Technische Universität Braunschweig

Institute of Aerospace Systems

Reducing variability in short term orbital lifetime prediction

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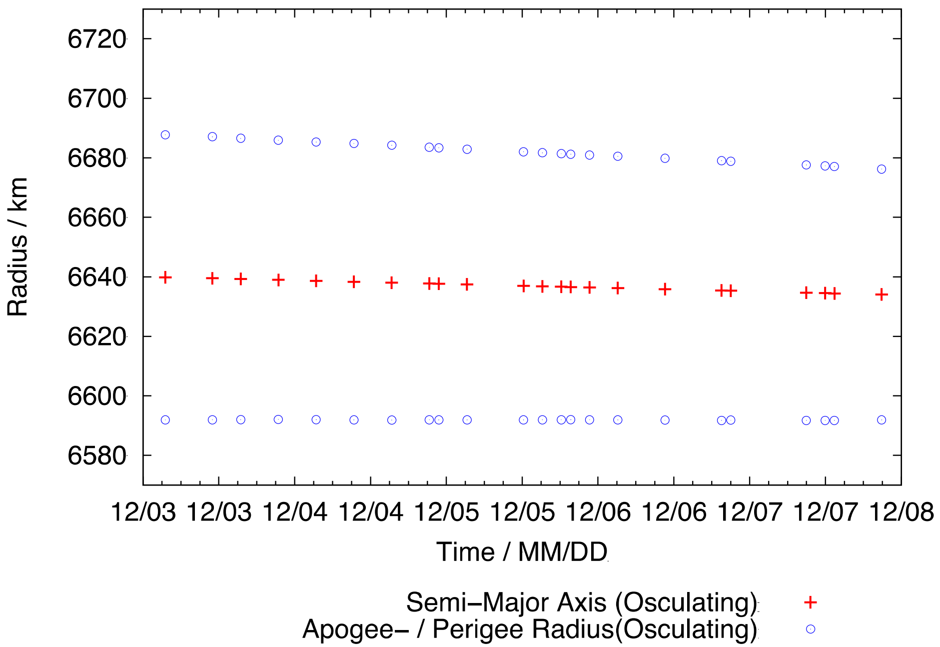
Re-entry Prediction

Re-entry campaigns are executed when an re-entry event is imminent

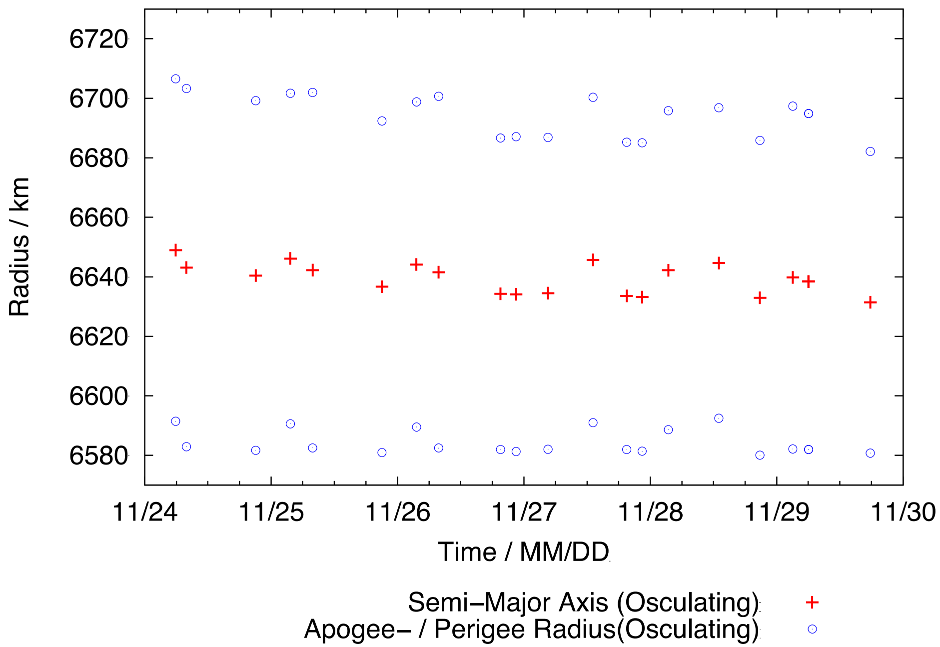
- Approximately 14 day of simulations before the object decays
- Using numerical propagator *zuniem* to determine the re-entry window
- Multiple simulations are executed per day - depending on the amount of data (TLE records) that is available
- Dealing with major uncertainties in the process:
  - Forecasting solar activity
  - Determining the satellite's ballistic coefficient
  - Accuracy of TLE records
- The accuracy of the position data (in the TLE records) is of importance
  - TLE data has a degree of inaccuracy
  - Influence of the position accuracy is investigated

Accuracy of TLE data 1/2

Example of scattered TLE data from a previous re-entry campaign:



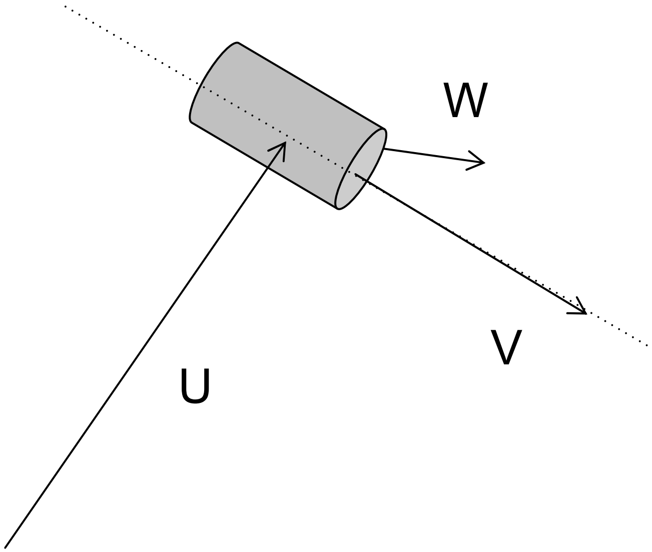
Semimajor axis near ascending node



Semimajor axis away from ascending node

Accuracy of TLE data 2/2

- Position and velocity error of objects have been investigated in previous studies as shown in the table below
- Depending on the object's perigee, eccentricity and inclination - errors fluctuate
- Errors are given in the satellite centered UVW-space

