An investigation of positioning accuracy transmitted by connected heavy vehicles using DSRC

Adriana Simona MIHAITA
DATA|CSIRO, Australia

9th of January 2017

Contents

1. Introduction

Background:

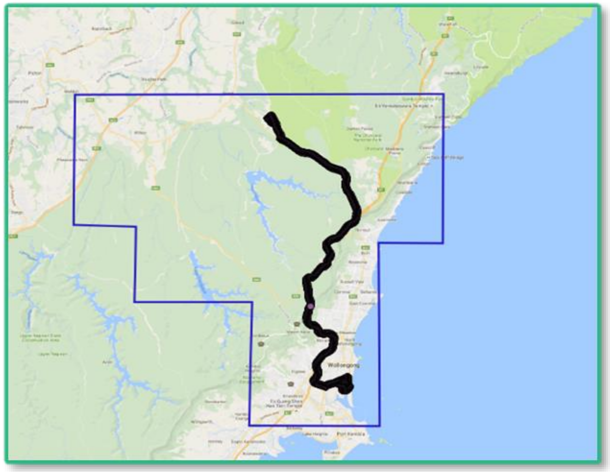
The Cooperative Intelligent Transport Initiative (CITI) is a project being conducted by Transport for NSW (TfNSW) in partnership with Data61 and the Federal Government's Heavy Vehicle Safety Productivity Program under the Nation Building Program. It is meant to be Australia's first semi-permanent test bed site for testing Cooperative Intelligent Transport Systems.

Objectives:

- Equip heavy-truck vehicles with **DSRC** (Dedicated Short Range Communications)
- Ensure **road safety** by sending alerts for potential collisions and curve speed warnings in **V2V** (vehicle to vehicles) and **V2I** (vehicle to infrastructure) applications.
- Provide **incident detection.**

Focus Area:

The vehicles operate in an area of 917 km^2 in the Illawarra Region of NSW south of Sydney, focusing on a 42 km length of road the connects the Hume Highway in the south of Sydney to the Port Kembla (2km south of Wollongong CBD).

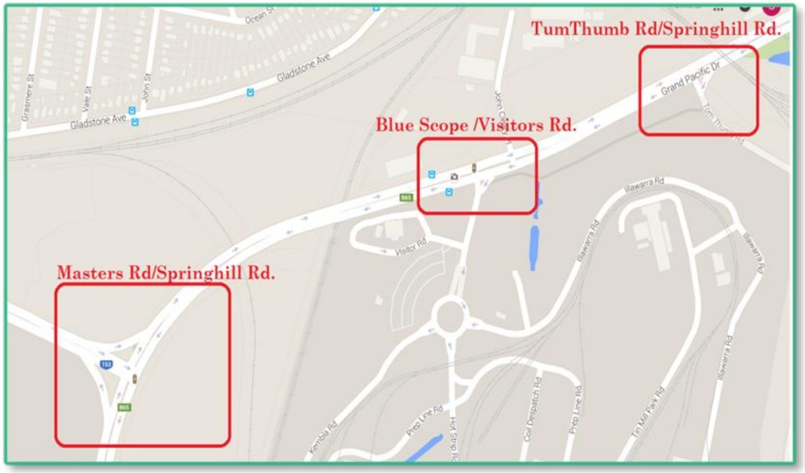


1. Introduction

Current Deployment:

The DSRC technology has been installed on:

- 58 heavy vehicles,
- 2 light vehicles,
- 3 DSRC equipped Intersections:
  - Master Rd – (Masters Rd / Springhill Rd)
  - Blue Scope – (Blue Scope Rd / Springhill Rd)
  - TomThumb Rd – (close to Blue Scope)



- There are over 150 drivers from 3 transport companies that are involved in 24x7 trips routes towards the West Cliff Colliery near Wollongong, NSW.

- Data is collected every two weeks from two data point collectors (Trailer 2 and 3)

1. Project challenges

- How to determine the GPS accuracy of DSRC equipped vehicles broadcasting their positioning 10 times a second?
- Understand how the positioning accuracy of DSRC equipped vehicles changes over time ?
- How can the location accuracy influence the transmission of collision alerts?
- What are the most important factors that influence the most positioning?
- How to establish a proper ground truth for positioning investigation?

Contents

2. Data profiling

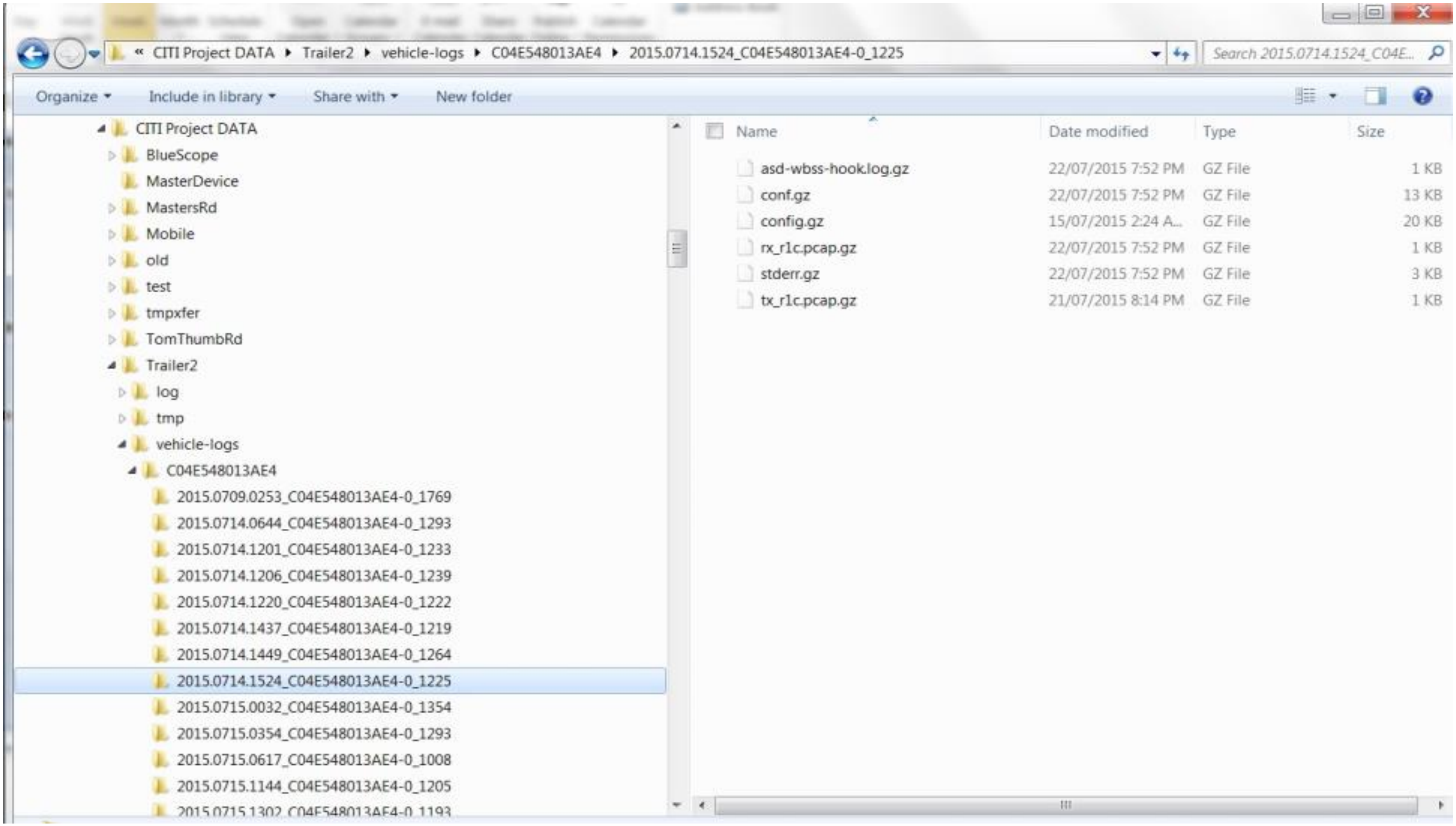
- Received: 400 million BSMs, stored from July – November 2015.

- Data received from 2 trailers:
  - Trailer 2 – active - 63 Vehicle logs.
  - Trailer 3 – active – 47 Vehicle logs (3 trucks come only to this trailer).

- The log files maintain a history of all the stopping that the vehicles did at the specific trailer.

2. Data profiling

The structure of the truck Data:



2. Data profiling

Observations:

1. Every folder designating a truck ID (C04E548013AE4) contains various folders of the type:
   – 2015.0709.0253_C04E548013AE4-0_1769 which should contain :
     – rx_r1c.pcap.gz : **received** messages when the engine is on
     – tx_r1c.pcap.gz : **transmitted** messages when the engine is on.

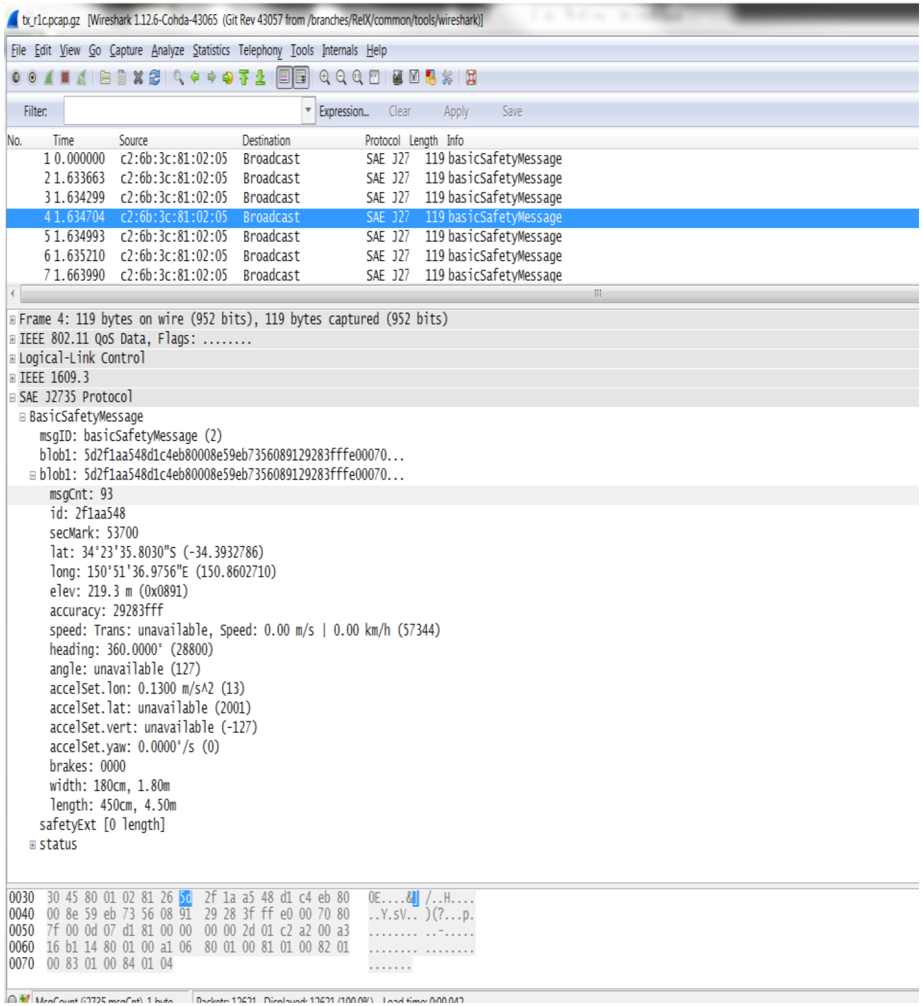
2. Some transmission files are incomplete/empty (<100 bytes):
   - **Trailer 2**: 7,364 out of 19,434 **(37.8924%)** are not considered for analytics.
   - **Trailer 3**: 1,042 out of 9736 **(10.7025%)** are not considered for analytics.

3. Trucks stay longer near Trailer 3 than near Trailer 2.

2. Data profiling

Extracting the "useful" data from the RAW data

Wireshark – read ".pcap" files



2. Data profiling

Extracting the “useful” data from the RAW data

Wireshark – read “.pcap” files

↓

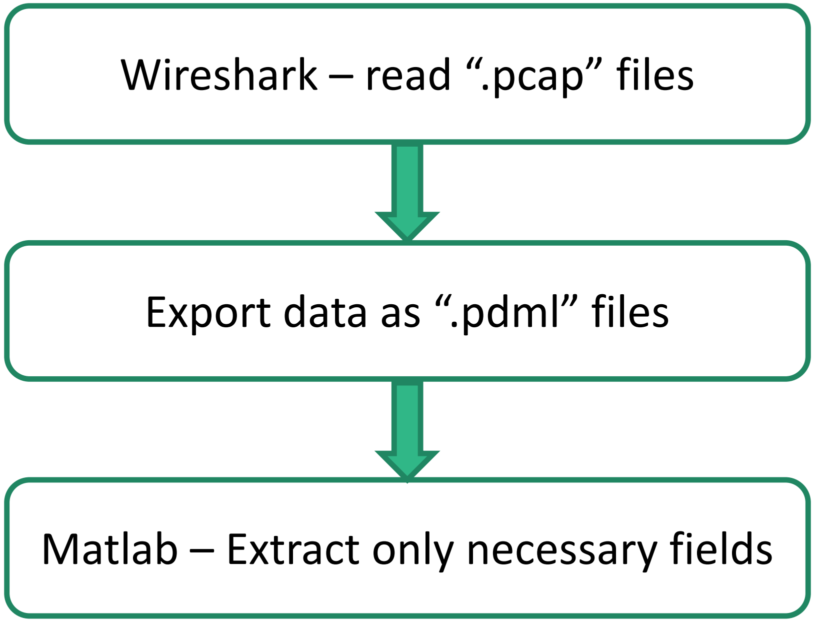
Export data as “.pdml” files

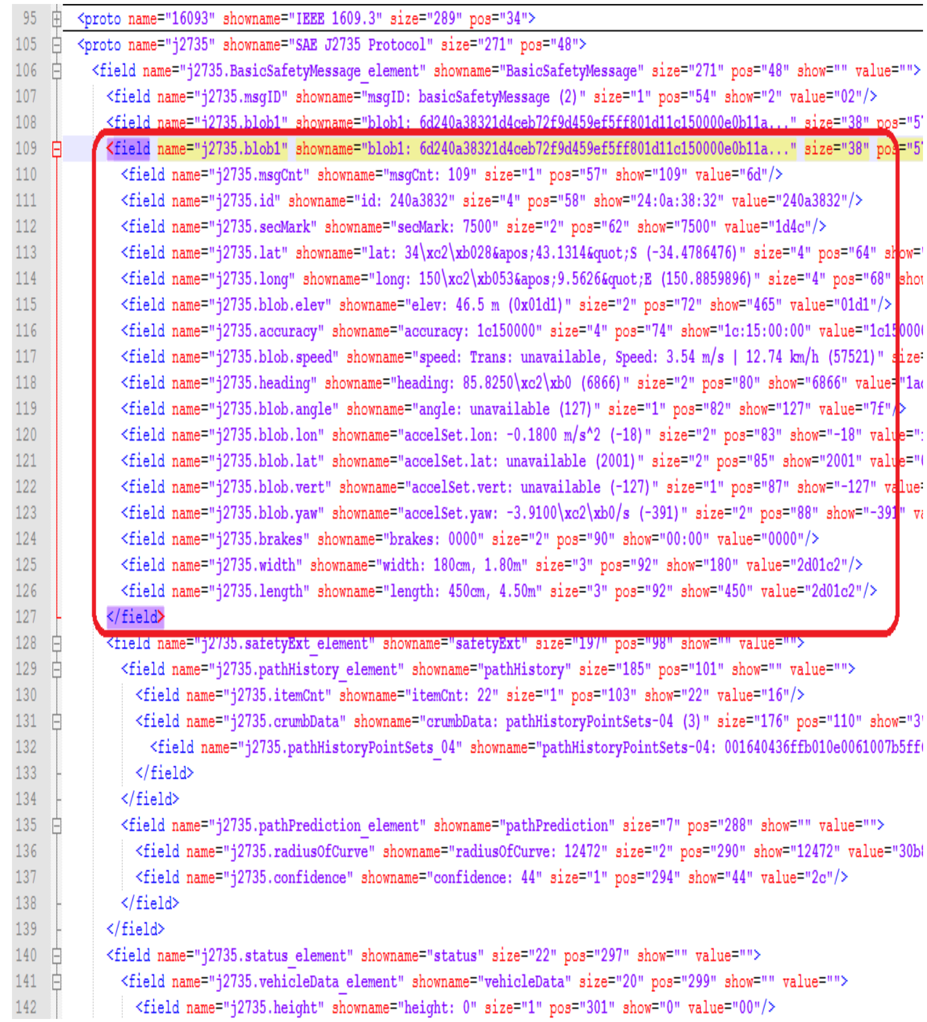

test_data_export_from_wireshark.xml | rx_r1_test_SHORT.pdml | WebClient.java | 19_02_2016.xml | info.xml | new 1 | new 2 | rx_r1_test.pdml | new 3


```xml
<?xml version="1.0"?>
<?xml-stylesheet type="text/xsl" href="pdml2html.xsl"?>
<!-- You can find pdml2html.xsl in C:\Program Files (x86)\Wireshark or at http://anonsvn.wireshark.org/trunk/wireshark/pdml2html.xsl.
<pdml version="0" creator="wireshark/1.12.6-Cohda-43065" time="Fri Feb 12 11:28:10 2016" capture_file="C:\Users\smihaita\Desktop\NICT
<packet>
  <proto name="geninfo" pos="0" showname="General information" size="323">
  <proto name="frame" showname="Frame 1: 323 bytes on wire (2584 bits), 323 bytes captured (2584 bits)" size="323" pos="0">
  <proto name="wlan" showname="IEEE 802.11 QoS Data, Flags: ........" size="26" pos="0">
  <proto name="llc" showname="Logical-Link Control" size="8" pos="26">
  <proto name="16093" showname="IEEE 1609.3" size="289" pos="34">
  <proto name="j2735" showname="SAE J2735 Protocol" size="271" pos="48">
    <field name="j2735.BasicSafetyMessage_element" showname="BasicSafetyMessage" size="271" pos="48" show="" value="">
      <field name="j2735.msgID" showname="msgID: basicSafetyMessage (2)" size="1" pos="54" show="2" value="02"/>
      <field name="j2735.blob1" showname="blob1: 6d240a38321d4ceb72f9d459ef5ff801d11c150000e0b11a..." size="38" pos="57" show="6d:24:
      <field name="j2735.blob1" showname="blob1: 6d240a38321d4ceb72f9d459ef5ff801d11c150000e0b11a..." size="38" pos="57" show="6d:24:
        <field name="j2735.msgCnt" showname="msgCnt: 109" size="1" pos="57" show="109" value="6d"/>
        <field name="j2735.id" showname="id: 240a3832" size="4" pos="58" show="24:0a:38:32" value="240a3832"/>
        <field name="j2735.secMark" showname="secMark: 7500" size="2" pos="62" show="7500" value="1d4c"/>
        <field name="j2735.lat" showname="lat: 34\xc2\xb028&apos;43.1314&quot;S (-34.4786476)" size="4" pos="64" show="-344786476" va
        <field name="j2735.long" showname="long: 150\xc2\xb053&apos;9.5626&quot;E (150.8859896)" size="4" pos="68" show="1508859896"
        <field name="j2735.blob.elev" showname="elev: 46.5 m (0x01d1)" size="2" pos="72" show="465" value="01d1"/>
        <field name="j2735.accuracy" showname="accuracy: 1c150000" size="4" pos="74" show="1c:15:00:00" value="1c150000"/>
        <field name="j2735.blob.speed" showname="speed: Trans: unavailable, Speed: 3.54 m/s | 12.74 km/h (57521)" size="2" pos="78" s
        <field name="j2735.heading" showname="heading: 85.8250\xc2\xb0 (6866)" size="2" pos="80" show="6866" value="1ad2"/>
        <field name="j2735.blob.angle" showname="angle: unavailable (127)" size="1" pos="82" show="127" value="7f"/>
        <field name="j2735.blob.lon" showname="accelSet.lon: -0.1800 m/s^2 (-18)" size="2" pos="83" show="-18" value="ffee"/>
        <field name="j2735.blob.lat" showname="accelSet.lat: unavailable (2001)" size="2" pos="85" show="2001" value="07d1"/>
        <field name="j2735.blob.vert" showname="accelSet.vert: unavailable (-127)" size="1" pos="87" show="-127" value="81"/>
        <field name="j2735.blob.yaw" showname="accelSet.yaw: -3.9100\xc2\xb0/s (-391)" size="2" pos="88" show="-391" value="fe79"/>
        <field name="j2735.brakes" showname="brakes: 0000" size="2" pos="90" show="00:00" value="0000"/>
        <field name="j2735.width" showname="width: 180cm, 1.80m" size="3" pos="92" show="180" value="2d01c2"/>
        <field name="j2735.length" showname="length: 450cm, 4.50m" size="3" pos="92" show="450" value="2d01c2"/>
      </field>
      <field name="j2735.safetyExt_element" showname="safetyExt" size="197" pos="98" show="" value="">
        <field name="j2735.pathHistory_element" showname="pathHistory" size="185" pos="101" show="" value="">
          <field name="j2735.itemCnt" showname="itemCnt: 22" size="1" pos="103" show="22" value="16"/>
          <field name="j2735.crumbData" showname="crumbData: pathHistoryPointSets-04 (3)" size="176" pos="110" show="3" value="001640
            <field name="j2735.pathHistoryPointSets_04" showname="pathHistoryPointSets-04: 001640436ffb010e0061007b5ff601fe012740be6f
          </field>
        </field>
        <field name="j2735.pathPrediction_element" showname="pathPrediction" size="7" pos="288" show="" value="">
          <field name="j2735.radiusOfCurve" showname="radiusOfCurve: 12472" size="2" pos="290" show="12472" value="30b8"/>
          <field name="j2735.confidence" showname="confidence: 44" size="1" pos="294" show="44" value="2c"/>
        </field>
      </field>
      <field name="j2735.status_element" showname="status" size="22" pos="297" show="" value="">
        <field name="j2735.vehicleData_element" showname="vehicleData" size="20" pos="299" show="" value="">
          <field name="j2735.height" showname="height: 0" size="1" pos="301" show="0" value="00"/>
```

