# Deformation Movements Observed at the European Synchrotron Radiation Facility

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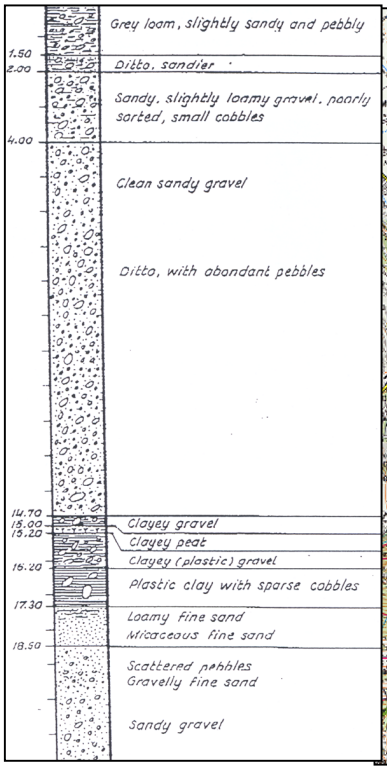
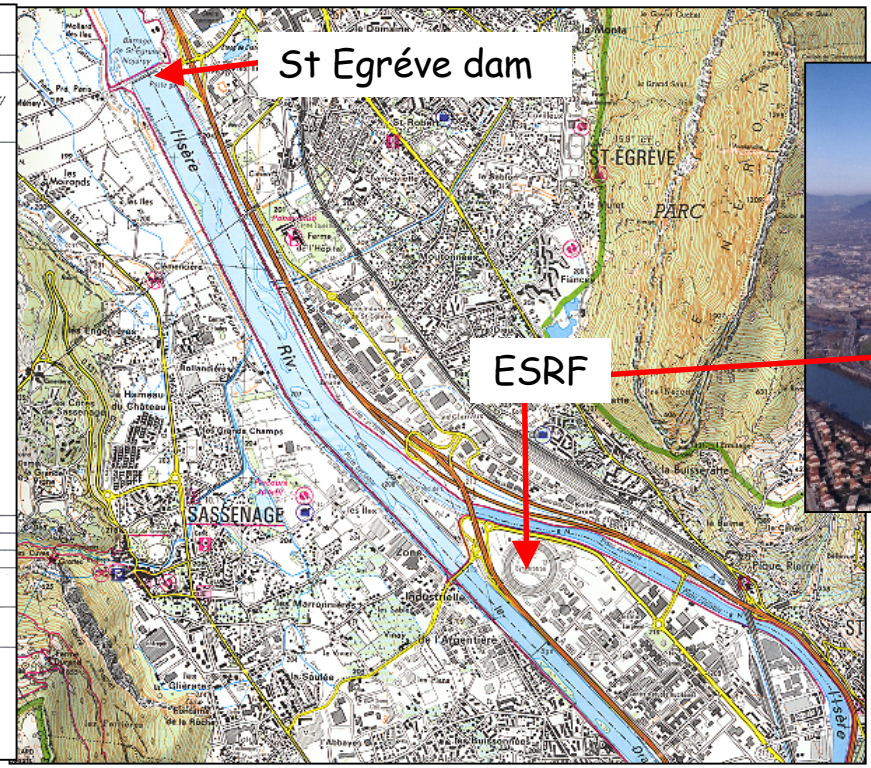
This presentation will cover the following topics:

- Vertical and horizontal movements observed on the ESRF site,
- Evaluation and interpretation of these movements with the aim of establishing generalized models,
- The ESRF Hydrostatic Leveling System (HLS) - results and pitfalls.

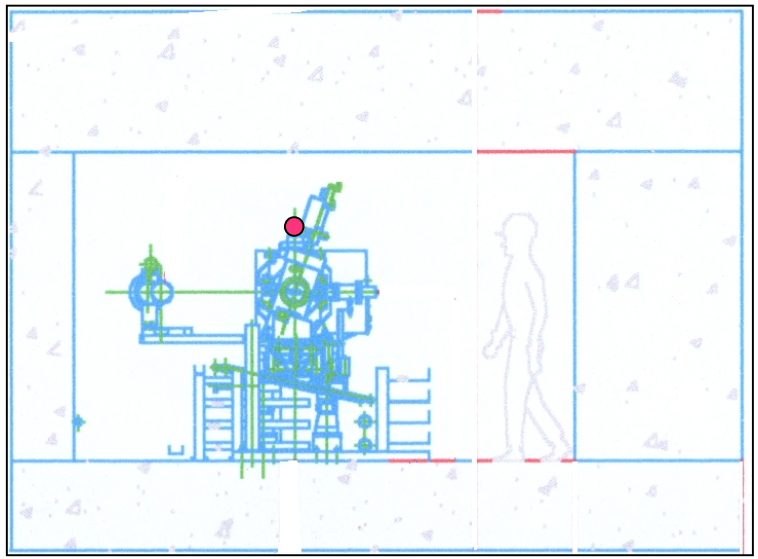
# Presentation of the ESRF Site

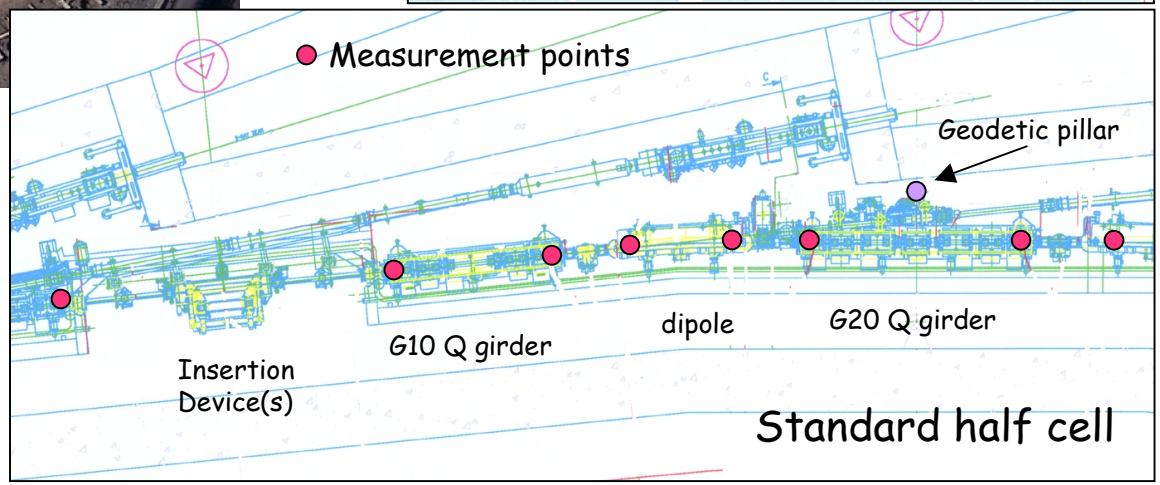


The ESRF is built on the confluence of the Drac and Isère Rivers. The valley geology is composed of a glacial deposit to a depth of at least 200 m (possibly up to 500 m) topped with alluvial material. A dam is located approximately 4 km downriver of the site. This dam is used to generate electricity and control the river water level. In doing so, it opens its sluice gates periodically, lowering the water level in the adjacent rivers. The area is surrounded by mountains up to 1000 m above the site altitude of 200 m. The local water level is 2.5 m below the accelerator.

# Presentation of the ESRF Tunnel





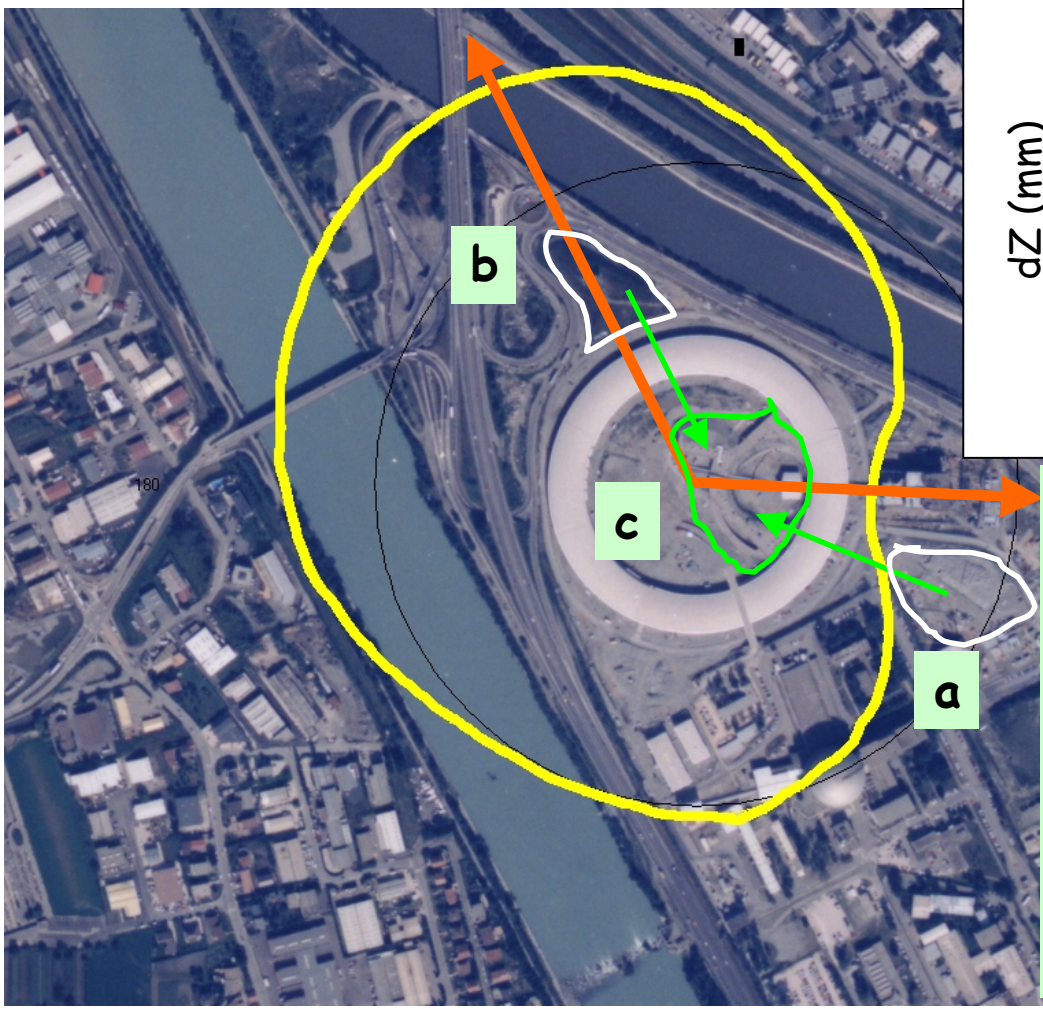

The ESRF tunnel is built on the site surface (i.e. there is no tunneling or excavation). The roof and walls are 1 m thick. The slab is 0.6 m thick.

