Long-term Trends in the VLTI Auxiliary Telescopes and ESO/APEX Pointing Models

Stan Štefl [a,b], Rodrigo Parra[a], Andreas Lundgren[b]

[a] European Organisation for Astronomical Research in the Southern Hemisphere, Casilla 19001, Santiago 19, Chile;

[b] Joint ALMA Observatory, Alonso de Córdova 3107, Vitacura Santiago, Chile

ABSTRACT

The database of the relocatable VLTI Auxiliary Telescopes was used to study their stability and long-term trends in their pointing models. The model parameters are functions of mechanical properties of the telescopes and station pads. The index error in elevation and non-perpendicularity in elevation depend mainly on telescope characteristics, while the tilt parameters on the pads. After some trends present in 2007-2010 the mechanical characteristics of all four VLTI 1.8m telescopes are stabilized. Some tilt trends are still present in recently opened stations, but unlike in APEX, the tilts are not significantly affected by seasonal temperature variations.

Keywords: Movable telescopes, pointing models

1. INTRODUCTION

The VLT interferometers can use four 8.2 m telescopes (UTs) or the movable 1.8 m Auxiliary Telescopes (ATs). While the UTs are mostly used for standalone observations with their own instruments and in average only few nights per months are reserved for interferometry, the ATs are fully dedicated to interferometry. Unlike UTs, ATs have passive ZeroDur M1 mirrors, their M2 mirror has five degrees of freedom and the M3 mirror is fixed to the Nasmyth focus. ATs have no active optics, rotator or adaptor and their enclosure is not moving during the telescope tracking. The field stabilization is done with the help of the fast moving M6 mirror. The first of the ATs, AT1 started it operations at Cerro Paranal in January 2004, the last one, AT4, in December 2006.

Nevertheless, the most conspicuous distinction of the ATs is their capability to move on the railway tracks and relocate to another station in order to provide different VLTI baselines. Fig. 1 shows all available ATs stations at the VLT platform. At the present time, only three quadruplets A1-B2-C1-D0, D0-H0-G1-I1, and A1-K0-G1-I1 are offered for regular service and visitor mode observations. The telescope structure containing the mirrors M1 to M11 is attached to the ground through the anchoring and clamping devises and the Relay OpticS interface (ROS) located underneath the telescope provides the optical interface to the coudé focus and later to the VLTI tunnel. Relocation of the ATs is done when the change between two of the quadruplets is scheduled and it can be characterized as a sequence of the following actions: unclamping of the ROS from the telescope, unclamping of the telescope, lifting of the telescope, unclamping of the transporter, lowering down the transporter wheels and lifting the transporter into driving position, driving the transporter besides the station, attaching the ROS to its handling device and lifting it, driving the AT to the next station. During the telescope movement, the transporter provides the air conditioning, hydraulic and power service for the telescope. The same sequence of actions is applied in the reverse order to settle the telescope at the new station. The guaranteed repeatability of the 33 ton telescope relocation is of ± 0.1mm in absolute position and ± 10 arcsec in tilt. The question is how the long-term mechanical properties are affected comparing with the classical fixed-station telescopes and which of them are more affected by the telescope or by the station aging.

Further author information: Send correspondence to S.S.: E-mail: sstefl@eso.org, Telephone: +56 2 463 3255; R.P.: E-mail: parrar@eso.org, Telephone: +56 55 448 223; A.L.: E-mail: alundgre@alma.cl, Telephone: +56 2 4676360

