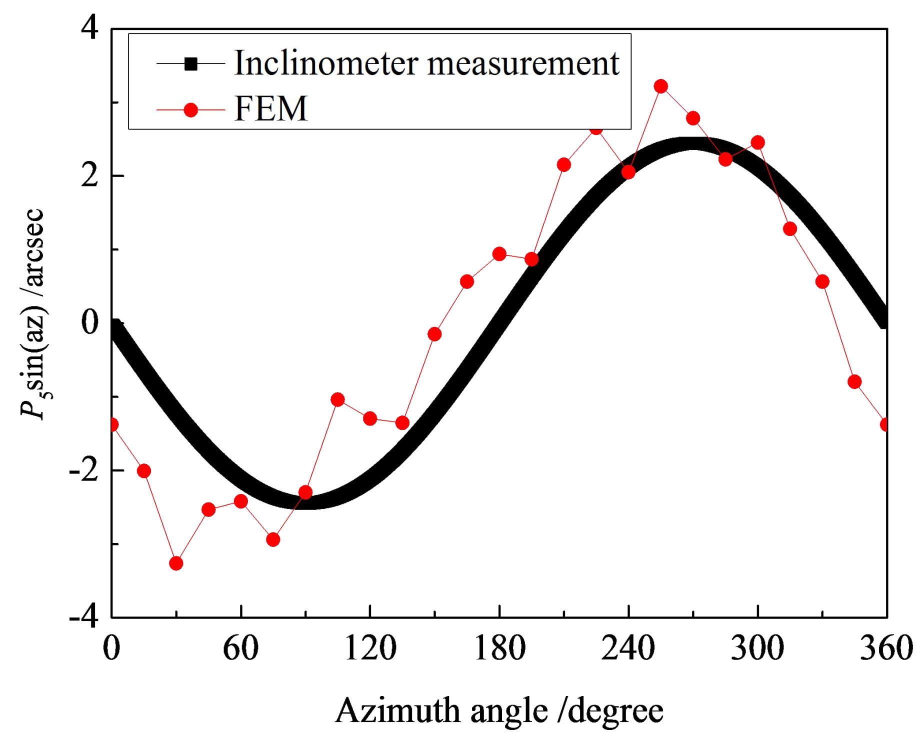
- The black line: the azimuth rotation on July 9 , 2016.
- The red line: the azimuth rotation on June 17, 2015.

The effect of track unevenness on pointing

Rotating azimuth from 0 to 360 degree → Obtaining Ix and Iy by inclinometer → $I_x(az) = \theta\cos(az-\varphi)$, $I_y(az) = \theta\sin(az-\varphi)$ → $P_4 = -\theta\cos(\varphi-180)$, $P_5 = -\theta\sin(\varphi-180)$

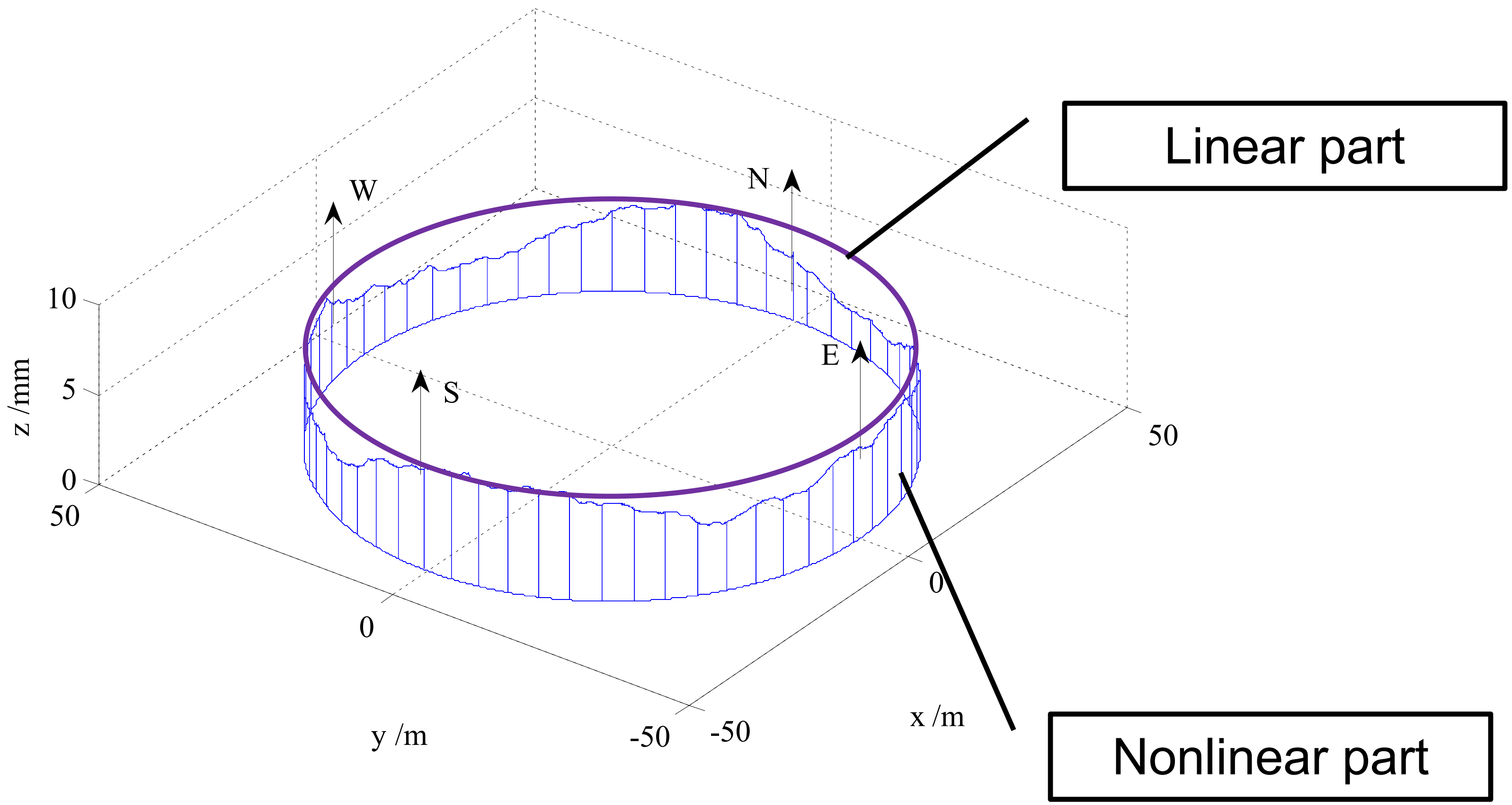
I_x , I_y——the readings from inclinometer sensors X and Y; θ ——the magnitude of the azimuth axis tilt; ϕ-90 ——azimuth angle toward the azimuth axis tilted [1].