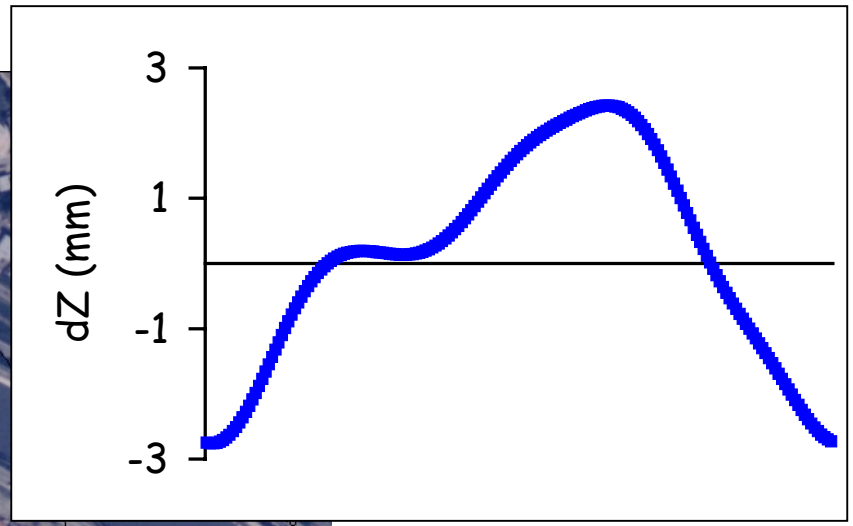
# Identifiable Movement Signatures

Several movement signatures have been observed on the ESRF site. Among these movements are:

- Excavation, Construction and landscaping on the ESRF site over an approximate $2\frac{1}{2}$ year period ending in January 1993 causing peak to peak movements of nearly 6 mm. These remain the largest movements observed to date. There is evidence that the long term effects of these activities are not yet terminated.
- Periodic purging of the St Egréve dam located 4 km downriver of the ESRF site to remove accumulated silt in the river bottom cause movements of approximately ±0.3 mm.
- Long term movements horizontal and vertical deformation of the site.
- Cyclical movements on the support girders located next to the the slab construction joints.
- Movements associated with the cooling of the tunnels and magnets.

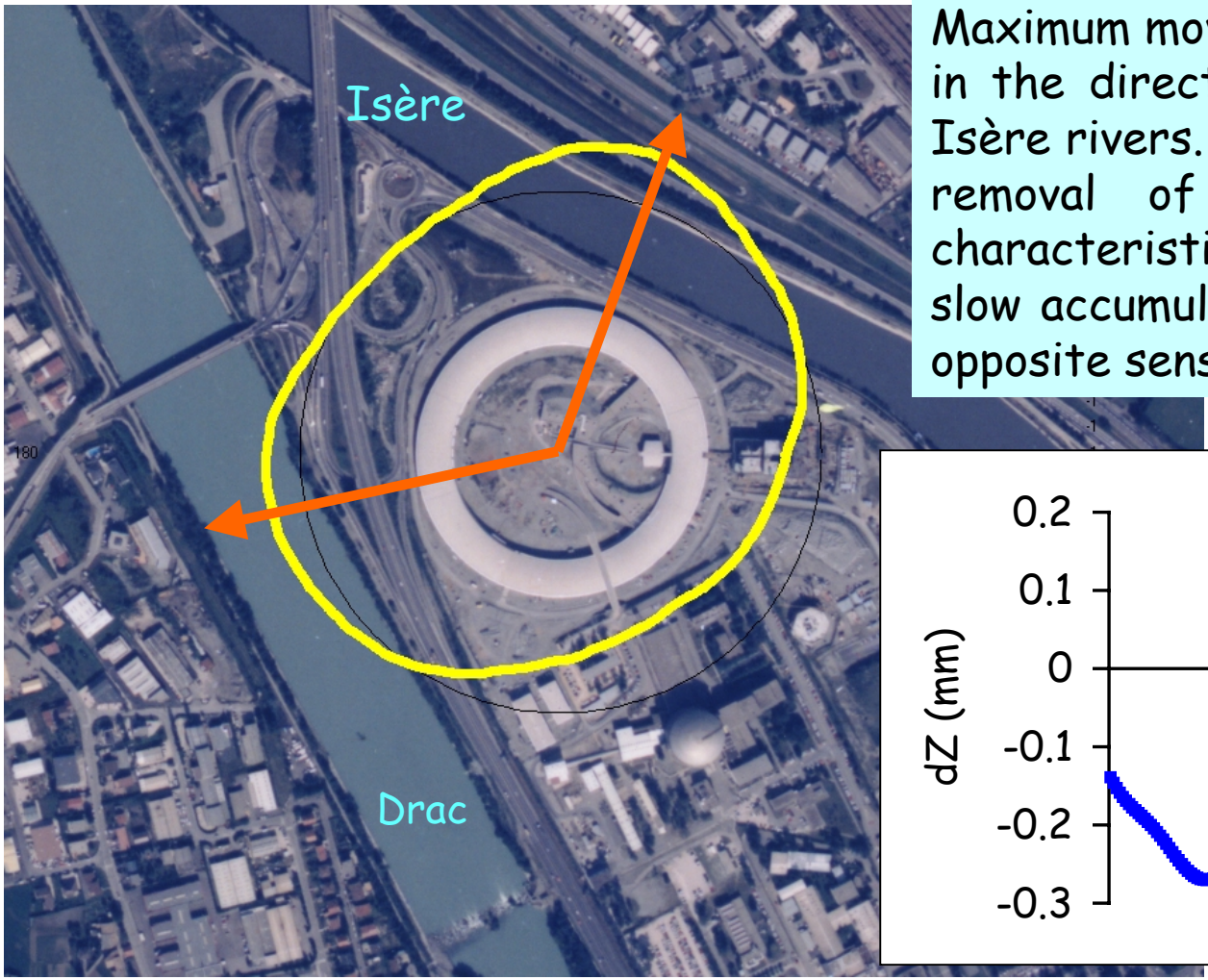
# Movements Due to Construction and Landscaping on the ESRF Site



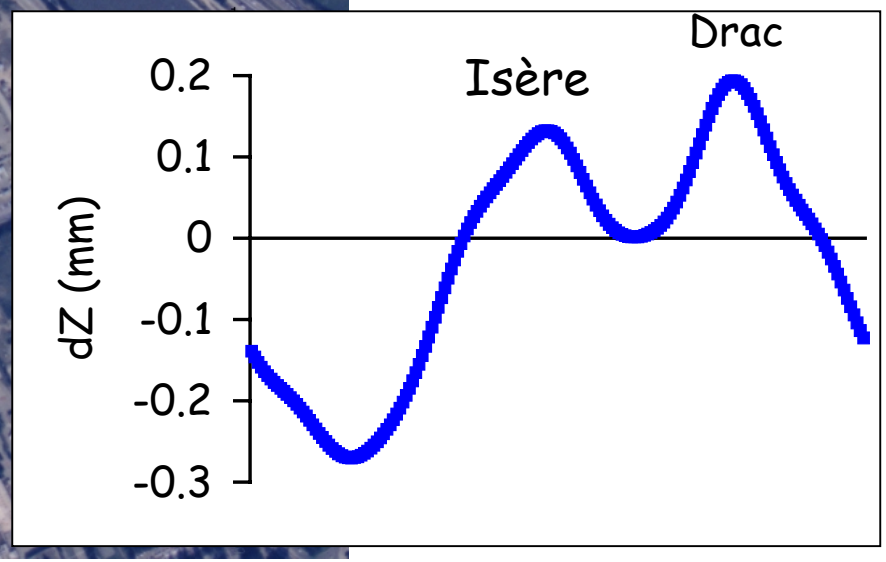




Large deposits of earth were moved from a and b to the booster zone in c. These deposits combined with the mass of concrete used in the construction of the Booster caused movements of ±3mm. The site center continued to sink by 2 mm over the four year period ending in summer 1999 (3 to 7 years after the end of the construction period).

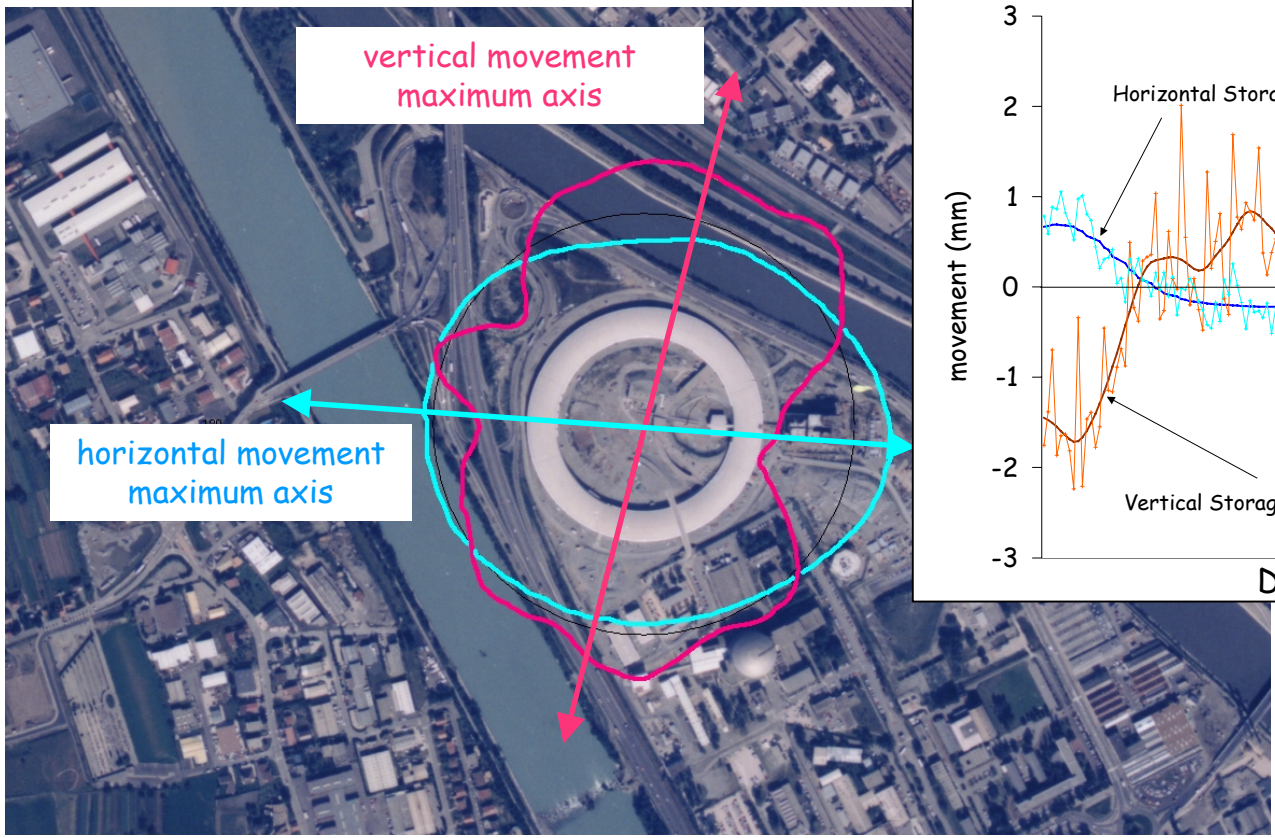
# Deformation Due to Silt Accumulation and Removal in the Adjacent Rivers