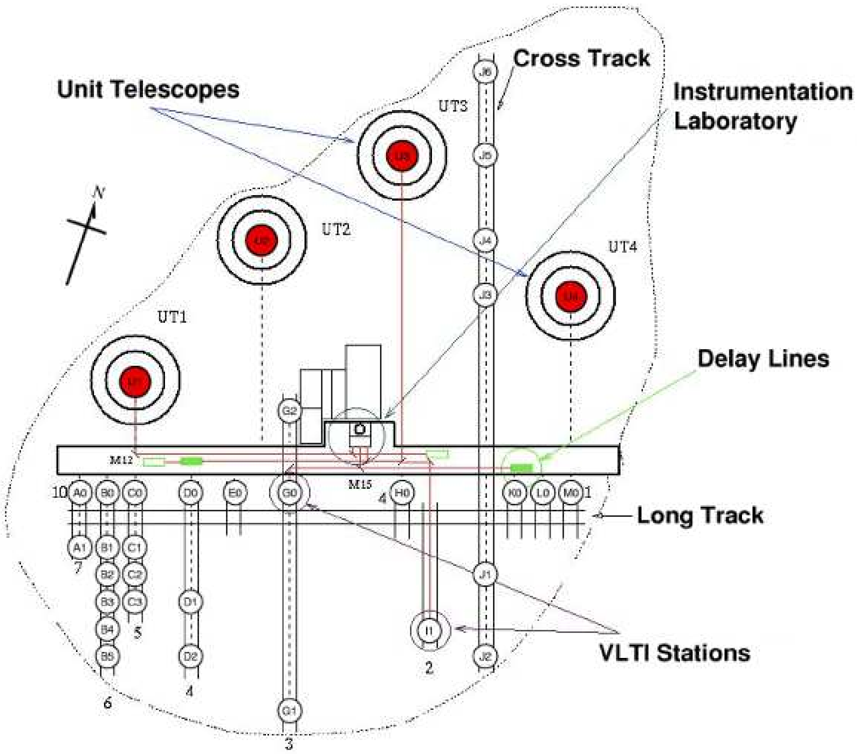

Figure 1. The layout of the Paranal platform showing positions of the UTs and 30 stations available for the ATs.

2. POINTING MODELS

Before the computers were established in the telescope control their pointing accuracy depended critically on the alignment of the telescope mechanical coordinate system to the celestial coordinates. In the era of cheap computers not only imperfections of the mechanical system can be modeled and corrected with the help of the pointing models (Spillar et al.[1]), but the model parameters allow us to monitor the mechanical properties and aging of the telescopes. The sets of pointing model parameters and their number depend on the telescope mount and inclusion of temperature effects. The number of parameters differs for particular optical or radio telescopes. For the VLTI alt-azimuth mount ATs the set of only 6 parameters (terms) was selected under the assumption that we can neglect the temperature variations. This is justified by the fact that the telescopes are housed in compact, thermally controlled domes, the temperature of which is stabilized during the day at the value expected at the beginning of the night. This helps to minimize the dome turbulence but also mechanical temperature dependent instabilities. Nevertheless, this assumption was not verified since the beginning of the ATs operations. After a short period of testing several model parameters at AT-1 in 2004-5 the set of six parameters listed in Tab. 1 was adopted.

After every AT relocation, a new pointing model is derived by the telescope operator using the TPOINT code (Wallace[2]) incorporated in the ATs telescope control software. Offsets derived from the pointing of typically 20–30 stars are used to correct the previous pointing model for the given station and telescope. The software package TPOINT can be run also independently at telescope control machines, but the code contains only few commands and a limited graphics to analyze individual model fits. It does not offer any diagnostic of the long-term model behaviour.

Table 1. TPOINT model parameters used for the VLTI ATs and their effect on the azimuth (A) and elevation (E).

TPOINT parameter name	structural error	multiplicative effect on azimuth	multiplicative effect on elevation
AN	azimuth axis offset north of vertical (N-S misalignment of the azimuth axis)	$-\sin(A) * \sin(E)$	$\cos(A)$
AW	azimuth axis offset east of vertical (E-W misalignment of the azimuth axis)	$-\cos(A) * \sin(E)$	$-\sin(A)$
CA	non-perpendicularity of elevation (telescope beam not perpendicular to the elevation axis)	-1	0
IA	azimuth encoder zero-point	$\cos(E)$	0
IE	elevation encoder zero-point	0	-1
TF	tube flexure (droop)	0	$\cos(E)$

Table 2. Average relative errors (in %) for the fitting of pointing models after telescope relocations. The relative error is computed as the mean of relative errors (ratio of the error and the related parameter at the TPOINT output) in individual pointing models.

