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Thomas Reinsch and Jan Henninges

Fibre Optic Distributed Temperature Sensing Behind Casing: Data From Geothermal Well HE-53, Hellisheiði Geothermal Field, SW Iceland

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Abstract

Reinsch et al. (2013) describe the installation of a novel fibre optic cable behind the anchor casing of the geothermal well HE-53, Hellisheiði geothermal field, SW Iceland. Within this data publication, DTS temperature data, acquired together with optical time domain reflectometry (OTDR) data during three different field campaigns are presented. Data have been acquired during the installation in spring 2009, during the onset of a production test in summer 2009 and after a 8.5 month shut-in period in summer 2010.

This data publication is supplementary to Reinsch et al. (2013). DTS and OTDR data can be accessed by by DOI:10.5880/GFZ.b103-12128.1.

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Nomenclature

Abbreviations		
DTS	distributed temperature sensing	
$OTDR$	optical time domain reflectometry	
SEL	surface excess length	
SRO	surface readout unit	
Greek symbols		
α	coefficient for polynomial fit	-
Roman symbols		
I	intensity of backscattered photons	counts
S_{DTS}	slope value for DTS temperature calculation	K
T	temperature	K
Subscript		
ast	Anti-Stokes	
DTS	values measured by DTS system	
ini	initial	
ref	reference	
rc	reference coil	
st	Stokes	
Superscripts		
$corr$	corrected	

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Chapter 1

Introduction

A practical application of the DTS technology was demonstrated within the geothermal well HE-53 in the Hellisheiði geothermal field in SW Iceland (Reinsch et al., 2013). A fibre optic cable has been installed behind the anchor casing, and temperatures were acquired during three different logging campaigns, the cementation of the anchor casing (May 2009), the onset of a flow test (July/August 2009) as well as after the termination of this flow test when wellbore temperatures reached static formation temperatures, again (August 2010).

During the three field campaigns, different types of data have been acquired:

1. DTS temperature data using a DTS 800 system from Sensa.
2. Stokes and Anti-Stokes intensity data using a DTS 800 system from Sensa.
3. Optical time domain reflectometry data at 1300 and 850 nm using a MTS5100 from Wavetek.

The quality of the acquired DTS temperature information is highly dependent on the calibration of the fibre optic cable as well as wellbore reference data like depth of installation.

The present data publication is focused on the temperature and attenuation information. For details on the installation of the fibre optic cable as well as a discussion of the measured data, please refer to (Reinsch et al., 2013).

For the data which are connected to this report please refer to DOI:10.5880/GFZ.b103-12128.1.

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Chapter 2

DTS Calibration

2.1 DTS Temperature Determination

Every fibre has to be calibrated to the DTS system. The manual provided by Sensa (Sensa, 2004a) suggests an iterative heating and cooling procedure to calibrate an optical fibre to the DTS system. An iterative heating and cooling procedure over a large temperature range, as desired within this study, is very time consuming. Therefore, a simple linear regression over multiple temperature points has been applied.

The DTS temperature is calculated using the ratio of the backscattered photons at the Stokes and Anti-Stokes wavelength. Actual temperatures can be determined by the linear relation (Al-Asimi et al., 2002):

$$\frac{1}{T_{DTS}(z)} = \frac{1}{T_{rc}} - \frac{1}{S_{DTS}}\left(\ln\left(\frac{I_{ast}(z)}{I_{st}(z)}\right) - \ln\left(\frac{I_{ast}(rc)}{I_{st}(rc)}\right)\right) \tag{2.1}$$

where T_{DTS} is the measured DTS temperature (K) at distance z along the fibre. T_{rc} and S_{DTS} are the reference coil temperature (K) and the slope value (K) for the DTS temperature calculation. $I_{ast}(z)$ and $I_{st}(z)$ are the intensities of the Anti-Stokes and the Stokes signal at point z, respectively. rc refers to the reference coil.

2.2 Calibration Procedure

During the calibration procedure, T_{rc} and S_{DTS} have to be determined. For an initial guess of $T_{rc,ini}$ and $S_{DTS,ini}$, initial DTS temperatures $T_{DTS,ini}$ can be monitored at different temperature conditions. Using Equation 2.1, the following ln-relation can be deduced:

$$\ln\left(\frac{I_{ast}(z)}{I_{st}(z)}\right) - \ln\left(\frac{I_{ast}(rc)}{I_{st}(rc)}\right) = -\left(\frac{1}{T_{DTS,ini}(z)} - \frac{1}{T_{rc,ini}}\right) S_{DTS,ini} \tag{2.2}$$

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Table 2.1: Calibration temperatures.