2. Data profiling

Extracting the “useful” data from the RAW data

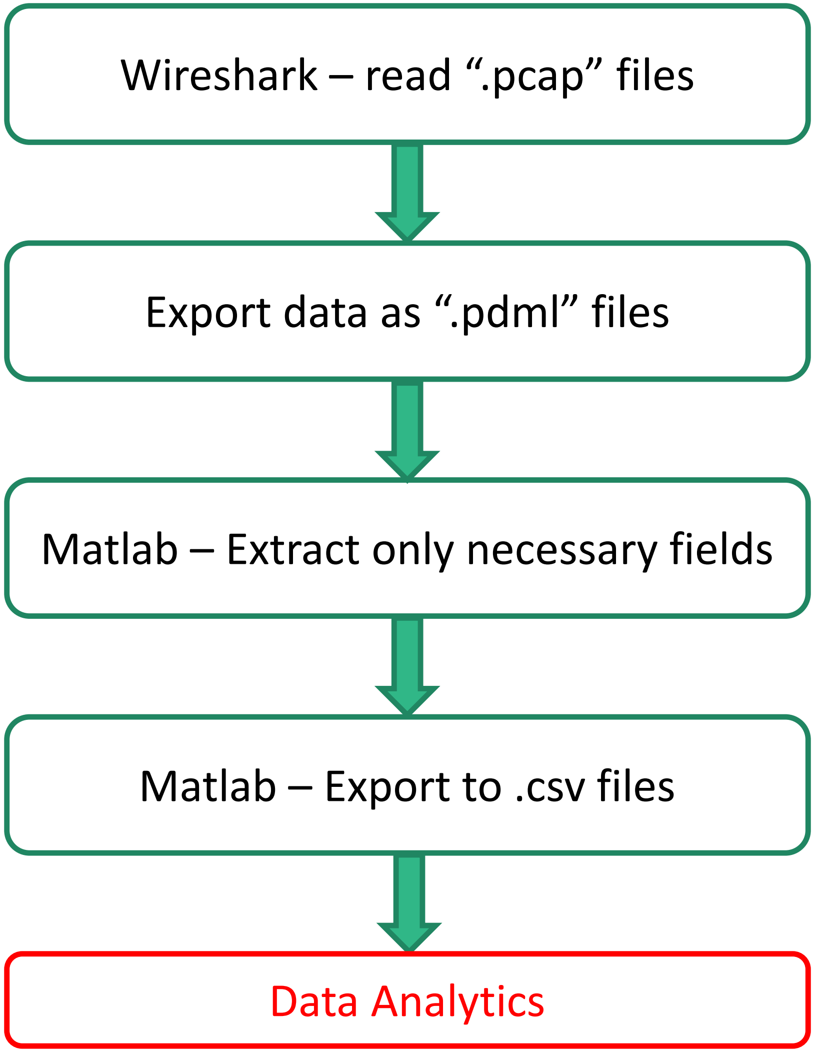




```
<proto name="16093" showname="IEEE 1609.3" size="289" pos="34">
<proto name="j2735" showname="SAE J2735 Protocol" size="271" pos="48">
  <field name="j2735.BasicSafetyMessage_element" showname="BasicSafetyMessage" size="271" pos="48" show="" value="">
    <field name="j2735.msgID" showname="msgID: basicSafetyMessage (2)" size="1" pos="54" show="2" value="02"/>
    <field name="j2735.blob1" showname="blob1: 6d240a38321d4ceb72f9d459ef5ff801d11c150000e0b11a..." size="38" pos="5
    <field name="j2735.blob1" showname="blob1: 6d240a38321d4ceb72f9d459ef5ff801d11c150000e0b11a..." size="38" pos="5
      <field name="j2735.msgCnt" showname="msgCnt: 109" size="1" pos="57" show="109" value="6d"/>
      <field name="j2735.id" showname="id: 240a3832" size="4" pos="58" show="24:0a:38:32" value="240a3832"/>
      <field name="j2735.secMark" showname="secMark: 7500" size="2" pos="62" show="7500" value="1d4c"/>
      <field name="j2735.lat" showname="lat: 34\xc2\xb028&apos;43.1314&quot;S (-34.4786476)" size="4" pos="64" show=
      <field name="j2735.long" showname="long: 150\xc2\xb053&apos;9.5626&quot;E (150.8859896)" size="4" pos="68" show
      <field name="j2735.blob.elev" showname="elev: 46.5 m (0x01d1)" size="2" pos="72" show="465" value="01d1"/>
      <field name="j2735.accuracy" showname="accuracy: 1c150000" size="4" pos="74" show="1c:15:00:00" value="1c150000
      <field name="j2735.blob.speed" showname="speed: Trans: unavailable, Speed: 3.54 m/s | 12.74 km/h (57521)" size=
      <field name="j2735.heading" showname="heading: 85.8250\xc2\xb0 (6866)" size="2" pos="80" show="6866" value="1a
      <field name="j2735.blob.angle" showname="angle: unavailable (127)" size="1" pos="82" show="127" value="7f"/>
      <field name="j2735.blob.lon" showname="accelSet.lon: -0.1800 m/s^2 (-18)" size="2" pos="83" show="-18" value="
      <field name="j2735.blob.lat" showname="accelSet.lat: unavailable (2001)" size="2" pos="85" show="2001" value="
      <field name="j2735.blob.vert" showname="accelSet.vert: unavailable (-127)" size="1" pos="87" show="-127" value=
      <field name="j2735.blob.yaw" showname="accelSet.yaw: -3.9100\xc2\xb0/s (-391)" size="2" pos="88" show="-391" va
      <field name="j2735.brakes" showname="brakes: 0000" size="2" pos="90" show="00:00" value="0000"/>
      <field name="j2735.width" showname="width: 180cm, 1.80m" size="3" pos="92" show="180" value="2d01c2"/>
      <field name="j2735.length" showname="length: 450cm, 4.50m" size="3" pos="92" show="450" value="2d01c2"/>
    </field>
    <field name="j2735.safetyExt_element" showname="safetyExt" size="197" pos="98" show="" value="">
      <field name="j2735.pathHistory_element" showname="pathHistory" size="185" pos="101" show="" value="">
        <field name="j2735.itemCnt" showname="itemCnt: 22" size="1" pos="103" show="22" value="16"/>
        <field name="j2735.crumbData" showname="crumbData: pathHistoryPointSets-04 (3)" size="176" pos="110" show="3
          <field name="j2735.pathHistoryPointSets_04" showname="pathHistoryPointSets-04: 001640436ffb010e0061007b5ff
        </field>
      </field>
      <field name="j2735.pathPrediction_element" showname="pathPrediction" size="7" pos="288" show="" value="">
        <field name="j2735.radiusOfCurve" showname="radiusOfCurve: 12472" size="2" pos="290" show="12472" value="30b
        <field name="j2735.confidence" showname="confidence: 44" size="1" pos="294" show="44" value="2c"/>
      </field>
    </field>
    <field name="j2735.status_element" showname="status" size="22" pos="297" show="" value="">
      <field name="j2735.vehicleData_element" showname="vehicleData" size="20" pos="299" show="" value="">
        <field name="j2735.height" showname="height: 0" size="1" pos="301" show="0" value="00"/>
```

2. Data profiling

Extracting the "useful" data from the RAW data



E13 | lat: 34\xc2\xb028'43.9284"S (-34.4788690)

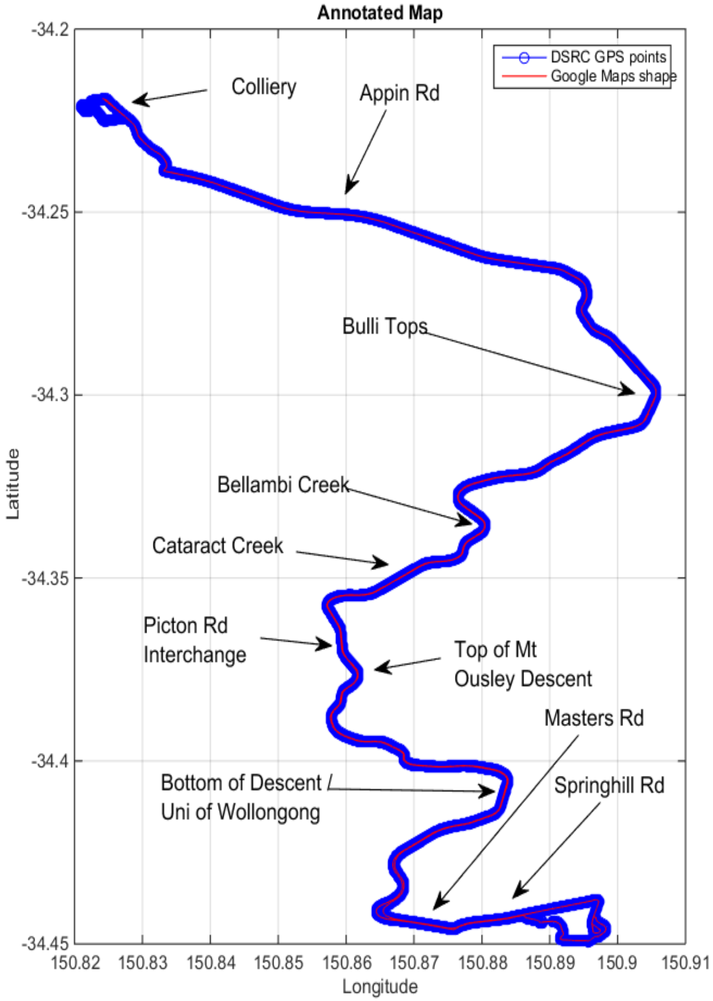
	A	B	C	D	E	F	G	H	
1	Nr of frames	j2735.msgCnt	j2735.id	j2735.secMark	j2735.lat	j2735.long	j2735.blob	j2735.accı	j2735
2	1	msgCnt: 109	id: 240a3832	secMark: 7500	lat: 34\xc2\xb028'43.1314"S (-34.4786476)	long: 150\xc2\xb053'9	elev: 46.5	accuracy:	spee
3	2	msgCnt: 46	id: 4d550cf4	secMark: 7500	lat: 34\xc2\xb028'43.9396"S (-34.4788721)	long: 150\xc2\xb053'7	elev: 54.1	accuracy:	spee
4	3	msgCnt: 110	id: 240a3832	secMark: 7600	lat: 34\xc2\xb028'43.1346"S (-34.4786485)	long: 150\xc2\xb053'9	elev: 46.4	accuracy:	spee
5	4	msgCnt: 47	id: 4d550cf4	secMark: 7600	lat: 34\xc2\xb028'43.9381"S (-34.4788717)	long: 150\xc2\xb053'7	elev: 54.1	accuracy:	spee
6	5	msgCnt: 111	id: 240a3832	secMark: 7700	lat: 34\xc2\xb028'43.1353"S (-34.4786487)	long: 150\xc2\xb053'9	elev: 46.4	accuracy:	spee
7	6	msgCnt: 48	id: 4d550cf4	secMark: 7700	lat: 34\xc2\xb028'43.9356"S (-34.4788710)	long: 150\xc2\xb053'7	elev: 54.1	accuracy:	spee
8	7	msgCnt: 112	id: 240a3832	secMark: 7800	lat: 34\xc2\xb028'43.1364"S (-34.4786490)	long: 150\xc2\xb053'9	elev: 46.4	accuracy:	spee
9	8	msgCnt: 49	id: 4d550cf4	secMark: 7800	lat: 34\xc2\xb028'43.9331"S (-34.4788703)	long: 150\xc2\xb053'7	elev: 54.1	accuracy:	spee
10	9	msgCnt: 113	id: 240a3832	secMark: 7900	lat: 34\xc2\xb028'43.1378"S (-34.4786494)	long: 150\xc2\xb053'9	elev: 46.4	accuracy:	spee
11	10	msgCnt: 50	id: 4d550cf4	secMark: 7900	lat: 34\xc2\xb028'43.9309"S (-34.4788697)	long: 150\xc2\xb053'7	elev: 54.1	accuracy:	spee
12	11	msgCnt: 114	id: 240a3832	secMark: 8000	lat: 34\xc2\xb028'43.1346"S (-34.4786485)	long: 150\xc2\xb053'9	elev: 46.4	accuracy:	spee
13	12	msgCnt: 51	id: 4d550cf4	secMark: 8000	lat: 34\xc2\xb028'43.9284"S (-34.4788690)	long: 150\xc2\xb053'7	elev: 54.1	accuracy:	spee
14	13	msgCnt: 115	id: 240a3832	secMark: 8100	lat: 34\xc2\xb028'43.1342"S (-34.4786484)	long: 150\xc2\xb053'9	elev: 46.4	accuracy:	spee
15	14	msgCnt: 52	id: 4d550cf4	secMark: 8100	lat: 34\xc2\xb028'43.9255"S (-34.4788682)	long: 150\xc2\xb053'7	elev: 54.1	accuracy:	spee
16	15	msgCnt: 116	id: 240a3832	secMark: 8200	lat: 34\xc2\xb028'43.1368"S (-34.4786491)	long: 150\xc2\xb053'9	elev: 46.4	accuracy:	spee
17	16	msgCnt: 53	id: 4d550cf4	secMark: 8200	lat: 34\xc2\xb028'43.9212"S (-34.4788670)	long: 150\xc2\xb053'7	elev: 54.0	accuracy:	spee
18	17	msgCnt: 117	id: 240a3832	secMark: 8300	lat: 34\xc2\xb028'43.1375"S (-34.4786493)	long: 150\xc2\xb053'9	elev: 46.4	accuracy:	spee
19	18	msgCnt: 54	id: 4d550cf4	secMark: 8300	lat: 34\xc2\xb028'43.9176"S (-34.4788660)	long: 150\xc2\xb053'7	elev: 54.0	accuracy:	spee
20	19	msgCnt: 118	id: 240a3832	secMark: 8400	lat: 34\xc2\xb028'43.1364"S (-34.4786490)	long: 150\xc2\xb053'9	elev: 46.4	accuracy:	spee
21	20	msgCnt: 55	id: 4d550cf4	secMark: 8400	lat: 34\xc2\xb028'43.9147"S (-34.4788652)	long: 150\xc2\xb053'7	elev: 54.0	accuracy:	spee
22	21	msgCnt: 119	id: 240a3832	secMark: 8500	lat: 34\xc2\xb028'43.1368"S (-34.4786491)	long: 150\xc2\xb053'9	elev: 46.4	accuracy:	spee
23	22	msgCnt: 56	id: 4d550cf4	secMark: 8500	lat: 34\xc2\xb028'43.9104"S (-34.4788640)	long: 150\xc2\xb053'7	elev: 54.0	accuracy:	spee
24	23	msgCnt: 120	id: 240a3832	secMark: 8600	lat: 34\xc2\xb028'43.1324"S (-34.4786479)	long: 150\xc2\xb053'9	elev: 46.4	accuracy:	spee
25	24	msgCnt: 57	id: 4d550cf4	secMark: 8600	lat: 34\xc2\xb028'43.9075"S (-34.4788632)	long: 150\xc2\xb053'7	elev: 54.0	accuracy:	spee
26	25	msgCnt: 121	id: 240a3832	secMark: 8700	lat: 34\xc2\xb028'43.1306"S (-34.4786474)	long: 150\xc2\xb053'9	elev: 46.4	accuracy:	spee
27	26	msgCnt: 58	id: 4d550cf4	secMark: 8700	lat: 34\xc2\xb028'43.9039"S (-34.4788622)	long: 150\xc2\xb053'7	elev: 54.0	accuracy:	spee
28	27	msgCnt: 122	id: 240a3832	secMark: 8800	lat: 34\xc2\xb028'43.1339"S (-34.4786483)	long: 150\xc2\xb053'9	elev: 46.4	accuracy:	spee
29	28	msgCnt: 59	id: 4d550cf4	secMark: 8800	lat: 34\xc2\xb028'43.8989"S (-34.4788608)	long: 150\xc2\xb053'7	elev: 54.0	accuracy:	spee
30	29	msgCnt: 123	id: 240a3832	secMark: 8900	lat: 34\xc2\xb028'43.1335"S (-34.4786482)	long: 150\xc2\xb053'9	elev: 46.4	accuracy:	spee
31	30	msgCnt: 60	id: 4d550cf4	secMark: 8900	lat: 34\xc2\xb028'43.8946"S (-34.4788596)	long: 150\xc2\xb053'7	elev: 54.0	accuracy:	spee
32	31	msgCnt: 124	id: 240a3832	secMark: 9000	lat: 34\xc2\xb028'43.1353"S (-34.4786487)	long: 150\xc2\xb053'9	elev: 46.4	accuracy:	spee
33	32	msgCnt: 61	id: 4d550cf4	secMark: 9000	lat: 34\xc2\xb028'43.8899"S (-34.4788583)	long: 150\xc2\xb053'7	elev: 54.0	accuracy:	spee
34	33	msgCnt: 125	id: 240a3832	secMark: 9100	lat: 34\xc2\xb028'43.1360"S (-34.4786489)	long: 150\xc2\xb053'9	elev: 46.4	accuracy:	spee
35	34	msgCnt: 62	id: 4d550cf4	secMark: 9100	lat: 34\xc2\xb028'43.8848"S (-34.4788569)	long: 150\xc2\xb053'7	elev: 54.0	accuracy:	spee
36	35	msgCnt: 126	id: 240a3832	secMark: 9200	lat: 34\xc2\xb028'43.1346"S (-34.4786485)	long: 150\xc2\xb053'9	elev: 46.3	accuracy:	spee
37	36	msgCnt: 63	id: 4d550cf4	secMark: 9200	lat: 34\xc2\xb028'43.8827"S (-34.4788563)	long: 150\xc2\xb053'7	elev: 53.9	accuracy:	spee
38	37	msgCnt: 127	id: 240a3832	secMark: 9300	lat: 34\xc2\xb028'43.1346"S (-34.4786485)	long: 150\xc2\xb053'9	elev: 46.3	accuracy:	spee

Contents

3. Heavy Vehicles Investigation

3.1 Pseudo "ground-truth" assessment:

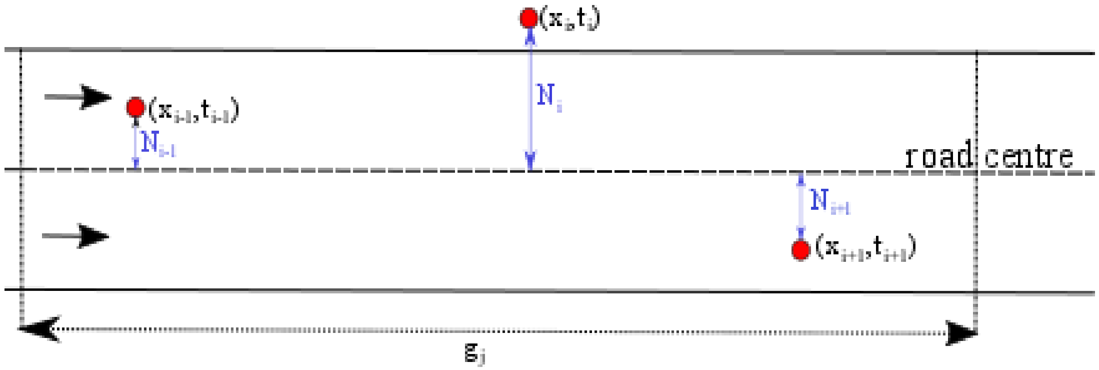
- Single transmission file analysis: "tx_r1c_84.pcap", Truck 1.
- Daily trips from Port Kembla to West Cliff Colliery.
- Finding ground truth available sources and testing their reliability:
  - **Google Street Map (GSM)**
  - **Open Street Map (OSM)**



3. Heavy Vehicles Investigation

Positioning Error from “ground-truth”(N_i):

- the Vicenty distance between a transmitted GPS point an the nearest point on the road centre, as represented in a map shape file (GSM, OSM).



