STIFFNESS MEASUREMENTS (RMSV)

TRACK SECTIONS
PROSENICE - LIPNÍK NAD BEČVOU - DRAHOTUŠE
POLOM – SUCHDOL NAD ODROU
IN THE CZECH REPUBLIC

Project report

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Table of Contents

1. INTRODUCTION

Banverket and the Czech Republic participate in the EU project INNOTRACK where the main objective in WP2.1 “Track bed quality assessment” is to test, compare and combine innovative methods for the identification of subgrade properties for an assessment of the track bed performance.

Work includes monitoring of physical parameters vital to subgrade performances on experimental sites or track sections on different European networks. Conventional lines with mixed traffic at moderate speed (100-160 km/h) are the main target of common interest, but particular conditions offered by high speed lines are also studied. Innovative non-destructive and continuous methods are developed and tested for site monitoring.

The study includes track sections with both poor and good quality areas regarding maintenance, as well as specific maintenance generating transition zones between plain track and bridges.

In the frame of the INNOTRACK project Czech Railways has suggested to perform measurements of two sections Prosenice - Drahotuše and Polom – Suchdol nad Odrou. Both sections have been recently upgraded but in a short time after opening of this railway line particular places have showed progressing irregularities of track geometry.

Since the mentioned sections are a subject of reclamation against a contractor Czech Railways has started a comprehensive investigation to clarify the purpose of problems. Classical geotechnical investigations and non-destructive methods like georadar, geophysical methods, and plate load test have been performed.

Banverket has developed a measurement vehicle RSMV (Rolling Stiffness Measurement Vehicle) that can measure both stationary and continuous dynamic stiffness. RSMV is used for assessment of track performance. Normally is track stiffness measured using plate load test with disadvantage that only particular spots are investigated.

It is well known that just changes of track stiffness can be one of many causes of problems dealing with irregularities of track geometry.

Banverket Production send en offer (PM 07-78 IN70) about measurements in the Czech Republic in May 2007. After that Banverket Production obtained an order (400/0692/2007) to perform measurements of above stated sections. Contract for the work had been signed by both partners and the measurements were carried out between 21 and 23 May 2007.

This report brings the main evaluation of stiffness measurements of the sections of interest, but there is an intention to carry out further studies and evaluations within WP 2.1 of the INNOTRACK project.

2. OVERVIEW OF PREFORMED MEASUREMENTS

Figure 2.1 shows the position of measurements between Prosenice and Suchdol nad Odrou in the Czech Republic. For measurement purposes the measured railway line has been divided in three sections starting at Prosenice.

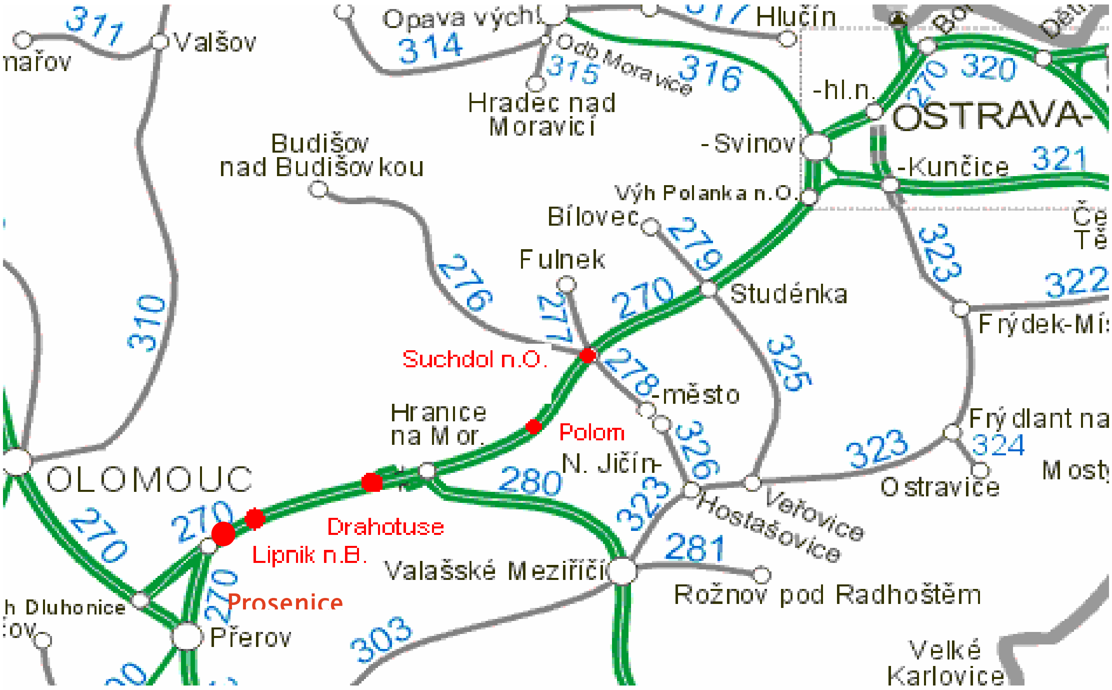


Figure 2.1 RSMV measurements, Prosenice – Suchdol nad Odrou

As mentioned both rolling and stationary measurements have been performed. The following stretches and type of measurement have been carried out in each of measured section:

Section 1 Prosenice –Lipnik nad Bečvou

1. Rolling measurements:

km 194+550 – 198+700

40 km/hour without dynamic excitation
40 km/hour dynamic excitation 6.8 Hz and 11.4 Hz
7 km/hour dynamic excitation 3 – 20 Hz

2. Stationary measurements:

Track 1: 197+960 track with problem, measurements Banverket 3-50 Hz,
excitation for Gimpuls 3, 10, 20, 30, 40 and 50 Hz

Track 2: 196+000 track without problem, measurements Banverket 3-50 Hz,

197+850 track with problem, measurements Banverket 3-50 Hz

Section 2 Lipnik nad Bečvou - Drahotuše

1. Rolling measurements:

km 198+700 – 205+900

40 km/hour without dynamic excitation
40 km/hour dynamic excitation 6.8 Hz and 11.4 Hz
7 km/hour dynamic excitation 3 – 20 Hz

2. Stationary measurements:

Track 1: 200+375 track with many problems, measurements Banverket 3-50 Hz,
excitation for Gimpuls 3, 10, 20, 30, 40 and 50 Hz

200+395 track with many problems, measurements Banverket 3-50 Hz

203+230 transition zone of bridge (no problems reported)
measurements Banverket 3-50 Hz,

Track 2: 200+375 track without problem, measurements Banverket 3-50 Hz,
excitation for Gimpuls 3, 10, 20, 30, 40 and 50 Hz

203+230 transition zone of bridge, track with problem, measurements
Banverket 3-50 Hz

203+800 track without problem, measurements Banverket 3-50 Hz,

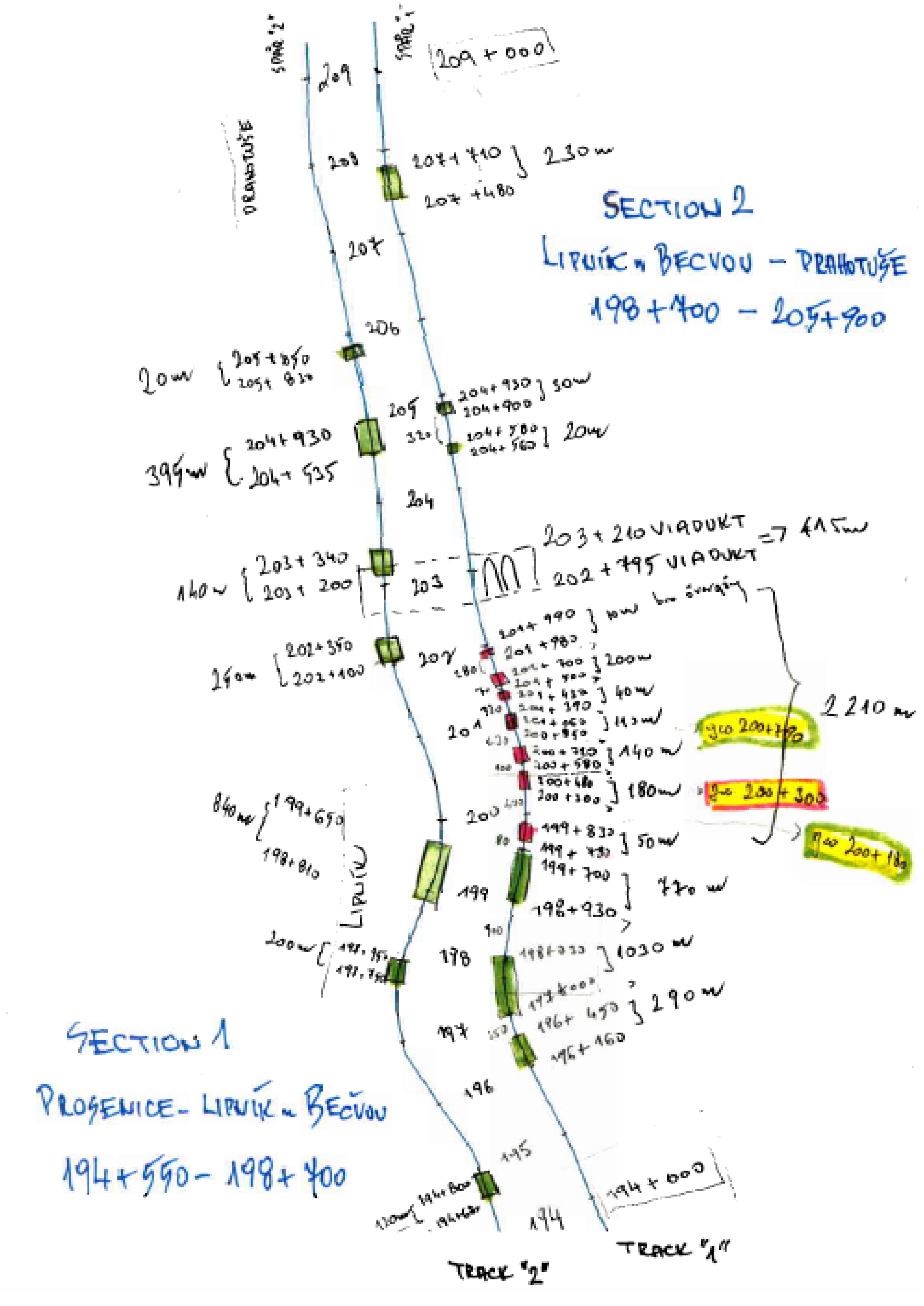


Figure 2.2 RSMV measurements, Section 1 nad 2 Prosenice – Drahotuše

Position of RSMV measurements on both tracks is shown in Figure 2.2. Red marked boxes show stretches where track irregularities have occurred for a long period, are progressing very fast and repeat again after track levelling.

Green marked stretches indicate parts of the track where irregularities have occurred as well, track levelling is required repeatedly, but this is not as expressive as the red ones. Yellow boxes show position of performed geotechnical investigations

Section 3 Polom – Suchdol nad Odrou

1. Rolling measurements:

km 221+800 – 227+300

40 km/hour without dynamic excitation
40 km/hour dynamic excitation 6.8 Hz and 11.4 Hz
7 km/hour dynamic excitation 3 – 20 Hz

2. Stationary measurements:

Track 1: 221+900 track without problem, measurements Banverket 3-50 Hz,

222+045 track with problems, measurements Banverket 3-50 Hz,

223+000 track without problem, measurements Banverket 3-50 Hz,

223+065 track with problems, measurements Banverket 3-50 Hz,

223+075 track with problems, measurements Banverket 3-50 Hz,

225+240 track with problems, measurements Banverket 3-50 Hz,

225+310 track without problems, measurements Banverket 3-50 Hz, excitation for Gimpuls 3, 10, 20, 30, 40 and 50 Hz

225+506 track with problems, measurements Banverket 3-50 Hz,

226+117 track with problems, measurements Banverket 3-50 Hz,

Track 2: 221+900 track without problem, measurements Banverket 3-50 Hz,

222+030 track with problems, measurements Banverket 3-50 Hz,

225+240 track with problem, measurements Banverket 3-50 Hz,

225+310 track without problems, measurements Banverket 3-50 Hz, excitation for Gimpuls 3, 10, 20, 30, 40 and 50 Hz

225+508 track with problems, measurements Banverket 3-50 Hz,

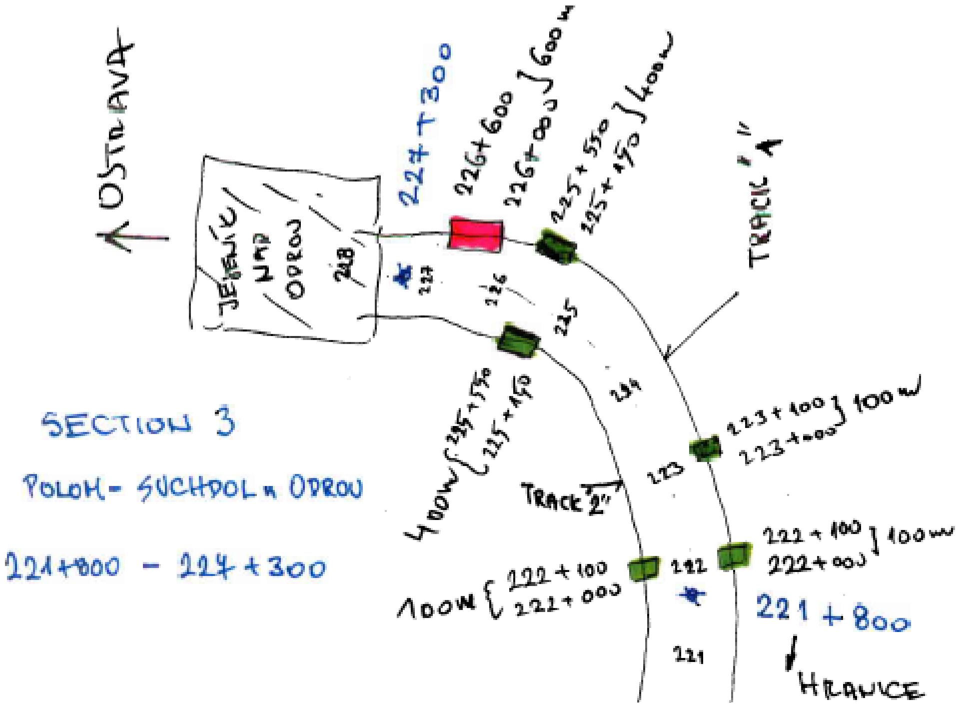


Figure 2.3 RSMV measurements, Section 3 Polom – Suchdol nad Odrou

Position of RSMV measurements on both tracks is shown in Figure 2.3. Red marked boxes show stretches where track irregularities have occurred for a long period, are progressing very fast and repeat again after track levelling.

Green marked boxes show stretches where track irregularities have occurred as well, track levelling is required repeatedly, but this is not as expressive as the red ones.

3. PRINCIPALS OF ROLLING STIFFNESS AND STATIONARY MEASUREMENTS WITH RSMV

Measurement principle

Track stiffness may seem as an easy parameter to define. However, vertical track stiffness varies with position, applied static and dynamic load and frequency. Besides that, stiffness is also a complex valued function, which means that it can be displayed by its real and imaginary part or, as chosen here, magnitude and phase. This means also that different measurement methods will differ, more or less, in result.

The RSMV is thorougly described in [Berggren 2005]. The track is dynamically excited through two oscillating masses above an ordinary wheel axle of a freight wagon as shown in Fig. 3.1. Track stiffness is calculated out of measured axle box forces and accelerations. Stiffness is evaluated at the excitation frequency where applied dynamic force and doubleintegrated acceleration at the specific frequency

result in the stiffness, which in these tests equals to 6.8 and 11.4 Hz for the test in 40 km/h and between 3 – 20 Hz for the test in 7 km/h. The track stiffness is presented as magnitude (kN/mm) and phase (degrees).
Figure 3.1 shows the principal components of the measuring system. The force of an oscillating mass, controled by hydraulics, is acting directly on the axlebox (not through the leaf spring). The force transducer measures both the force created by the oscillating mass as well as the normal vehicle force acting through the leaf spring. The accelerometer on the axle-box measure the wheel-acceleration, which has components from the oscillating mass, vehicle dynamics and track irregularities. By using an evaluation-method with insight in all different disturbances, the stiffness can be evaluated with high precision [Berggren 2005].

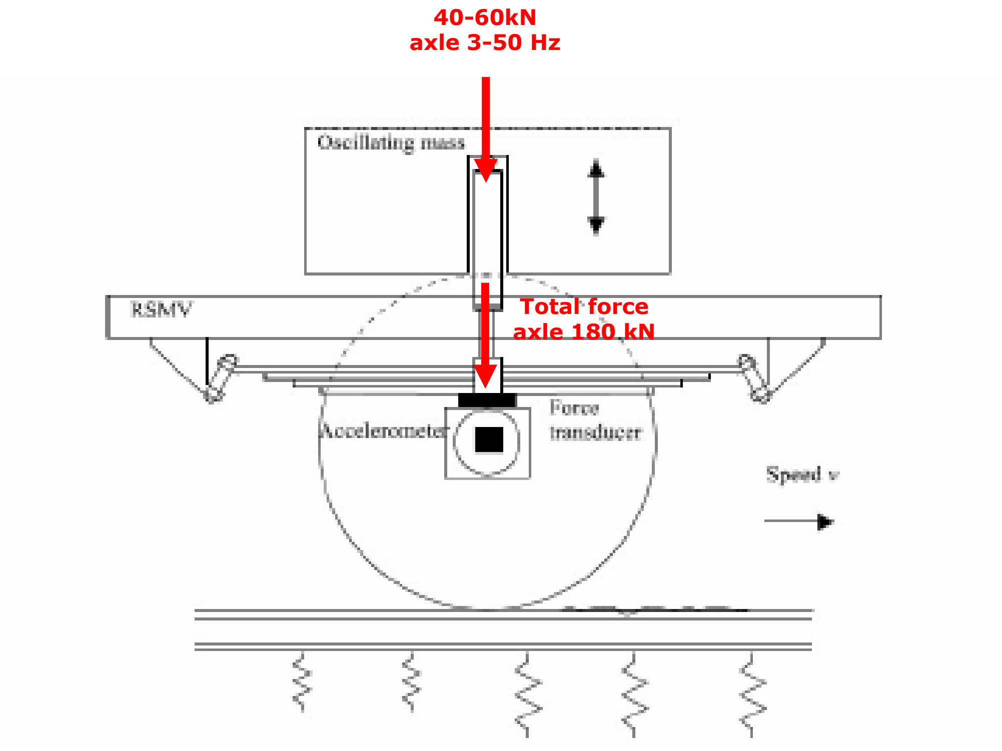


Figure 3.1 RSMV measurement principal and force transfer

In figure 3.2, a photograf of the oscillating mass above one wheel is shown (same above other wheel of axle).

Figure 3.2 The measurement equipment in the RSMV vehicle

In figure 3.3 a test from the Swedish stand-still Track Loading Vehicle is shown. The left part of the figure displays a force-deflection diagram where the rail is slowly (quasi-statically) loaded up to 150 kN while the corresponding deflection is measured. This type of test has not been done in the Czech republic, however, as an illustration of stiffness it is still included in the Figure 3.3. The curve is non-linear and also has a hysteresis, which indicates a damping factor. In the RSMV case, the static wheel-load is close to 90 kN, and the dynamic wheel-load is between 20 – 30 kN.

The variability due to frequency can be illustrated in the right part of figure 3.3. If we for example study measurements on one rail with a static preload of 90 kN and a superimposed dynamic load with amplitude of 10 kN and excite a broad frequency spectrum we can calculate the receptance, see the right part of figure 3.3 (magnitude of the receptance). In this particular case we find a resonance around 5 - 8 Hz due to soft soil (clay). We also see that the track is stiffer (lower receptance) for higher frequencies, at least up to 50 Hz.

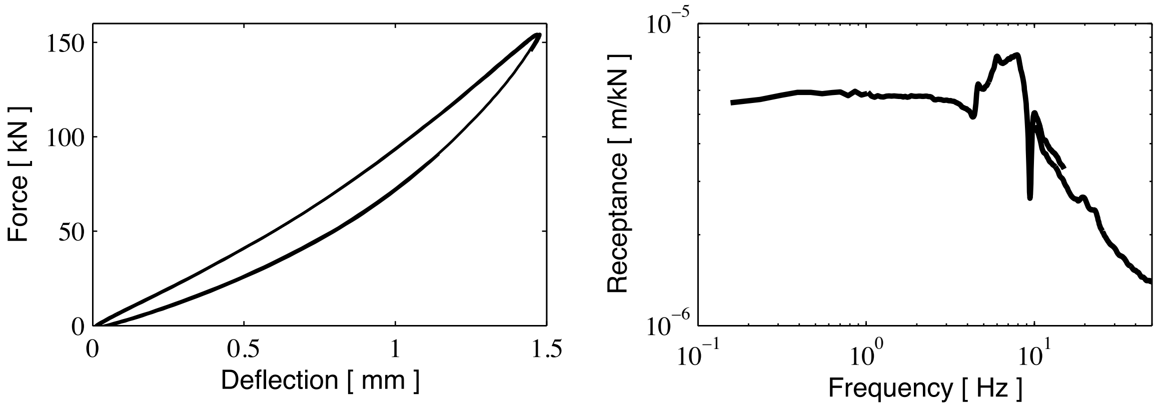


Figure 3.3: a: Vertical force-deflection diagram of track with quasi-static excitation (measured on rail), b: Magnitude of vertical track receptance with subsoil of clay (measured on rail), F_{stat} = 90 kN, F_{dyn} = 10 kN. Measurements made by Banverket with standstill track-loading test vehicle in Sweden.

From this figure we can conclude that the choise of frequency is important. In the measurement run of 40 km/h and dynamic excitation by two discrete frequencies, only two points for each position will be measured. These consecutive points will form a line diagram, which can be seen in Appendix B (and partly in D). In case the measurement is carried out in 7 km/h, a receptance curve can be plotted for each position. Consecutive receptances will form a surface diagram, which can be seen from Appendix C. The accelerometer in the measurement system could be used as a sensor for track geometry quality (longitudinal level). In appendix A this is shown. In appendix D, both the evaluation of stiffness and longitudinal level are shown. In this form it is easy to see similarities that indicate stiffness as reason for longitudinal level errors. Note however that both measurements are bandpass-filtered between 5 – 15 meters. This means that only variations of stiffness, and no absolute value is showed. Also the longitudinal level is scaled with a factor of two in order to obtain a better distinction in reading of diagrams.

Finally in figure 3.4, an example of stand-still measurement with the RSMV is shown. The results from these measurements are shown as in figure 3.3 b in Appendix E.

