Assessment of thermal deformation modelling for the geodetic VLBI telescopes at Onsala Space Observatory

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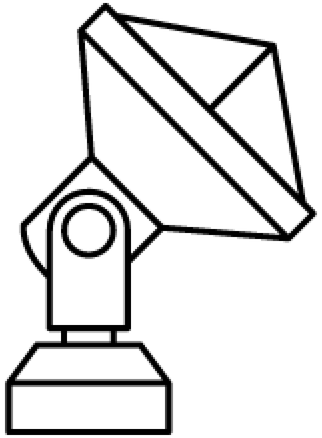
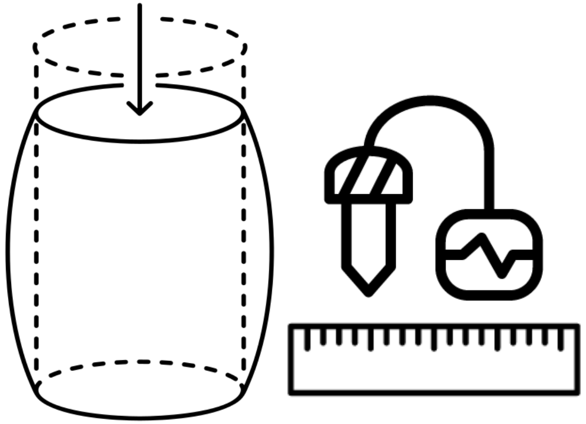
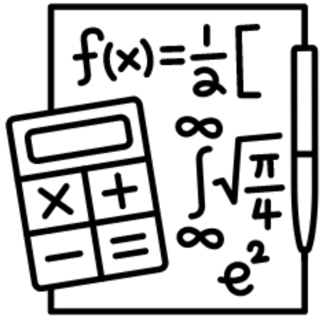
+++ NOTE +++

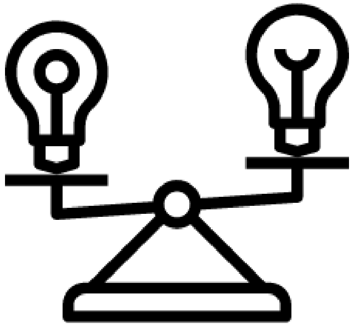
This presentation was originally given without most of the text on the slides. In this document, you will find additional text-only slides to explain the resp. previous slide.

Outline









Outline – sl. 3

- Telescopes at the Onsala Space Observatory
- Deformation of and sensors on telescopes
- Models that exist and how we use them
- Comparison and outlook

VLBI Telescopes

Credit: R. Hammargren

VLBI Telescopes – sl. 5

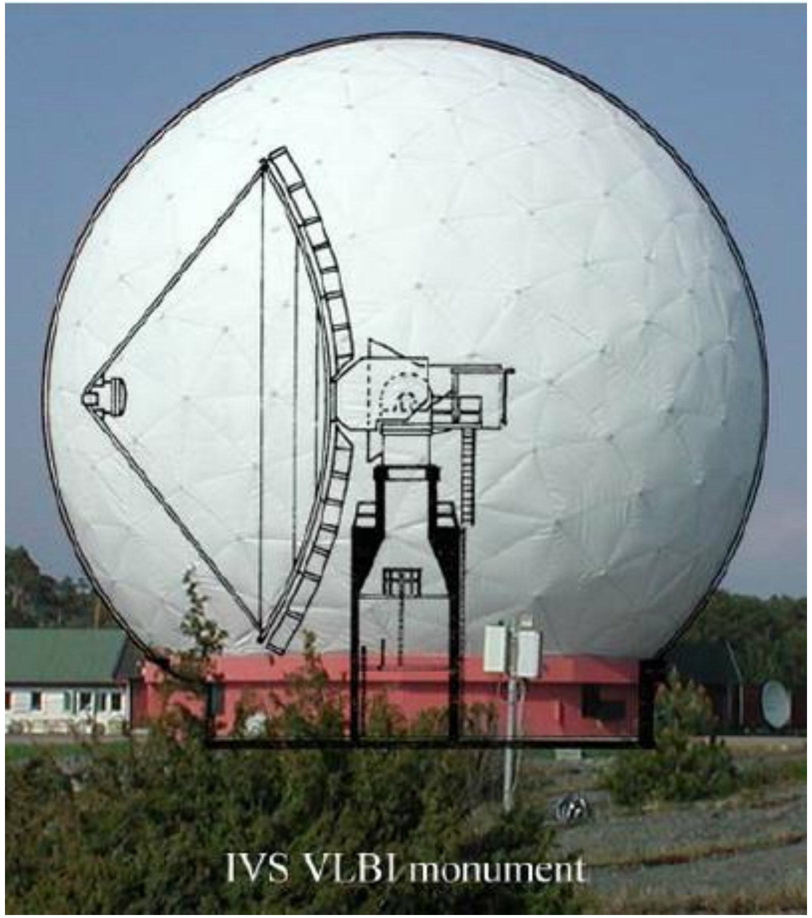
Onsala Space Observatory has four telescopes which can be used for VLBI. From left to right on the photo are:

- ONSALA80, the 25m dish which is currently mostly used for astronomic purposes, but takes part in e.g. geodetic eVLBI sessions

- ONSA13SW and ONSA13NE, the twin telescopes of the new VGOS generation, 13.2m diameter

- (in the radome) ONSALA60, 20m diameter, a legacy S/X telescope on which we will focus for the remainder of this presentation

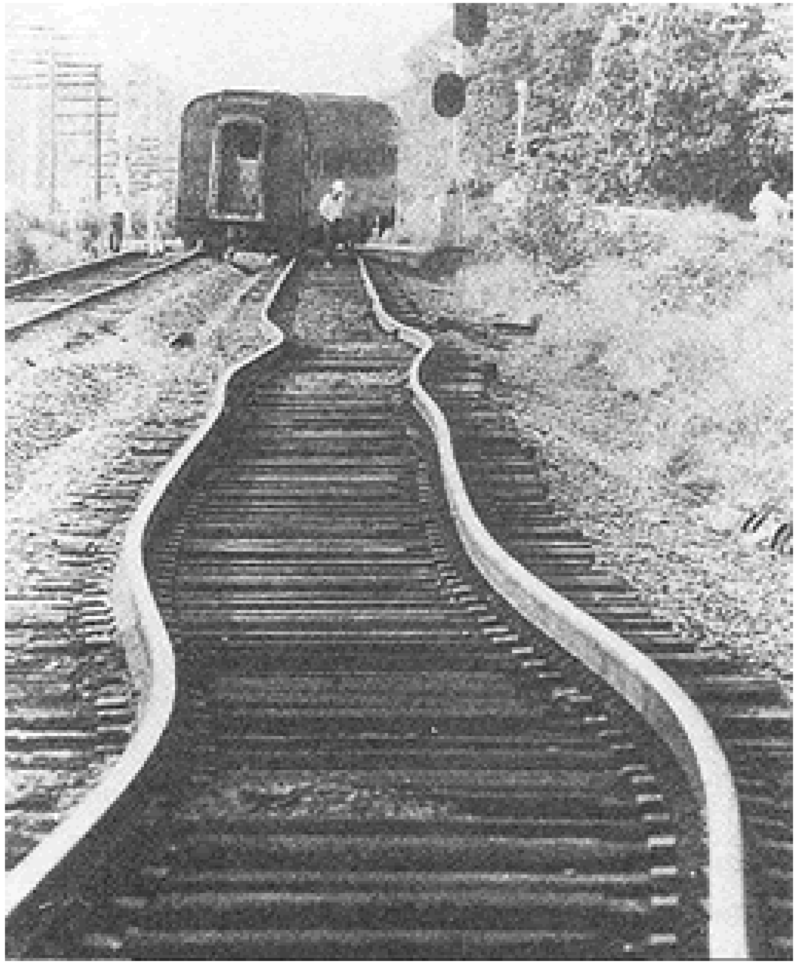
ONSALA60



Credit: R. Haas

- 20 m diameter
- S/X band
  - S: 2.15 - 2.35 GHz
  - X: 8.0 - 8.8 GHz
- R1, R&D, T2, RDV, EURO, CONT
- 1979 – 2022, longest time series in IVS