Anomaly definition (A_i):

- Any errors (distance) from the road centre that is bigger than 8 meters.

3. Heavy Vehicles Investigation

Steps for detecting noise anomalies:

1. Consider a road section $[\mathrm{A}, \mathrm{B}]$ defined by a starting point A and ending point B.

2. Apply a Map Matching procedure for identifying the trajectory of the DSRC GPS positioning.

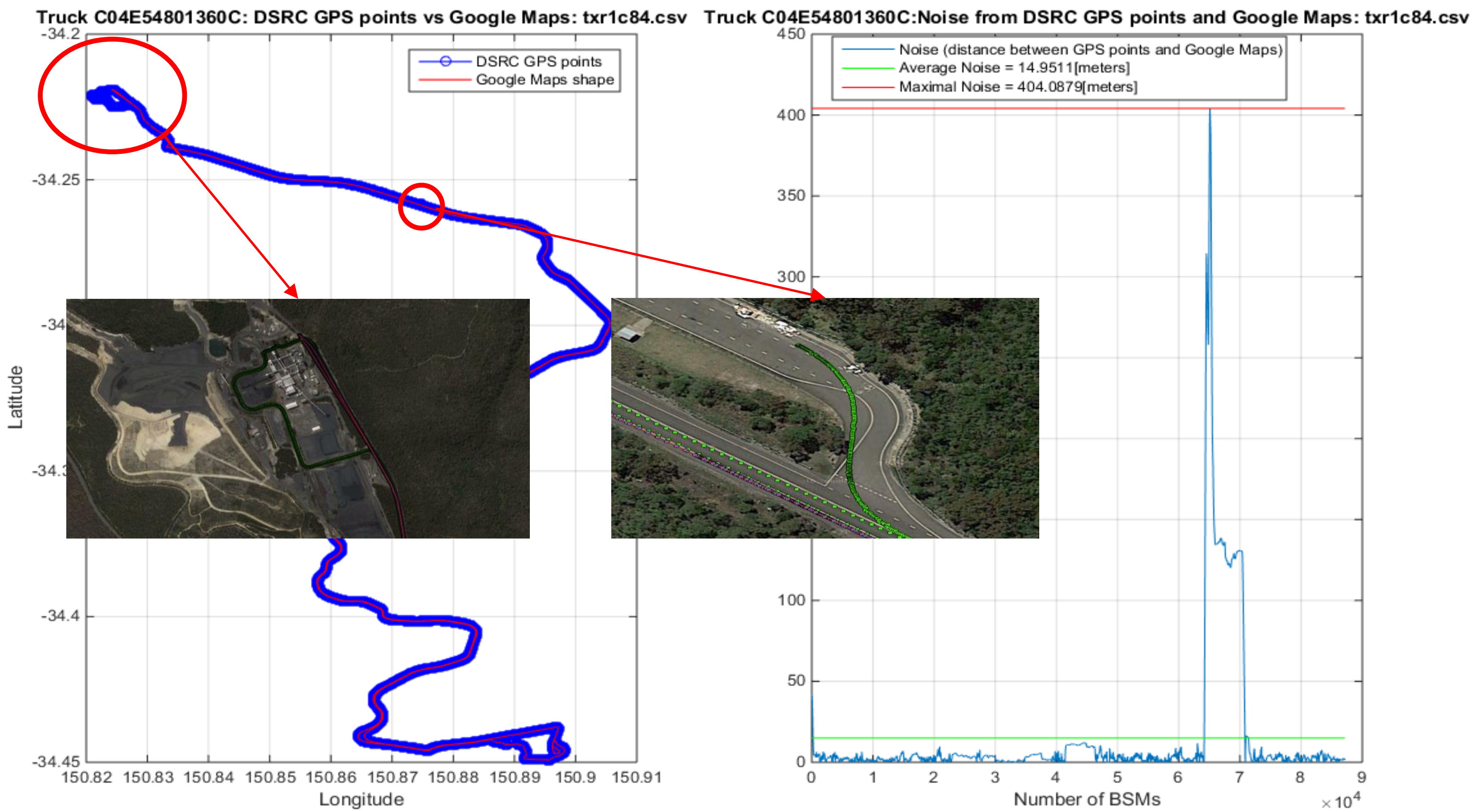
3. Compute deviations (positioning errors) from the road center for each intermediary points between $[\mathrm{A}, \mathrm{B}]$.

4. Compute mean deviations on the selected road section $(\bar{N})$, for all available trips undertaken during the total travel time of a truck.

3. Heavy Vehicles Investigation

Google Street Map as Ground Truth:

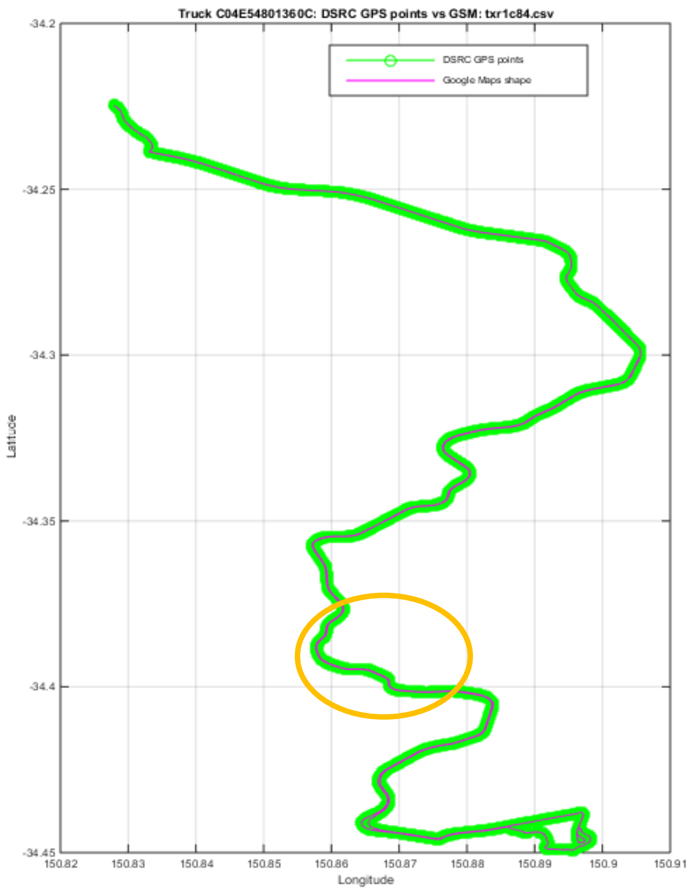
- Initial results including colliery:

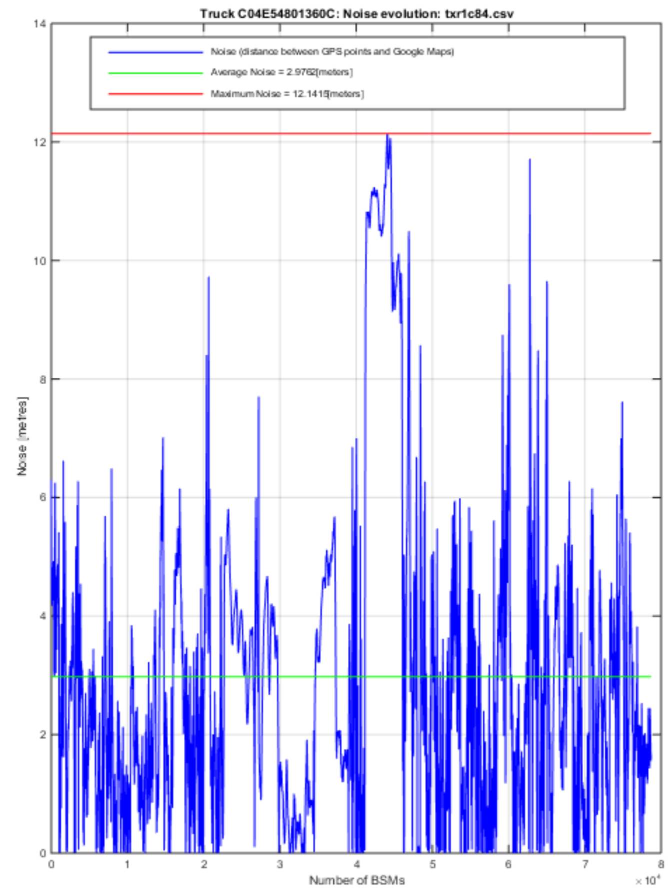


3. Heavy Vehicles Investigation

Google Street Map as Ground Truth:

- After Cleaning unsealed roads/departing parking area:





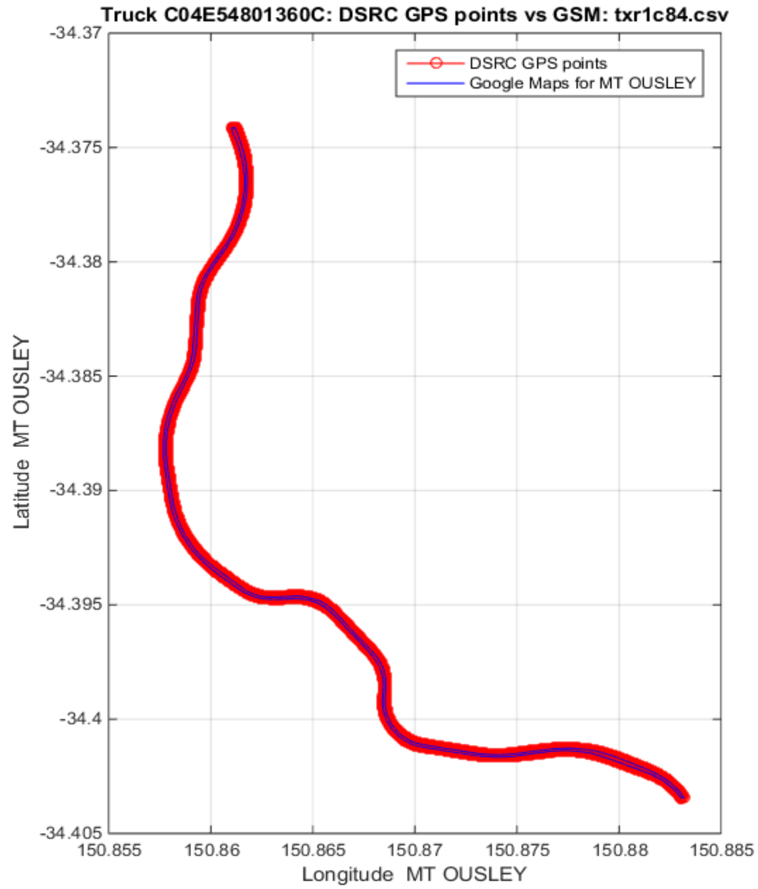
Main road section for investigating all trucks!

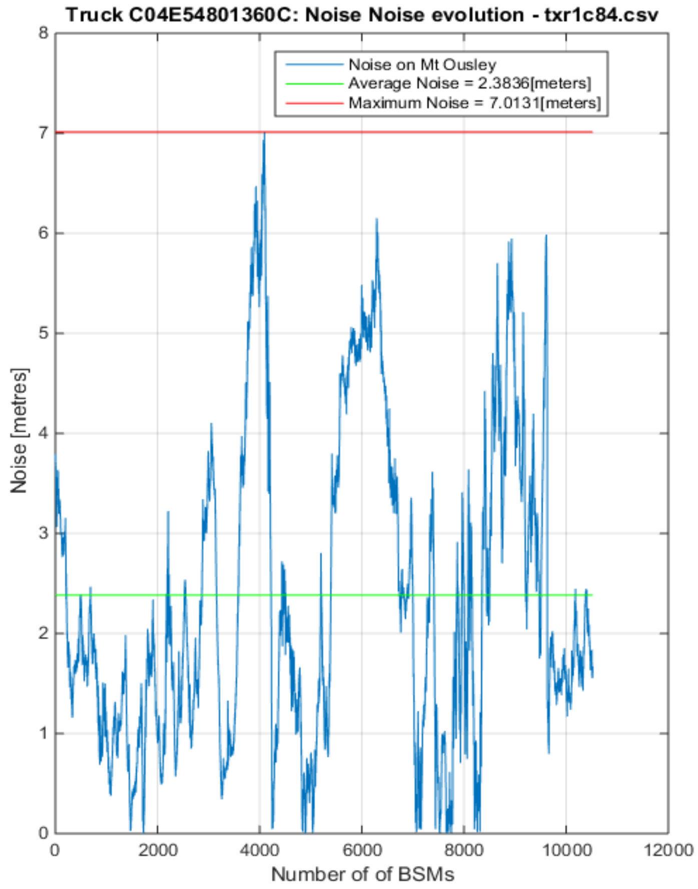
Average noise = 2.97 meters

3. Heavy Vehicles Investigation

Google Street Map as Ground Truth:

- Investigation on Mount Ousley road section (speed restrictions apply on descent)





Average noise = 2.38 meters

3. Heavy Vehicles Investigation

GSM and OSM comparison

	Google Maps (GSM)		Open Street Maps (OSM)		Difference between AVERAGE noise levels	Error between GSM and OSM
	Average noise[m]	Maximum noise[m]	Average noise [m]	Maximum noise[m]	meters	[%]
Daily road section	14.9511	404.0879	3.8721	114.6368	11.0790	74.10 %
Daily road section excluding colliery and parking	**2.9762**	12.1415	3.2883	12.6679	**0.3121**	10.48 %
Mt. Ousley road section	**2.3836**	7.0131	2.7480	8.0559	0.3644	15.28 %

Contents

3.2 Truck 1 (C04E54801360C) Analysis

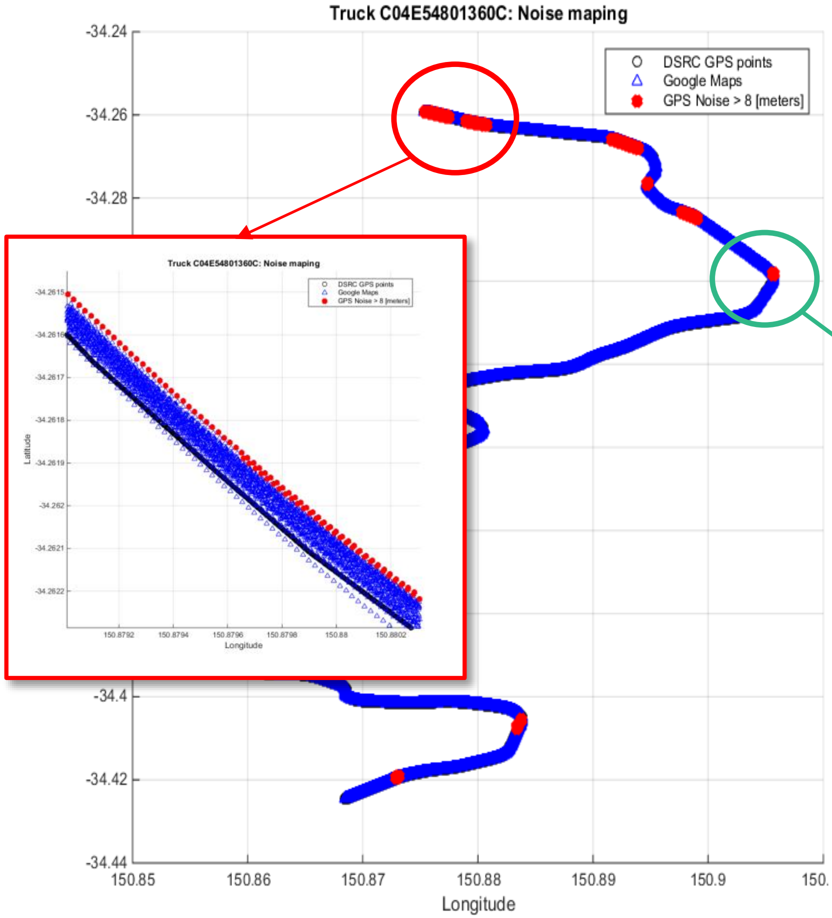
Details:

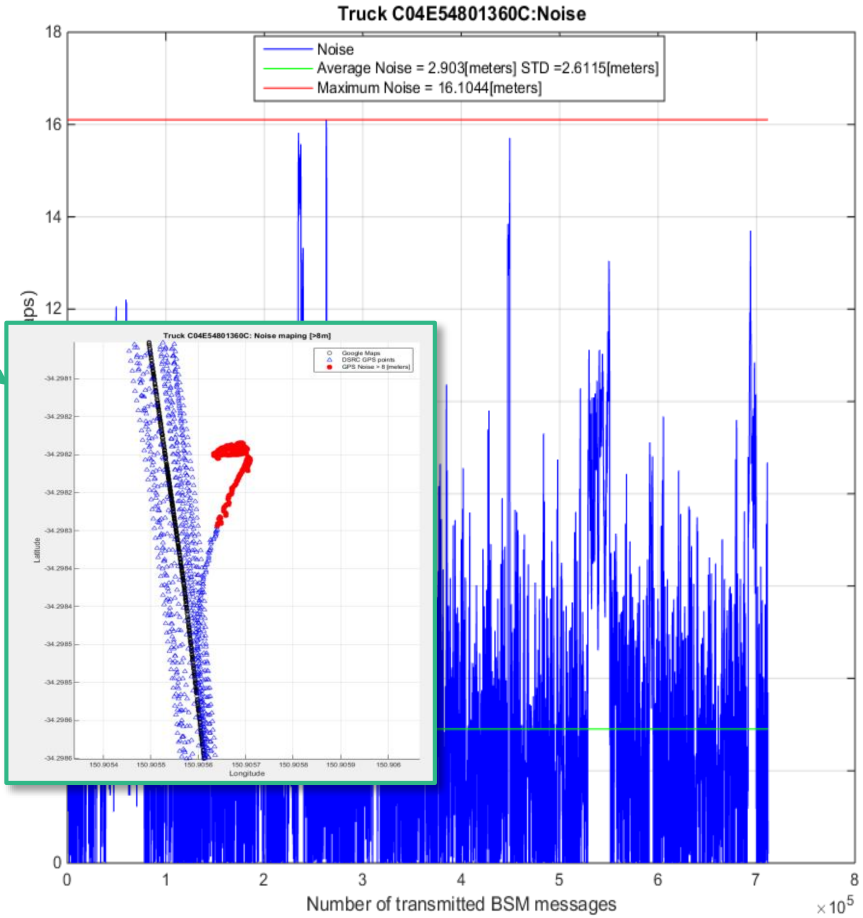
- operated by Bulktrans and equipped with an MK5 DSRC unit and GPS only (no GLONASS) antenna;.
- 1st most active truck of the investigation : 4.74 mil BSMs transmitted.
- 711,601 BSMs on the selected road section (after filtering road section)
- 42,342 anomalies (5.95%) on selected road section
- Average Noise registered = 2.9 m
- Maximum Noise registered = 16.1 m