TPOINT parameter / telescope	AN	AW	CA	IA	IE	TF
AT-1	5.2	0.7	1.8	0.02	1.0	6.4
AT-2	4.6	1.9	1.2	0.06	0.1	9.2
AT-3	6.8	0.6	4.1	0.03	1.9	7.6
AT-4	4.1	0.6	7.9	0.02	0.2	11.2

3. DISCUSSION

3.1 VLTI model stability and errors

Before 2007, only data from AT-1 and AT-2 can be found in our database. Moreover, the scatter of these values is large and the errors were often not computed. We assume that in this period still some experimental mechanical modifications were applied and procedures for model calculations were in an experimental phase. Thus, in order to prepare a consistent dataset, we omitted all data before 2007.

In the next step, we checked the errors for individual model parameters computed by TPOINT, see Tab. 2. The fact that the values are consistent for all four telescopes indicates that significant differences between relative errors of individual parameters are not caused by different characteristics of the telescopes but they reflect some imperfections of the applied method. Significantly larger errors appear for the TF and partly also AN fitting. TF represents a pointing correction in elevation and AN in both directions. We can speculate that the pointing models, particularly in elevation, are not described sufficiently by the adopted six parameters.

3.2 VLTI telescope vs. station dependent parameters

Unlike classical telescopes, in the case of movable telescopes we must assume that the pointing model parameters are determined not only by mechanical properties of the telescopes themselves, but also by properties of the station pads, to which the telescopes are fixed after every relocation. Anomalies in the orientation of individual pads can cause systematic differences of the given parameter and telescope. We cannot exclude variations of pads orientation on a long time-scale, particularly in seismically active and exposed high-altitude regions.

To reveal the telescope or pad dependence of individual parameters, in Fig. 2 we plotted all six parameters as functions of the station and with telescopes distinguished by different colours. The apparent scatter for the