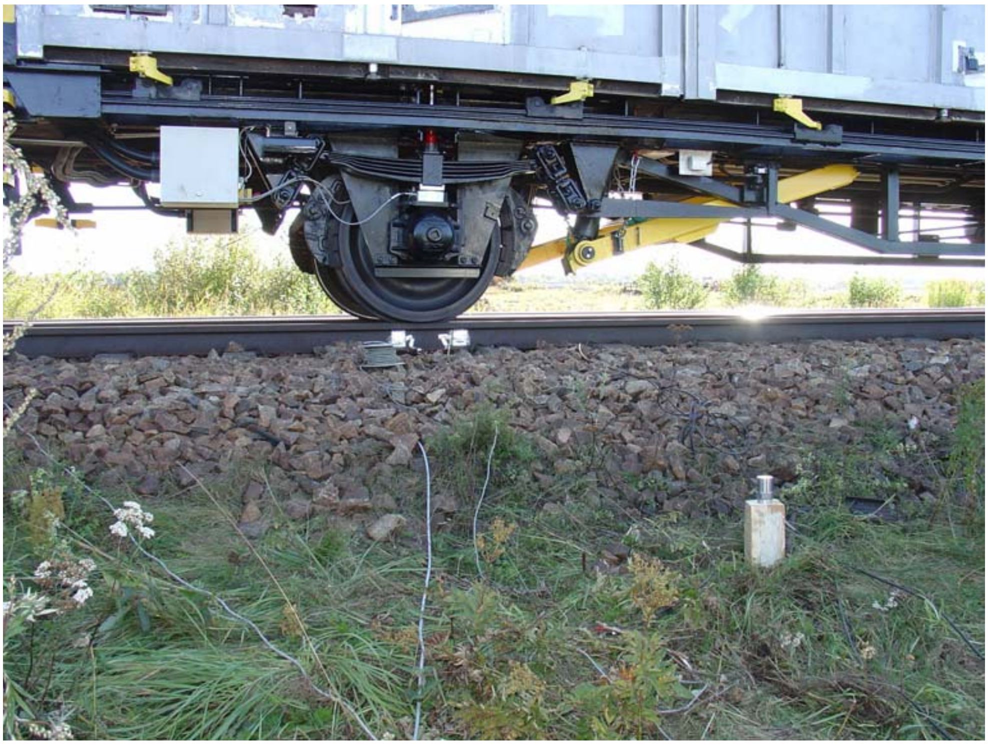


Figure 3.4 Stationary measurement with RSMV

Diagram description

In Appendix A, measurements of longitudinal level are shown. The upper figure shows a swept standard deviation of 200 meters for the left and right rail. The lower figure shows the original longitudinal level for the left and right rail. Both quantities are displayed in mm.

In Appendix B, measurements of track stiffness at the frequencies 6.8 and 11.4 Hz are shown. In the upper figure stiffness phase is shown and in the lower figure there is stiffness magnitude. Large difference between the two frequencies indicates some resonance phenomenon in the track. To get more insight of the stiffness behaviour at these positions, Appendix C could be used.

Appendix C contains surface plots for the test where several frequencies (frequency band between 3 and 20 Hz) were excited simultaneously. In the upper figure stiffness phase is shown and in the lower figure stiffness magnitude. The stiffness phase and magnitude are color coded according to the color map at the right hand side. Black color is interpreted as low stiffness / large phase shift.

Appendix D shows a combination of parts of the information from Appendix A and B. Longitudinal level (mean value of the left and right side) is collected from Appendix A and stiffness magnitude with excitation frequency 11.4 Hz is collected from Appendix B. By showing these quantities together it is possible to clearly see where there are correlation. To get proper scaling between the quantities, the longitudinal level multiplicates by a factor of two. This means that when 10 mm is displayed in the diagram, there is only 5 mm in track. Both quantities are bandpass filtered between the wavelengths 5 - 15 meters. It is important to mention that only variations and no original magnitudes are shown.

Finally, Appendix E shows the stationary measurements. These are divided so that no more than three positions are shown at the same time. The upper part shows stiffness phase; the middle part stiffness magnitude and the lower part transfer function coherence. Coherence is briefly described in chapter 4.4.

4. RESULTS OF MEASUREMENTS

Results of all of all performed measurements are presented in form of diagrams in Chapter 9 - Attachments.

Results of rolling measurements starting from km 194+500are presented for 500 m of track on one A4 page for each track.

The following is plotted:

- 40 km/hour without dynamic excitation
- 40 km/hour dynamic excitation 6.8 Hz and 11.4 Hz
- 7 km/hour dynamic excitation 3 – 20 Hz
- marked position of problem places

- red colour places with many problems
- orange colour places with problems

- marked position of RSMV stationary measurements
- position of the track in km
- position of viaduct (section 2) – black colour

Result of stationary measurements is presented in form of vertical track receptance diagrams for all measured spots.

Evaluation of measurements has concentrated on assessment of stiffness at stretches where track irregularities have been detected.

5. Section 1 Prosenice –Lipnik nad Bečvou, km 194+550 – 198+700

Problem stretches:

Track 1	Track 2
196+160 -196+450	194+680 -194+800
197+000 -198+030	197+750 -197+950

Stretches have shown problems but not as expressive as those marked with * described in section 2 and 3

Stationary measurements:

Track 1: 197+960 track with problem

Track 2: 196+000 track without problem
197+850 track with problem

Track 1

For evaluation of track stiffness frequencies 6.8 and 11.4 Hz have been studied. The average values are128 kN/mm (6.8 Hz) and 129kN/mm (11.4 Hz). Phase -19 and -24 degrees respectively. The highest stiffens has been measured on the bridge (round the km 197+050) up to 230 kN/mm. There is no essential variation of stiffness along the track. The lowest value 80 kN/mm was measured locally close to the km 195+930. Both already known problem stretches have showed higher variation of stiffness in comparison with the part of track where no problems have been reported.

196+160 -196+450 marked as a problem stretch shows variation of stiffness especially round the km 196+300.

Appendix D5 clearly shows that in the middle of the problem stretch longitudinal level follows the stiffness pattern.

197+000 -198+030 the second problem stretch shows as well variation of stiffness, especially in transition between embankment and cutting (km 197+270) there is a drop of stiffness from 170 kN/mm to 110 kN/mm. Of course transitions zones close to the bridge (round the km 197+050) show highest differences of stiffness on bridge in the vicinity. Those ones are sure the main reason for track deterioration problems.

At some minor part of the second problem stretch, the stiffness variations correlate to the longitudinal level (Appendix D7-8).

Track 2

The average values of track stiffness are 111 kN/mm (6.8 Hz) and 125kN/mm (11.4 Hz). Phase -17 and -25 degrees respectively. The lowest values are varying between 70 – 100 kN/mm. There is not noticeable variation of stiffness along the track between km 198+325 to 198+500. The Czech railways have not marked this part of the track as problem one, but it should be worth to clarify the reason for variation of stiffness there. The highest stiffness has been measured at the same place like on the Track 1 on the bridge (round the km 197+050) up to 230 kN/mm.

194+680 -194+800 is the stretch where measured stiffness variation is obvious. At this stretch the purpose of problems is the presence of bridge and culverts on both sides of the bridge. Transition zones and backfills have created different stiffness and this can cause problems reflecting to the deterioration of track geometry.

Appendix D11 clearly shows that longitudinal level follows the stiffness pattern.

197+750 -197+950 is the stretch where measured stiffness has not showed special variation. Problem at this area can not be explained due to variation or low stiffness. The purpose for track deterioration has to be found in other area.

However, Appendix D17 shows correlation between stiffness and longitudinal level.

4.2 Section 2 Lipnik nad Bečvou – Drahotuše, km 198+700 – 205+900

Problem stretches:

Track 1	Track 2
198+930-199+700	198+810-199+650
199+780-199+830*	202+100-202+350
200+300-200+480**	203+200-203+340
200+580-200+720*	204+535-204+930
200+950-201+060*	
201+390-201+430*	
201+500-201+700*	
201+980-201+990*	
204+580-204+560	
204+900-204+930	

stretches where track irregularities have occurred, track levelling is required, but those are not as expressive as those marked with *

* stretches where track irregularities have occurred for a long period, are progressing very fast and repeat again after track levelling

** The most problematic stretch of all measured sections

Stationary measurements:

Track 1: 200+375 track with many problems
200+395 track with many problems
203+230 transition zone of bridge (no problems reported)

Track 2: 200+375 track without problem
203+230 transition zone of bridge, track with problem
203+800 track without problem

Track 1

Measured stiffness of the Track 1 has not shown a considerable variation. The average values are about 127 kN/mm (6.8 Hz) and 128kN/mm (11.4 Hz). Phase -20 and -22 degrees respectively. The only places where variation is obvious are transitions of bridges (km 199+620 – 199+670) like on the viaduct transition on Drahotuše side km 203+220.

Another bridge transitions are around km 204+730 and 204+880. The lowest stiffness is between km 205+025 and km 205+200 and has been measured to 90 kN/mm. Viaduct km 202+795 to km 203+210 has slightly higher stiffness with average value of 175 kN/mm.

198+930-199+700 is the stretch of 770 m where any great differences in variation of stiffness have been measured. There are only two places; one round the km 199+380 and transition of bridge (km 199+620 – 199+670) where one can see evident stiffness differences.

Some parts show correlation between longitudinal level and stiffness (Appendix D20-22).

199+780-199+830 there is nearly no variation of stiffness with excitation 6.4 Hz, little more can be seen when we applied 11.4 Hz, especially at the beginning of this stretch where stiffness of 170 kN/mm drops to 105 kN/mm.

There is also correlation between longitudinal level and stiffness (Appendix D22).

200+300-200+480 – this is the most problematic stretch on the measured railway line. The railway is in a cutting. Number of investigations and other measurements has been performed here. Stiffness measurements have not shown directly obvious variation of stiffness. Both measured frequencies show approximately the same values. The only difference can be seen between km 200+400 and km 200+450 where values alternate between 100 and 150 kN/mm.

There is clear correlation between longitudinal level and stiffness as can be seen from Appendix D23, that can not be seen on the same part on Track 2 Appendix D38.

200+580-200+720 has been marked like stretch with serious problems. Just studying variation stiffness of 11.4 Hz excitation, there is a difference especially km 200+625 where one can see a decrease from 145 kN/mm to 75 kN/mm, which is the lowest value on Track 1, Section 1.

Almost the whole stretch shows correlation between longitudinal level and stiffness (Appendix D24).

200+950-201+060 stretch shows higher stiffness then the previous one even if this one has been marked as well as seriously problematic. Variation of stiffness is not evident there. The problem can be due to transition between track in a cutting and embankment where drainage does not fulfil its function properly.

Part of the stretch show correlation between longitudinal level and stiffness (Appendix D24-25).

201+390-201+430 the track is in a little cutting. Slight stiffness variation has been detected where the drop from 160kN/mm to 125 kN/mm at km 201+400 has been measured.

201+500-201+700 stretch with serious problem where tack is on an embankment up to the km 201+550 and then there is a cutting. One can not see obvious distinctive variation of stiffness on the embankment and in the cutting. Average value is about 140 kN/mm on embankment and drops to 100 kN/mm at the end of problematic stretch in cutting.

Large part of the stretch shows correlation between longitudinal level and stiffness (Appendix D26).

201+980-201+990 is very short part of track with problems where variation of stiffness is typical for transition zone close to the bridge.

204+560-204+580 is a short problematic stretch where track is founded on an embankment. We have not measured variation of stiffness there but the value 90kN/mm is lower than outside of this area.

204+900-204+930 is the transition area of a bridge where stiffness is about 140 kN/mm and drops to 90 kN/mm on adjacent embankment. It is obvious that this change in stiffness can cause track problems there.

Track 2

Even Track 2 has not a great variation of stiffness. There is not obvious difference in comparison with the Track 1. The average values are about 123 kN/mm (6.8 Hz) and 129kN/mm (11.4 Hz). Phase -19 and -23 degrees respectively. The lowest stiffness has been measured 90 kN/mm. Variation has been measured close to the bridges in transition zones and even on both sides of viaduct km 202+795 to km 203+210. Special parts of the track where one can observe variation can be seen between 202+000 to km 204+052 and 205+750 to km 205+900. Unfortunately we have not obtained complete information about man made structures. The explanation and the reason of stiffness variation should be studied in more detailed way, even if those places have not been included and marked as problem stretches.

198+810-199+650 has a bridge at km 198+830 where change of stiffness is obvious on both sides at transitions zones. Quite great variation of stiffness has been measured from km 199+400 to km 199+620, where especially round km 199+430 stiffness measured with 11.4 Hz excitation increases from 70 kN/mm to nearly 240 kN/mm. Unfortunately we do not know if there is some man made structures at this part. The rest of this problematic stretch does not show large stiffness variation.

Parts of this stretch show clear correlations between longitudinal level and stiffness (Appendix D35-37).

202+100-202+350 is a stretch of railway placed on embankment. Despite deterioration has been encountered there is a little variation of stiffness here. Only close to the km 202+300 one see a change with 11.4 Hz excitation.

Parts of this stretch show clear correlations between longitudinal level and stiffness (Appendix D42).

203+200-203+340 is problematic area in transition zone of viaduct. Drop in stiffness has been measured where average stiffness on the viaduct 170 kN/mm decrease to 120 kN/mm on adjacent embankment.

204+535-204+930 is a stretch with two bridges. Variation of stiffness on the bridges and adjacent embankments can be the reason of track irregularities requiring repeated track levelling.

Minor correlation can be seen between longitudinal level and stiffness, except after the second bridge where the correlation is clear (Appendix D 47).

4.3 Section 3 Polom – Suchdol nad Odrou, km 221+800 – 227+300

Problem stretches:

Track 1	Track 2
222+000-222+100	222+000-222+100

223+000-223+100 225+150-225+550
225+150-225+550
226+000-226+600*

stretches where track irregularities have occurred, track levelling is required, but those are not as expressive as those marked with *

* stretches where track irregularities have occurred for a long period, are progressing very fast and repeat again after track levelling

Stationary measurements:

Track 1: 221+900 track without problem
222+045 track with problems
223+000 track without problem
223+065 track with problems
223+075 track with problems
225+240 track with problems
225+310 track without problems
225+506 track with problems
226+117 track with problems

Track 2: 221+900 track without problem
222+030 track with problems
225+240 track with problem
225+310 track without problems
225+508 track with problems

Track 1

The average values of track stiffness have been measured around 149 kN/mm (6.8 Hz) and 164 kN/mm (11.4 Hz). Phase -13 and -26 degrees respectively. The lowest stiffness at km 222+580 is 75 kN/mm. Unfortunately Banverket has got no information about structures like bridges, culverts etc. More detailed study to explain variation of stiffness and especially particular higher values can be explained by presence of bridges, culverts, switches, level crossings etc. Station area of Polom station shows higher stiffness than the next track. Stiffness measurements have shown considerable variation of stiffness between km 222+400 and 223 +000, even if the average stiffness in this part of the track is quite high.

222+000-222+100 is marked as the first stretch with problems. Variation of stiffness has been measured especially at transition close to Polom station.There is a decrease from 200 kN/mm to 130 kN/mm. At the end of this marked stretch one see increase of stiffness to 170 kN/mm again.

There is a clear correlation between longitudinal level and stiffness as can be seen in Appendix D51.

223+000-223+100 is the stretch where we measured variation of stiffness between 150 to 250 kN/mm. Even if the average stiffness is high, just variation can be an explanation to recorded tack problems.

It can also be seen from Appendix D53 that the high stiffness variation correlates with longitudinal level.

225+150-225+550 showed the same problem as those stretches already mentioned, namely repeating track geometry deterioration. There are bridges at km 225+130 and 225+353, like a culvert km 225+430. Transitions have much lower stiffness than the track on firm structures what can be a cause of problems resulting in repeated track deterioration.

Parts of this stretch one can find correlations between longitudinal level and stiffness as can be seen in Appendix D57.

226+000-226+600 has been marked as more problematic stretch than the previous ones. The variation of stiffness is not so obvious. A plan drawing shows that the railway at this part is founded on embankment starting from the km 226+258 with slightly higher stiffness than the section between km 226+000 and 226+258 where track is in a cutting on the left side and on en embankment on the right side.

There is low correlation between longitudinal level and stiffness on this stretch (Appendix D59-60).

Track 2

The average values of track stiffness are 161 kN/mm (6.8 Hz) and 179kN/mm (11.4 Hz). Phase -13 and -25 degrees respectively. Track 2 has lower variation of stiffness than Track 1. High variation has been observed close to the Polom and between km 222+400 and 222+550. At this section we measured even the lowest stiffness about 80 kN/mm. Since we do not have information about the railway structure and man made objects we recommend further studies to find explanation for this stiffness variation. There are some places with higher stiffness and we assume that at those areas the track is placed on bridges. The Czech Technical University (CVUT) has measured static stiffness of the track between km 223+936 and 223+960 (23,40 m). Average stiffness of left rail was 92,6 kN/mm and right rail had stiffness of 153,7 kN/mm. Even if it is very difficult to compare dynamic and static stiffness it can be noticed that dynamic stiffness measured by RSMV of 200 kN/mm correspond to the values measured by CVUT.

222+000-222+100 showed slight variation of stiffness especially for excitation with 11.4 Hz. This part is situated in the vicinity of Polom station with 4 tracks and such variation is usual for station areas with a few tracks and switches.

Parts of this stretch show correlation between longitudinal level and stiffness (Appendix D64).

225+150-225+550 this problematic stretch like the Track 1 has shown considerable stiffness variation mainly close to the bridges at km 225+130 and 225+3537, like close a culvert at km 225+430.

Only the final 150 m of this stretch show correlation between longitudinal level and stiffness (Appendix D70-71).

4.4 Discussion on noise excitation and stationary measurements

The results from RSMV test in 7 km/h with noise excitation (appendix C) and stationary measurements (Appendix E) are not analysed in previous chapters.

The previous experience from noise excitation is mostly on very soft soils. In that case there are methodologies giving a possibility to extract estimate thickness of the soft layers as well as shear wave velocities. However during these measurements the track was not founded on such very soft soils. There is an intention that within the INNOTRACK project to develop better evaluation methodologies for ordinary soils, and hopefully to come back with deeper analysis of these measurements as well.

The stationary (stand-still) measurements are presented as receptances in Appendix E. They are clustered in order to make comparisons directly in the graphs. The coherence in the bottom part of all graphs is a measure of how good the estimate is. It should at least exceed 0.8 for results to be acceptable. Studying the graphs, it is hard to draw conclusions. There is no pattern between good or bad positions on the track. This is mainly due to the fact that the stiffness is quite variable (as can be seen from Appendix B). One can not be sure from one position to another whether the excitation has been done on a local maximum or minimum stiffness spot. The differences of stationary measurements between good and bad spots are quite small (often only around 10%).

Also, as should be clear after these investigations, that it is not always the absolute value of the stiffness that causes a good or bad track. Instead the variation can cause problems, and these are captured by rolling measurements. During the stationary measurements there were as well some measurement problems. One displacement sensor broke and the applied excitation has in some cases not been the same as the design excitation.

4.5 Discussion on correlation of stiffness and longitudinal level

As Appendix D perhaps gives the most interesting result a few more words could be in place for explanation. If the track develops errors in longitudinal level more in the soft part than in the stiff part of a stiffness variation, that must mean that the track is deterioration sensitive at those spots. As the ballast and sub-ballast layer are recently upgraded, the reason is below those layers; either in the stabilised layer or in the subsoil. If the same problem with the same wavelength was there before the upgrading, it is clear, that the upgrading have not cured/mitigated the problem. Often old tracks have a “soil memory”. If a track for instance first was constructed as a jointed track and afterward upgraded to a CWR track, track geometry problems could appear at the position of old joints. This is a result of that the soil beneath the joints is partly fatigued and exposed to higher level of stress under long time period. The wavelength in this case is around 8 – 10 m and do not coincide with possible former joints (joint example only as illustration). However old track geometry faults (longitudinal level) can cause the same type of history in the track where old problems in subsoil can propagate to new upgraded superstructure.

6. CONCLUSIONS

Banverket have successfully carried out stiffness measurements for CD within the INNOTRACK project. The following conclusions could be drawn from the measurements:

- The overall global track stiffness for the whole railway line is normal.
- Variation of global track stiffness along the track is normal and we have not detected any place with particular low stiffness. Some transition zones have shown higher variations; however that is usual on railway tracks.
- Sections 1 and 2 were less stiff than section 3, although all three sections could be considered as normal.
- The superstructure consisting of ballast and sub-ballast is new and homogeneous and we think that problems can occur either in the lime stabilisation or the subsoil.
- Correlations between track stiffness variations and longitudinal level have been found. Many of the indicated problem areas have shown this correlation. It is obvious that the stiffness variations copies to the track (longitudinal level) and cause deterioration of track with time.
- If these problems in longitudinal level were present before the upgrading of the track, it is well known that the upgrading (lime stabilisation) didn't mitigate the problem.
- Since the wavelength of problems are quite limited (8-12 metres), the traffic can contribute to the propagation of problem. Vehicle axle geometry and speed combinations should be investigated if these coincide with current problems.
- Directly from stiffness measurements, we can not decide if the problem is in stabilisation or subsoil. Our suggestion is to study results from georadar measurements (GPR) and compare waves on and under stabilisation and to find if those match with the stiffness measurements.
- To decide exact position of problem, field investigations (excavations) have to be done in particular places that have to be decided with results of all already obtained measurements.
- Our experience is that in order to find the root-cause of track problems, thorough simultaneous studies and comparisons of all available information and measurements about the actual railway line are necessary. The stiffness measurements are only one part of that necessary information.

7. REFERENCES

Nehomogenity železnicní trati jako aspect její kvality – Grantový projekt č. 103/00/0200, ČVUT Fakulta Stavební, katedra železničníich staveb, 2002

Doplňkový geotechnický a stavebně technický průzkum – Modernizace úseku tratě Přerov – Hranice, GeoTec –GS, a.s. 1998.

E. G. Berggren, Dynamic Track Stiffness Measurement – A New Tool for Condition Monitoring of Track Substructure, Licentiate thesis TRITA AVE 2005:14, Royal Institute of Technology (KTH), Stockholm 2005.