Start date of the transmission files:	Jul 15, 2015 16:38:07.995023000
End date of the transmission files:	Nov 3, 2015 19:47:24.243018000

3.2 Truck 1 (C04E54801360C) Analysis

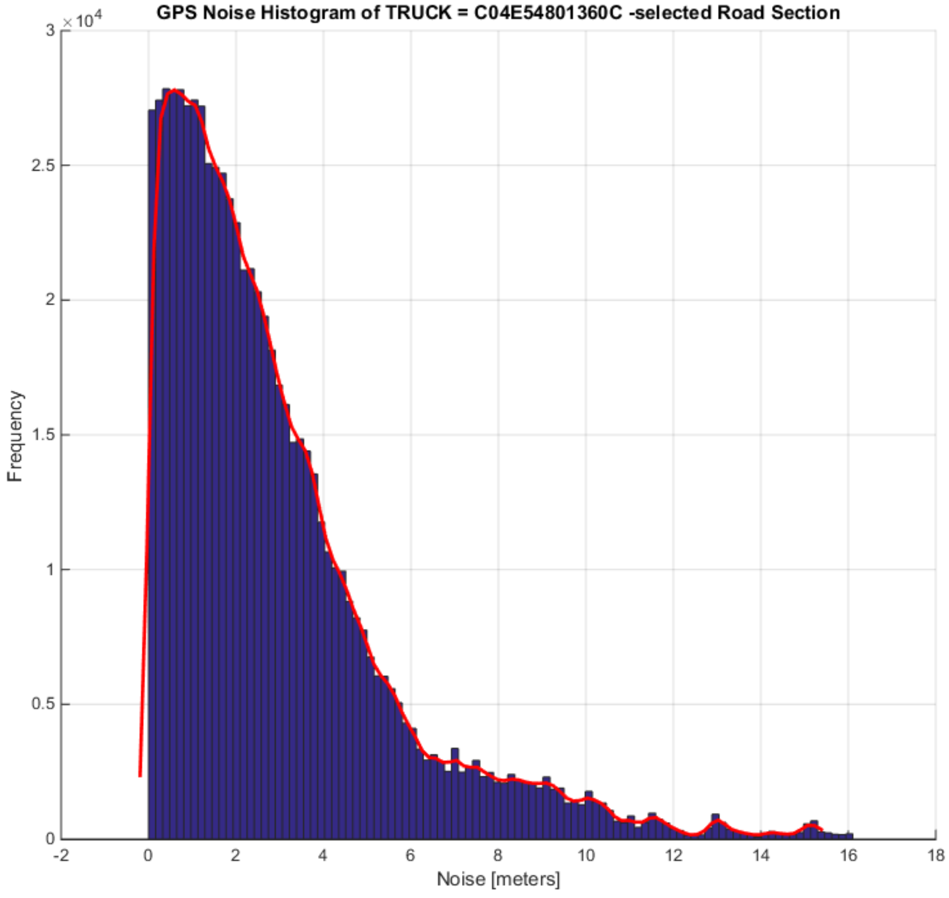
Selected road section investigation:





3.2 Truck 1 (C04E54801360C) Analysis

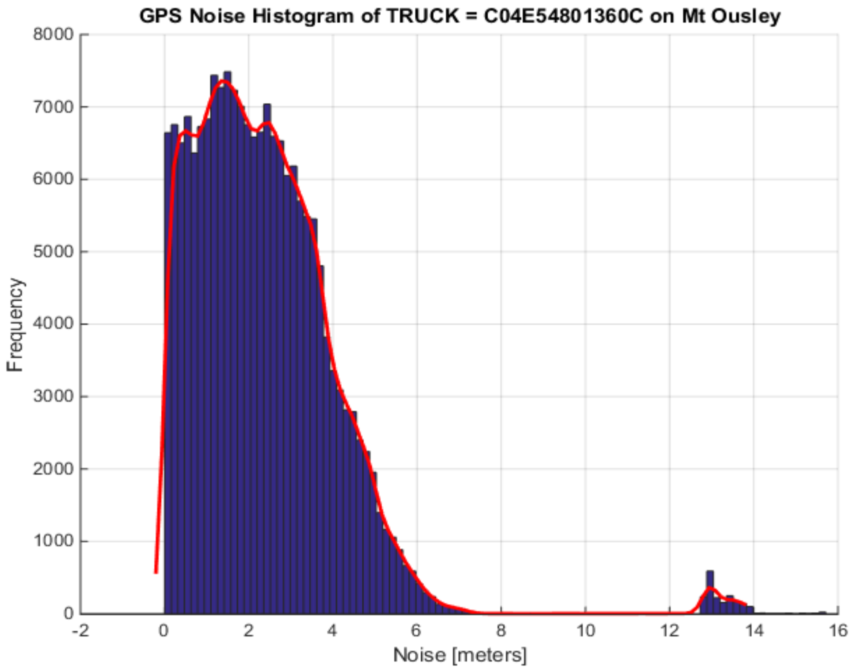
Selected road section investigation: Noise distribution

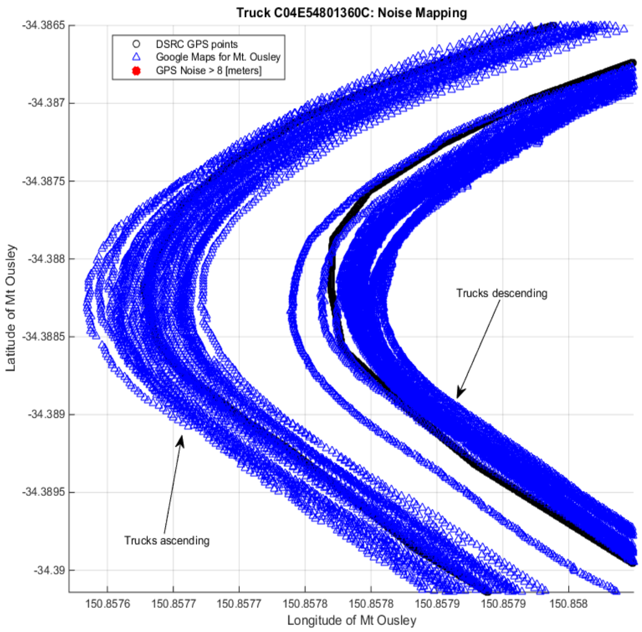


3.2 Truck 1 (C04E54801360C) Analysis

Mt. Ousley investigation:

- Very good positioning accuracy (1.08% anomalies on Mt. Ousley).
- Truck drives mostly at 1.5-2 meters from the road centre.
- Anomaly in the tail indicates only a rest area stop.
- Particular behaviour noticed in curved road sections (ascending and descending)

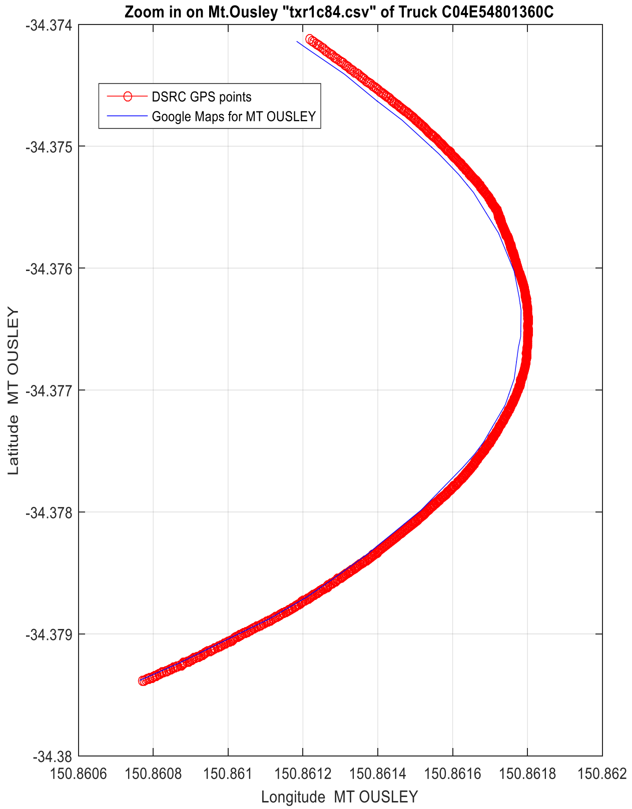


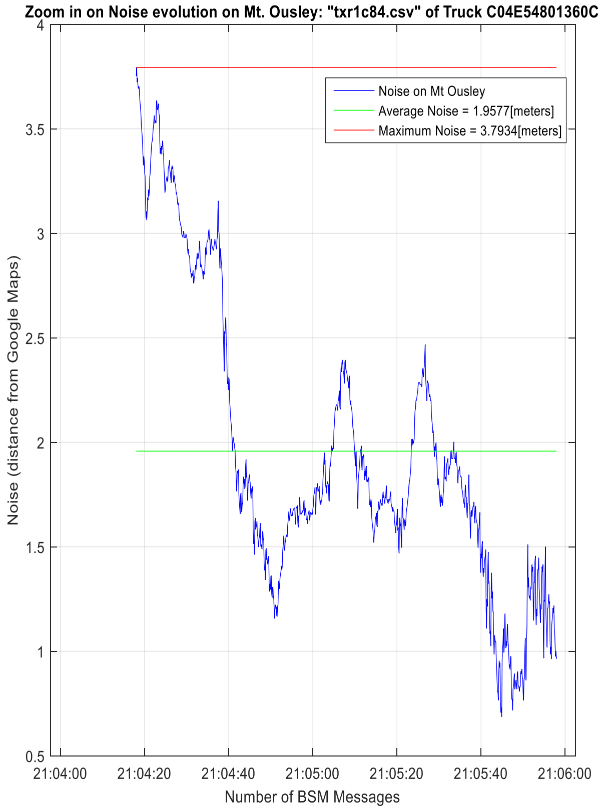


3.2 Truck 1 (C04E54801360C) Analysis

Short BSM sequence investigation:

- 2 minute analysis at the top of Mt. Ousley descent
- we observe a 2 meter shift from the beginning of the journey :
  - driving behaviour (change of lanes), GPS inaccuracy (lack of Satellite signal), topology errors (GSM).

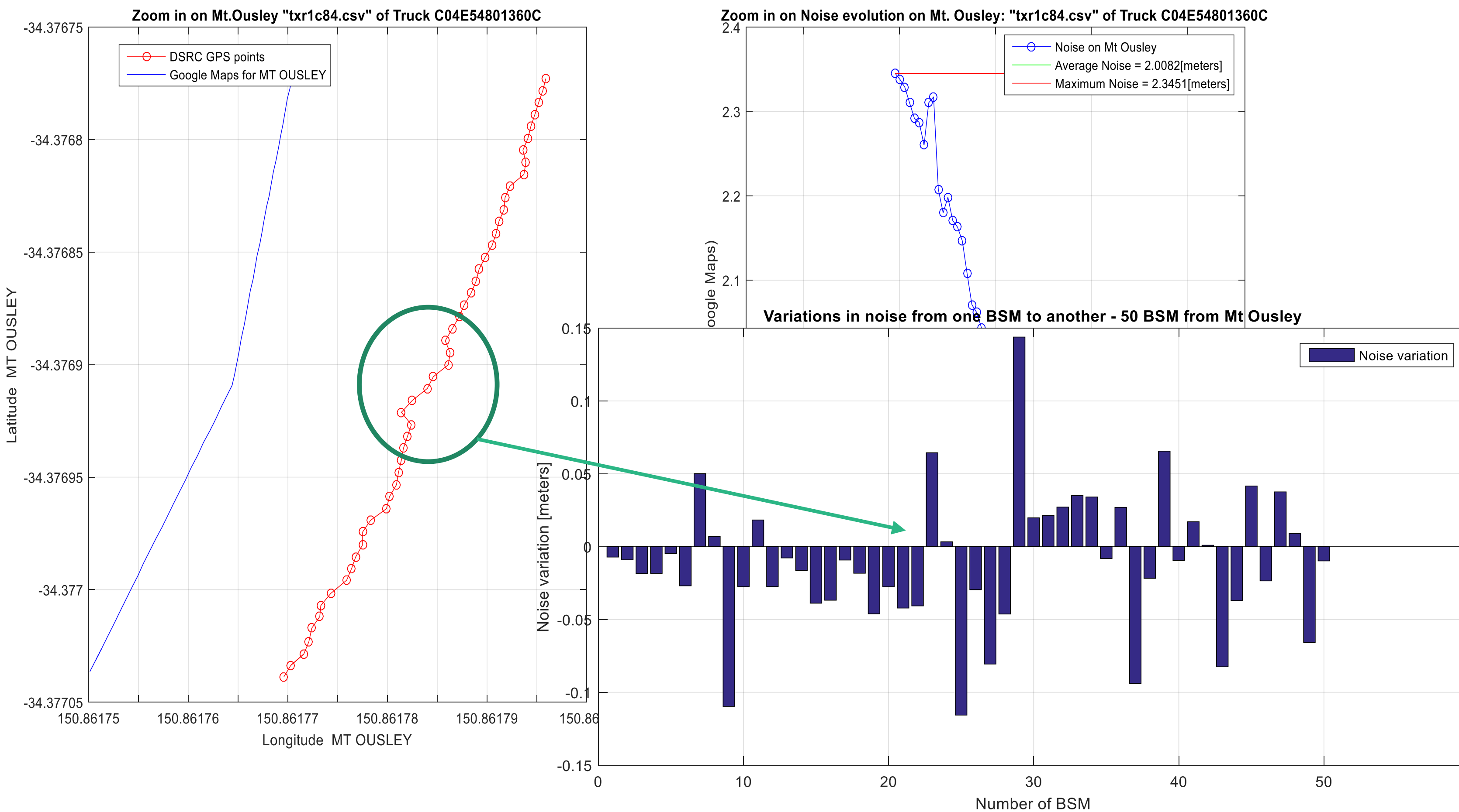




3.2 Truck 1 (C04E54801360C) Analysis

Variations between consecutive BSMs:

- 50 consecutive BSMs analysis on Mt. Ousley descent: small jitter appears on certain road sections



3.3 Truck 2 (C04E548017010) Analysis

Details:

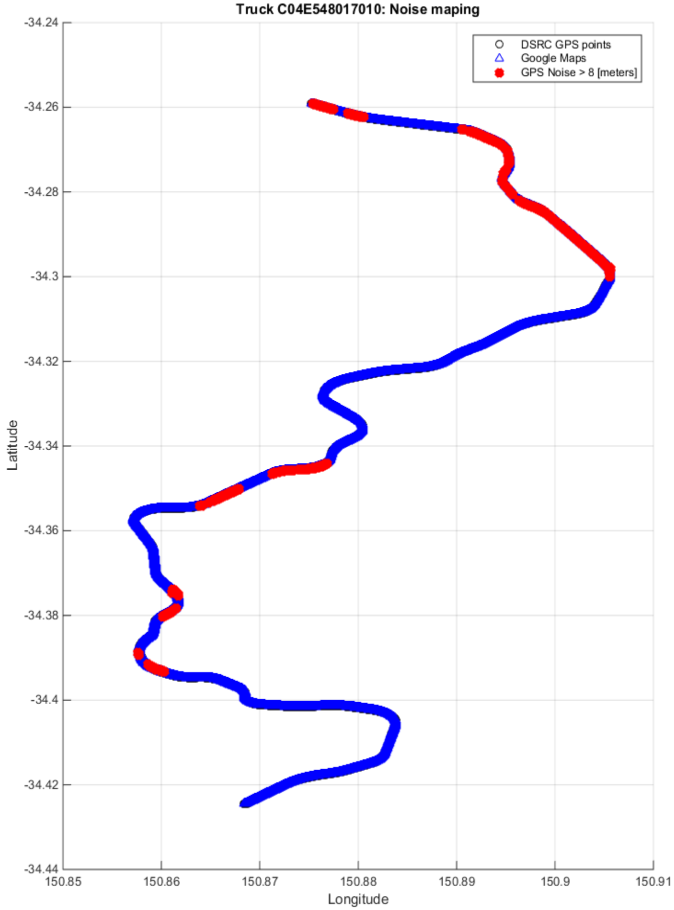
- operated by Bulktrans and equipped with an MK5 DSRC unit and GPS only (no GLONASS) antenna;.
- 2nd most active truck of the investigation : 3.73 mil BSMs transmitted.
- 1st most active truck on the selected road section : 903,209 BMs
- 42,363 anomalies (4.69%) on selected road section
- Average Noise registered = 2.85 m
- Maximum Noise registered = 16.8 m
- Presents smallest jitter between consecutive BSMs.

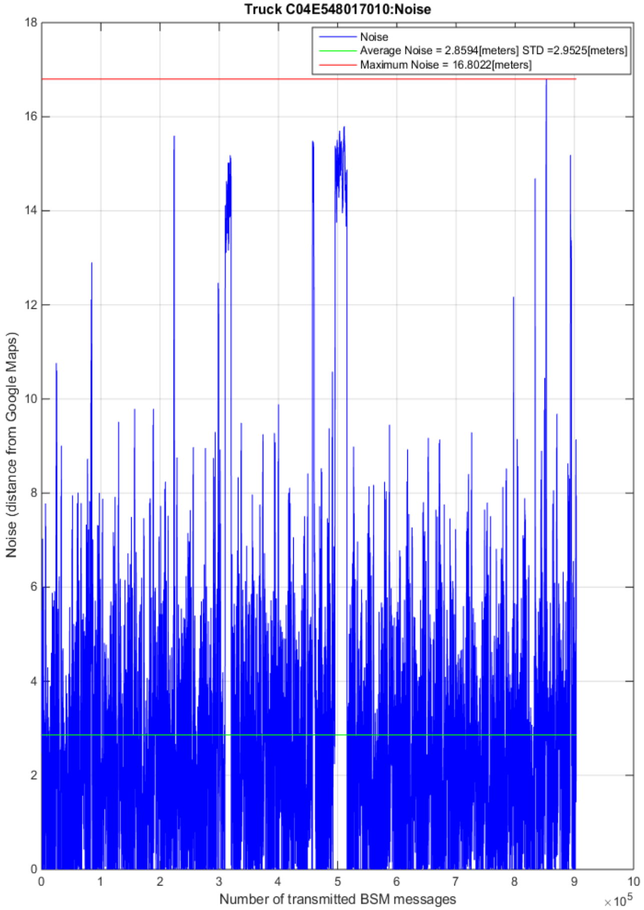
Start date of the transmission files:	Aug 22, 2015 23:12:01.866107000
End date of the transmission files:	Oct 30, 2015 05:26:16.002918000

3.3 Truck 2 (C04E548017010) Analysis

Selected road section investigation:

Less registered anomalies than Truck 1, but more spread-out along the North part of the Road selection.



