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Offshore assessment of induced electric and magnetic fields of Viking HVDC link

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Project information

A high voltage direct current (HVDC) submarine cable link is proposed to connect the UK to Denmark. The proposed route of the HVDC link crosses Danish, German, Dutch and British waters each of which has different design criteria. The link would operate as a bipole with two cables at ± 525 kV carrying 1400 A each giving 2x700 MW power transfer. This report will investigate the magnetic fields and associated effects including compass deviation and induced electric field for each cable design.

When HVDC cables are installed in a bipole arrangement the magnetic field produced by the cable will depend on the current flowing in the cables, the separation of the cables and the distance from the cables. The normal bipole system proposed by the project will result in a cancellation of the magnetic fields when the cables are in close proximity. As the cables move apart they will act more like single cables which is the worst-case condition for magnetic fields.

This assessment will investigate the magnetic fields produced by the various options proposed by the project and their impacts in terms of:

- Maximum magnetic fields from different installation techniques
- Magnetic compass deviations
- Induced electric fields

Cable design

The minimum design criteria of the Danish, German, Dutch and British authorities are set out in Table 1. These are the worst-case requirements in terms of magnetic fields and assume the same separation irrespective of sea depth. Additionally a minimum burial depth below the sea bed for British and Danish waters are stated as 0.5m but these are still to be confirmed.

Table 1: Minimum bipole design criteria for each respective country

Country	Current (A)	Bipole separation (centre-to-centre)	Burial depth
Denmark	1400	50m	0.5m
Germany	1400	Bundled (0.13m)	1.5m
Netherlands	1400	Bundled (0.13m)	1.0m
United Kingdom	1400	50m	0.5m

Induced electric and magnetic field assessment

Magnetic fields

The bipole system proposed by the project will result in a cancellation of the magnetic fields when the cables are in close proximity to each other. As the cables move apart they will act more like single cables which is the worst case condition for magnetic fields. The magnetic field was calculated as the maximum field strength at distances ranging from the cable surface to 50 meters from the cable centre for each of the design criteria. All calculations assume the load currents are equal and in opposite directions in the two cables.

It has been assumed the cables will either be laid on the sea bed with material on top to anchor the cable or will be installed in trenches and both will be to the minimum burial depth stated in Table 1. The magnetic field at the closest physical point will therefore vary depending on the installation method and hence the cable separation. The magnetic field produced by the cables will also combine with the geomagnetic field and the effect of this has also been calculated. The way the fields combine will depend on cable orientation and background field, but for all calculations it has been assumed the cables are in a North-South orientation and the Earth's magnetic field is 49.2 μT with geomagnetic field angle of dip 67°.

Electric fields

The cables themselves produce no external electric field because of the presence of a metallic outer sheath.

The magnetic field produced by the HVDC cable decreases with distance from the cables. The movement of the sea through the magnetic field will result in a small localised electric field being produced; this is the induced electric field. A background electric field will also be present in the sea due to the geo-magnetic field and localised magnetic anomalies. The strength of this field varies continuously due to the strength, speed and directions of the tide.

The convention for calculating induced electric fields for the Basslink, BritNed HVDC and Western Link connections is:

Induced electric field (μV/m) = Velocity (m/s) x Magnetic field (μT)

The induced electric field was calculated for two different velocities to represent a range. The background geomagnetic field in the area is around 49 μT. Given this the background induced electric field could range between 24.5 and 61.3 μV/m in tidal velocities ranging between 0.5 m/s and 1.25 m/s. This does not take account of localised magnetic anomalies, which could result in higher localised electric fields, or of greater tidal velocities. The induced electric field was calculated for the combined

Assessment results

The calculation results for the Danish, German, Dutch and British design criteria can be found in Tables 2 and 3. The design criteria for the Danish and British waters were the same so both are presented in Table 2 as were the German and Dutch criteria, presented in Table 3.

