Doris Phase measurements

Analyses on Spot5 data

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Summary

Definition of the observables (pseudo-range – phase)

Construction of phase using Spot5 data in chained mode

Analysis of pseudo-range and phase measurements
- pseudo-range characteristics
- cycle slips
- phase ionospheric correction
- zero Doppler issues

Evaluation of performances using Phase or Doppler
- theoretical cases (white noise, random walk)
- oscillator measured ground characteristics

Orbit determination results using phase measurements

Background

Idea : the information given by phase measurement is more efficient than for derivative of phase (Doppler)

True if the only error is uncorrelated measurement noise
(but improvement is not drastic for current orbits configurations)

To be studied for other clock errors structures
(time correlations in the measurement errors)

Application : Spot5 in orbit measurements

Spot 5 measurements

Construction of code and phase observables :

Phase : cumulated Doppler counts (chained 10 s) for each frequency

initial value set close to 0
correction of all instrument biases
passes definition (no interruption in the Doppler counts)
construction of the iono-free observable
(synchronisation differences negligible for Spot5)
(modelisation will use corresponding iono-free centre of phase)

$$\frac{\lambda_{2GHz}\varphi_{2GHz} - \gamma\lambda_{400MHz}\varphi_{400MHz}}{1-\gamma}$$

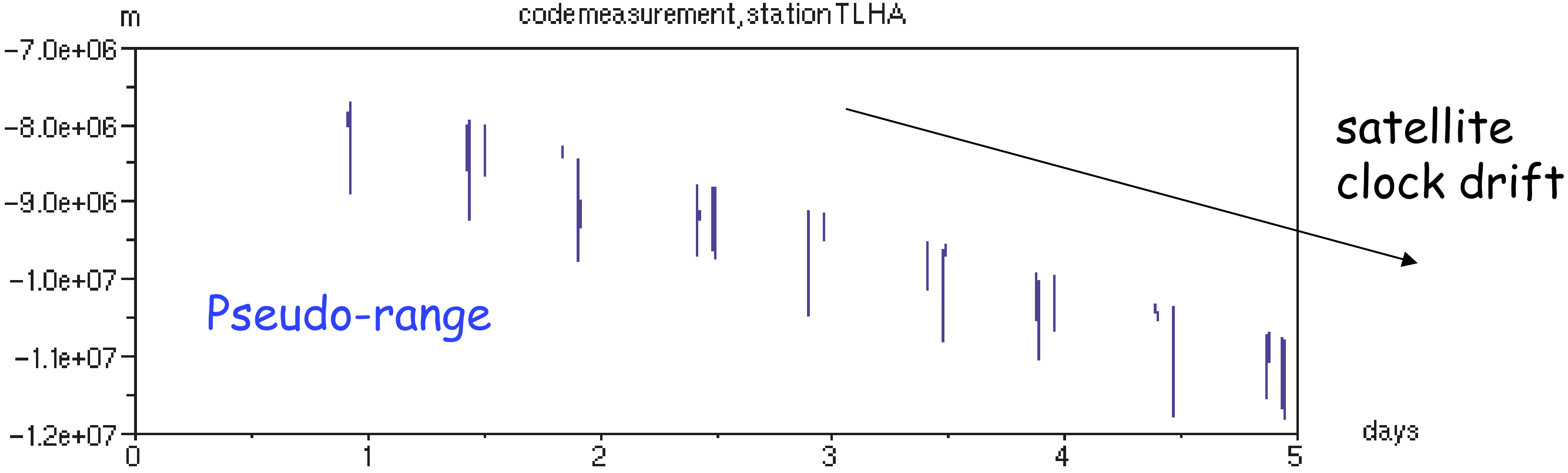
Pseudo-range : construction using it3

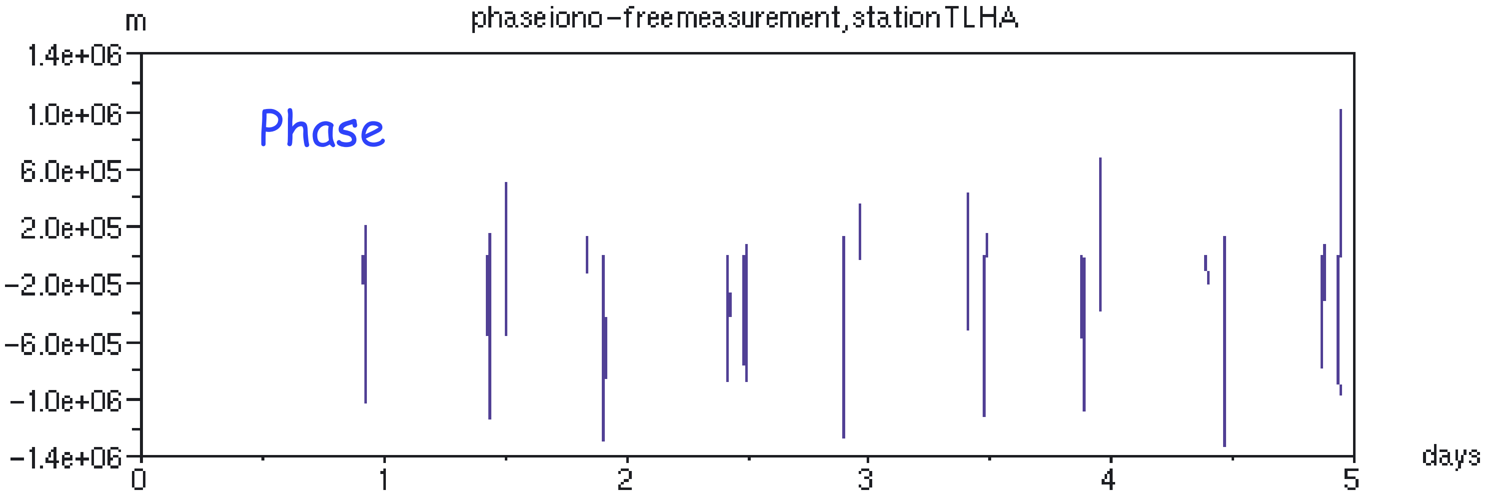
→ correction of all instrument and system biases

Pb : the on board time is given in cycle counts
not close to the true time of the event

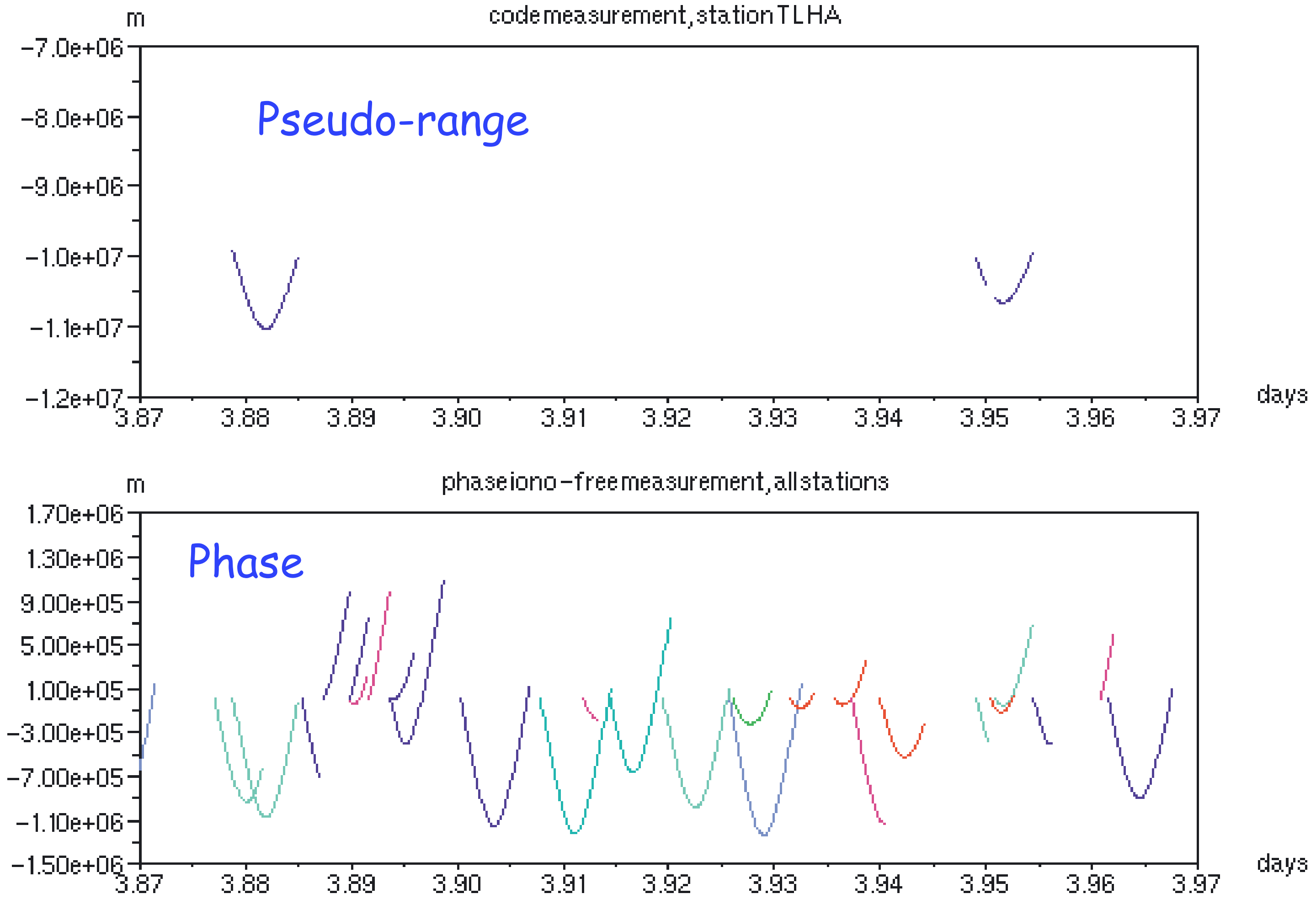
For this study : a bias is added to the on board time data set
to have usable pseudo-ranges