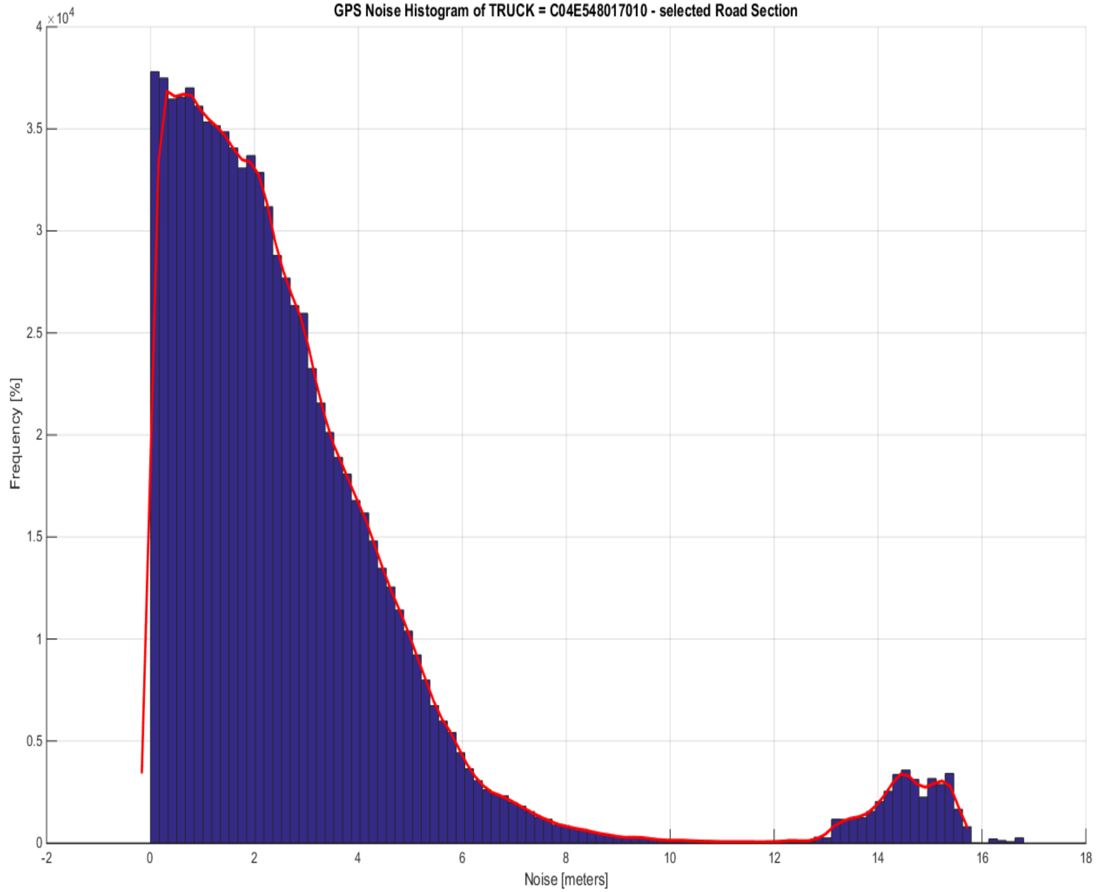


Average Noise = 2.85 m, Maximum Noise = 16.8 m

3.3 Truck 2 (C04E548017010) Analysis

Selected road section distribution:

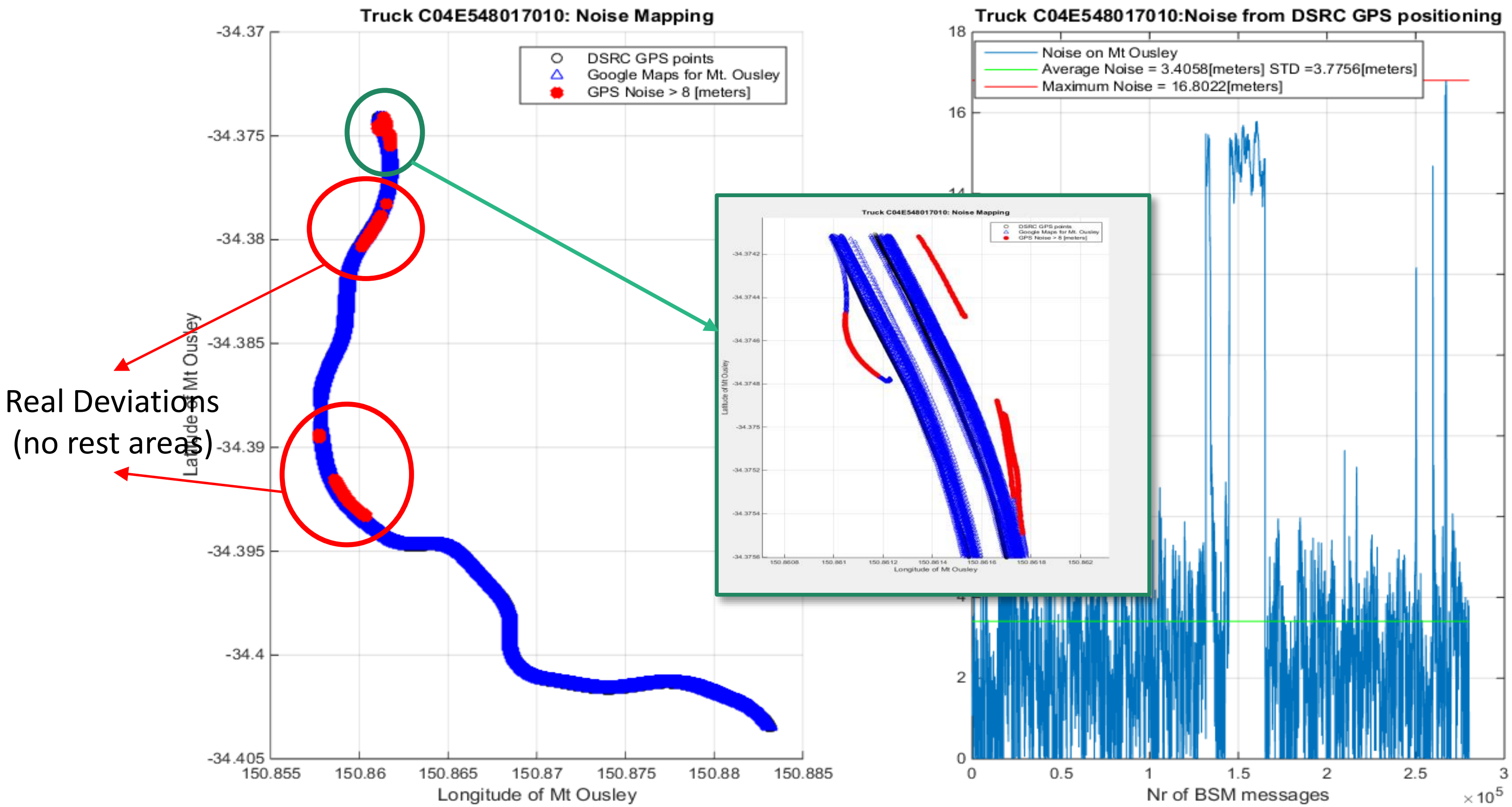
Anomalies are shown in the noise distribution



3.3 Truck 2 (C04E548017010) Analysis

Mt. Ousley investigation

Higher number of anomalies detected on Mt. Ousley compared to Truck 1



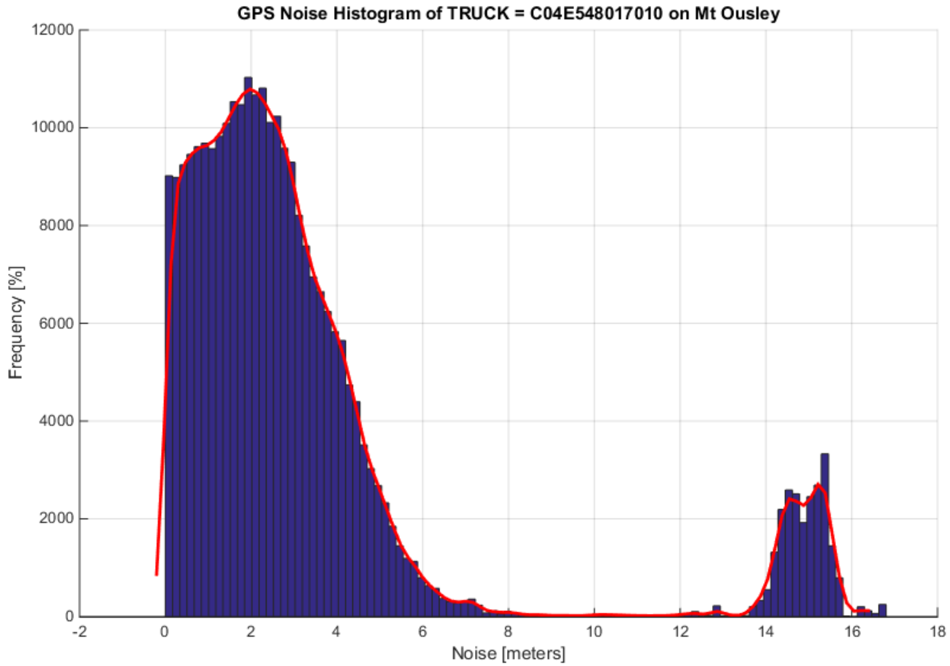
Average Noise = 3.4 m, Maximum Noise = 16.8 m

3.3 Truck 2 (C04E548017010) Analysis

Mt. Ousley investigation

- Higher number of anomalies detected on Mt. Ousley (8.65%) compared to Truck 1 (1.08%).
- Distribution indicates a preferred driving behaviour of mostly 3 meters from the road centre.

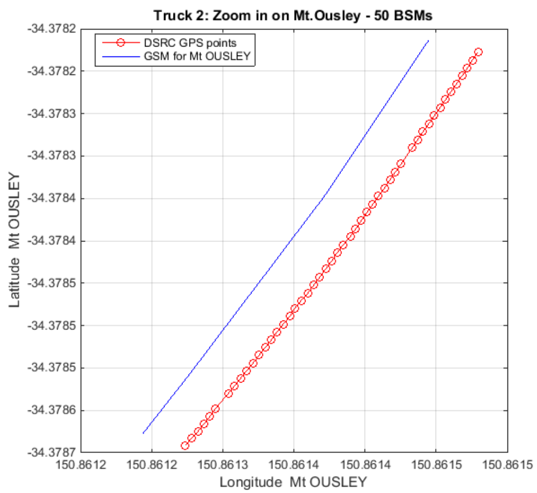
Name	Start Date	End Date	Number of BSM messages
Mt. Ousley road section	Aug 24, 2015 01:06:09.146352000	Oct 29, 2015 03:30:38.730758000	280,057
Anomalies on Mt. Ousley	Sep 6, 2015 13:48:56.872012000	Oct 19, 2015 09:33:46.141116000	**24,234 (8.65%)**

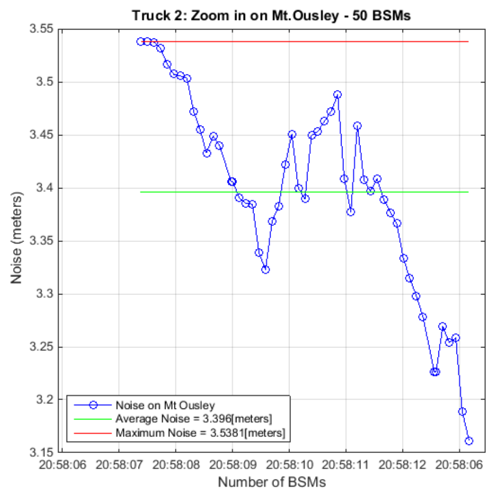


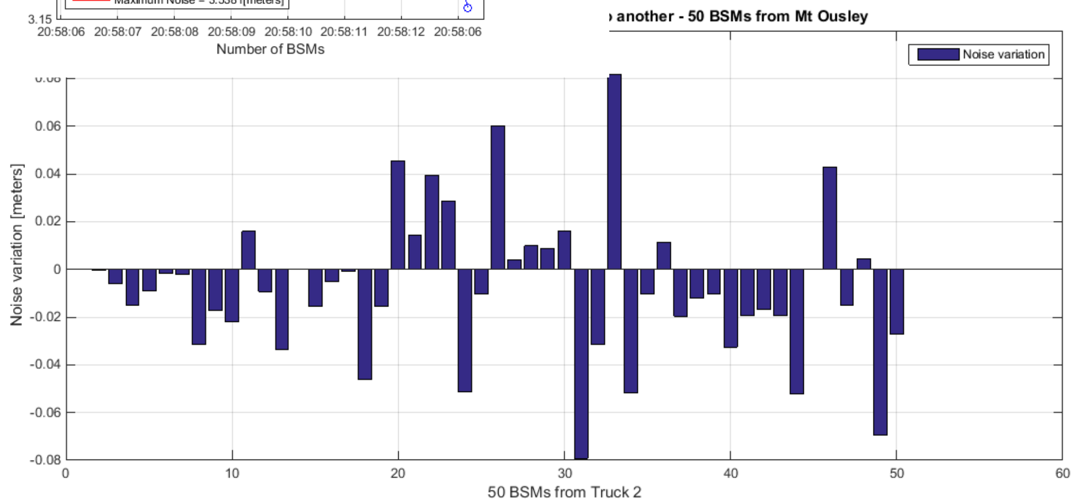
3.3 Truck 2 (C04E548017010) Analysis

Short BSM investigations

- Despite on having more anomalies on Mt. Ousley, the jitter between consecutive BSMs is better than that of Truck 1.







3.4 Truck 3 (C04E548013B40) Analysis

Details:

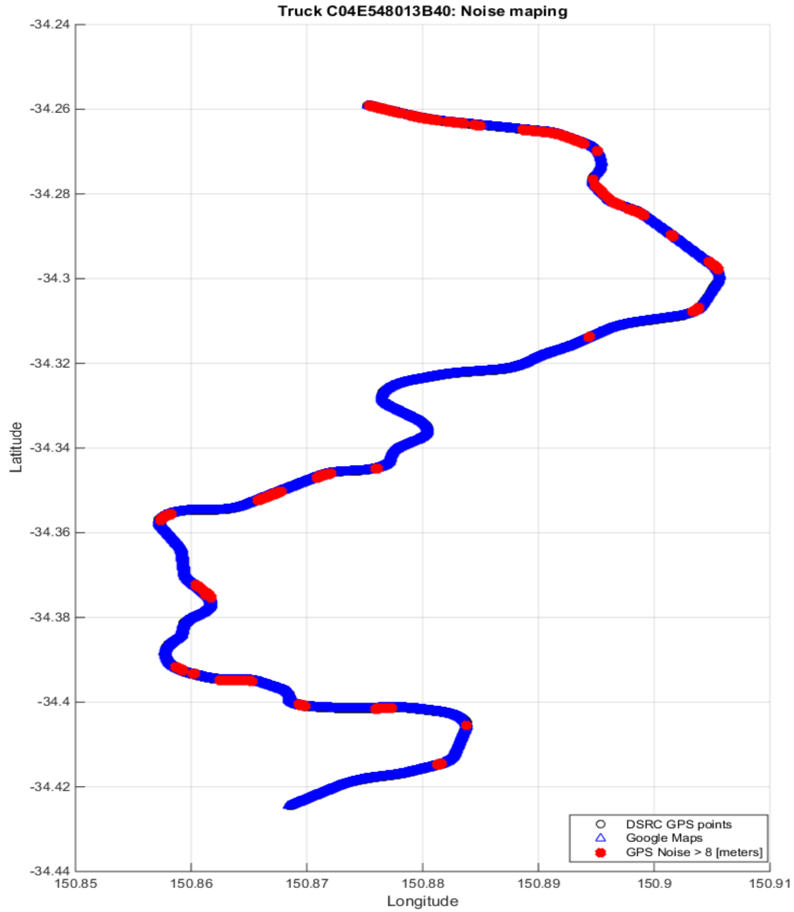
- operated by Bulktrans and equipped with an MK5 DSRC unit and GPS only (no GLONASS) antenna;.
- 2.76 mil BSMs transmitted.
- 3rd most active truck on the selected road section : 363,506 BMs
- 6,904 anomalies (1.9%) on selected road section
- Average Noise registered = 2.71 m
- Maximum Noise registered = 17.07 m (highest form all trucks)
- Presents the largest spread of anomalies amongst the trucks, but the smallest jitter between consecutive BSMs.

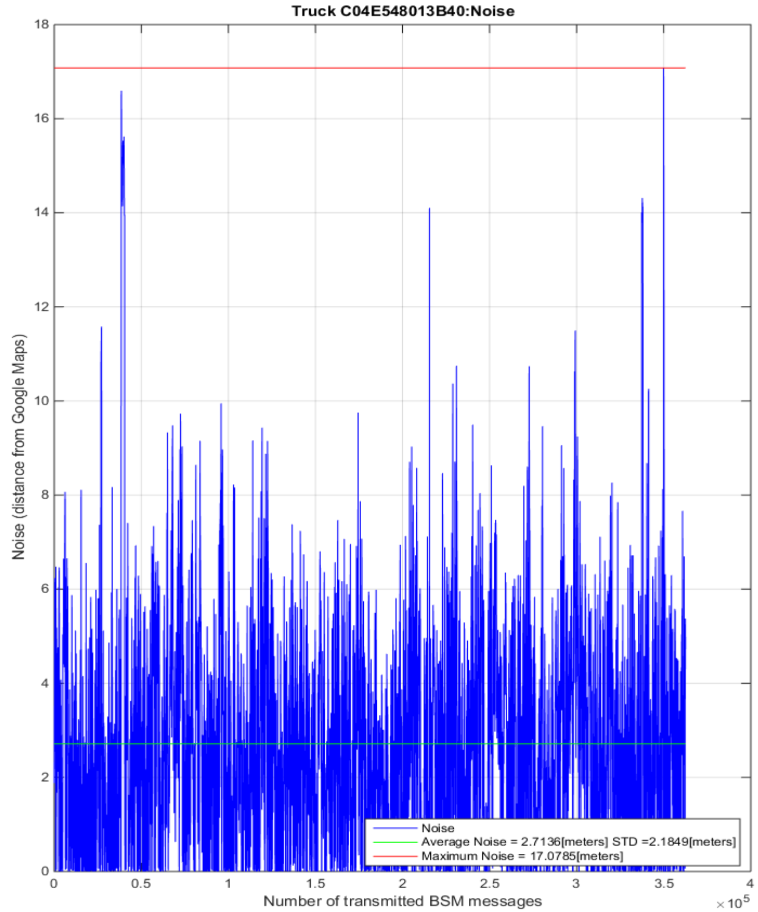
Start date of the transmission files:	Aug 22, 2015 10:50:13.875742000
End date of the transmission files:	Nov 2, 2015 23:14:16.176066000

3.4 Truck 3 (C04E548013B40) Analysis

Selected road section investigation:

Multiple noisy areas detected along the route even in dangerous sections (no parking permitted).