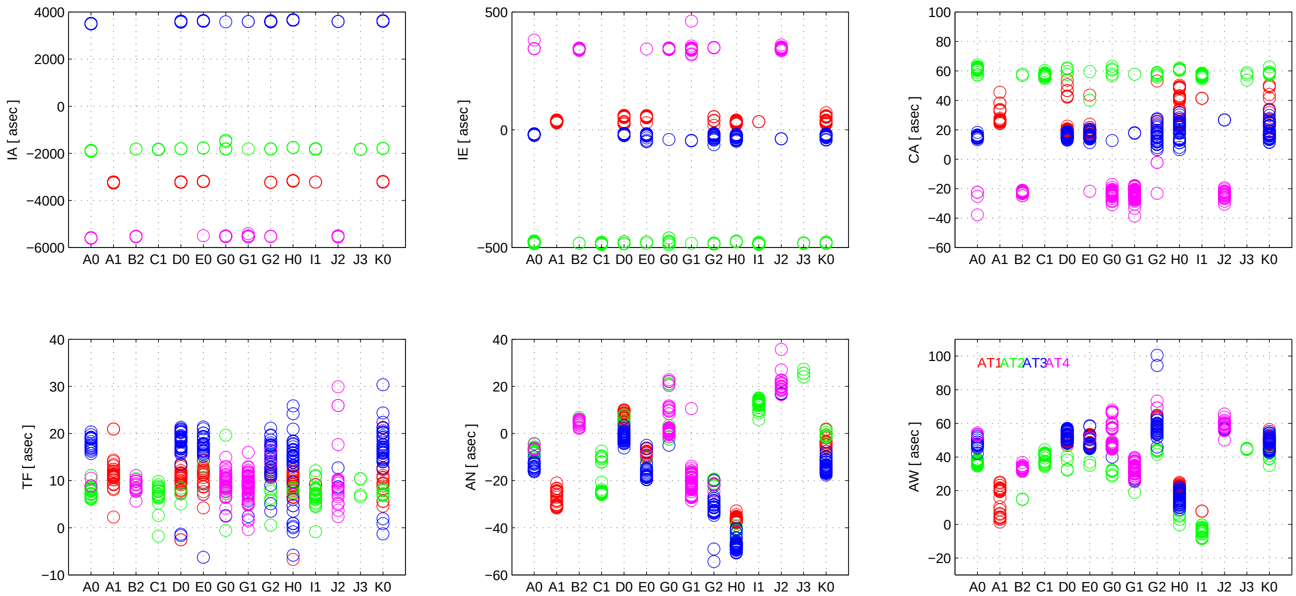

Figure 2. Pointing model parameters versus pads. Different AT units are represented by different colours as indicated in the bottom-right panel.

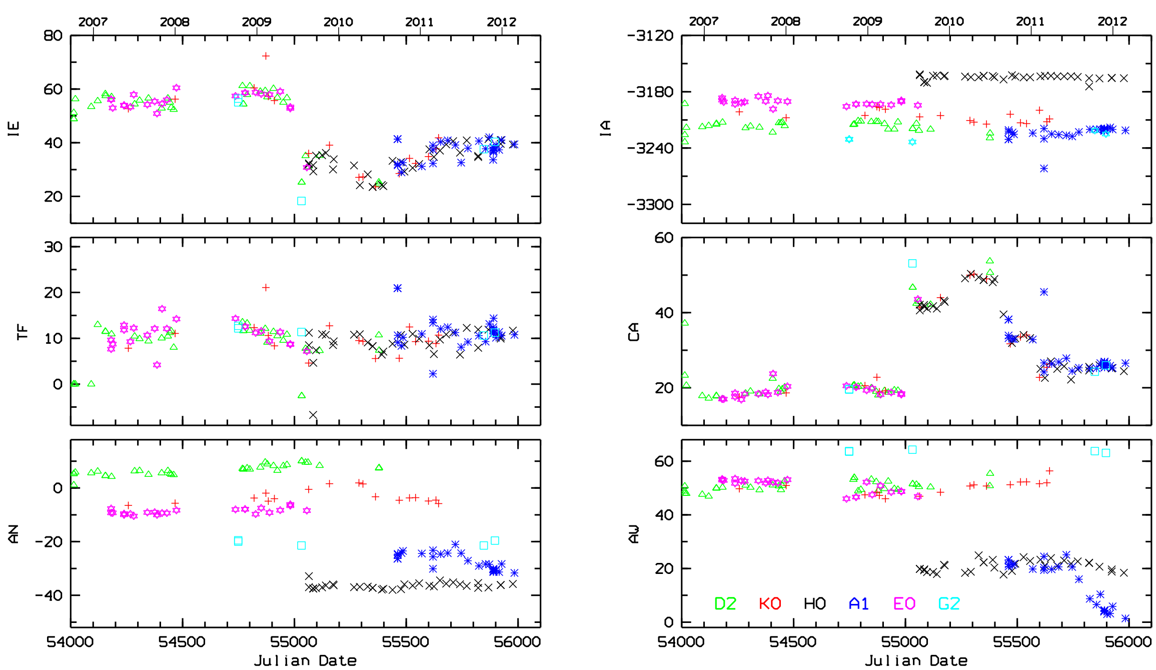

Figure 3. Pointing model parameters for the auxiliary telescope AT-1. Each panel represents one of the six pointing model parameters. Data from different stations listed in the bottom right panel are plotted with different colours and symbols.