All of the calculated magnetic fields for all of the cable designs are compliant with International Commission on Non-Ionizing Radiation Protection (ICNIRP) 1994 public static magnetic field exposure limits, as incorporated in the 1999 EU Recommendation on public exposure, at the sea surface (or in fact below the sea surface and on the surface of the cables as well). The highest magnetic field observed was 3733 μT at the cable surface for the British and Danish cable design whereas the basic exposure limit is 40,000 μT.

When the cables are installed with a 50m separation there is less cancellation of the magnetic field. It can been seen from Table 2 that even at 50m from the cable there is still some effect on the geomagnetic field although this is very small. The bundled cables proposed for the German and Dutch waters have less than 1% impact 10m or greater from the cable. As the induced electric field is directly related to the magnetic field this is also true for the electric field.

Magnetic compass deviations

The currents that flow in a DC transmission cable produce a magnetic field, whose horizontal component has the potential to alter the direction of the horizontal component of the earth's field, and thereby alter the direction that would be indicated by a magnetic compass. The amount of this compass deviation depends on the spacing of the pair of cables, their depth beneath the compass, their orientation relative to the earth's magnetic field, and the electrical current flowing in them. Because there are two cables carrying equal currents in opposite directions, their magnetic fields partly cancel, and the closer together the cables are the more complete the fields cancel and the smaller the compass deviation.

The magnetic fields from the HVDC cables were calculated along the length of the proposed route assessing the effects this would have on the angle of deviation of the earth's magnetic field perceived by a compass at the sea's surface. All orientation and depth information was obtained from Metoc and design changes for different waters territories were taken into account. The orientation of the cable is given in relation to magnetic north and both depth and angle of the cable to North is plotted in Figure 1. The background geomagnetic field and dip of the geomagnetic field was taken for each territory as follows:

	UK	NL	DE	DK
Geomagnetic magnitude (μT)	49.2	49.5	49.6	49.9
Geomagnetic dip (degrees)	67.9	68.4	68.7	69.3

As the route is many hundreds of kilometres long selective points were taken along the route of the cable and a representative sample of compass deviations were taken in each country's waters. Overall calculations are shown in Figure 2, where the compass deviations are shown in green. The maximum calculated magnetic fields and compass deviations along the proposed cable route for each of the four countries can be found in Tables 4, 5, 6 and 7.

The compass deviations observed for bundled cables in German and Dutch waters (KP 210.9-403.5) were all below 5°, a standard previously set by the British Admiralty. The greatest deviations were observed where the cables were in shallowest waters in British and Danish waters when cable separation was 50m. To achieve compass deviations of less than 5° cables would have to be designed with a closer separation.

6. Conclusions

- Bipole HVDC systems result in a cancellation of the magnetic fields when the cables are in close proximity. As the cables move apart they will act more like single cables which is the worst-case condition for magnetic fields.
- All cables are compliant with EMF exposure guidelines even at the surface of the cable.
- Bundled cables have no significant impact on the earth's geomagnetic fields at distance greater than 10m from the cables.
- Cables installed with 50m separation produce magnetic fields lower than the earth geomagnetic field at a distance of 10m, but still have an impact of the earth's magnetic field at distances greater than 50m although this is very small.
- The induced electric field is highly dependant on tidal velocity and effects around the cables are highly localised and directly proportional to the magnetic field.
- Bundled cables result in the lowest compass deviations, therefore the German and Dutch installation proposals resulted in lowest compass deviations.

Table 2: Calculated magnetic and induced electric field from bipole HVDC cables operating at ± 525 kV carrying 1400 A with 50m cable separation representing Danish and British criteria. Magnetic field calculations assume a North-South cable orientation and geomagnetic field of 49.2 μT with 67° angle. Induced electric field calculations are calculated from combined cable and geomagnetic field.

