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Risk assessment of tunnelling-induced hydrogeological interference on springs using a machine learning approach

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Electronic Supplementary Materials

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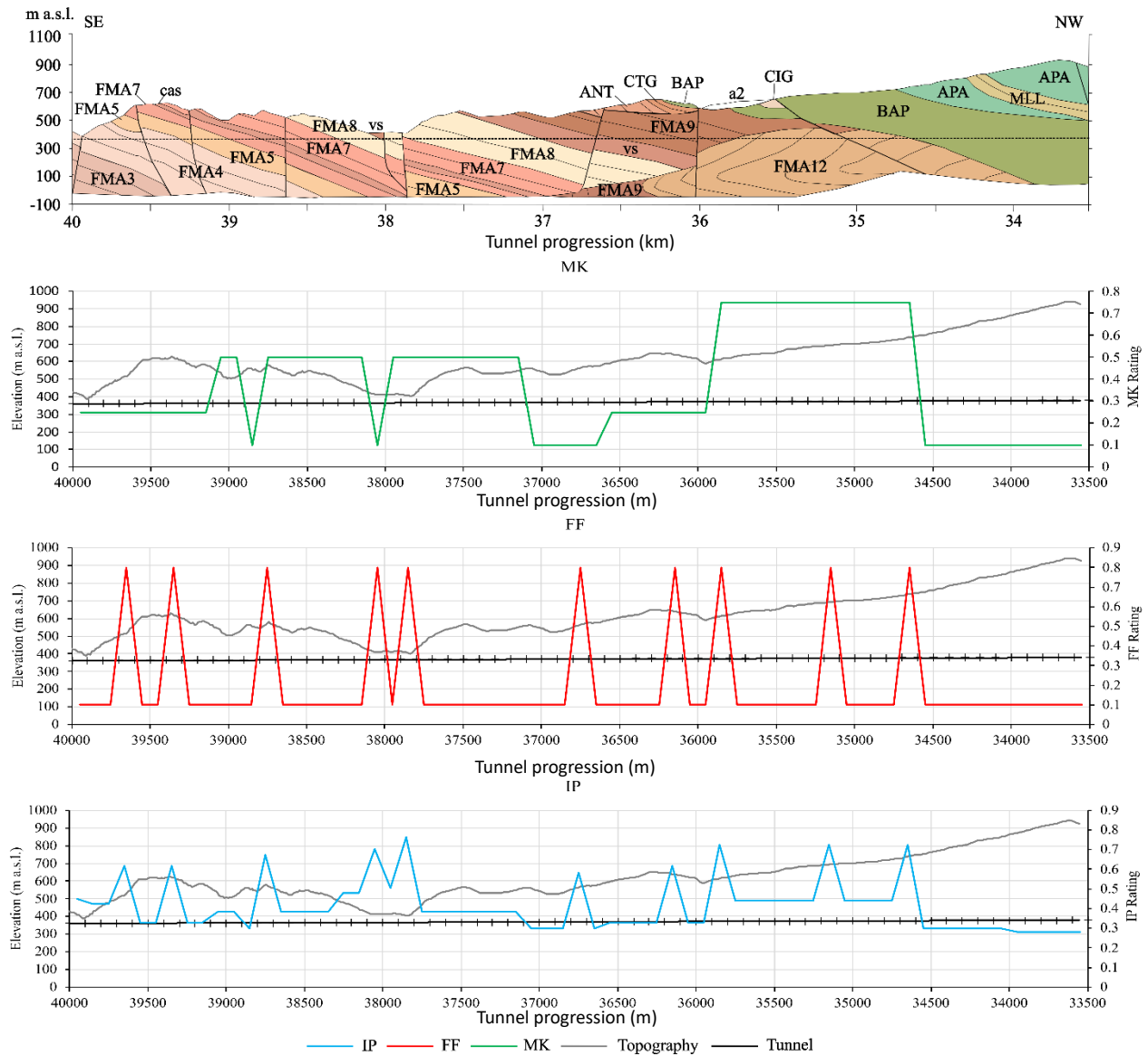


Figure 1: Three hazard parameters from the DHI method applied to the Raticosa tunnel (Canuti et al., 2009). The rock mass permeability (MK, green), fracture frequency (FF, red), and inflow potential (IP, blue) were calculated on 100 m sectors. Geology: FMA: Marnoso-arenacea Formation; FMA3: Premilcuore member; FMA4: Galeata member; FMA5: Collina member; FMA7: Bassana member; FMA8: Nepoli member; FMA9: Civitella member; FMA12: Castel del Rio member; BAP: Polygenic argillaceous breccias; APA: Palombini Formation; MLL: Monte Morello Formation; CTG: Contignano Formation; ANT: Antognola Marls Formation; cas: Casaglia chaotic Unit; a2: Inactive landslides.