Measurements (1)

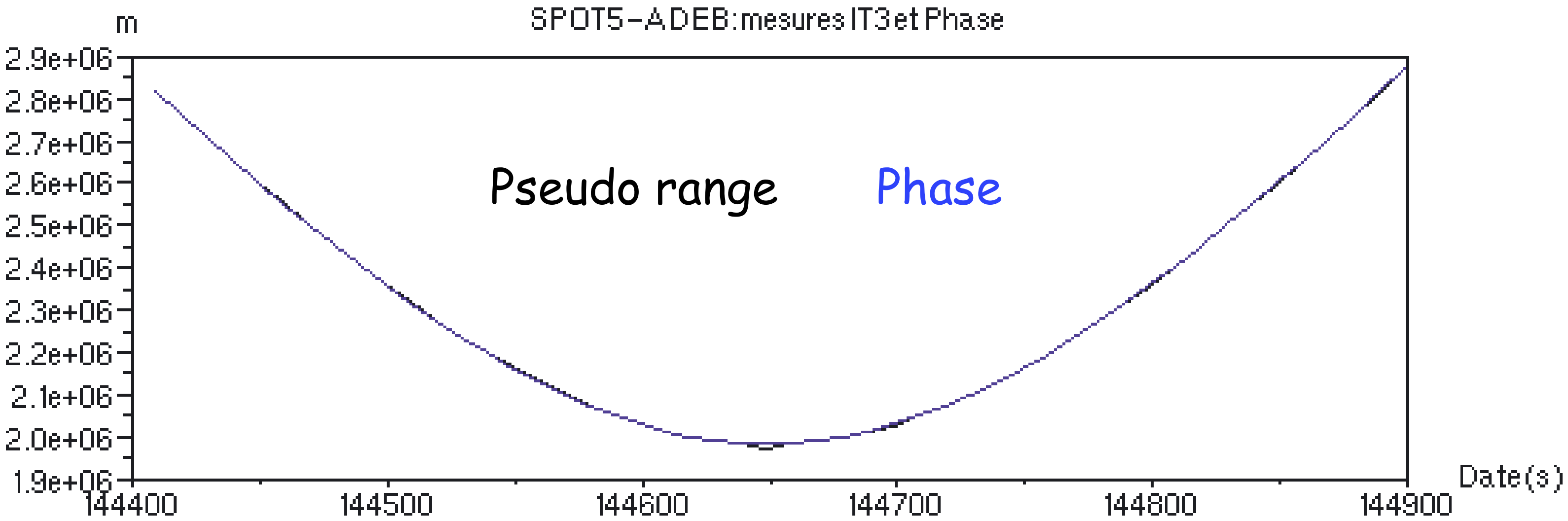


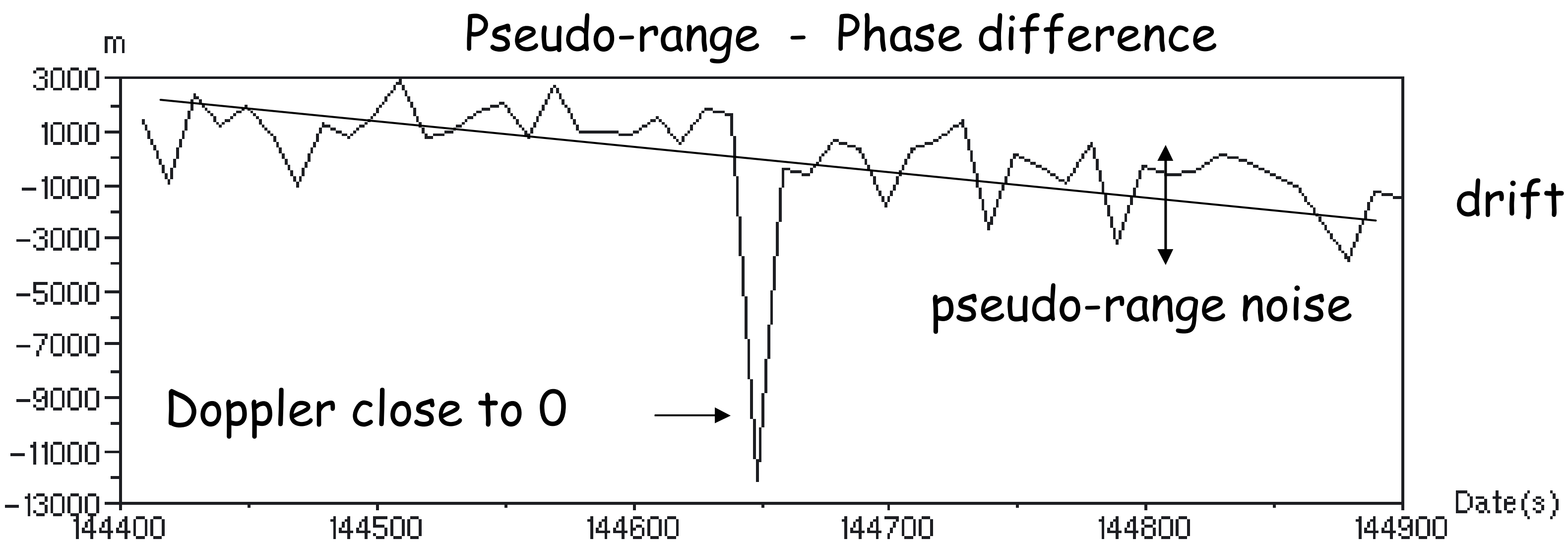


Measurements (2)



Measurements (3)





General characteristics

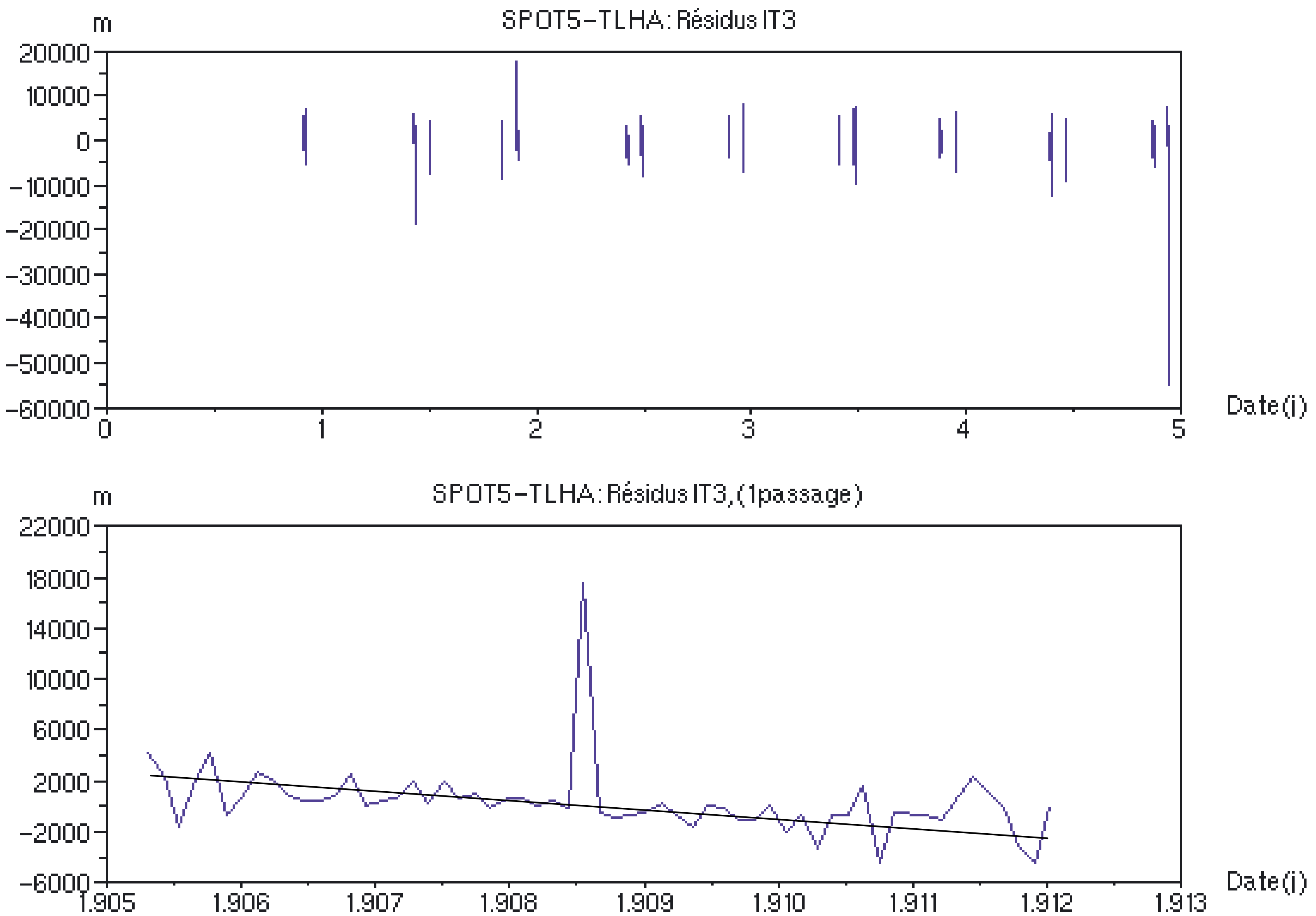
Phase measurement :