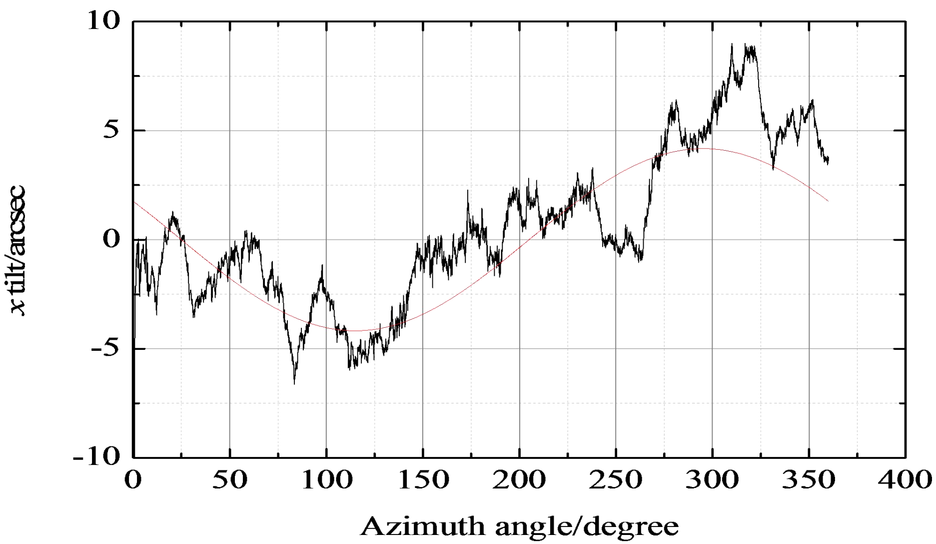


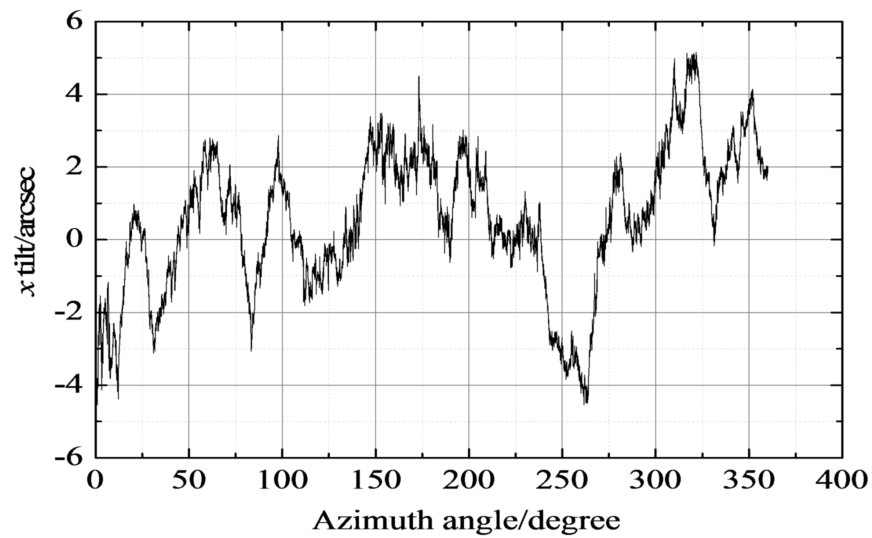
- The simulation results show a good agreement with the theoretical analysis.
- The effect of track unevenness on the pointing accuracy is within ±4 arcsec.