8. ATTACHMENTS

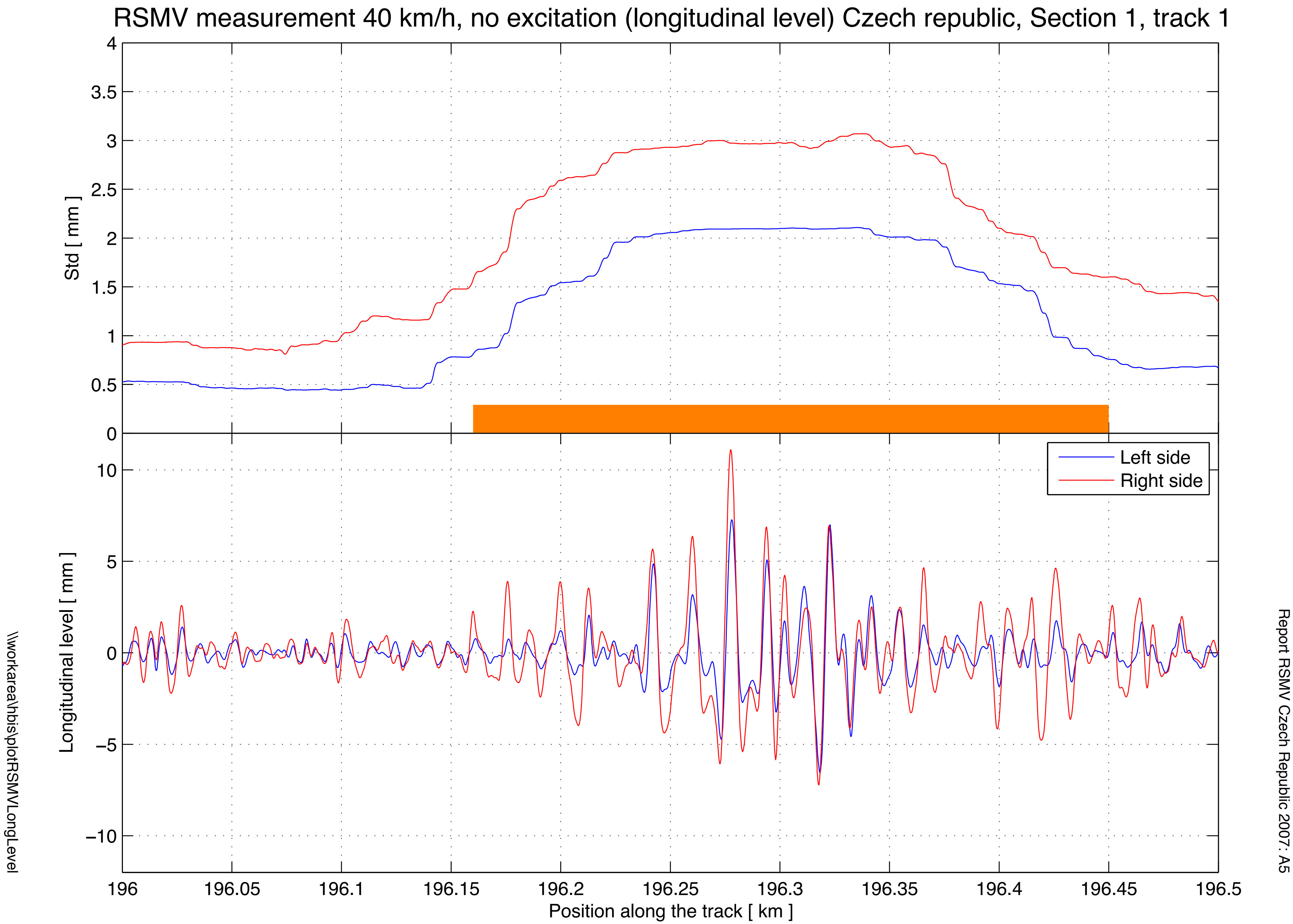
A. RSMV measurements 40 km/h no excitation (longitudinal level)

B. RSMV measurements 40 km/h excitation 6,8 and 11,4 Hz

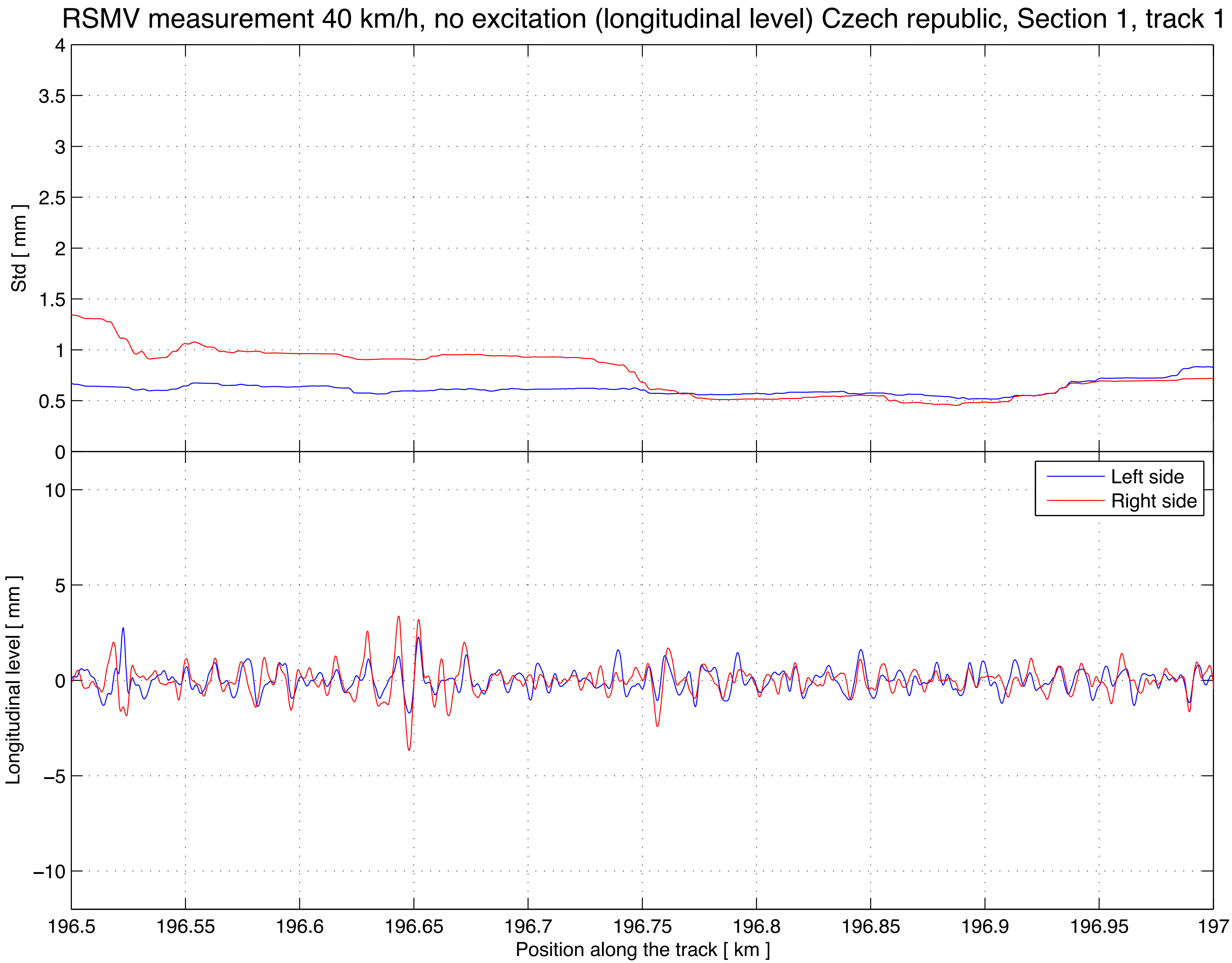
C. RSMV measurements 7 km/h excitation 2-20 Hz

D. RSMV presentation of measurements 40 km/h excitation 11,4 Hz and longitudinal level λ=5-15 m

E. RSMV Stationary measurements



RSMV measurement 40 km/h, no excitation (longitudinal level) Czech republic, Section 1, track 1
Std [mm]
4
3.5
3
2.5
2
1.5
1
0.5
0
Left side
Right side
Longitudinal level [mm]
10
5
0
−5
−10
196
196.05
196.1
196.15
196.2
196.25
196.3
196.35
196.4
196.45
196.5
Position along the track [km]
\\workarea\hbis\plotRSMVLongLevel
Report RSMV Czech Republic 2007: A5



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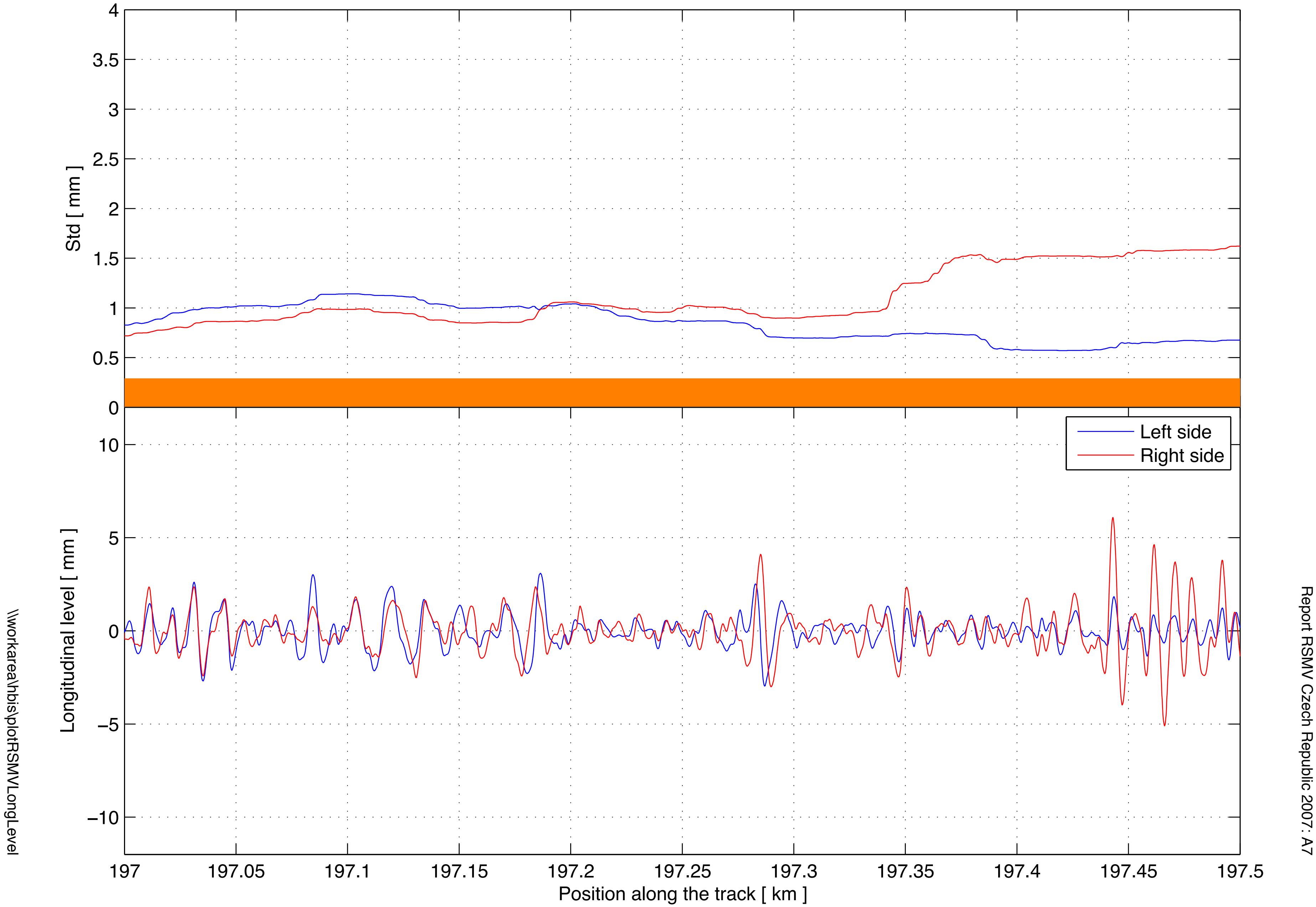
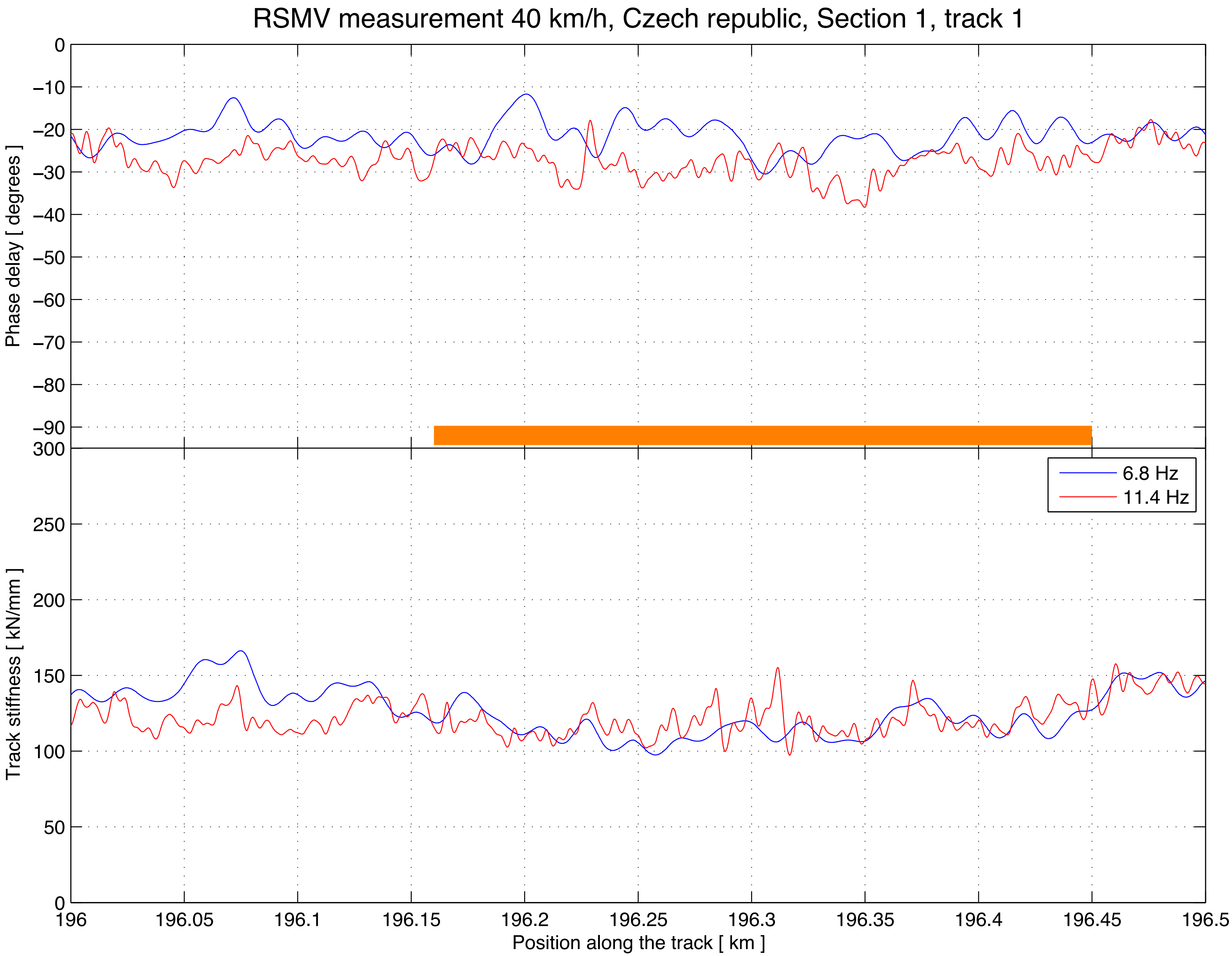
Report RSMV Czech Republic 2007: A6

RSMV measurement 40 km/h, no excitation (longitudinal level) Czech republic, Section 1, track 1





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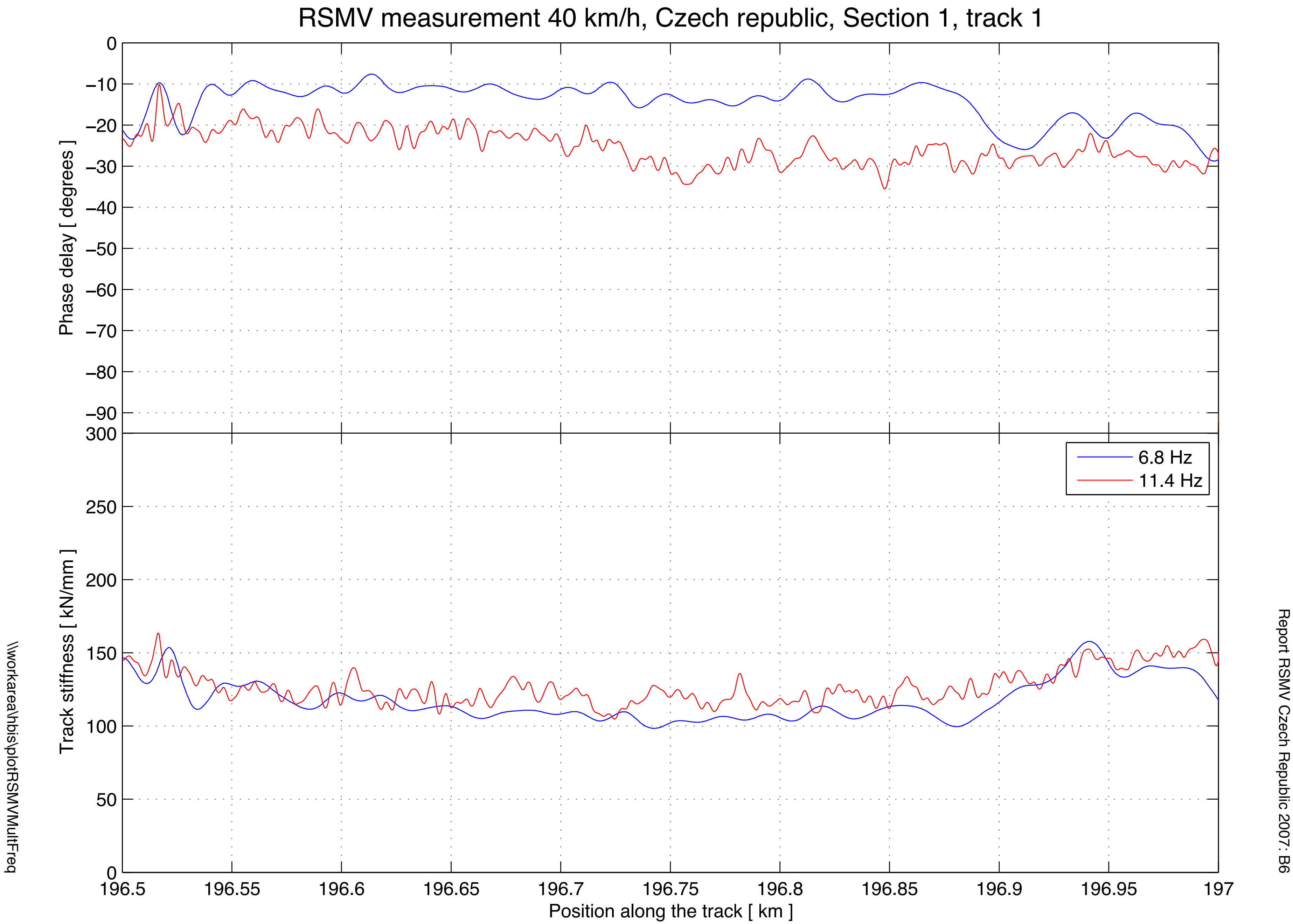
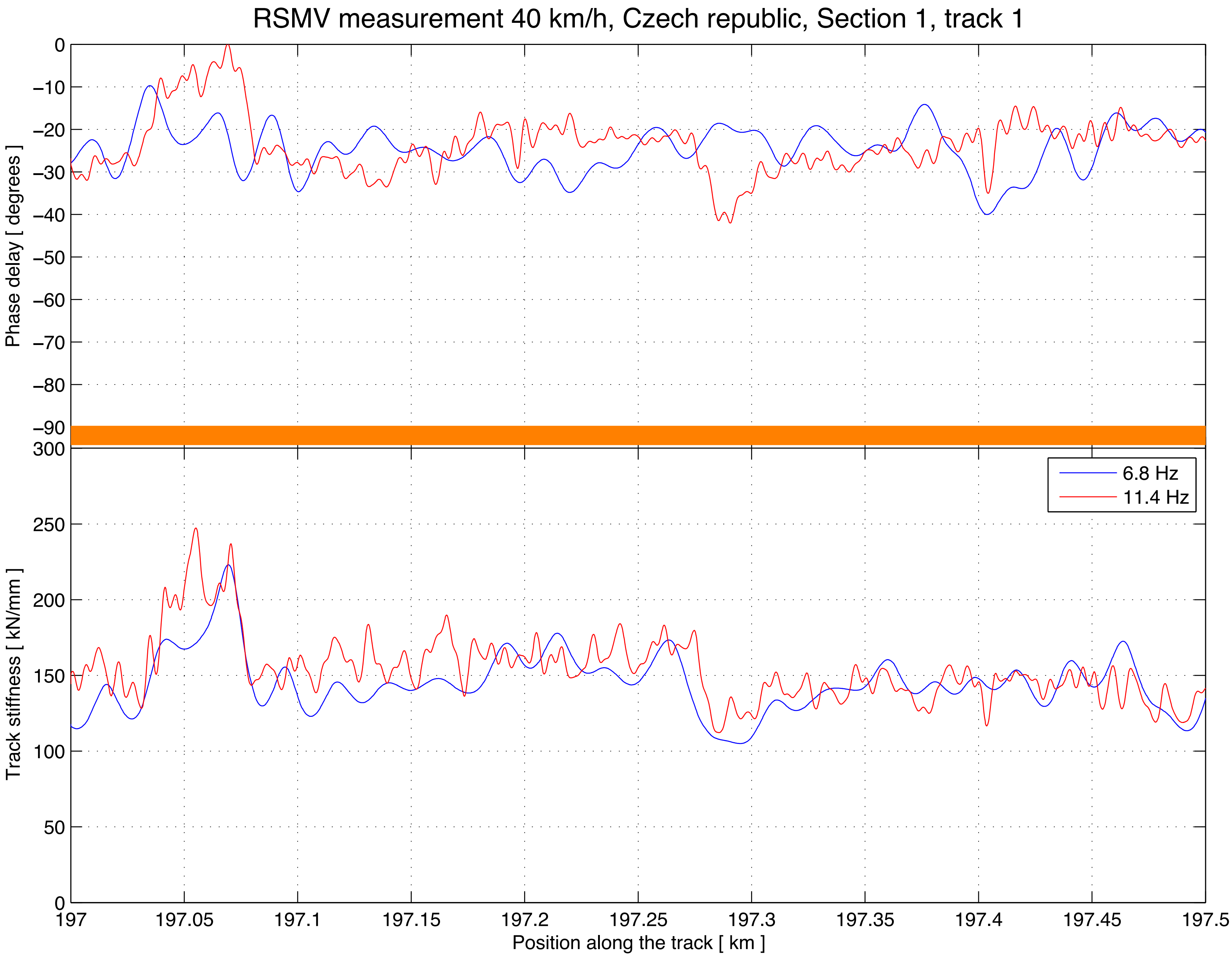

RSMV measurement 40 km/h, Czech republic, Section 1, track 1
Phase delay [degrees]
0
−10
−20
−30
−40
−50
−60
−70
−80
−90
300
250
200
150
100
50
0
Track stiffness [kN/mm]
6.8 Hz
11.4 Hz
196.5
196.55
196.6
196.65
196.7
196.75
196.8
196.85
196.9
196.95
197
Position along the track [km]
\\workarea\hbis\plotRSMVMultFreq
Report RSMV Czech Republic 2007: B6