Deformation



Credit: https://faraday.physics.utoronto.ca/IYearLab/Intros/ThermalExpans/ThermalExpans.html

Credit: AP/Gene J. Puskar

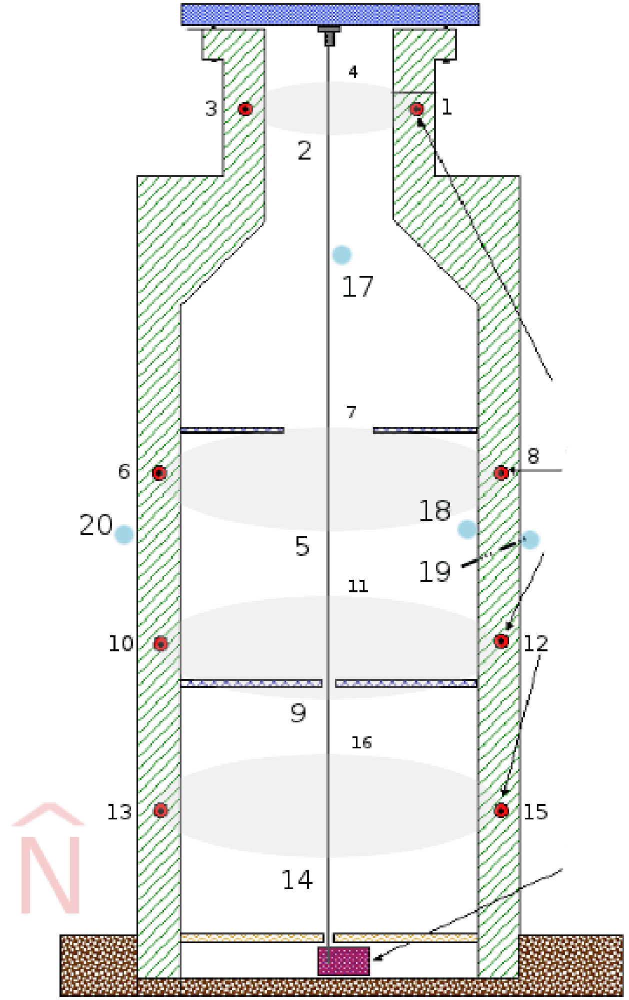
Deformation – sl. 9

Two types of deformation that we take into account when modelling:

- thermal deformation (left image)

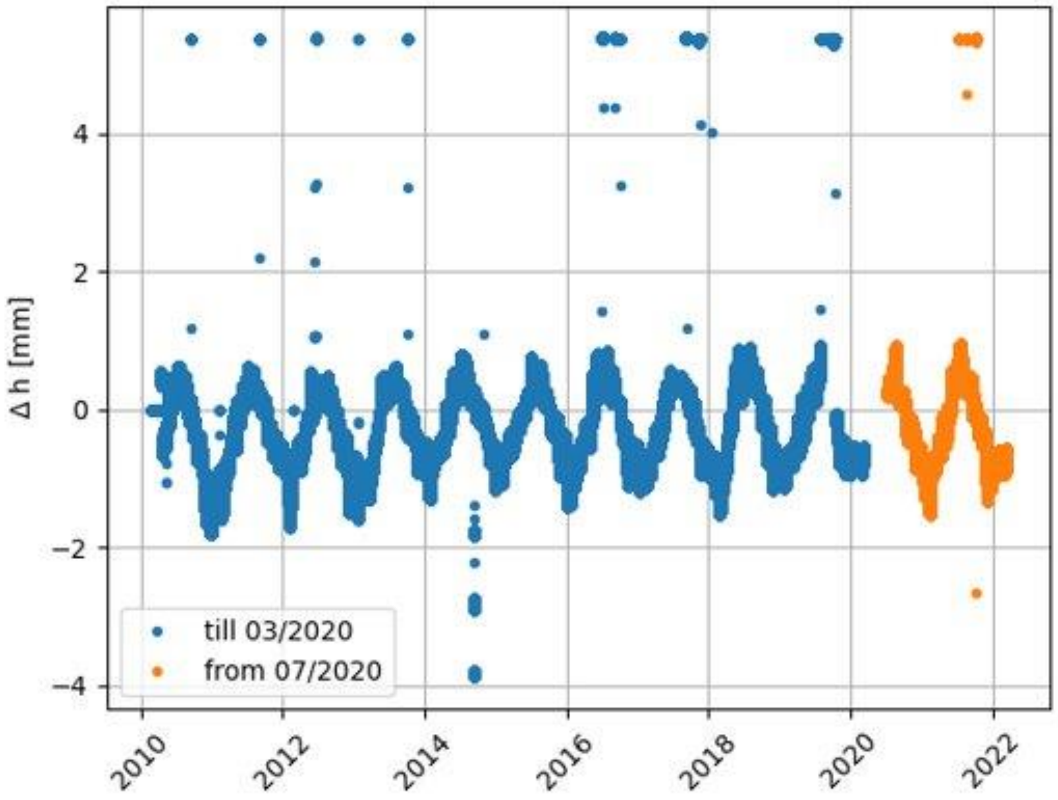
- gravitational deformation (right image)

Invar rod



Credit: J. Wahlbom

Credit: R. Handirk



Credit: R. Handirk

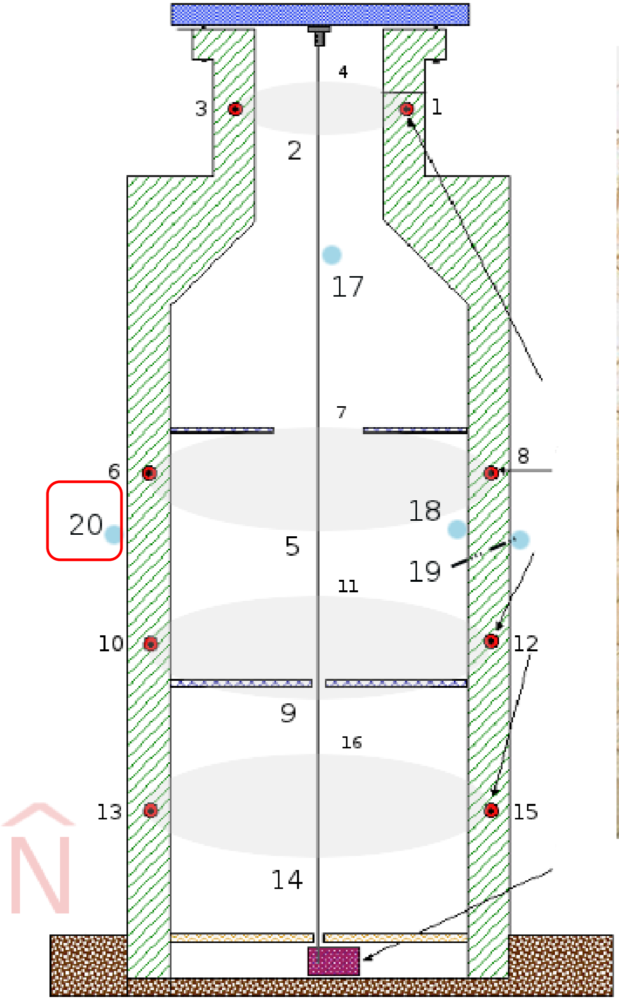
Invar rod – sl. 10

- Invar rod hangs down from azimuth cabin down all the way through the tower and ends up in the little red-coloured box at the bottom