- cycle slips : only one 2 GHz case observed
- some interruptions in the Doppler measurements
  lead to new initialisation of the phase (new pass)
- no specific losses of data around zero Doppler
  (no loss of lock, sometimes one wrong measurement)

Pseudo-range measurement

- some erroneous measurements around zero Doppler
- noise ~ 1 km
- drift (~ 2 km per pass), present on all stations
  observed by comparison with phase measurements
  under investigation

Pseudo range residuals after on board clock identification



Pseudo-range drift

The pseudo-range drift is also present in the TLHA code residuals

It is present on all passes (comparison with phase)

It was also observed on others satellites

No impact on the current datation precision

- symmetry of the passes
- orbit constrained
  100 m error gives 0.3 µs (2.4 mm along track)

A simultaneous Pseudo-range/Phase solution is not possible due to this inconsistency, without a special process to eliminate direct coupling between datation and orbit parameters

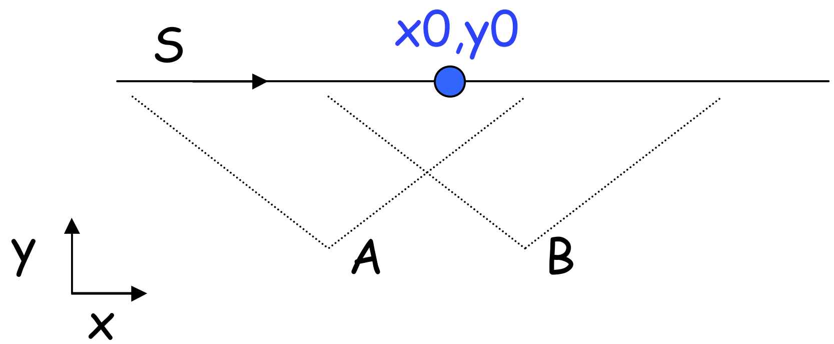
Comparison of phase and Doppler solutions

Formulation : simple problem

two stations

plane trajectory

4 parameters (x,y,vx,vy)



Two passes :

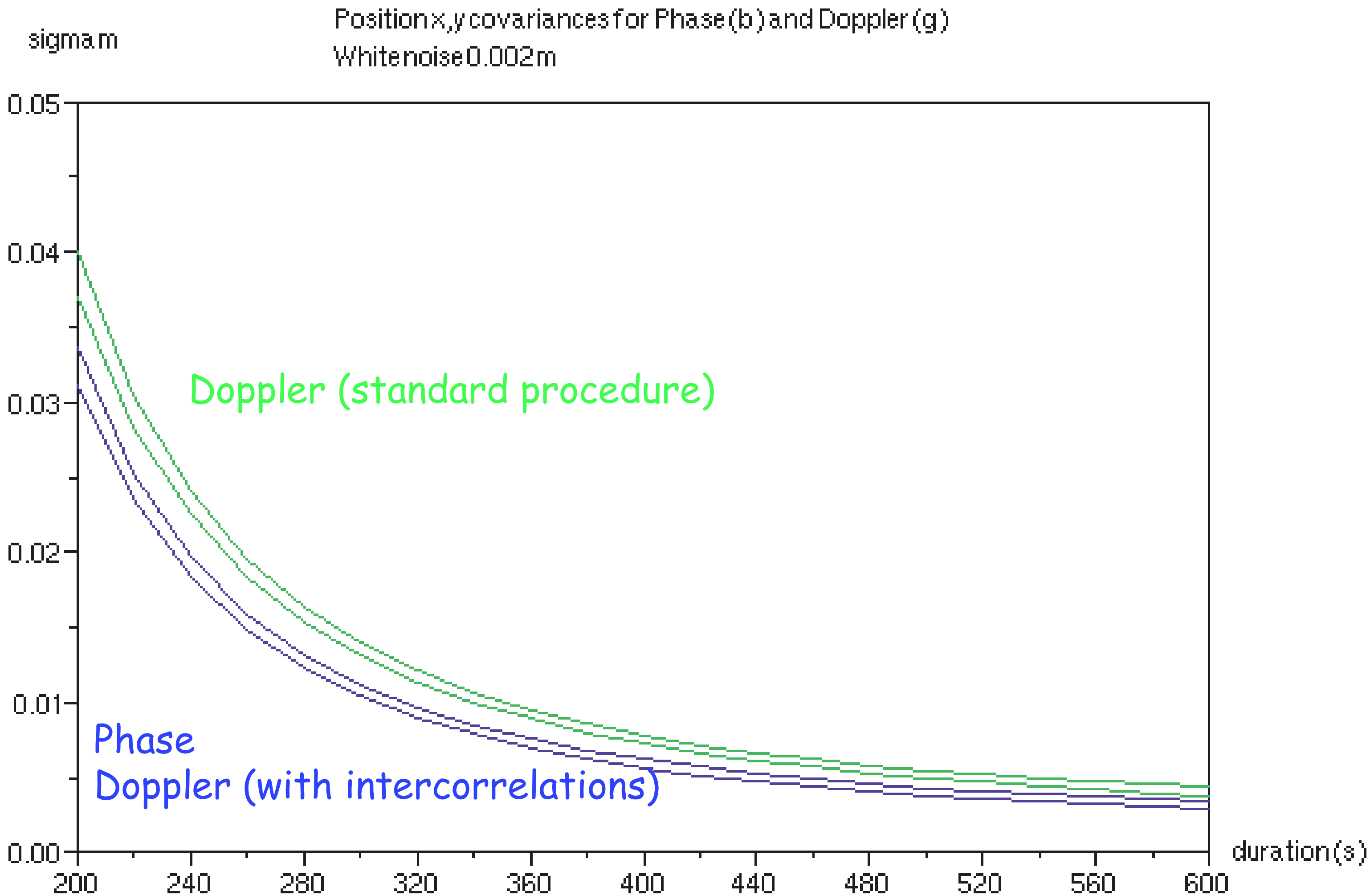
ambiguity
emitter frequency bias
parabolic term (tropo…)

Phase : second degree polynomial per pass

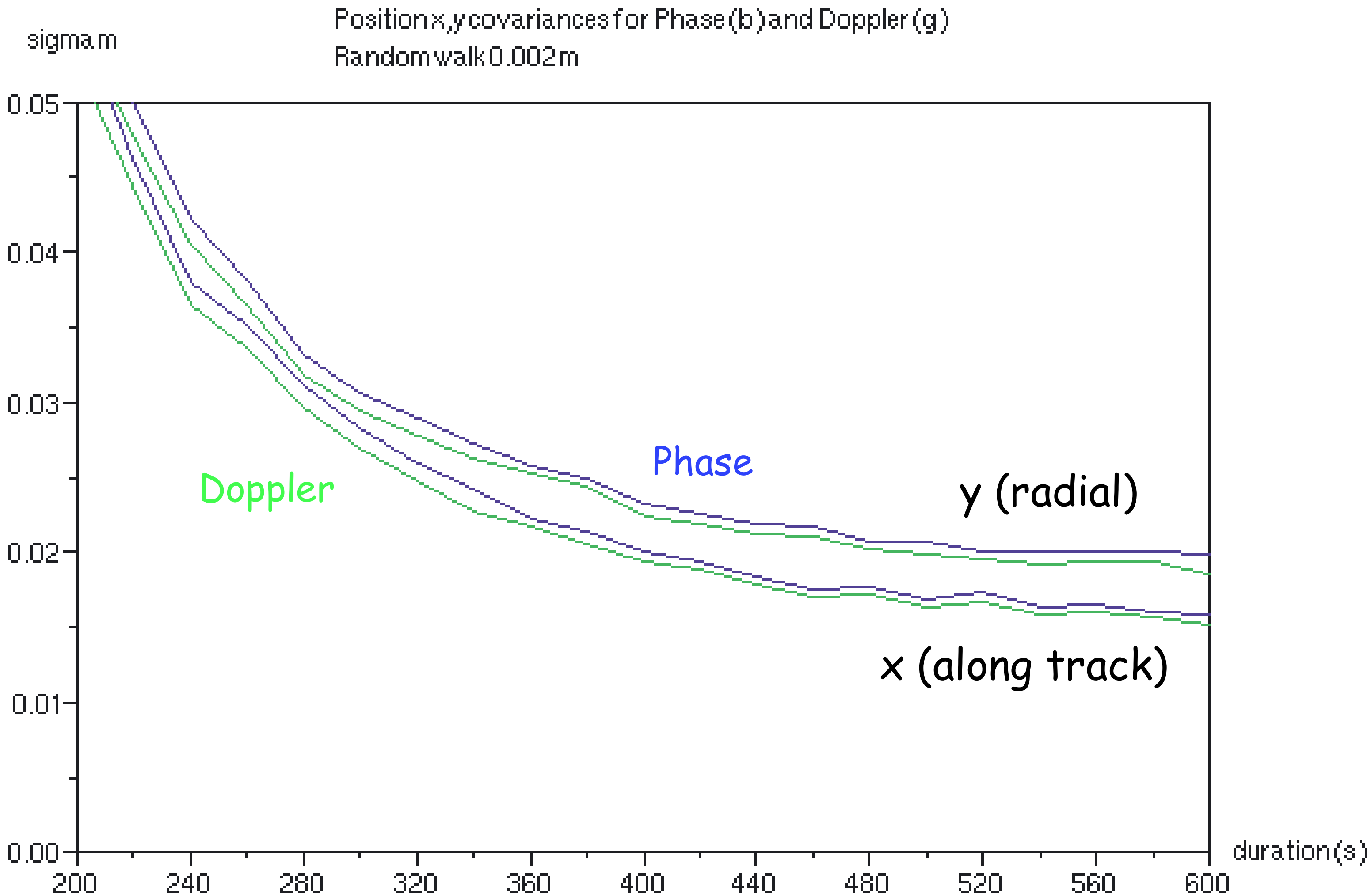
Covariance of the estimated position x0,y0, with phase or Doppler formulations