\\workarea\hbis\plotRSMVMultFreq

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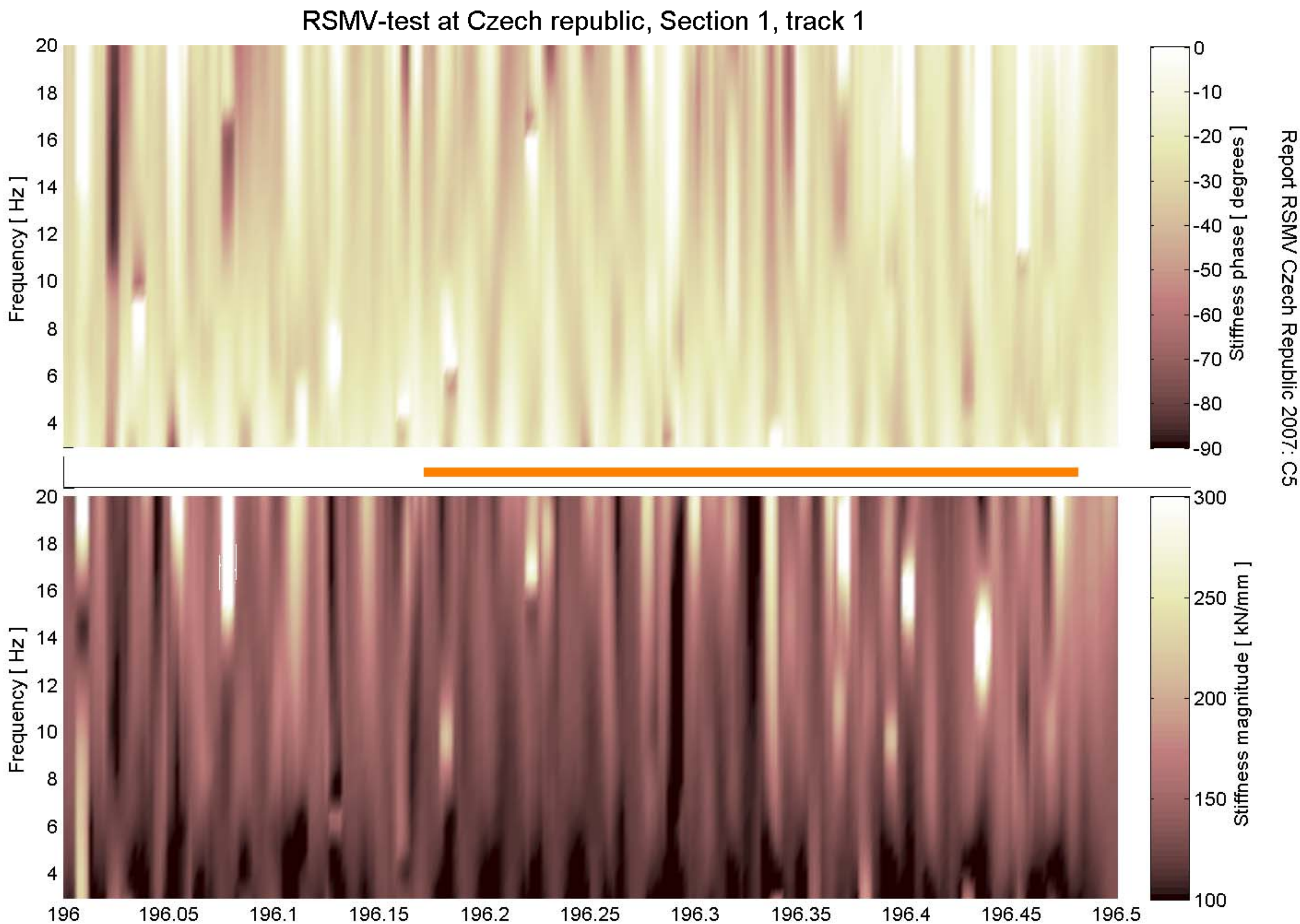
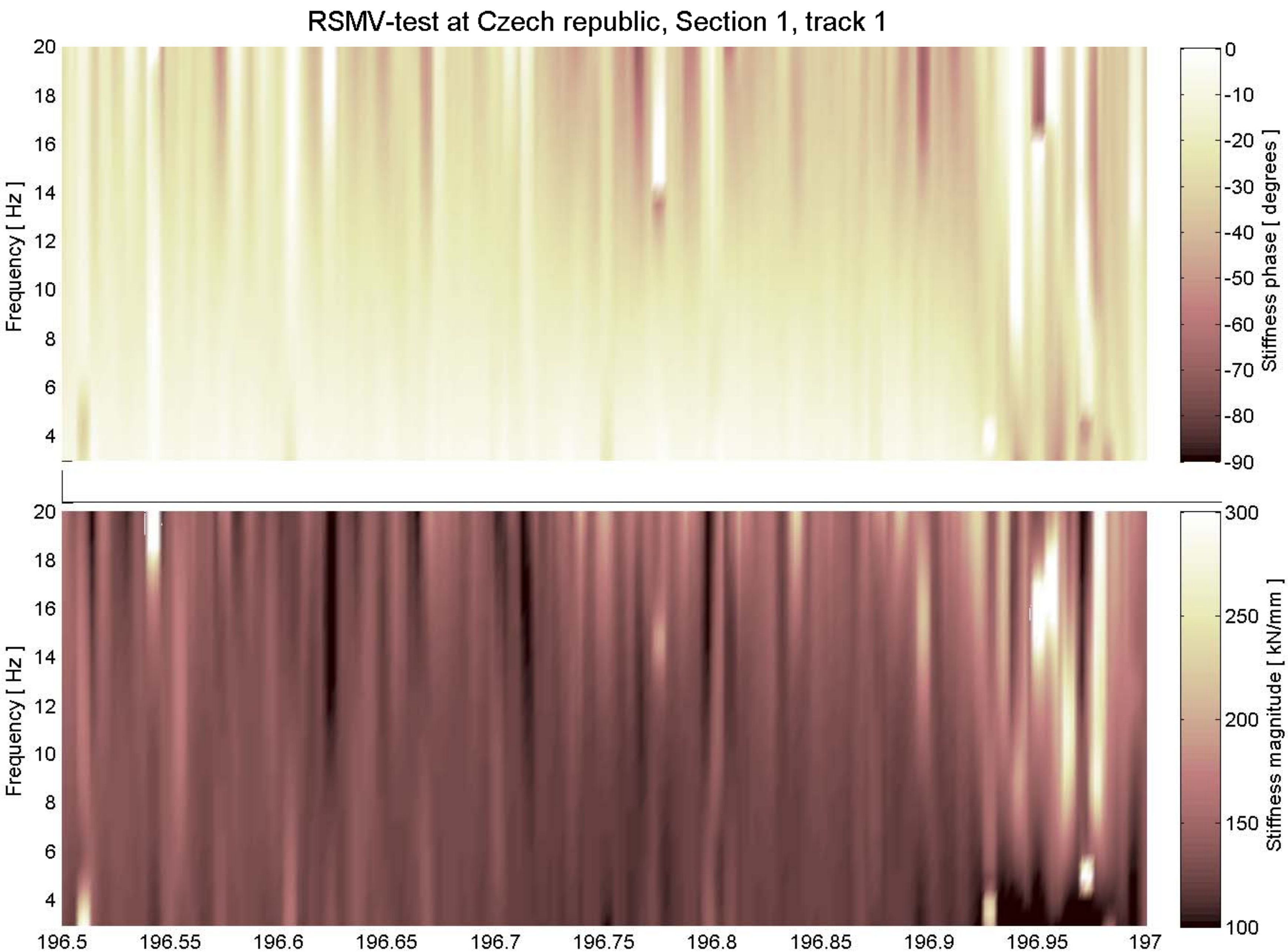
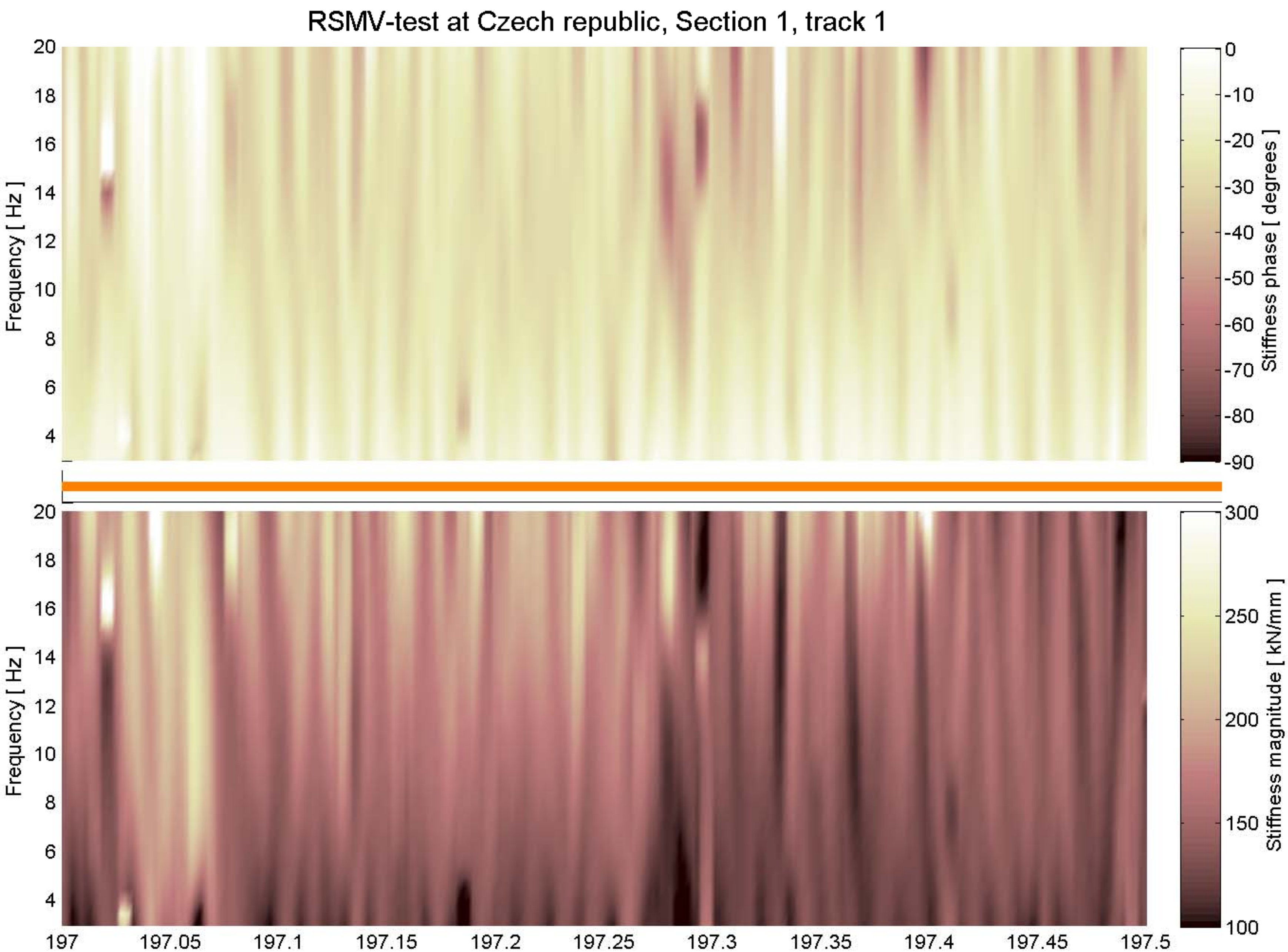
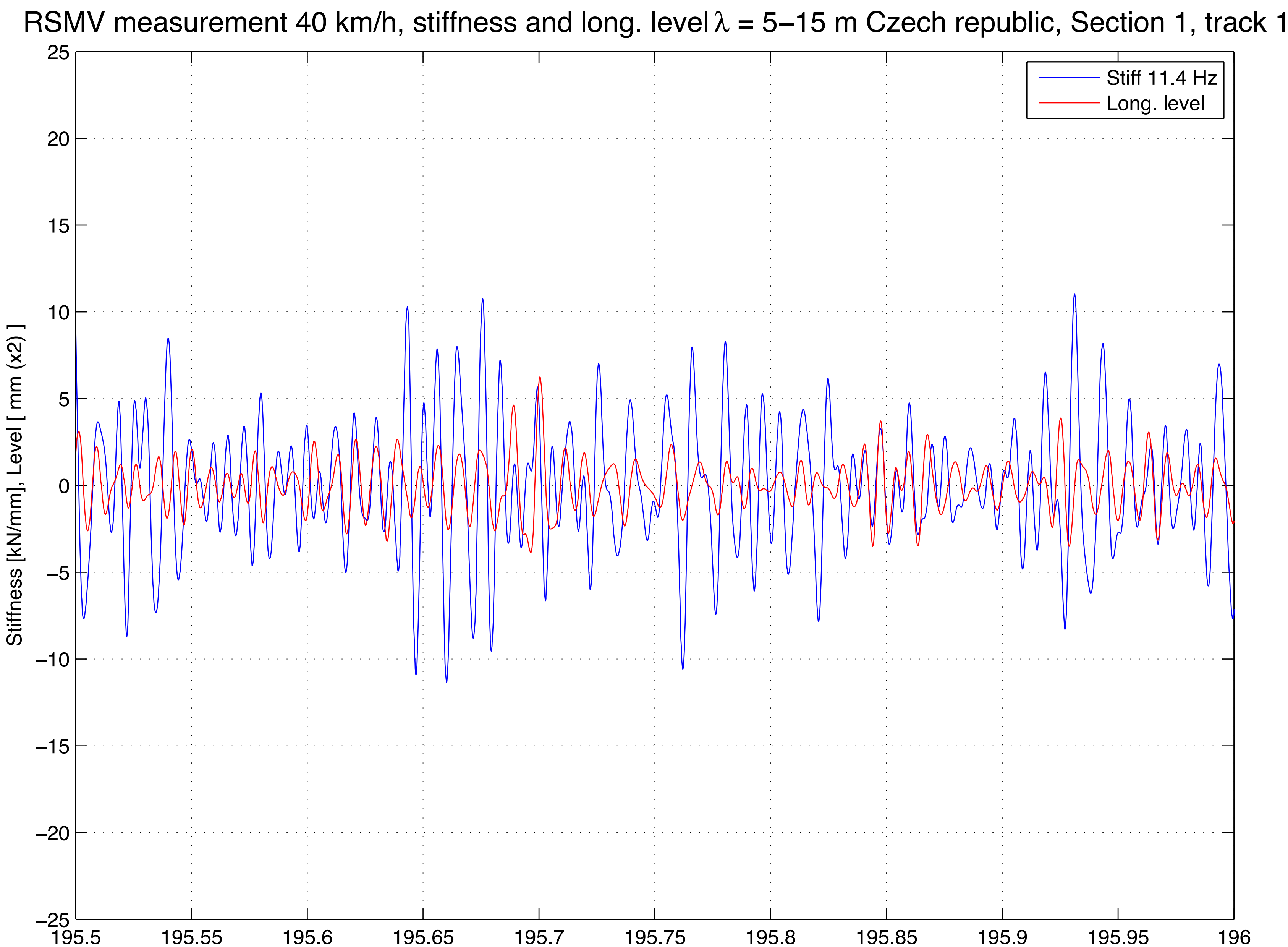

RSMV-test at Czech republic, Section 1, track 1
Frequency [Hz]
Stiffness phase [degrees]
Stiffness magnitude [kN/mm]
Report RSMV Czech Republic 2007: C5
196
196.05
196.1
196.15
196.2
196.25
196.3
196.35
196.4
196.45
196.5



RSMV-test at Czech republic, Section 1, track 1
Frequency [Hz]
20
18
16
14
12
10
8
6
4
0
-10
-20
-30
-40
-50
-60
-70
-80
-90
Stiffness phase [degrees]
300
250
200
150
100
Stiffness magnitude [kN/mm]
196.5
196.55
196.6
196.65
196.7
196.75
196.8
196.85
196.9
196.95
197


RSMV-test at Czech republic, Section 1, track 1
Frequency [Hz]
Stiffness phase [degrees]
0
-10
-20
-30
-40
-50
-60
-70
-80
-90
Stiffness magnitude [kN/mm]
300
250
200
150
100
20
18
16
14
12
10
8
6
4
197
197.05
197.1
197.15
197.2
197.25
197.3
197.35
197.4
197.45
197.5



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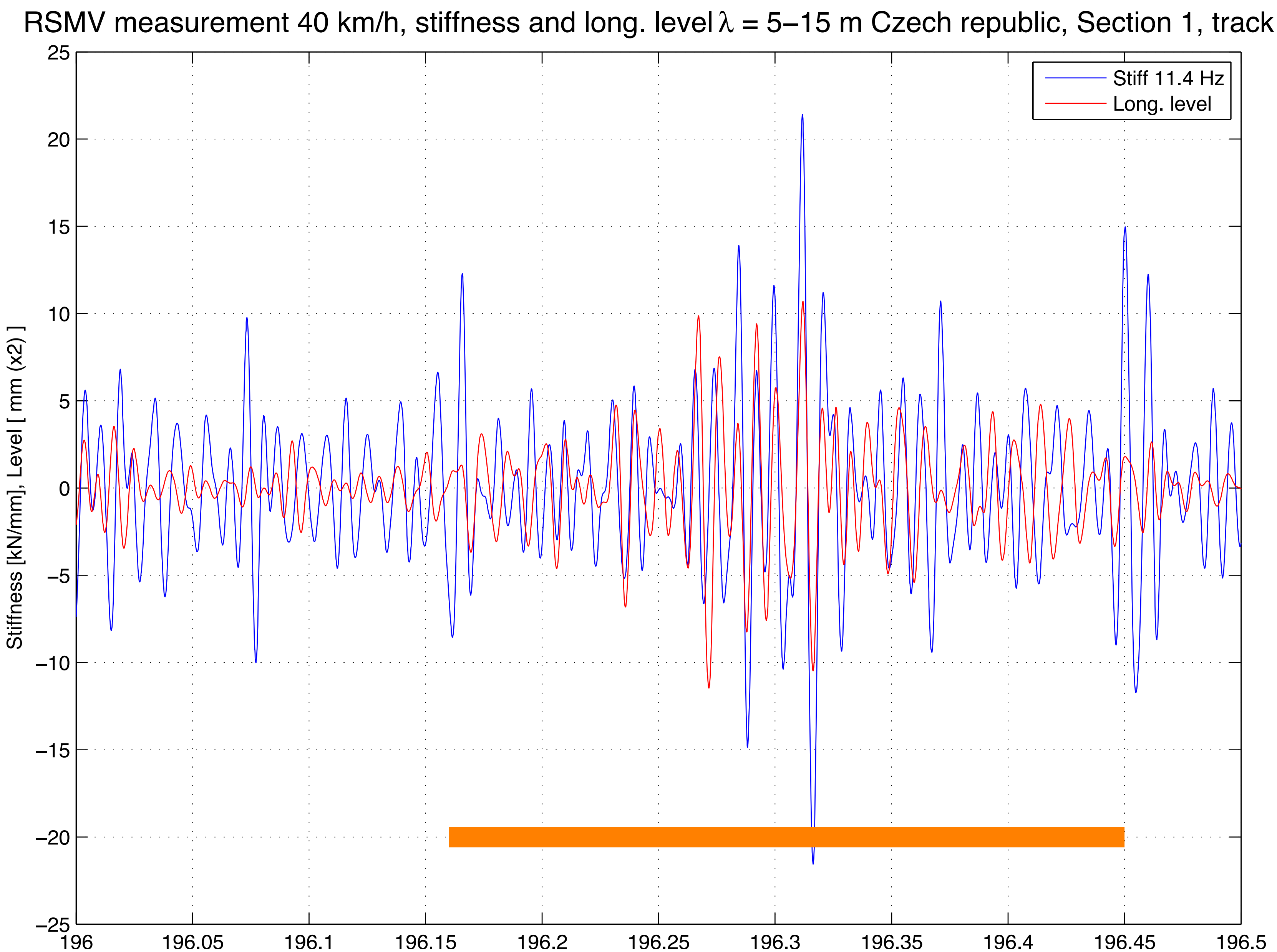

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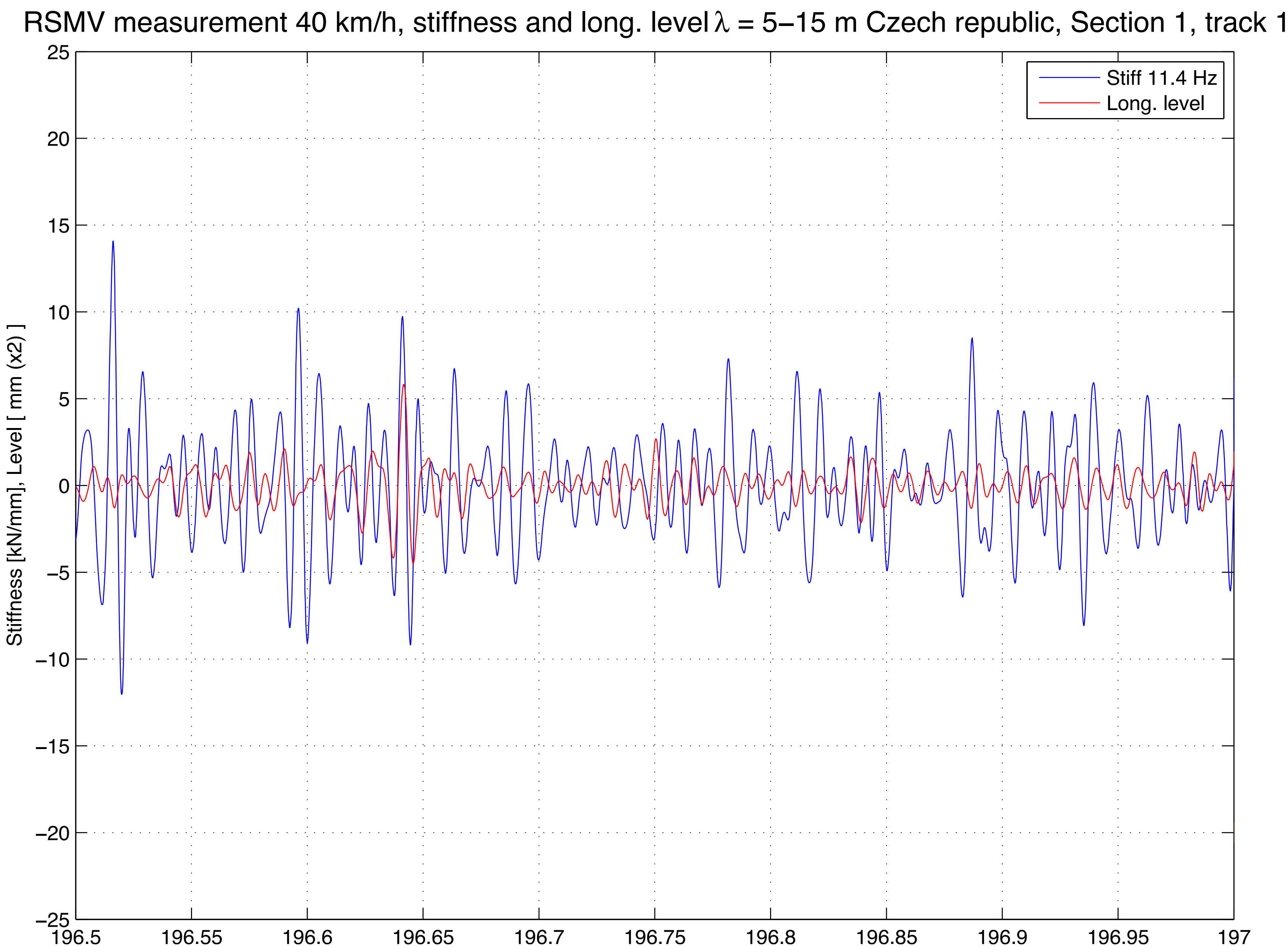