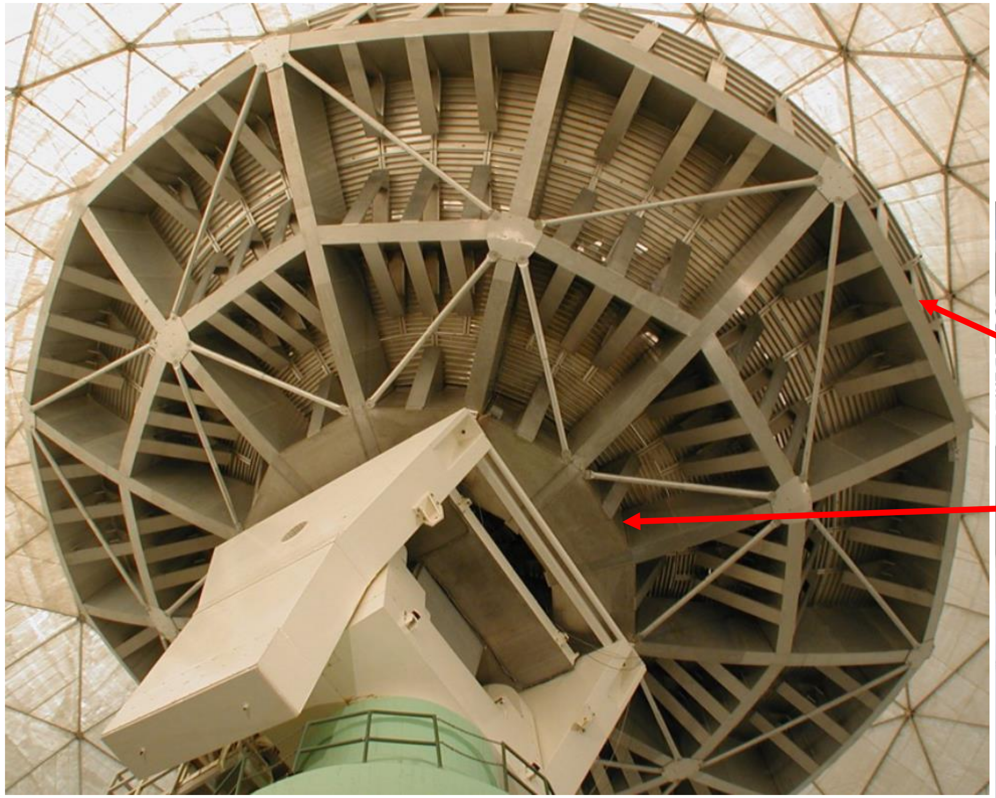
- Rod usually sits on the pin (middle picture: rod is NOT on the pin); pin is shaped like an upside-down biro and is pressed down by the invar bar. We measure how far the pin is being pressed down and by that measure relative changes of the tower height. -> Note: Although this system has been in place for many years now, we currently do not know what the "zero" on the scale of our relative measurements is.

- The plot to the right shows changes in height vs time. We see pretty clearly a seasonal pattern and a number of outliers. The points which look like a straight line at the very top, close to Δh = +6 mm, show when the rod was actually off the pin and the pin therefore was at its maximum extension (i.e. not pressed down at all).
We have a gap in our data of 3-4 months duration in the year 2020 due to a change in the measuring system.

Temperature sensors



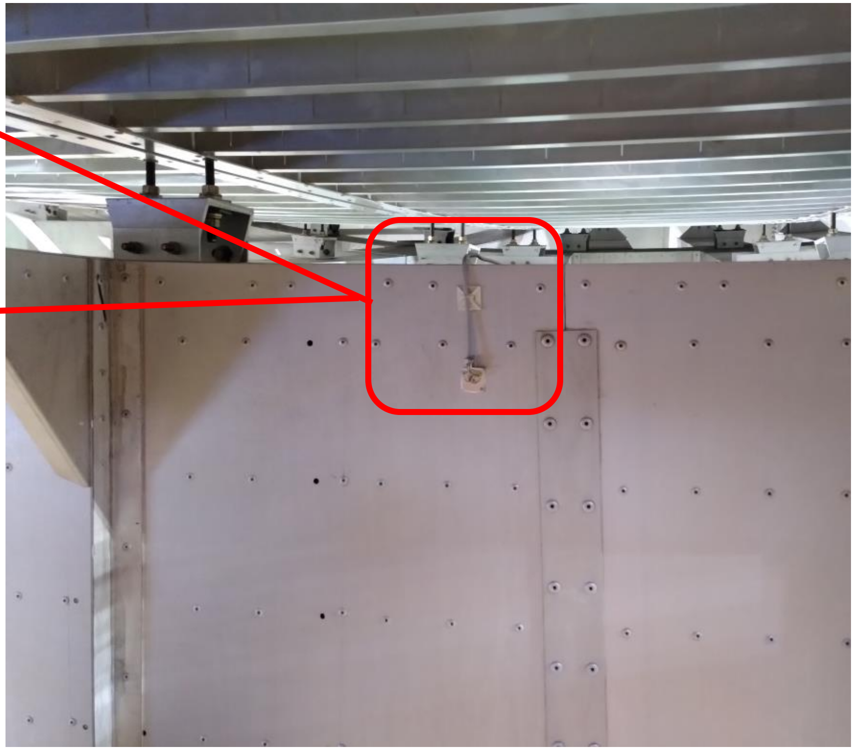
Credit: J. Wahlbom



8 sensors

Credit: R. Handirk

Credit: R. Handirk



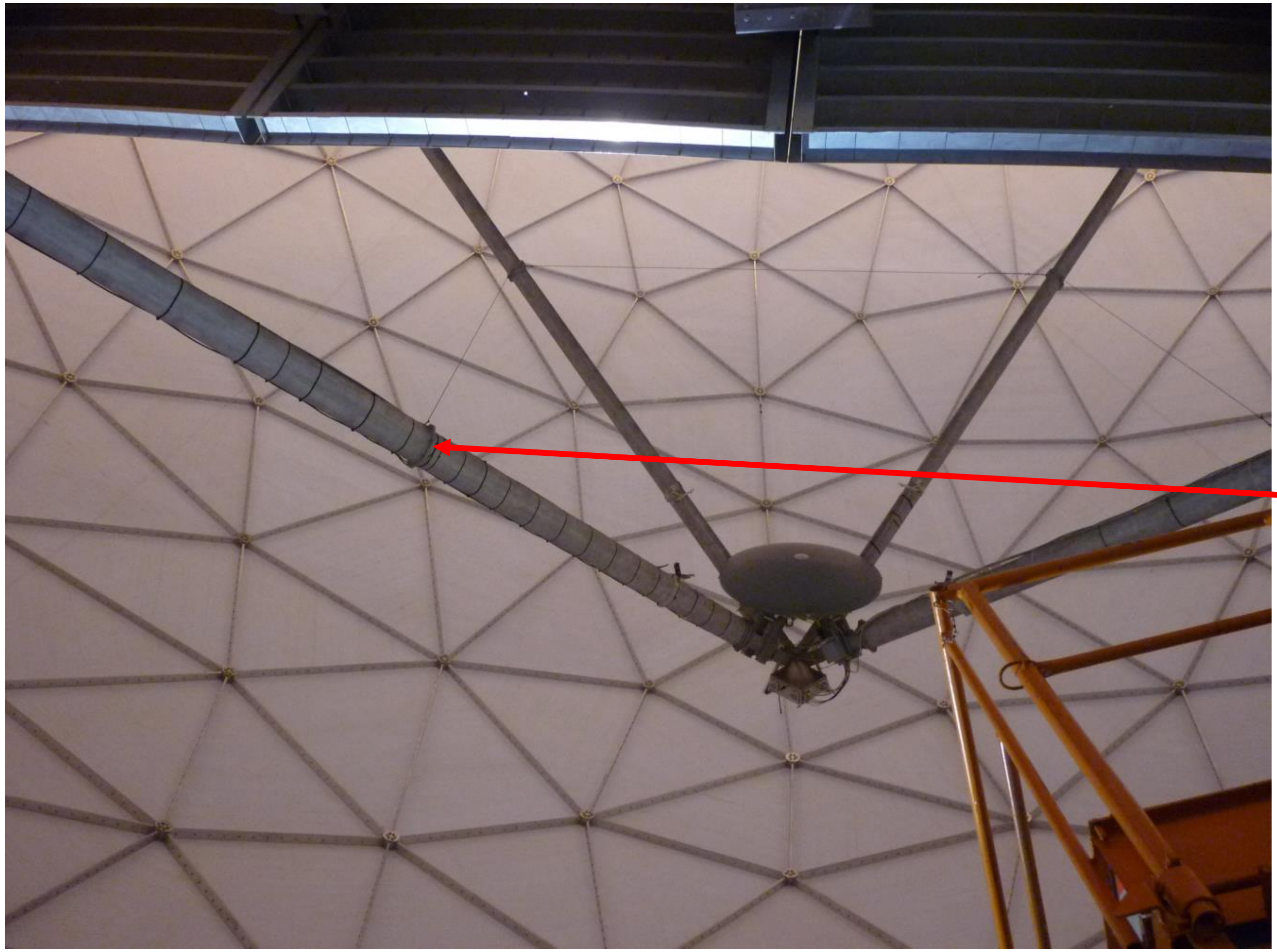
Temperature sensors – sl. 12

- 20 temperature sensors in the tower:
  - 16 sensors (marked as red dots) in the walls on four different levels (marked as grey planes), always oriented towards North, South, East, West per level
  - 4 additional sensors (marked as light blue dots) out of which 3 are on the walls and one attached to the invar rod