The track unevenness——
linear and nonlinear parts



The effect of track unevenness on pointing ——nonlinear part

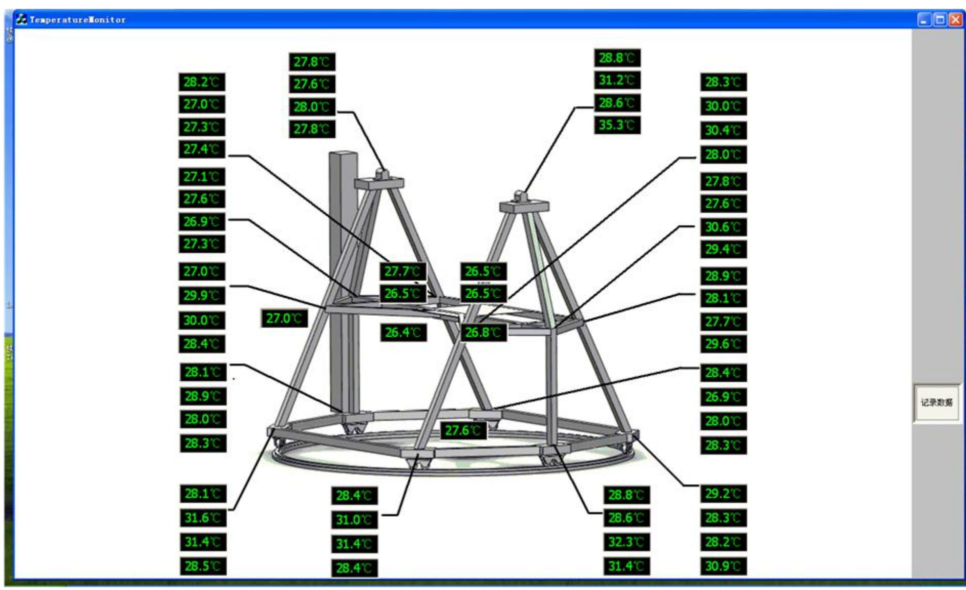




- The left figure:
  - Black line: x tilt measured by the inclinometer
  - Red line: sinusoidal fit from the inclinometer measurement
- The right figure: residuals after subtracting the sinusoidal fit from the inclinometer measurement.
- Further work: creating an azimuth-track-level look-up table and adding it to pointing model to modify the effect of this nonlinear part on pointing.

Temperature acquisition system

- System components: thermometers, master node controllers, electricity supplies, computer and cables.
- Thermometer: DS18B20 digital thermometer , ±0.5 ºC (temperature range of -10 ºC to +85 ºC).
- Location and number: totally 56 thermometers that were installed on the four sides named a, b, c and d of 14 nodes respectively.



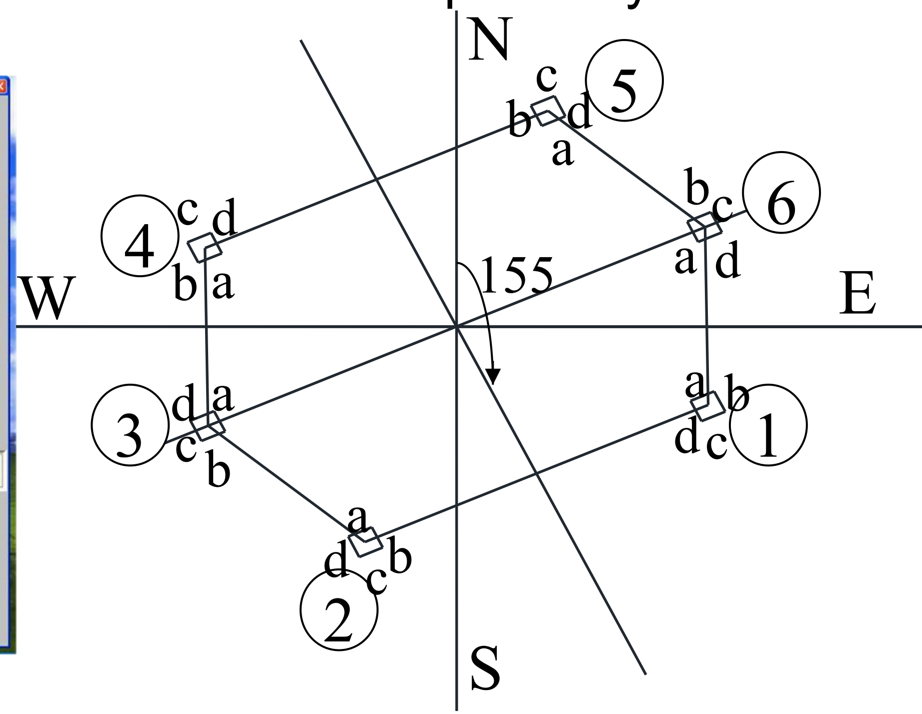
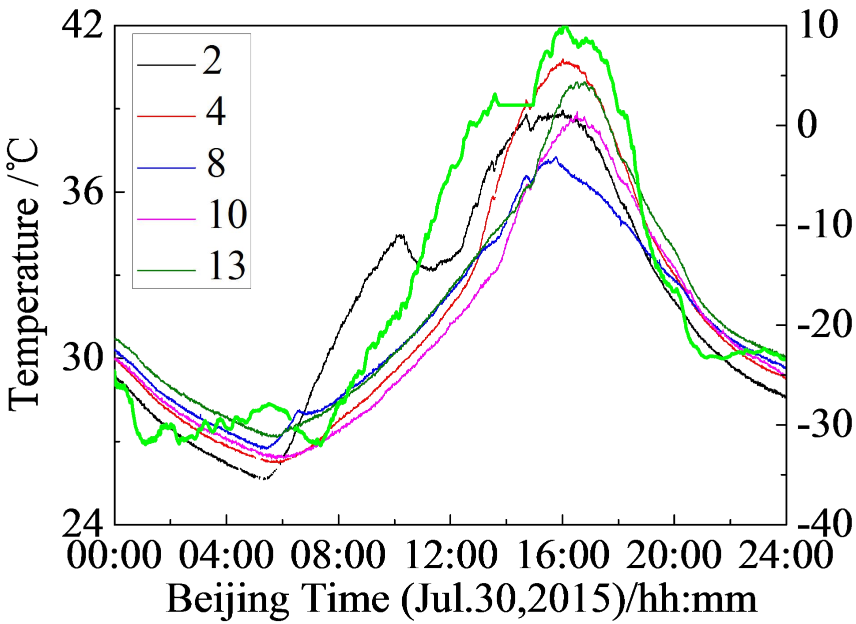