$T_{DTS,ini}$ °C	T_{ref} °C	$T_{rc,ini}$ °C	$S_{DTS,ini}$ °C
56.60	49.66	40.00	500.00
118.19	99.48	40.00	500.00
182.43	149.26	40.00	500.00
248.87	198.98	40.00	500.00
317.93	248.94	40.00	500.00
360.33	279.15	40.00	500.00

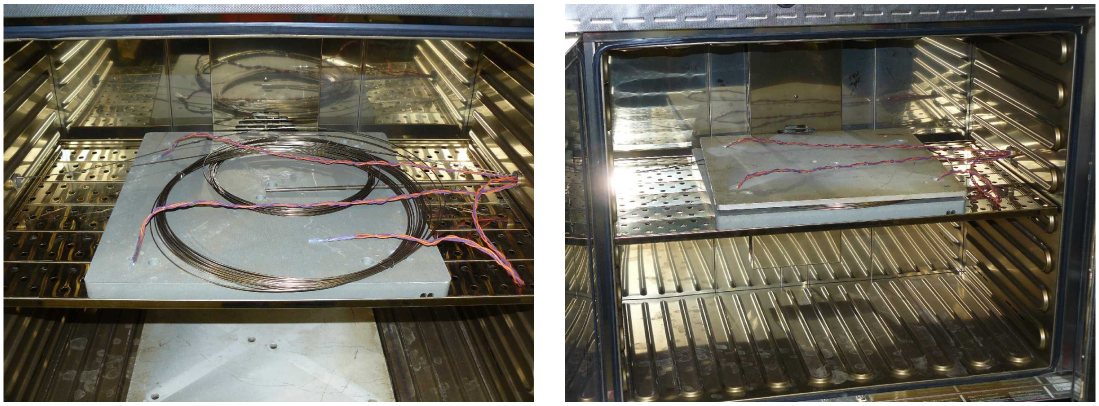
Comparing DTS temperature readings T_{DTS} to a reference temperature measurement T_{ref}, a simple linear regression can be applied to calculate a new T_{rc} and S_{DTS} value.

$$
\begin{aligned}
y &= ax + b \qquad (2.3)\\
\text{with } y &= \frac{1}{T_{ref}(z)}\\
a &= -\frac{1}{S_{DTS}}\\
b &= \frac{1}{T_{rc}}\\
x &= \ln\left(\frac{I_{ast}(z)}{I_{st}(z)}\right) - \ln\left(\frac{I_{ast}(rc)}{I_{st}(rc)}\right)
\end{aligned}
$$

2.3 Calibration of the DTS sensor cable

The calibration of the DTS sensor cable up to 280 °C has been performed in an oven with forced air circulation (UFE 600, Memmert). As reference temperature sensor, a thermometry bridge (ASL-F300 with a PT-25) has been used. The inner stainless steel loose tube containing the optical fibre has been placed between two aluminium plates to increase the temperature stability. Table 2.1 lists the measured DTS temperatures together with the reference temperature. From the linear regression, T_{rc} and S_{DTS} values have been determined to be 308.14 K and 565.03 K.

Three successive heating tests have been performed and the resulting DTS temperatures have been compared to the reference temperatures. During the tests using this experimental set-up, a non-linear relation between actual and measured DTS temperatures was observed when measured over a wide temperature range of more than 150 °C. In order to account for this non-linear response of the DTS unit, a fourth order



(a) (b)

Figure 2.1: Experimental set-up for the calibration of the fibre optic cable. The inner stainless steel loose tube, containing the optical fibre, has been placed in the centre of an oven. For temperature stabilization, it has been placed between two aluminium plates. The coil with the larger diameter contains the calibration fibre. At the tip of the orange cables, PT-100 sensors have been placed to ensure the temperature stability between the plates. As reference, a PT-25 has been used (placed in the centre of the coil).

polynomial function $f(T_{DTS})$ (Equation 2.4) has been fitted to the calibration data and used to correct measured temperature data (Figure 2.2).

$$f(T_{DTS}) = \sum_{k=0}^{4} \alpha_k T_{DTS}^k \tag{2.4}$$

The fitted parameters α are listed in Table 2.2. In order to correct for the non-linear response of the system, the following equation has been applied to calculate corrected DTS temperature data:

$$T_{DTS}^{corr} = T_{DTS} + f(T_{DTS}) \tag{2.5}$$

From Figure 2.2 it can be seen that a residual error of less than ΔT_{DTS}^{corr} =0.5 °C was observed below 240 °C, which is the temperature range measured during the flow test.

Table 2.2: Parameters for polynomial fitting of DTS temperature data.

Parameter	Value	R^2
α_0	$1.21 * 10^{0}$	0.00
α_1	$-1.62 * 10^{-2}$	0.05
α_2	$2.43 * 10^{-5}$	0.84
α_3	$-2.84 * 10^{-7}$	0.92
α_4	$1.59 * 10^{-9}$	0.92

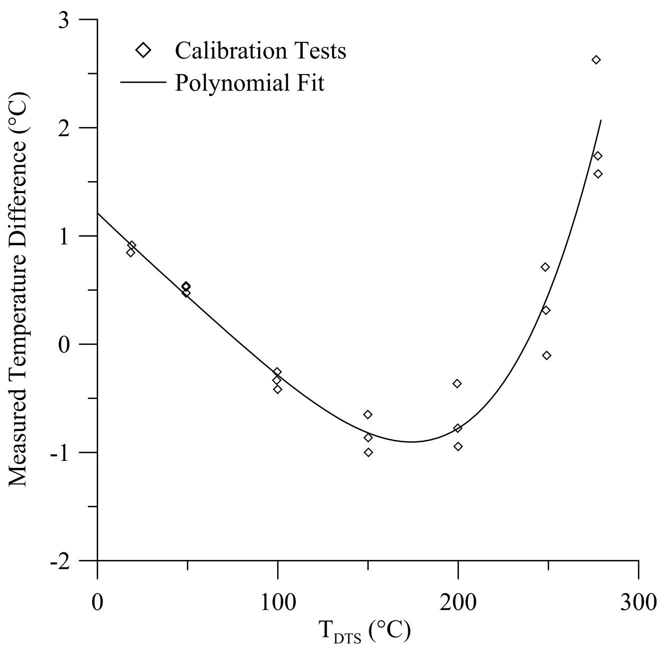


Figure 2.2: Polynomial correction for the measures DTS data. The difference $T_{ref} - T_{DTS}$ is displayed. The correction based on three heating cycles measured in the lab, prior to the installation.