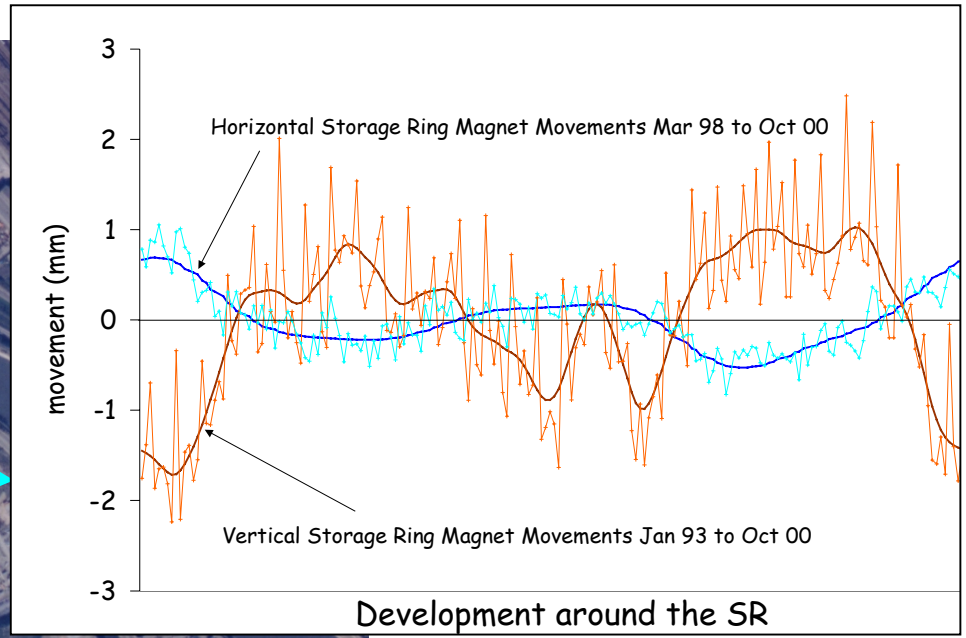



Maximum movements are observed in the direction of the Drac and Isère rivers. This graph shows the removal of sediment and its characteristic upward motion. The slow accumulation of silt is in the opposite sense.



# Accumulated Horizontal and Vertical Site Movements




Over the long term (Jan 93 to Oct 00 for vertical and Mar 98 to Oct 00 for horizontal) 'smooth' vertical and horizontal movements are roughly inversely correlated!

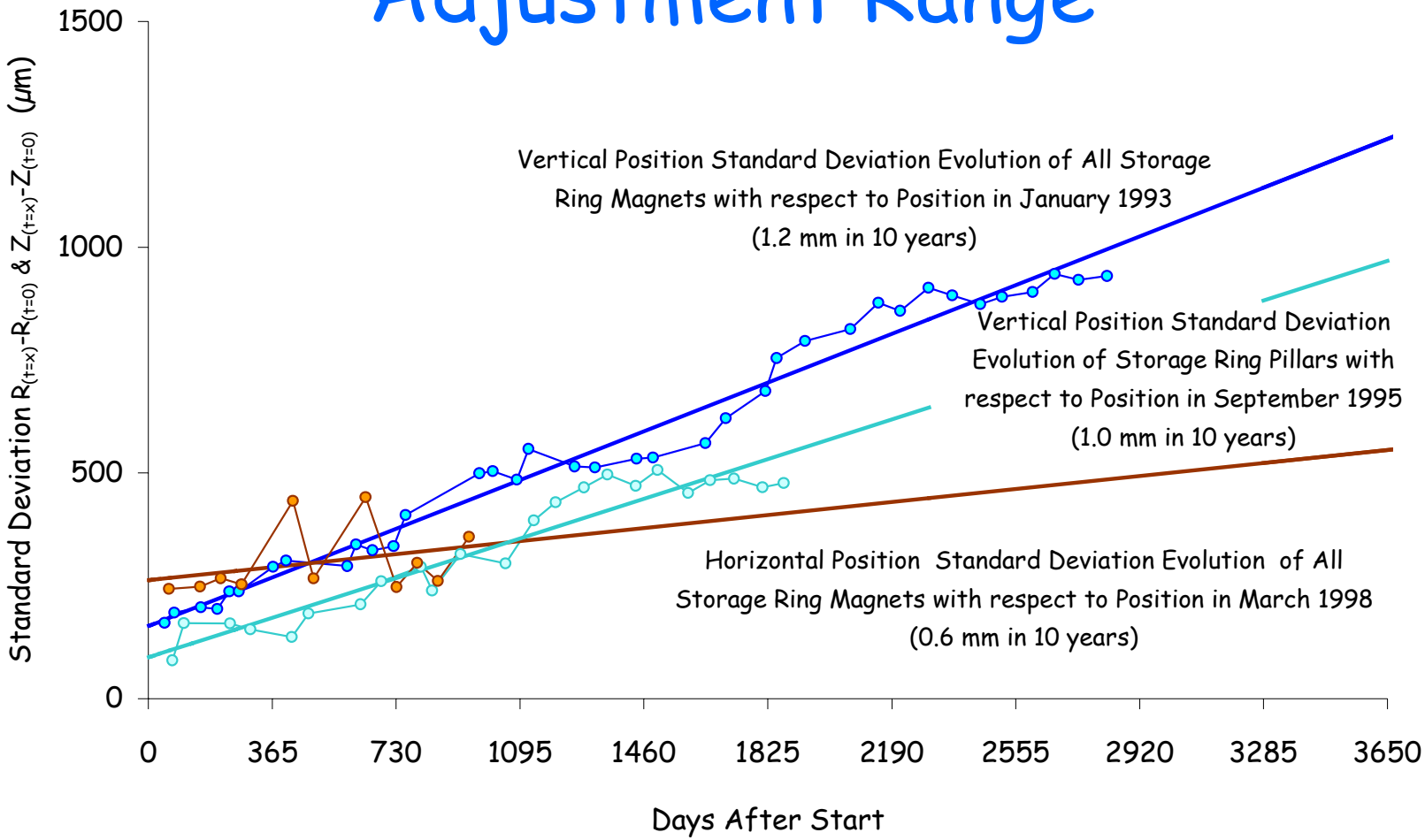
# 'Smooth' Movements Discussion

If these movements can be considered in light of this workshop to be of 'local' interest, and of little value in elucidating the 'big picture' in terms of general ground motion, they do underline at least one important concept. On the large scale in terms of amplitude of the movements and in terms of time, both horizontal and vertical movements observed on the ESRF site can be said to be deterministic and not random! This is to say they have a reason for being. Secondly, although they are observed at the ESRF, their nature can be considered as representative of similar events at any site. For example, any large scale construction will have consequences for an accelerator. Often, as was the case at the ESRF, these movements are the largest a site may experience. Furthermore they can last a very long time. It is particularly important to note that they are maximum during the 'commissioning' period – a difficult time at best!

Nevertheless, as the next graph shows, these movements can be used to predict the range requirements for horizontal and vertical adjustment in the long term – at least on the ESRF site. This graph also indicates that vertical movements on the magnets are double the magnitude of the horizontal movements. One can also imply a ratio of ground movement as observed on the SR pillars to magnet movement.

Vertical Ground Movement = 0.83 x Vertical Magnet Movement

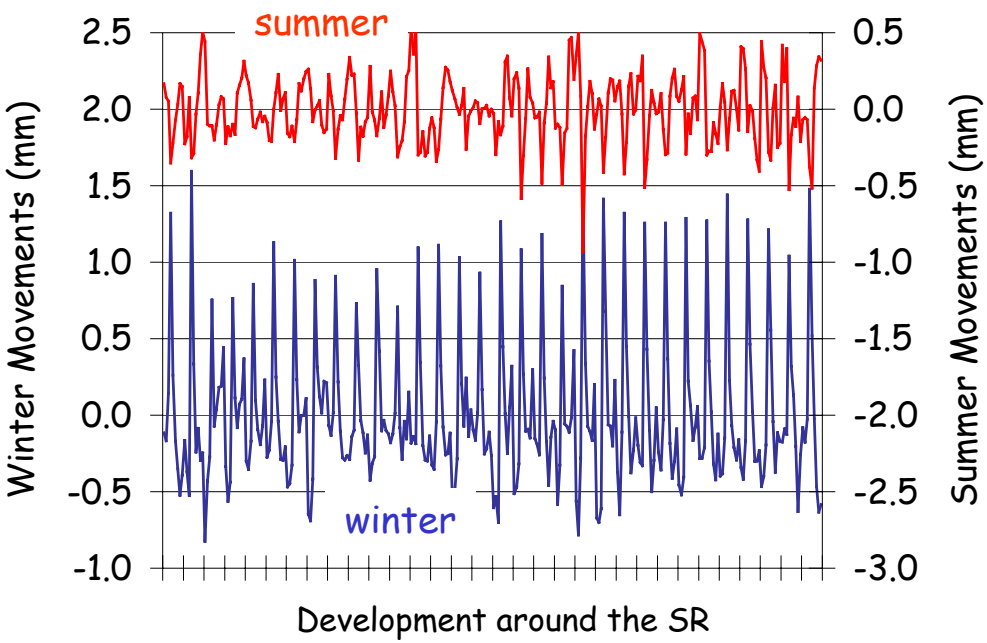
# Adjustment Range

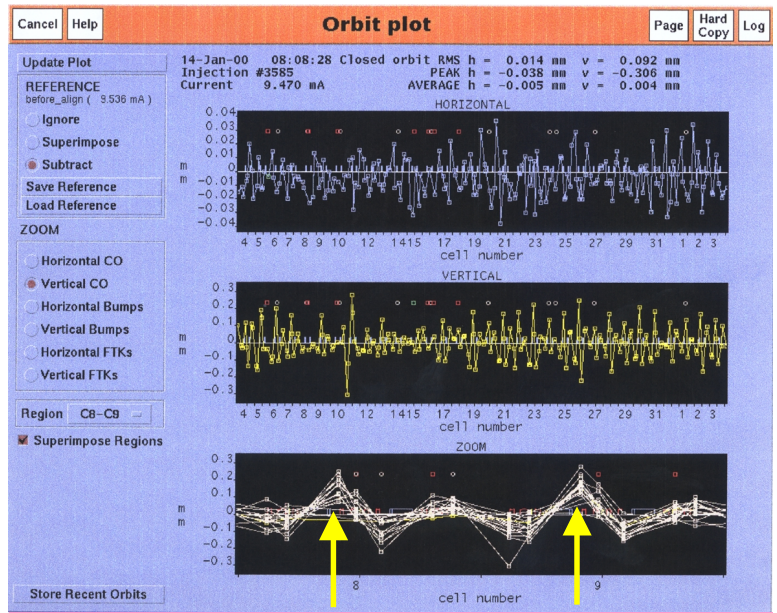



This graph shows the evolution in the standard deviation of the horizontal and vertical position of the ESRF SR magnets and the vertical position of pillars anchored into the concrete slab with respect to an origin. This information can be used to predict adjustment range requirements. Note this graph does not include the very large movements encountered in the period ending in January 1993.