Fig. The display interface measured temperature and installation positions of thermometers on the left; the schematic diagram of thermometer number on the right.

The distributions of temperature field of alidade

- Parked position: azimuth angle=155°, elevation angle=89°.
- Date: July 30, 2015 and February 9, 2016.
- Illustrations: green line is cross-elevation tilt with time and the others are variations of average node temperature (the average temperature of 4 sides of every node) .



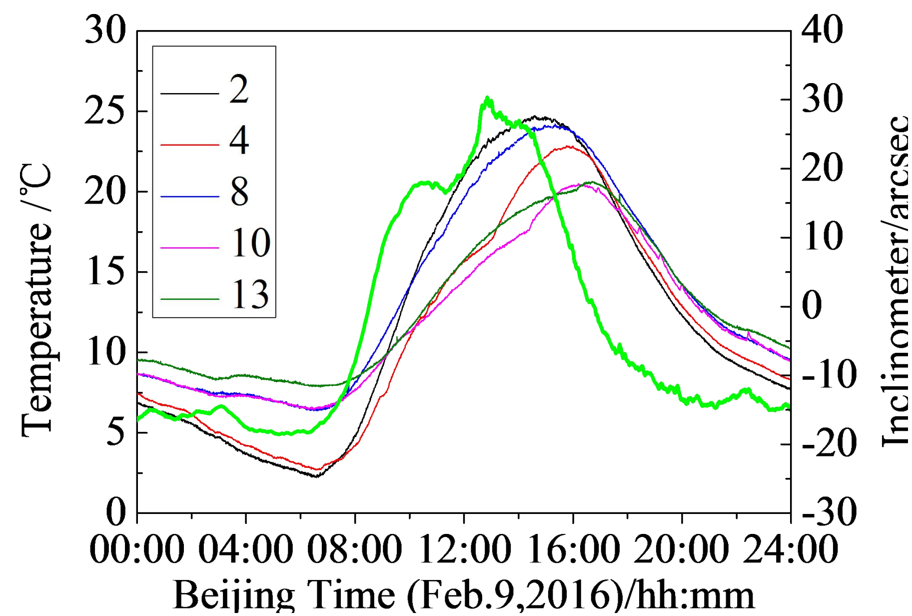


Fig. The variations of average temperature of nodes and cross-elevation tilt with time.