- 8 sensors on the back side of the dish: 4 on the outer ring and inner ring respectively

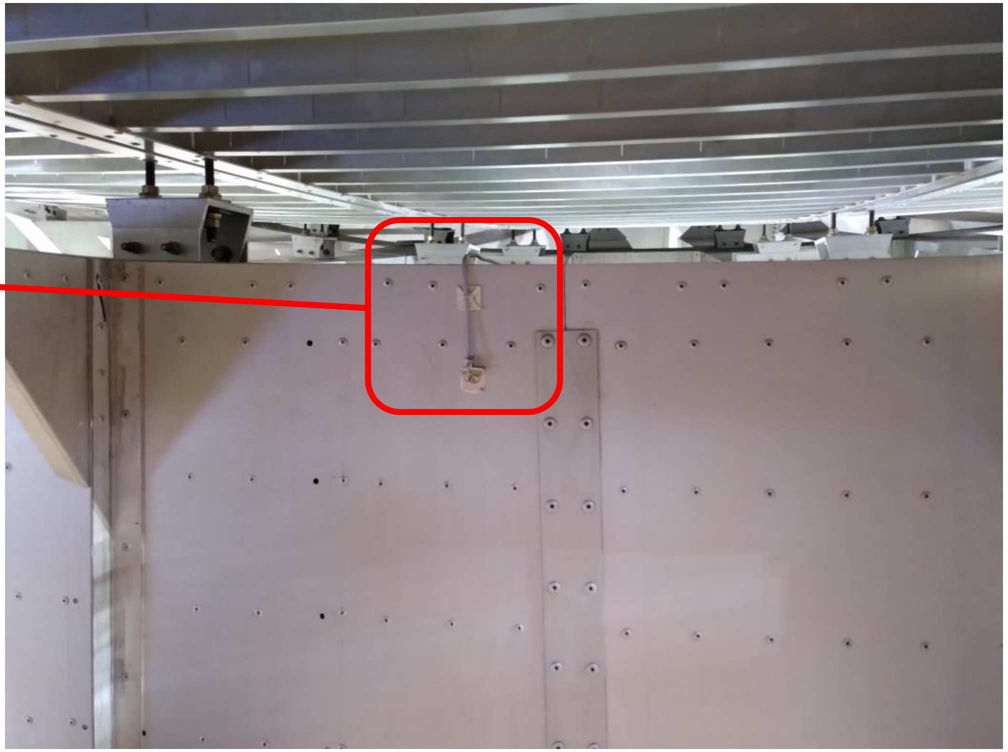
- right image shows one such sensor on the ring structure

Temperature sensors



Credit: R. Handirk

4 sensors



Credit: J. Wahlbom

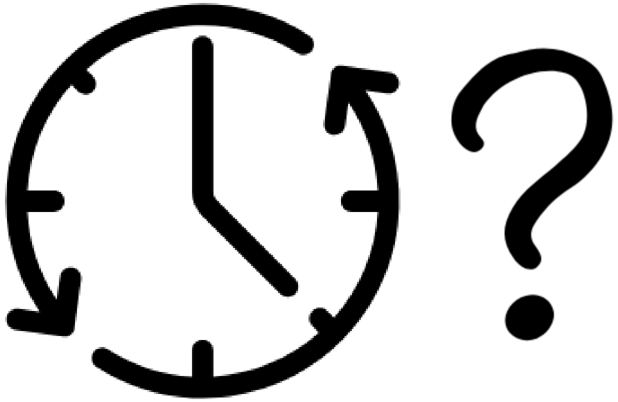
Temperature sensors – sl. 14

- sensors of the same kind as the ones on the back side of the dish are mounted on the supporting legs for the subreflector
- one sensor on each leg, ca. in the middle of the leg

Nothnagel's model (2009)

$$\Delta\tau_{therm,i} = \frac{1}{c}\cdot\left[\gamma_f\cdot\left(\boxed{T}-\left(t-\boxed{\Delta t_f}\right)-\boxed{T_0}\right)\cdot\left(h_f\cdot\sin\varepsilon\right)\right.$$
$$+\gamma_a\cdot\left(\boxed{T}-\left(t-\boxed{\Delta t_a}\right)-\boxed{T_0}\right)$$
$$\left.\cdot\left(h_p\cdot\sin\varepsilon + AO\cdot\cos\varepsilon + h_v - F_a\cdot h_s\right)\right]$$

Credit: R. Hammargren



Credit: thenounproject.com

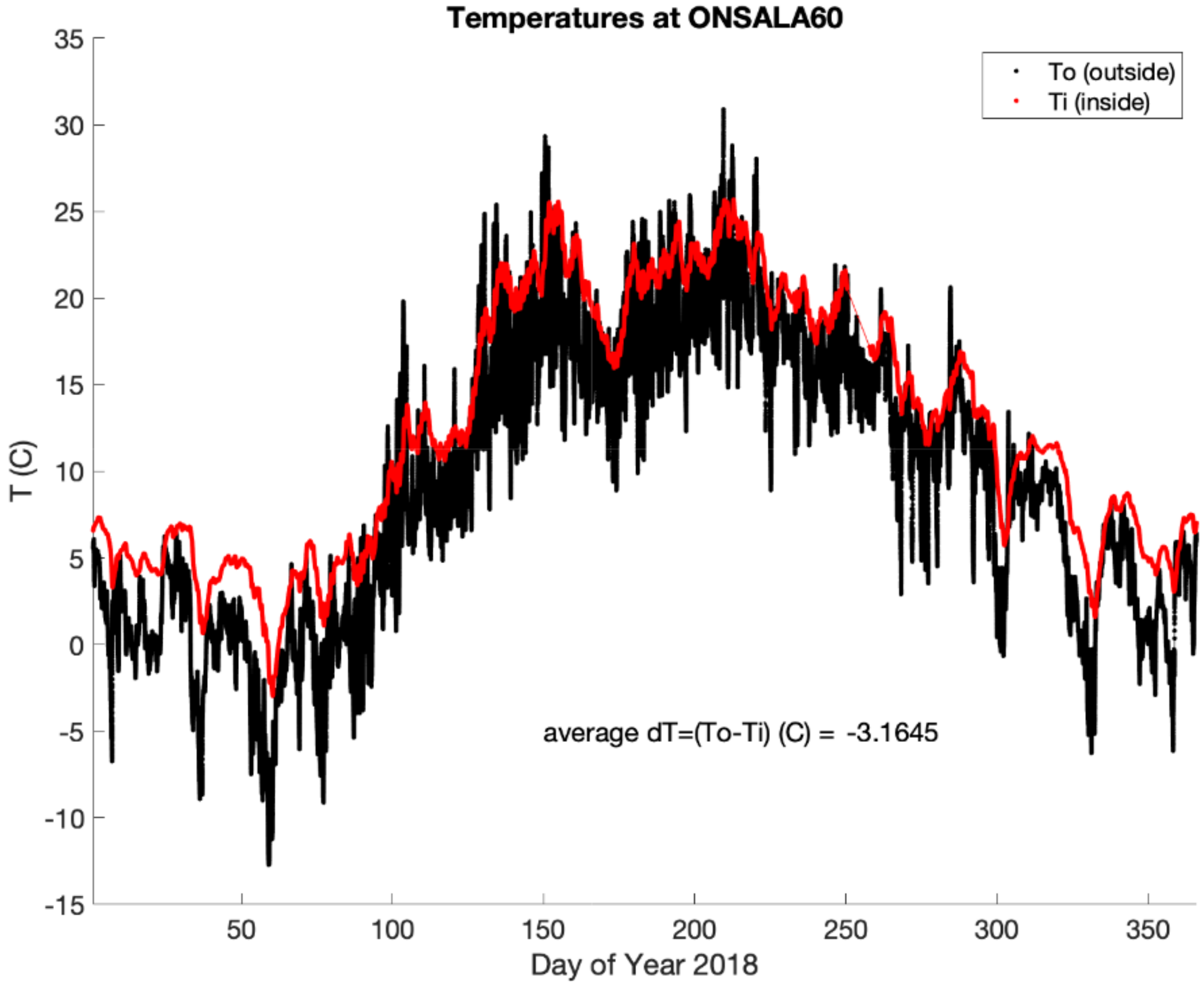
Nothnagel's model (2009) – sl. 16

- model taken from paper "Conventions on thermal expansion modelling of radio telescopes for geodetic and astrometric VLBI" by Axel Nothnagel
- considers only thermal deformation
- model is recommended and widely used for telescopes participating in IVS sessions
- here, we focus on the marked variables:

- blue: Δt -> time lags for antenna and foundation that describe how long it takes for a change in temperature to affect the whole structure. Considered to be 2 – 6 hours, but actually unknown exact values for ONSALA60 (and also other telescopes). Therefore often ignored, i.e. set to zero.