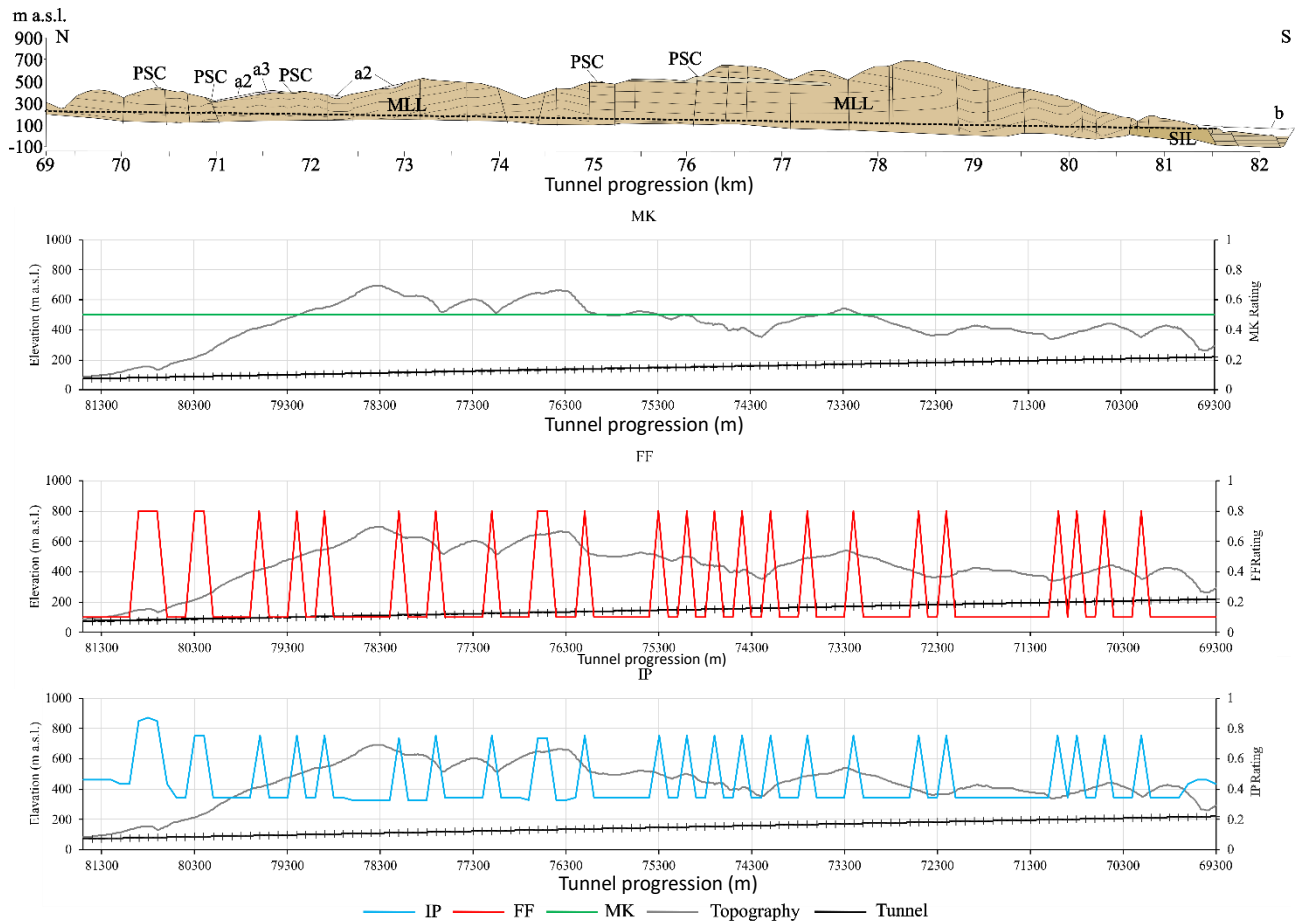


Figure 2: Three hazard parameters from the DHI method applied to the Vaglia tunnel (Canuti et al., 2009). The rock mass permeability (MK, green), fracture frequency (FF, red), and inflow potential (IP, blue) were calculated on 100 m sectors. Geology: MLL: Monte Morello Formation; PSC: Pescina Shale Formation; SIL: Sillano Formation; a2: Inactive landslides; a3: colluvial deposits.

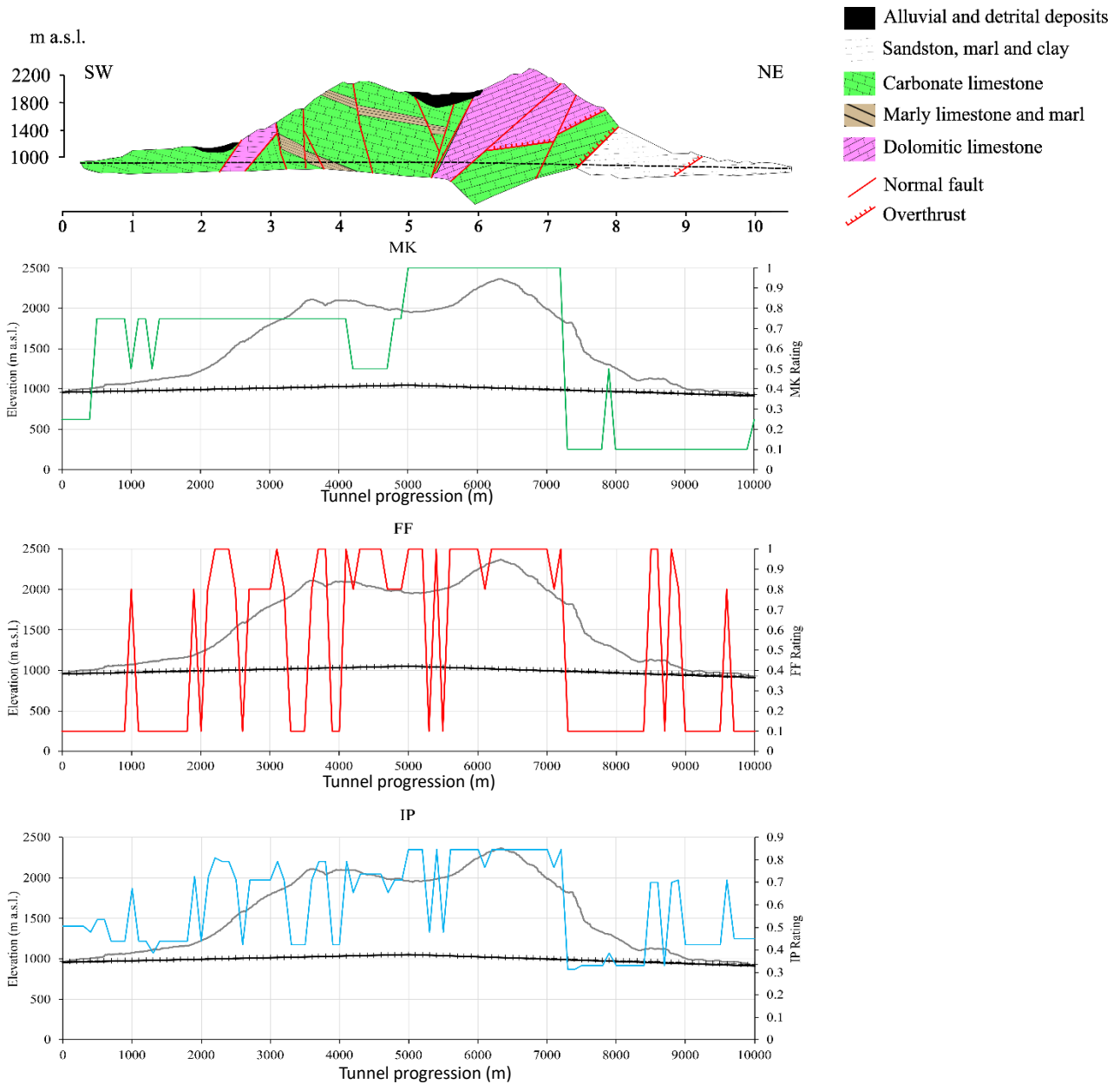


Figure 3: Three hazard parameters from the DHI method applied to the Gran Sasso tunnel (Celico et al., 2005). The rock mass permeability (MK, green), fracture frequency (FF, red), and inflow potential (IP, blue) were calculated on 100 m sectors.