The distributions of temperature field of alidade

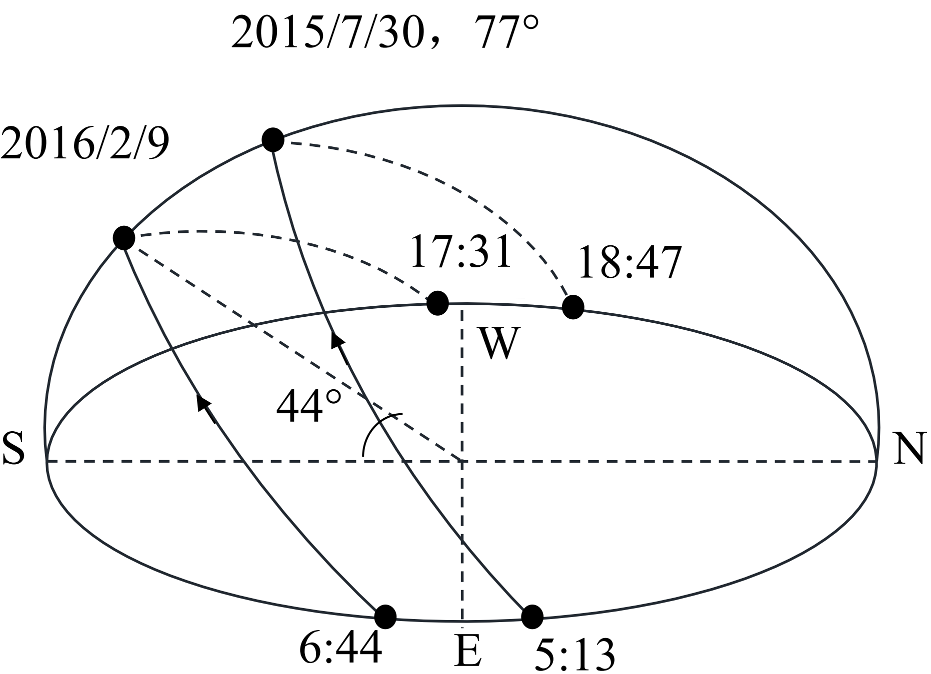
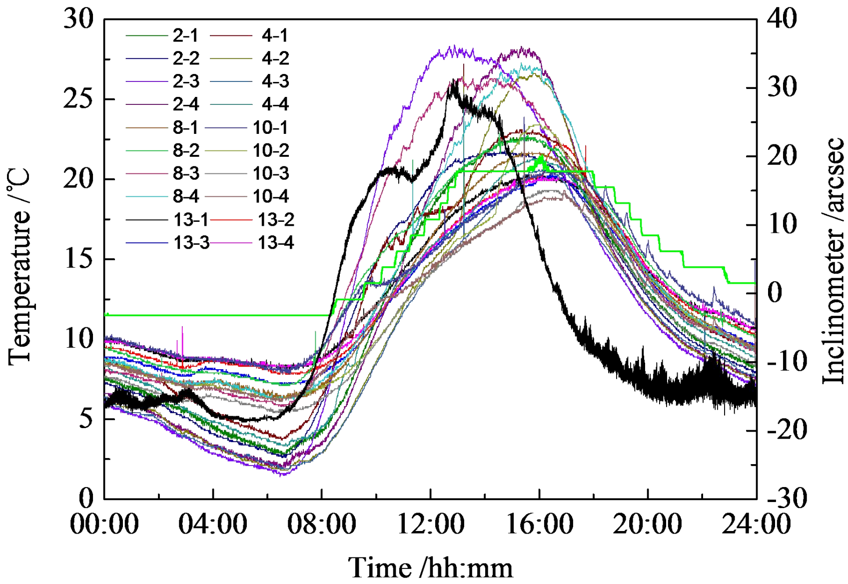


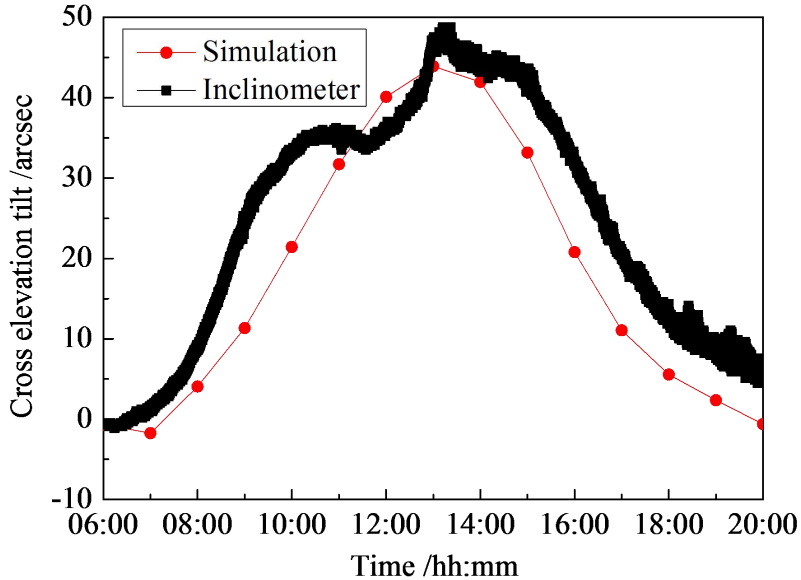
Table 2. The comparison of results.

	Feb. 9	Jul. 30
The solar elevation angle	44°	77°
The length of sunshine	10.8 hrs	13.6 hrs
The maximum diurnal temperature difference	27.0 ºC	14.6 ºC

- Results:
  - In summer, the day-length is longer and the sunrise is earlier so the structural temperature rises smoothly.
  - However, shorter sunshine time and later sunrise contribute to the temperature variation per unit time is larger in winter.

The cross elevation tilt——FEM+Inclinometer





- The left figure: variations of node temperature and inclinometer with time.
- The right figure: the comparision between the inclinometer measurement and FEM.
- The temperature induced cross elevation pointing error: 1.7 arcsec /℃.

The effect of thermal deformation of alidade on pointing

- April 30, 2016 : fine, clear and calm day.
- Source: polestar, 2344+8226.
- Results:
  - good agreement pointing check and inclinometer measurement
  - Around 20 arcsec pointing error from 8:00 to 10:00 am

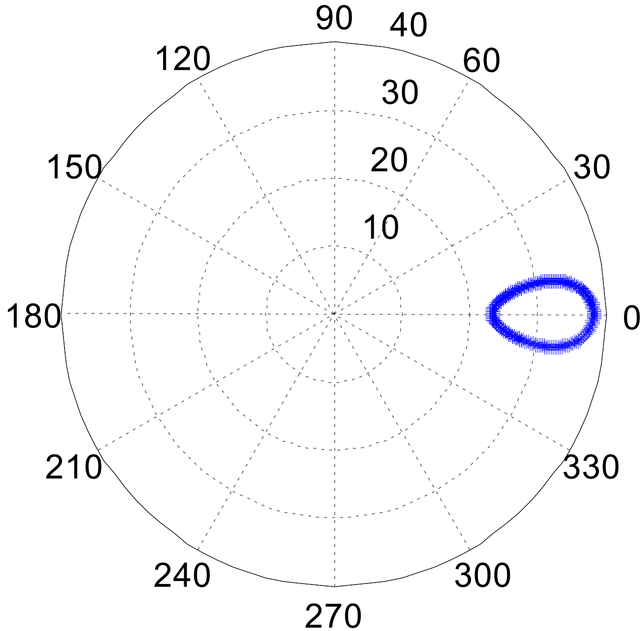


Fig. The polestar motion locus.