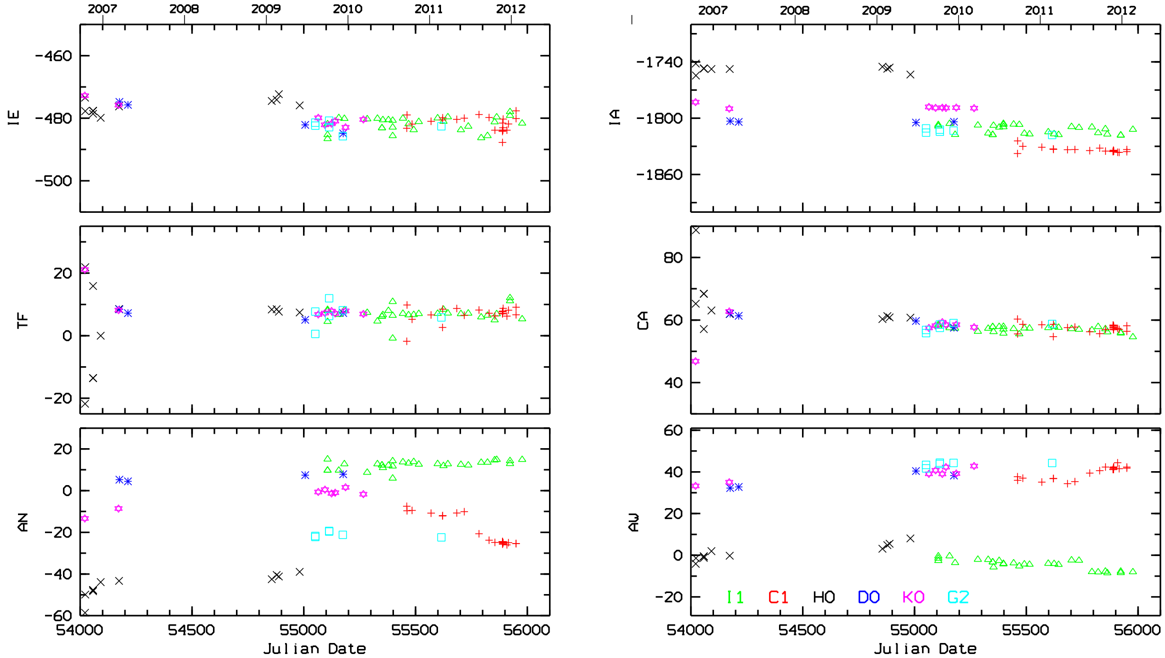

Figure 4. Pointing model parameters for the auxiliary telescope AT-2.

given station can still hide temporal variations (see Sect. 3.3) and it is also affected by the scale determined by differences of mean values for individual telescopes.

For IA, IE and CA the data points form horizontal lines of the same colour, it is the parameters for the given telescope do not depend on the station. Nevertheless, there are systematic and large differences from telescope to telescope. These parameters can be assigned to the telescope units. The conclusion is less convincing for the CA parameter using only Fig. 2, but its dominant telescope dependence is confirmed by Figs. 3 - 6. AN and AW parameters document an opposite extreme case. Their station to station variations are several times larger than the scatter of the values for the given station. This means that the parameters depend mainly on the characteristics of the pads. An unambiguous conclusion can be hardly drawn for TF. Data for individual stations show systematic differences between the telescopes, but due to the large scatter for individual stations and telescopes, we cannot exclude also small station to station variations.

3.3 Stability of the VLTI pointing models and their long-term variations

Our database of pointing models over more than 5 years provides valuable information about the stability of mechanical characteristics of the telescopes and their station pads. Figs. 3 - 6 show the temporal variations of pointing model parameters for individual telescopes. The plots also confirm the dominant telescope dependence for IE, CA and TF, pad dependence for AN and AW, but they reveal also a small pad dependence of the IA offset.

Figs. 3 - 6 show a different measure of stability for individual ATs. AT-4 is the most stable one with all telescope dependent parameters constant over the given period. AT-3 shows systematic increase for IE and TF and some oscillations of CA during 2007-10, but then the parameters stabilized. Some decreasing trend was present in AT-2 offset IA before 2010. The largest telescope related trends can be seen in the AT-1 parameters IE and CA in 2009 - 2011.5, but they seem to stabilize again in the end of 2011. The two parameters are related to the elevation pointing.