Vertical distance from cable	Magnetic field (μT)		Induced electric field (μV/m) Tidal Velocity	
	Cable only	With geomag	0.5m/s	1.25m/s
Cable surface (0.065m)	3733	3733	1867	4666
0.1m	2800	2801	1401	3501
0.2m	1400	1401	701	1751
0.3m	933	935	468	1169
0.4m	700	702	351	878
0.5m	560	563	282	704
1m	280	290	145	363
1.5m	187	201	101	251
2m	140	158	79.0	198
5m	56.0	88.3	44.2	110
10m	28.0	69.9	35.0	87.4
15m	18.7	64.8	32.4	81.0
20m	14.0	62.0	31.0	77.5
50m	4.48	53.4	26.7	66.8

Table 3: Calculated magnetic and induced electric field from bipole HVDC cables operating at ± 525 kV carrying 1400 A with bundled cables representing German and Dutch requirements. Magnetic field calculations assume a North-South cable orientation and geomagnetic field of 49.2 μT with 67° angle. Induced electric field calculations are calculated from combined cable and geomagnetic field.

Vertical distance from cable	Magnetic field (μT)		Induced electric field (μV/m) Tidal Velocity	
	cable only	With geomag.	0.5m/s	1.25m/s
Cable surface (0.065m)	3695	3741	1871	4676
0.1m	2559	2605	1303	3256
0.2m	823	869	435	1086
0.3m	386	432	216	540
0.4m	222	268	134	335
0.5m	143	190	95	238
1m	36.2	83.9	42.0	105
1.5m	16.1	64.4	32.2	80.5
2m	9.10	57.7	28.9	72.1
5m	1.46	50.5	25.3	63.1
10m	0.37	49.5	24.8	61.9
15m	0.16	49.3	24.7	61.6
20m	0.09	49.3	24.7	61.6
50m	0.01	49.2	24.6	61.5

Figure 1: Cable installation parameters including **cable depth below the surface of sea including burial depth and angle of cable installation to North.**