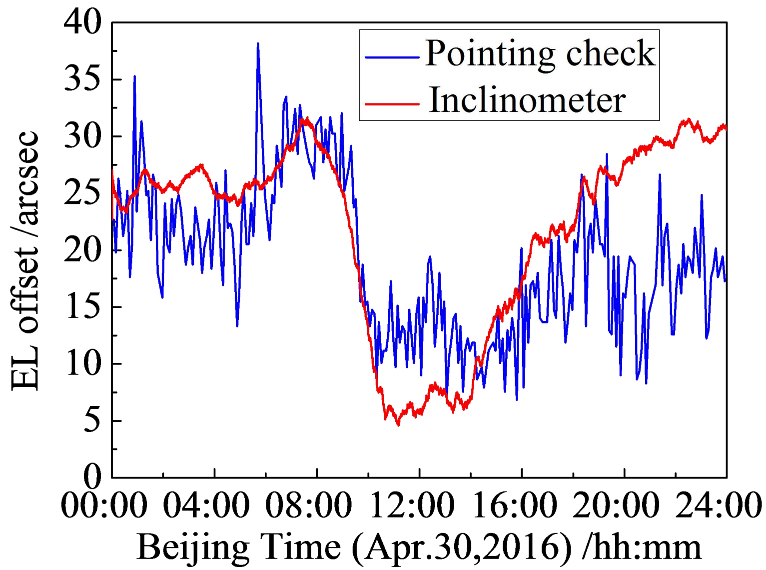
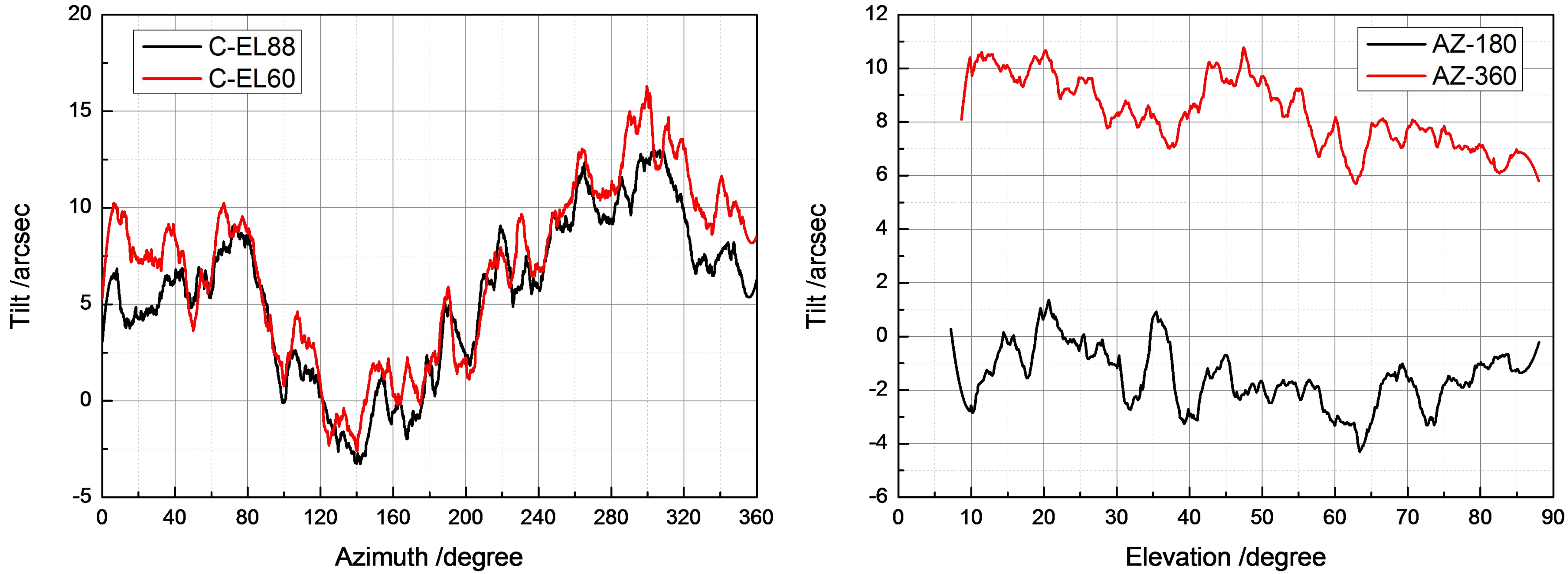


Fig. The EL offset with time.