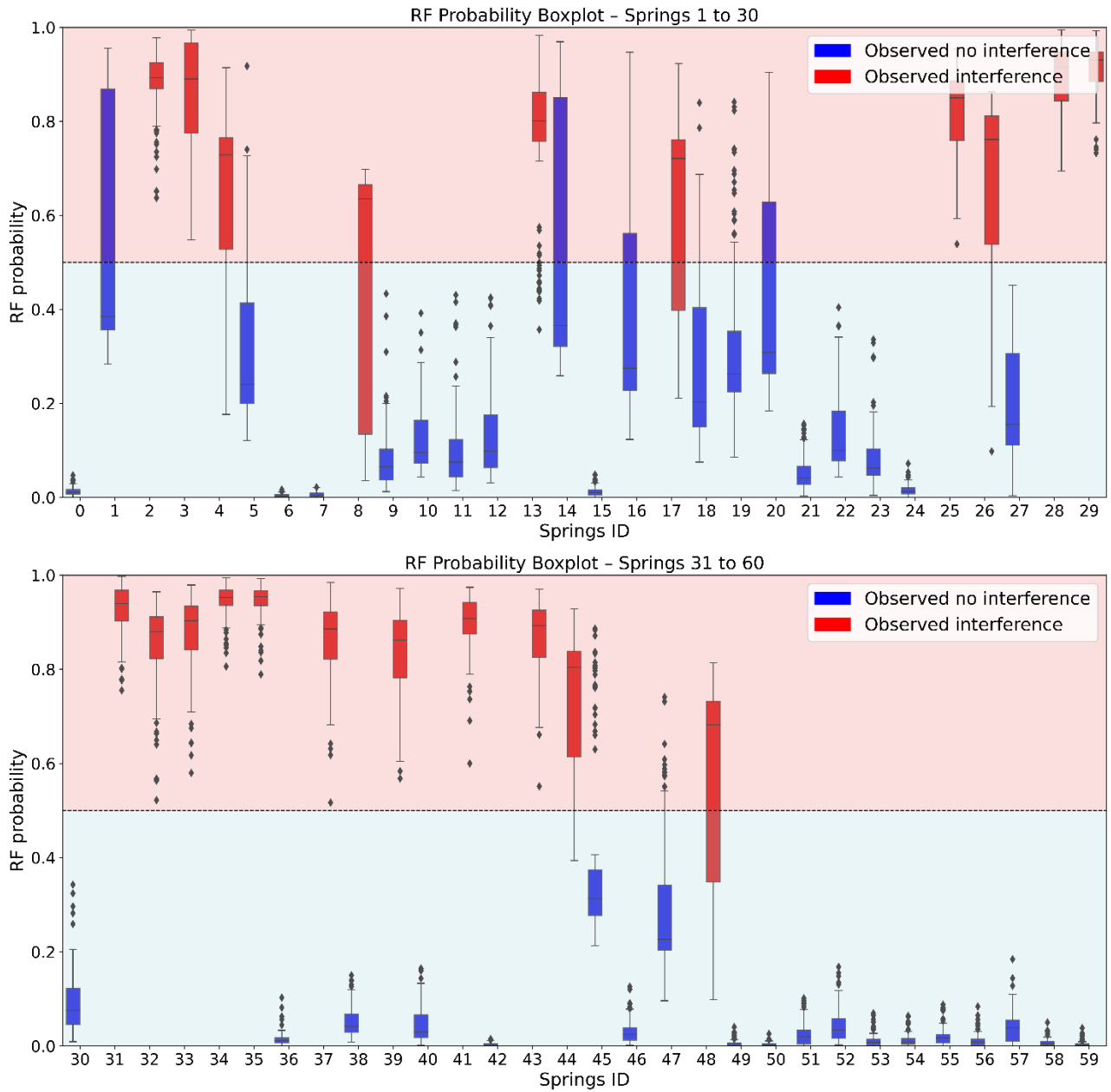


Figure 4: Boxplot of the probability distribution of impact for each spring in the original dataset, based on 100 models. Bologna-Florence case study. From spring 1 to spring 60.