- analytical (white noise measurement errors)
- simulations (random walk, measured oscillator)

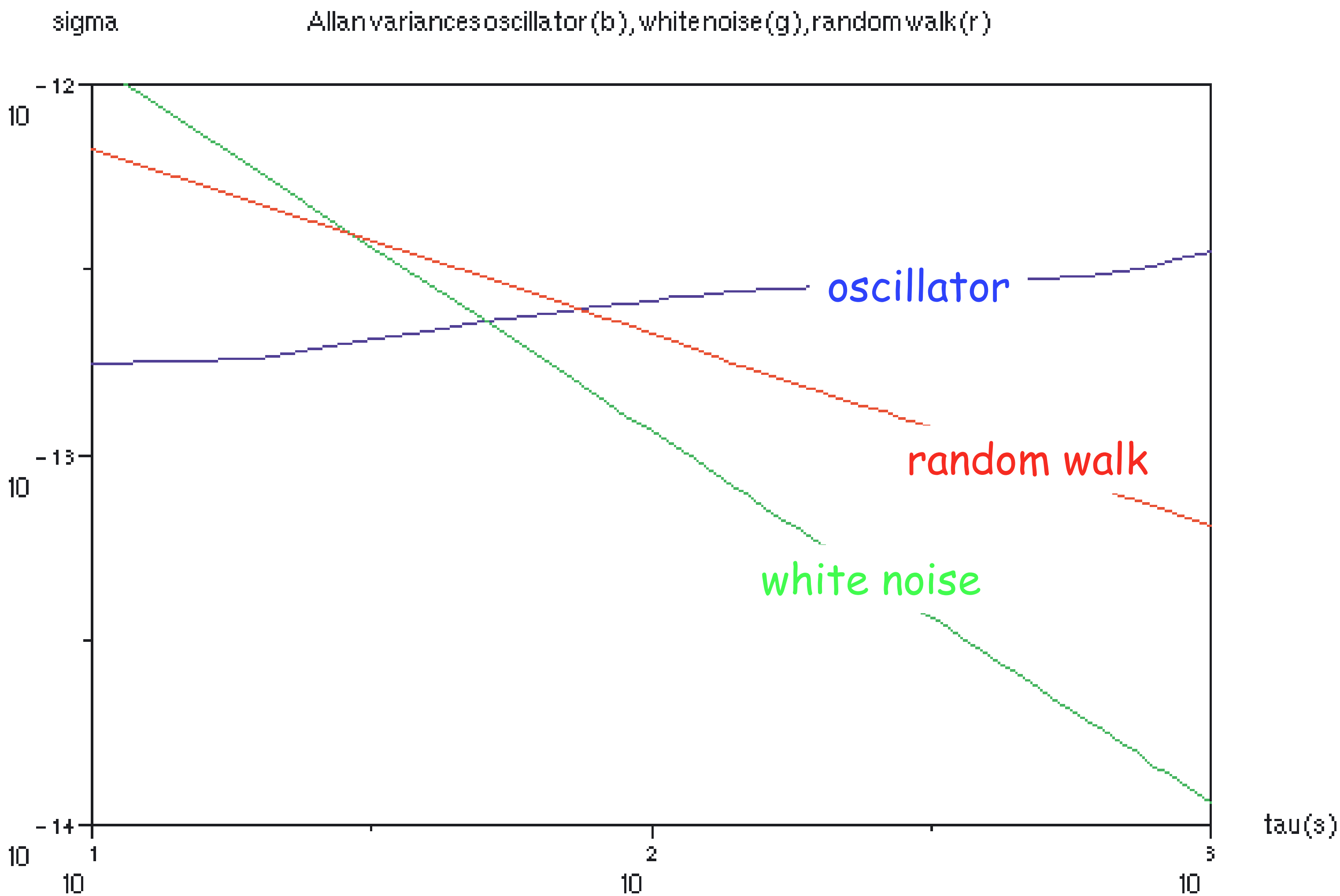
Covariances of position (white noise)



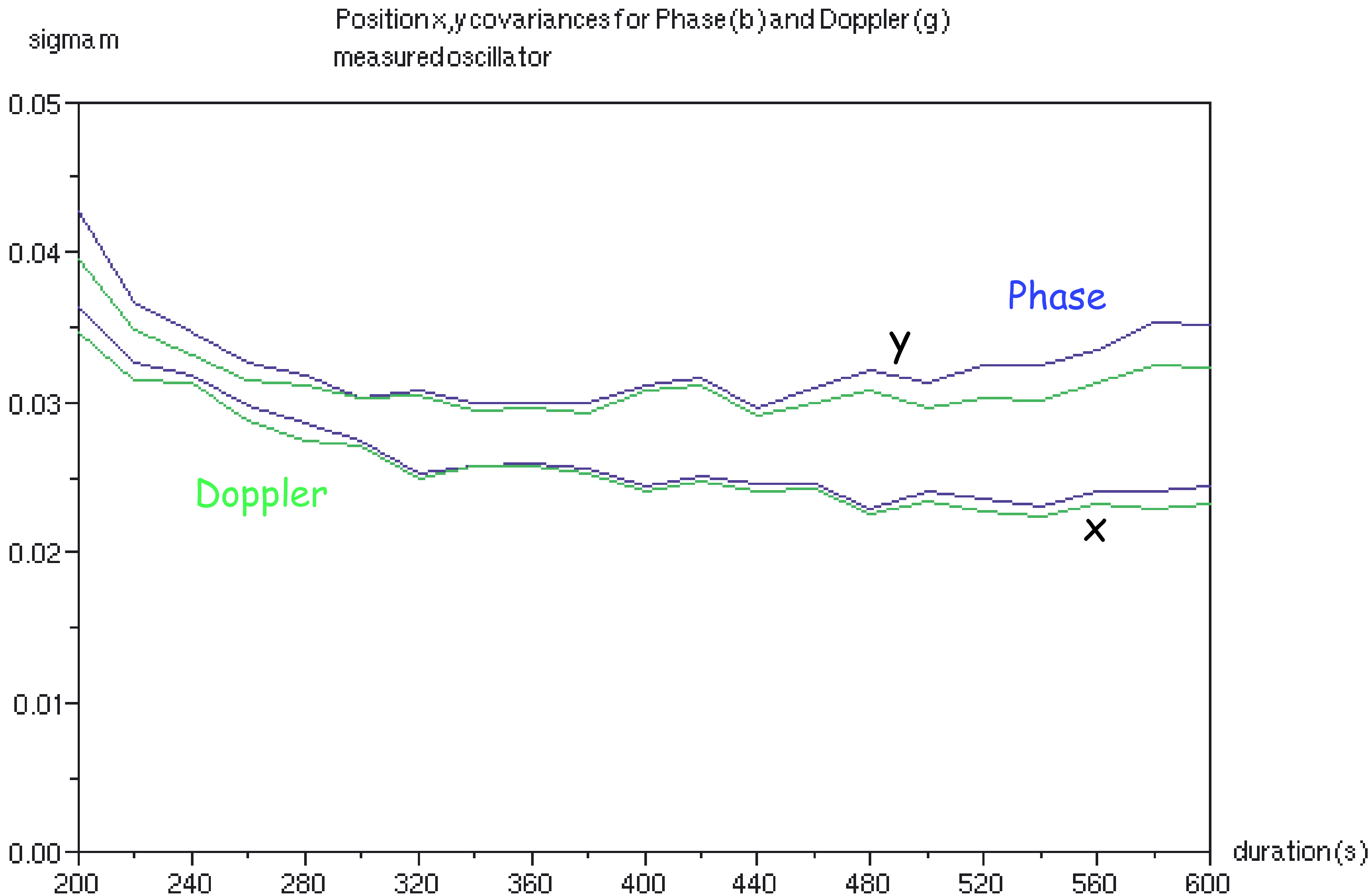
Covariances of position (random walk)