Chapter 3

Installation of DTS Sensor cable

3.1 Downhole Geometry

The fibre optic cable has been installed behind the anchor casing[1] of well HE-53 down to a depth[2] of 261.3 m using rigid blade centralizers. Conventional button head ties were used to attached the cable to the centralizers. During the installation, a centralizer was installed underneath every joint below the surface casing and underneath every second joint within the surface casing. For further protection, tape and ties were used between the joints to attach the cable to the casing. Furthermore, tape was used to attach the cable on the joints itself. The distance between anchor casing and cable, therefore, varies along the well between zero and approximately three centimetres (Figure 3.1).

Based on available casing collar locator log data (courtesy of Reykjavik Energy), the location of the different data points has been determined. Using the depth information for each data point together with the position of the centralizers, the distance between casing and cable could be estimated. The average distance of each sampling point for the second field campaign, i.e. the flow test, in listed in Appendix A. For measurement purposes, the DTS sensor cable was installed in a loop configuration with a 180° separation between both cable branches around the perimeter of the casing (for further details on the installation concept, see Reinsch et al., 2013).

3.2 Field Work

During the installation, the cable was accidentally damaged. It was cut two times, leaving a western end accessible down to 179.5 m and an eastern end down to the

[1]According to the Icelandic nomenclature, the first two casing strings are referred to as *surface* and *anchor/safety* casing, respectively.

[2]Depth information given in meter below surface, measured depth.

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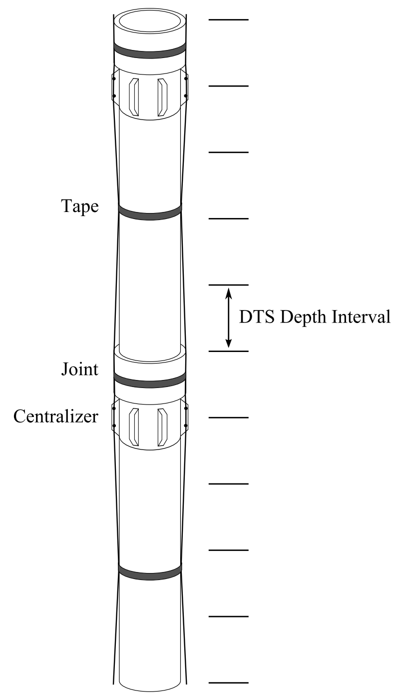

Figure 3.1: Sketch showing the position of the cable behind casing. DTS temperatures are averaged over a 1 m interval, which is indicated (not to scale; Figure from Reinsch et al., 2013).

turnaround at 261.3 m. At the eastern cable branch, another damage was detected in a depth of about 235 m. As similar optical attenuation values were measured before and after the installation, no further damages have been detected along the accessible parts of the cable.

Chapter 4

Fibre Optic Measurements

4.1 Experimental Set-Up and Measurement Schedule

A similar experimental set-up was used for the three field campaigns (Figure 4.1). The wellbore cable was connected to the surface readout (SRO) unit using a 100 m fibre optic extension. Approximately 15 m of the wellbore cable were left at the surface. This surface excess length (SEL) was used to gather reference temperature data. For the distributed temperature measurements, a DTS 800 from Sensa with a 1064 nm Nd:YAG-laser has been used.

Beside temperature measurements, Stokes and Anti-Stokes intensities (Chapter 2) have been stored using the DTS system. In order to evaluate the degradation of the optical fibre over time, optical time domain reflectometry (OTDR) measurements were performed. The optical attenuation at 850 and 1300 nm has been measured using a MTS5100 from Wavetek.

4.2 DTS Field Data

Temperature data acquired during the different measurement campaigns (Table 4.1) have been recorded using the calibration parameters acquired during the calibration procedure described above (Chapter 2). The calibration has been performed in double ended configuration, meaning both ends of the fibre were connected to the DTS system. As only single ended measurements could be performed during the field experiments, the Stokes and Anti-Stokes intensities have to be compensated for a differential loss between the Stokes and Anti-Stokes band (Smolen and van der Spek, 2003). Therefore, a standard differential loss factor of 0.33 has been applied for the three measurement

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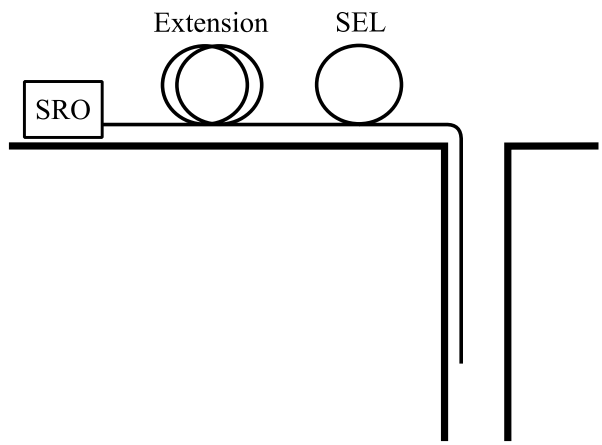

Figure 4.1: Schematic experimental set-up for DTS and OTDR measurements. The surface readout unit (SRO) is connected via an optical extension to the surface excess length (SEL) of the wellbore cable (Figure from Reinsch et al., 2013).

