

1 **Supplementary Material:**

2 **Changes in the dynamical properties of the North-Atlantic atmospheric**
3 **circulation in the past 150 years.**

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ABSTRACT

14 In the supplementary material we present the results of the statistical tests
15 discussed in the main paper (Tables S1, S2) and the joint histograms of (d, θ)
16 (Figures S1-S26) for all the models analysed, corresponding to Figure 8 in
17 the main paper. Table S1 presents the results of a Wilcoxon ranksum test
18 (Von Storch 1999) comparing the median values of d and θ between the mod-
19 els and the reanalysis and between sub-periods within the same dataset. The
20 null hypothesis is that the variables are samples from continuous distributions
21 with equal medians. A rejection of the null hypothesis therefore indicates a
22 significant difference between the medians (bold entries). The columns la-
23 beled $P12$, $P23$ and $P13$ compare the median values of the same dataset over
24 the three sub-periods: 1851-1900, 1901-1950 and 1951-2000. There is no
25 clear trend across the models, with some showing significant changes in both
26 d and θ and others showing no variations. The columns labeled Pra compare
27 the medians of the models to those of the reanalysis over the full 1851-2000
28 period. All but three of the higher resolution models yield statistically differ-
29 ent medians from the reanalysis for both of the dynamical systems metrics.
30 Table S2 presents the Root Mean Square Error (RMSE) between 20CR and
31 CMIP5 models for SLP extreme anomalies corresponding to days beyond the
32 0.02 and 0.98 quantiles of the d, θ distributions.

³³ **References**

³⁴ Von Storch, H., 1999: Misuses of statistical analysis in climate research. *Analysis of Climate*
³⁵ *Variability*, Springer, 11–26.

36 **LIST OF TABLES**

37 **Table 1.** p-values of the ranksum test to study whether the median P_{med} of the dimen-
38 sion (d) or the persistence (θ) changes between the periods of each model
39 ($P12, P23, P13$) and between each model and the 20CR reanalysis (Pra). p-
40 values $< 0,00001$ are represented as 0. Bold numbers show significant changes
41 at the 0.05 level using a ranksum test. Models are ordered by increasing in
42 resolution. 5

43 **Table 2.** RMSE between 20CR and CMIP5 models for SLP extreme anomalies obtained
44 considering the SLP fields beyond the 0.02 and 0.98 quantiles of the d, θ distri-
45 butions. 6

46 TABLE 1. p-values of the ranksum test to study whether the median P_{med} of the dimension (d) or the
47 persistence (θ) changes between the periods of each model ($P12, P23, P13$) and between each model and the
48 20CR reanalysis (Pra). p-values $< 0,00001$ are represented as 0. Bold numbers show significant changes at the
49 0.05 level using a ranksum test. Models are ordered by increasing in resolution.

N.	Models	Pmed (d)				Pmed (θ)			
		P12	P23	P13	Pra	P12	P23	P13	Pra
1	20CR	0	0	0	–	0	0,00019	0	–
2	CMCC-CESM	0,14932	0,18834	0,90453	0	0,01286	0,16537	0,27336	0
3	CanESM2	0,75710	0,01868	0,00754	0	0,01868	0,14011	0,40354	0
4	MIROC-ESM-CHEM	0,71166	0,18351	0,33392	0	0,06156	0,96734	0,05805	0
5	MIROC-ESM	0,60922	0,53551	0,89892	0	0,09860	0,57164	0,02486	0
6	BCC-CSM1-1	0,16301	0,43325	0,53587	0	0,03806	0,10650	0,00021	0
7	IPSL-CM5B	0	0,01041	0	0	0,05955	0,19765	0,54816	0
8	NorESM1-M	0,08539	0	0,00001	0	0,36281	0,34488	0,06340	0
9	FGOALS-S2	0,00839	0,03568	0	0	0,27269	0,00094	0,02321	0
10	MPI-ESM-P	0,05314	0,96271	0,04909	0	0,00310	0,40551	0,00017	0
11	MPI-ESM-LR	0,87446	0,00532	0,00316	0	0,90788	0,48649	0,55772	0
12	CSIRO-MK3-6-0	0,07196	0,00140	0	0	0,01158	0	0,00015	0,02506
13	CMCC-CMS	0,62410	0,09515	0,02891	0	0,00338	0,97717	0,00328	0
14	MPI-ESM-MR	0,40856	0,00050	0,00002	0	0,55003	0,01951	0,00318	0
15	IPSL-CM5A	0	0,17916	0,00098	0	0,61061	0,15644	0,05223	0
16	INM-CM4	0	0,91457	0,00093	0	0,32157	0,00289	0,05065	0
17	ACCESS-1-0	0,22330	0,01967	0,27733	0	0,03324	0,28185	0,00145	0
18	MIROC5	0,44975	0,76702	0,63848	0	0,33047	0,62295	0,13261	0
19	CNRM-CM5	0,00227	0,02928	0,37598	0	0	0,23172	0,00073	0
20	MRI-ESM1	0,09510	0,01032	0,00002	0	0,56039	0,26909	0,07458	0
21	BCC-CSM1-M	0,44241	0,01528	0,00141	0	0,59750	0,00077	0,00515	0
22	MRI-GCM3	0,96671	0,13074	0,12073	0	0,54675	0,13894	0,03884	0
23	EC-EARTH	0,75276	0,15889	0,28299	0	0,00330	0,14022	0,00001	0,58680
24	CESM1-FAST	0,30229	0,01851	0,18630	0,12823	0,69600	0,01400	0,04269	0
25	CESM1-CAM5	0,00022	0,00009	0,84053	0	0,00247	0,07079	0,20712	0
26	CESM1-BGC	0,02373	0,00001	0,03104	0,60554	0,94591	0,02543	0,02028	0
27	CCSM4	0	0,00107	0,00205	0,01807	0,08769	0,35862	0,41889	0