Allan variances



Covariances of position (oscillator only)



Formulations properties

The phase solution is the best in case of measurement noise only
the improvement is about 20 %
(not realistic, due to oscillator behaviour)

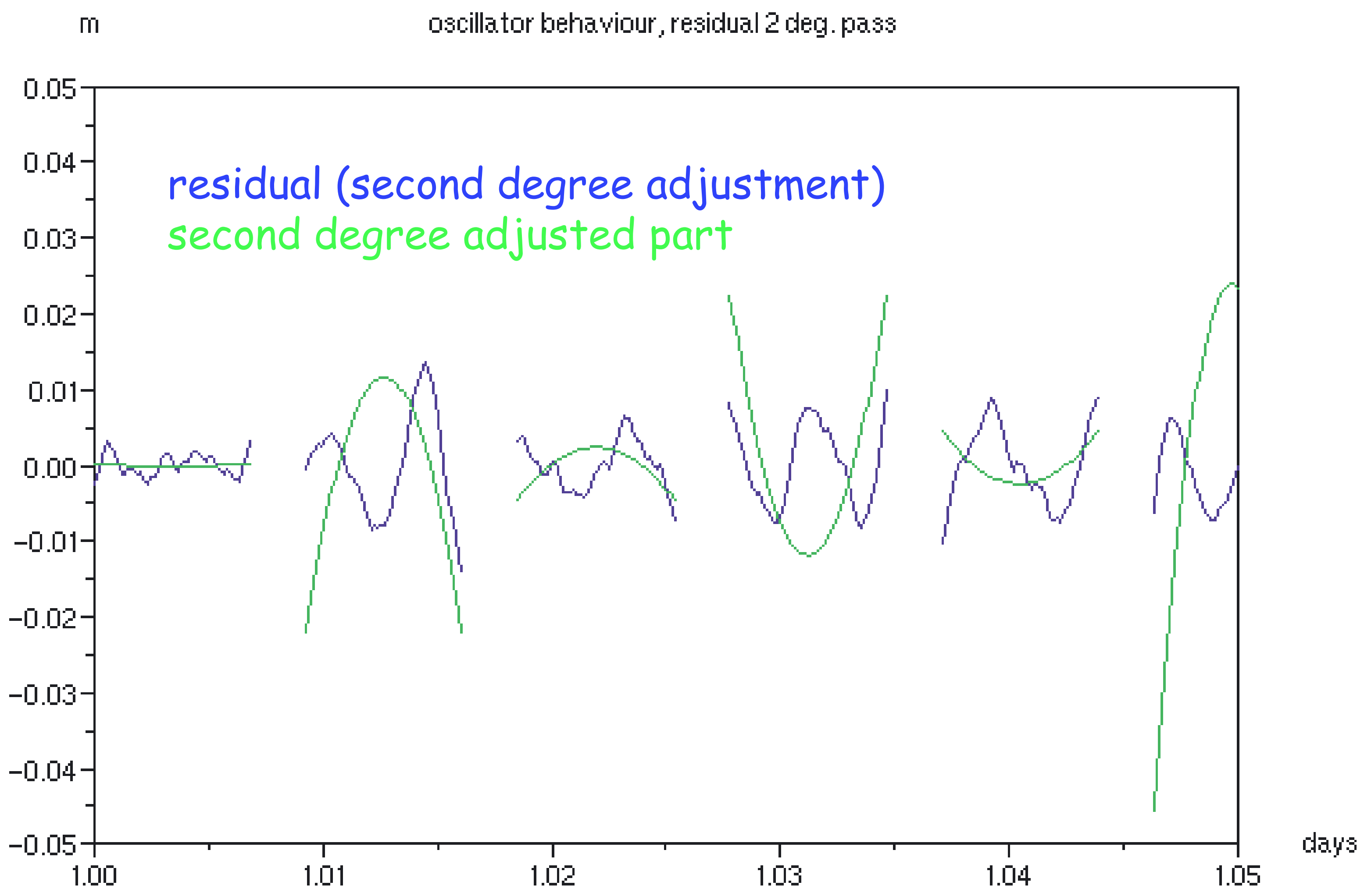
The oscillator noise is the current limitation of performance

The measurement noise is not the current limitation (hyp : 2 mm rms)

With realistic hypotheses the phase solution is close to the Doppler
(hyp : measured oscillator and 2 mm noise)

rem : oscillator effect to be multiplied by sqrt(2) (on board and ground)

clock error residuals (1)



clock error residuals (2)

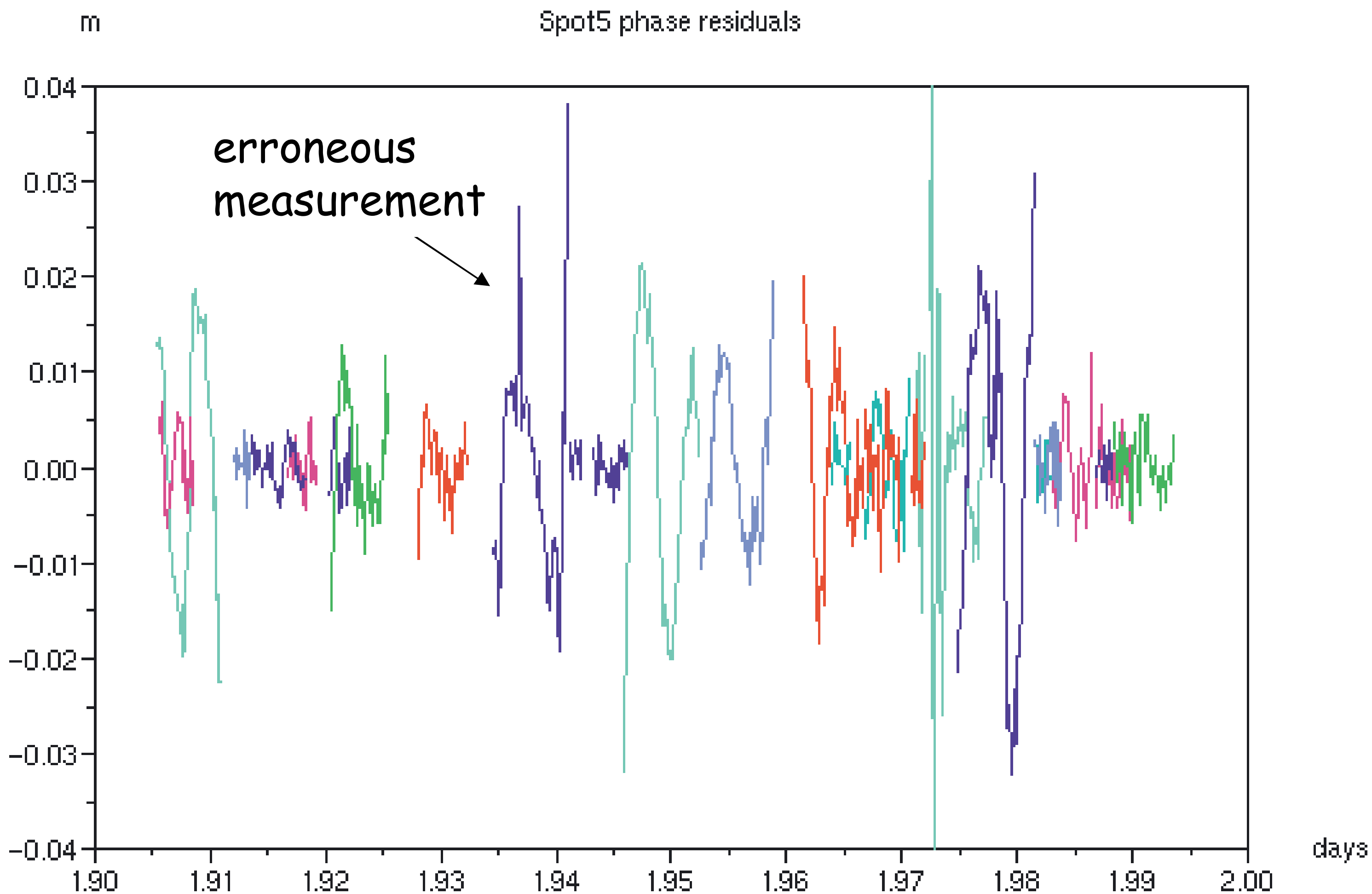
Residuals after elimination of polynomials

- polynomial adjustment (on board clock long term evolution)
- pass polynomial adjustment (2d degree, short term evolutions)

Signatures of higher order (>=3), with amplitudes of ~ 2 cm

Second degree contribution ~ 6 cm complete amplitude
(consequence : uncertainties in troposphere results)