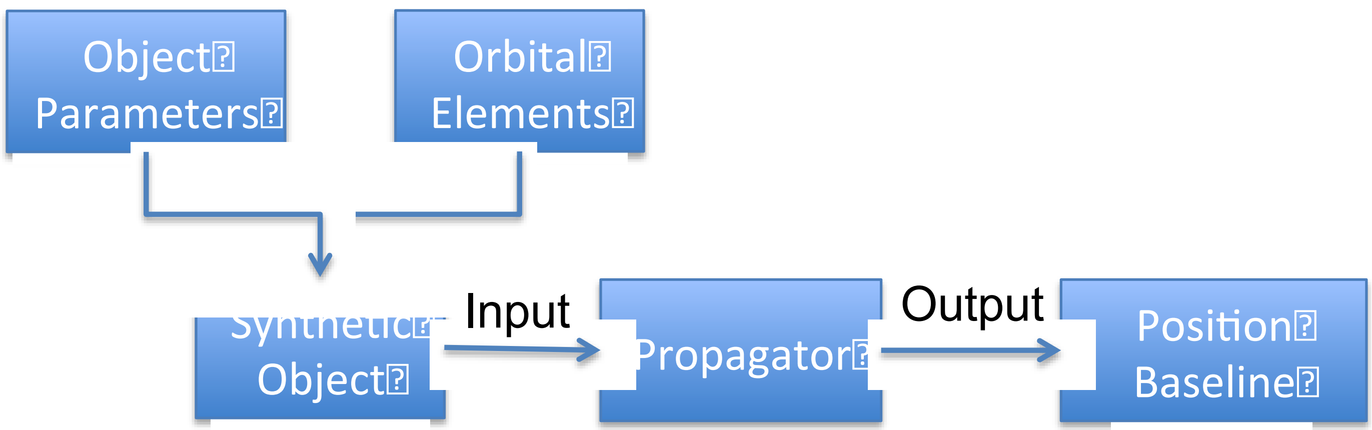


Position error [m]		Velocity error [mm/s]	
$r_{U,1\sigma}$	104	$v_{U,1\sigma}$	559
$r_{V,1\sigma}$	556	$v_{V,1\sigma}$	110
$r_{W,1\sigma}$	139	$v_{W,1\sigma}$	148

Position and velocity errors for satellites with $h_p < 800$ km and $i > 60°$ (Klinkrad, Alarcon, Sanchez)

Synthetic object 1/3

- A synthetic object has been created to eliminate uncertainties (ballistic coefficient, solar flux, etc…) to just focus on the TLE error
- A position baseline has been created using the propagator *zuniem* with synthetic object specifications
- The position baseline takes the place of TLE records in the re-entry campaigns



Process of creating the position baseline

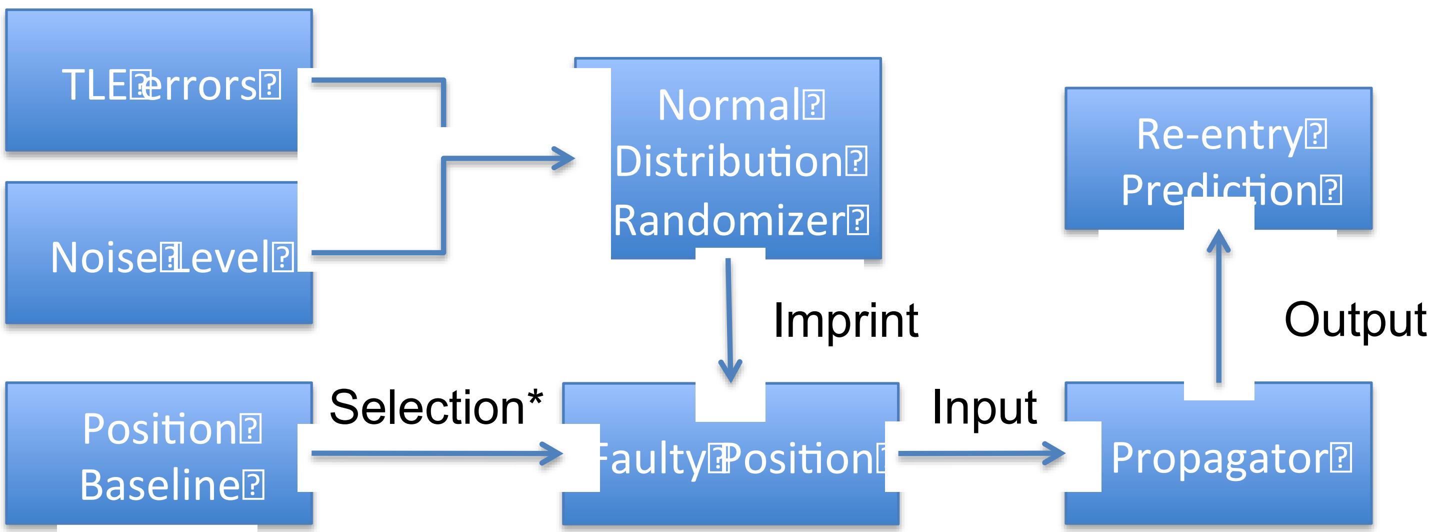
Synthetic object 2/3

Parameter	Value
Mass	1000 kg
Mass to Area ratio	100 kg/m^2
Semimajor Axis	6745.5 km
Eccentricity	0.01
Inclination	98.0°
Right Ascension of the Ascending Node	0.0°
Argument of Perigee	0.0°
True Anomaly	0.0°