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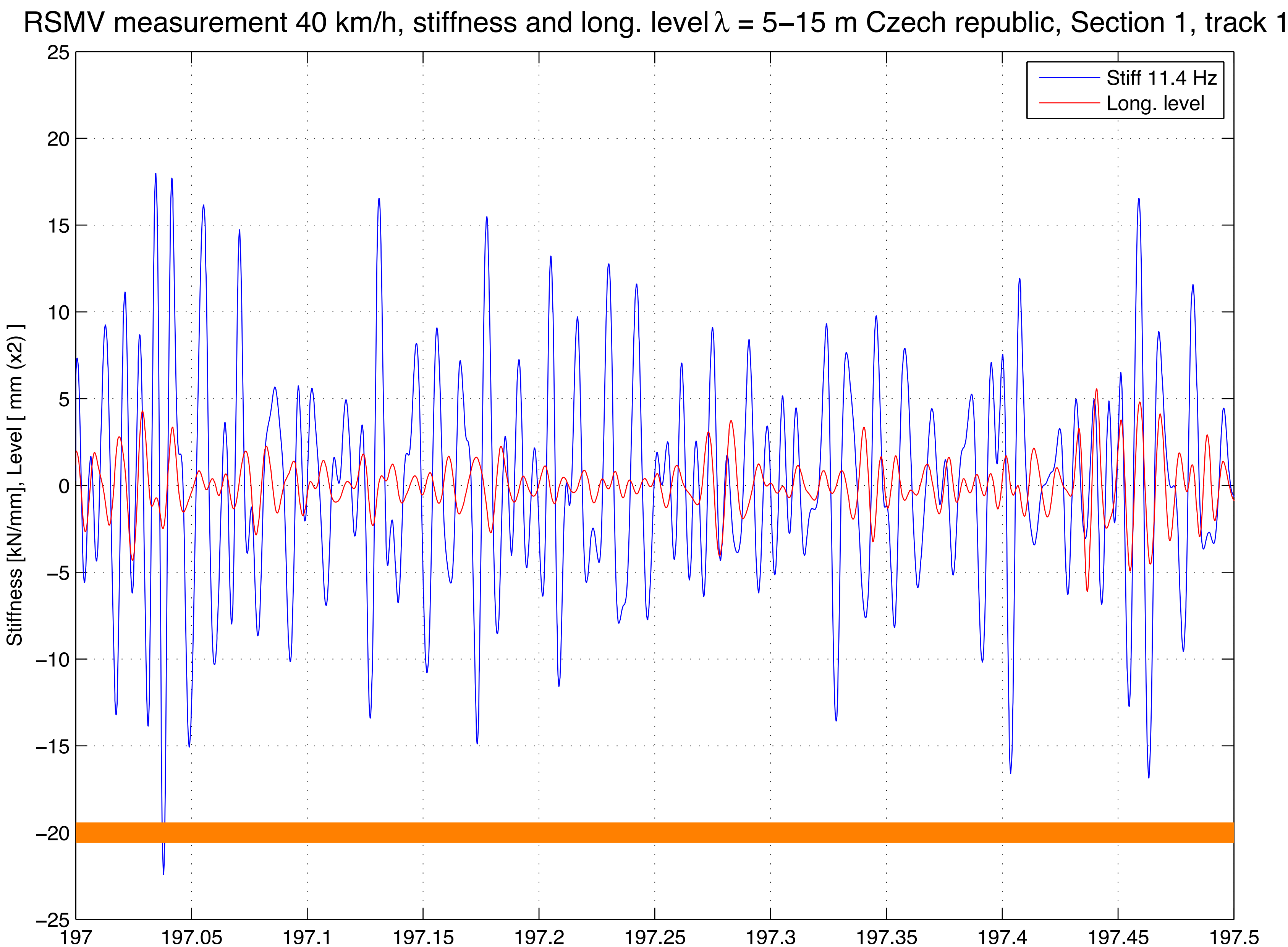
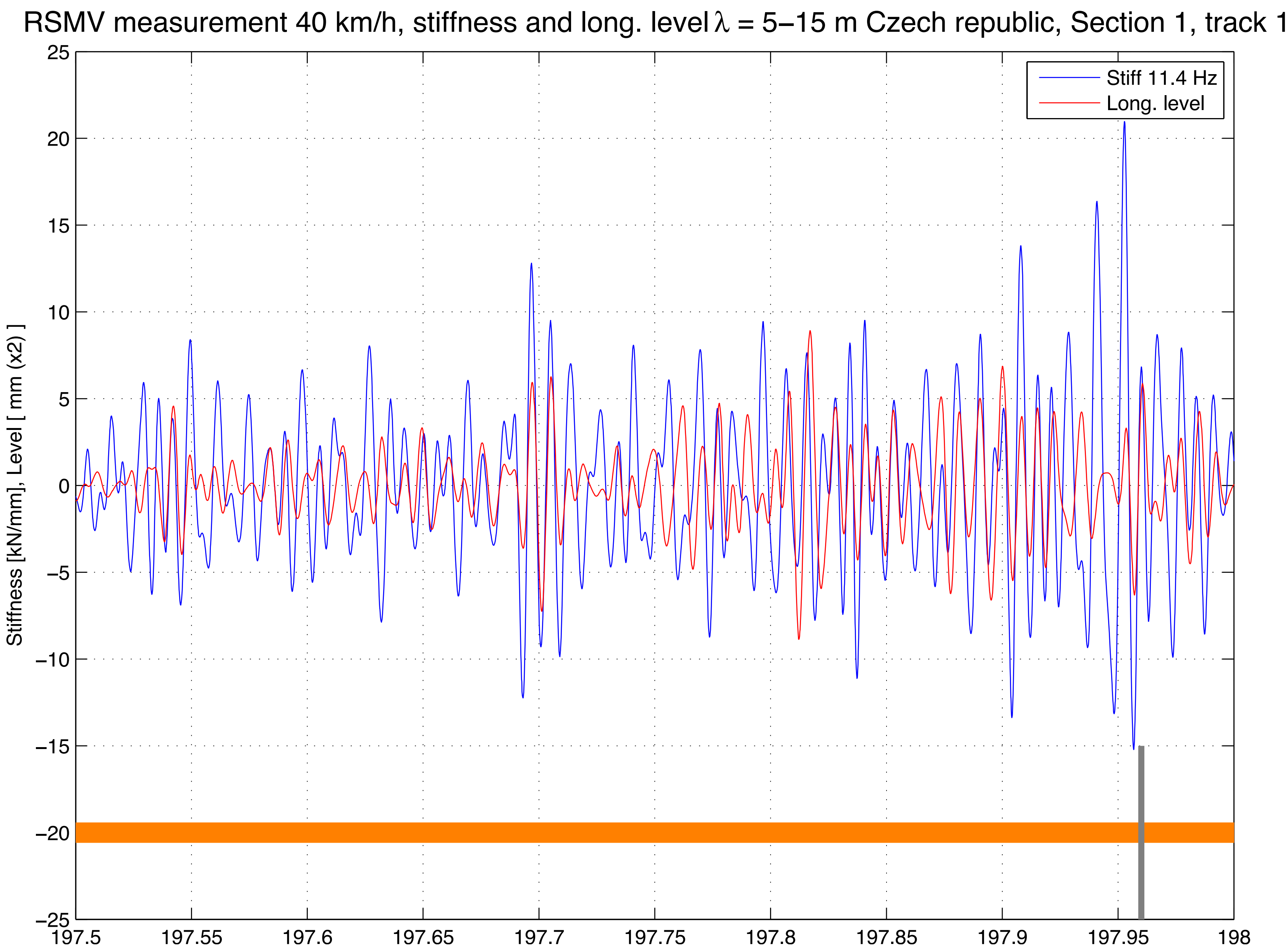


RSMV measurement 40 km/h, stiffness and long. level λ = 5–15 m Czech republic, Section 1, track 1
Stiff 11.4 Hz
Long. level
Stiffness [kN/mm], Level [mm (x2)]
25
20
15
10
5
0
−5
−10
−15
−20
−25
197
197.05
197.1
197.15
197.2
197.25
197.3
197.35
197.4
197.45
197.5



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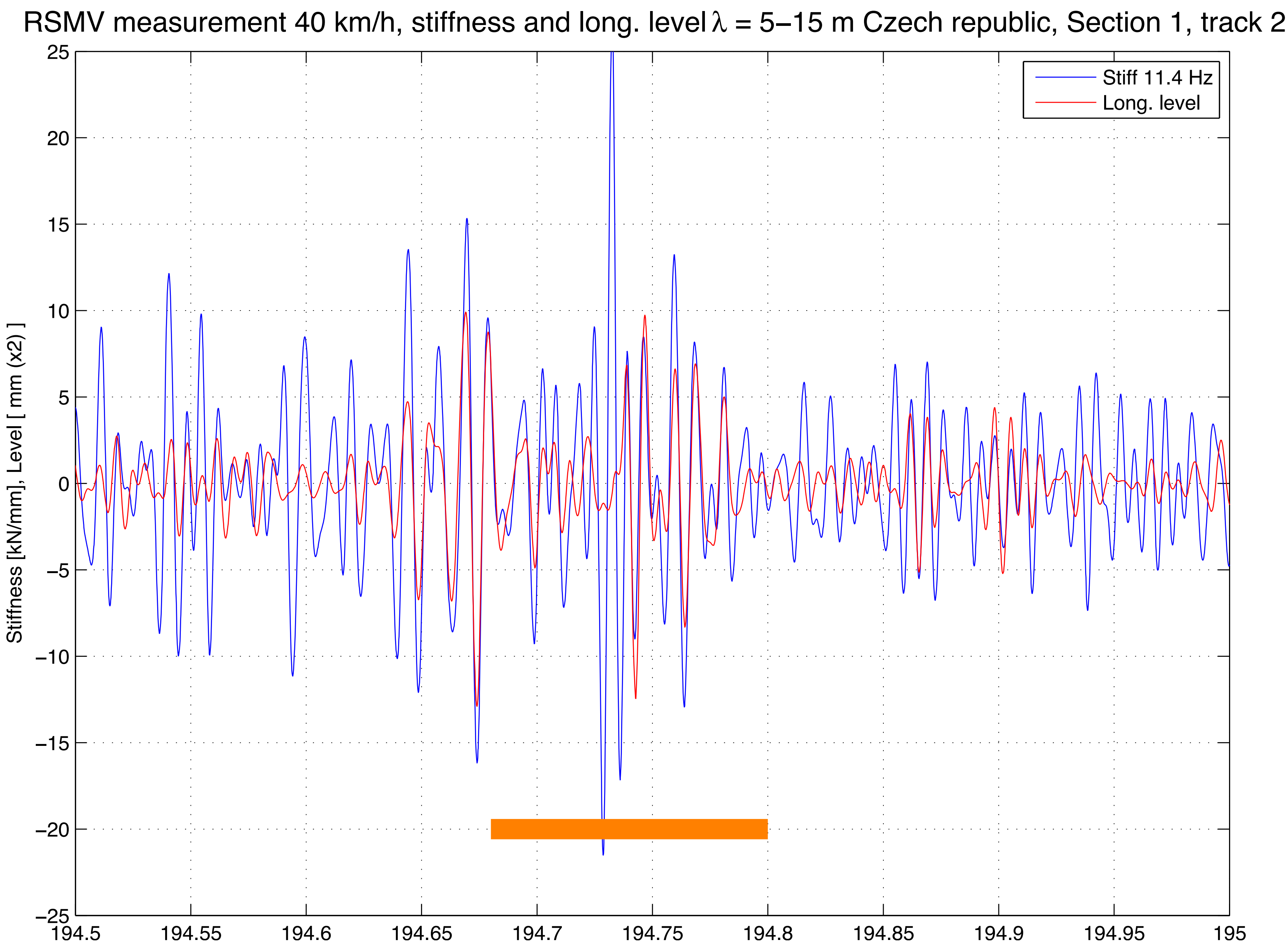
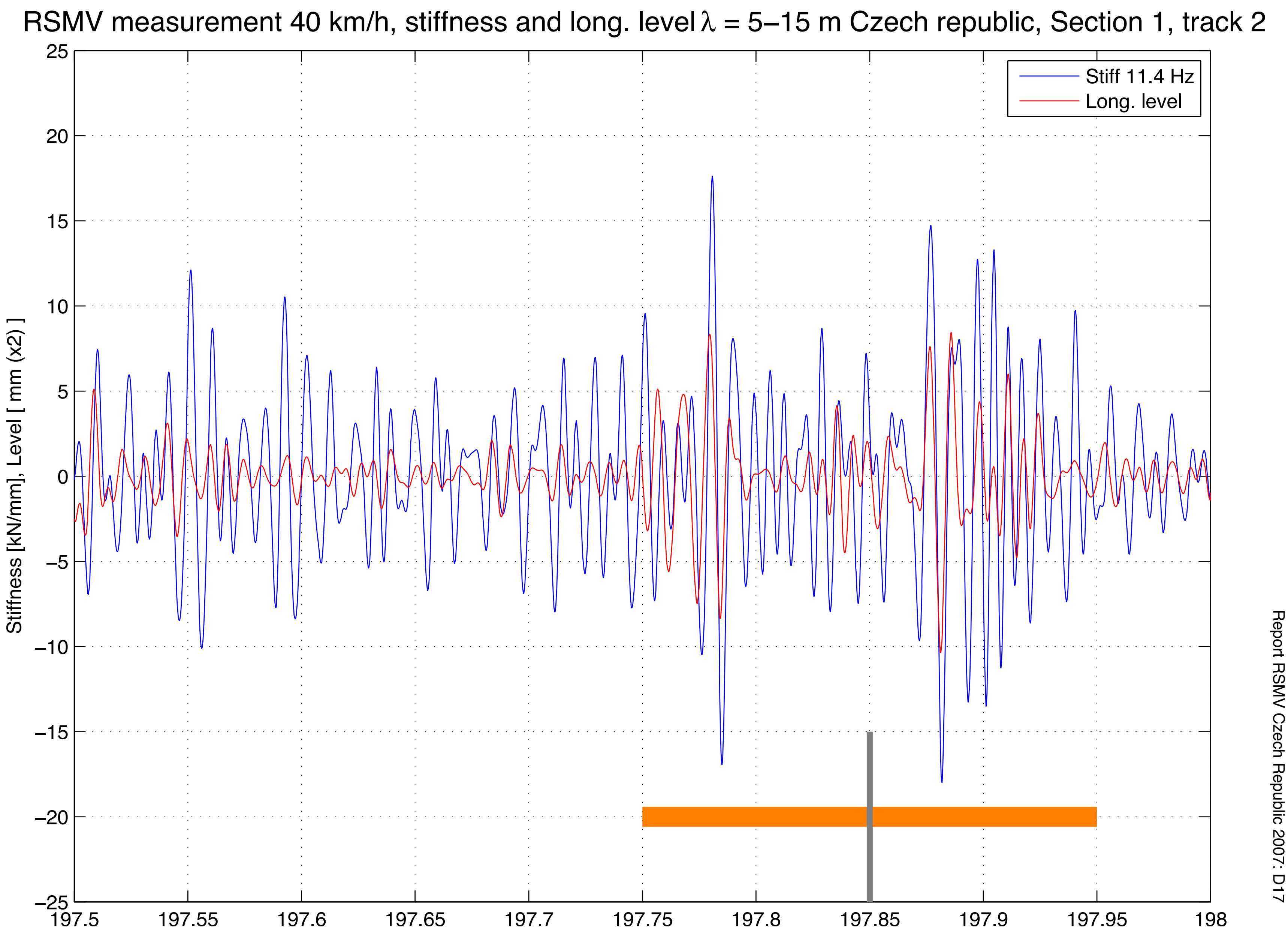
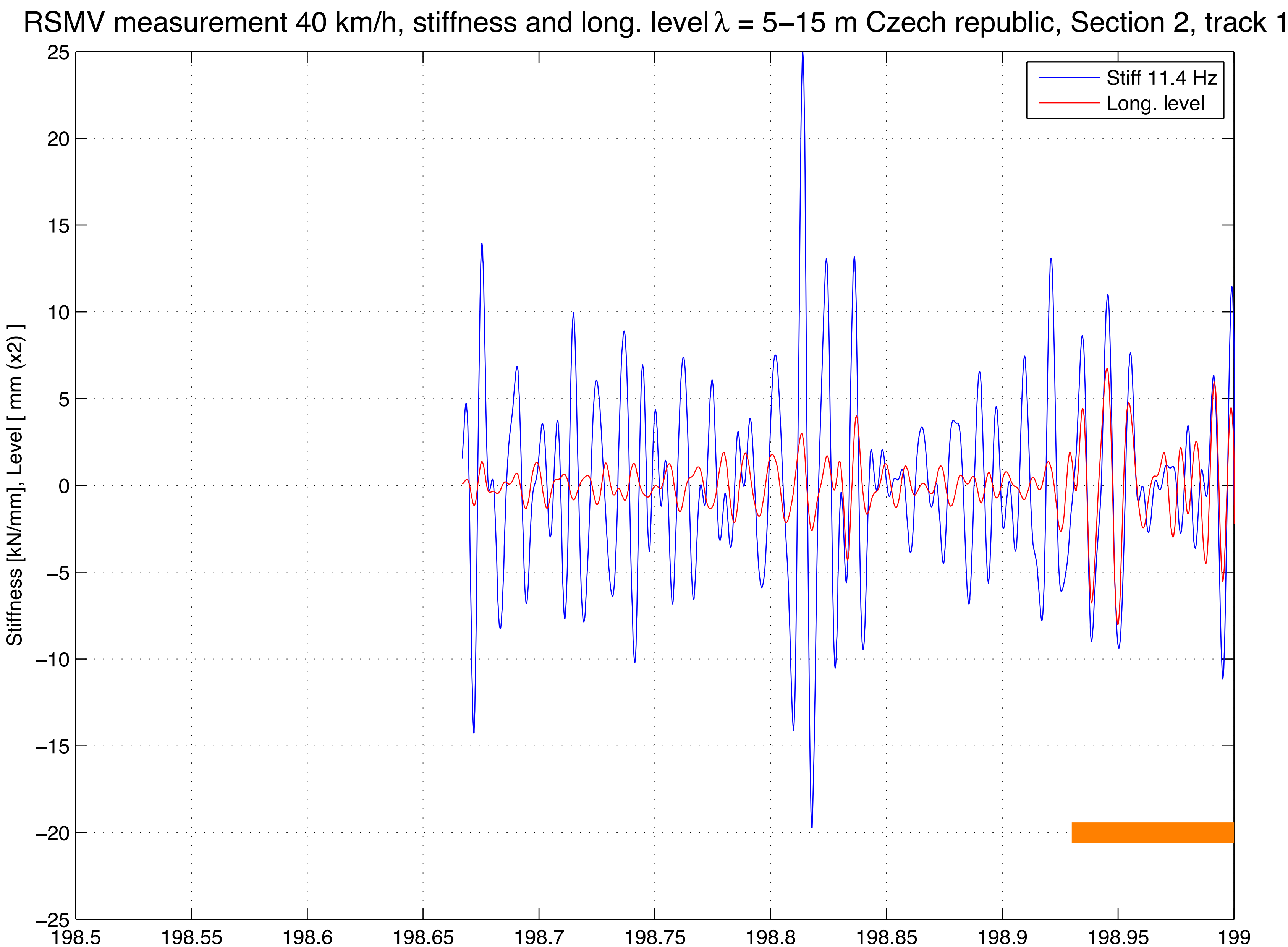

RSMV measurement 40 km/h, stiffness and long. level λ = 5–15 m Czech republic, Section 1, track 2
Stiff 11.4 Hz
Long. level
Stiffness [kN/mm], Level [mm (x2)]
25
20
15
10
5
0
−5
−10
−15
−20
−25
194.5
194.55
194.6
194.65
194.7
194.75
194.8
194.85
194.9
194.95
195


RSMV measurement 40 km/h, stiffness and long. level λ = 5–15 m Czech republic, Section 1, track 2
Stiff 11.4 Hz
Long. level
Stiffness [kN/mm], Level [mm (x2)]
25
20
15
10
5
0
−5
−10
−15
−20
−25
197.5
197.55
197.6
197.65
197.7
197.75
197.8
197.85
197.9
197.95
198
Report RSMV Czech Republic 2007: D17



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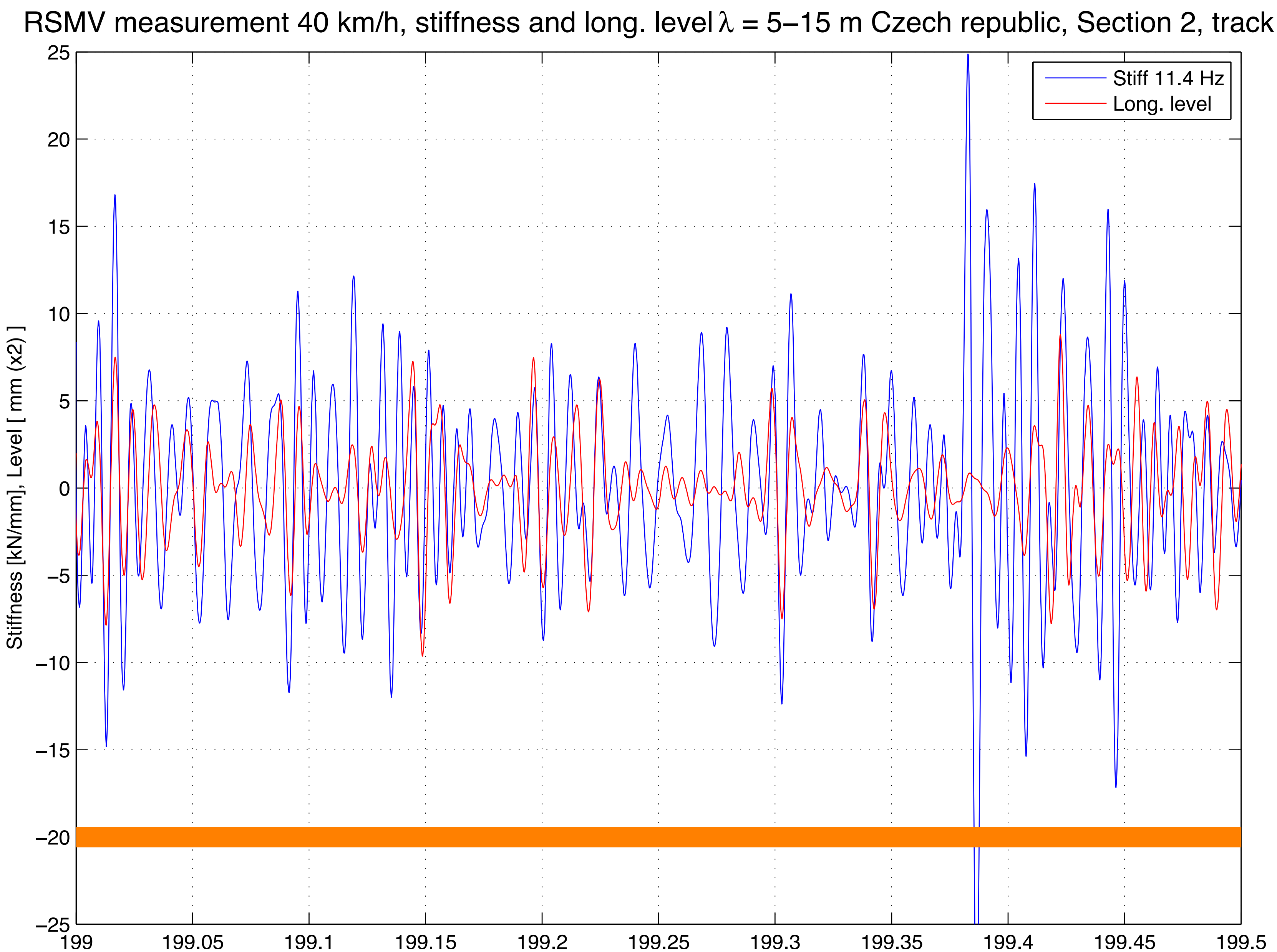

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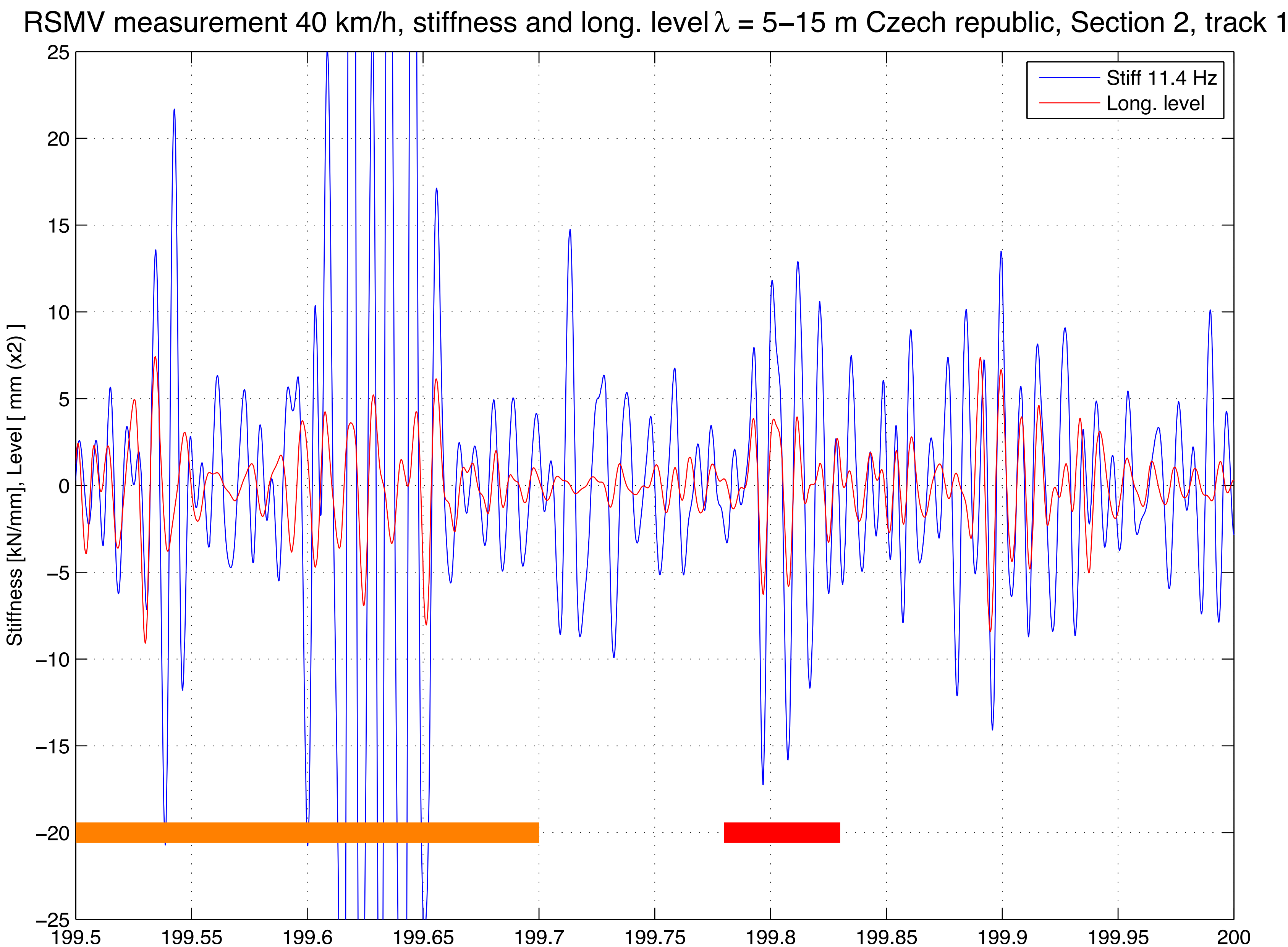