The relationship between inclinometer reading and azimuth and elevation

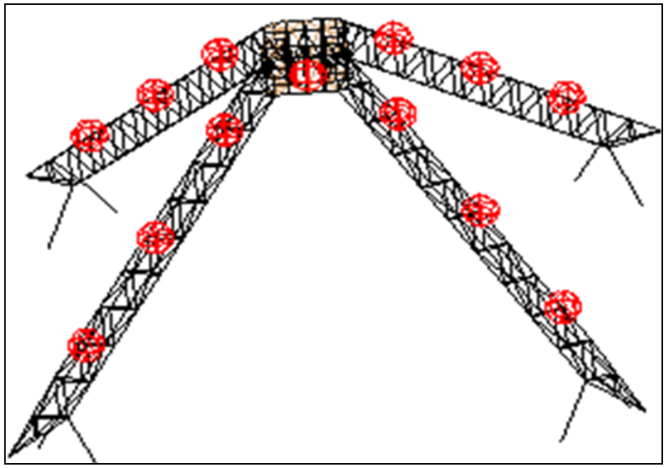


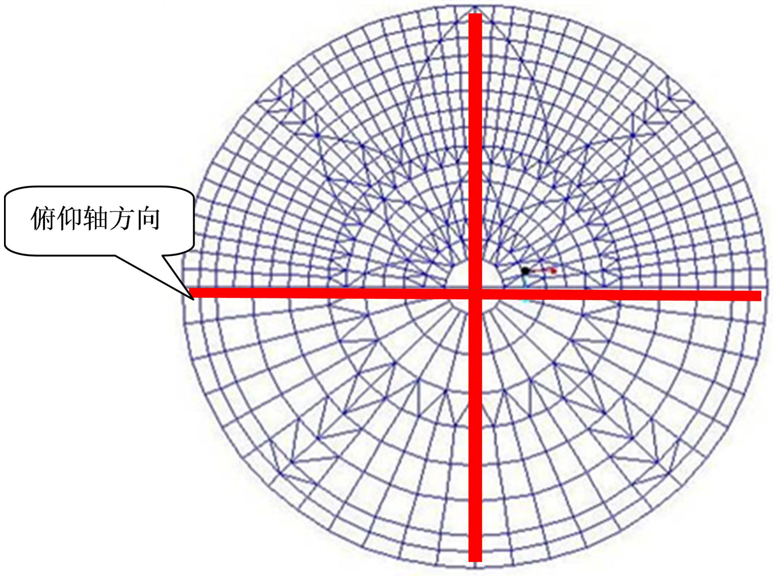
- Independence of the inclinometer reading on elevation
- Dependence of the inclinometer reading on azimuth

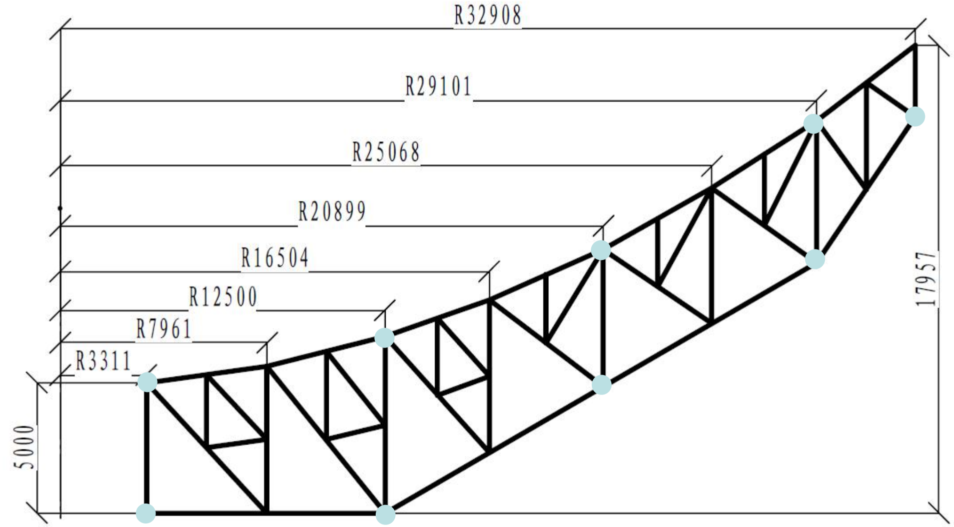
Further work

1. The temperature behavior of backup structure (36 sensors) and sub-reflector legs (12 sensors)

- **Methods:** FEM + Temperature measurement
- **Aims[2]:**
  - Temperature induced the deformation of the primary reflector surface
  - Temperature induced the variation of the focal length