50 TABLE 2. RMSE between 20CR and CMIP5 models for SLP extreme anomalies obtained considering the
 51 SLP fields beyond the 0.02 and 0.98 quantiles of the d, θ distributions.

N	Models	AR	NAO-	BLO	NAO+
1	20CR	0	0	0	0
2	CMCC-CESM	3,19	10,86	4,86	8,77
3	CanESM2	3,20	8,86	4,72	6,60
4	MIROC-ESM-CHEM	2,99	10,41	5,81	5,77
5	MIROC-ESM	2,79	10,19	6,00	5,51
6	BCC-CSM1-1	3,65	9,91	6,21	8,41
7	IPSL-CM5B	3,51	10,38	6,17	6,92
8	NorESM1-M	3,56	10,11	6,11	8,64
9	FGOALS-S2	3,70	9,16	5,86	6,53
10	MPI-ESM-P	3,21	10,67	4,10	9,37
11	MPI-ESM-LR	3,68	10,94	4,10	8,78
12	CSIRO-MK3-6-0	3,36	7,17	3,50	7,20
13	CMCC-CMS	3,30	10,32	4,27	8,84
14	MPI-ESM-MR	3,43	9,91	4,15	9,22
15	IPSL-CM5A	3,72	10,26	6,20	6,26
16	INM-CM4	2,89	9,35	4,44	6,56
17	ACCESS-1-0	3,37	9,18	4,36	7,36
18	MIROC5	3,57	7,42	3,02	6,64
19	CNRM-CM5	3,01	9,44	4,83	6,42
20	MRI-ESM1	3,60	10,29	6,81	8,48
21	BCC-CSM1-M	3,60	8,73	5,94	8,62
22	MRI-GCM3	3,62	10,07	7,03	8,16
23	EC-EARTH	3,38	10,32	4,18	8,36
24	CESM1-FAST	3,48	9,43	6,08	8,03
25	CESM1-CAM5	3,55	10,05	6,01	8,06
26	CESM1-BGC	3,51	10,21	5,62	8,30
27	CCSM4	3,44	9,63	5,88	8,26

52 **LIST OF FIGURES**

53 **Fig. 1.** Bivariate histograms of (d, θ) for the 20CR (left), the model CMCC-CESM (centre) and
54 their difference Δ (right) for three periods: 1851-1900 (top), 1901-1950 (centre), 1951-2000
55 (bottom). The violet lines indicate the median values. The colorbar represents the frequency
56 of joint d, θ observations in number of days. 10

57 **Fig. 2.** Bivariate histograms of (d, θ) for the 20CR (left), the model CanESM2 (centre) and their
58 difference Δ (right) for three periods: 1851-1900 (top), 1901-1950 (centre), 1951-2000 (bot-
59 tom). The violet lines indicate the median values. The colorbar represents the frequency of
60 joint d, θ observations in number of days. 11

61 **Fig. 3.** Bivariate histograms of (d, θ) for the 20CR (left), the model MIROC-ESM-CHEM (centre)
62 and their difference Δ (right) for three periods: 1851-1900 (top), 1901-1950 (centre), 1951-
63 2000 (bottom). The violet lines indicate the median values. The colorbar represents the
64 frequency of joint d, θ observations in number of days. 12

65 **Fig. 4.** Bivariate histograms of (d, θ) for the 20CR (left), the model MIROC-ESM (centre) and
66 their difference Δ (right) for three periods: 1851-1900 (top), 1901-1950 (centre), 1951-2000
67 (bottom). The violet lines indicate the median values. The colorbar represents the frequency
68 of joint d, θ observations in number of days. 13