The telescope pads are relatively stable. A lower stability can be seen for the G1 station, for which AN was slowly decreasing till 2011, then an increasing trend appeared both for AN and AW. During 2010-12 systematic trends can be seen also in A1, C1 and in a less extent for the B2 station. It is worth noting that these stations

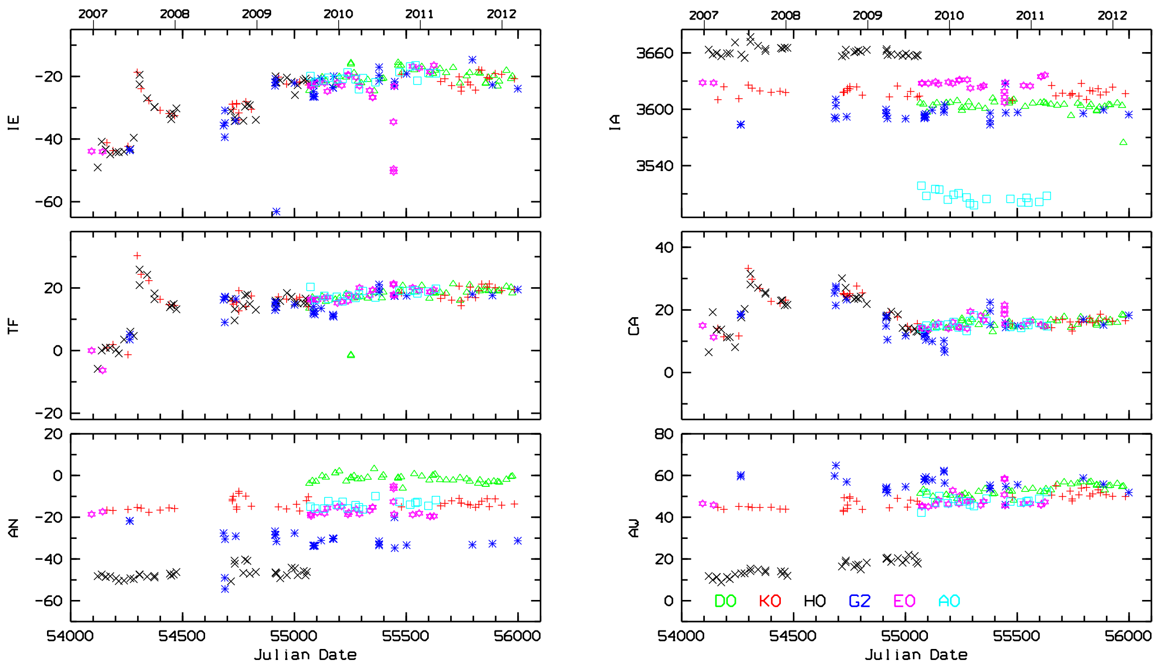

Figure 5. Pointing model parameters for the auxiliary telescope AT-3.

were commissioned only in 2010 and we may assume that the pads were still not perfectly stabilized during the first two years of their operations.

3.4 APEX long-term tilt variations

Regular monitoring of pointing models of the APEX mm/sub-mm telescope located at the Chajnator plateau (altitude 5000m) brings another example of the long-term variations. For a comparison with VLTI ATs we show only AN and AW tilts here.

The telescope tilt (AN, AW) is usually derived using astrometric measurements (i.e. optical pointing runs). Such estimates are model dependent and are not sensitive to rapid time variability of the tilt. However, the tilt of the APEX telescope is also measured on a regular basis using the embedded inclinometers. These measurements are necessary to calibrate the metrology system used to compensate in real time the pointing offsets caused by telescope tilt variations. Figure 7 shows five years of their measurements. These time series contain clear seasonal components mounted on a linear trend. Comparing these data with the astrometric data, it was found that the zenith direction and gravity vector are not parallel at the Chajnantor site producing another calibration factor for the metrology system.