# Movements at the Construction Joints

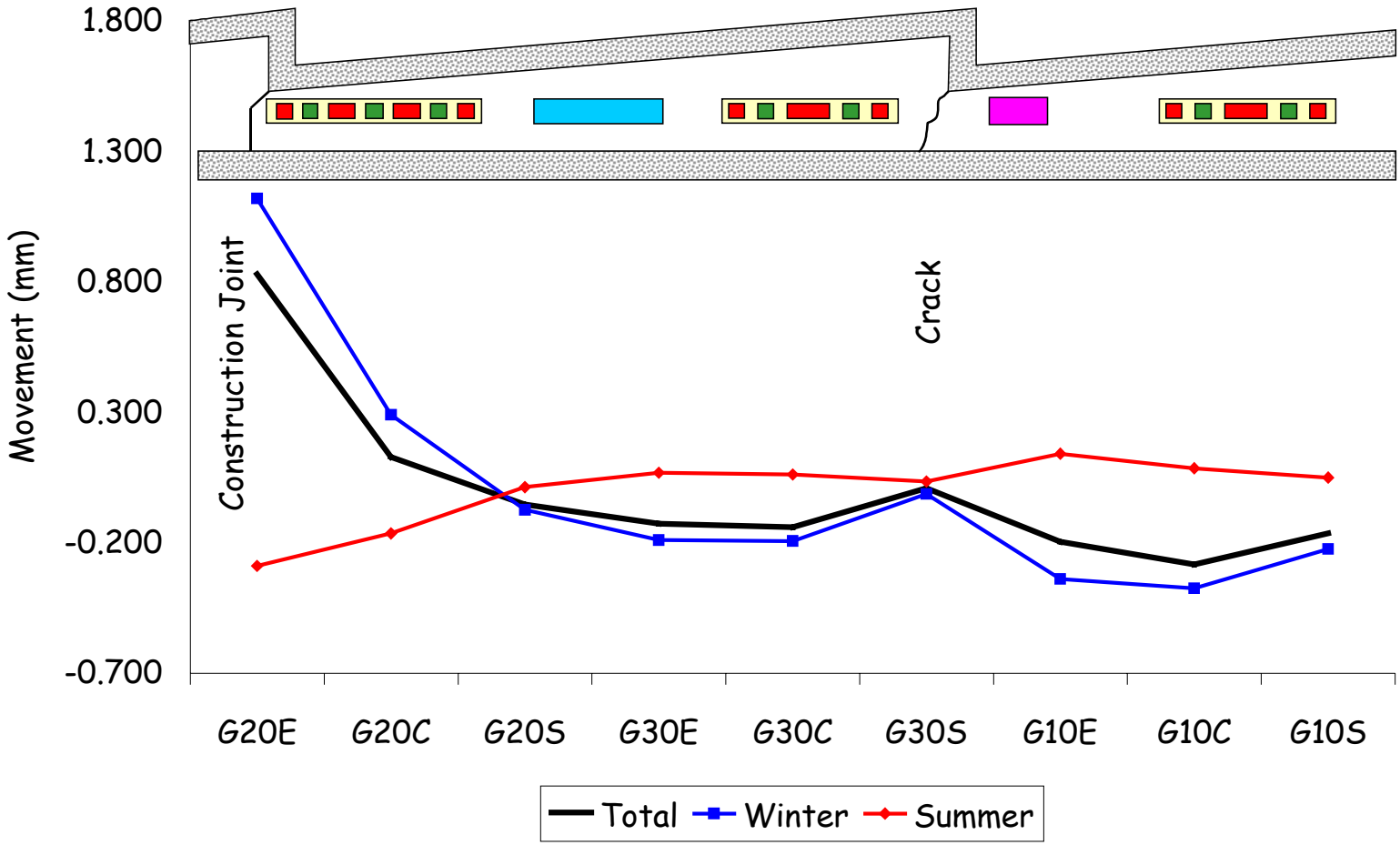
To this point 'smooth' deformations have been discussed. They have relatively little consequence on the operation of the machine. However, there are more perturbing movements. Among these are the movements seen at the construction joints in the SR slab. They are characterized by a large upward movement in the autumn followed by a relatively small relaxation in the spring. They are clearly seen on the beam closed orbit.



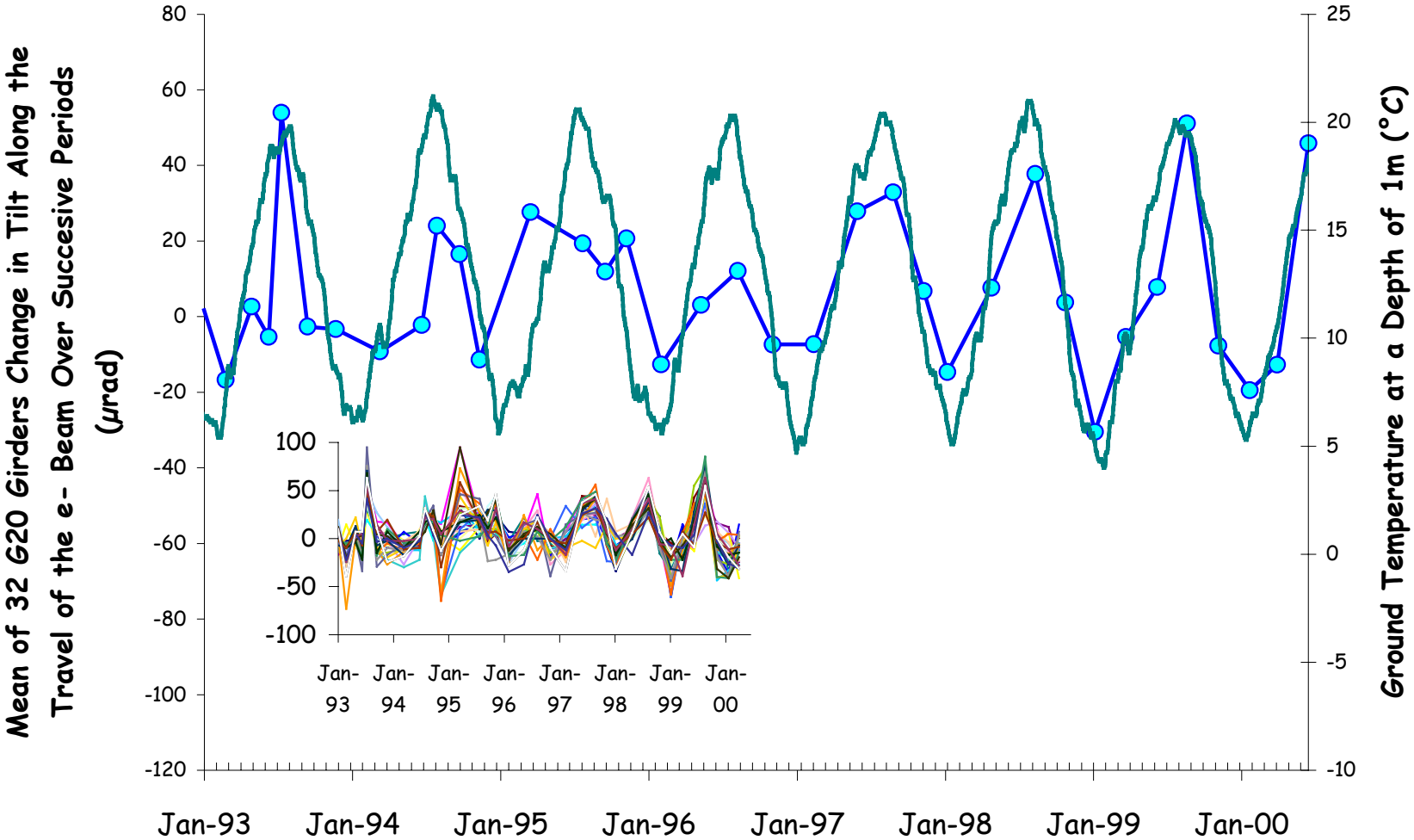

Peaks on orbit plot due to movements at the joints

# Movements at the Construction Joints



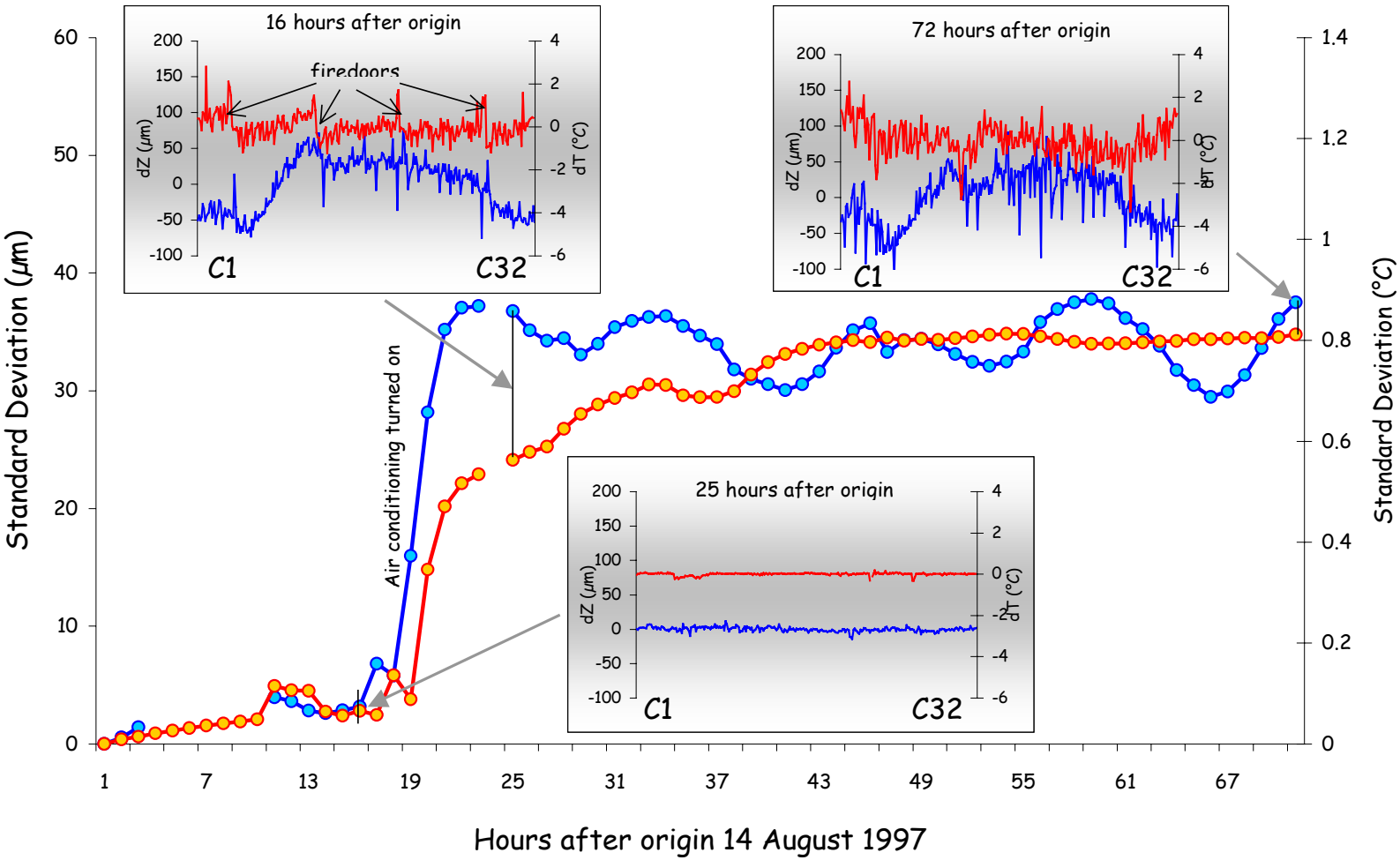

The movement is maximum at the construction joint. However, it is also clearly visible at the naturally formed crack in the floor as well!