Parameters of the synthetic object

Synthetic object 3/3

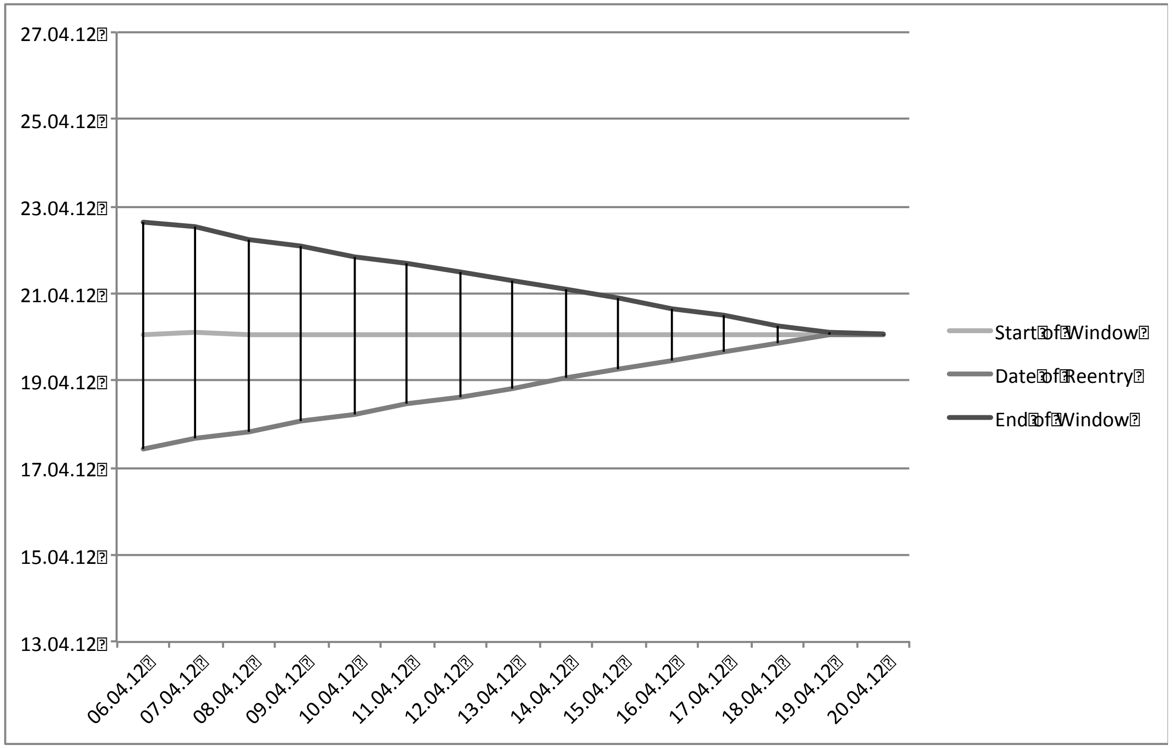
- Based on the known position and velocity errors the baseline position is imprinted with artificial noise
- A noise level n has been defined which influences the degree of which the position is altered



* 10 random points per day

Re-entry Simulations 1/6

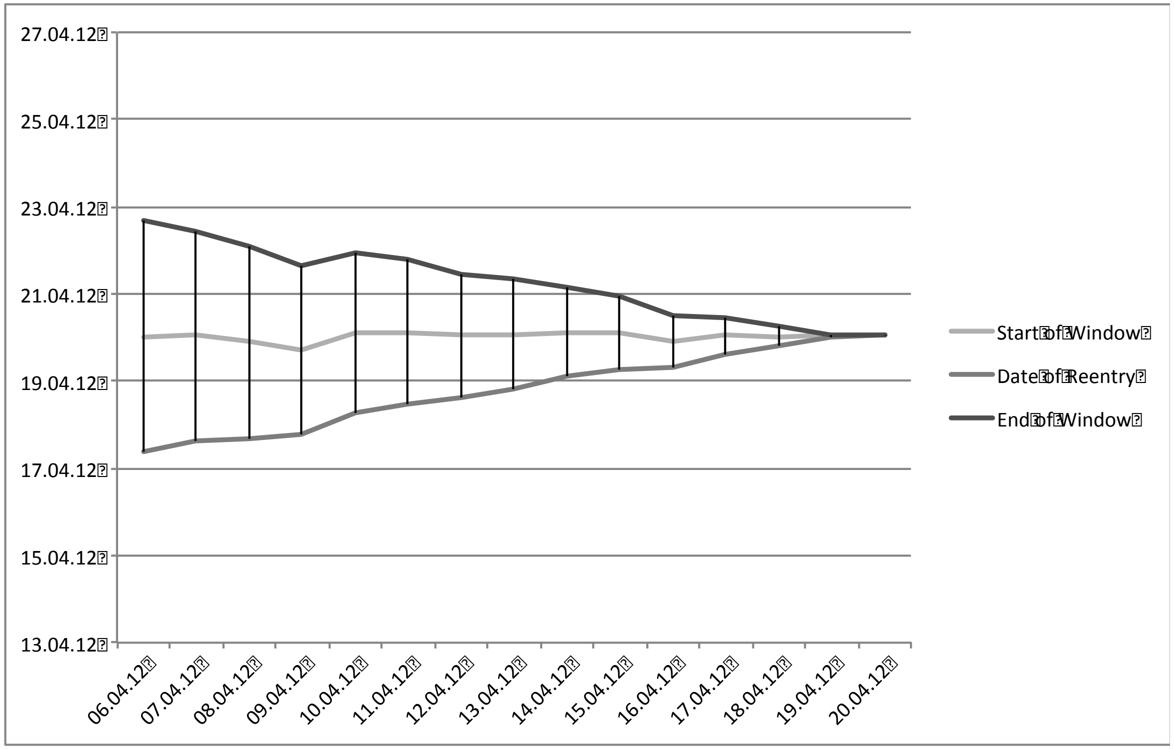
- Different test cases have been created using the same synthetic object but different noise levels n → Each of the test cases has a different degree of error
- Re-entry simulations have been executed in order to inspect the impact of errors on the re-entry window evolution