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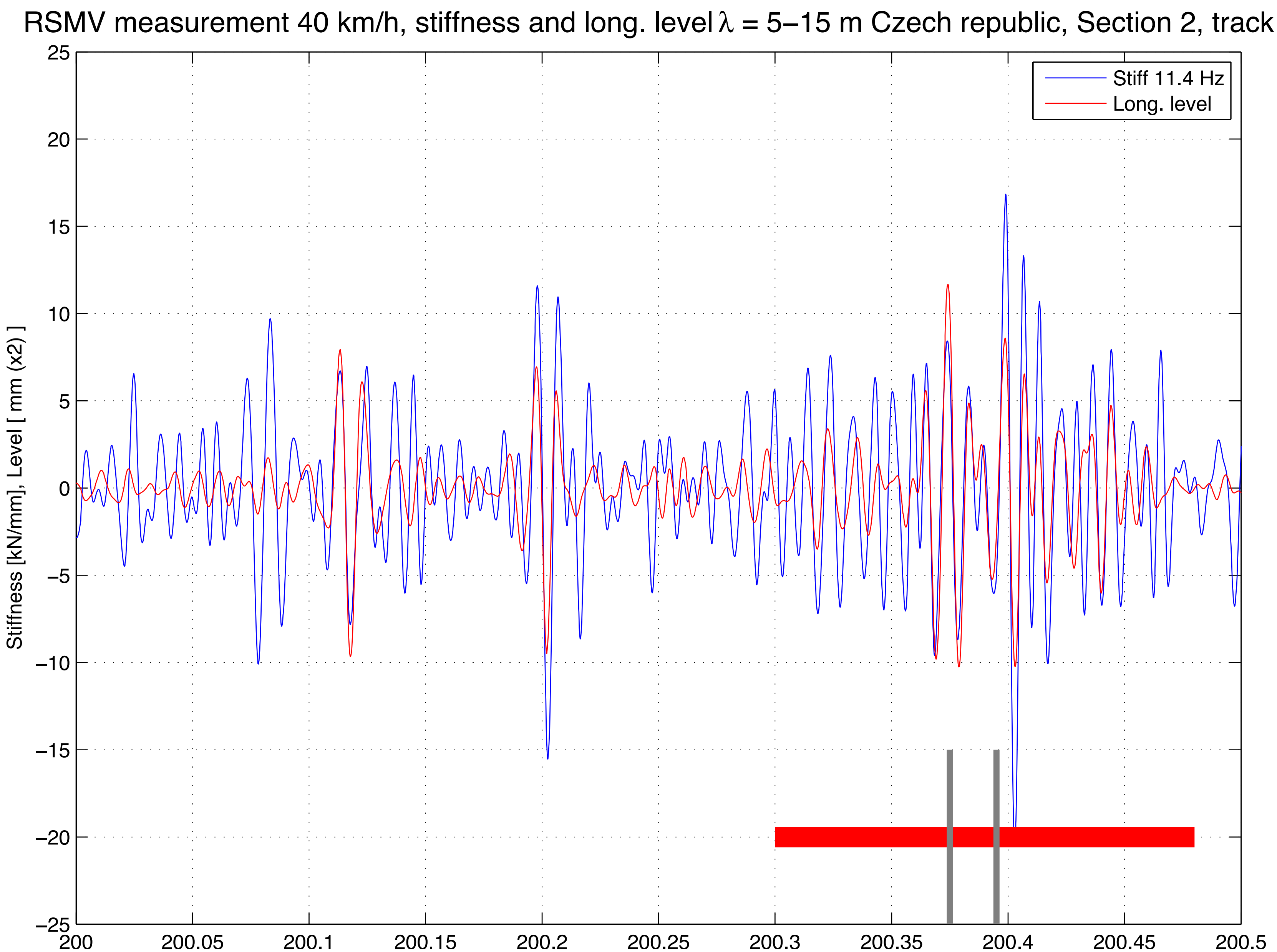

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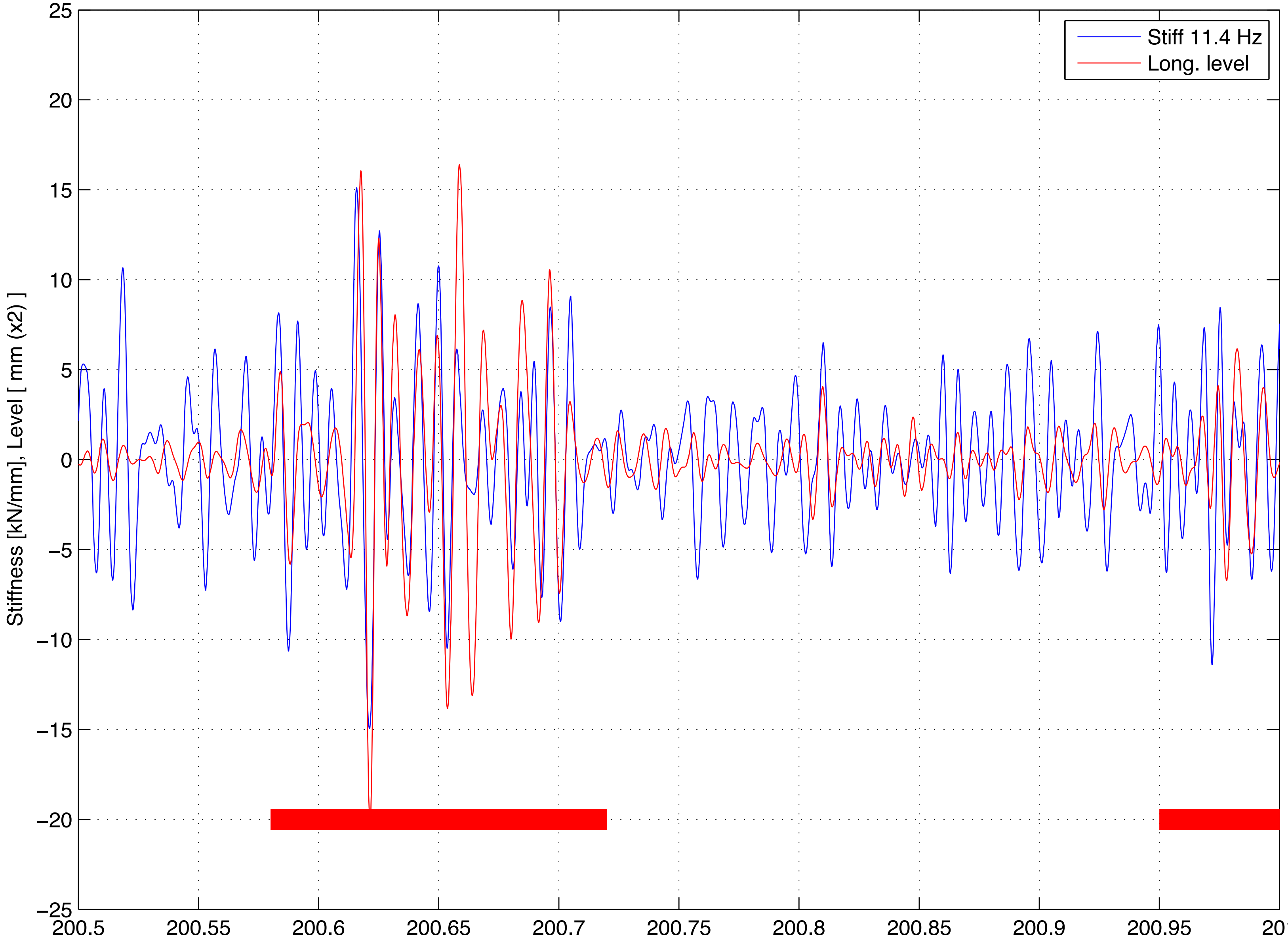
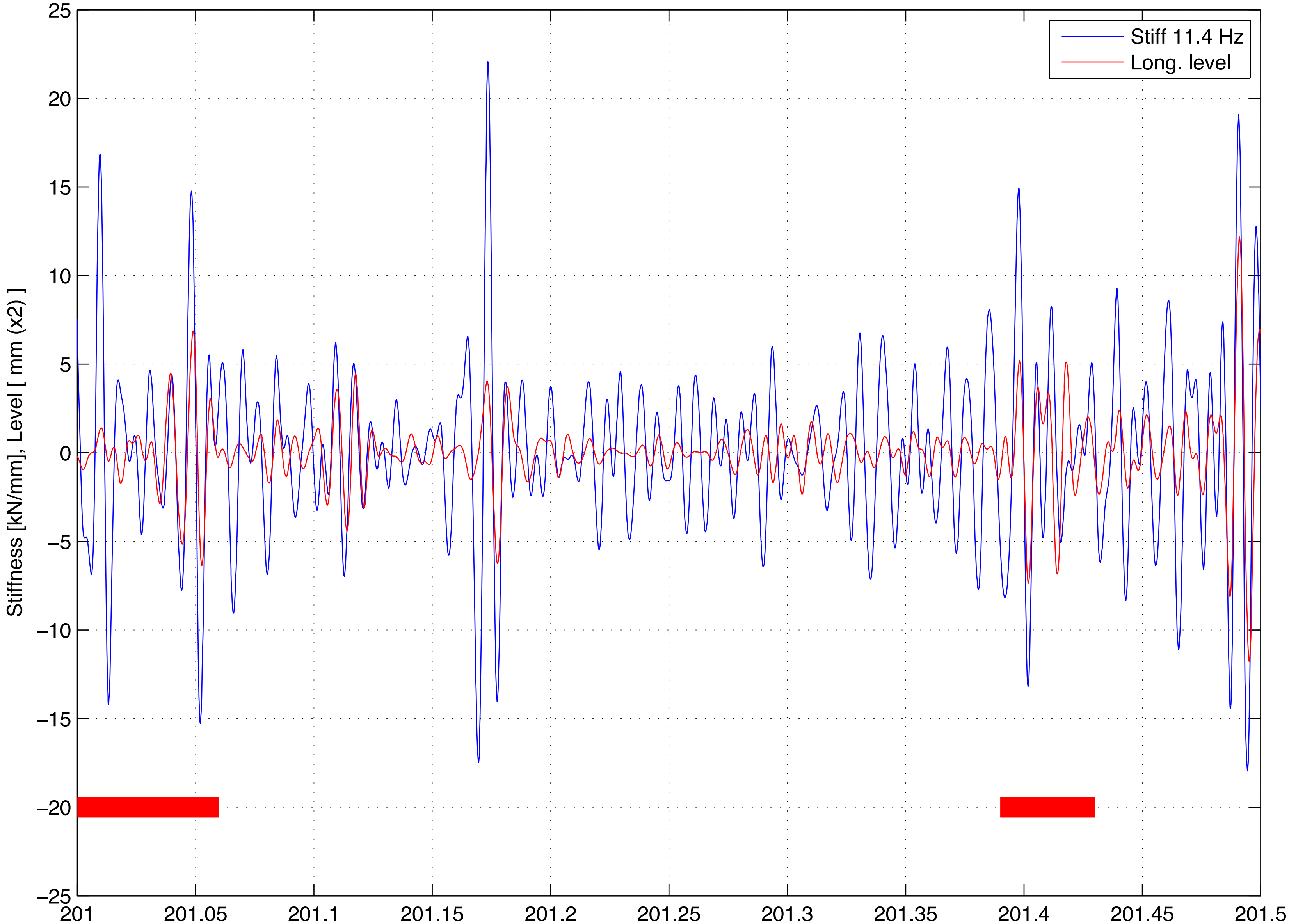
RSMV measurement 40 km/h, stiffness and long. level λ = 5–15 m Czech republic, Section 2, track 1



RSMV measurement 40 km/h, stiffness and long. level λ = 5–15 m Czech republic, Section 2, track 1



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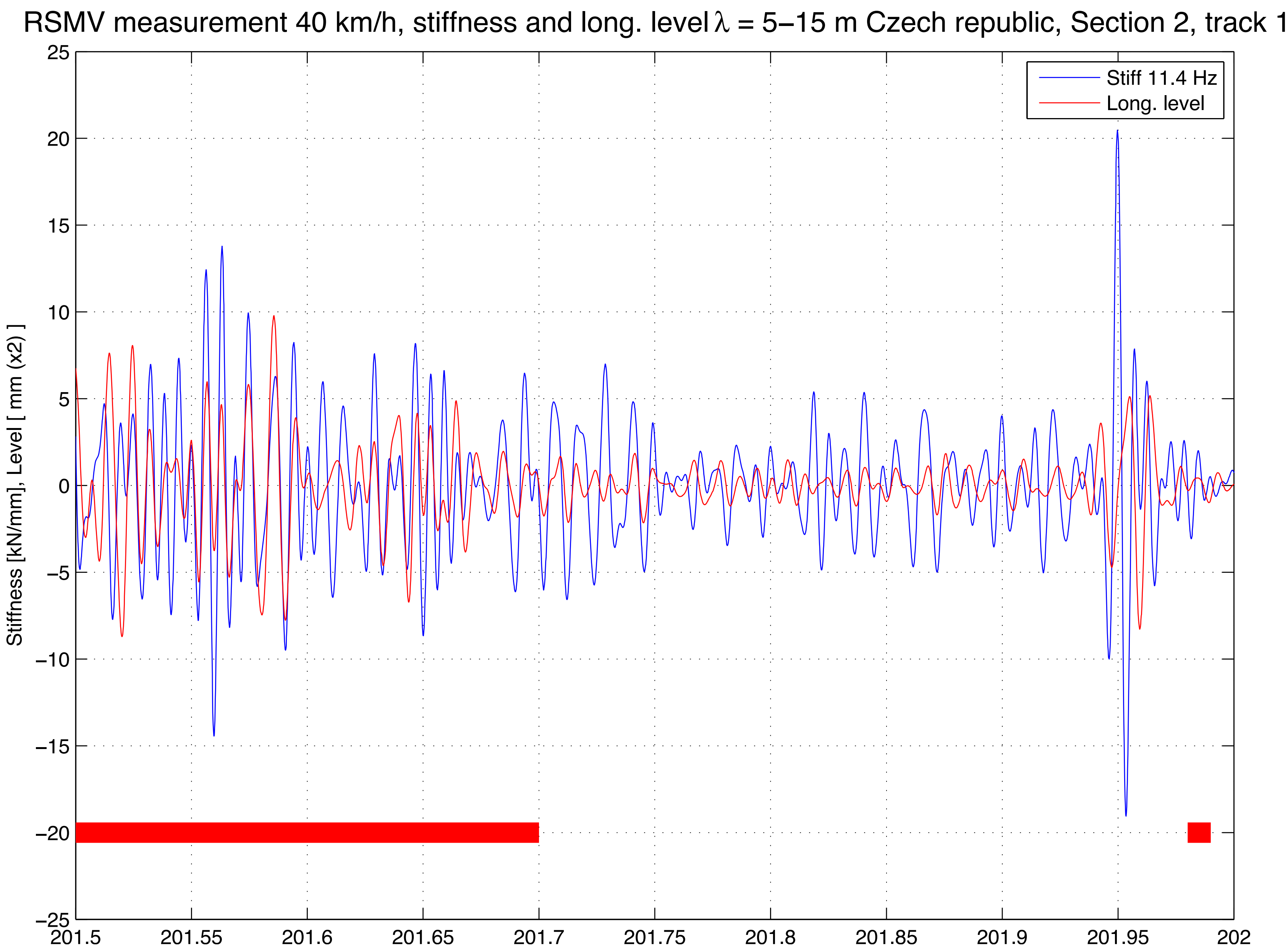

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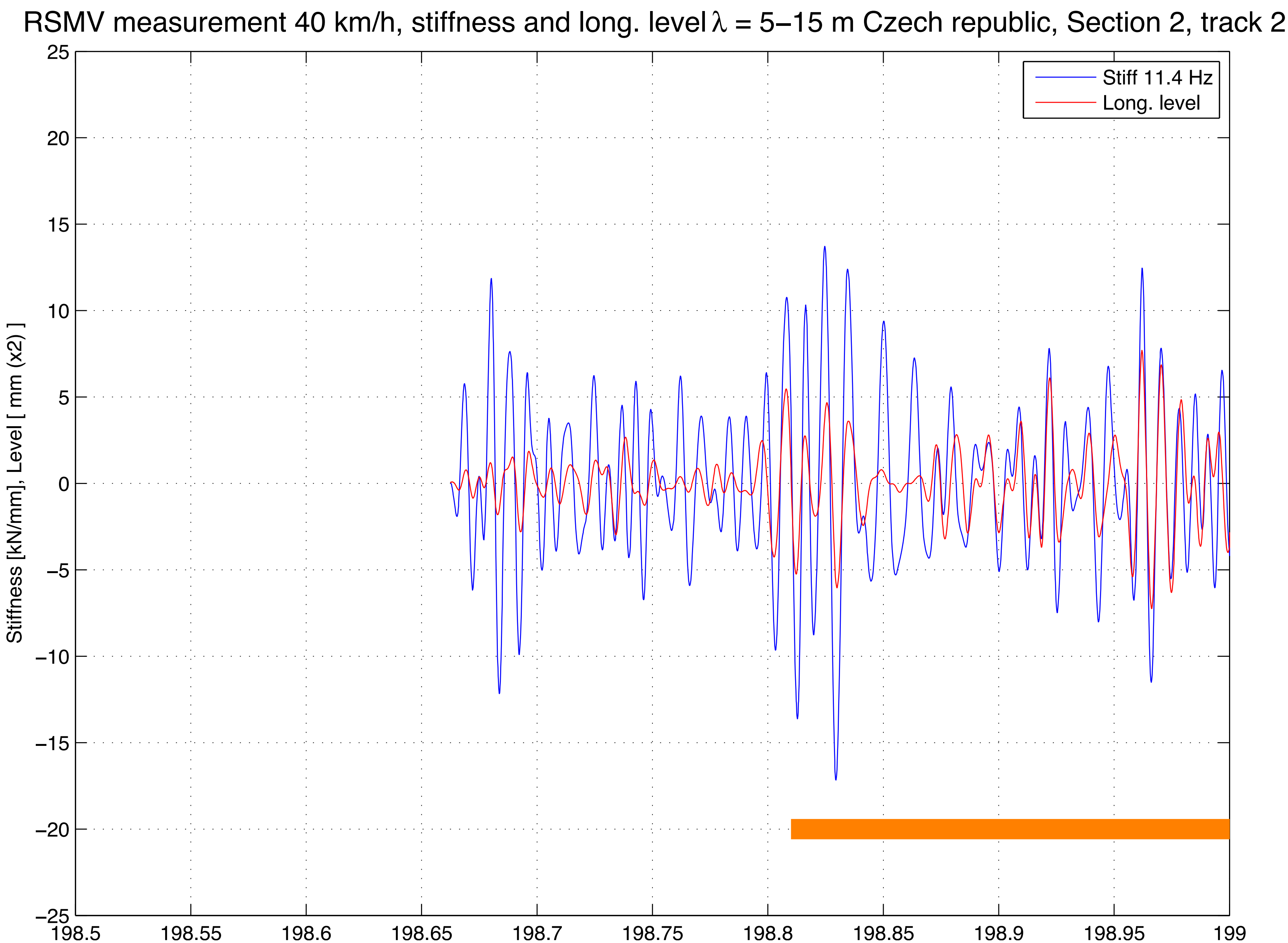

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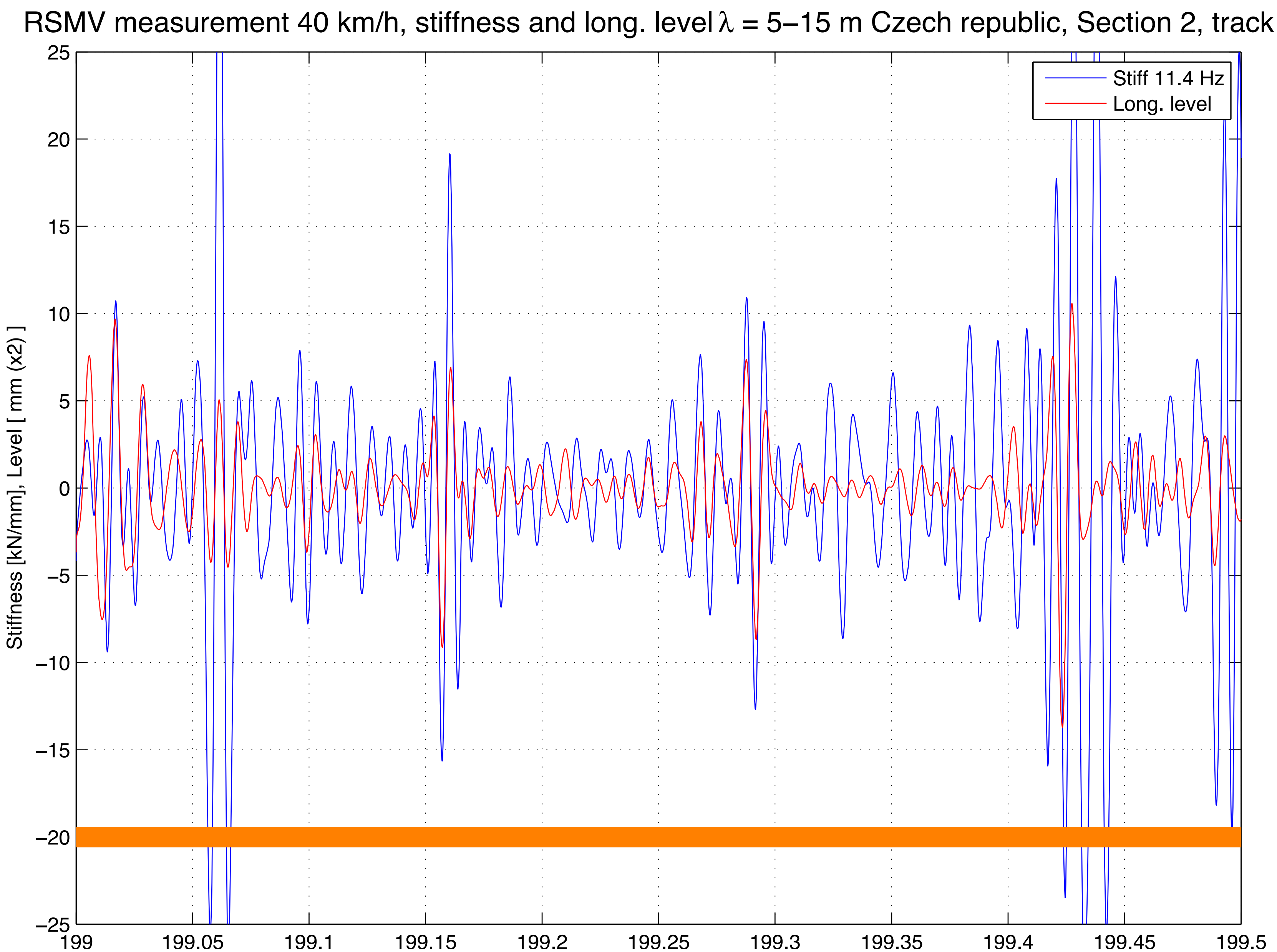