# Movements at the Construction Joints




It is surprisingly well correlated with the ground temperature variation at 1m depth suggesting that it is due to a fluctuating vertical temperature gradient as a function of season in the 1 m thick slab.

# Magnet Movements due to Cooling




When the air conditioning and cooling is started, the SR magnets move vertically by more than 100 μm.

# Towards Models of Vertical and Horizontal Movements

To this point all analysis of data in this presentation has been of the evolution of a point (or points) with respect to its position at an origin. This is arguably of marginal interest outside of the context of the ESRF and its local geography and geology. We will now try to extrapolate movement information which can be considered as more generally applicable. The following results (leveling, horizontal positioning, Hydrostatic Leveling System and Wire Positioning System) are presented in the form of evolution of a point with respect to its neighbor and with respect to an origin. It is argued that this type of measure is more representative of the smoothing of the machine and consequently what the accelerator beam 'sees'. This eliminates the large scale deformation movements discussed previously and concentrates on the more disturbing movements such as those seen at the construction joints and when the cooling systems are started.

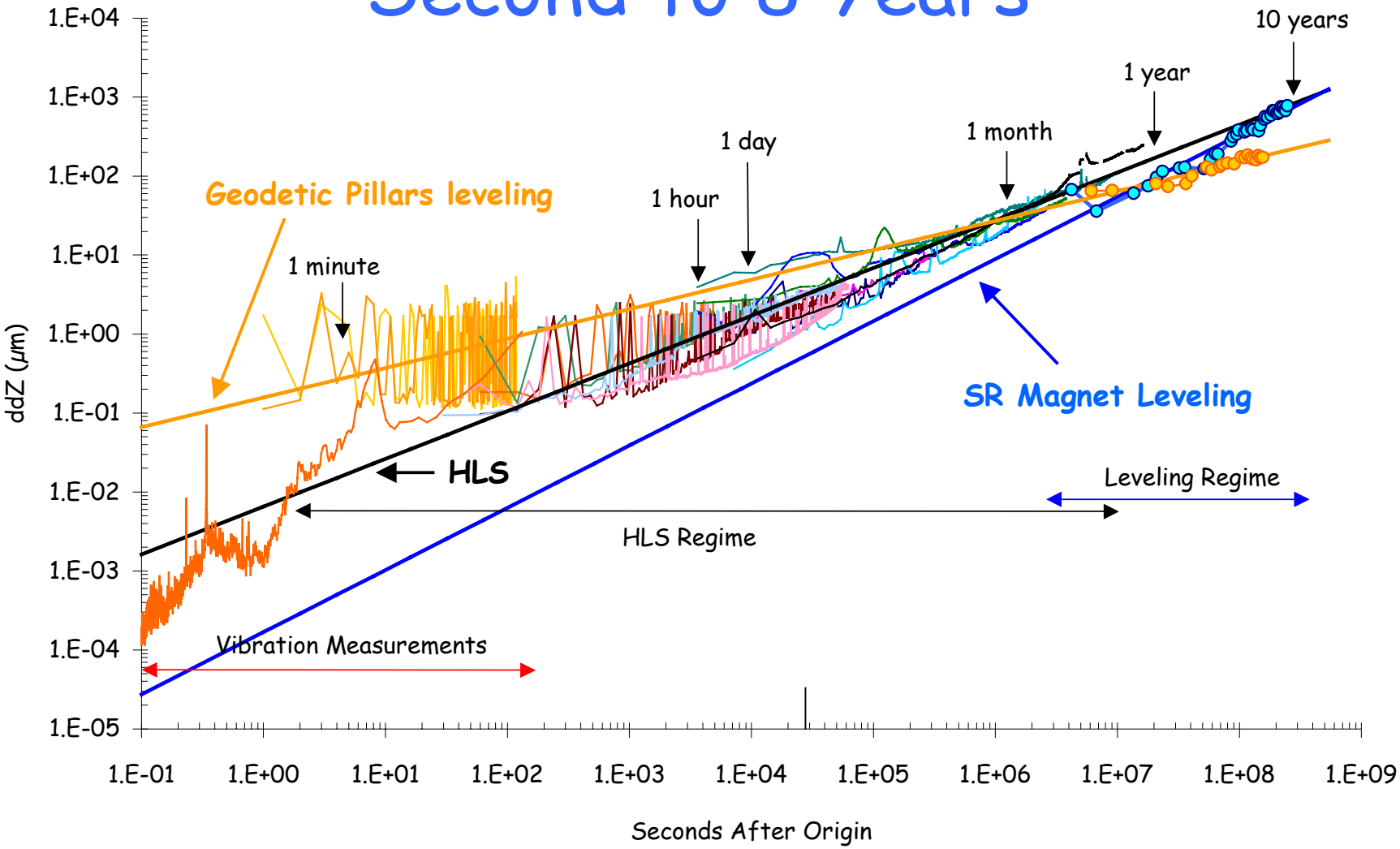
$$(value_i - value_{i-1})_{t=x} - (value_i - value_{i-1})_{t=0}$$

# Vertical Movements Regime 0.1 Second to 8 Years

The following graph presents three independent data sets ranging over a time period of 0.1 second to 8 years. Vibration measurements from L. Zhang are presented in the 0.1 to 130 second range. HLS dZ values cover the range 1 second to 6 months and leveling values for the machine and geodetic pillars cover the range 2 months to 8 years. Recall, with the exception of the vibration measurements, that these results are the standard deviations of the full data set of neighbor differences with respect to an origin.

It is immediately clear that these results are well correlated and coherent over this remarkable range. The first thing this relationship implies is that one can extrapolate level data taken at the month to year time period to the hours, minutes and seconds regime. This is true at least to the 1 $\mu$m level. This graph also puts a lower limit of validity on ESRF HLS data between 0.5 and 1 $\mu$m. We will address the important aspect of the upper limit of validity in the next section.

# Vertical Movements Regime 0.1 Second to 8 Years

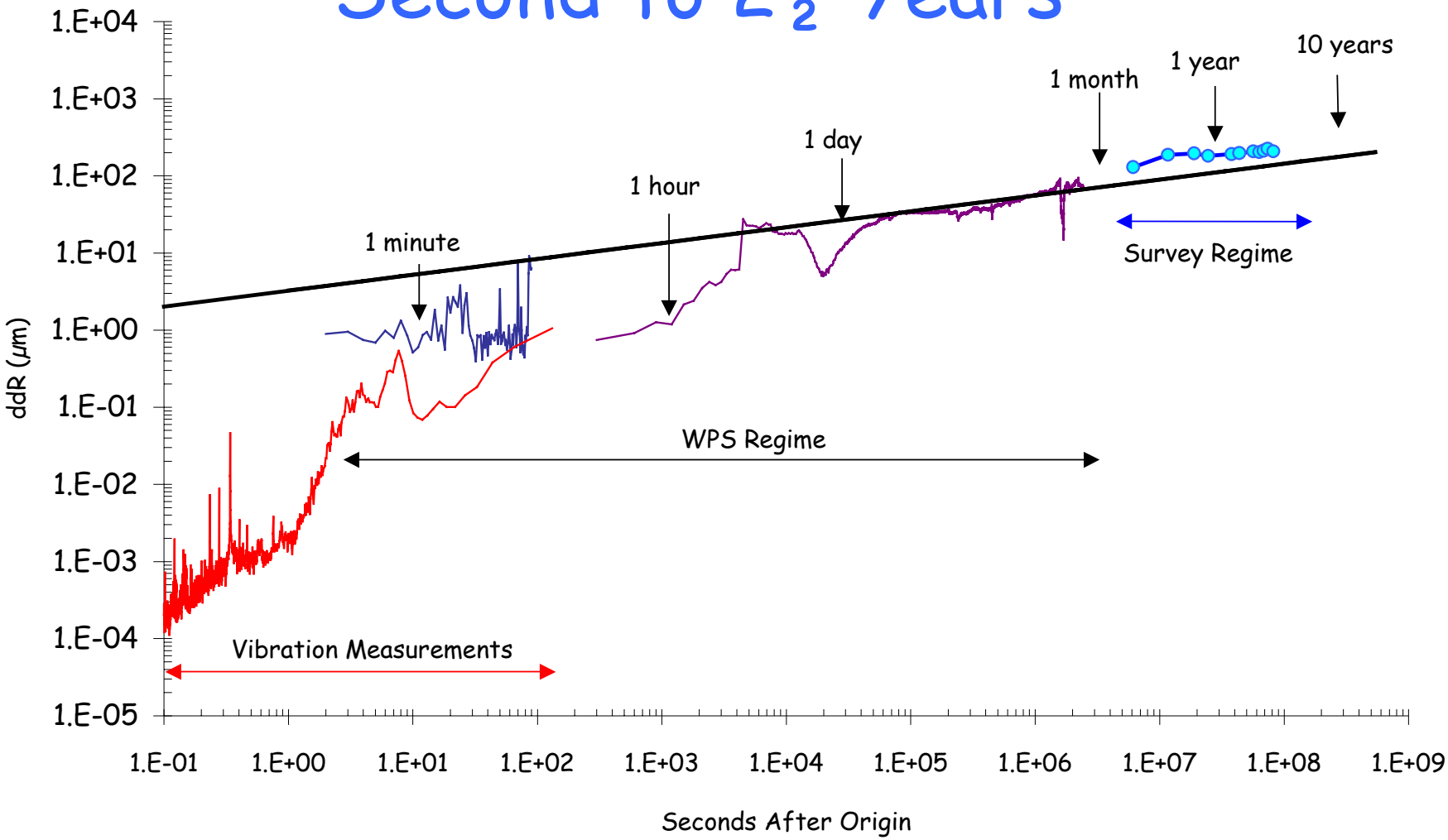


# Horizontal Movements Regime 0.1 Second to 2½ Years

The following graph presents three independent data sets ranging over a time period of 0.1 second to nearly 2½ years. Vibration measurements from L. Zhang are presented in the 0.1 to 130 second range. Wire Positioning System (WPS) dR values cover the range 1 second to 1 month and survey results for the machine cover the range 2 months to 2½ years. Recall, with the exception of the vibration measurements, that these results are the standard deviations of the full data set of neighbor differences with respect to an origin.