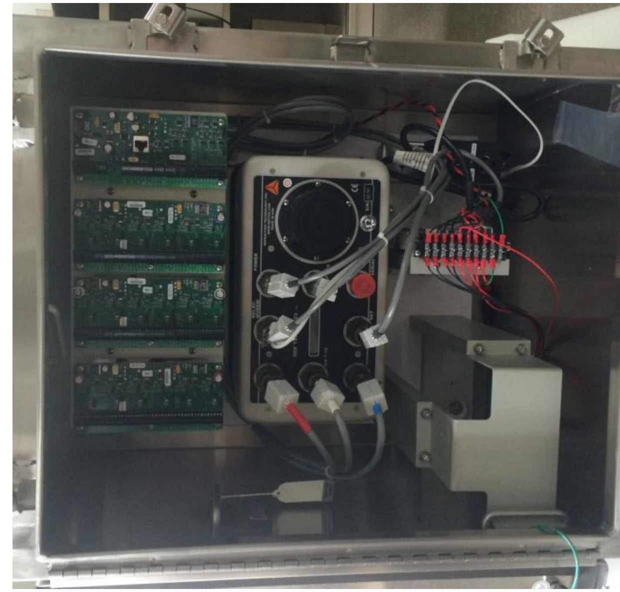


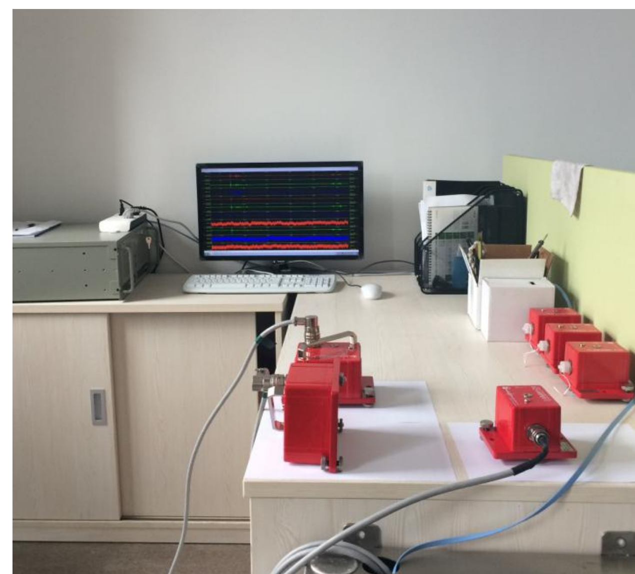
[2] Greve A, Bremer M, Penalver J, et al. Improvement of the IRAM 30-m Telescope from Temperature Measurements and Finite-Element Calculations. IEEE Transactions on antenna and propagation, 2005,53(2):851-858

Further work

Wind vibration test system

- **Hardware:**
  - 130-MC12A/AC220 Recorder, Multi-Channel, 12, Single DAS Enclosure, 220V
- **Software:**
  - Command Line GUI, 130-SM
  - 130 DAS's, Command Line
  - REF TEK Interface
- **Accelerometer:**
  - SLJ100-FBA: single axis, tri-axis
  - Test range: ±2g
  - Dynamic range: >135dB
  - Sentivity: 2.5v/g
  - Noise: $<10^{-6.75}$g
  - Bandwidth: 0~80Hz
  - Zero drift: $<100\ \mu$g/ºC





Further work

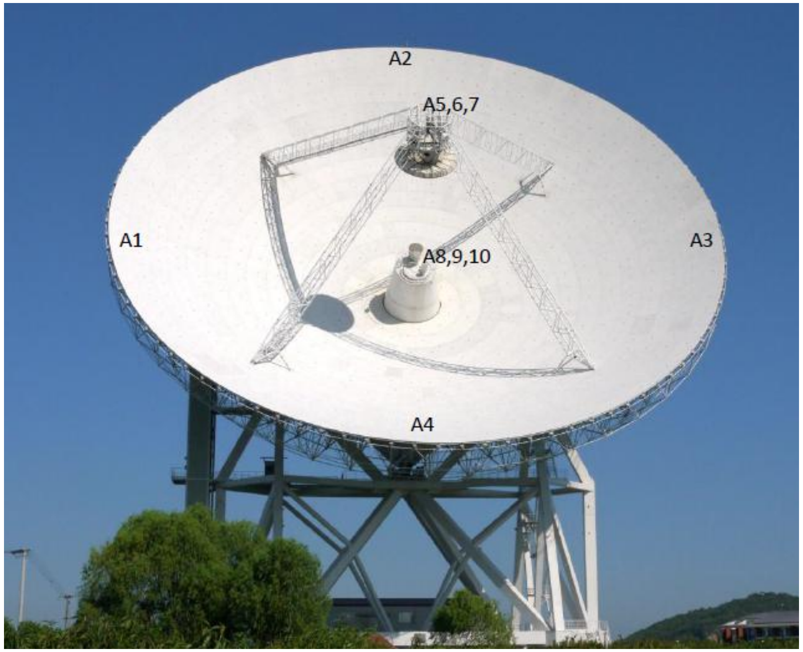
2. The effect of wind on the antenna based on the accelerometer.

- **Methods:** FEM + Accelerometer + PSD + Pointing test
- **Aims[3~5]:**
  - Wind induced the pointing error at elevation and cross-elevation directions.
  - Relative position relationship between the sub-reflector and the feed.

[3] P. Ries, T. R. Hunter, K. T. Constantikes, et al. Measurement and Correcting Wind-Induced Pointing Errors of the Green Bank Telescope Using an Optical Quadrant Detector. Instrumentation and Methods for Astrophysics, 2011: 1-17.

[4] R. C. Snel, J. G. Mangum, J. W. M. Baars. Study of the Dynamics of Large Reflector Antennas with Accelerometers. IEEE Transactions on Antennas and Propagation Magazine, 2007, 4(49): 84-101.

[5] J. R. Blough, D. R. Smith, C. DeVries. Gathering Operating Vibration Data on the Nobeyama 45M Radio Telescope. SPIE-The International Society for Optical Engineering, 2001, 4359: 870-873.



Thank you !