Reference test case with noise level n = 0.0

Re-entry Simulations 2/6

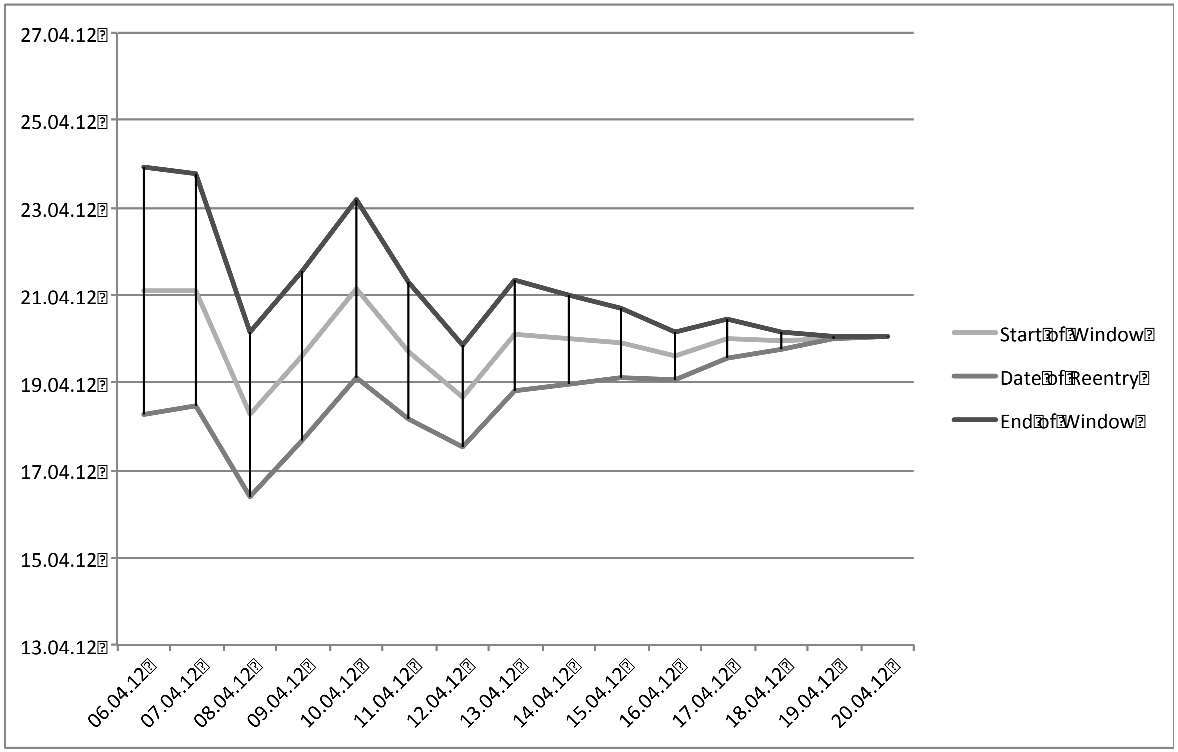
- With an increasing noise level the the re-entry windows show an increasing amount of fluctuations



Test case with noise level n = 0.1

Re-entry Simulations 3/6

- With an increasing noise level the the re-entry windows show an increasing amount of fluctuations



Test case with noise level n = 0.5

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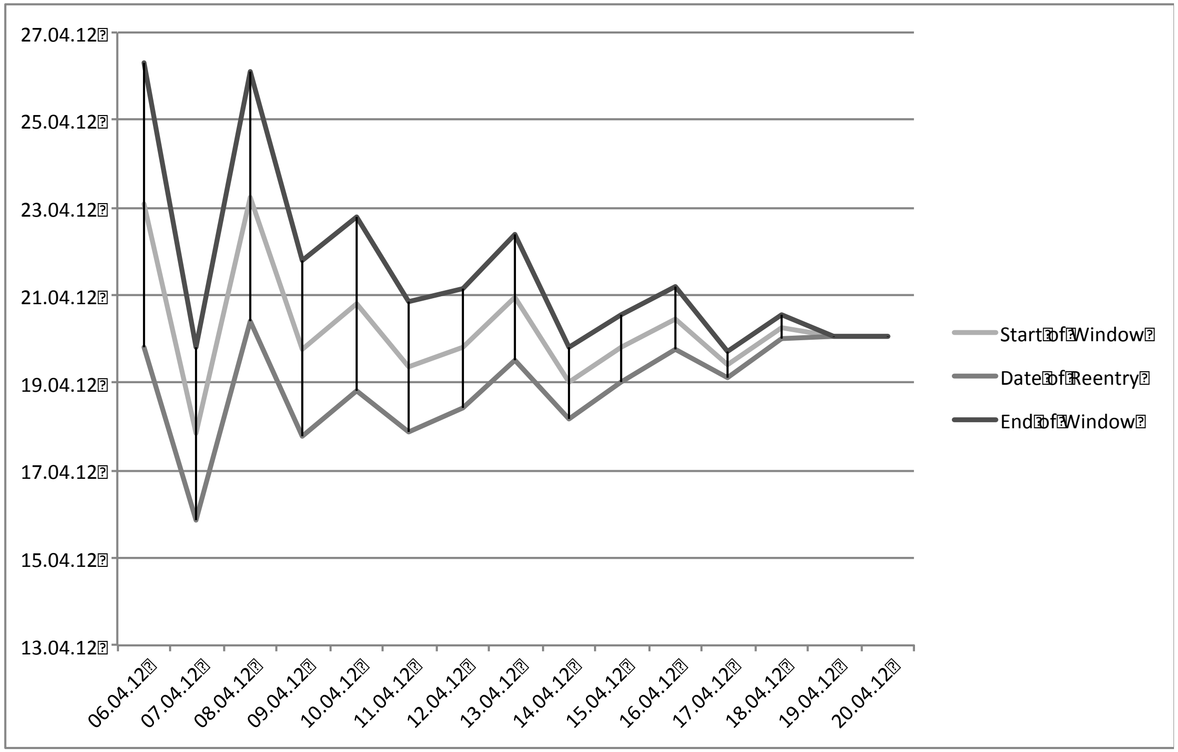
Re-entry Simulations 4/6

- With an increasing noise level the the re-entry windows show an increasing amount of fluctuations