Table 4.1: List of the three logging campaigns. The duration as well as the integration time for individual temperature profiles is listed.

Campaign	Begin DTS Measurement	Duration (h)	Integration Time (s)
1	05/04/2009 00:25	46	27
2	07/28/2009 16:52	115	18
	since 08/02/2009 12:20:	241	104
3	08/10/2010 15:54	25	103

campaigns (Sensa, 2004b).

Details on the position of the SEL along the fibre are given in Table 4.2 together with the position of the wellhead and the depth to the last DTS data point. Raw DTS data is stored in a comma separated value file format (.csv). The file name is given according to the time of the first profile within this file. The file structure is explained in detail in Appendix B.

4.2.1 First DTS Logging Campaign: Cementation

Measurements have been performed during the cementation of the anchor casing in May 2009.

Table 4.2: Relation between depth and data point for the identification of the raw data position.

Logging Campaign			Reference	Wellhead		End of Installation	
Number	Side	DTS Channel	Points (SEL)	DTS Point	Depth (m)	DTS Point	Depth (m)
1	West	1	157-180	178	-6.7	360	179.3
	East	2	157-180	177	-6.7	439	261.3
2	West	1	158-171	186	-1.5	363	179.5
	East	2	162-174	190	-1.2	446	261.3
3	West	2	160-175	186	-1.5	363	179.5
	East	1	161-175	189	-1.2	364	175.1

4.2.2 Second DTS Logging Campaign: Flow Test

Measurements have been performed at the onset of a flow test in July/August 2009. Here, the surface excess length of the cable was placed within an ice bath. SEL temperature data could be used to perform an offset correction according to the measured ice bath temperature. Two times a day, additional OTDR measurements were performed to evaluate the degradation of the optical fibre at high temperature conditions during the flow test.

4.2.3 Third DTS Logging Campaign: Shut-In

Measurements have been performed after the well was flow tested for three months and a subsequent 8.5 months shut-in and thermal recovery period in August 2010. The surface excess length of the cable was placed within an ice bath, again, to correct for a constant temperature offset.

4.3 OTDR Field Data

Regular OTDR measurements were only performed during the second logging campaign. Here, OTDR data were acquired twice a day. For the other campaigns, OTDR measurements have been prior and after DTS temperature logging. A list of all OTDR measurements can be found in Appendix C.

Based on the length of the installed fibre optic cable, the lengths of the OTDR data sets have been determined. Figure 4.2 shows an exemplary attenuation profile, acquired using the MTS5100 from Wavetek. Different points along the fibre optic line have been

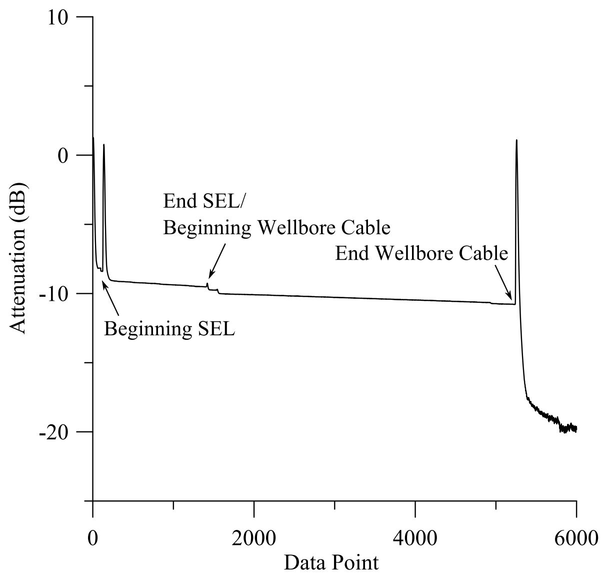

Figure 4.2: Attenuation profile recorded using the Wavetek MTS5100. Reference points for the length determination are indicated.

indicated. Prominent features are the plug to the surface excess length (SEL), the plug to the logging cable as well as the end of the fibre. For the different logging campaigns, a correlation between the distance between the plug to the SEL and the end of the fibre, compared to the length determined by the DTS system, has been calculated and listed in Table 4.3.

The OTDR data has been stored in a tab-delimited file structure (.txt). The file structure is explained in Table B.4.

Table 4.3: Length of the OTDR measurements. The length has been determined based on the length of SEL+logging cable of the DTS system.