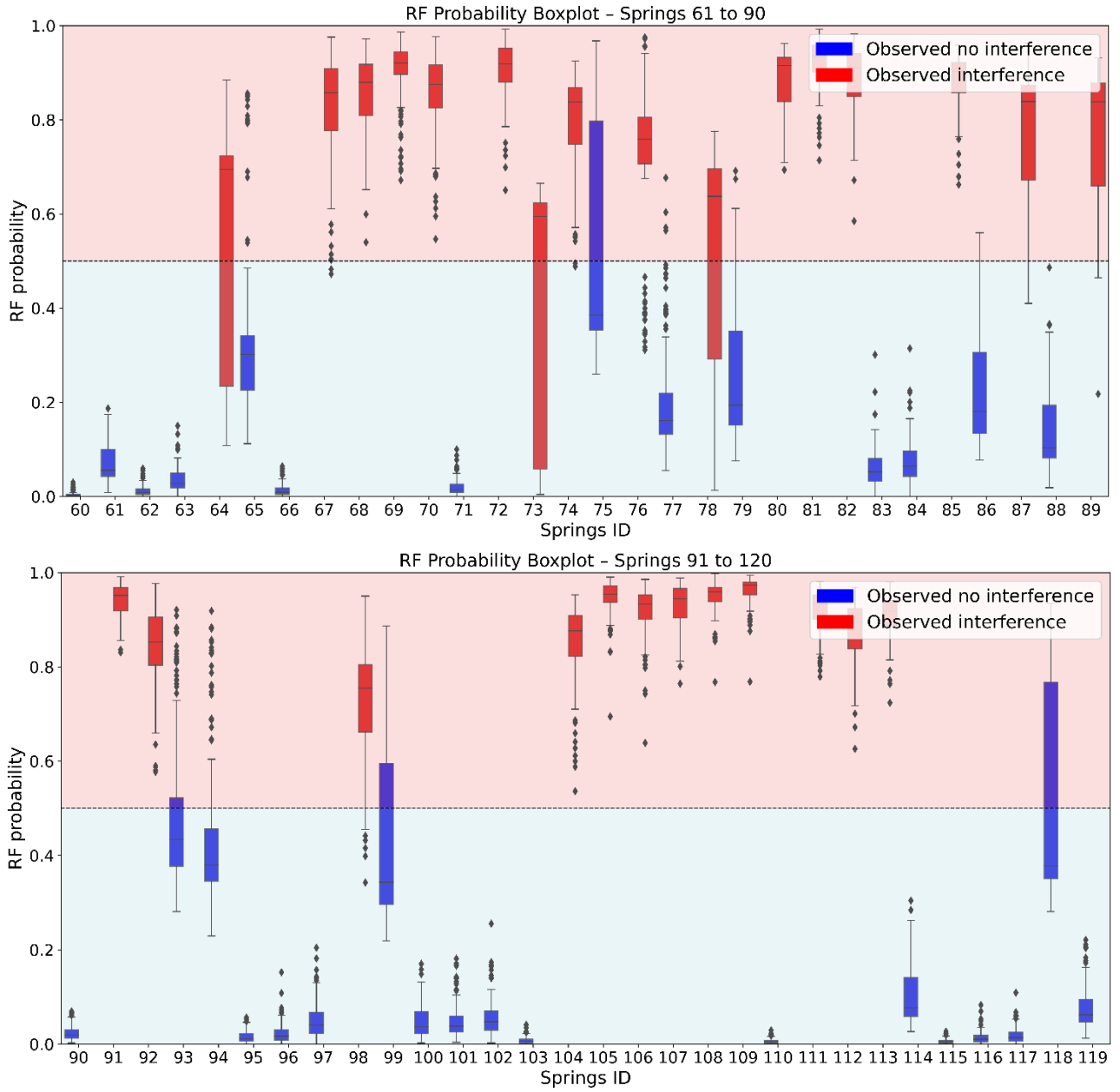


Figure 5: Boxplot of the probability distribution of impact for each spring in the original dataset, based on 100 models. Bologna-Florence case study. From spring 61 to spring 120.

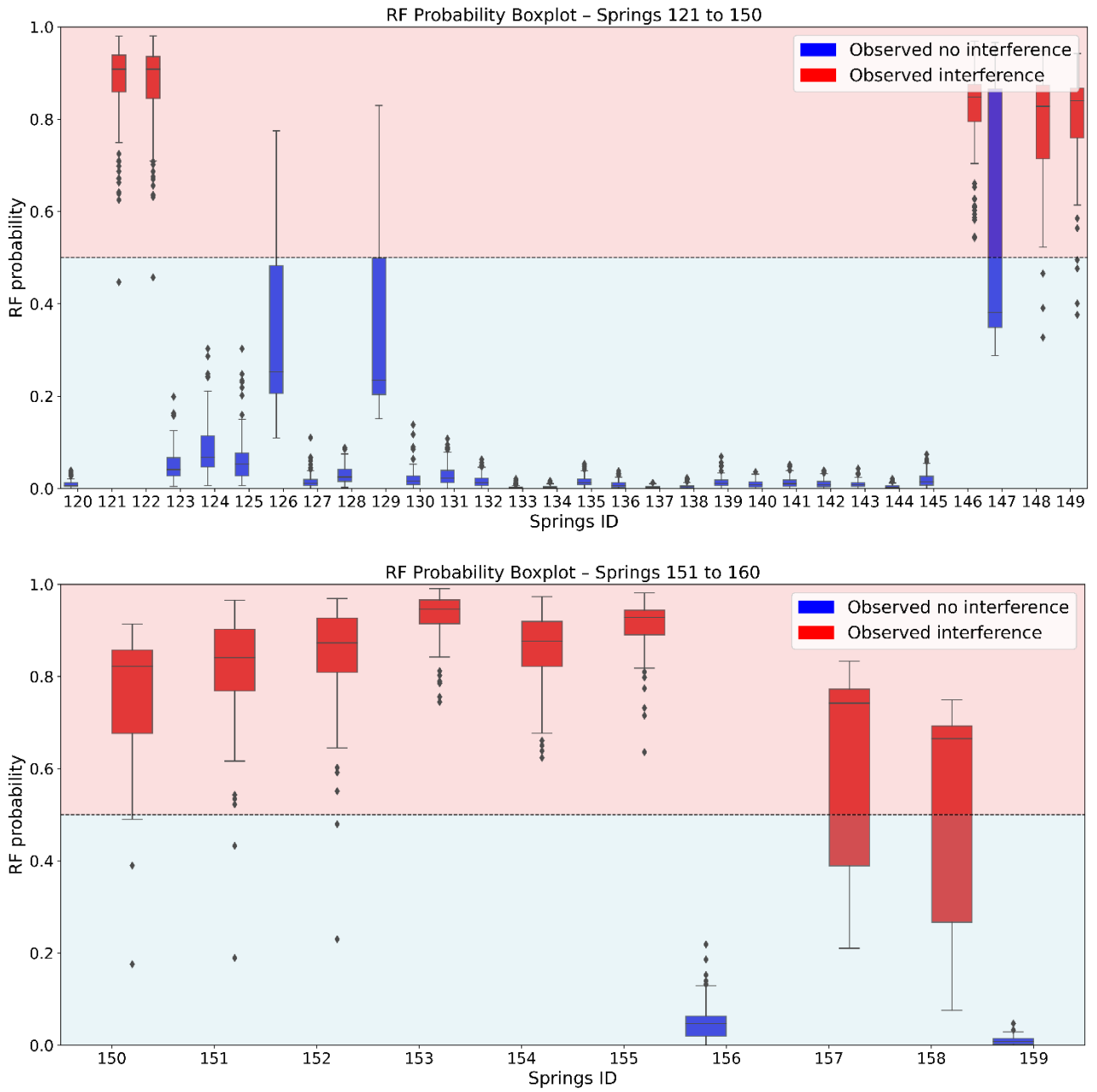


Figure 6: Boxplot of the probability distribution of impact for each spring in the original dataset, based on 100 models. Bologna-Florence case study. From spring 121 to spring 160.