Test case with noise level n = 1.0

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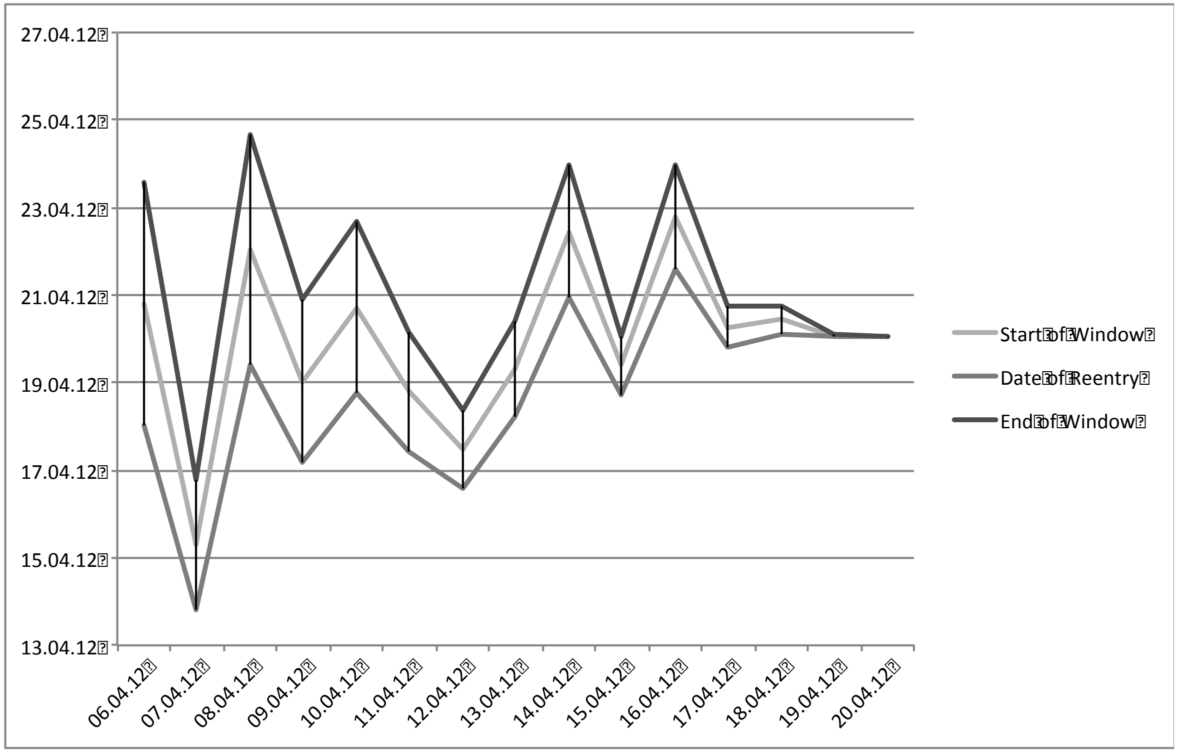
Re-entry Simulations 5/6

- With an increasing noise level the the re-entry windows show an increasing amount of fluctuations



Test case with noise level n = 1.5

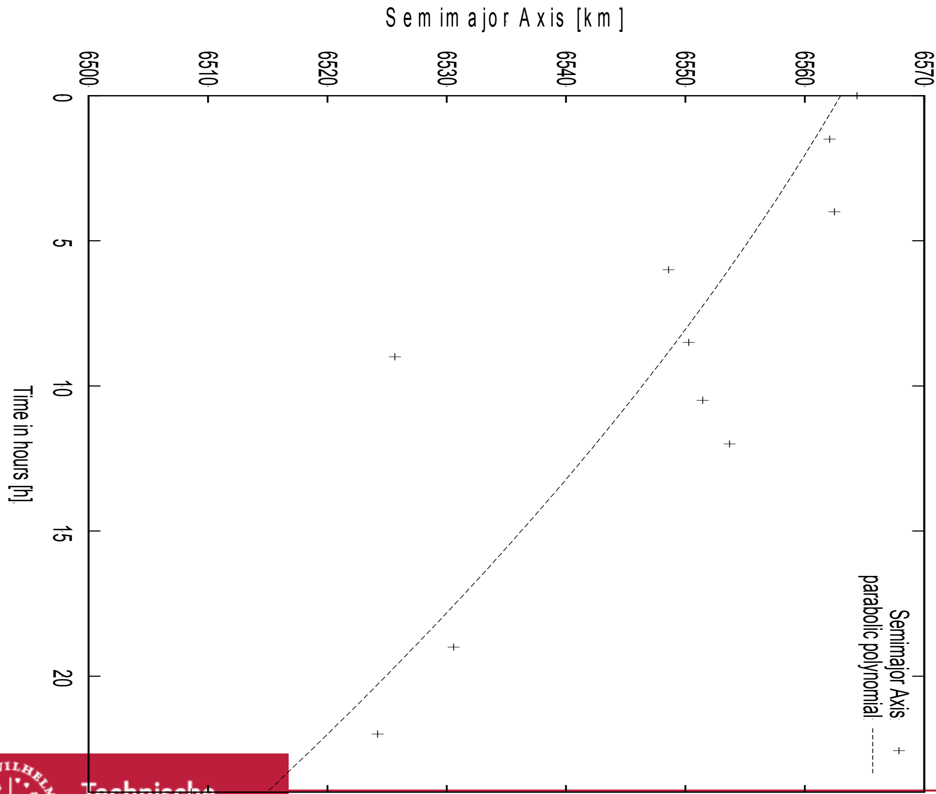
Re-entry Simulations 6/6

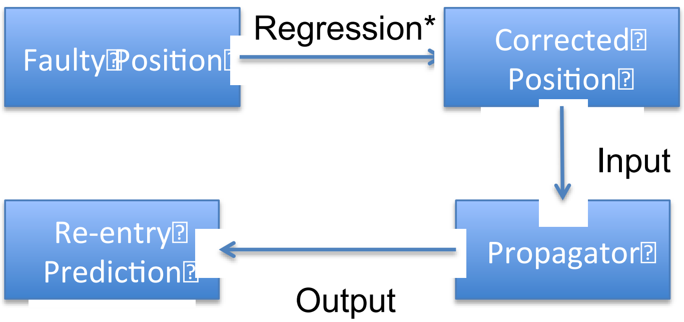
- With the noise level increasing by 0.5 the average deviation from the reference increases by 10 hours:

Noise Level n	Average Deviation from Reference Window [hours]
0.1	1.77
0.5	12.87
1.0	22.52
1.5	32.47

Regression Analysis 1/5

- Reducing the variability of the re-entry predictions through regression analysis
- Each orbital element was looked at separately
- Corrected position data were derived
- Simulations were repeated