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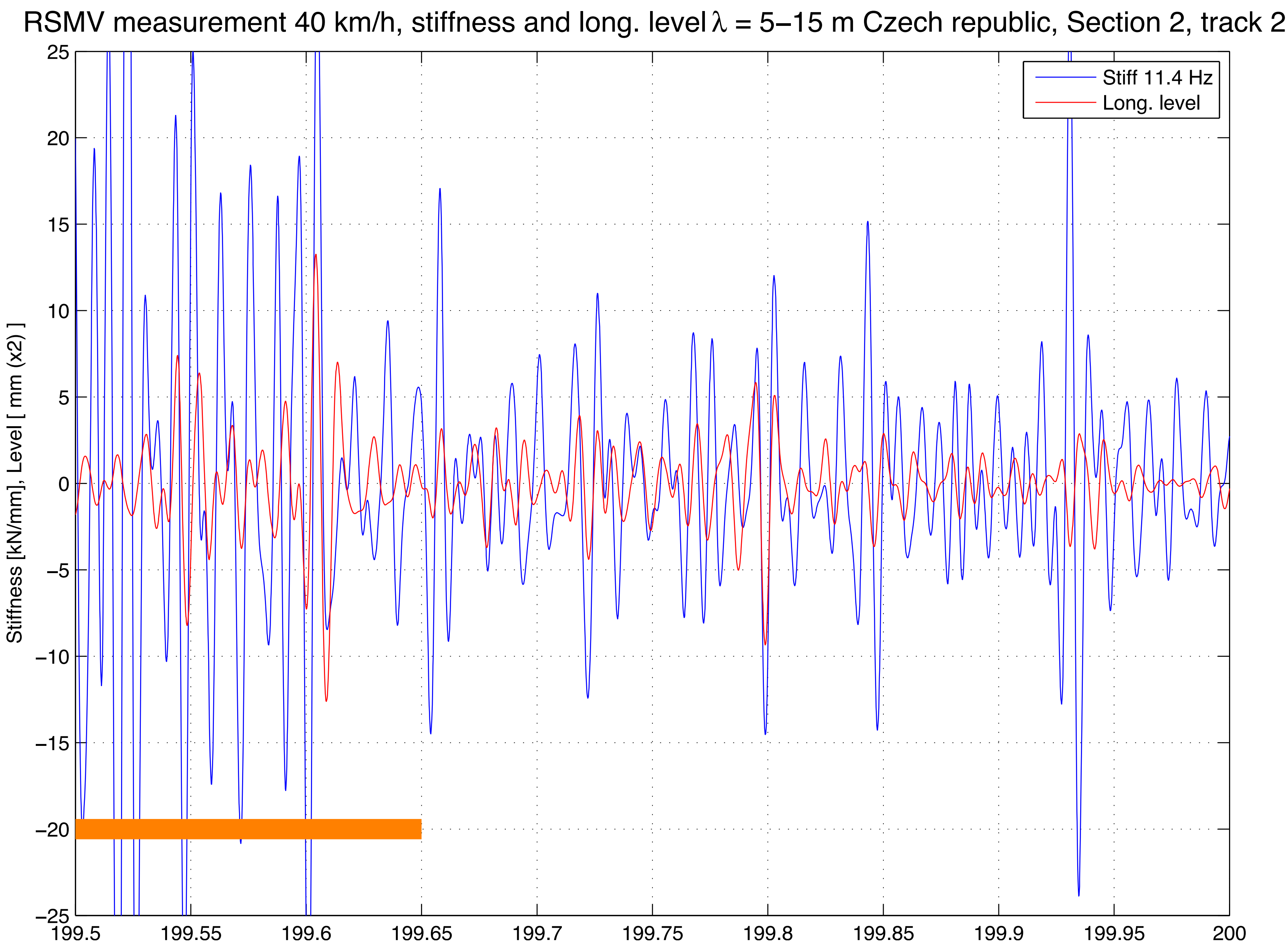

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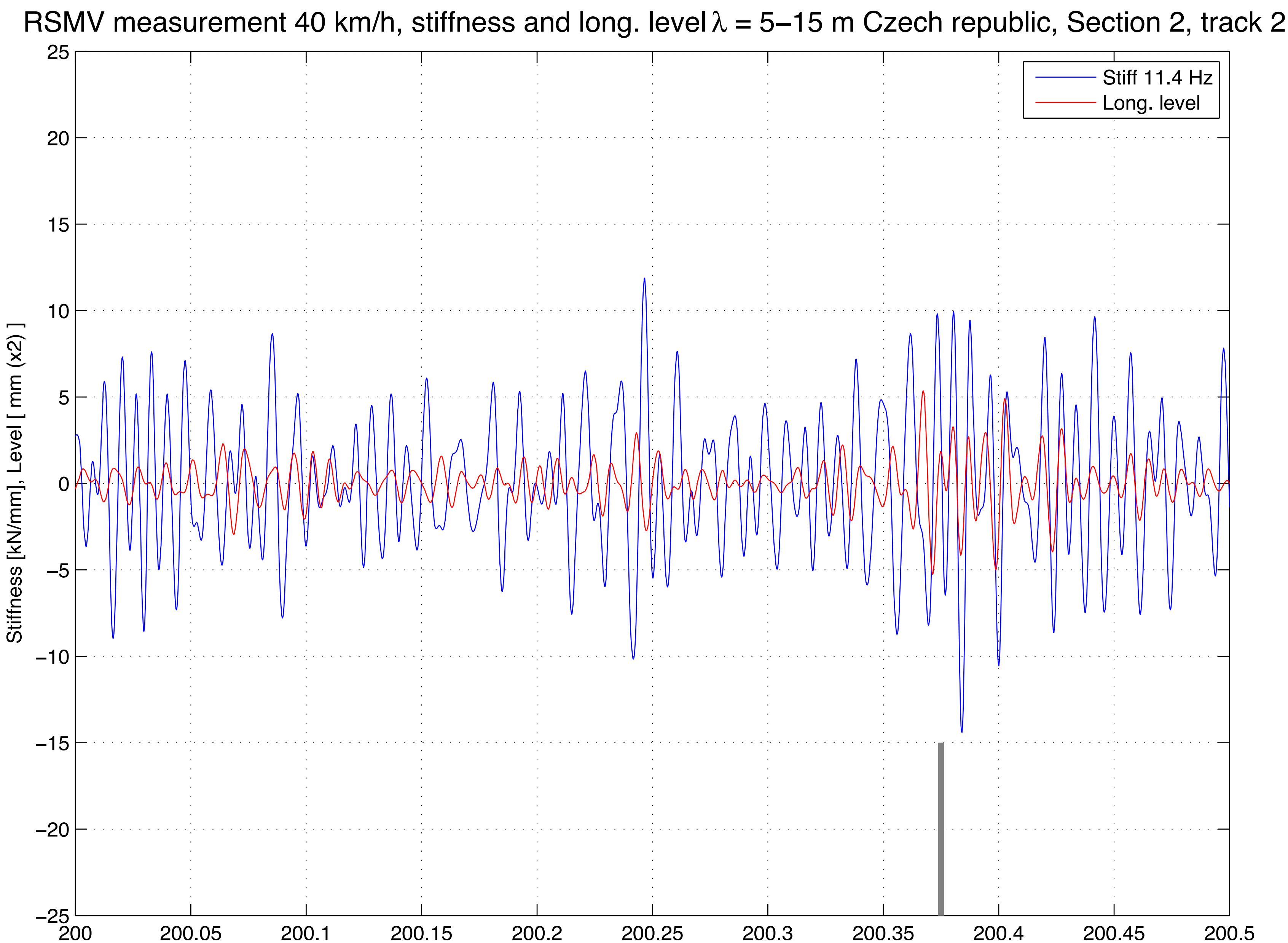

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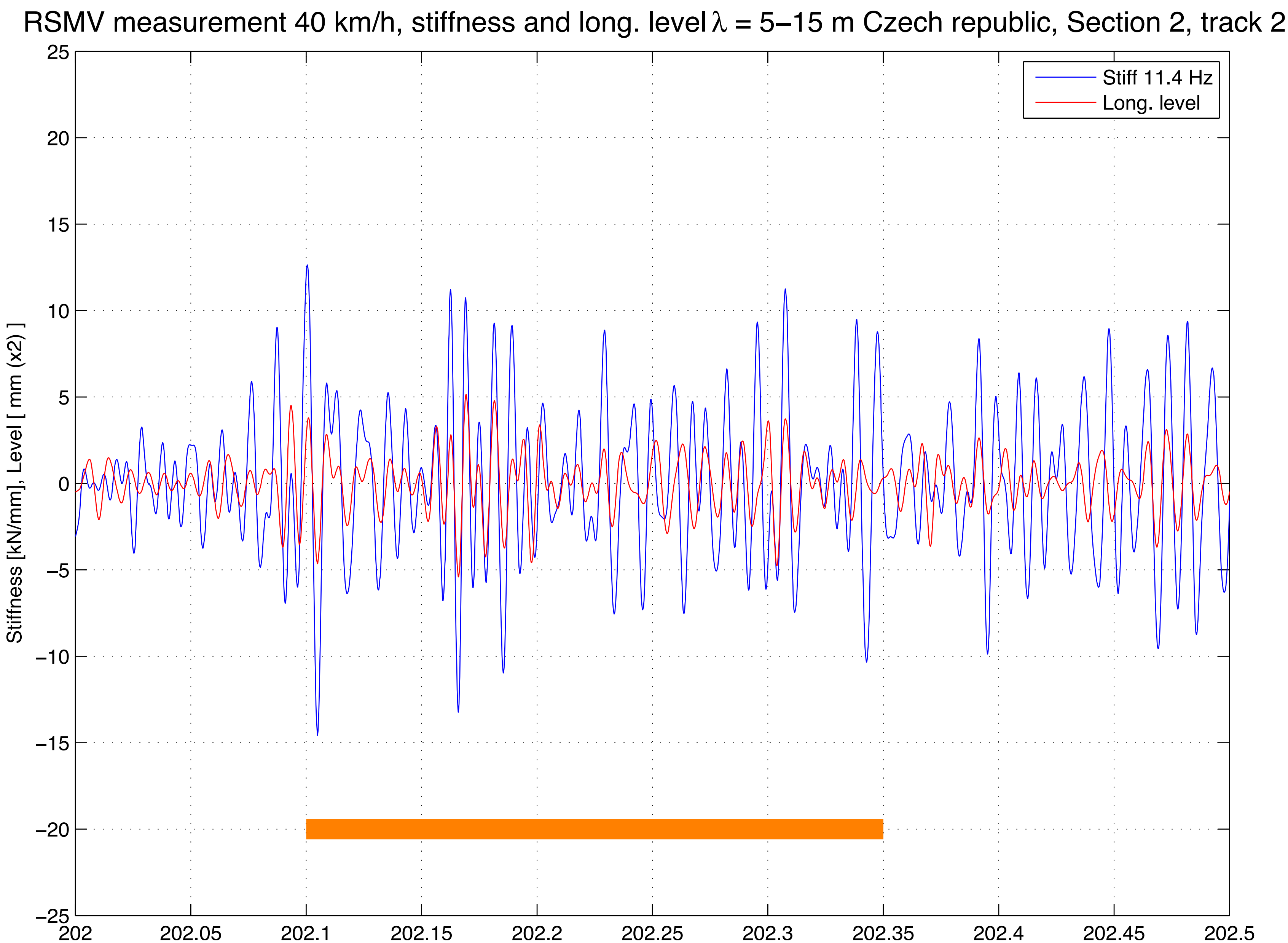

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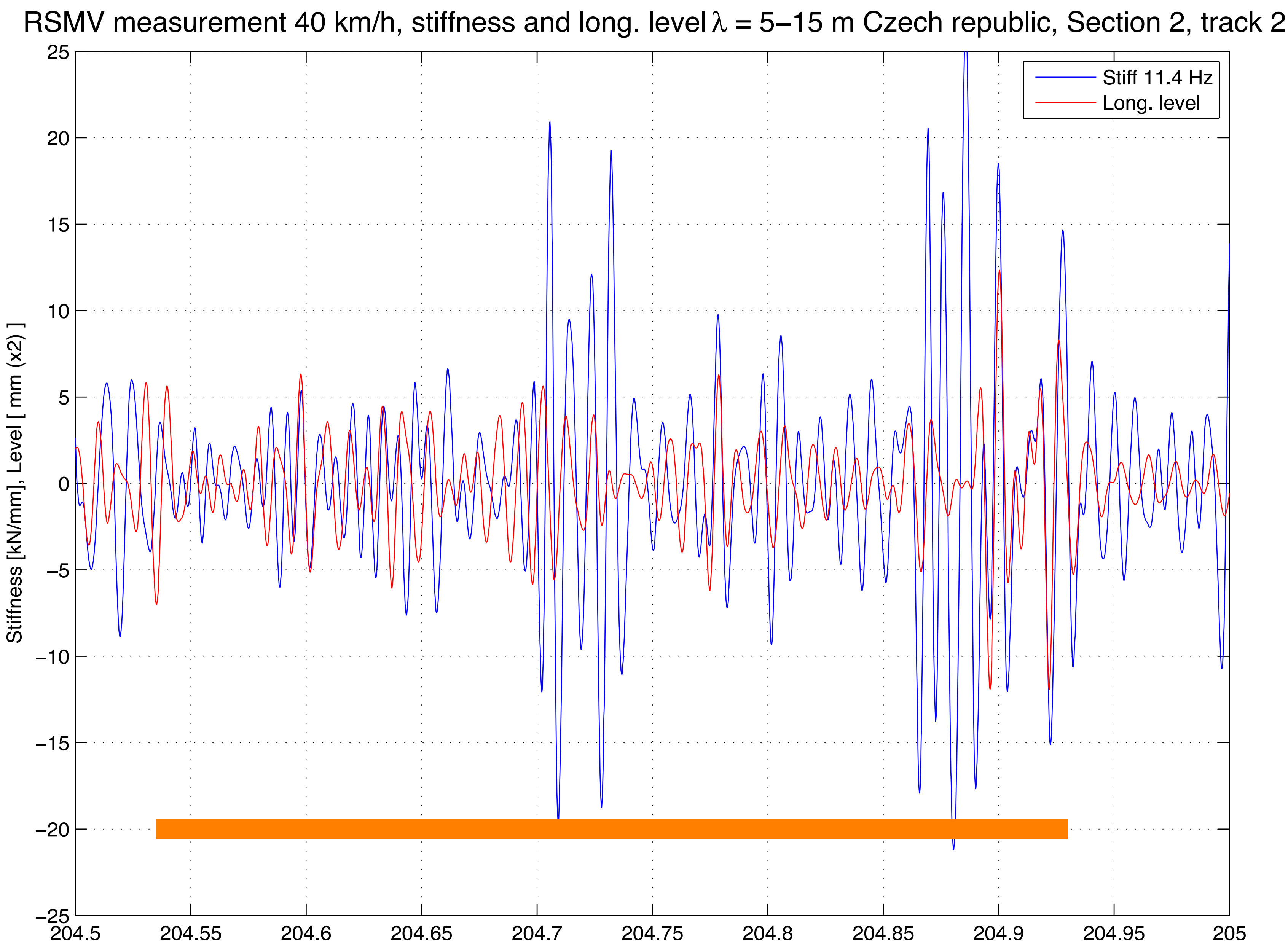

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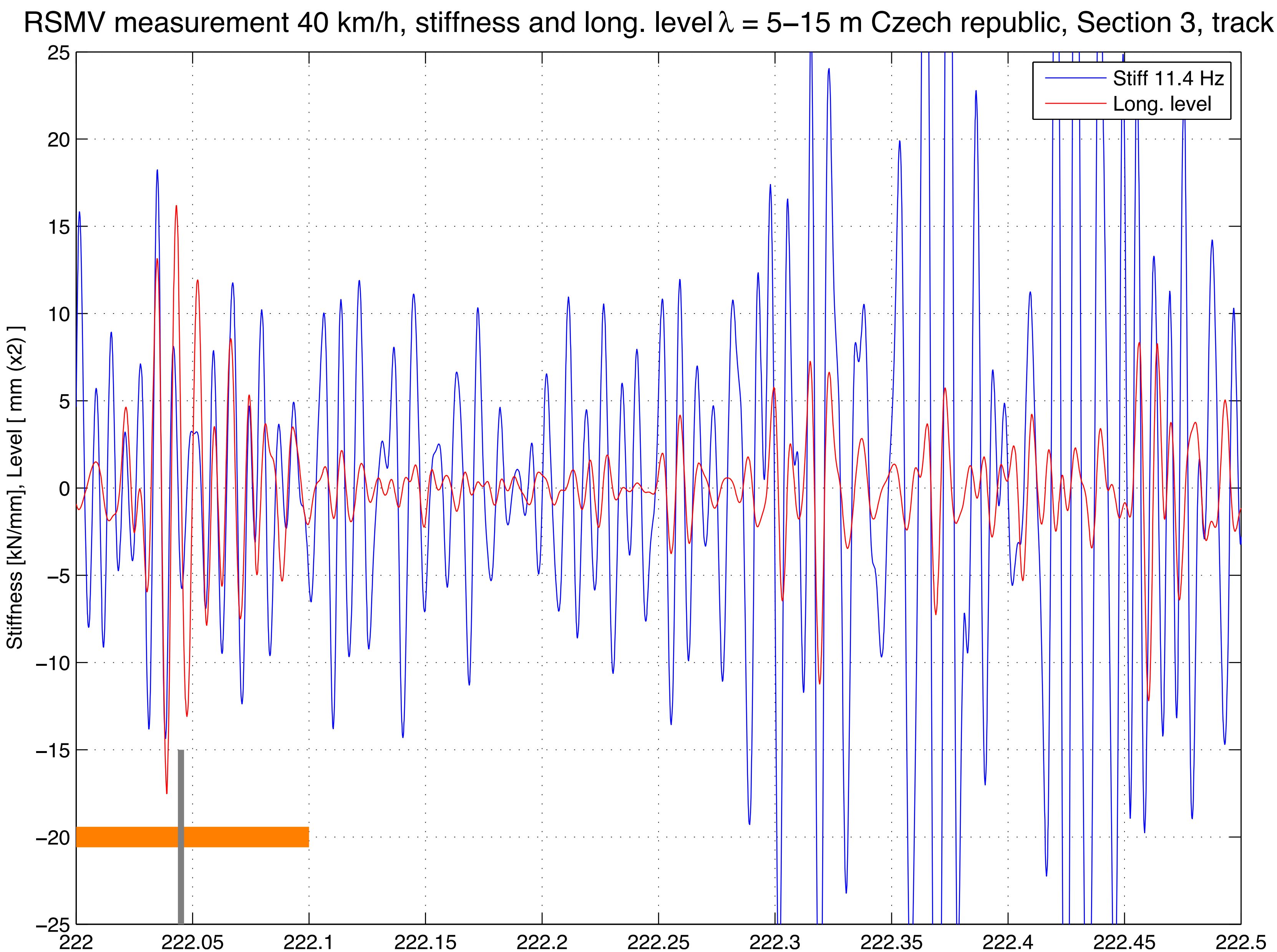

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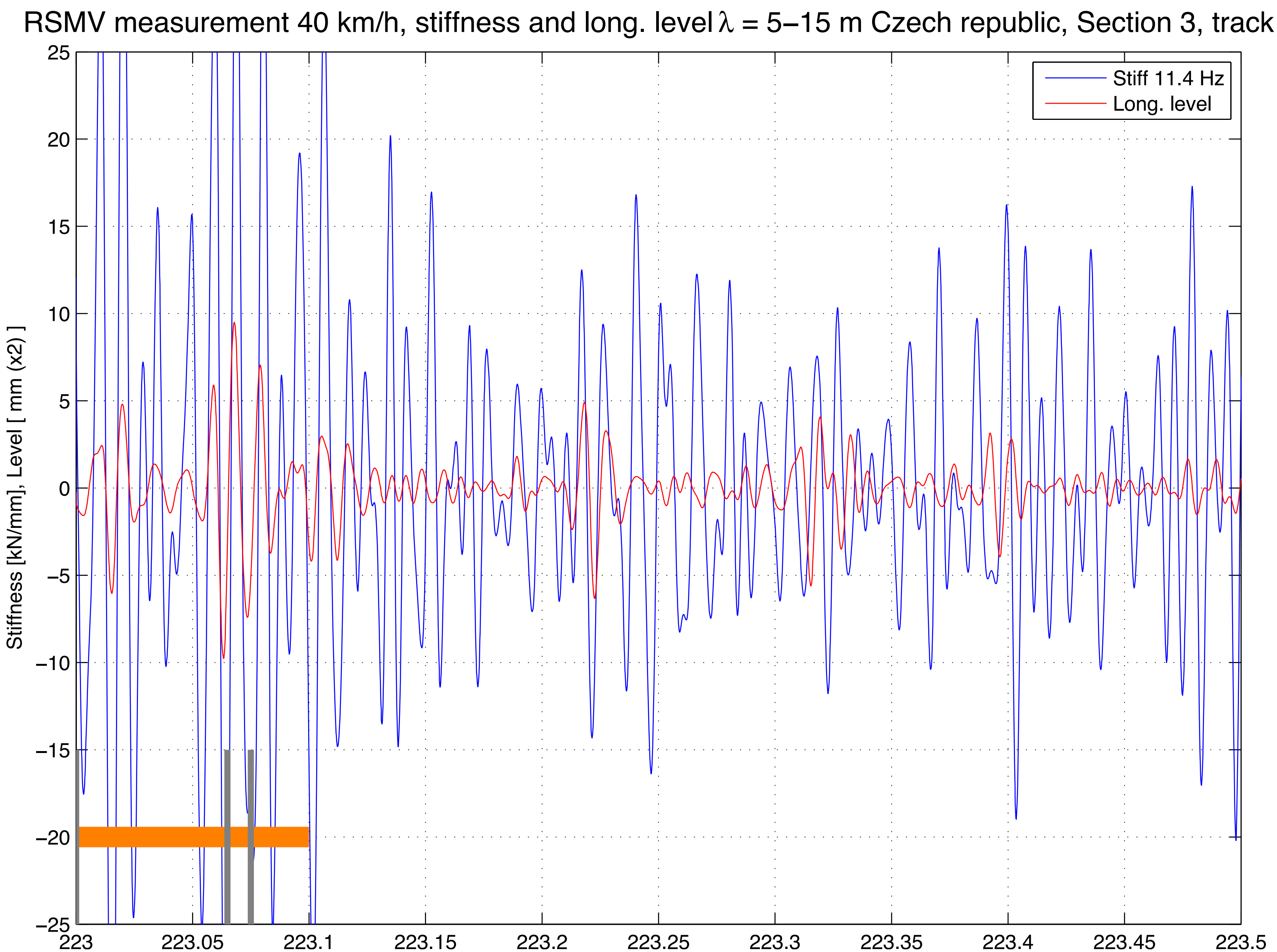