It is clear that these results are well correlated and coherent over this range. WPS data is sparse. Furthermore these data were taken on single SR cell (8 readings). Nevertheless, one can only be encouraged by the correlation and the similar results to the vertical case shown in the previous graph.

# Horizontal Movements Regime 0.1 Second to 2½ Years

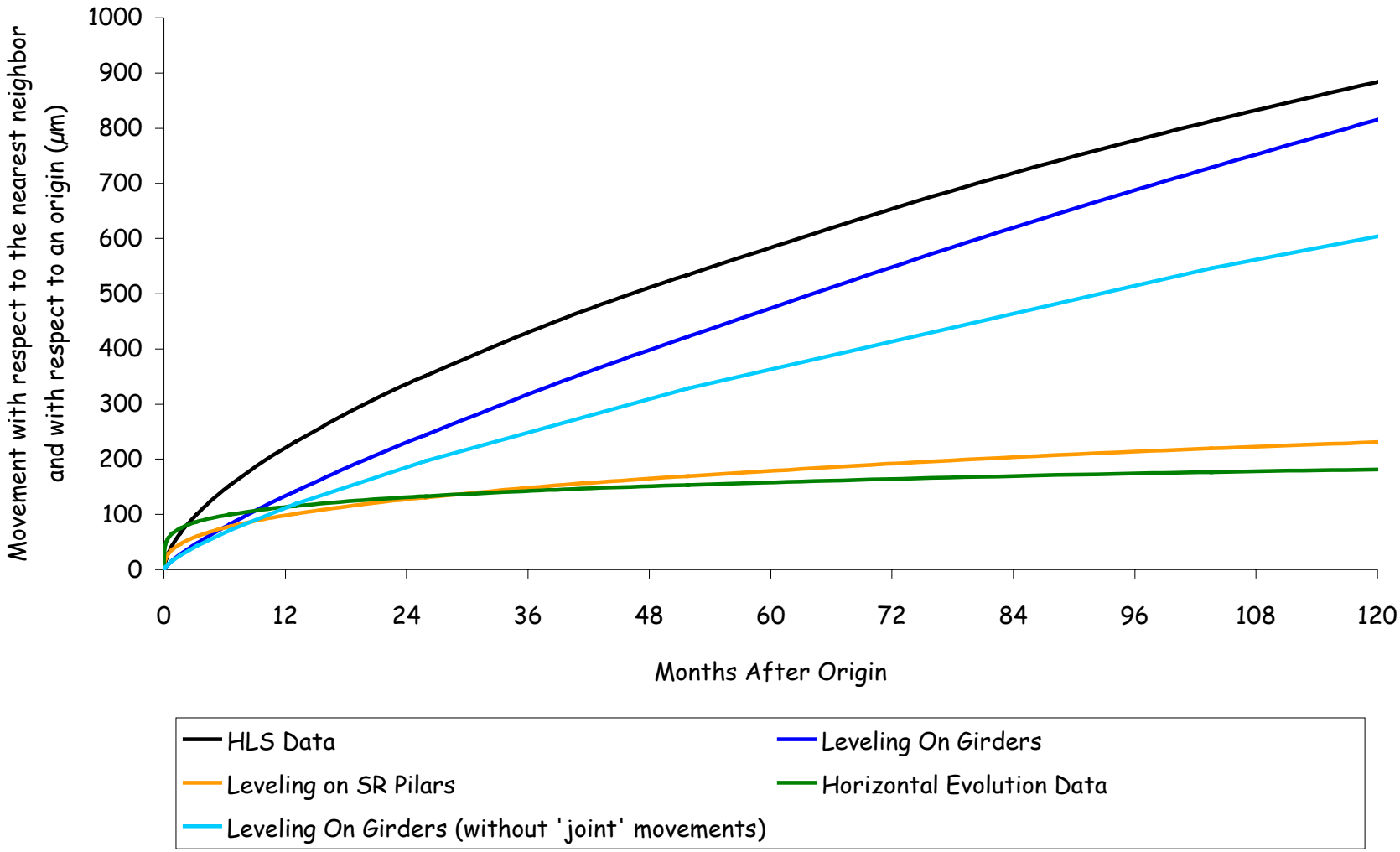


# Development of Models for Horizontal and Vertical Movements

The following graph presents models for the vertical and horizontal cases discussed in the previous graphs. One must be aware that the curve for the pillars which represents 'true' vertical ground movements are derived from a five year data set with no values below the 2 month time range. Secondly horizontal data is sparse as was discussed in the previous slide. Finally, one must remember that vertical magnet movements are strongly conditioned by activity at the construction joints.

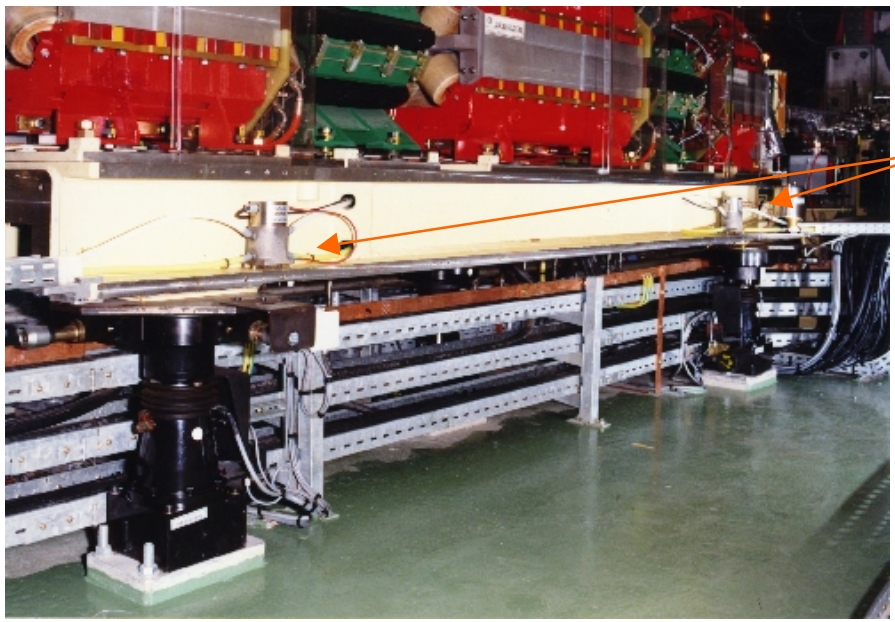
Having said this, one can conclude that ground as well as horizontal magnet movements are smaller by a factor of 4 than vertical magnet movements. If we eliminate the 'joint' movements, this factor can be reduced to 3.

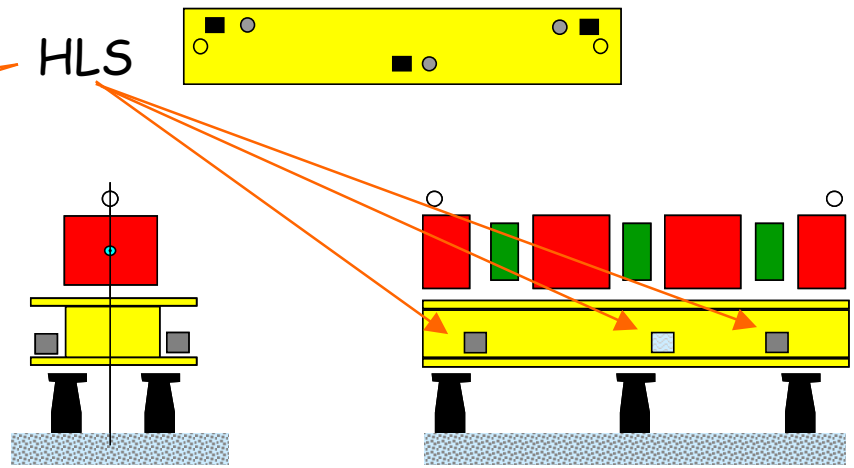
# Models of Horizontal and Vertical Movements of Adjacent Elements



# The ESRF Hydrostatic Leveling System (HLS) - Results and Pitfalls

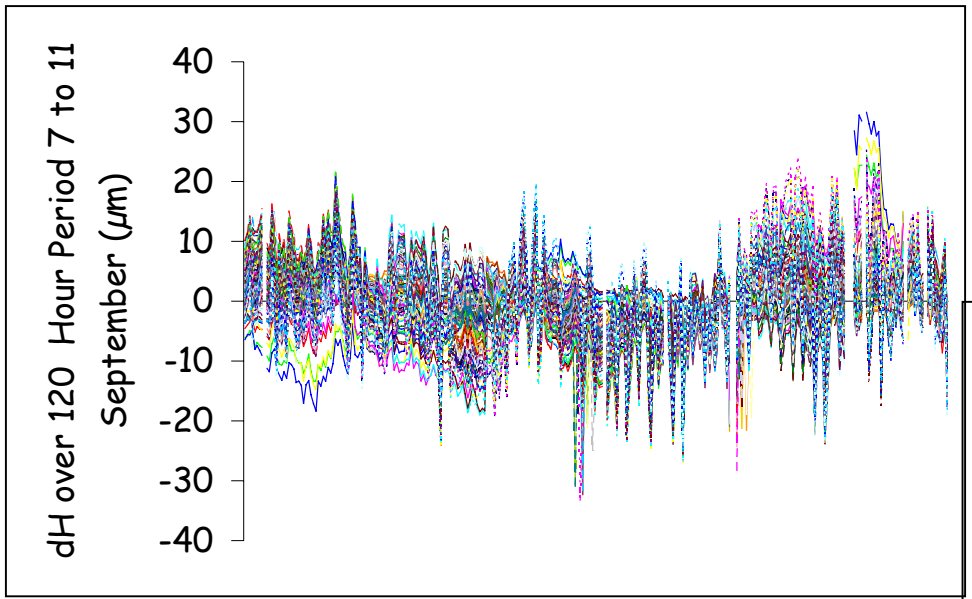
The ESRF has an HLS composed of 288 height (dH) and temperature sensors three each installed on the 96 quadrupole girders in the SR. The system has a precision of ~1 to 3 μm over short time spans (less than 24 to 48 hours). The precision degrades significantly with time. Nevertheless, the system is robust and relatively trouble free. The captors have been gathering data 24 hours per day over the last 9 years with only a handful of breakdowns.