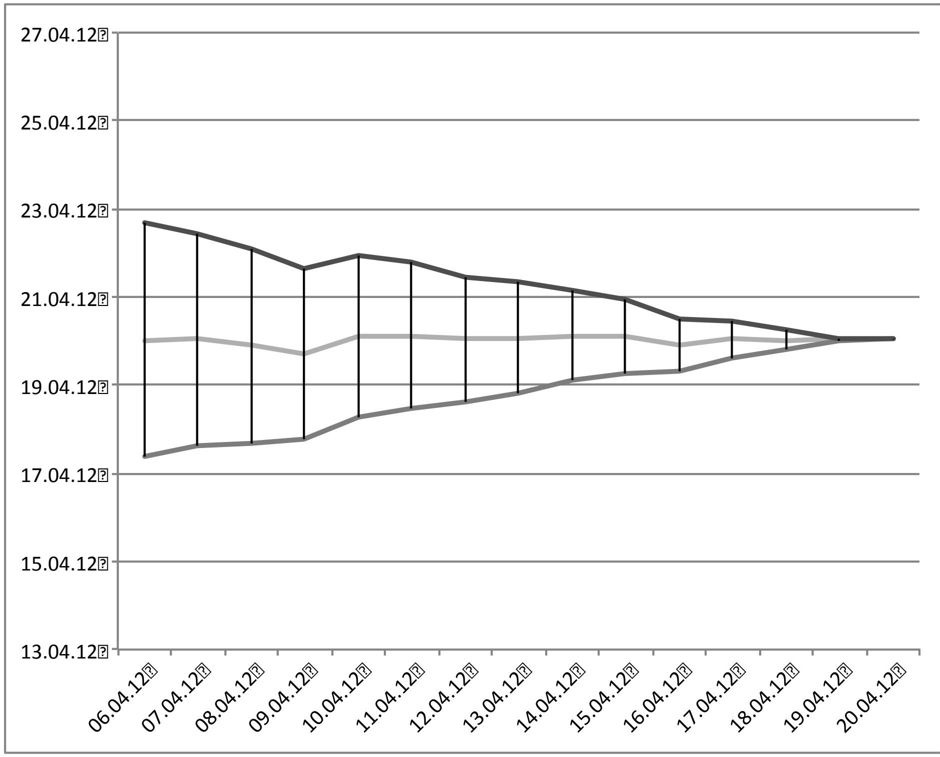


*over 24 hour period

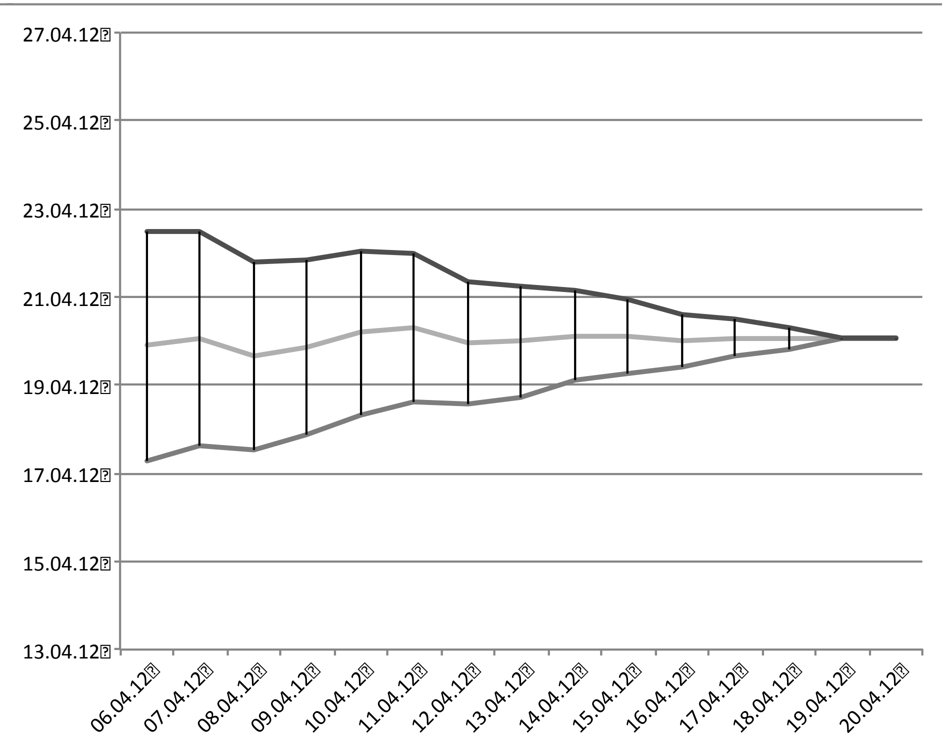
Example of a regression of the semimajor axis one day before re-entry, n= 1.5 using a parabolic equation