Logging Campaign			Length (SEL+logging cable)
Number	Side	DTS Channel	(m)
1	West	1	366.7
	East	2	445.7
2	West	1	369.1
	East	2	451.5
3	West	2	380.5
	East	1	369.7

Appendix A

DTS Data Points

Data Point	Depth (m) East	Distance (m) East	Depth (m) West	Distance (m) West
1	-1.15		-1.50	
2	-0.12		-0.48	
3	0.90	0.0000	0.55	
4	1.93	0.0000	1.57	0.0000
5	2.95	0.0000	2.59	0.0000
6	3.98	0.0005	3.61	0.0001
7	5.00	0.0023	4.64	0.0014
8	6.03	0.0047	5.66	0.0038
9	7.05	0.0072	6.68	0.0063
10	8.08	0.0083	7.70	0.0087
11	9.10	0.0185	8.73	0.0218
12	10.13	0.0223	9.75	0.0243
13	11.15	0.0168	10.77	0.0188
14	12.18	0.0113	11.79	0.0134
15	13.20	0.0059	12.82	0.0079
16	14.23	0.0019	13.84	0.0026
17	15.25	0.0016	14.86	0.0009
18	16.28	0.0033	15.88	0.0026
19	17.30	0.0050	16.91	0.0043
20	18.33	0.0066	17.93	0.0060
21	19.35	0.0083	18.95	0.0077
22	20.38	0.0049	19.97	0.0082
23	21.40	0.0000	21.00	0.0003
24	22.43	0.0000	22.02	0.0000
25	23.45	0.0000	23.04	0.0000
26	24.48	0.0000	24.06	0.0000
27	25.50	0.0000	25.09	0.0000
28	26.53	0.0007	26.11	0.0004
29	27.55	0.0023	27.13	0.0016
30	28.58	0.0041	28.16	0.0034

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31	29.60	0.0059	29.18	0.0051
32	30.63	0.0076	30.20	0.0069
33	31.65	0.0079	31.22	0.0086
34	32.68	0.0257	32.25	0.0167
35	33.70	0.0233	33.27	0.0256
36	34.73	0.0177	34.29	0.0201
37	35.75	0.0121	35.31	0.0145
38	36.78	0.0066	36.34	0.0090
39	37.80	0.0021	37.36	0.0034
40	38.83	0.0014	38.38	0.0010
41	39.85	0.0031	39.40	0.0024
42	40.88	0.0048	40.43	0.0041
43	41.90	0.0065	41.45	0.0058
44	42.93	0.0082	42.47	0.0075
45	43.96	0.0053	43.49	0.0090
46	44.98	0.0000	44.52	0.0003
47	46.01	0.0000	45.54	0.0000
48	47.03	0.0000	46.56	0.0000
49	48.06	0.0000	47.58	0.0000
50	49.08	0.0000	48.61	0.0000
51	50.11	0.0005	49.63	0.0001
52	51.13	0.0018	50.65	0.0010
53	52.16	0.0035	51.68	0.0027
54	53.18	0.0052	52.70	0.0044
55	54.21	0.0069	53.72	0.0061
56	55.23	0.0086	54.74	0.0078
57	56.26	0.0152	55.77	0.0077
58	57.28	0.0260	56.79	0.0264
59	58.31	0.0205	57.81	0.0232
60	59.33	0.0150	58.83	0.0177
61	60.36	0.0095	59.86	0.0122
62	61.38	0.0040	60.88	0.0067
63	62.41	0.0013	61.90	0.0022
64	63.43	0.0021	62.92	0.0013
65	64.46	0.0038	63.95	0.0030
66	65.48	0.0055	64.97	0.0047
67	66.51	0.0072	65.99	0.0064
68	67.53	0.0089	67.01	0.0081
69	68.56	0.0190	68.04	0.0087
70	69.58	0.0249	69.06	0.0184
71	70.61	0.0194	70.08	0.0222
72	71.63	0.0139	71.10	0.0168
73	72.66	0.0084	72.13	0.0113
74	73.68	0.0029	73.15	0.0058
75	74.71	0.0009	74.17	0.0019
76	75.73	0.0025	75.19	0.0016
77	76.76	0.0042	76.22	0.0033
78	77.78	0.0059	77.24	0.0050

79	78.81	0.0076	78.26	0.0067
80	79.83	0.0086	79.29	0.0084
81	80.86	0.0236	80.31	0.0125
82	81.88	0.0238	81.33	0.0268
83	82.91	0.0184	82.35	0.0213
84	83.93	0.0129	83.38	0.0159
85	84.96	0.0075	84.40	0.0105
86	85.98	0.0024	85.42	0.0050
87	87.01	0.0011	86.44	0.0016
88	88.04	0.0027	87.47	0.0018
89	89.06	0.0044	88.49	0.0035
90	90.09	0.0061	89.51	0.0052
91	91.11	0.0078	90.53	0.0068
92	92.14	0.0077	91.56	0.0085
93	93.16	0.0265	92.58	0.0142
94	94.19	0.0231	93.60	0.0263
95	95.21	0.0176	94.62	0.0207
96	96.24	0.0120	95.65	0.0152
97	97.26	0.0065	96.67	0.0097
98	98.29	0.0021	97.69	0.0041
99	99.31	0.0014	98.71	0.0013
100	100.34	0.0031	99.74	0.0021
101	101.36	0.0048	100.76	0.0038
102	102.39	0.0065	101.78	0.0055
103	103.41	0.0083	102.81	0.0072
104	104.44	0.0114	103.83	0.0090
105	105.46	0.0270	104.85	0.0193
106	106.49	0.0216	105.87	0.0249
107	107.51	0.0161	106.90	0.0194
108	108.54	0.0107	107.92	0.0140
109	109.56	0.0052	108.94	0.0085
110	110.59	0.0016	109.96	0.0031
111	111.61	0.0018	110.99	0.0009
112	112.64	0.0035	112.01	0.0024
113	113.66	0.0051	113.03	0.0041
114	114.69	0.0068	114.05	0.0058
115	115.71	0.0085	115.08	0.0075
116	116.74	0.0143	116.10	0.0092
117	117.76	0.0262	117.12	0.0214
118	118.79	0.0206	118.14	0.0241
119	119.81	0.0151	119.17	0.0186
120	120.84	0.0095	120.19	0.0130
121	121.86	0.0039	121.21	0.0075
122	122.89	0.0012	122.23	0.0024
123	123.91	0.0022	123.26	0.0011
124	124.94	0.0039	124.28	0.0028
125	125.96	0.0056	125.30	0.0045
126	126.99	0.0074	126.32	0.0062