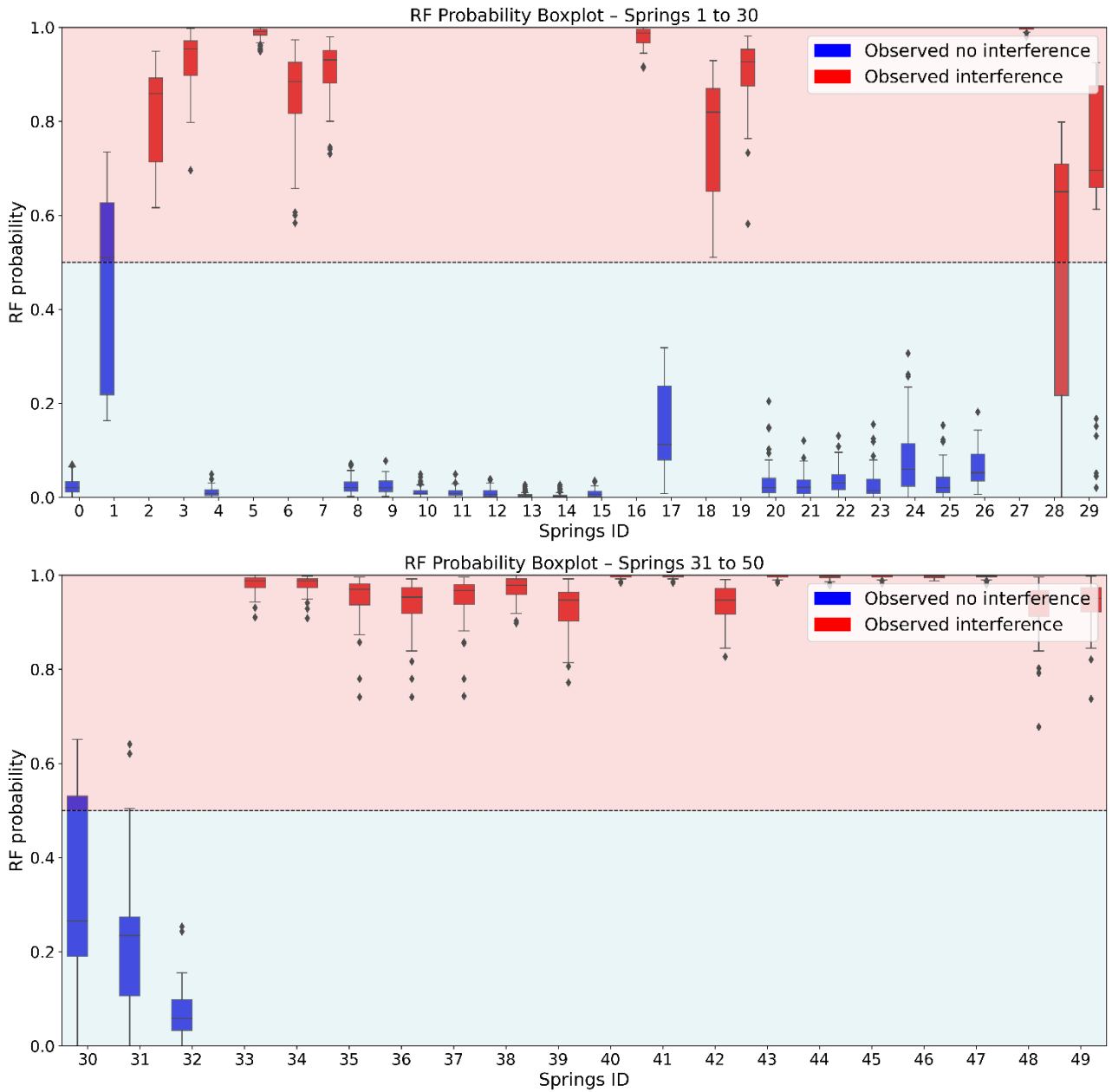


Figure 7: Boxplot of the probability distribution of impact for each spring in the original dataset, based on 100 models. Gran Sasso case study. All the 50 springs.

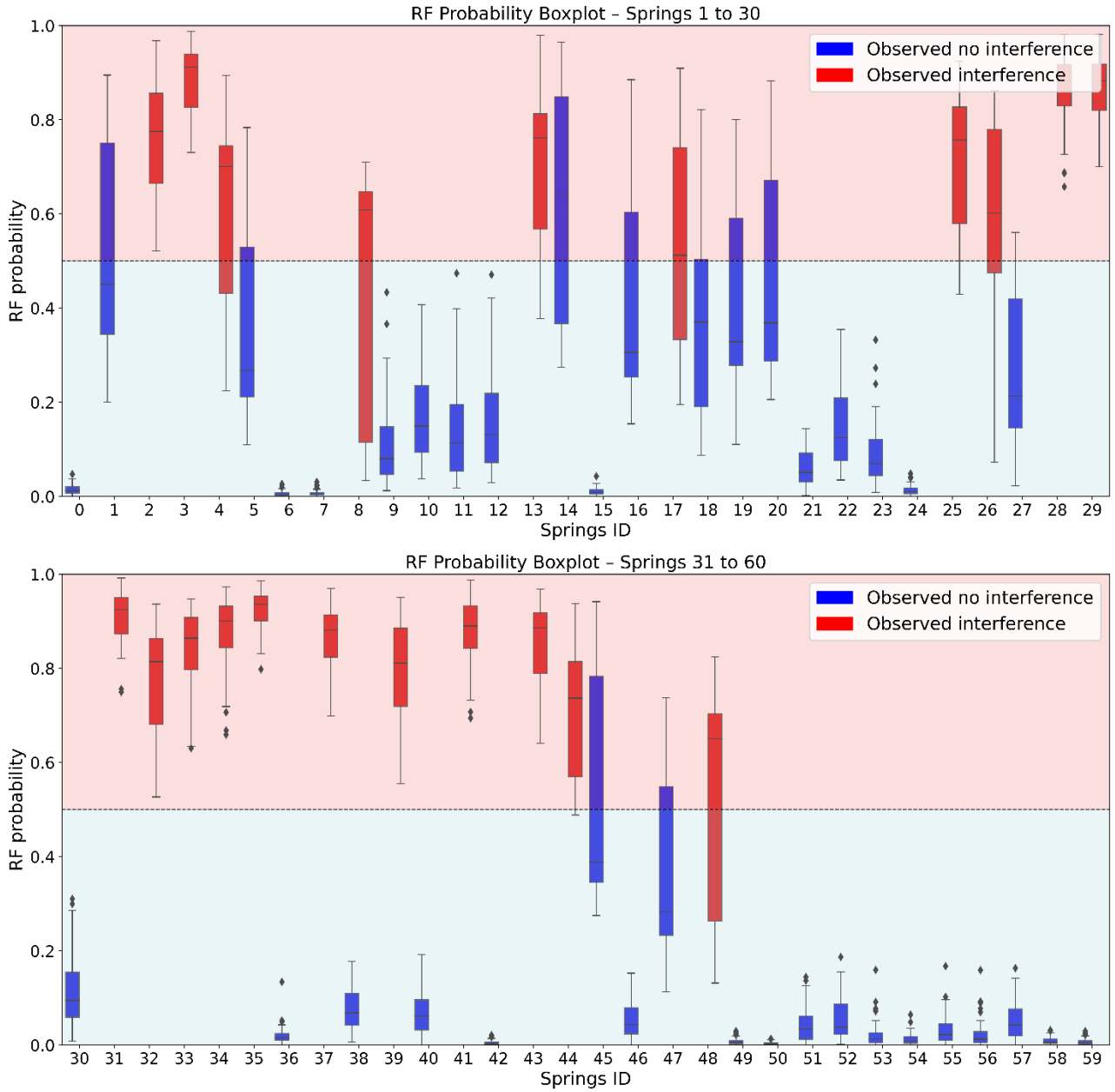


Figure 8: Boxplot of the probability distribution of impact for each spring in the original dataset, based on 100 models. Bologna-Florence + Gran Sasso case study. From spring 1 to spring 60.