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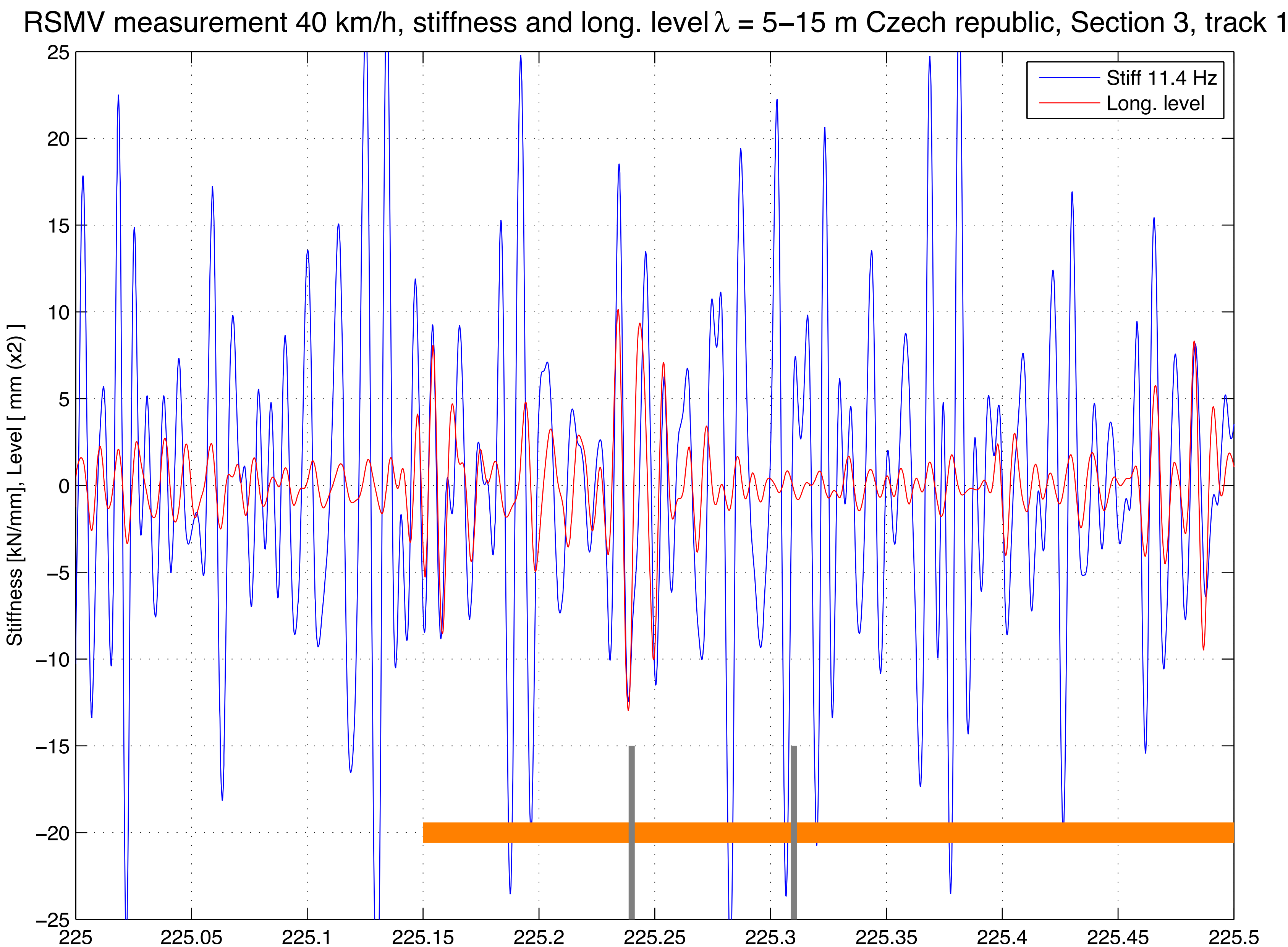
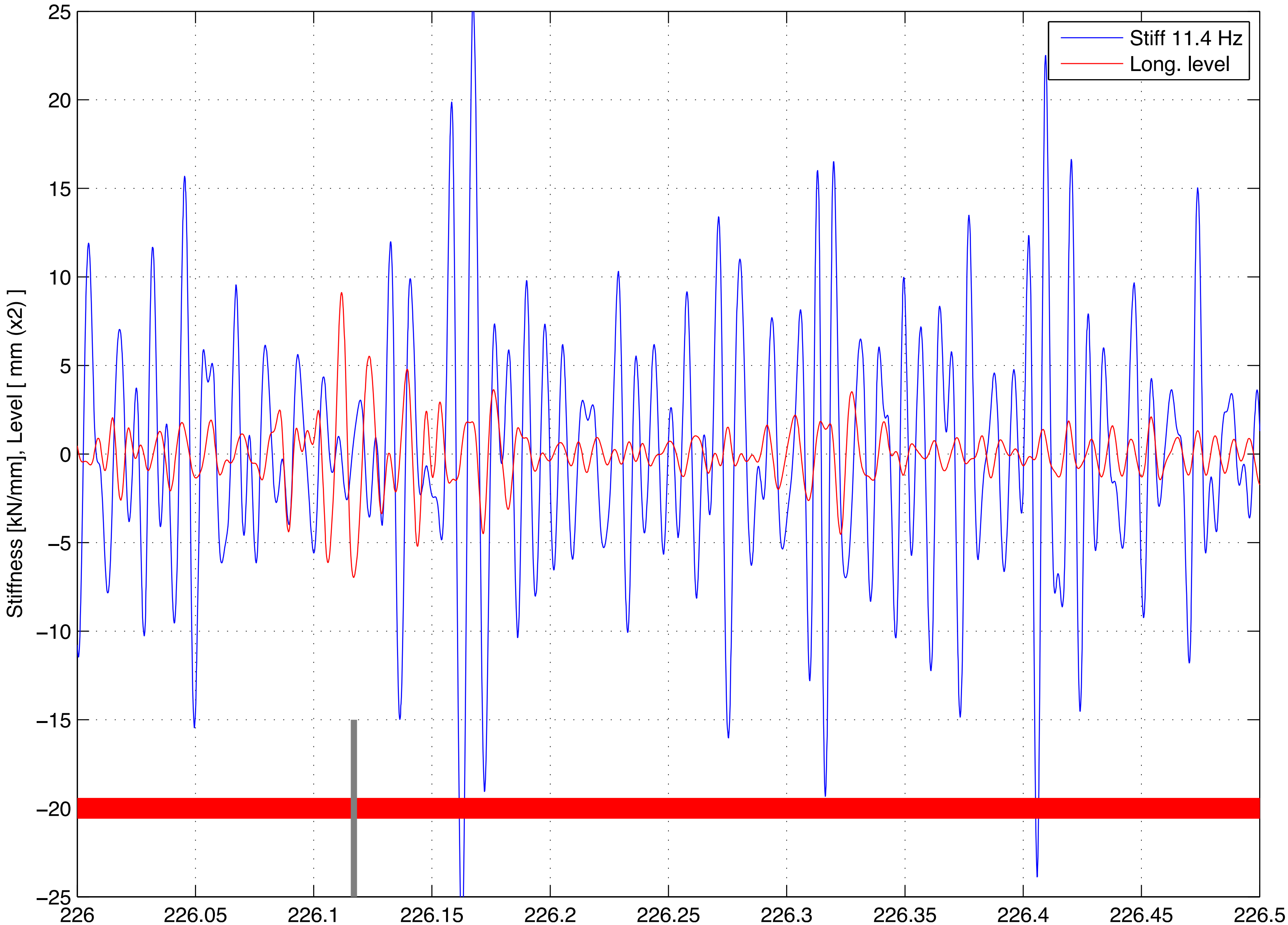
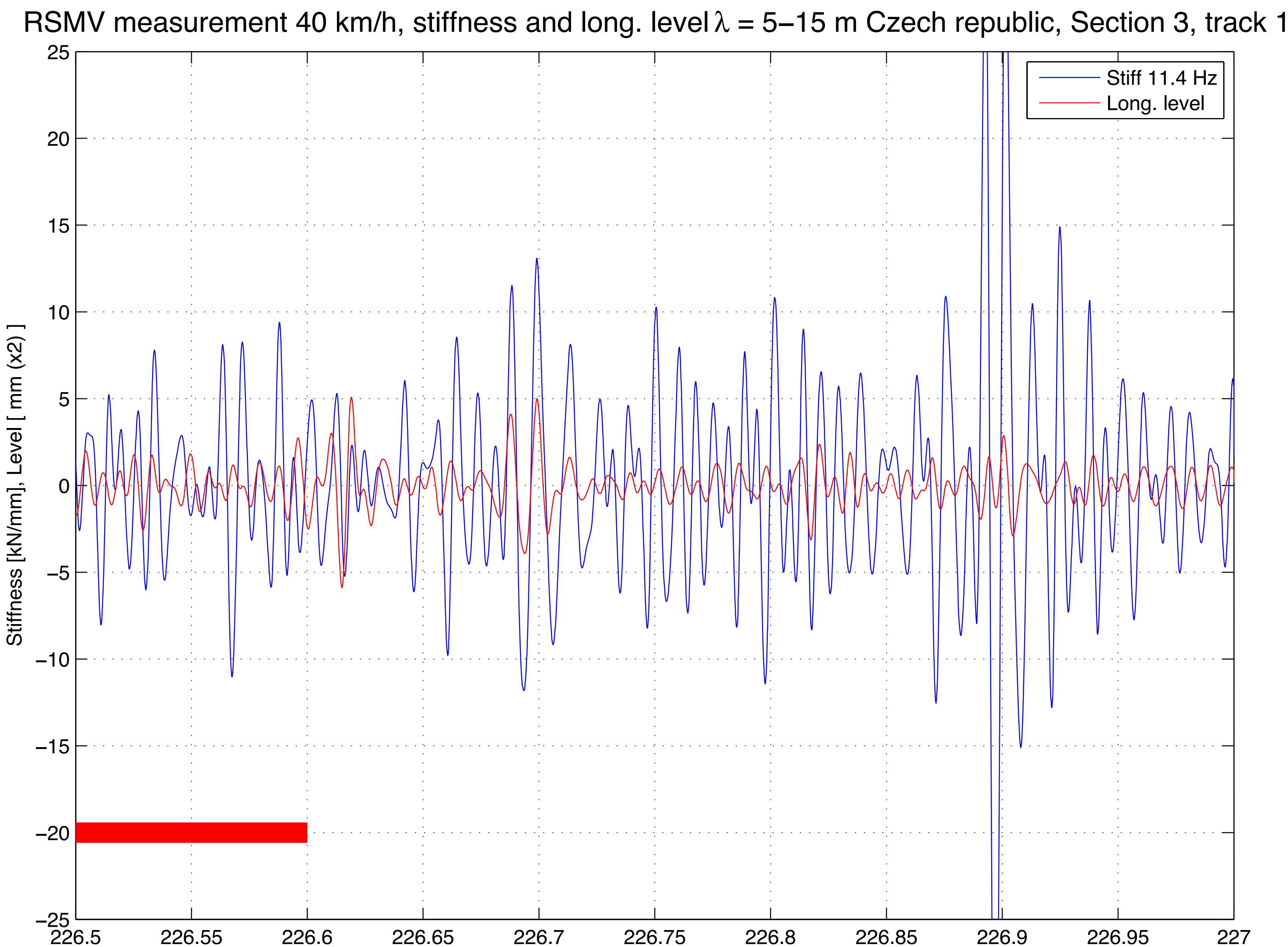
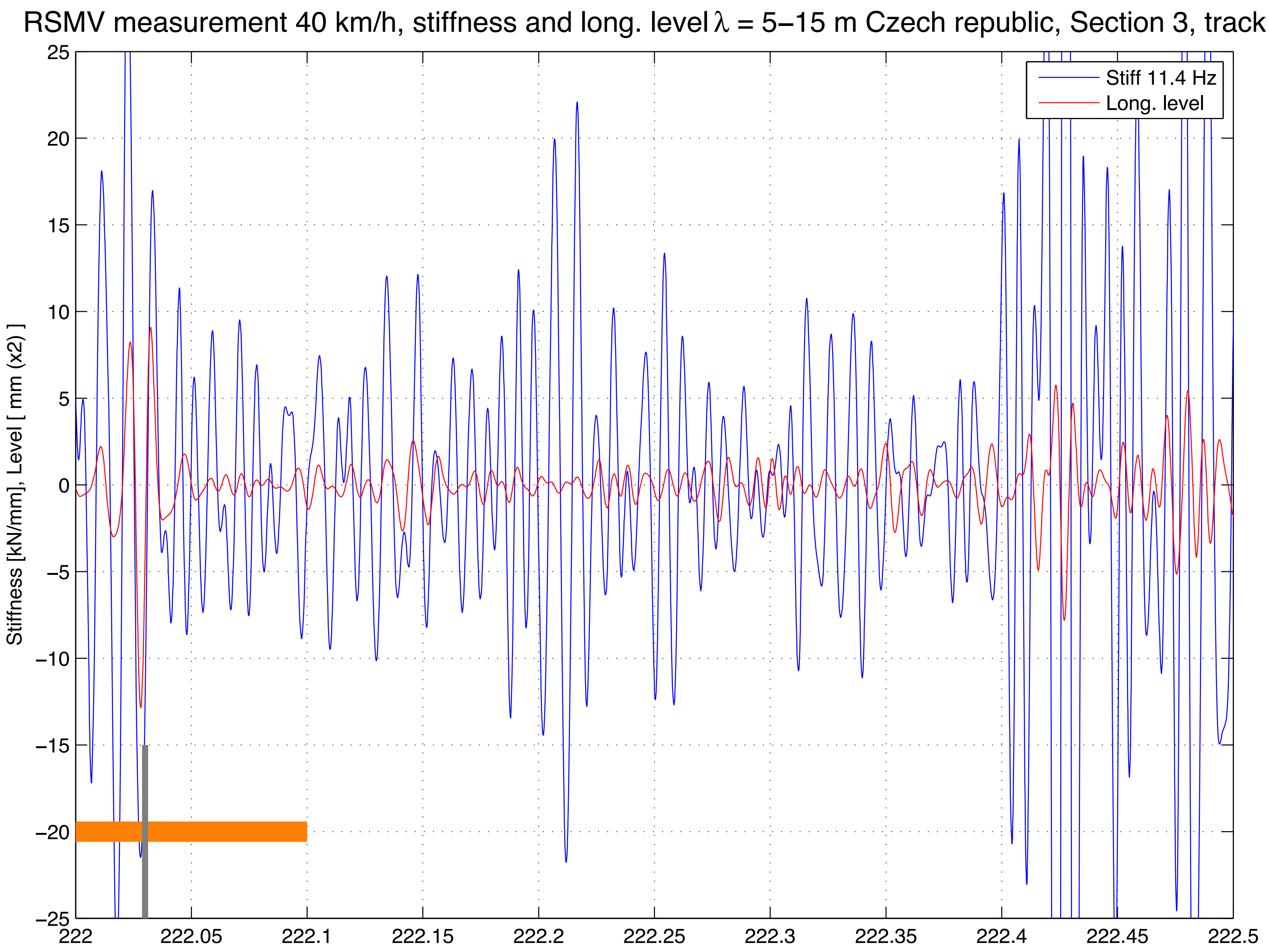

RSMV measurement 40 km/h, stiffness and long. level λ = 5–15 m Czech republic, Section 3, track 1
Stiffness [kN/mm], Level [mm (x2)]
Stiff 11.4 Hz
Long. level
25
20
15
10
5
0
−5
−10
−15
−20
−25
225
225.05
225.1
225.15
225.2
225.25
225.3
225.35
225.4
225.45
225.5

RSMV measurement 40 km/h, stiffness and long. level λ = 5–15 m Czech republic, Section 3, track 1




RSMV measurement 40 km/h, stiffness and long. level λ = 5–15 m Czech republic, Section 3, track 1
Stiff 11.4 Hz
Long. level
Stiffness [kN/mm], Level [mm (x2)]
25
20
15
10
5
0
−5
−10
−15
−20
−25
226.5
226.55
226.6
226.65
226.7
226.75
226.8
226.85
226.9
226.95
227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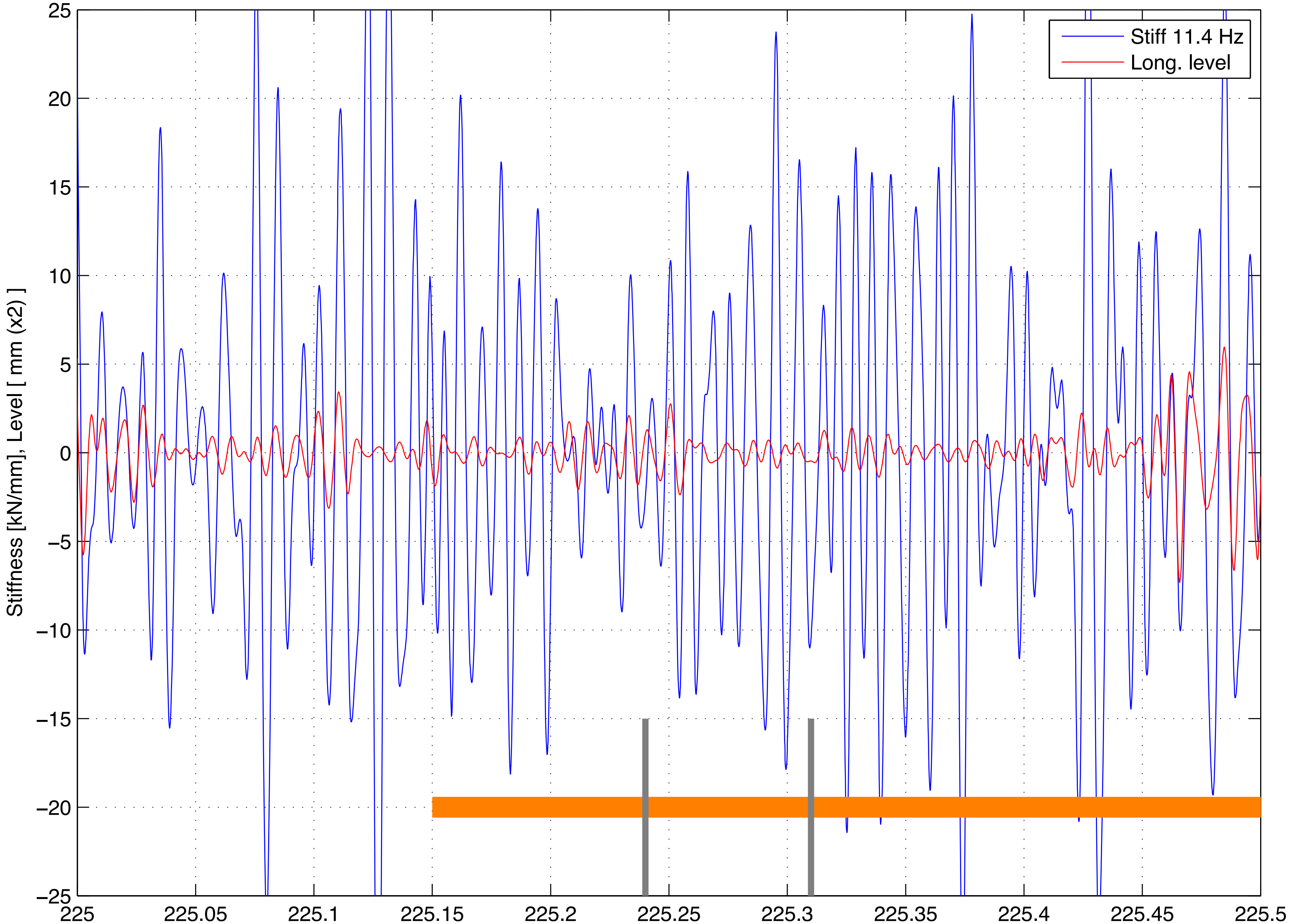
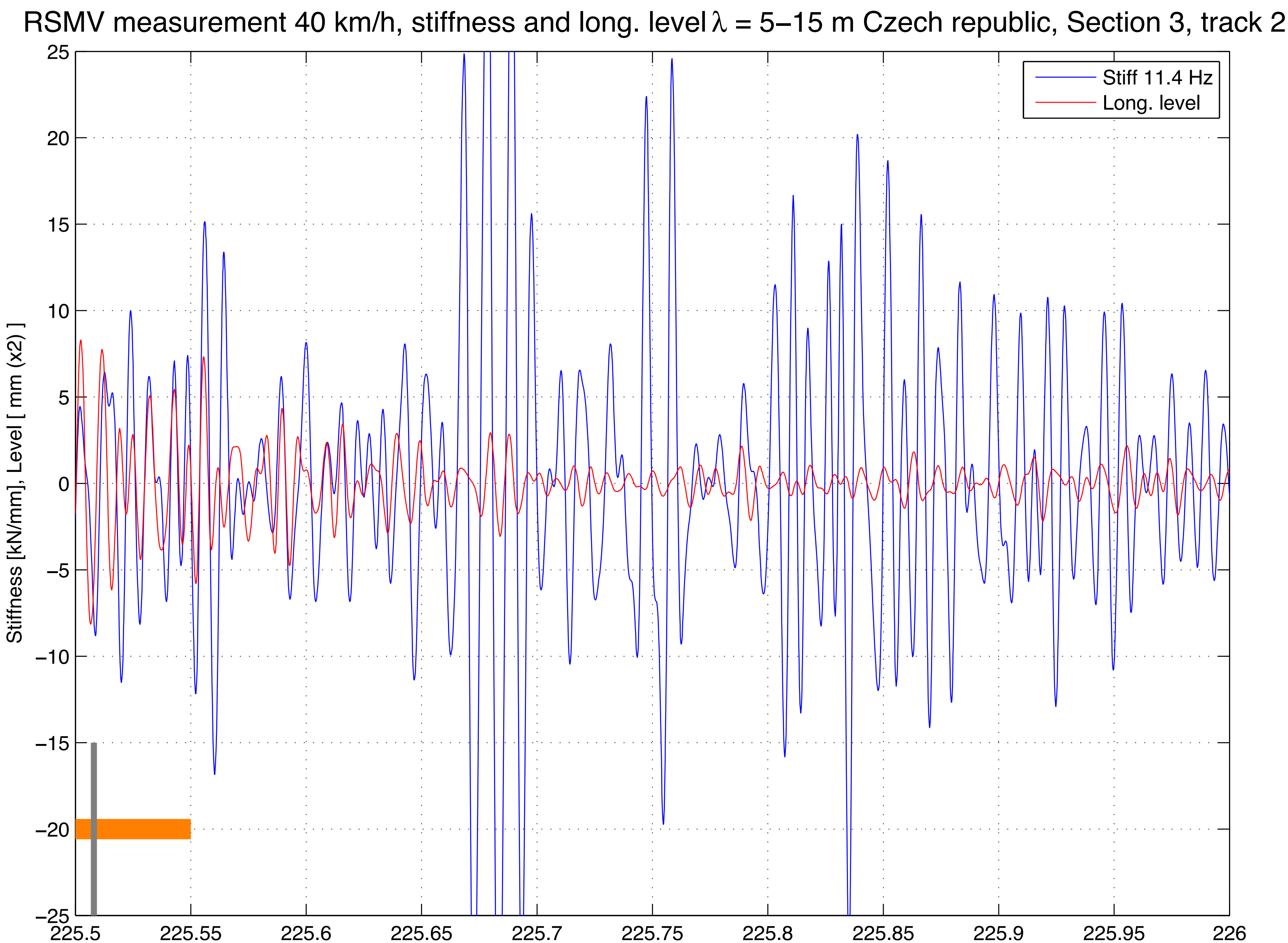
Stiffness [kN/mm], Level [mm (x2)]
Stiff 11.4 Hz
Long. level
25
20
15
10
5
0
−5
−10
−15
−20
−25
222
222.05
222.1
222.15
222.2
222.25
222.3
222.35
222.4
222.45
222.5

RSMV measurement 40 km/h, stiffness and long. level λ = 5–15 m Czech republic, Section 3, track 2





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