The total tilt variation of the APEX telescope, as well as the Paranal's ATs, is the combination of both pad and telescope components. There is an evidence that the seasonal APEX tilt variations can be attributed – similarly as for ATs – to the telescope pads affected probably by large seasonal temperature variations.

4. CONCLUSIONS

The first analysis of the VLTI ATs pointing models, completed by APEX tilt measurements, is also the first analysis done for optical/near-IR relocatable telescopes. It can be summarized in the following points:

- Larger fitting errors for the flexure parameter TF and possibly CA may indicate that the set of only six parameters does not describe completely the transformation between the telescope and celestial coordinate systems. However, a typical error of the pointing models is less than 5 arcsec and the telescope field of

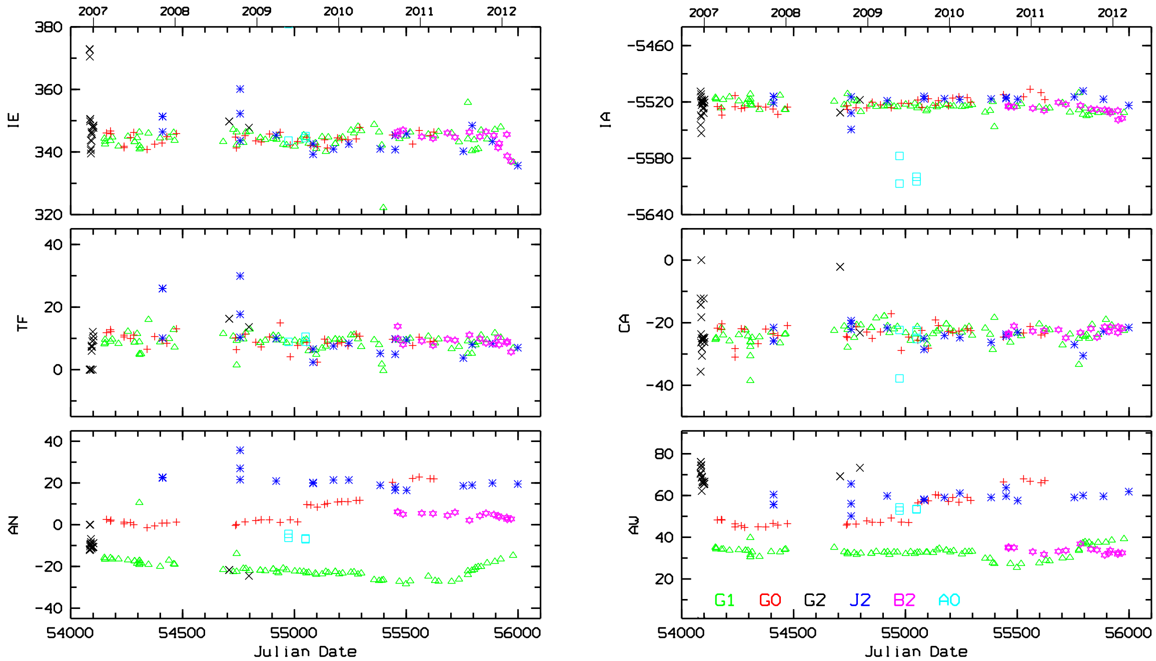

Figure 6. Pointing model parameters for the auxiliary telescope AT-4.