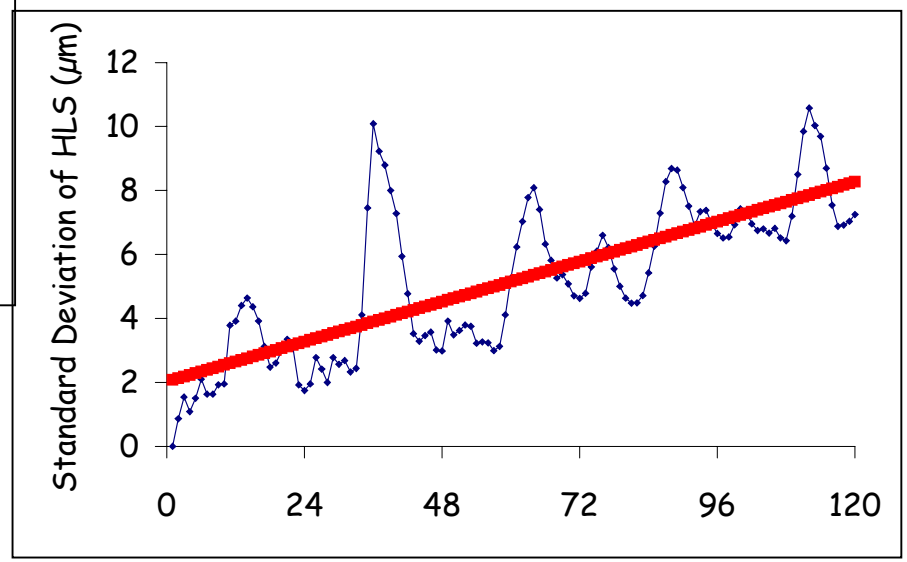




# The ESRF Hydrostatic Leveling System (HLS) - Results

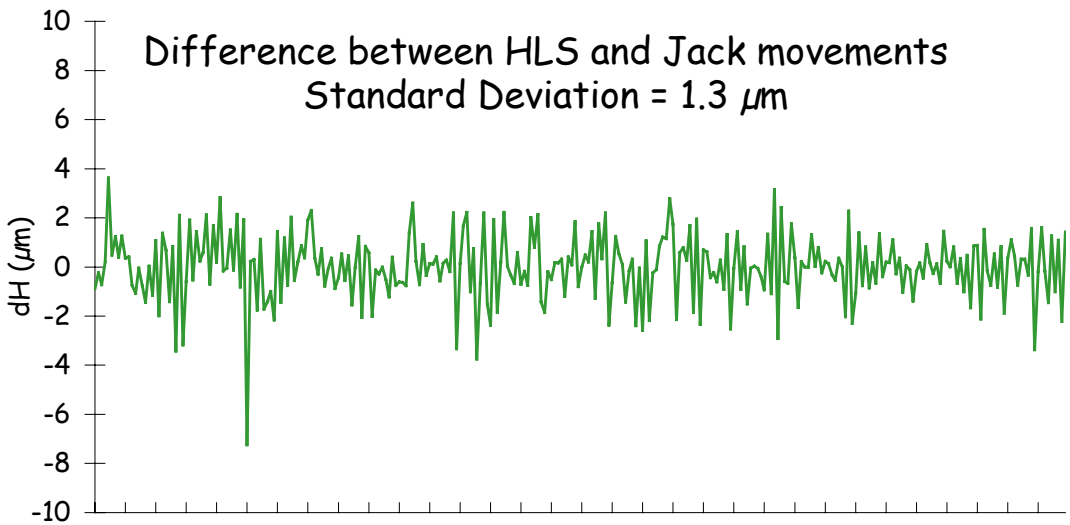
The system performance over a calm five day period in September 2000 shows a degradation in the standard deviation of 2.5 μm in 48 hours.

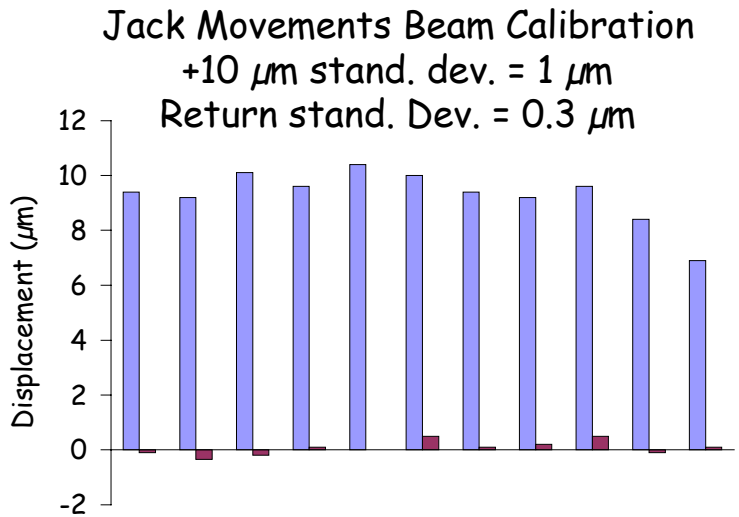


# The ESRF Hydrostatic Leveling System (HLS) - Results

The system has been used very successfully to control the 6 month vertical realignment operations of the SR with jacks as well as a number of experiments* using mechanical corrections to reduce the overall strength of the magnetic correctors, the vertical closed orbit and the coupling.

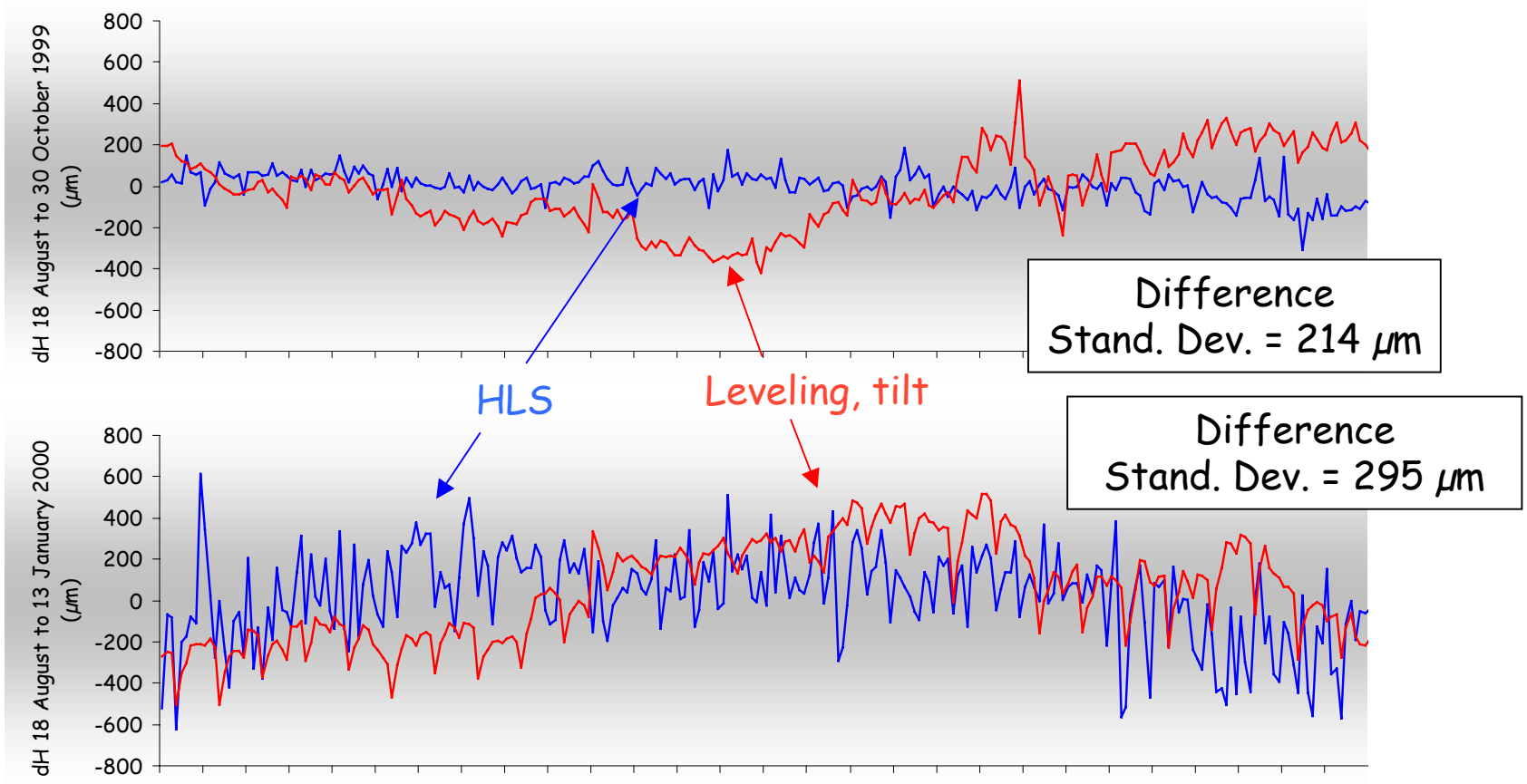



*These experiments are outlined in Farvacque L., Martin D., Nagaoka R., Mechanical Alignment Based on Beam Diagnostics, Invited Paper, International Workshop on Accelerator Alignment 1999, Grenoble France.

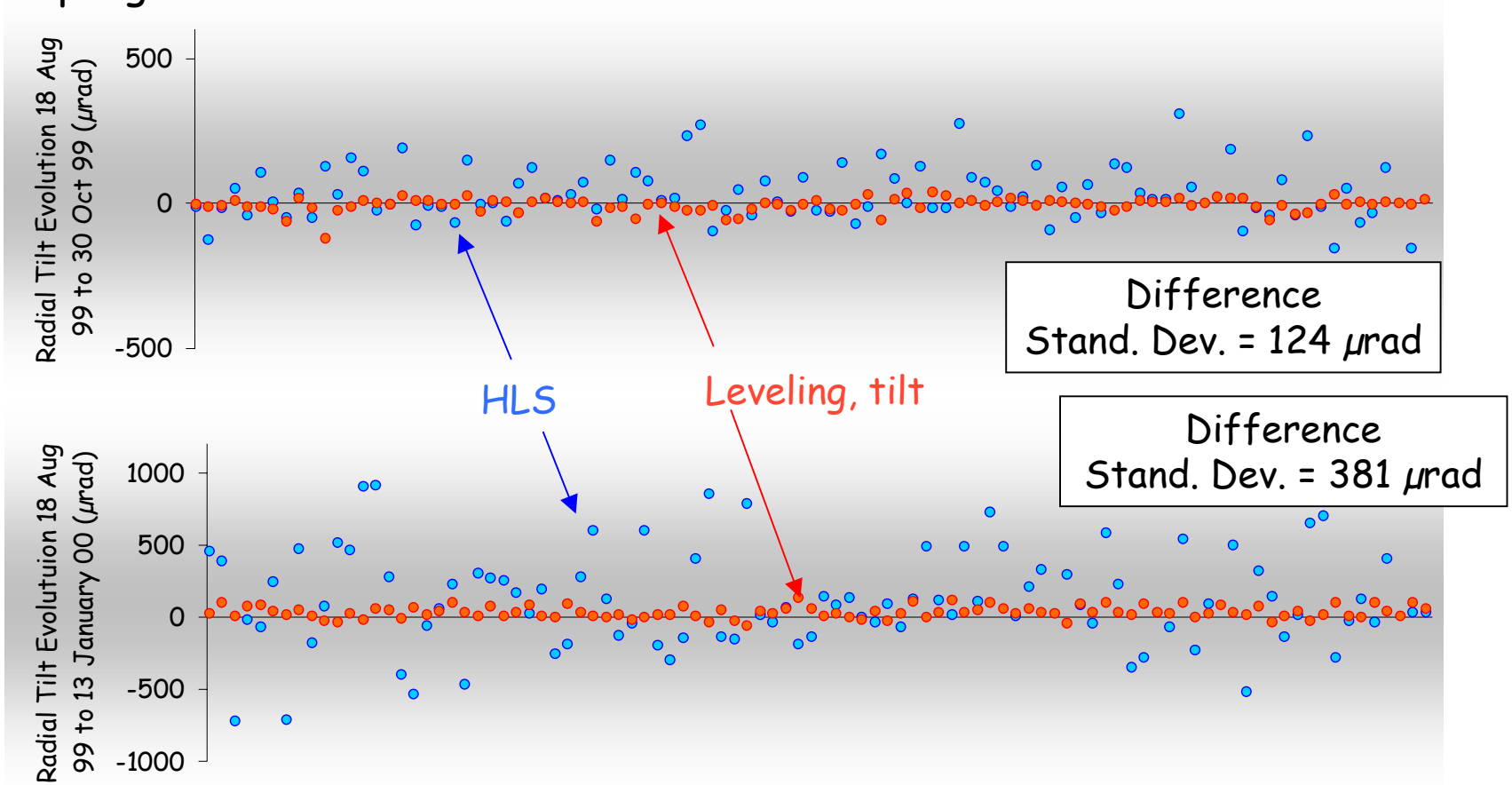
# The ESRF Hydrostatic Leveling System (HLS) - Pitfalls