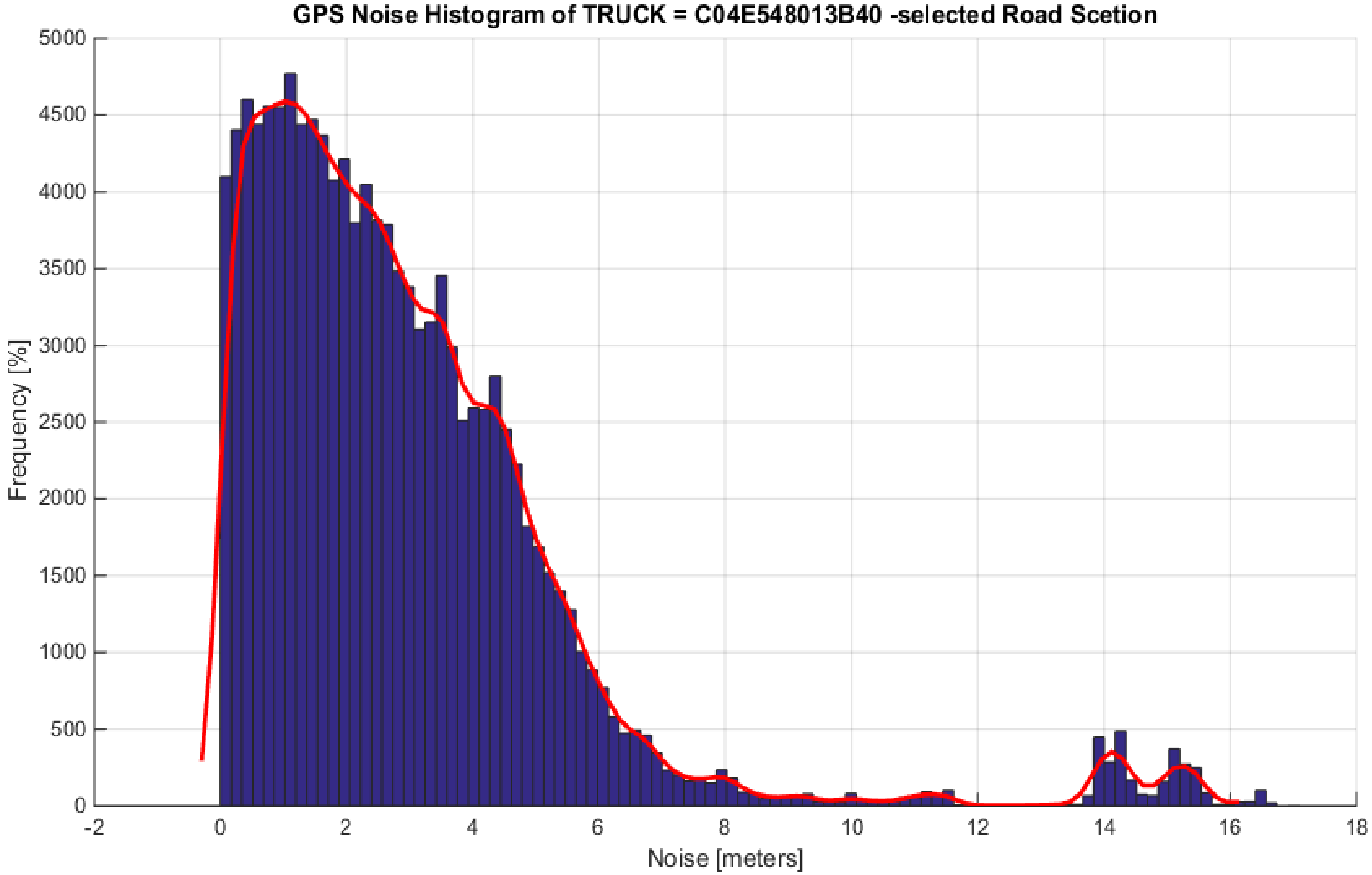


Average Noise = 2.71 m, Maximum Noise = 17.07 m

3.4 Truck 3 (C04E548013B40) Analysis

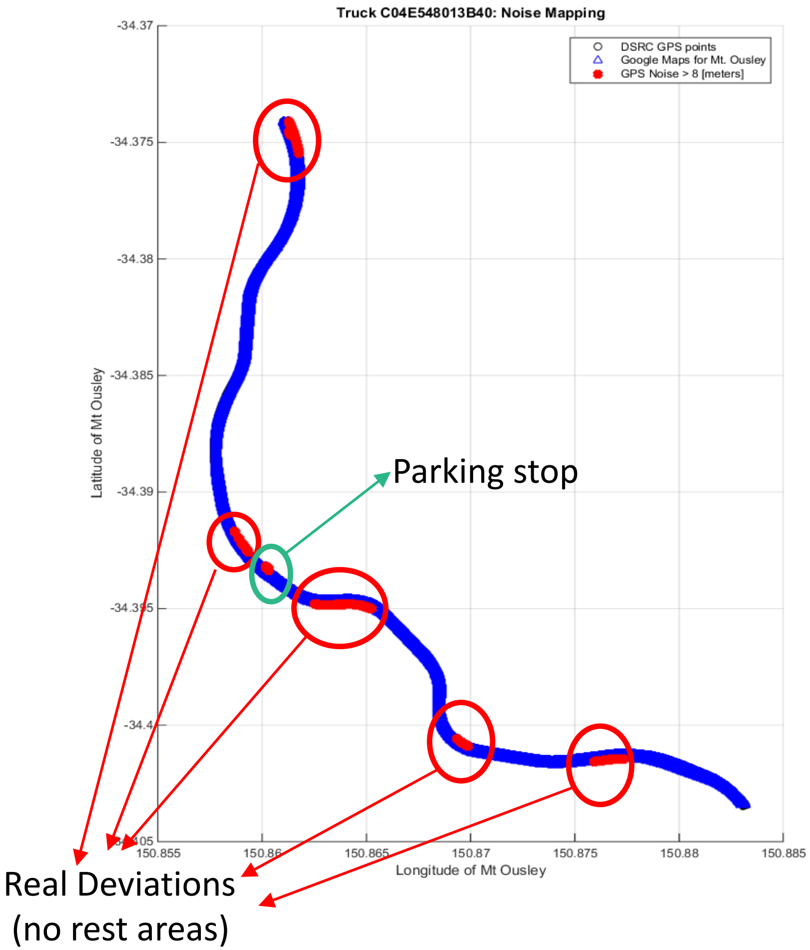
Selected road section investigation:

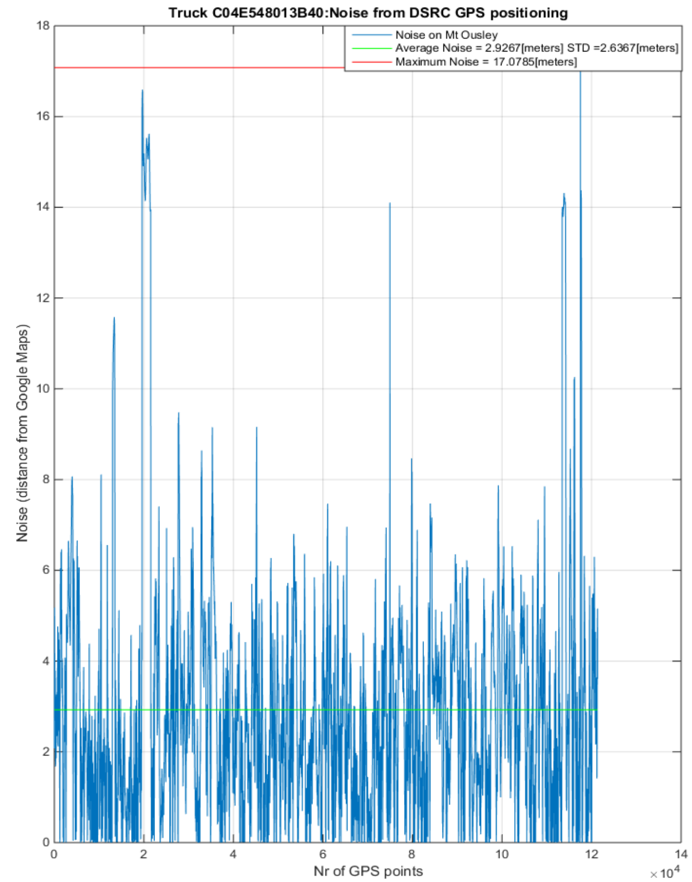
- Irregular noise distribution of the error.
- Truck drives mostly at 2m from the road centre.



3.4 Truck 3 (C04E548013B40) Analysis

Mt. Ousley investigation:

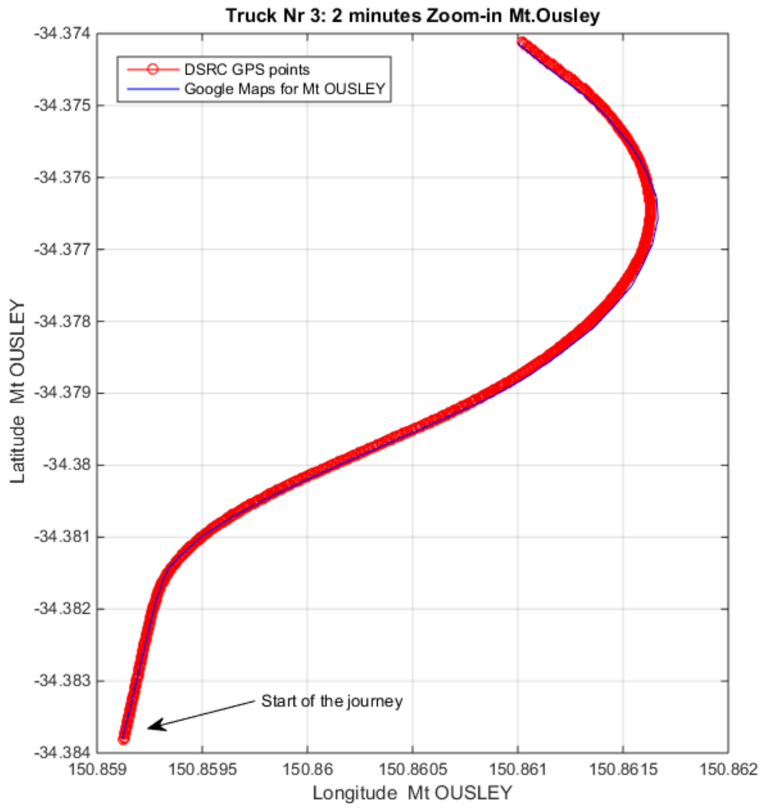


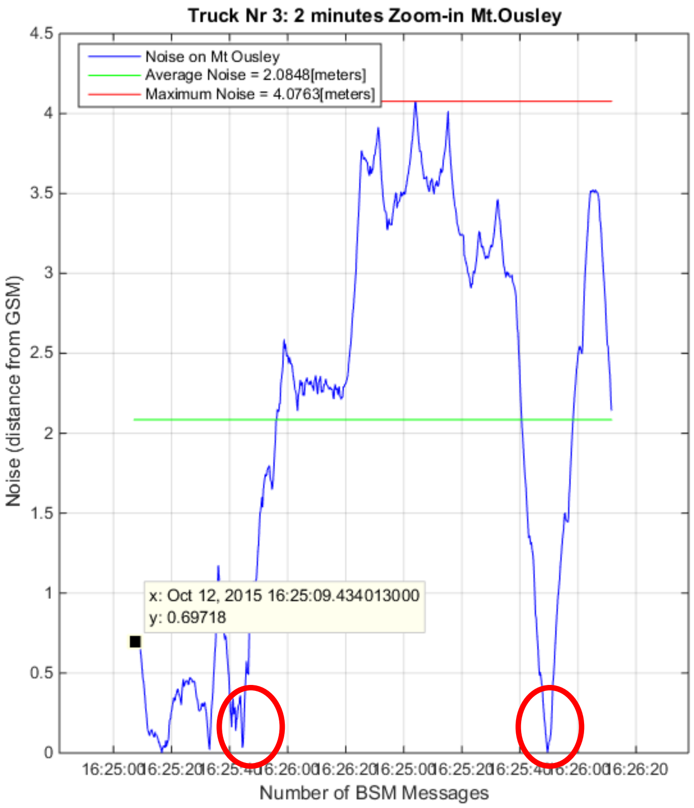


3.4 Truck 3 (C04E548013B40) Analysis

Short BSM sequence investigation:

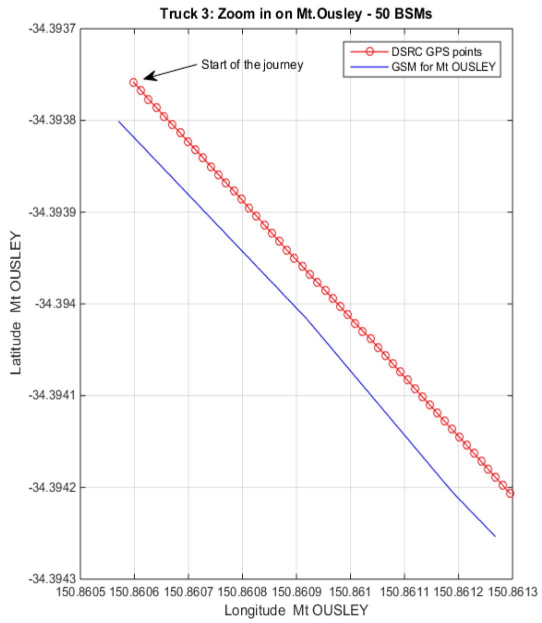
- 1.5 minute analysis at the top of Mt. Ousley descent indicates 2 changes in the lane position (16:25:00 and 16:26:00)
- Possible causes: GPS drift/error, topology, driving behaviour

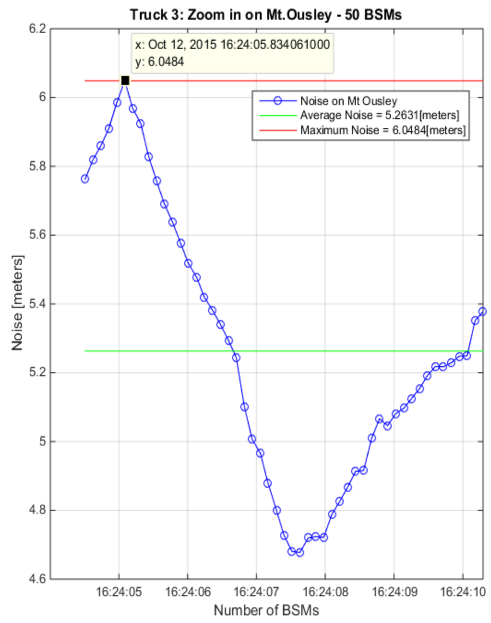


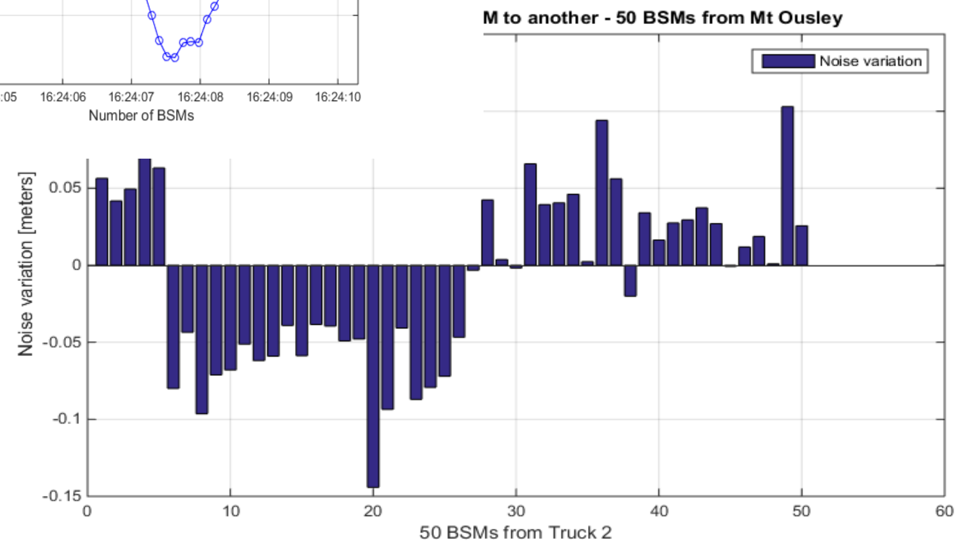


3.4 Truck 3 (C04E548013B40) Analysis

50 BSMs sequence investigation: smallest jitter from all the trucks +/-0.1m







3.5 Truck 4 (C04E548013968) Analysis

Details:

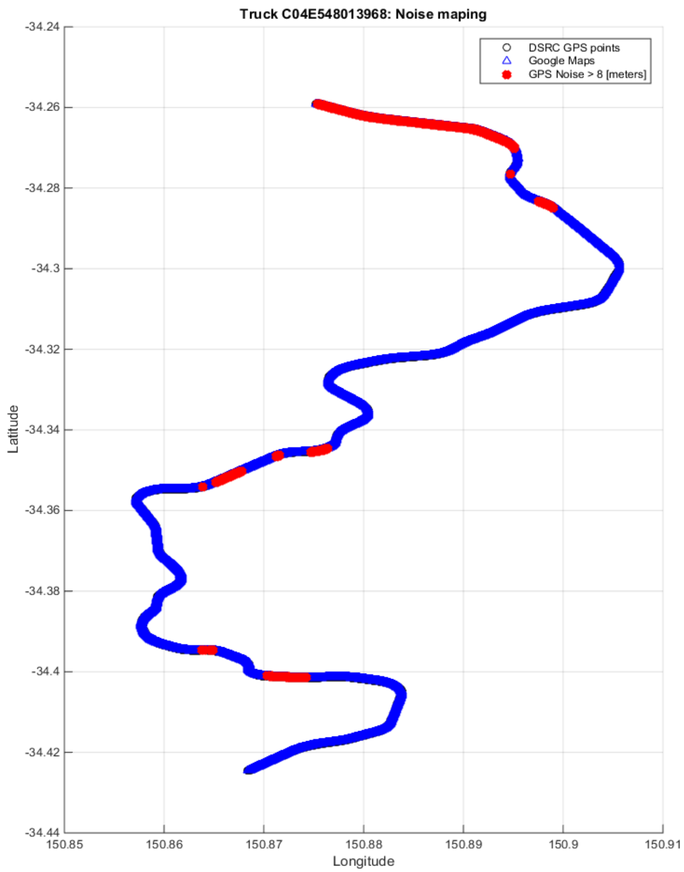
- operated by Bulktrans and equipped with an MK5 DSRC unit and GPS only (no GLONASS) antenna.
- 2.85 mil BSMs transmitted.
- 4th most active truck on the selected road section : 329,612 BMs.
- 3,345 anomalies (1.01%) on selected road section.
- Average Noise registered = 2.42 m.
- Maximum Noise registered = 13.78 m.
- Presents jitter between consecutive BSMs on curved road sections.

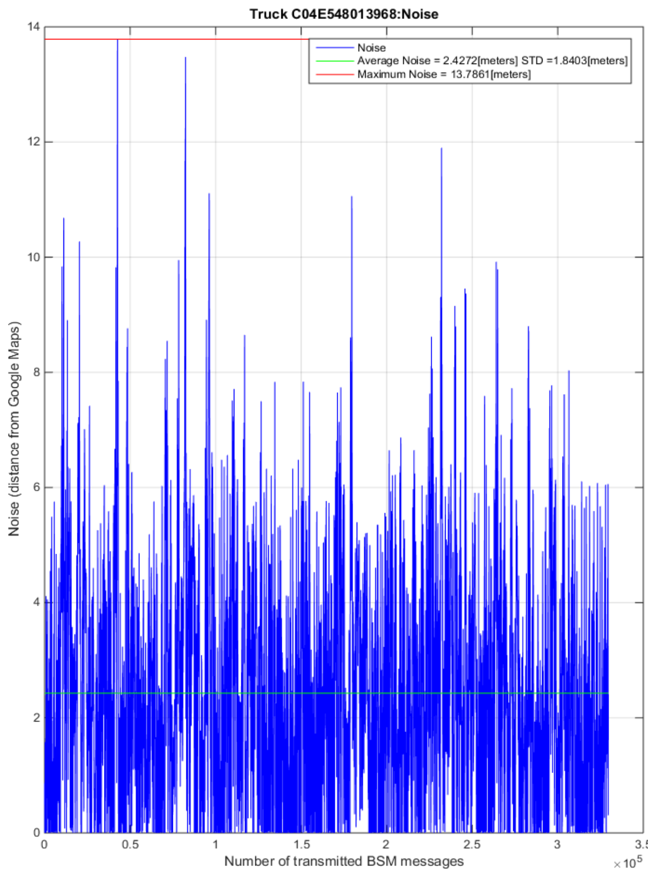
Start date of the transmission files:	Aug 23, 2015 07:04:38.270970000
End date of the transmission files:	Oct 23, 2015 03:31:06.089445000

3.5 Truck 4 (C04E548013968) Analysis

Selected road section investigation:

Presents the majority of anomalies in the north part of the road section.