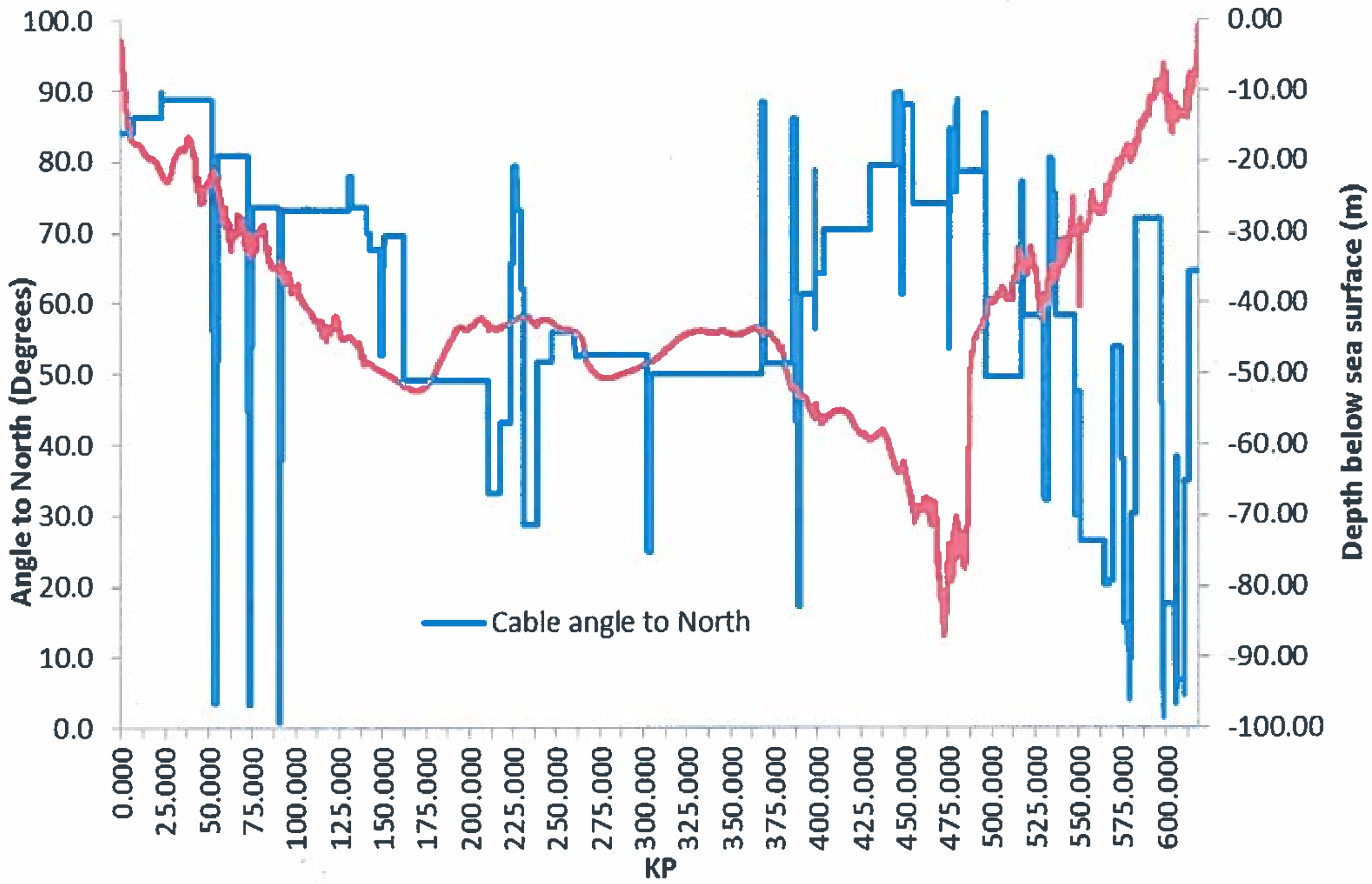

Figure 2 Calculated compass deviations along route of Viking Link. All calculations account for design changes that occur along the route.