127	128.01	0.0091	127.35	0.0080
128	129.04	0.0207	128.37	0.0076
129	130.07	0.0244	129.39	0.0189
130	131.09	0.0189	130.42	0.0225
131	132.12	0.0134	131.44	0.0171
132	133.14	0.0079	132.46	0.0116
133	134.17	0.0026	133.48	0.0061
134	135.19	0.0009	134.51	0.0020
135	136.22	0.0026	135.53	0.0015
136	137.24	0.0043	136.55	0.0032
137	138.27	0.0060	137.57	0.0049
138	139.29	0.0077	138.60	0.0066
139	140.32	0.0081	139.62	0.0082
140	141.34	0.0254	140.64	0.0109
141	142.37	0.0235	141.66	0.0272
142	143.39	0.0181	142.69	0.0218
143	144.42	0.0126	143.71	0.0164
144	145.44	0.0072	144.73	0.0110
145	146.47	0.0023	145.75	0.0055
146	147.49	0.0011	146.78	0.0018
147	148.52	0.0028	147.80	0.0016
148	149.54	0.0045	148.82	0.0033
149	150.57	0.0062	149.84	0.0050
150	151.59	0.0078	150.87	0.0066
151	152.62	0.0075	151.89	0.0083
152	153.64	0.0270	152.91	0.0116
153	154.67	0.0230	153.94	0.0270
154	155.69	0.0175	154.96	0.0215
155	156.72	0.0120	155.98	0.0160
156	157.74	0.0065	157.00	0.0105
157	158.77	0.0021	158.03	0.0050
158	159.79	0.0014	159.05	0.0016
159	160.82	0.0031	160.07	0.0018
160	161.84	0.0048	161.09	0.0035
161	162.87	0.0065	162.12	0.0052
162	163.89	0.0082	163.14	0.0069
163	164.92	0.0103	164.16	0.0086
164	165.94	0.0272	165.18	0.0157
165	166.97	0.0216	166.21	0.0258
166	167.99	0.0159	167.23	0.0202
167	169.02	0.0103	168.25	0.0145
168	170.04	0.0047	169.27	0.0089
169	171.07	0.0015	170.30	0.0033
170	172.09	0.0020	171.32	0.0010
171	173.12	0.0038	172.34	0.0024
172	174.15	0.0055	173.36	0.0042
173	175.17	0.0072	174.39	0.0059
174	176.20	0.0090	175.41	0.0076

175	177.22	0.0197	176.43	0.0081
176	178.25	0.0245	177.45	0.0252
177	179.27	0.0188	178.48	0.0232
178	180.30	0.0131	179.50	0.0175
179	181.32	0.0074		
180	182.35	0.0024		
181	183.37	0.0012		
182	184.40	0.0030		
183	185.42	0.0047		
184	186.45	0.0065		
185	187.47	0.0082		
186	188.50	0.0116		
187	189.52	0.0270		
188	190.55	0.0215		
189	191.57	0.0160		
190	192.60	0.0106		
191	193.62	0.0051		
192	194.65	0.0016		
193	195.67	0.0018		
194	196.70	0.0035		
195	197.72	0.0052		
196	198.75	0.0069		
197	199.77	0.0085		
198	200.80	0.0147		
199	201.82	0.0262		
200	202.85	0.0207		
201	203.87	0.0152		
202	204.90	0.0097		
203	205.92	0.0042		
204	206.95	0.0013		
205	207.97	0.0021		
206	209.00	0.0038		
207	210.02	0.0055		
208	211.05	0.0072		
209	212.07	0.0088		
210	213.10	0.0181		
211	214.12	0.0252		
212	215.15	0.0197		
213	216.17	0.0142		
214	217.20	0.0086		
215	218.23	0.0031		
216	219.25	0.0009		
217	220.28	0.0024		
218	221.30	0.0041		
219	222.33	0.0058		
220	223.35	0.0075		
221	224.38	0.0089		
222	225.40	0.0227		