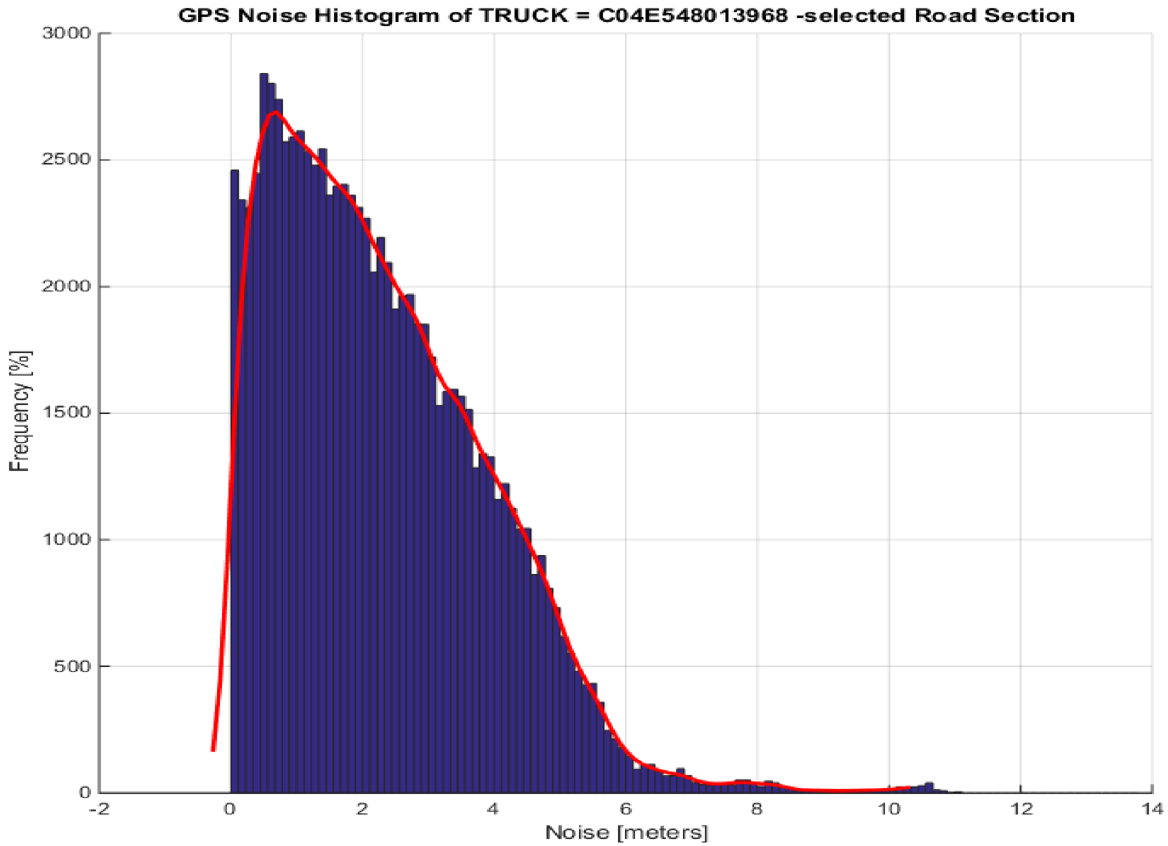


Average Noise = 2.42 m, Maximum Noise = 13.78 m

3.5 Truck 4 (C04E548013968) Analysis

Selected road section investigation:

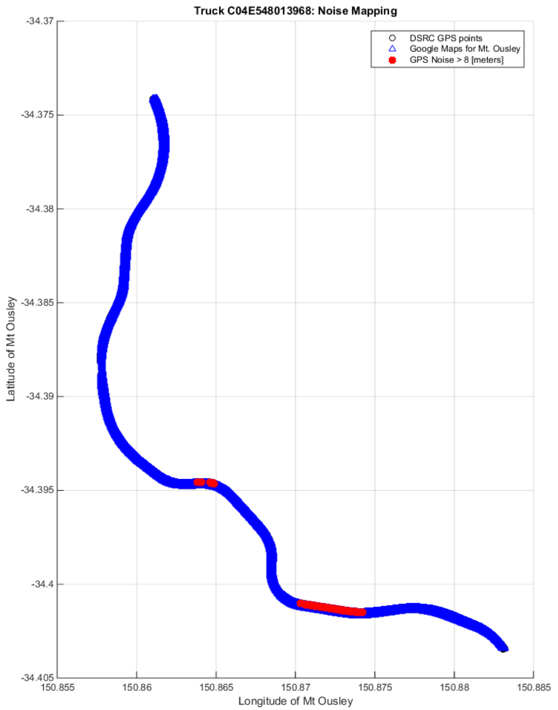
- Noise distribution doesn't present big outliers from the general behaviour of the trucks.
- The driving behaviour indicates a preference of circulating at almost 1 meter the road centre.

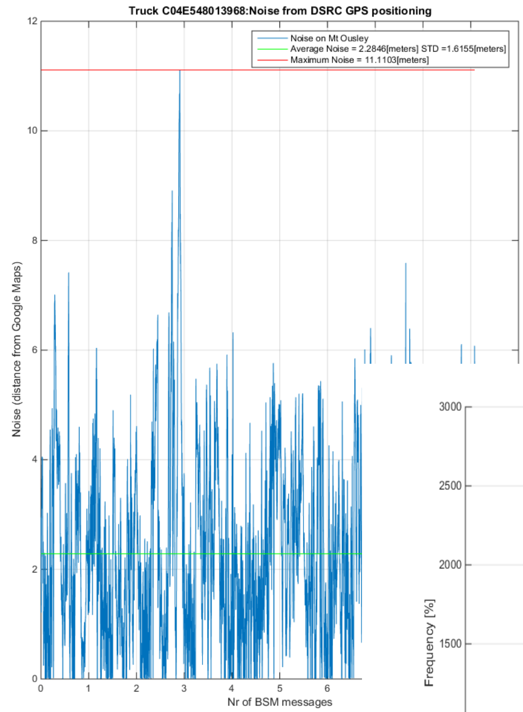


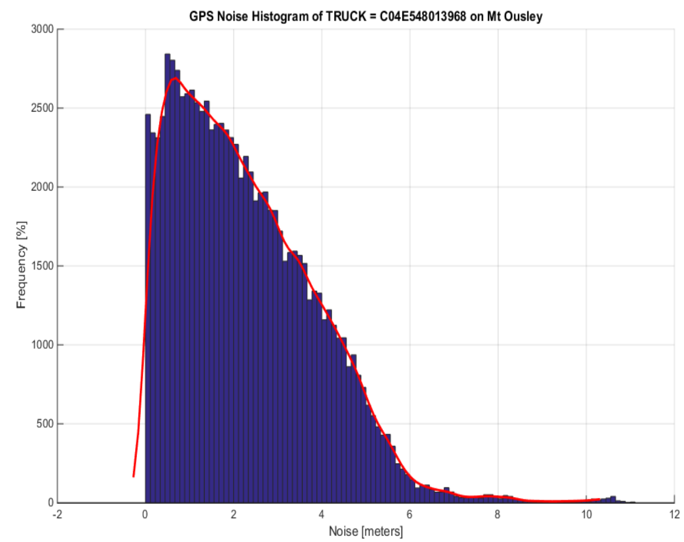
3.5 Truck 4 (C04E548013968) Analysis

Mt. Ousley investigation:

- Small number of anomalies: 0.49% on Mt. Ousley.



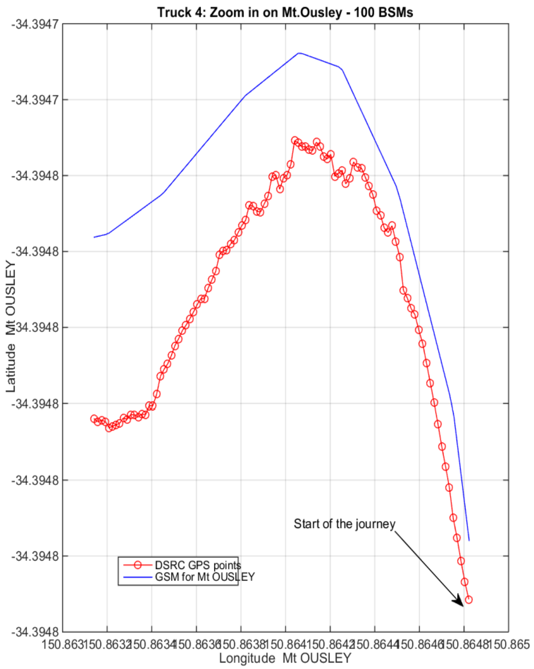


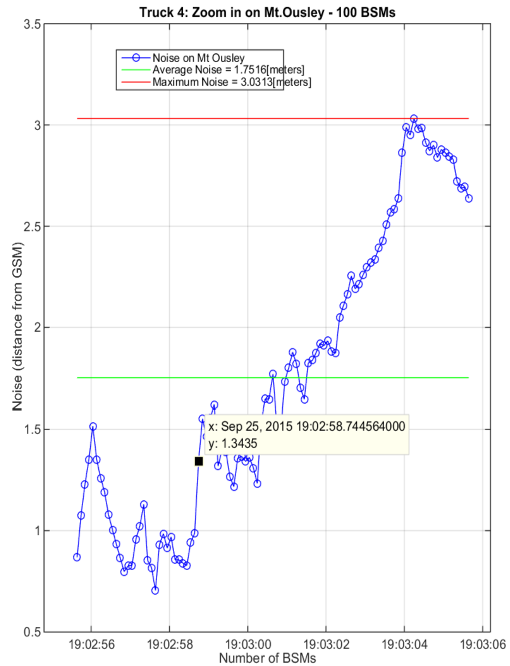


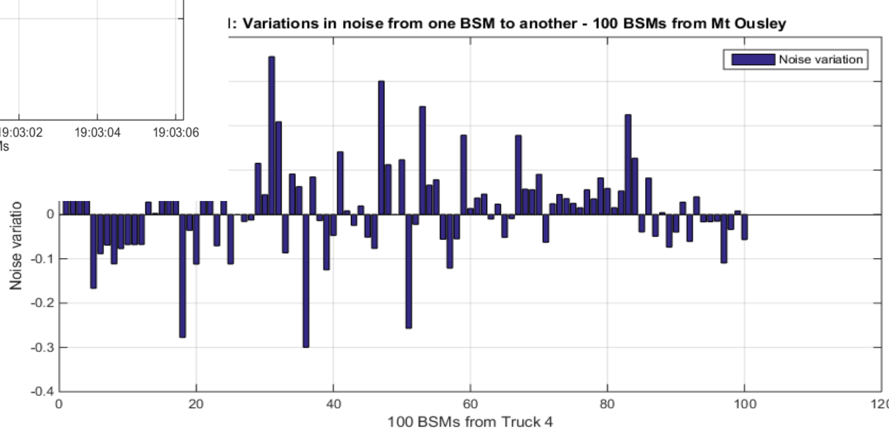
3.5 Truck 4 (C04E548013968) Analysis

100 BSMs investigation:

- Truck 4 presents a very particular behaviour in terms of jitter between consecutive BSMs in curved areas.







3.6 Truck 5 (C04E548013980) Analysis

Details:

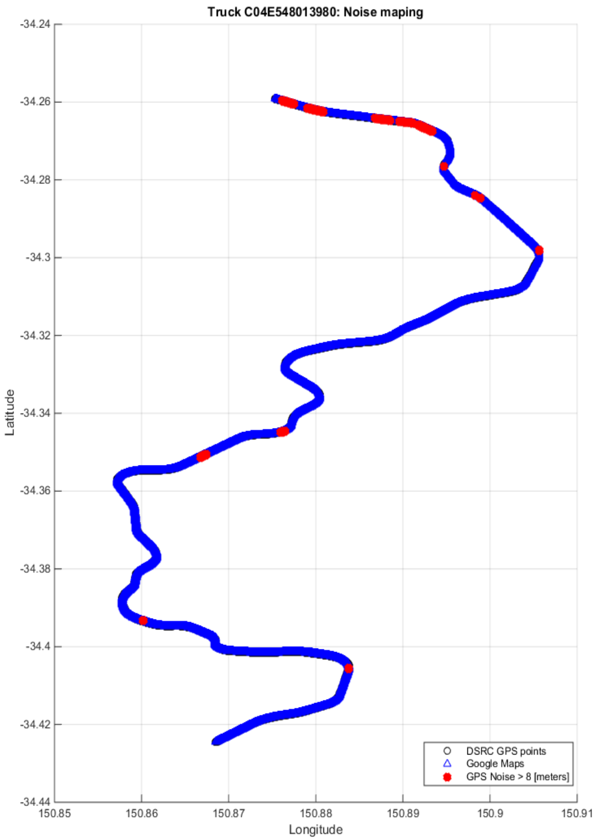
- operated by Bulktrans and equipped with an MK5 DSRC unit and GPS only (no GLONASS) antenna.
- 1.67 mil BSMs transmitted.
- 5th most active truck on the selected road section : 345,849 BMs.
- Most accurate truck: 2,093 anomalies (0.6%) on selected road section and Mt. Ousley.
- Average Noise registered = 2.09 m.
- Maximum Noise registered = 14.95 m.
- Presents jitter between consecutive BSMs on curved road sections.

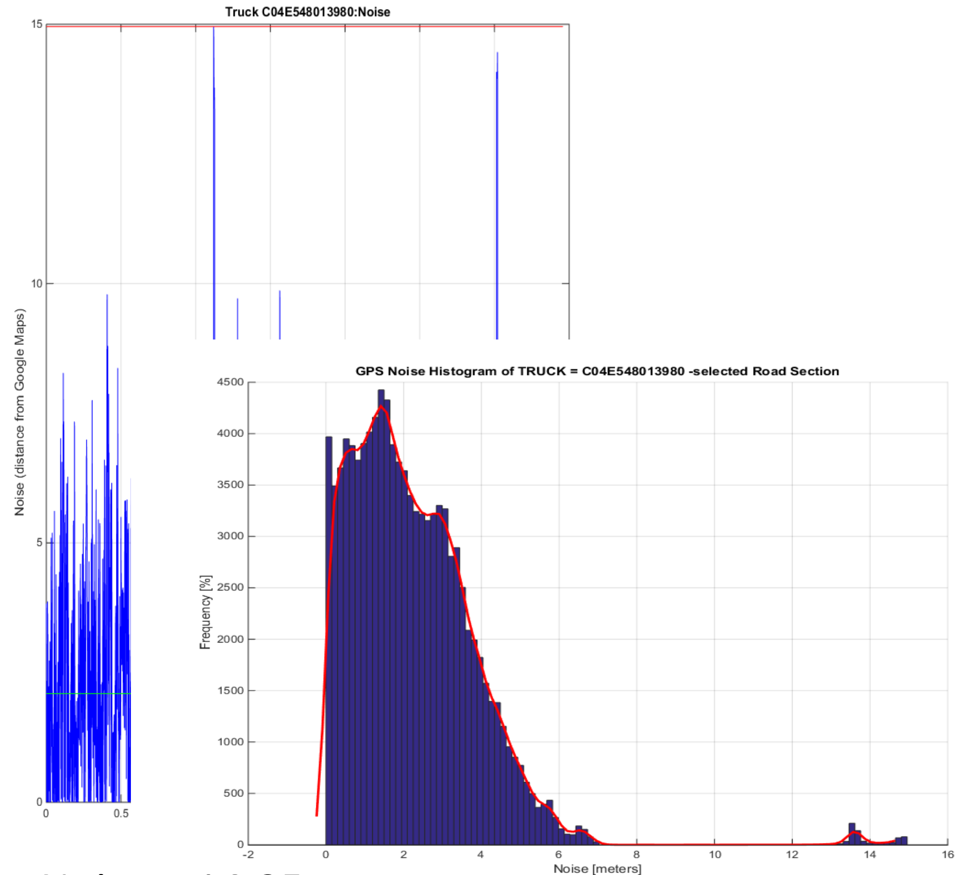
Start date of the transmission files:	Aug 22, 2015 14:11:35.674519000
End date of the transmission files:	Oct 26, 2015 15:42:51.925330000

3.6 Truck 5 (C04E548013980) Analysis

Selected Road Sections:

Anomalies accumulate in the north part of the road.



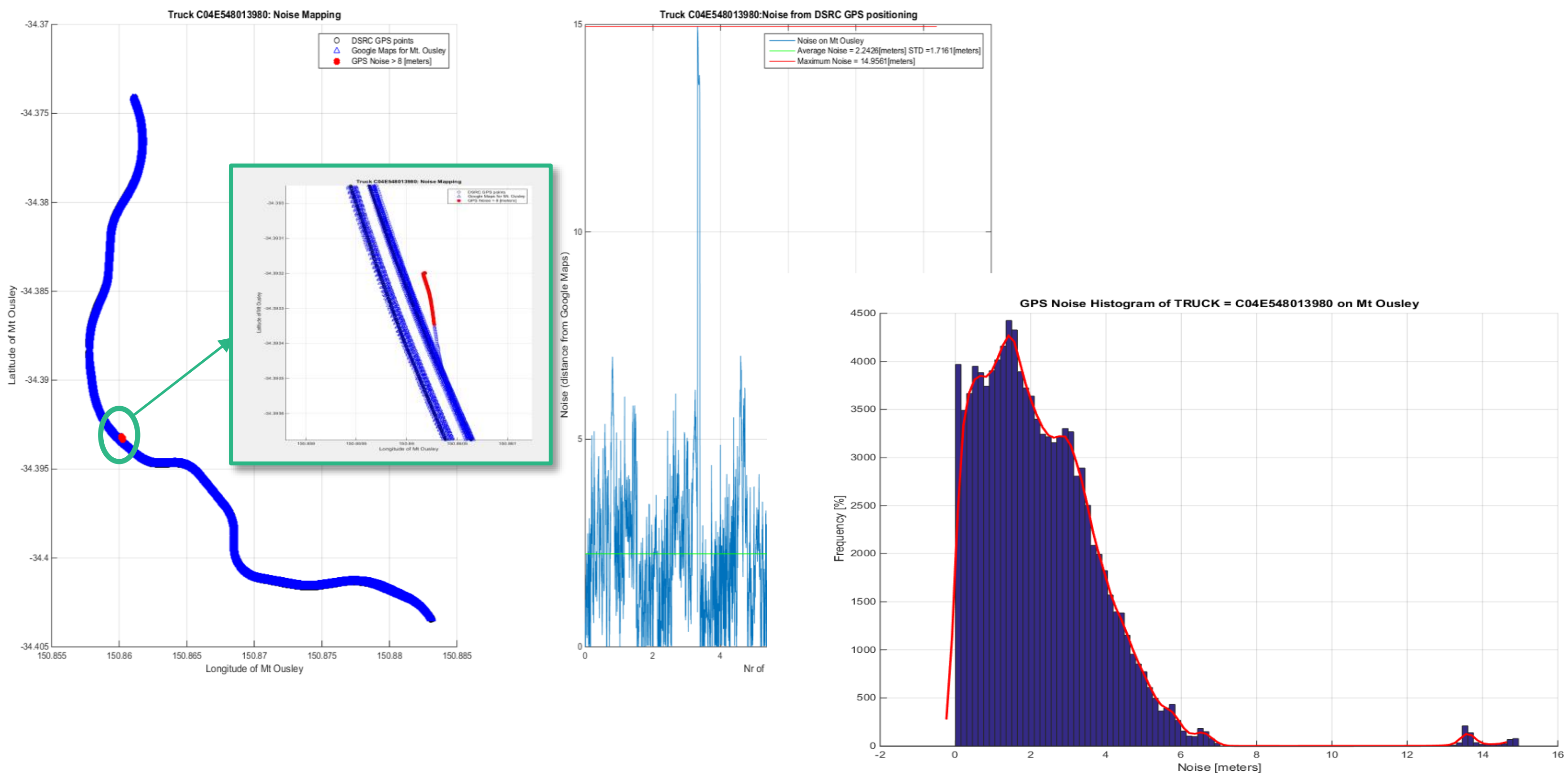


Average Noise = 2.09 m, Maximum Noise = 14.95 m

3.6 Truck 5 (C04E548013980) Analysis

Mt. Ousley investigation:

Highest accuracy on Mt. Ousley from all the trucks: 0.69% anomalies – which are given by a parking stop.