Spot 5 residuals, oscillator behaviour

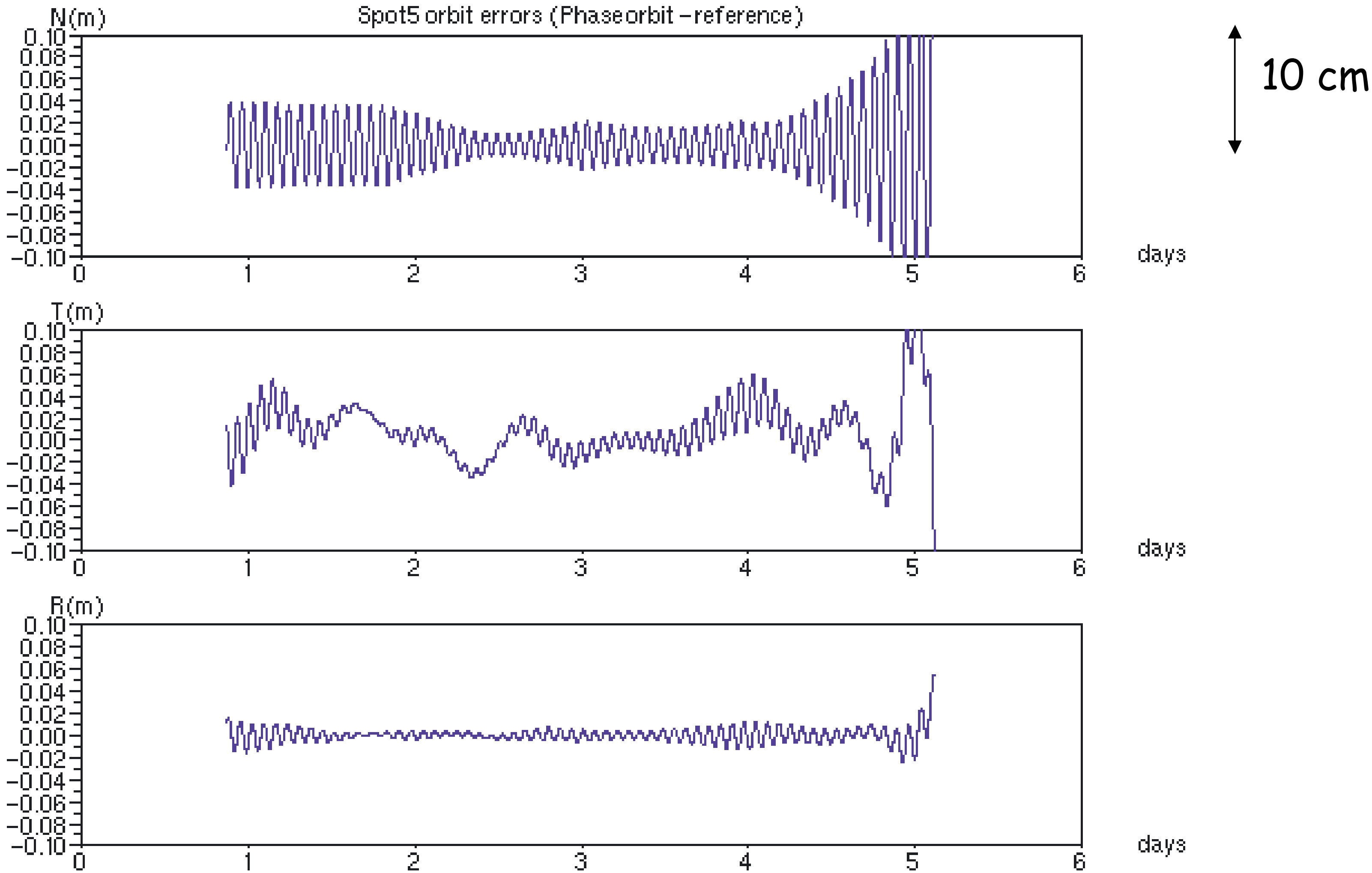


Comparison with Doppler orbit

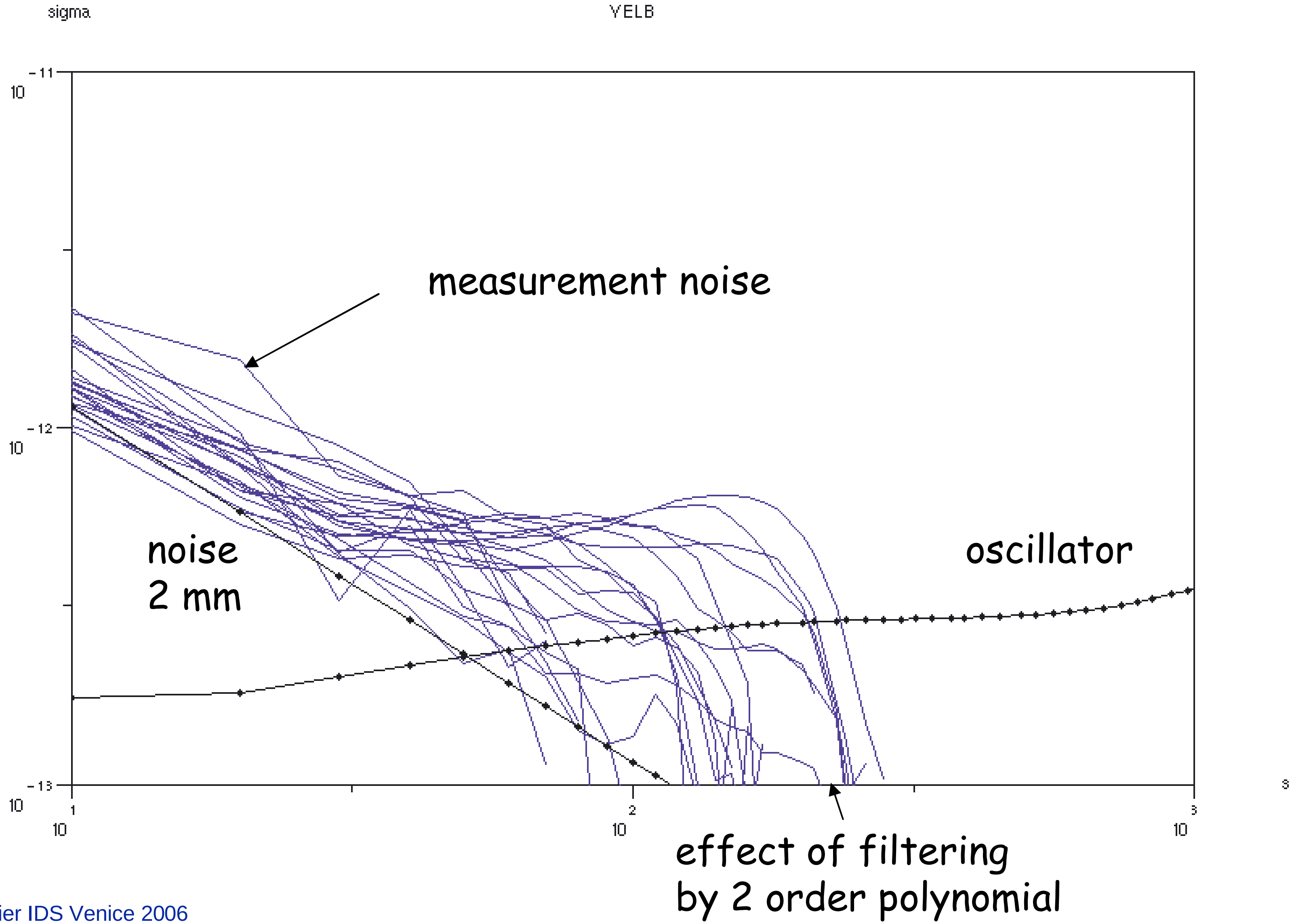
Normal

Tangential