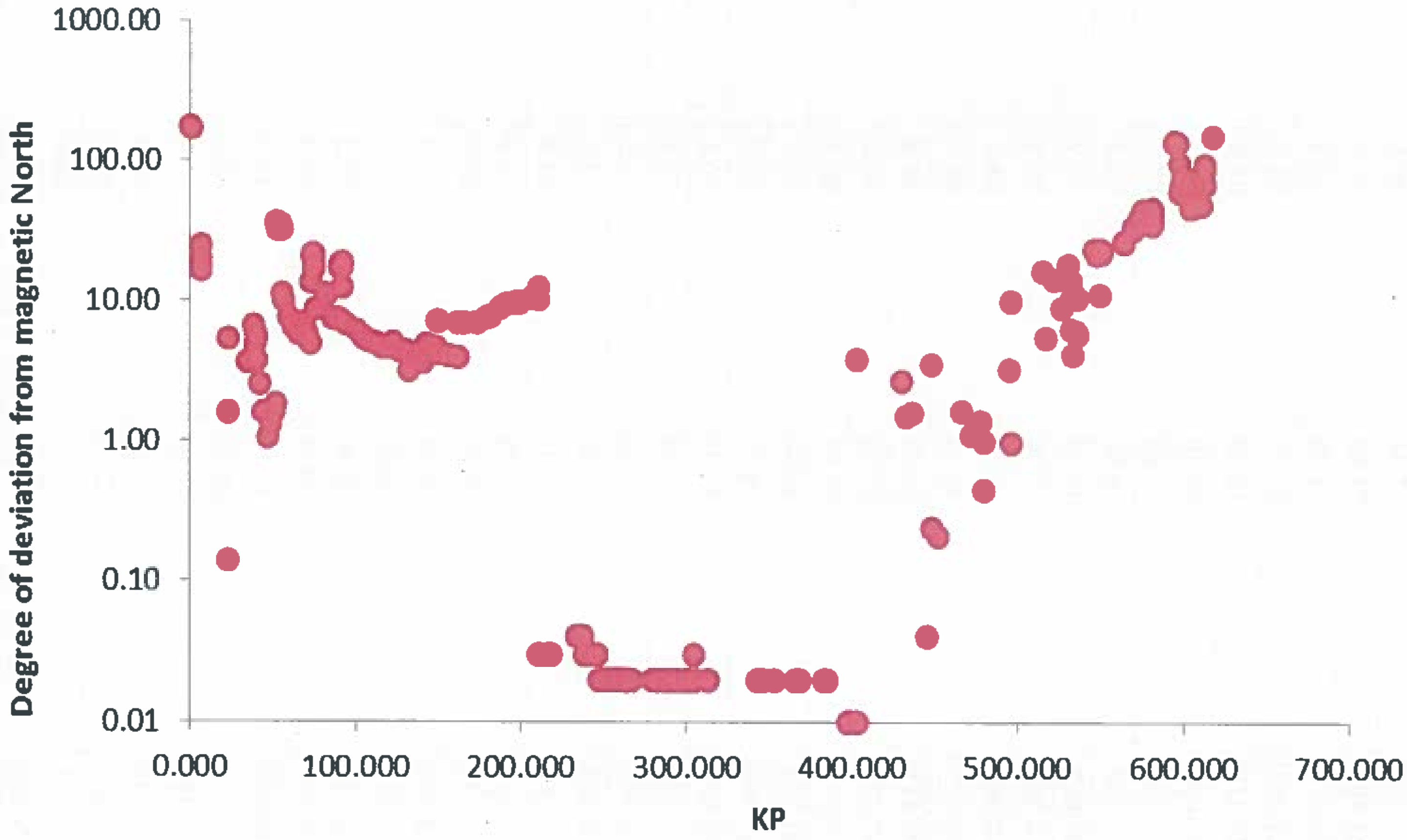

Table 4: Calculated compass deviations along the proposed cable route for Danish design criteria and routing through territories waters. Cable orientations were taken from magnetic north.

KP	Depth from surface of water (m)	Cable orientation from N-S	Maximum compass deviations
0.525	-2.84	84.2	172.90
1.000	-5.97	84.2	170.60
7.075	-17.26	84.2	24.62
7.100	-17.28	85.5	19.61
7.125	-17.31	86.3	16.22
23.250	-21.69	86.3	5.30
23.275	-21.72	89.9	0.14
23.300	-21.74	88.9	1.57
34.225	-18.30	88.9	3.60
37.000	-18.15	88.9	3.76
38.750	-16.69	88.9	6.54
39.150	-16.88	88.9	5.97
39.800	-17.34	88.9	4.93
40.200	-17.10	88.9	5.43
40.800	-18.14	88.9	3.77
42.425	-19.71	88.9	2.55
44.625	-22.40	88.9	1.60
47.075	-25.59	88.9	1.06
48.600	-23.86	88.9	1.32
51.375	-22.50	88.9	1.58
51.950	-21.54	88.9	1.82
52.025	-21.49	56.2	35.95
53.050	-21.51	56.2	35.90
53.100	-21.53	3.5	32.90
54.425	-22.00	3.5	32.18
54.600	-22.12	51.9	35.27
55.625	-23.15	51.9	32.33
55.775	-23.40	80.9	11.19
56.375	-24.34	80.9	10.00
59.825	-26.96	80.9	7.62
62.150	-28.80	80.9	6.47
64.875	-30.27	80.9	5.74
69.000	-27.82	80.9	7.04
69.325	-28.56	80.9	6.60
70.125	-30.00	80.9	5.86
70.725	-30.57	80.9	5.60
71.900	-32.01	80.9	5.03
72.525	-32.22	80.9	4.96
72.850	-32.52	61.4	13.65
73.475	-30.53	44.7	21.60