- red: T and T_0 -> current temperature and a reference temperature. For IVS sessions, the temperature used is the one which is recorded in the log file. In our particular case, this is data coming from an outdoor weather station, while our telescope in inside a radome.

Temperature sensors



Credit: R. Haas

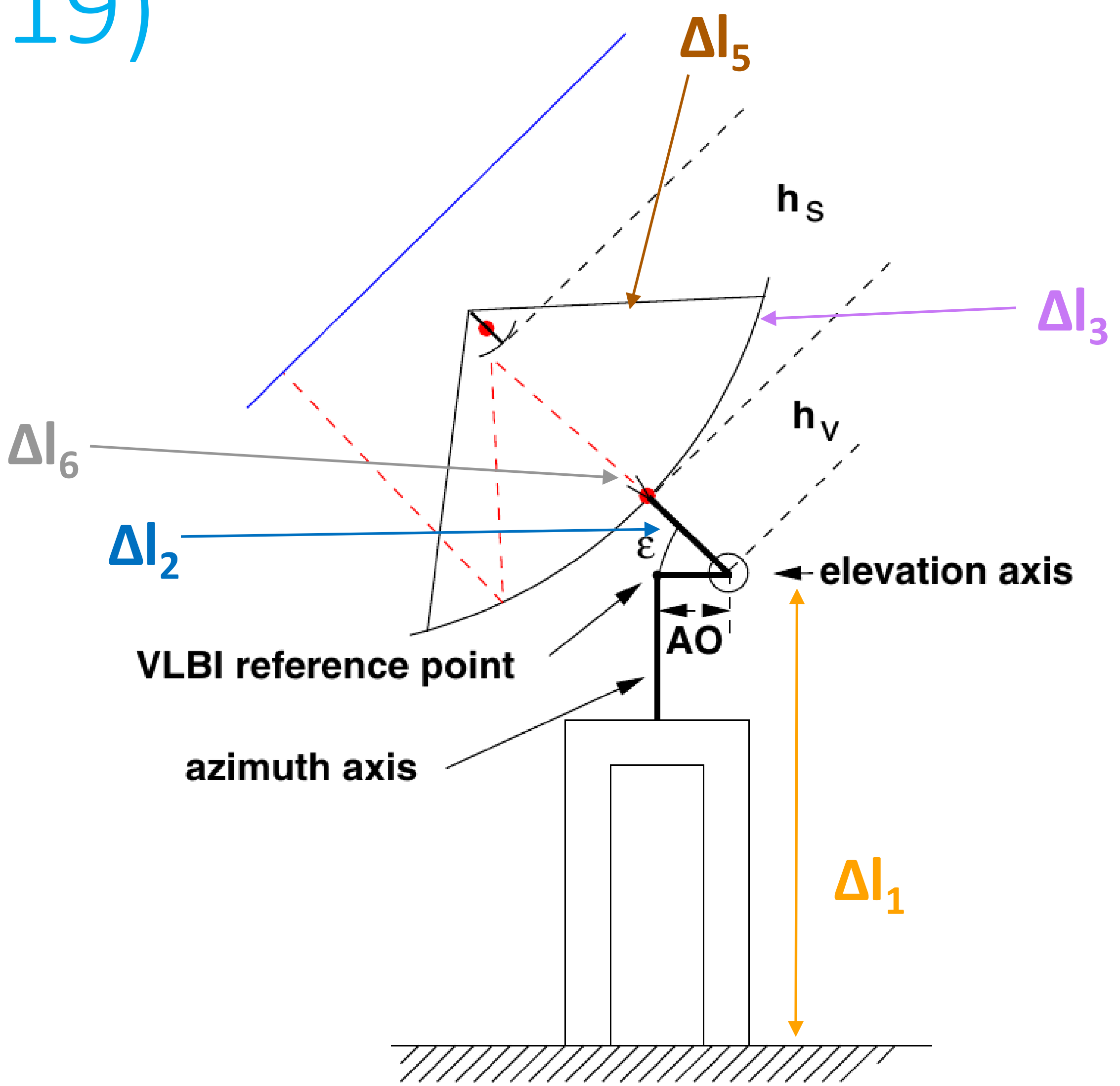
Temperature sensors – sl. 18

- plot shows temperature vs time for the course of one year
- black curve: outdoor temperature
- red curve: indoor temperature

- we observe that the indoor temperature curve is smoother than the outdoor temperature curve, and that it is mostly warmer inside the radome
- the average difference of indoor and outdoor temperature is ca. 3.2 °C

Nothnagel's model (2019)

$$\Delta\ell_{\text{total}}(\varepsilon) = \Delta\ell_1(\varepsilon) + \Delta\ell_2(\varepsilon) + \Delta\ell_3(\varepsilon) + \Delta\ell_5(\varepsilon) + \Delta\ell_6(\varepsilon)$$