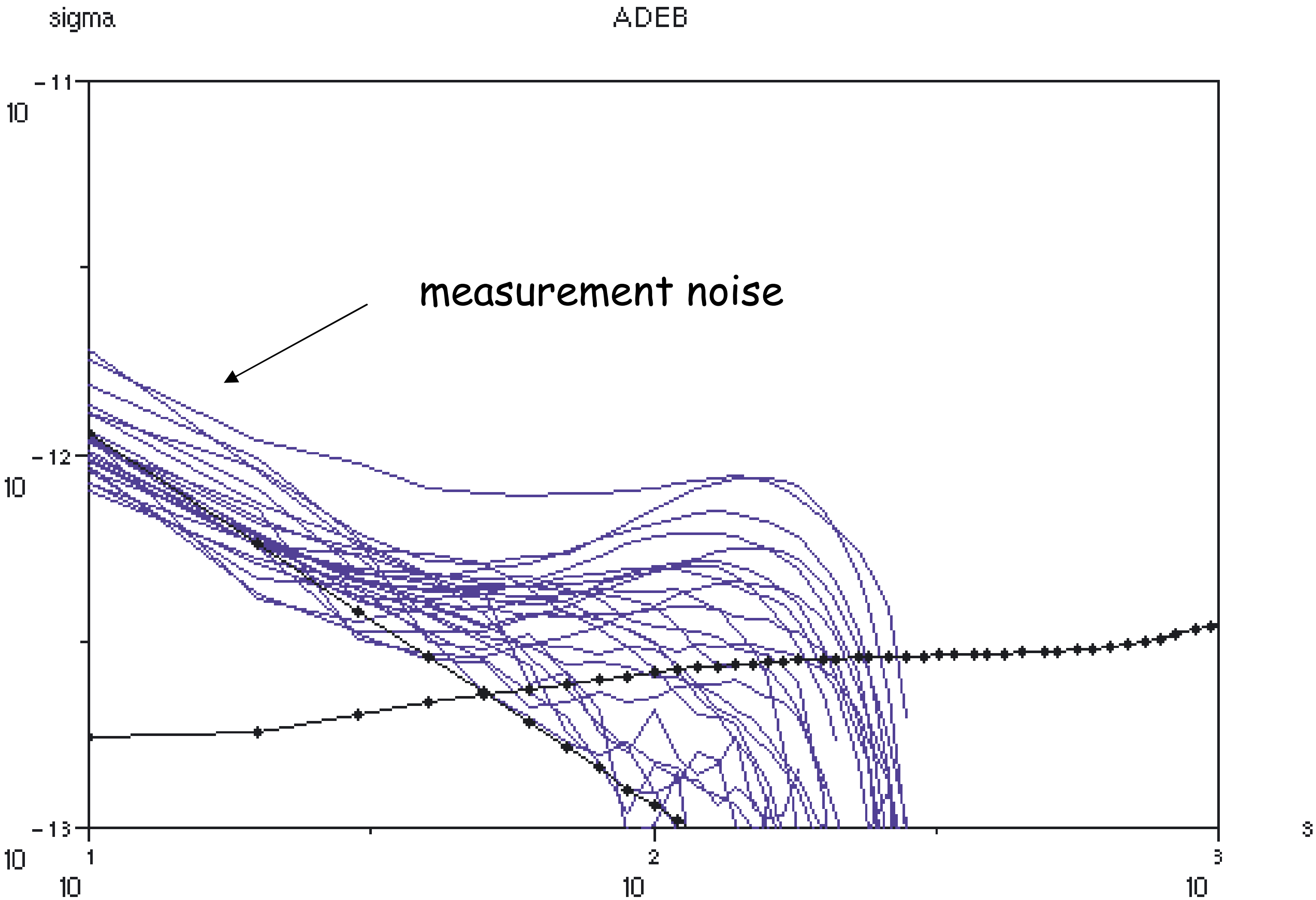
Radial



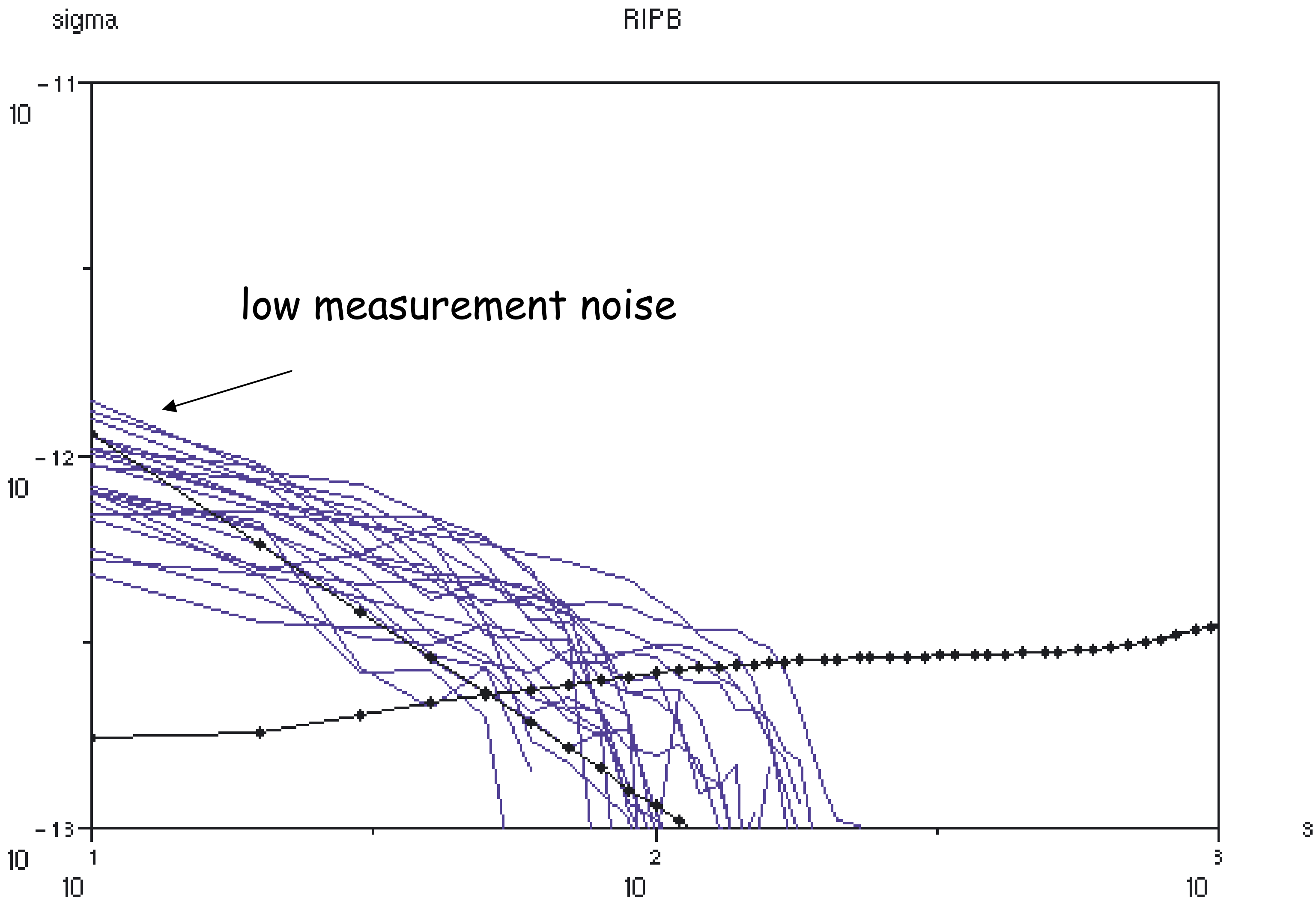
Allan variance of residuals (YELB)



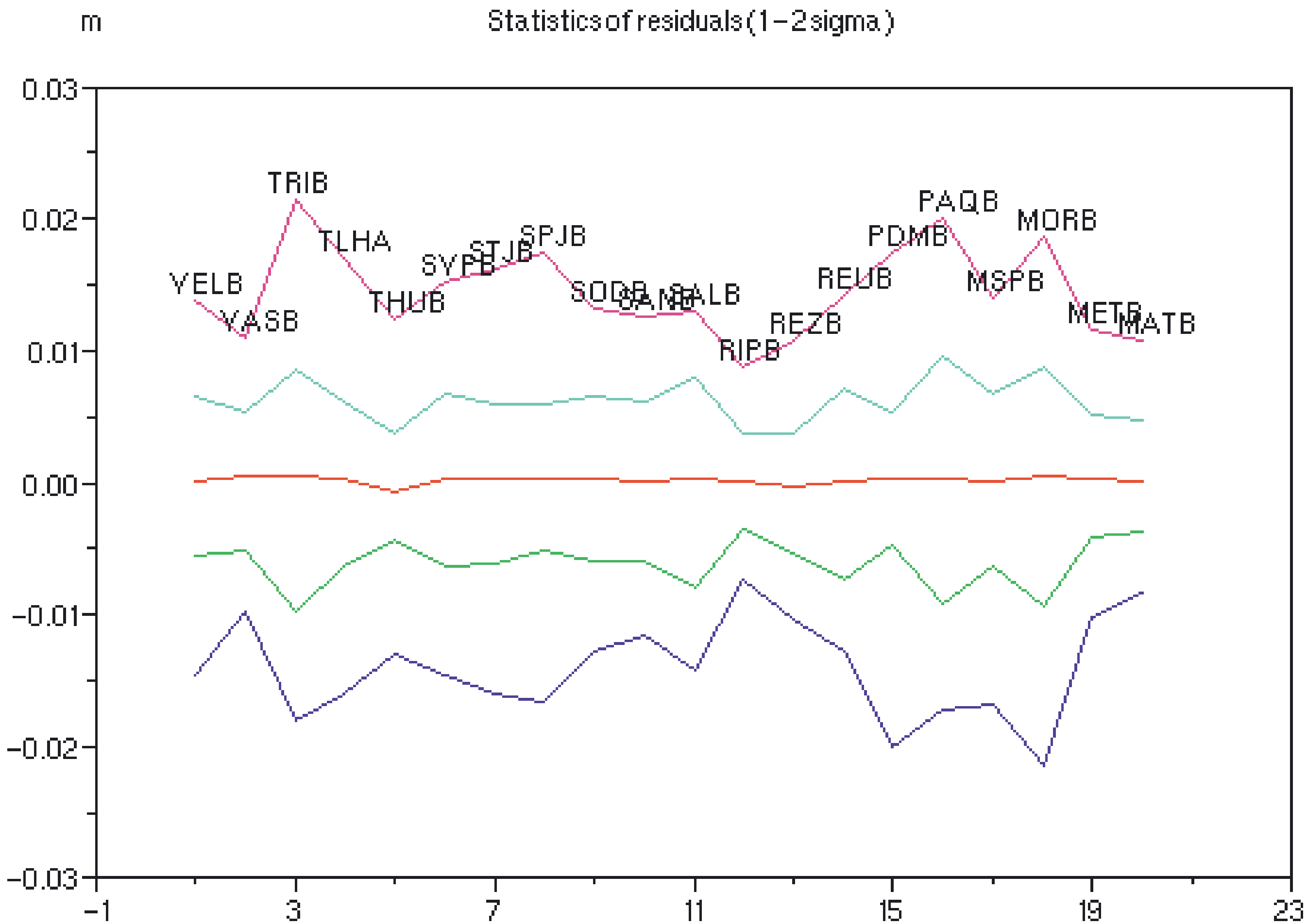
Allan variance of residuals (ADEB)