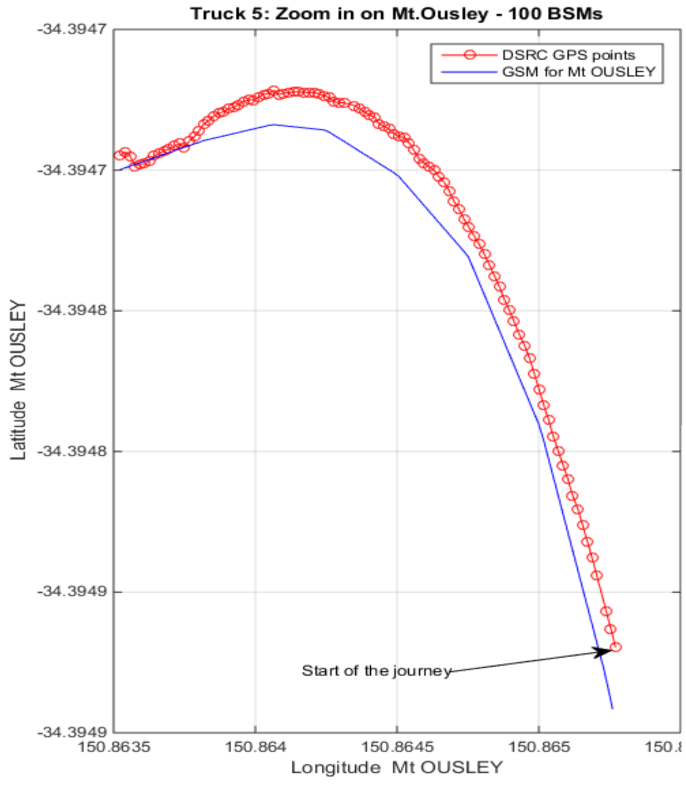


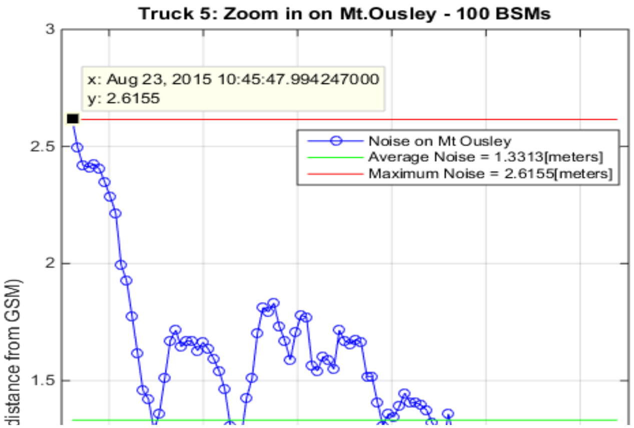
Average Noise = 2.24 m, Maximum Noise = 14.95 m

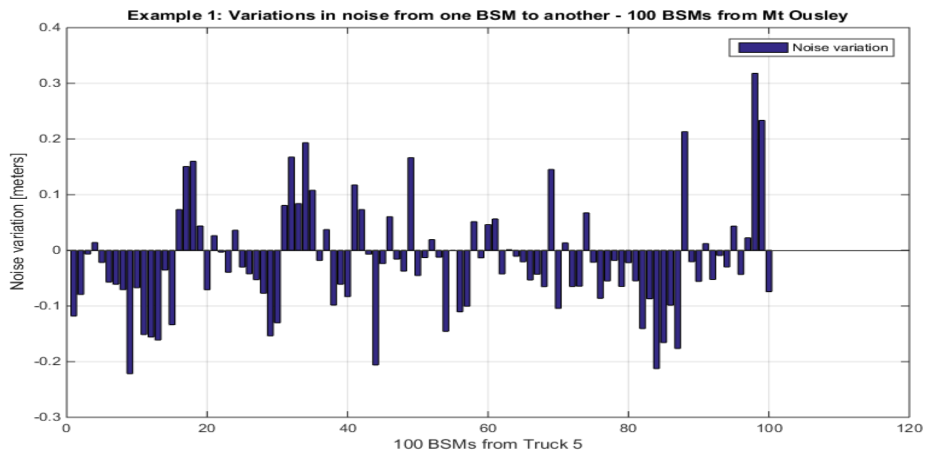
3.6 Truck 5 (C04E548013980) Analysis

100 BSMs investigation:

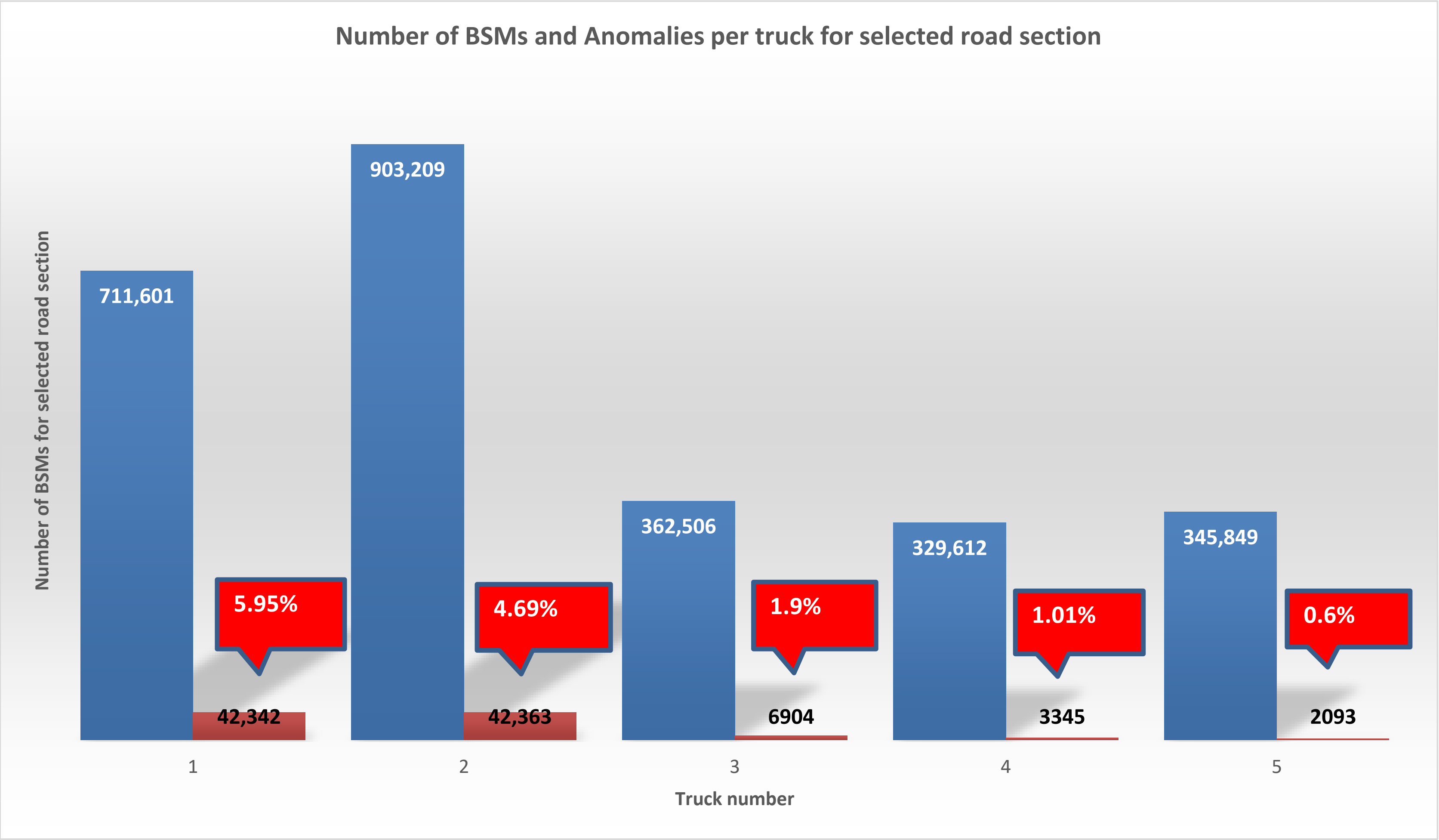
Jitter appears more on curved road sections.



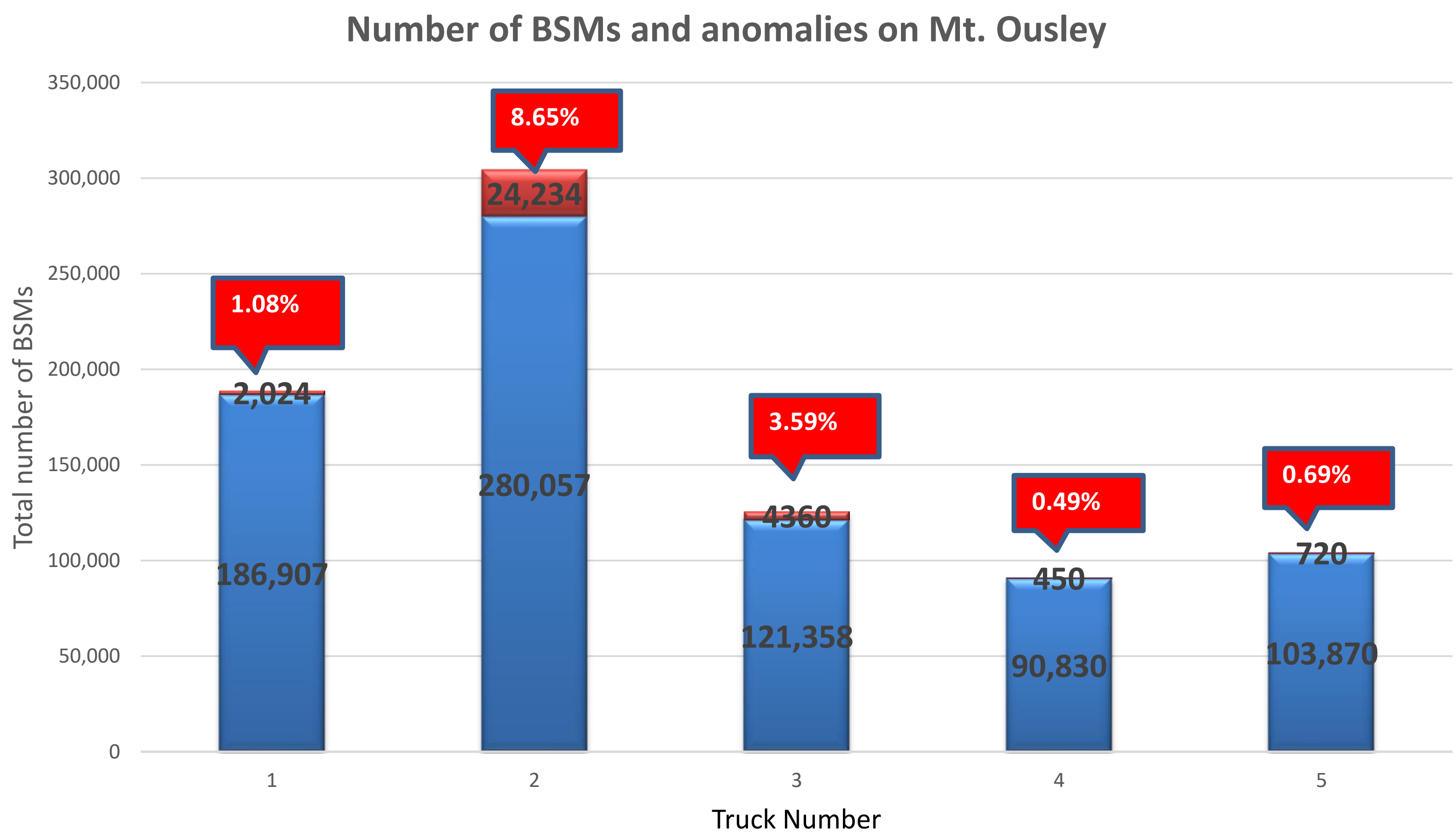




3.7 Truck comparison



3.7 Truck comparison



Contents

4. Regression models for noise analysis.

- **Features matrix:**

$$\mathbf{X_t} = [\mathbf{X_{i,j}}]_{i=1,..N_d^{GPS}}^{j=1,..8} \Leftrightarrow$$

$$\mathbf{X_t} = \begin{bmatrix} \text{Elevation} & \text{Speed} & \text{Heading} & \text{Brakes} & \text{Acceleration Long.} & \text{Acceleration Lat.} \\ & & & \cdots & & \\ & & & \cdots & & \end{bmatrix}$$

- **Noise vector:**

$$\boldsymbol{N_t} = [N_i]_{i=1,..N_d^{GPS}}$$

- **Regression problem:**

Predict $\boldsymbol{N_t}$ from $\boldsymbol{X_t}$, so as to determine the highly predictive features which influence GPS noise.

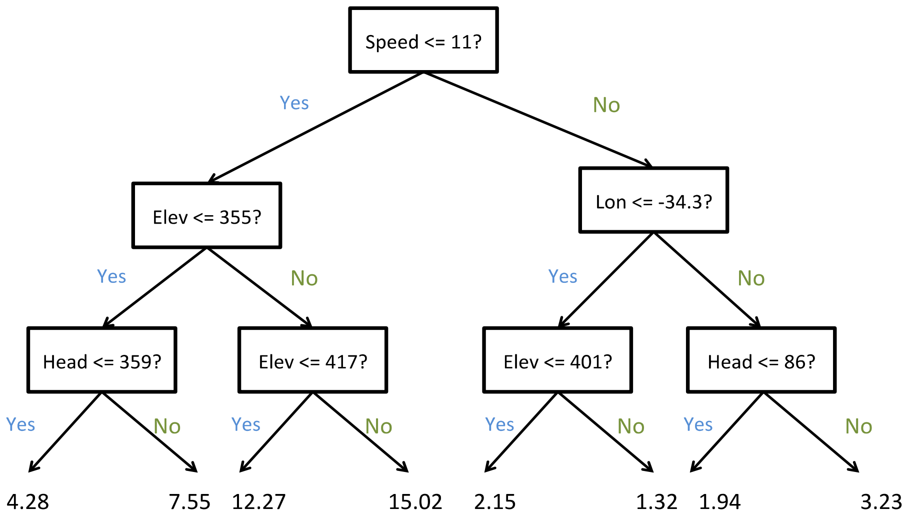
- **Training/testing set:** 80/20 % of the data set.

- **Performance evaluation:** $\boldsymbol{MSE} = \frac{1}{n}\sum_{i=1}^{n}\left(\widehat{\boldsymbol{N_t}} - \boldsymbol{N_t}\right)^2$

4. Regression models for noise analysis.

I. Decision tree using CART algorithm*

- is intuitive to explain.
- can easily fit nonlinear relationships in the data.
- splits the data based on thresholds of the features values.
- fits a sub-model (another decision tree).

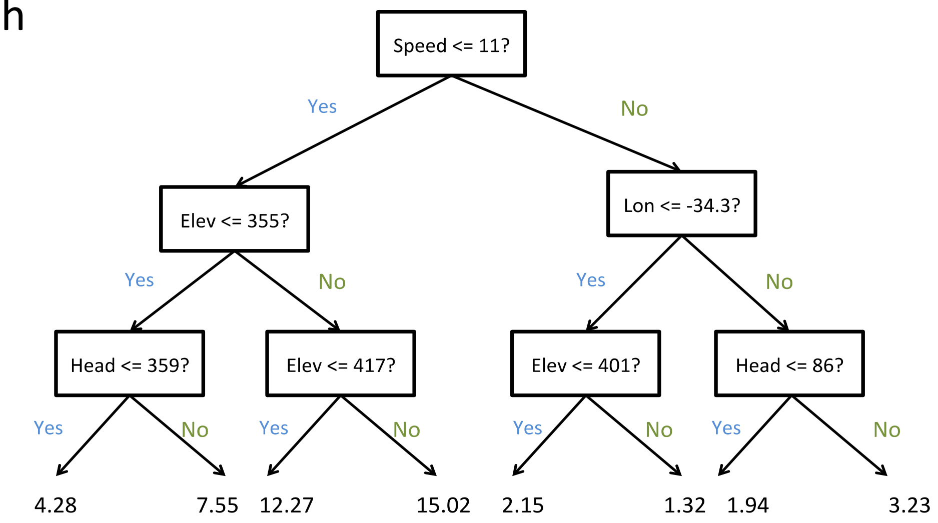


* L. Breiman, J. F., R. Olshen, and C. Stone. . *Classification and Regression Trees*. Wadsworth, Belmont, CA, 1984.

4. Regression models for noise analysis.

I. Decision tree using CART algorithm*

Example:
We fit a decision tree with a fixed depth of 3 levels.



Results:

- Baseline MSE = 5.7864.
- MSE = 2.4261 – 60% improvement.
- The most predictive features:
  - Speed
  - Elevation
  - Heading

* L. Breiman, J. F., R. Olshen, and C. Stone. . *Classification and Regression Trees*. Wadsworth, Belmont, CA, 1984.

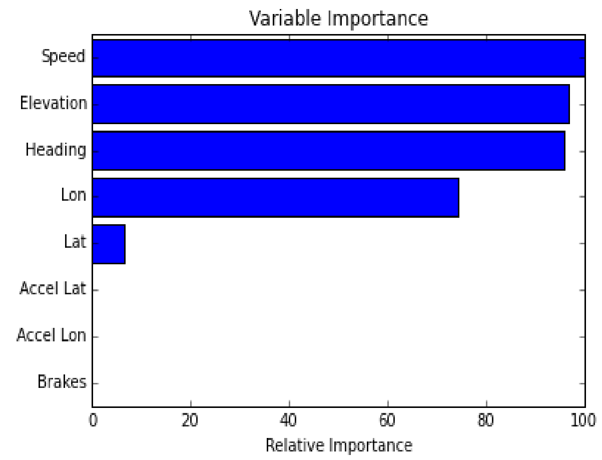
4. Regression models for noise analysis.

II. Gradient boosted decision trees (GBDT)**

- Is an ensemble method: computes a number of individual sub-models, and then considers an appropriately weighted average of them.
- Is more robust against spurious signals in the data.
- We fit a GBDT comprising 500 individual sub-models, to a maximum depth of 2 levels.

Results:

- MSE = **2.2696**, a further 6% improvement over the single decision tree model.
- Hard to visualize: hundreds of sub-models.
- Most predictive features:
  - Speed
  - Elevation
  - Heading



** Friedman, J. H. Greedy function approximation: a gradient boosting machine. *Annals of statistics*, 2001, pp. 1189-1232.

5. Discussions, learnings and Reflections

Heavy vehicles:

- Accuracy of the five trucks is within expectations.
- Performance in the trucks was not uniform.
- Noise distributions for each truck are not particularly similar.
- Truck 5 is the most accurate: needs further investigation of the installation to know what is influencing the accuracy.

Straight vs. Curved Road Sections:

- low variations (jitter) between consecutive BSMs on straight road sections.
- Truck 4 and 5 : particular behaviour in GPS positioning in curved road sections.

Jitter:

- Some individual tracks present jitter (changes in error jumps between sequential BSMs), usually of a small magnitude.
- from the samples observed, jitter itself is unlikely to cause a vehicle's reported position to suddenly jump a significant distance – for example to another lane.
- **Explanations:**
  - a) change in accessible GPS satellites,
  - b) terrain obscures view of GPS satellites, or
  - c) environment conditions which can cause performance changes in GPS signals.

5. Perspectives

- **Road Safety**
  - Detect which factors influence most the positioning accuracy and are crucial for ensuring Road Safety (speed, elevation, etc.)
  - Build speed/acceleration/deceleration profile on accident prone locations.

- **Cooperative positioning:**
  - Propose a cooperative positioning method to improve GPS accuracy when the signal is lost, or the vehicle is passing through noisy areas.

- **Ongoing work CITI – phase 2**
  - Collision alert investigations on light vehicles.
  - Improve road safety especially in high concern public areas: schools, kindergartens, etc.

Thank you!