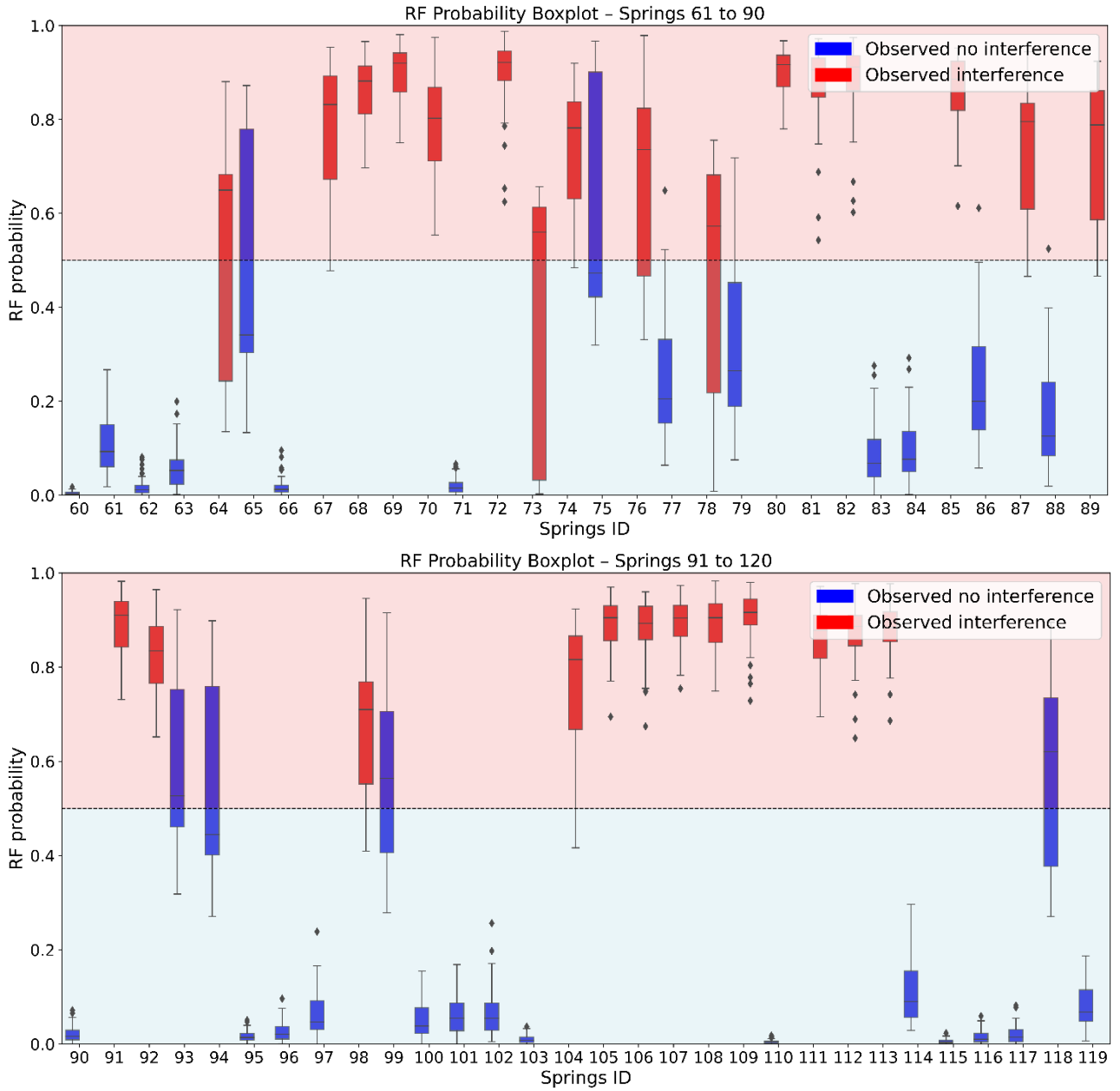


Figure 9: Boxplot of the probability distribution of impact for each spring in the original dataset, based on 100 models. Bologna-Florence + Gran Sasso case study. From spring 61 to spring 120.