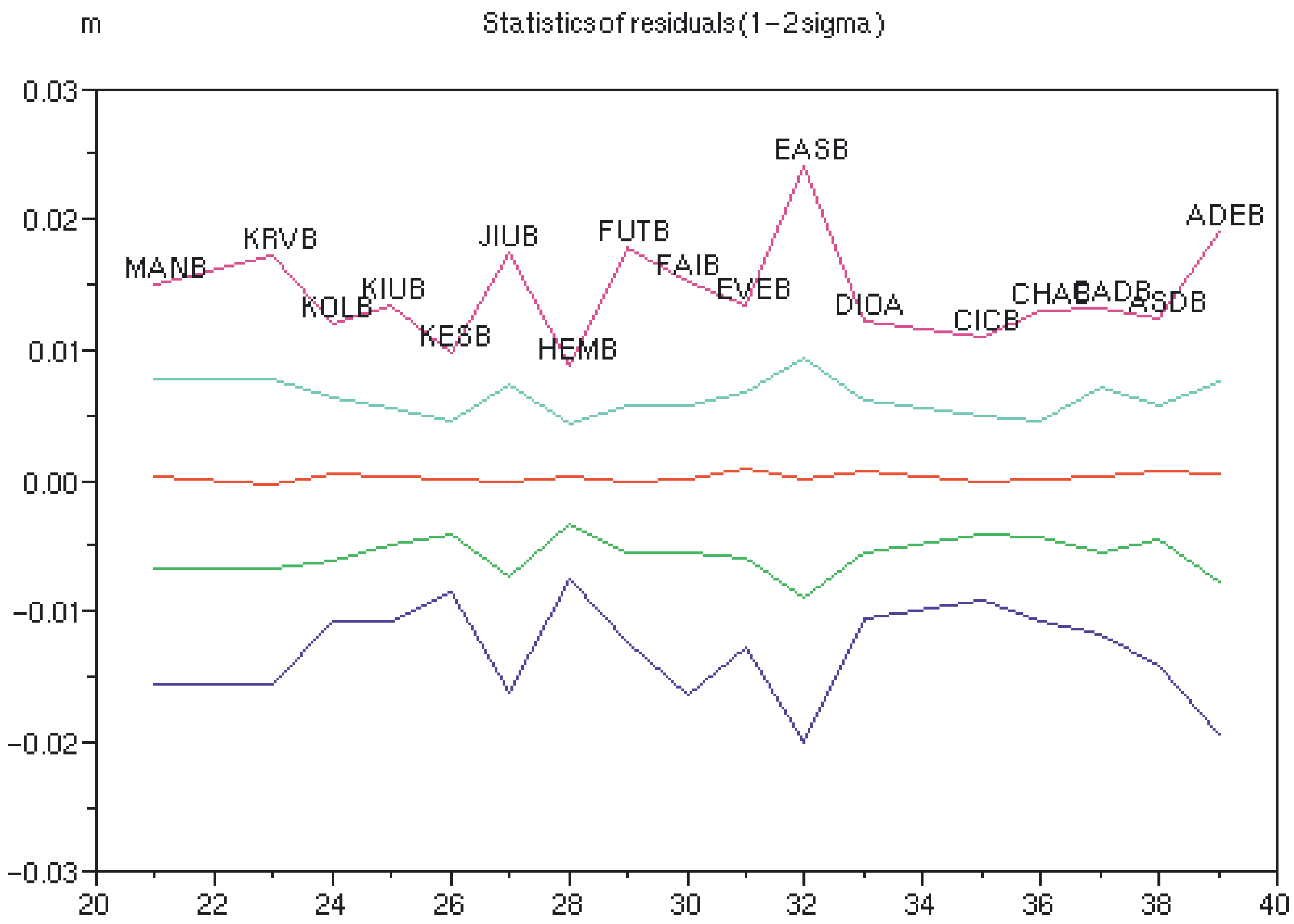
Allan variance of residuals (RIPB)



Stations residuals statistics (1)



Stations residuals statistics (2)



Stations residuals statistics (3)

Station rms residuals reflect oscillators behaviour
depending on the station

Measurement noise depends also on the station
values estimated from 1 mm to 4 mm (iono-free combination)

Conclusion

First complete phase/datation resolution has been performed on Spot5
5 days arc, to be improved now

Signatures (systematic drifts) in the datation, to be studied

Very good phase measurements (1 cycle slip for 19000 measures)

Orbit close to the Doppler solution (1 cm radial)

Further validations : use of satellite with external verifications (Envisat ?)

Residuals precise analysis

results coherent with ground measurements
structure depending on the station
- Allan variance shows the behaviour of the oscillators
- measurement noise has been evaluated (1 mm – 4 mm)

Definition

Event measured in receiver (or emitter) scale

Example : on board event ‘a’

reference time scale

receiver clock
time scale

receiver clock correction
at epoch of event ‘a’

$$t_a^{rec} = t_a + h_a$$

event

Pseudo-range definition

Pseudo-range :

Pseudo-range (it3 measurement) : two values t_{rec}^{rec} and t_{emi}^{emi}

or t_{rec}^{rec} and p

$$p = c\left(t_{rec}^{rec} - t_{emi}^{emi}\right)$$

satellite

$$t_{rec}^{rec} = t_{rec} + h_{rec}$$

station

$$t_{emi}^{emi} = t_{emi} + h_{emi}$$

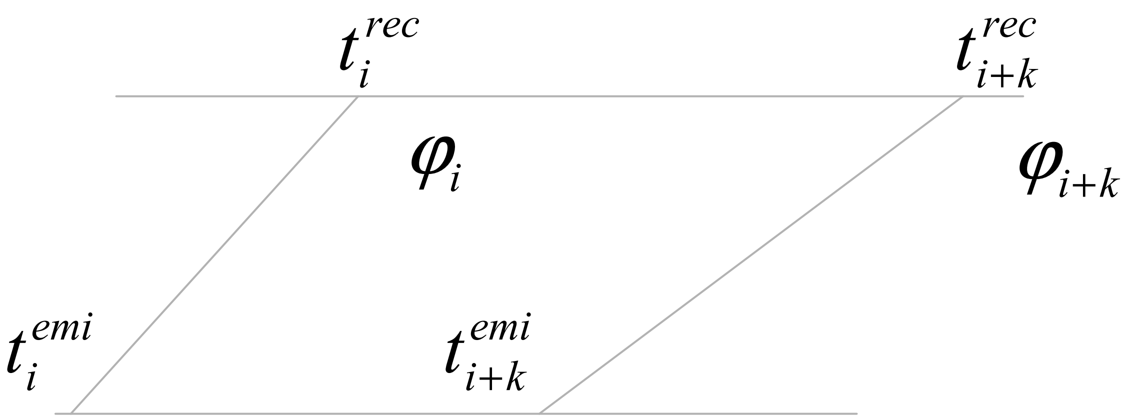
Polynomial representation of receiver clock h_{rec}

only for the long term variations
(typically 2d order for three days)

short term variations not represented

Phase definition

Cycle count between two epochs (on board time)



$$\varphi_{i+k} - \varphi_i = f\left(\left(t_{i+k}^{emi} - t_i^{emi}\right) - \left(t_{i+k}^{rec} - t_i^{rec}\right)\right)$$

$$= \frac{-p'_{i+k} + p'_i}{\lambda}$$

pseudo-range with tropo and iono
phase propagation effects

$$\varphi_i = \frac{p'_i}{\lambda} + \varphi_0$$

Change of sign convention to have
same evolution as pseudo-range measurements

Datation : polynomial identification

Input : raw orbit (few meters precision), for estimation of pseudo-range

$$p\left(t_{rec}^{rec}\right) = d\left(t_{emi}^{emi} - h_{emi}\right) + c\left(h_{rec} - h_{emi}\right)$$

h_{emi} known on master stations (e.g. bias)

h_{rec} polynomial expression defined in receiver time, long term evolution

$$\frac{1}{c}\left(p\left(t_{rec}^{rec}\right) + ch_{emi} - d\left(t_{emi}\right)\right) = h_{rec} \leftrightarrow P\left(t_{rec}^{rec}\right)$$

measured

known
(master station)

model

polynomial expression for h_{rec}

On board event defined in receiver time : $t_{evt} = t_{evt}^{rec} - P\left(t_{evt}^{rec}\right)$