223	226.43	0.0240
224	227.45	0.0185
225	228.48	0.0130
226	229.50	0.0076
227	230.53	0.0025
228	231.55	0.0010
229	232.58	0.0027
230	233.60	0.0044
231	234.63	0.0061
232	235.65	0.0078
233	236.68	0.0077
234	237.70	0.0264
235	238.73	0.0230
236	239.75	0.0173
237	240.78	0.0117
238	241.80	0.0061
239	242.83	0.0019
240	243.85	0.0016
241	244.88	0.0033
242	245.90	0.0051
243	246.93	0.0068
244	247.95	0.0086
245	248.98	0.0152
246	250.00	0.0259
247	251.03	0.0204
248	252.05	0.0148
249	253.08	0.0093
250	254.10	0.0037
251	255.13	0.0011
252	256.15	0.0023
253	257.18	0.0040
254	258.20	0.0057
255	259.23	0.0074
256	260.25	0.0091
257	261.28	0.0211

Table A.1: Depth to DTS data points together with the distance between cable and casing, averaged over a one meter interval, for the eastern and western cable branch during the second logging campaign.

Appendix B

File Formats

B.1 DTS Data

The file structure for the temperature data, as exported using the DataManager Version 3.5.0 from Sensa (© Schlumberger, unpublished work, created 22. Nov. 2005), is given in Table B.1. The first row gives the channel used for data acquisition. Below, the separation value indicates the spatial resolution. It is automatically calculated on the basis of a pre-set refractive index value. The third row gives the time, different profiles have been acquired in Central European Time (CET). From row four, each column n gives the measured temperature profile at the time given in column $n+1$.

For the Stokes intensities, Table B.2 shows the exported file structure. The structure is similar to Table B.1. The same applies to the Anti-Stokes intensities (Table B.3). Due to a DTS storage error, Anti-Stokes intensities for the first logging campaign are only available from May 4th, 2009, 00:42 onwards.

Table B.1: Example of the .csv file structure exported by the DTS system for the temperature data.

Temperature Channel 1,	,	,	,...
Separation (m),	1.01849447513812,	,	,...
Data Point,	2009-05-04T00:25:03,	2009-05-04T00:25:44,	,...
36.30,	35.90,	35.55,	35.85,...
34.70,	35.05,	35.05,	35.55,...
...			

Scientific Technical Report STR12/12 Data, Deutsches GeoForschungsZentrum GFZ. http://doi.org/10.2312/GFZ.b103-12128

Table B.2: Example of the .csv file structure exported by the DTS system for the Stokes intensities.

Cleaned Backscatter NTS Channel 1 End 1,	,	...
Separation (m),	1.01849447513812,	...
Data Point,	2009-05-04T00:25:02,	...
12606,	12619,	...
12743,	12736,	...
...		

Table B.3: Example of the .csv file structure exported by the DTS system for the Anti-Stokes intensities.

Cleaned Backscatter TTS Channel 1 End 1,	,	...
Separation (m),	1.01849447513812,	...
Data Point,	2009-05-04T00:42:14,	...
17424,	17300,	...
17554,	17346,	...
...		

B.2 OTDR Data

Table B.4: Example of the tab-delimited .txt file structure exported from the Wavtek MTS5100.

File Structure		Explanation
	MTS 5100	Name of Instument
	MTS 5100	Name of Instument
	1300 nm	Operating Wavelength
	3 ns	Pulse Width
	90	Aquisition Time (s)
	25560	Number of Averages
	2.035 km	Range
	1	
	31744	Number of Data Points
-0.920100		Attenuation Value
-0.795200		Attenuation Value
-0.643800		Attenuation Value
...		...

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Appendix C

Wavetek Measurements

File #	Branch	Wavelength (nm)	Date	Time (CET)
1	Prior to Installation	850	4/18/2009	10:35
2	Prior to Installation	1300	4/18/2009	10:35
3	West	1300	5/3/2009	11:20
4	West	850	5/3/2009	11:20
5	East	1300	5/3/2009	11:20
6	East	850	5/3/2009	11:20
7	West	850	5/5/2009	20:32
8	West	1300	5/5/2009	20:35
9	East	1300	5/5/2009	20:37
10	East	850	5/5/2009	20:39
11	West	850	7/28/2009	0:20
12	East	850	7/28/2009	0:20
13	West	850	7/28/2009	15:49
14	West	1300	7/28/2009	15:52
15	East	1300	7/28/2009	15:53
16	East	850	7/28/2009	15:55
17	West	850	7/29/2009	23:25
18	West	1300	7/29/2009	23:27
19	East	1300	7/29/2009	23:30
20	East	850	7/29/2009	23:32
21	West	850	7/30/2009	11:10
22	West	1300	7/30/2009	11:13
23	East	1300	7/30/2009	11:15
24	East	850	7/30/2009	11:17
25	West	850	7/30/2009	16:49
26	West	1300	7/30/2009	16:52
27	East	1300	7/30/2009	16:54
28	East	850	7/30/2009	16:56
29	West	850	7/30/2009	19:48
30	West	1300	7/30/2009	19:50