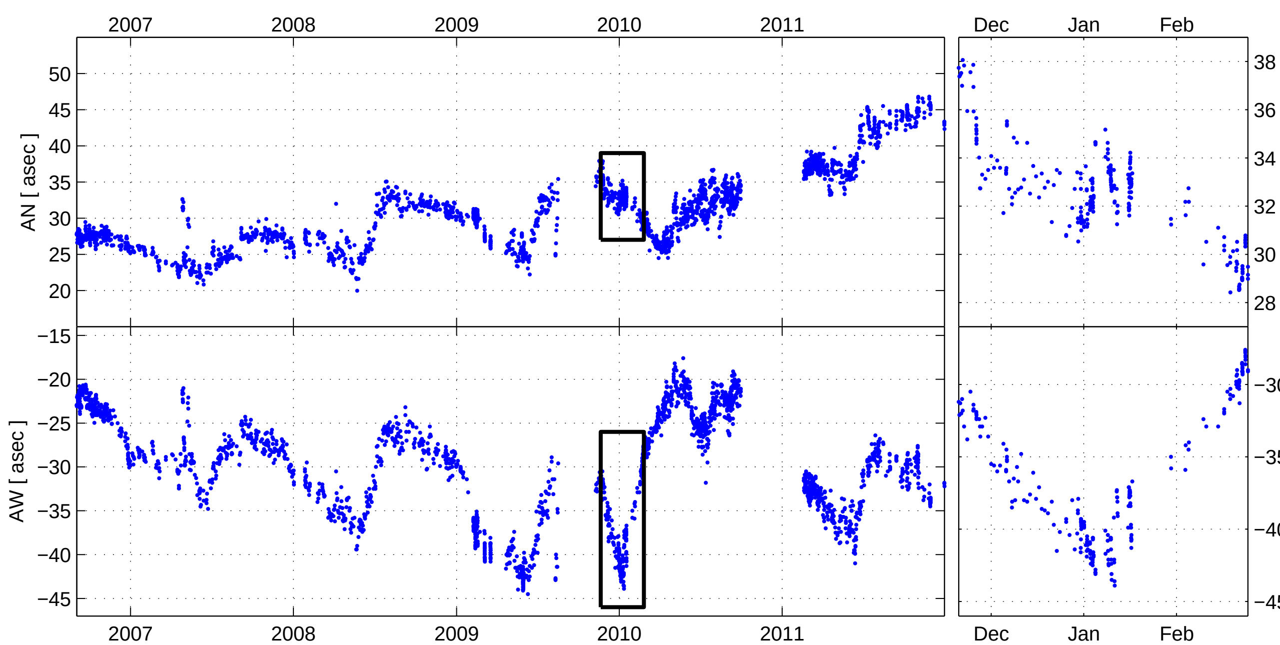

Figure 7. APEX telescope tilt (AN, AW) versus time. The tilt was measured using the high precision inclinometer system embedded in the yoke. The accuracy of the measurements is better than 0.2 asec. These values are completely independent of those derived using optical pointing measurements. The black rectangles indicate the regions blown-up to the right showing large and rapid tilt variations.

view is 80x60 arcsec. The presetted star is always within the telescope field of view, the preset can be optimized automatically and the model inaccuracy does not affect observations.

- The simple analysis of the models can separate the telescope (IE, CA) and pad (AN, AW) predominately dependent parameters. The IA offsets are mainly telescope dependent, but they also show small pad dependence. The flexure TF probably combines both dependencies but the larger errors do not permit a firm conclusion.
- Investigation of long-term trends shows a very good stability of the station pads, with the exception of G1. The trends present in the recently opened stations A1, B2 and C1 indicate that a period of at least 2 years is needed to get the pads stabilized. The comparison with the APEX telescope/pad long-term tilt variations shows that the VLTI pads are not significantly affected by annual temperature variations, which are relatively small at Paranal.
- The telescopes show different measure of stability, with almost no trends in AT-4 (possibly IE) and only small trends for AT-2 (IE, IA), which stabilized before 2010. Relatively large IE, IA and CA trends were present in AT-3 till 2010. Large IE and CA variations related to the pointing in elevation appeared also for AT-1 in 2009-2011. At the present time, the parameters of all four ATs show no significant trend.

Although our analysis does not imply any urgent modifications from the point of view of routine VLTI observations, it helps to understand the long-term stability of the telescope units and station pads. It can be also understood as a methodological simplified study for more complex systems of telescopes or antennas as ALMA. An example of APEX seasonal tilt variations shows that for pointing models of the ALMA antennas, working under much more extreme climatic conditions at the Chajnator plateau, larger pointing corrections must be expected and the pointing models will have to include temperature dependent terms.

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