73.750	-31.60	3.3	20.50
74.450	-32.60	3.3	19.61
74.600	-31.45	21.7	21.65
75.250	-31.71	53.9	16.93
75.550	-32.44	73.5	8.59
81.750	-28.85	73.5	11.23
82.200	-29.23	73.5	10.89
86.325	-34.69	73.5	7.41
90.075	-34.86	73.5	7.32
90.500	-34.30	41.8	17.10
90.900	-34.86	14.5	18.36
91.575	-34.17	0.8	18.11
91.750	-34.54	24.1	18.59
92.300	-34.95	37.9	17.10
92.450	-34.64	59.7	12.50
94.150	-36.33	73.3	6.77
101.225	-37.94	73.3	6.17
103.775	-39.66	73.3	5.61
105.875	-40.41	73.3	5.37
107.300	-40.94	73.4	5.22
110.150	-41.85	73.1	5.07
113.650	-42.29	73.1	4.96
116.025	-43.59	73.1	4.65
120.750	-43.91	73.1	4.58
123.125	-41.83	73.1	5.07
126.900	-45.13	73.1	4.33
130.375	-44.76	73.1	4.40
131.925	-45.00	77.9	3.16
132.800	-45.20	73.7	4.17
138.125	-47.24	73.7	3.80
140.600	-48.53	73.7	3.60
140.900	-48.50	70.0	4.37
142.600	-48.57	70.0	4.36
142.825	-48.60	67.6	4.83
145.300	-49.12	67.6	4.72
148.425	-49.51	67.6	4.65
149.350	-49.64	52.7	7.14
150.225	-49.78	52.7	7.10
151.025	-49.87	69.6	4.20
156.375	-50.70	69.6	4.06
161.800	-51.66	69.6	3.91
161.850	-51.67	49.7	7.03
166.025	-52.19	49.1	6.93
173.900	-52.05	49.1	6.96

179.800	-50.13	49.1	7.50
182.200	-48.86	49.1	7.88
188.400	-45.73	49.1	8.97
191.175	-44.50	49.1	9.45
196.975	-43.82	49.1	9.74
199.375	-43.65	49.1	9.82
207.225	-42.20	49.1	10.50
210.775	-42.83	49.1	10.20
210.875	-42.81	33.4	12.30

Table 5: Calculated compass deviations along the proposed cable route for German design criteria and routing through territories waters.

KP	Depth from surface of water (m)	Cable orientation from N-S	Maximum compass deviations
210.950	-43.80	33.4	0.03
213.050	-43.52	33.4	0.03
217.200	-43.43	33.4	0.03
219.050	-43.29	43.1	0.03
233.525	-42.00	28.9	0.04
237.675	-43.09	28.9	0.04
239.125	-43.18	35.8	0.03

Table 6: Calculated compass deviations along the proposed cable route for Dutch design criteria and routing through territories waters. Cable orientations were taken from magnetic north.

KP	Depth from surface of water (m)	Cable orientation from N-S	Maximum compass deviations
243.450	-42.35	51.5	0.03
245.950	-42.42	51.5	0.03
246.475	-42.46	51.5	0.03
247.100	-42.58	55.9	0.02
249.975	-43.43	55.9	0.02
251.325	-43.57	55.9	0.02
254.125	-43.78	55.9	0.02
256.400	-43.77	55.9	0.02
258.675	-44.02	55.9	0.02
259.175	-44.00	55.9	0.02
261.225	-44.24	52.4	0.02
263.125	-44.77	52.4	0.02
265.050	-45.26	52.6	0.02
267.950	-48.73	52.6	0.02
280.250	-50.69	52.6	0.02
284.000	-50.44	52.6	0.02
288.900	-49.96	52.6	0.02
292.500	-49.66	52.6	0.02
295.625	-49.36	52.6	0.02
301.150	-48.60	52.6	0.02
301.300	-48.59	52.6	0.02
304.650	-48.31	25.0	0.03
305.450	-48.23	49.9	0.02
313.300	-46.57	49.9	0.02
342.975	-44.22	49.9	0.02
346.775	-44.08	49.9	0.02
353.900	-44.50	49.9	0.02
365.975	-43.83	49.9	0.02
369.325	-43.90	88.5	0.00
369.475	-43.89	51.3	0.02
383.225	-50.68	51.3	0.02
385.100	-52.24	51.3	0.02
385.700	-52.50	86.1	0.00
398.075	-56.37	61.3	0.01
398.600	-54.91	56.3	0.01
403.475	-56.53	64.2	0.01

Table 7: Calculated compass deviations along the proposed cable route for British design criteria and routing through territories waters. Cable orientations were taken from magnetic north.