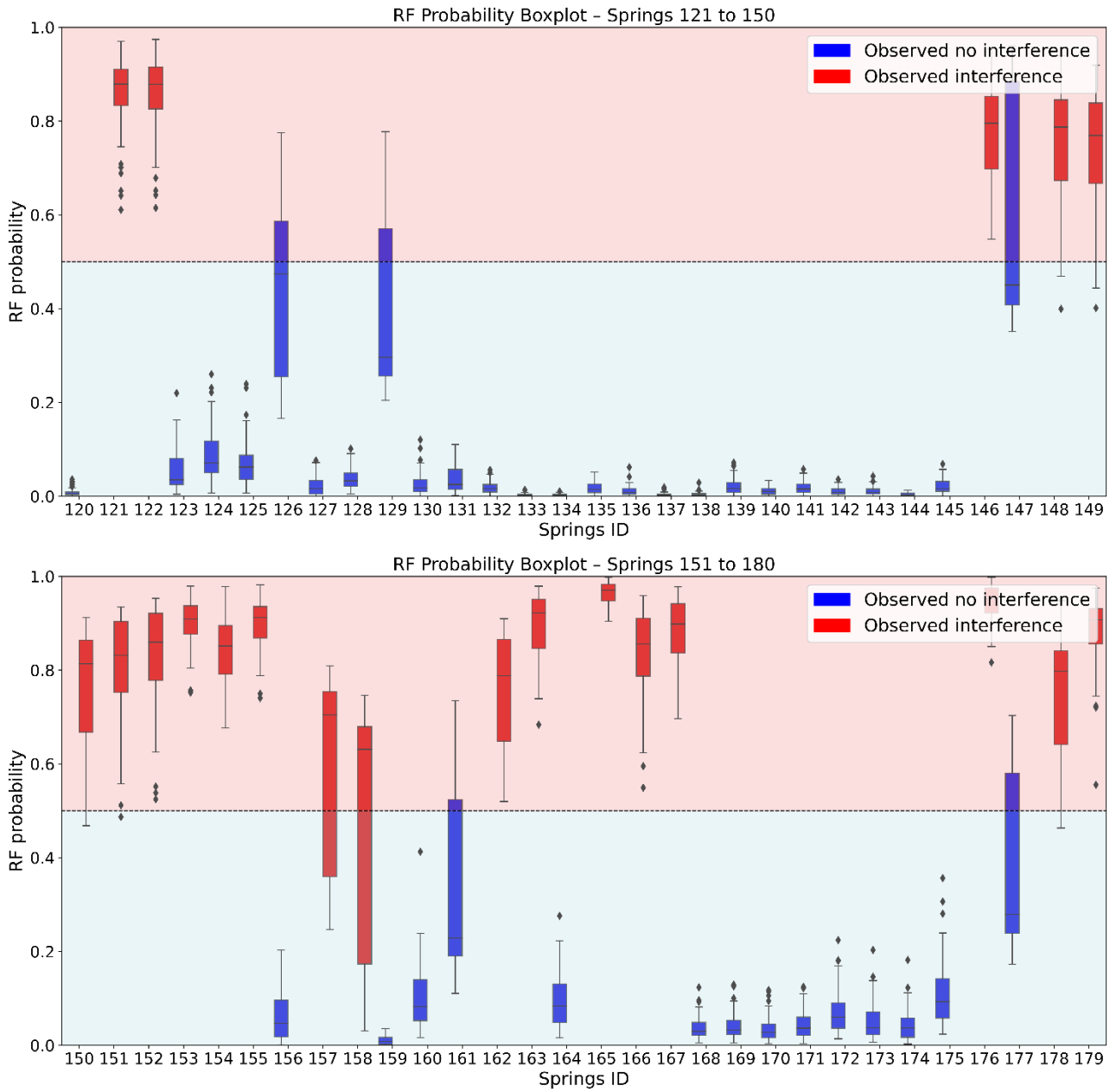


Figure 10: Boxplot of the probability distribution of impact for each spring in the original dataset, based on 100 models. Bologna-Florence + Gran Sasso case study. From spring 121 to spring 180.

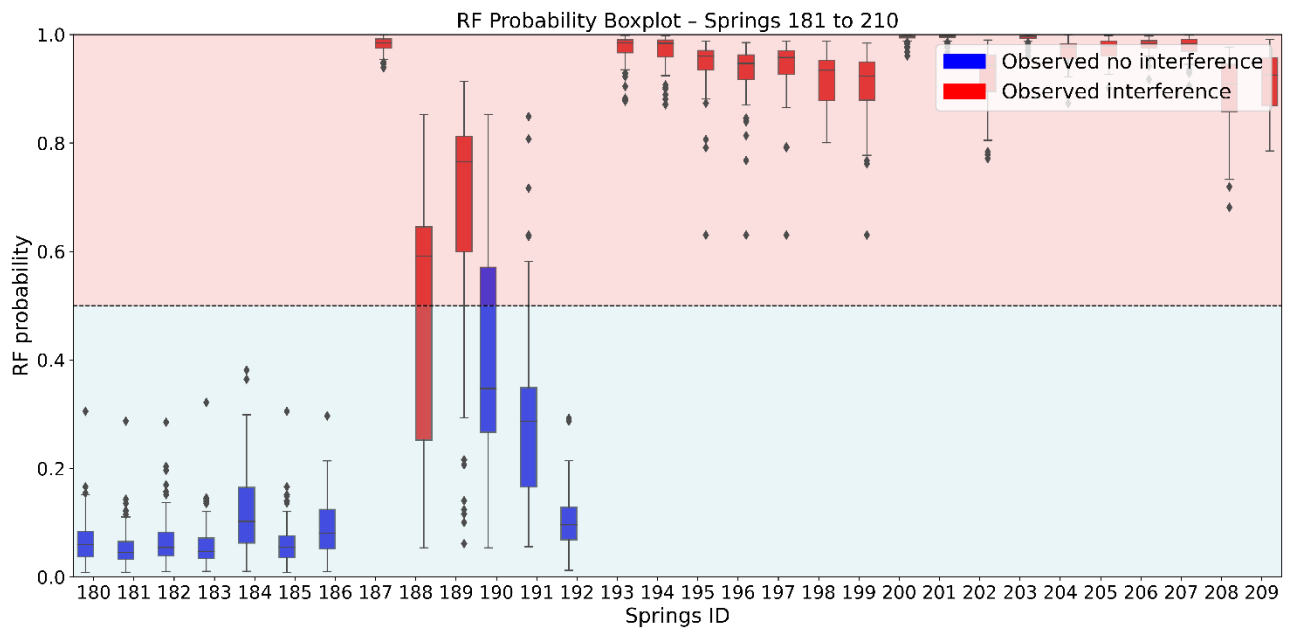


Figure 11: Boxplot of the probability distribution of impact for each spring in the original dataset, based on 100 models. Bologna-Florence + Gran Sasso case study. From spring 181 to spring 210.

Index	Very low	Low	Medium	High	Risk Class	Impact
0	0	76	20	4	Low	0
1	100	0	0	0	Very low	0
2	0	0	11	89	High	1
3	0	0	36	64	High	1
4	0	11	56	33	Medium	1
5	10	64	26	0	Low	0
6	100	0	0	0	Very low	0
7	100	0	0	0	Very low	0
8	100	0	0	0	Very low	0
9	25	3	72	0	Medium	1
10	0	11	47	42	Medium	1
11	86	13	1	0	Very low	0
12	0	71	5	24	Low	0
13	68	32	0	0	Very low	0
14	80	18	2	0	Very low	0
15	74	24	2	0	Very low	0
16	100	0	0	0	Very low	0
17	2	57	38	3	Low	0
18	1	27	62	10	Medium	1
19	36	47	17	0	Low	0
20	2	68	30	0	Low	0
21	0	56	41	3	Low	0
22	100	0	0	0	Very low	0
23	70	28	2	0	Very low	0
24	82	18	0	0	Very low	0
25	100	0	0	0	Very low	0
26	6	23	69	2	Medium	1
27	2	11	48	39	Medium	1
28	0	1	39	60	High	1
29	25	63	12	0	Low	0
30	0	0	17	83	High	1
31	70	28	2	0	Very low	0
32	0	0	7	93	High	1
33	0	0	4	96	High	1
34	0	1	30	69	High	1
35	0	0	14	86	High	1
36	0	0	3	97	High	1
37	0	0	5	95	High	1
38	99	1	0	0	Very low	0
39	0	0	13	87	High	1
40	99	1	0	0	Very low	0
41	0	0	24	76	High	1
42	95	5	0	0	Very low	0
43	0	0	13	87	High	1
44	100	0	0	0	Very low	0