Regression Analysis 2/5

Test case with noise level n = 0.1



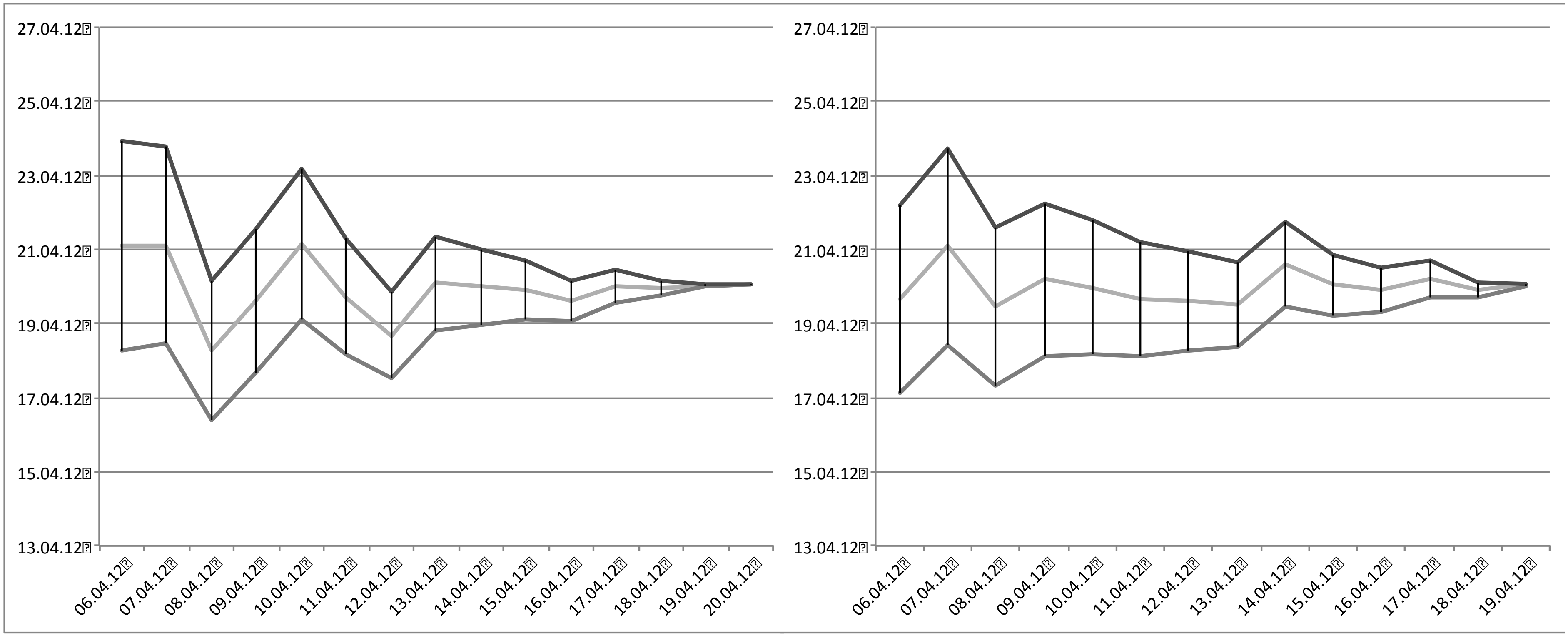
Original re-entry window



Re-entry window with regression

Regression Analysis 3/5

Test case with noise level n = 0.5

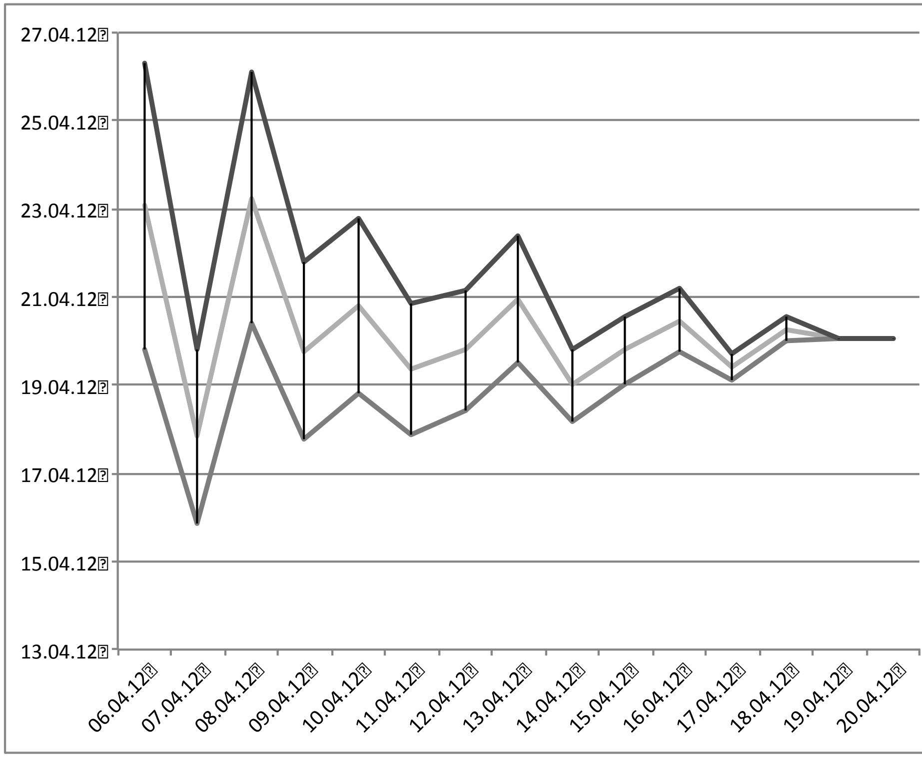


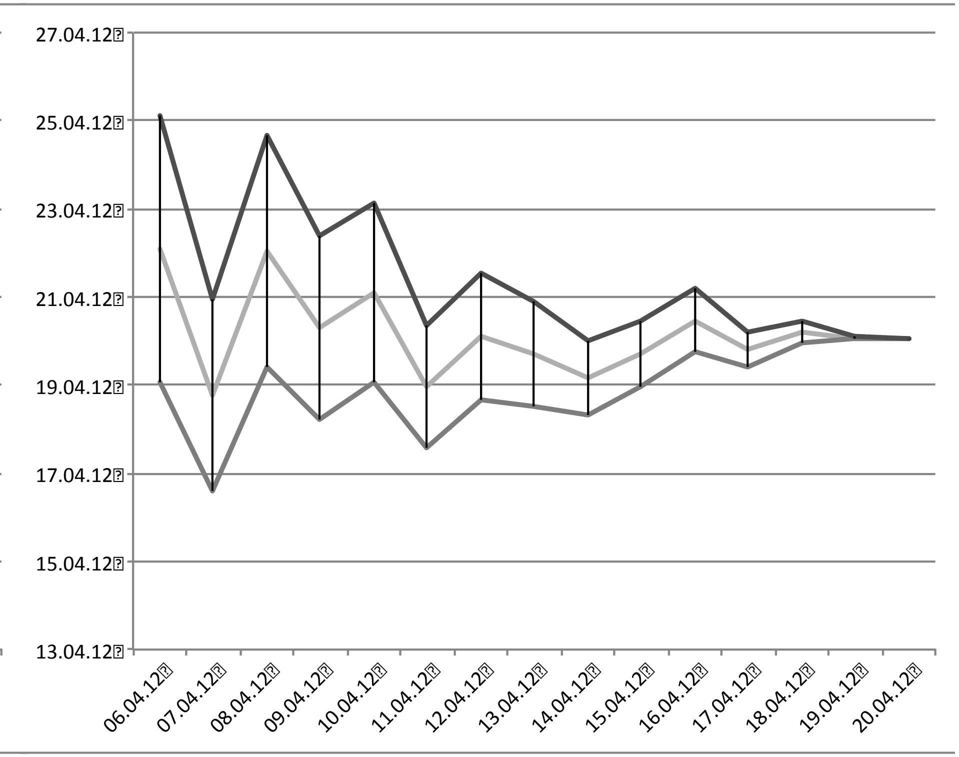
Original re-entry window

Re-entry window with regression

Regression Analysis 4/5

Test case with noise level n = 1.0



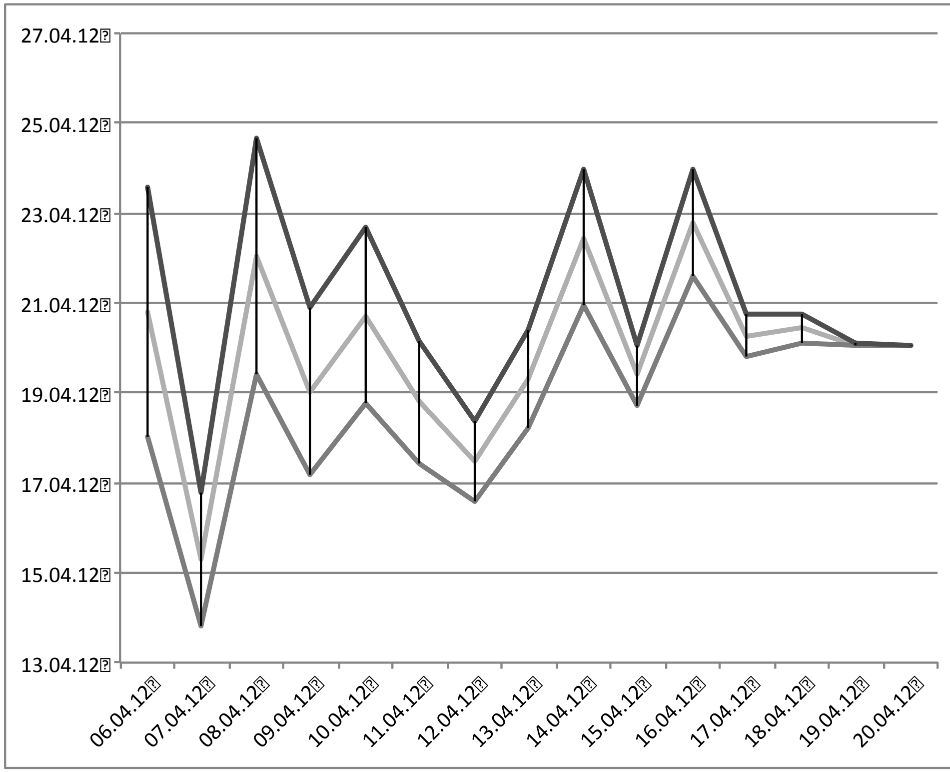


Original re-entry window

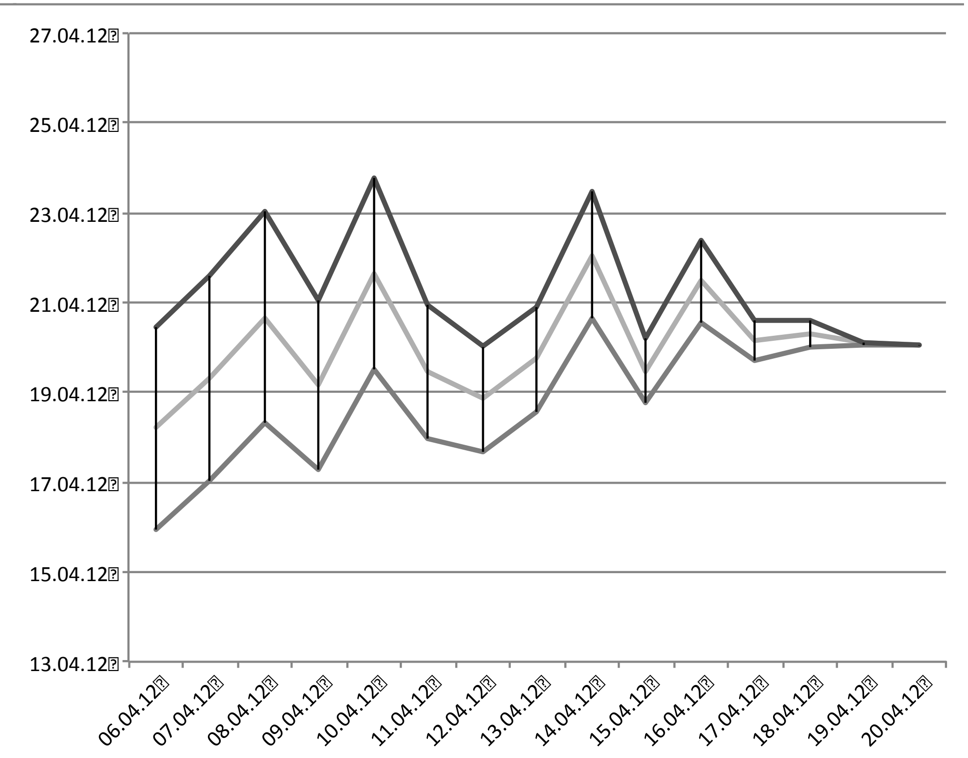
Re-entry window with regression

Regression Analysis 5/5

Test case with noise level n = 1.5



Original re-entry window



Re-entry window with regression

Conclusion

- Re-entry windows with high noise levels look smoother
- However low noise levels do not seem to improve
  - ➢ Increasing the range in which the regression is applied might show further improvements

Noise Level n	Average Deviation from Reference Window [h]		Improvement [%]
	Without regression	With regression	
0.1	1.77	2.37	-33.9
0.5	12.87	7.32	43.1
1.0	22.52	16.47	26.9
1.5	32.47	19.62	39.6

Thank you for your attention.