Credit: A. Nothnagel

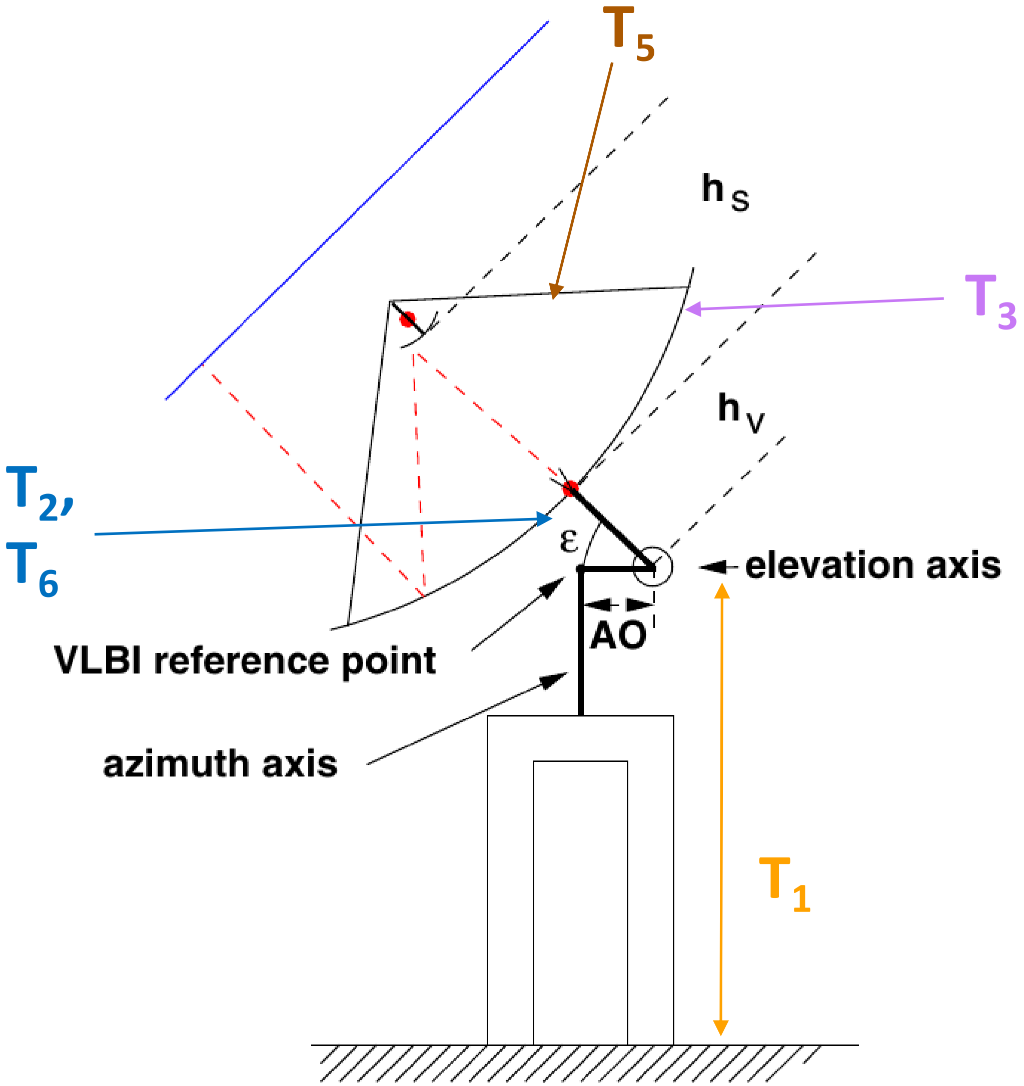
Nothnagel's model (2019) – sl. 20

- model taken from paper "A VLBI delay model for gravitational deformations of the Onsala 20 m radio telescope and the impact on its global coordinates" by A. Nothnagel, C. Holst, and R. Haas
- model was specifically developed for OSNALA60, and includes both thermal and gravitational deformation

- Δl_1 -> change in secondary axis (az.)
- Δl_2 -> change in the separation of the vertex of paraboloid from the primary axis (el.)
- Δl_3 -> change in paraboloid
- Δl_5 -> change in distance of subreflector, i.e. change in support legs
- Δl_6 -> displacement of the feed horn

Extended thermal deformation model

$$\Delta\ell_{\text{total}}(\varepsilon) = \Delta\ell_1(\varepsilon) + \Delta\ell_2(\varepsilon) + \Delta\ell_3(\varepsilon) + \Delta\ell_5(\varepsilon) + \Delta\ell_6(\varepsilon)$$



Credit: A. Nothnagel

Extended thermal deformation model – sl. 22

This is which data we use for which part of the telescope:

- T_1 -> sensors in the tower walls, currently using average of all 16
- T_2 -> sensors on the inner ring of the dish, currently using average of all 4
- T_3 -> sensors on the outer ring of the dish, currently using average of all 4
- T_5 -> sensors on the support legs, currently using average of all 4
- T_6 -> sensors on the inner ring of the dish, currently using average of all 4

Data Processing

- Existing S/X VLBI-Db's
- c5++
- ITRF2020, EOP 20 C04, ICRF3

- 20 R1-sessions in 2020 and 2021 reprocessed
- All stations fixed except for ONSALA60

IVS / Sessions / 2021

Master Schedule 2021

Previous Next

Name	Code	Start	DOY	Dur	Stations	DB Code	Ops Center	Correlator	Status	Analysis
January										
IVS-R1980	R1980	2021-01-04 17:00	4	24:00	Ht Kk Kv Ma Ns Nt Wn Wz Yg ~~Ag~~ ~~Ft~~ ~~Is~~ ~~Ny~~	XA	NASA	BONN	Released	NASA
VGOS-O1007	VO1007	2021-01-07 18:00	7	24:00	Gs Is K2 Mg Oe Ow Wf Yj ~~Ws~~	VG	HAYS	BONN	Released	NASA
IVS-R4980	R4980	2021-01-07 18:30	7	24:00	Ht Kk Mc Ns Wn Wz ~~Ft~~ ~~Is~~ ~~Ny~~ ~~Ur~~ ~~Yg~~	XE	USNO	WASH	Released	USNO
IVS-R1981	R1981	2021-01-11 17:00	11	24:00	Ho Ht Kk Kv Ma Mc Ns Nt On Sh Wz Ys ~~Ag~~ ~~Ft~~ ~~Is~~ ~~Ny~~	XA	NASA	BONN	Released	NASA
IVS-T2P144	T2P144	2021-01-12 17:30	12	24:00	Bd Eb Hh Ho Ht Kg Kk Kv Ma Mh Ns Nt On Sh Sv Vm Wn Wz Ys Zc ~~Ag~~ ~~Ft~~ ~~Is~~ ~~Mc~~ ~~Ny~~ ~~Oh~~ ~~Ww~~ ~~Yg~~	XH	DACH	BONN	Released	BKG
IVS-R&D-1	RD2101	2021-01-13 18:00	13	24:00	Hh Ho Kk Km On Wz ~~Ft~~ ~~Is~~ ~~Ny~~	XA	OSO	SHAO	Released	NASA

Data Processing – sl. 24

To test our adjusted version of the Nothnagel 2019 model we reprocessed 20 R1-sessions from the years 2020 and 2021, and kept all station coordinates fixed except for ONSALA60.
For reprocessing, we used the software package c5++. Important settings for the reprocessing are:
- the choice of ITRF20 and the corresponding EOP C04 series
- the choice of ICRF3

The databases for these sessions are available via the IVS master schedule.

Station position repeatability

		
N	3.753 mm	3.749 mm
E	2.680 mm	2.687 mm
U	10.756 mm	10.216 mm

Conclusion: 5 % improvement in UP

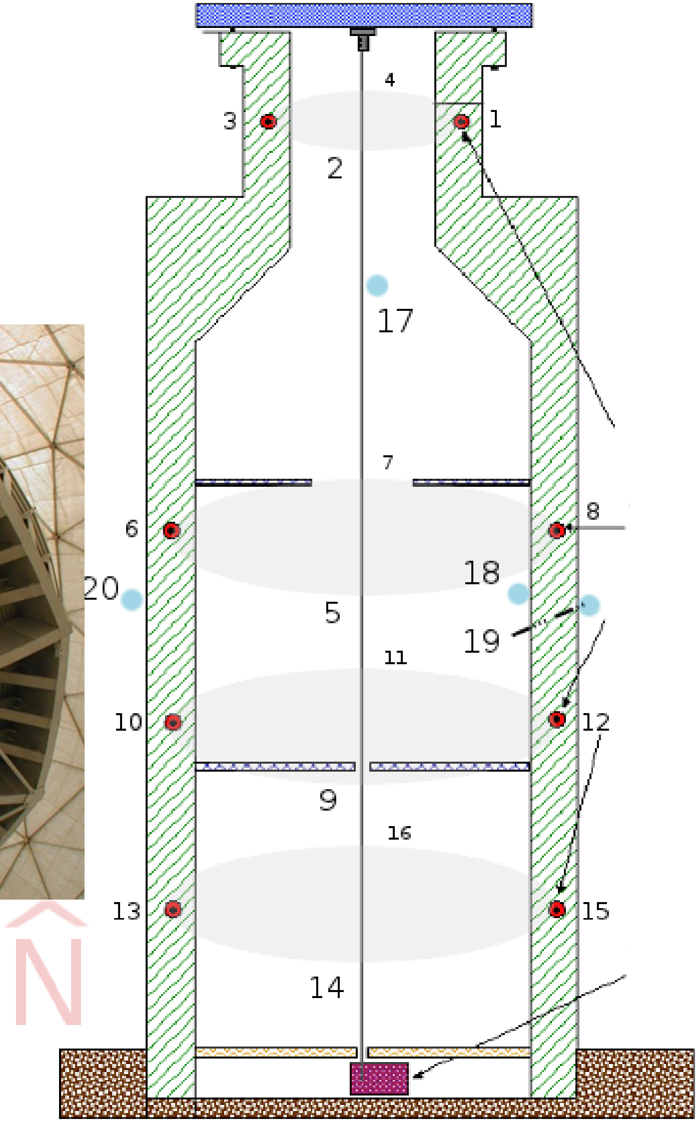
Station position repeatability – sl. 26

We evaluate and compare the results of the adjusted model against the original model (Nothnagel 2019) by looking at the station position repeatability:

- very similar results for North and East components

- improvement of 0.5 mm in the Up component, which corresponds to 5%

Future scope



Future scope – sl. 28-33

This and the following slides summarise some of our ideas what we want to do next.