45	0	0	17	83	High	1
46	0	5	53	42	Medium	1
47	0	73	10	17	Low	0
48	97	3	0	0	Very low	0
49	22	62	16	0	Low	0
50	100	0	0	0	Very low	0
51	100	0	0	0	Very low	0
52	100	0	0	0	Very low	0
53	100	0	0	0	Very low	0
54	100	0	0	0	Very low	0
55	0	15	39	46	High	1
56	100	0	0	0	Very low	0
57	100	0	0	0	Very low	0
58	100	0	0	0	Very low	0
59	100	0	0	0	Very low	0
60	100	0	0	0	Very low	0
61	100	0	0	0	Very low	0
62	100	0	0	0	Very low	0
63	98	2	0	0	Very low	0
64	5	25	56	14	Medium	1
65	5	66	13	16	Low	0
66	100	0	0	0	Very low	0
67	97	3	0	0	Very low	0
68	0	0	5	95	High	1
69	100	0	0	0	Very low	0
70	100	0	0	0	Very low	0
71	19	8	73	0	Medium	1
72	0	0	3	97	High	1
73	0	0	18	82	High	1
74	0	0	7	93	High	1
75	0	0	3	97	High	1
76	0	0	39	61	High	1
77	0	4	30	66	High	1
78	0	0	2	98	High	1
79	0	0	9	91	High	1
80	0	74	6	20	Low	0
81	55	41	4	0	Very low	0
82	0	24	55	21	Medium	1
83	8	16	56	20	Medium	1
84	54	41	5	0	Very low	0
85	0	0	12	88	High	1
86	99	1	0	0	Very low	0
87	99	1	0	0	Very low	0
88	0	31	58	11	Medium	1
89	0	1	30	69	High	1
90	68	31	1	0	Very low	0
91	100	0	0	0	Very low	0

92	65	32	3	0	Very low	0
93	0	4	32	64	High	1
94	100	0	0	0	Very low	0
95	0	0	3	97	High	1
96	0	0	22	78	High	1
97	0	55	24	21	Low	0
98	0	18	61	21	Medium	0
99	100	0	0	0	Very low	0
100	95	5	0	0	Very low	0
101	98	2	0	0	Very low	0
102	0	3	66	31	Medium	1
103	0	41	46	13	Medium	0
104	0	8	46	46	Medium	1
105	100	0	0	0	Very low	0
106	100	0	0	0	Very low	0
107	100	0	0	0	Very low	0
108	98	2	0	0	Very low	0
109	100	0	0	0	Very low	0
110	0	0	5	95	High	1
111	0	0	1	99	High	1
112	0	0	3	97	High	1
113	0	0	2	98	High	1
114	0	0	0	100	High	1
115	0	0	9	91	High	1
116	100	0	0	0	Very low	0
117	90	10	0	0	Very low	0
118	100	0	0	0	Very low	0
119	0	0	9	91	High	1
120	100	0	0	0	Very low	0
121	0	70	14	16	Low	0
122	0	0	27	73	High	1
123	100	0	0	0	Very low	0
124	0	0	8	92	High	1
125	0	0	8	92	High	1
126	100	0	0	0	Very low	0
127	100	0	0	0	Very low	0
128	0	0	7	93	High	1
129	100	0	0	0	Very low	0
130	100	0	0	0	Very low	0
131	0	65	33	2	Low	0
132	100	0	0	0	Very low	0
133	100	0	0	0	Very low	0
134	100	0	0	0	Very low	0
135	100	0	0	0	Very low	0
136	0	73	24	3	Low	0
137	100	0	0	0	Very low	0
138	100	0	0	0	Very low	0

139	100	0	0	0	Very low	0
140	100	0	0	0	Very low	0
141	97	3	0	0	Very low	0
142	100	0	0	0	Very low	0
143	100	0	0	0	Very low	0
144	100	0	0	0	Very low	0
145	100	0	0	0	Very low	0
146	0	67	9	24	Low	0
147	100	0	0	0	Very low	0
148	0	0	30	70	High	1
149	100	0	0	0	Very low	0
150	100	0	0	0	Very low	0
151	4	2	25	69	High	1
152	100	0	0	0	Very low	0
153	100	0	0	0	Very low	0
154	0	4	46	50	High	1
155	0	4	52	44	Medium	1
156	3	2	14	81	High	1
157	4	2	26	68	High	1
158	0	0	23	77	High	1
159	0	0	7	93	High	1
160	86	14	0	0	Very low	0
161	94	6	0	0	Very low	0
162	100	0	0	0	Very low	0
163	100	0	0	0	Very low	0
164	100	0	0	0	Very low	0
165	100	0	0	0	Very low	0
166	95	5	0	0	Very low	0
167	100	0	0	0	Very low	0
168	100	0	0	0	Very low	0
169	88	12	0	0	Very low	0
170	0	70	30	0	Low	0
171	0	1	44	55	High	1
172	0	0	11	89	High	1
173	97	3	0	0	Very low	0
174	99	1	0	0	Very low	0
175	96	4	0	0	Very low	0
176	97	3	0	0	Very low	0
177	91	9	0	0	Very low	0
178	97	3	0	0	Very low	0
179	91	9	0	0	Very low	0
180	19	16	64	1	Medium	1
181	9	2	52	37	Medium	1
182	27	55	18	0	Low	0
183	47	48	5	0	Low	0
184	90	10	0	0	Very low	0
185	0	0	0	100	High	1

186	0	0	0	100	High	1
187	0	0	0	100	High	1
188	0	0	0	100	High	1
189	0	0	0	100	High	1
190	0	0	0	100	High	1
191	0	0	0	100	High	1
192	0	0	0	100	High	1
193	0	0	0	100	High	1
194	0	0	0	100	High	1
195	16	61	23	0	Low	0
196	0	0	26	74	High	1
197	0	0	5	95	High	1
198	0	0	0	100	High	1
199	0	0	18	82	High	1
200	0	0	8	92	High	1
201	0	0	0	100	High	1
202	0	0	0	100	High	1
203	0	0	0	100	High	1
204	0	0	0	100	High	1
205	0	0	0	100	High	1
206	0	0	0	100	High	1
207	0	0	0	100	High	1
208	0	0	6	94	High	1
209	0	0	2	98	High	1

Table 1: Classification results for all the springs.