KP	Depth from surface of water (m)	Cable orientation from N-S	Maximum compass deviations
430.200	-59.46	70.4	2.70
433.575	-58.88	79.4	1.51
437.200	-57.93	79.4	1.58
445.700	-63.25	89.7	0.04
448.825	-62.50	61.2	3.50
448.925	-62.42	88.1	0.24
452.425	-66.30	88.1	0.21
466.475	-68.83	74.1	1.64
472.725	-87.07	74.1	1.10
474.075	-81.85	74.1	1.17
478.275	-71.24	75.8	1.40
479.775	-70.11	85.5	0.45
480.250	-74.61	78.5	1.01
495.700	-42.19	78.5	3.23
496.650	-42.09	86.6	0.97
496.725	-41.97	49.6	9.90
515.525	-32.19	49.6	16.50
517.925	-34.89	77.0	5.50
522.225	-32.16	58.4	14.10
527.200	-40.11	58.4	9.03
531.125	-39.00	32.2	18.50
532.475	-36.75	44.2	13.80
532.600	-37.62	57.4	10.52
533.050	-36.06	73.7	6.30
533.700	-34.77	80.5	4.10
535.700	-34.76	75.6	6.10
536.475	-35.92	75.6	5.70
536.775	-37.03	58.4	10.60
546.725	-25.11	58.4	23.40
548.350	-30.09	30.1	21.80
550.600	-40.42	47.3	11.10
551.225	-28.19	47.3	21.90
551.400	-29.13	26.3	23.10
564.425	-26.50	26.3	26.70
564.475	-26.63	20.3	26.40
569.850	-22.12	20.9	34.00
569.925	-22.05	53.9	32.50
573.925	-20.25	53.9	38.30
573.975	-20.28	38.0	39.90
575.850	-18.56	38.0	45.40
575.900	-18.61	14.9	40.30

577.900	-17.74	14.9	43.00
577.950	-17.73	12.5	41.60
578.575	-18.06	12.5	40.80
578.825	-19.03	4.1	36.10
579.900	-19.08	9.7	37.74
580.275	-20.04	14.4	37.00
580.975	-19.98	30.2	40.14
581.500	-17.82	30.2	46.41
581.975	-18.08	30.2	45.60
582.225	-18.43	67.2	40.10
582.250	-18.45	72.0	35.55
595.450	-8.68	72.0	139.35
595.600	-9.09	72.0	136.90
597.175	-9.43	72.0	134.67
597.625	-9.40	45.8	96.00
597.875	-10.05	9.4	61.85
598.600	-7.46	5.4	67.61
598.625	-7.27	1.4	65.00
600.000	-7.33	17.5	78.50
604.575	-11.79	17.5	61.31
604.900	-12.71	17.5	58.10
605.200	-13.99	3.3	46.74
605.400	-11.92	38.1	74.70
606.000	-14.07	38.1	63.85
606.150	-13.00	38.1	69.12
606.175	-12.88	5.8	51.00
606.250	-14.46	6.7	47.20
610.900	-13.58	6.7	49.50
611.075	-13.46	4.6	48.76
611.400	-10.15	35.0	81.30
613.050	-12.73	35.0	68.60
613.175	-12.61	35.0	69.10
613.225	-12.72	59.3	86.05
613.250	-12.30	64.5	95.36
618.400	-2.00	64.5	150.80

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