- use only the dish OR the tower temperatures to see which part of the structure has the major effect (or if both are more or less equal in contribution)

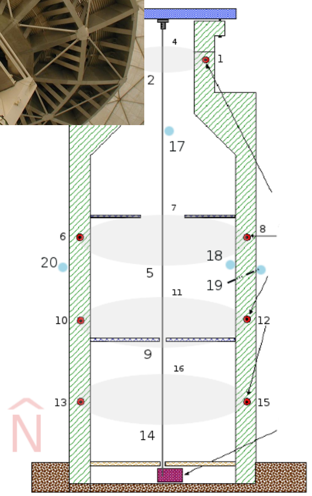
- refine temperature modelling: align sensors better in time (there are small lags between all of them), and create different sections for the tower. We see differences of ca. 5 °C between the lowest and highest sensors.
- find a transfer function from outdoor to indoor temperature

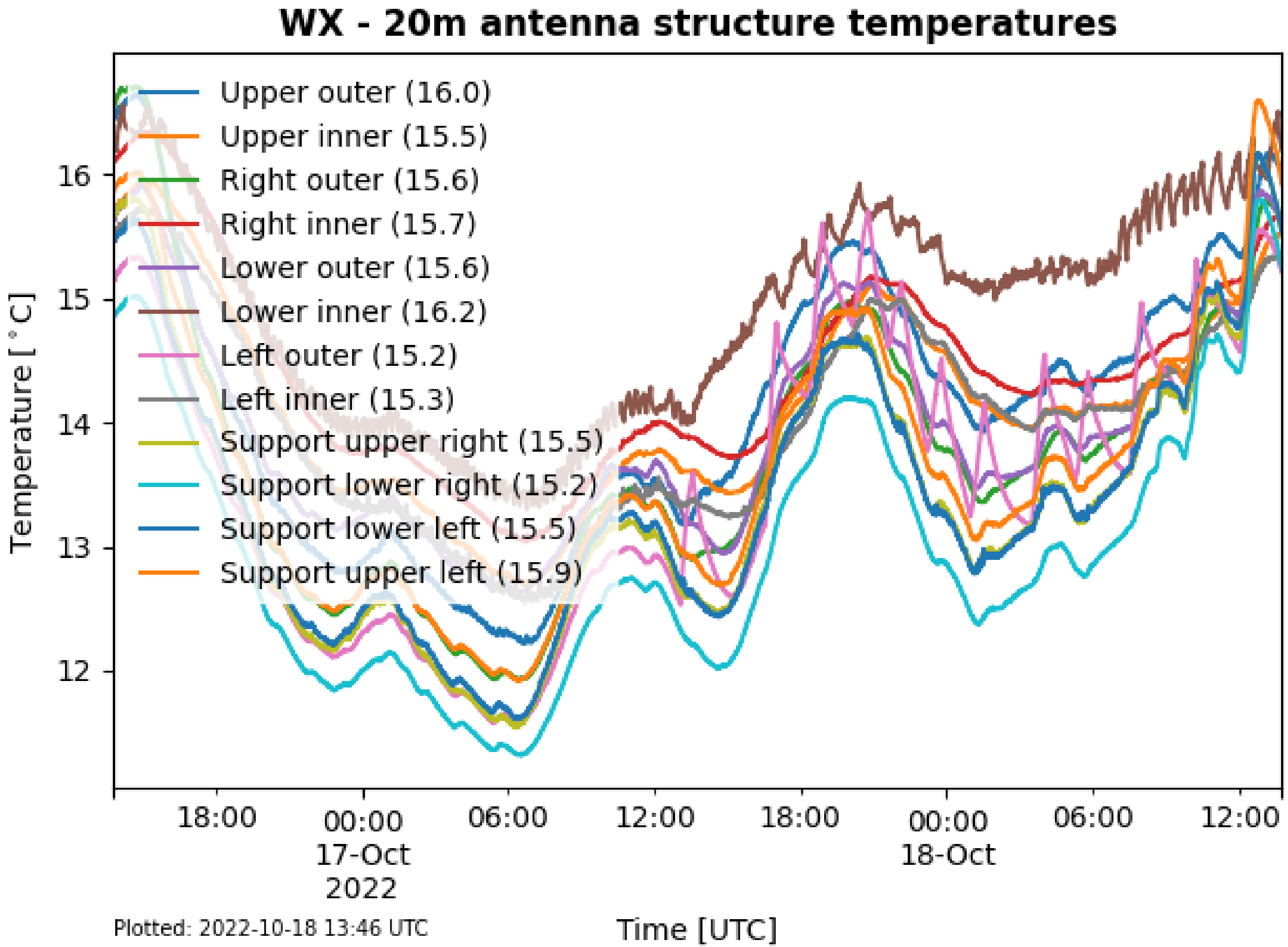
- decide about usage of the invar rod: just for validation or use it to replace the modelling of the foundation?

- extend the idea to our VGOS telescopes, which currently have temperature sensors in the towers, but not on the dishes. A gravitational deformation model is available.

- extend the idea to other telescopes that participate in IVS sessions. Some already have a graviational deformation model