However, as successful as the previous results have proved, there is a problem with the system and long term results are unsatisfactory!



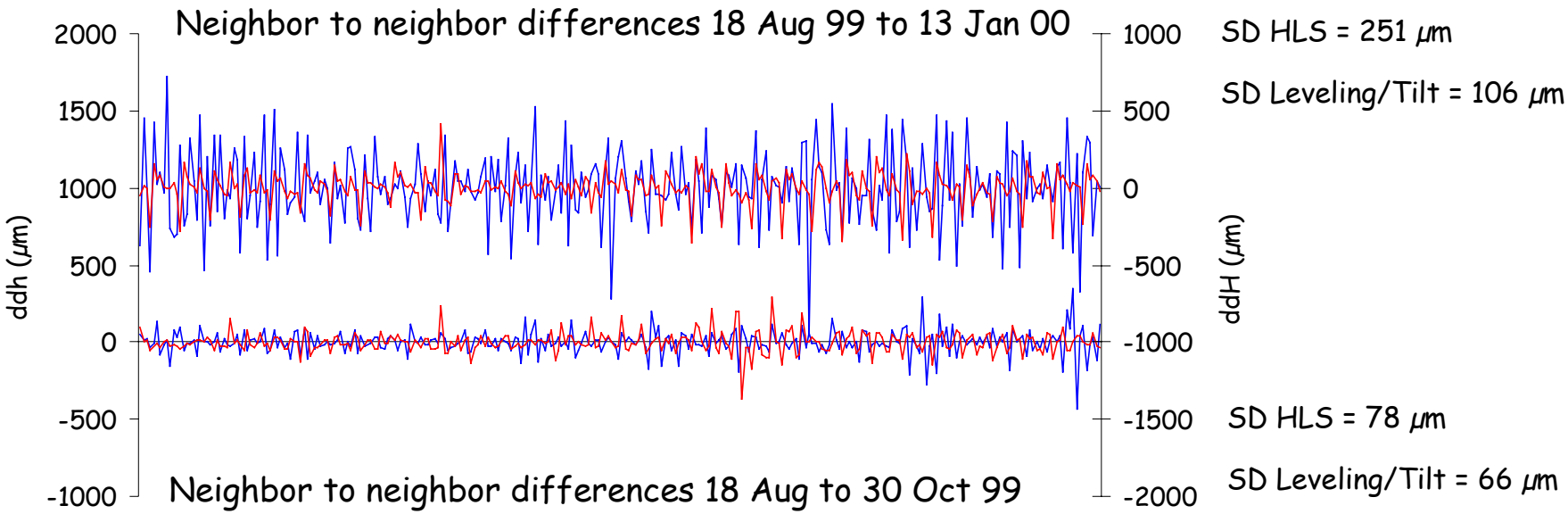
# The ESRF Hydrostatic Leveling System (HLS) - Pitfalls

This is particularly true with the radial tilt. (i.e. in the direction perpendicular to the travel of the beam) This is critical importance in the coupling of the beam at the ESRF.



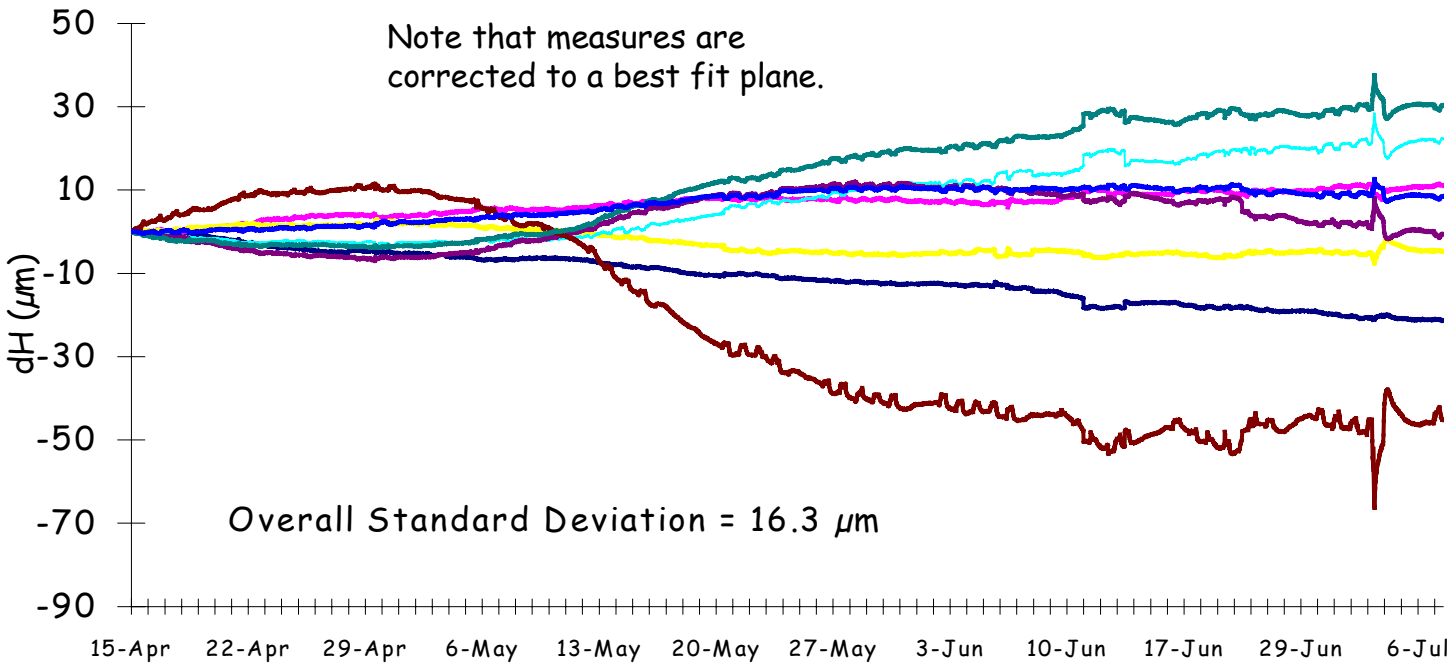
# The ESRF Hydrostatic Leveling System (HLS) - Pitfalls

How is it then that HLS values were coherent in the establishment of models outlined in the previous section and yet are completely erroneous? Recall that the standard deviation of the full data set of neighbor differences with respect to an origin were being used. Using this same logic, we find that the differences between the HLS and the leveling & tilt are less obvious. Even though the overall results are completely wrong, they are in the right ballpark. It is for this reason the HLS data is so pernicious and difficult to use in long term monitoring!



# The ESRF Hydrostatic Leveling System (HLS) - Pitfalls

Long term monitoring in the ESRF ALGE laboratory on a marble shows a 'drift' standard deviation associated with this system of 16.3 μm over 82 days or normalized to 0.20 μm per day! Tunnel differences taking into account the uncertainty in the leveling and tilt imply a 'drift' of 1.57 μm per day. There is nearly a factor of 8 between the drift of the system in the laboratory and in the tunnel!



# The ESRF Hydrostatic Leveling System Discussion

We have seen that the ESRF HLS can be considered to give 'valid' results in the 1 second to ~48 hour range. In the scale of 6 months – a reasonable time to expect validity – we have large errors. However, the results even though they are erroneous, are entirely plausible! Finally, one can imply the system is performing differently in the tunnel than from in the laboratory.

Taking all of this into consideration, if we require a certainty of 100 $\mu$m (at 95% confidence) over six months in the neighbor differences between HLS (this is the uncertainty in the level & tilt survey determination of this difference), and we factor into this the apparent performance difference 'drift' factor (8), captor stability cannot exceed 0.025 $\mu$m per day in laboratory tests (i.e. 100 $\mu$m/185 days/8 'drift'/2$\sigma$)! It is worth noting that ESRF has another system (the so called 2$^{nd}$ generation system) with a drift of 0.02 $\mu$m per day. It will be installed in the tunnel next year ( 2 captors per girder) permitting comparative studies.

# Deformation Movements Observed at the ESRF Conclusions

- Several movement signatures on the ESRF site have been identified. These movements are such that one can only conclude there are underlying factors influencing them. In other words they are deterministic and not random.
- We have shown that vertical ground movements are approximately 20% less than vertical magnet movements (at the ESRF). Also that horizontal movement magnitudes are half of those in the the vertical direction.
- We have successfully constructed models in both vertical and horizontal (with certain reservations) directions for neighbor to neighbor movements with respect to an origin in time using a combination of different observations. It is argued that these models (or at least similar types of models) may be applied in a more general sense outside of the context of the ESRF. Furthermore they are representative of what the accelerator beam 'sees'.
- We have discussed the ESRF HLS and shown it to give reliable results in the 2 to 3 μm range over a 48 hour period. However, it gives erroneous results over long time periods. The disturbing fact is that the results are entirely believable. The system appears to behave differently in the SR tunnel than in the laboratory. We have concluded that for a system to monitor 100 μm movements successfully over a six month period it must not 'drift' by more that 0.025 μm per day! Finally, the ESRF HLS is robust and reliable instrument. This underlines the absolute necessity of prudence when using this type of instrument!

# References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