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31	East	1300	7/30/2009	19:52
32	East	850	7/30/2009	19:54
33	West	850	7/31/2009	11:49
34	West	1300	7/31/2009	11:51
35	East	1300	7/31/2009	11:55
36	East	850	7/31/2009	11:58
37	West	850	7/31/2009	21:02
38	West	1300	7/31/2009	21:04
39	East	1300	7/31/2009	21:08
40	East	850	7/31/2009	21:11
41	West	850	7/31/2009	23:44
42	West	1300	7/31/2009	23:47
43	East	1300	7/31/2009	23:50
44	East	850	7/31/2009	23:51
45	West	850	8/1/2009	11:57
46	West	1300	8/1/2009	11:59
47	East	1300	8/1/2009	12:01
48	East	850	8/1/2009	12:04
49	West	850	8/1/2009	16:36
50	West	1300	8/1/2009	16:38
51	East	1300	8/1/2009	16:40
52	East	850	8/1/2009	16:52
53	West	850	8/1/2009	22:11
54	West	1300	8/1/2009	22:14
55	East	1300	8/1/2009	22:16
56	East	850	8/1/2009	22:18
57	West	850	8/2/2009	12:01
58	West	1300	8/2/2009	12:03
59	East	1300	8/2/2009	12:05
60	East	850	8/2/2009	12:07
61	West	850	8/2/2009	22:20
62	West	1300	8/2/2009	22:23
63	East	1300	8/2/2009	22:25
64	East	850	8/2/2009	22:27
65	West	850	8/3/2009	12:47
66	West	1300	8/3/2009	12:49
67	East	1300	8/3/2009	12:51
68	East	850	8/3/2009	12:56
69	West	850	8/3/2009	20:47
70	West	1300	8/3/2009	20:29
71	East	1300	8/3/2009	20:32
72	East	850	8/3/2009	20:34
73	West	850	8/4/2009	12:18
74	West	1300	8/4/2009	12:20
75	East	1300	8/4/2009	12:22
76	East	850	8/4/2009	12:24
77	West	850	8/4/2009	22:13
78	West	1300	8/4/2009	22:15

79	East	1300	8/4/2009	22:17
80	East	850	8/4/2009	22:19
81	West	850	8/5/2009	11:52
82	West	1300	8/5/2009	11:54
83	East	1300	8/5/2009	12:05
84	East	850	8/5/2009	12:07
85	East	850	8/5/2009	12:10
86	East	1300	8/5/2009	12:12
87	West	1300	8/5/2009	22:12
88	West	850	8/5/2009	22:14
89	East	850	8/5/2009	22:17
90	East	1300	8/5/2009	22:19
91	West	1300	8/6/2009	12:11
92	West	850	8/6/2009	12:15
93	East	850	8/6/2009	12:17
94	East	1300	8/6/2009	12:18
95	West	1300	8/6/2009	22:42
96	West	850	8/6/2009	22:44
97	East	850	8/6/2009	22:49
98	East	1300	8/6/2009	22:51
99	West	1300	8/7/2009	11:56
100	West	850	8/7/2009	11:58
101	East	850	8/7/2009	12:00
102	East	1300	8/7/2009	12:02
103	West	1300	8/7/2009	23:03
104	West	850	8/7/2009	23:07
105	East	850	8/7/2009	23:11
106	East	1300	8/7/2009	23:14
107	West	1300	8/8/2009	13:18
108	West	850	8/8/2009	13:21
109	East	850	8/8/2009	13:25
110	East	1300	8/8/2009	13:27
111	West	1300	8/8/2009	20:22
112	West	850	8/8/2009	20:24
113	East	850	8/8/2009	20:27
114	East	1300	8/8/2009	20:31
115	West	1300	8/9/2009	12:22
116	West	850	8/9/2009	12:25
117	East	850	8/9/2009	12:28
118	East	1300	8/9/2009	12:30
119	West	1300	8/9/2009	20:16
120	West	850	8/9/2009	20:18
121	East	850	8/9/2009	20:20
122	East	1300	8/9/2009	20:22
123	West	1300	8/10/2009	11:57
124	West	850	8/10/2009	11:59
125	East	850	8/10/2009	12:02
126	East	1300	8/10/2009	12:04

127	West	1300	8/10/2009	20:35
128	West	850	8/10/2009	20:38
129	East	850	8/10/2009	20:42
130	East	1300	8/10/2009	20:45
131	West	1300	8/11/2009	13:04
132	West	850	8/11/2009	13:06
133	East	850	8/11/2009	13:11
134	East	1300	8/11/2009	13:13
135	West	1300	8/11/2009	18:41
136	West	850	8/11/2009	18:46
137	East	850	8/11/2009	18:49
138	East	1300	8/11/2009	18:51
139	West	1300	8/12/2009	12:54
140	West	850	8/12/2009	12:56
141	East	850	8/12/2009	12:58
142	East	1300	8/12/2009	13:00
143	East	850	8/10/2010	14:32
144	East	1300	8/10/2010	14:40
145	West	1300	8/10/2010	14:43
146	West	850	8/10/2010	14:45
147	East	850	8/10/2010	15:56
148	East	1300	8/10/2010	15:59
149	East	1300	8/10/2010	23:17
150	East	850	8/10/2010	23:19
151	West	850	8/11/2010	0:23
152	West	1300	8/11/2010	0:24
153	East	1300	8/11/2010	10:28
154	East	850	8/11/2010	10:30
155	West	850	8/11/2010	10:38
156	West	1300	8/11/2010	10:41
157	East	1300	8/12/2010	10:43
158	East	850	8/12/2010	10:44
159	West	850	8/12/2010	10:54
160	West	1300	8/12/2010	10:56

Table C.1: List of OTDR measurements.

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