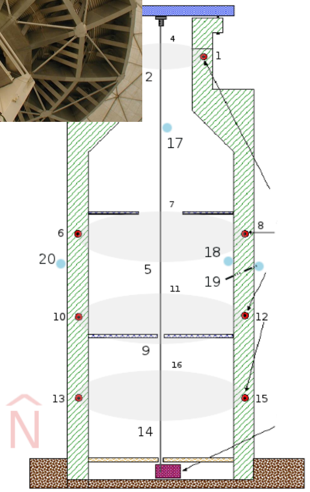
Future scope

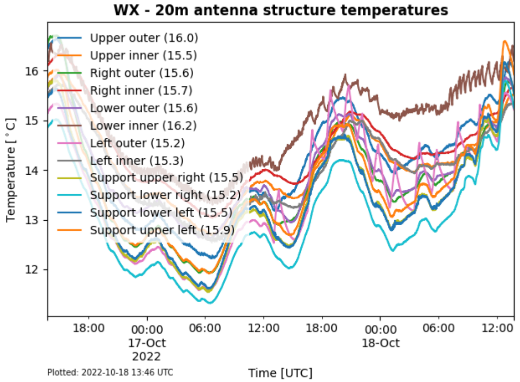


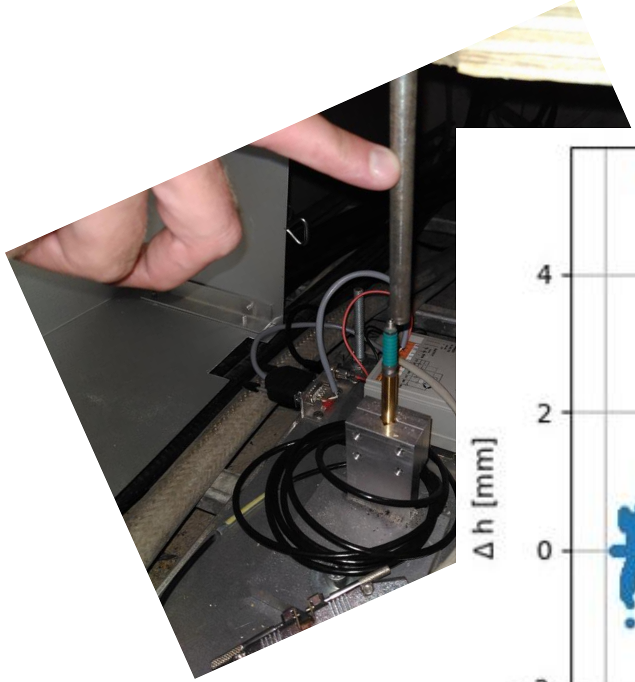


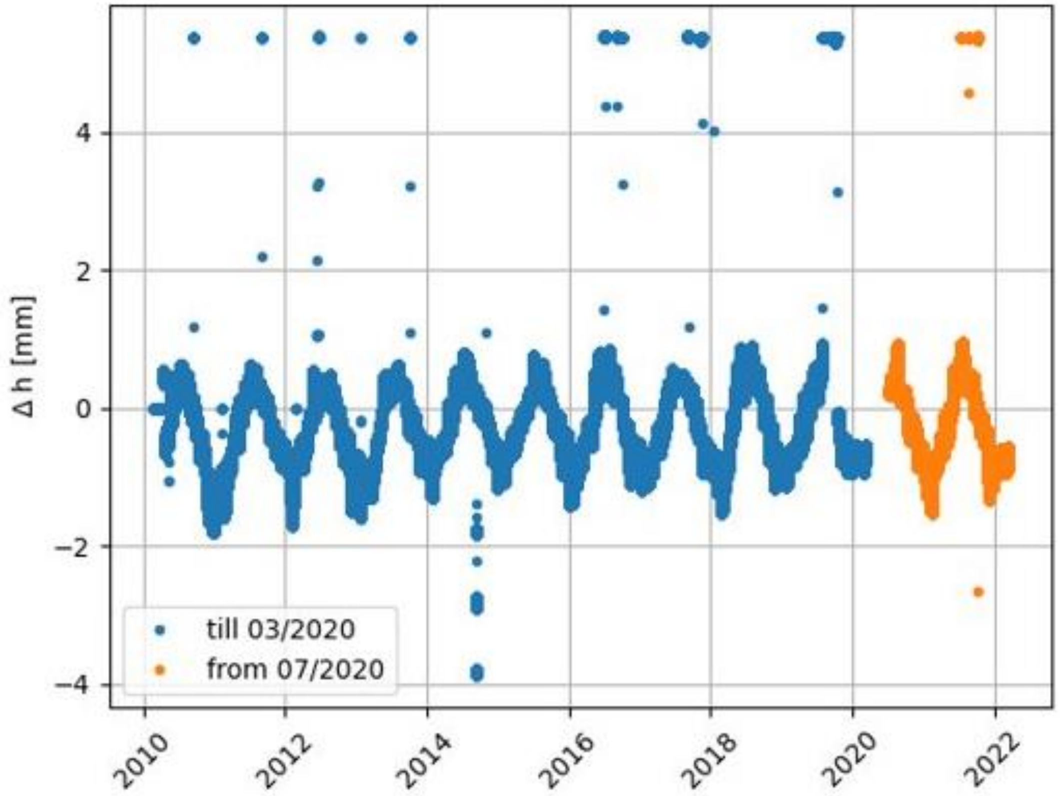
Credit: L.Pettersson

Future scope

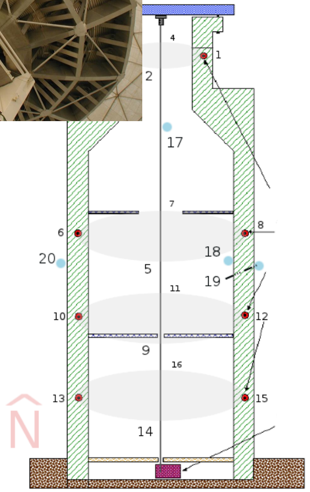


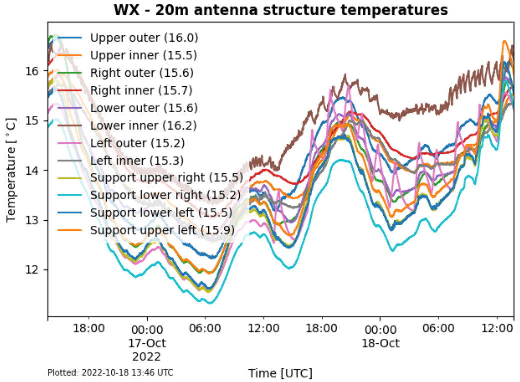


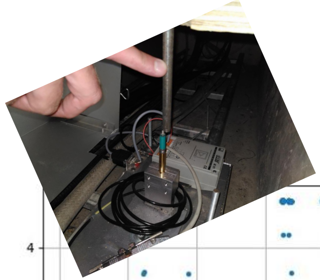


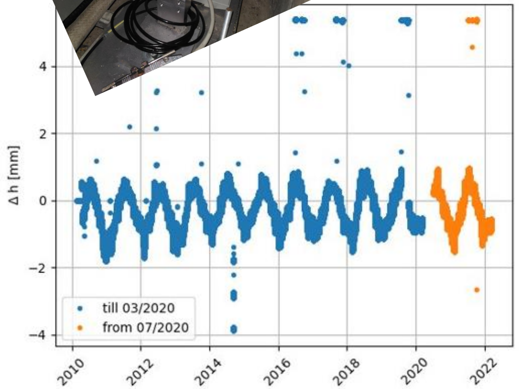


Future scope



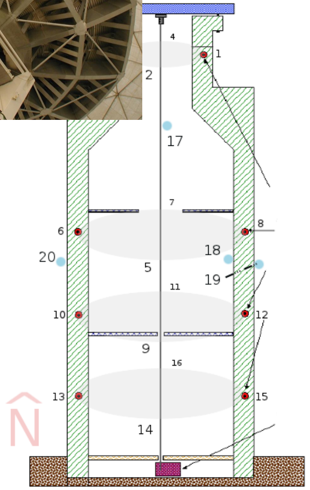


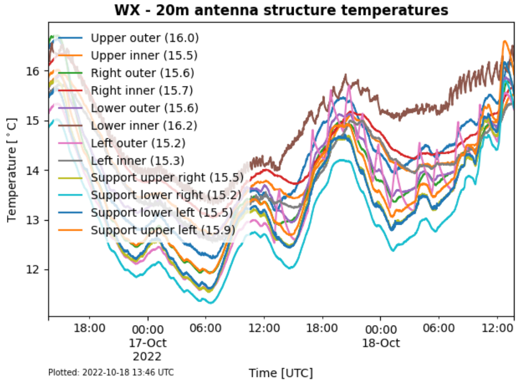


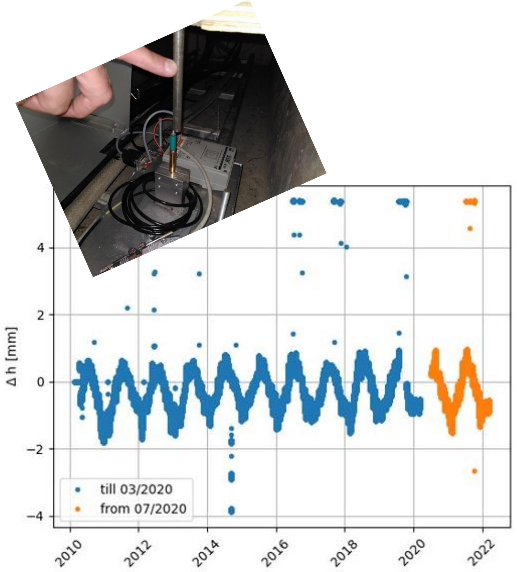


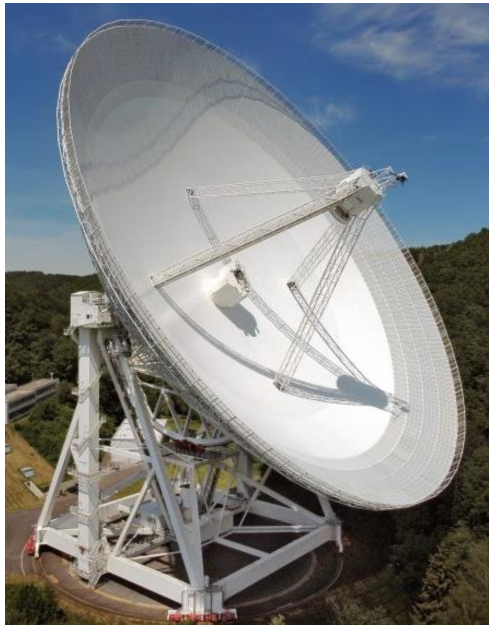
Credit: R. Handirk

Future scope









Credits: https://www.ngs.noaa.gov/corbin/iss/reports/Westford_Report_2019.pdf; N. Tacken (MPIfR); https://www.raege.eu/coresite/yebes; https://ivscc.gsfc.nasa.gov/publications/br2017+2018/nswett.pdf