69 **Fig. 5.** Bivariate histograms of (d, θ) for the 20CR (left), the model BCC-CSM1-1 (centre) and
70 their difference Δ (right) for three periods: 1851-1900 (top), 1901-1950 (centre), 1951-2000
71 (bottom). The violet lines indicate the median values. The colorbar represents the frequency
72 of joint d, θ observations in number of days. 14

73 **Fig. 6.** Bivariate histograms of (d, θ) for the 20CR (left), the model IPSL-CM5B (centre) and their
74 difference Δ (right) for three periods: 1851-1900 (top), 1901-1950 (centre), 1951-2000 (bot-
75 tom). The violet lines indicate the median values. The colorbar represents the frequency of
76 joint d, θ observations in number of days. 15

77 **Fig. 7.** Bivariate histograms of (d, θ) for the 20CR (left), the model NOrESM1-M (centre) and
78 their difference Δ (right) for three periods: 1851-1900 (top), 1901-1950 (centre), 1951-2000
79 (bottom). The violet lines indicate the median values. The colorbar represents the frequency
80 of joint d, θ observations in number of days. 16

81 **Fig. 8.** Bivariate histograms of (d, θ) for the 20CR (left), the model FGOALS-S2 (centre) and their
82 difference Δ (right) for three periods: 1851-1900 (top), 1901-1950 (centre), 1951-2000 (bot-
83 tom). The violet lines indicate the median values. The colorbar represents the frequency of
84 joint d, θ observations in number of days. 17

85 **Fig. 9.** Bivariate histograms of (d, θ) for the 20CR (left), the model MPI-ESM-P (centre) and their
86 difference Δ (right) for three periods: 1851-1900 (top), 1901-1950 (centre), 1951-2000 (bot-
87 tom). The violet lines indicate the median values. The colorbar represents the frequency of
88 joint d, θ observations in number of days. 18

89 **Fig. 10.** Bivariate histograms of (d, θ) for the 20CR (left), the model MPI-ESM-LR (centre) and
90 their difference Δ (right) for three periods: 1851-1900 (top), 1901-1950 (centre), 1951-2000
91 (bottom). The violet lines indicate the median values. The colorbar represents the frequency
92 of joint d, θ observations in number of days. 19

93 **Fig. 11.** Bivariate histograms of (d, θ) for the 20CR (left), the model CSIRO-MK3-6-0 (centre) and
94 their difference Δ (right) for three periods: 1851-1900 (top), 1901-1950 (centre), 1951-2000
95 (bottom). The violet lines indicate the median values. The colorbar represents the frequency
96 of joint d, θ observations in number of days. 20

97 **Fig. 12.** Bivariate histograms of (d, θ) for the 20CR (left), the model CMCC-CMS (centre) and their
98 difference Δ (right) for three periods: 1851-1900 (top), 1901-1950 (centre), 1951-2000 (bot-
99 tom). The violet lines indicate the median values. The colorbar represents the frequency of
100 joint d, θ observations in number of days. 21

101 **Fig. 13.** Bivariate histograms of (d, θ) for the 20CR (left), the model MPI-ESM-MR (centre) and
102 their difference Δ (right) for three periods: 1851-1900 (top), 1901-1950 (centre), 1951-2000
103 (bottom). The violet lines indicate the median values. The colorbar represents the frequency
104 of joint d, θ observations in number of days. 22

105 **Fig. 14.** Bivariate histograms of (d, θ) for the 20CR (left), the model IPSL-CM5A (centre) and their
106 difference Δ (right) for three periods: 1851-1900 (top), 1901-1950 (centre), 1951-2000 (bot-
107 tom). The violet lines indicate the median values. The colorbar represents the frequency of
108 joint d, θ observations in number of days. 23

109 **Fig. 15.** Bivariate histograms of (d, θ) for the 20CR (left), the model INM-CM4 (centre) and their
110 difference Δ (right) for three periods: 1851-1900 (top), 1901-1950 (centre), 1951-2000 (bot-
111 tom). The violet lines indicate the median values. The colorbar represents the frequency of
112 joint d, θ observations in number of days. 24

113 **Fig. 16.** Bivariate histograms of (d, θ) for the 20CR (left), the model ACCESS-1-0 (centre) and
114 their difference Δ (right) for three periods: 1851-1900 (top), 1901-1950 (centre), 1951-2000
115 (bottom). The violet lines indicate the median values. The colorbar represents the frequency
116 of joint d, θ observations in number of days. 25

117 **Fig. 17.** Bivariate histograms of (d, θ) for the 20CR (left), the model MIROC5 (centre) and their
118 difference Δ (right) for three periods: 1851-1900 (top), 1901-1950 (centre), 1951-2000 (bot-
119 tom). The violet lines indicate the median values. The colorbar represents the frequency of
120 joint d, θ observations in number of days. 26

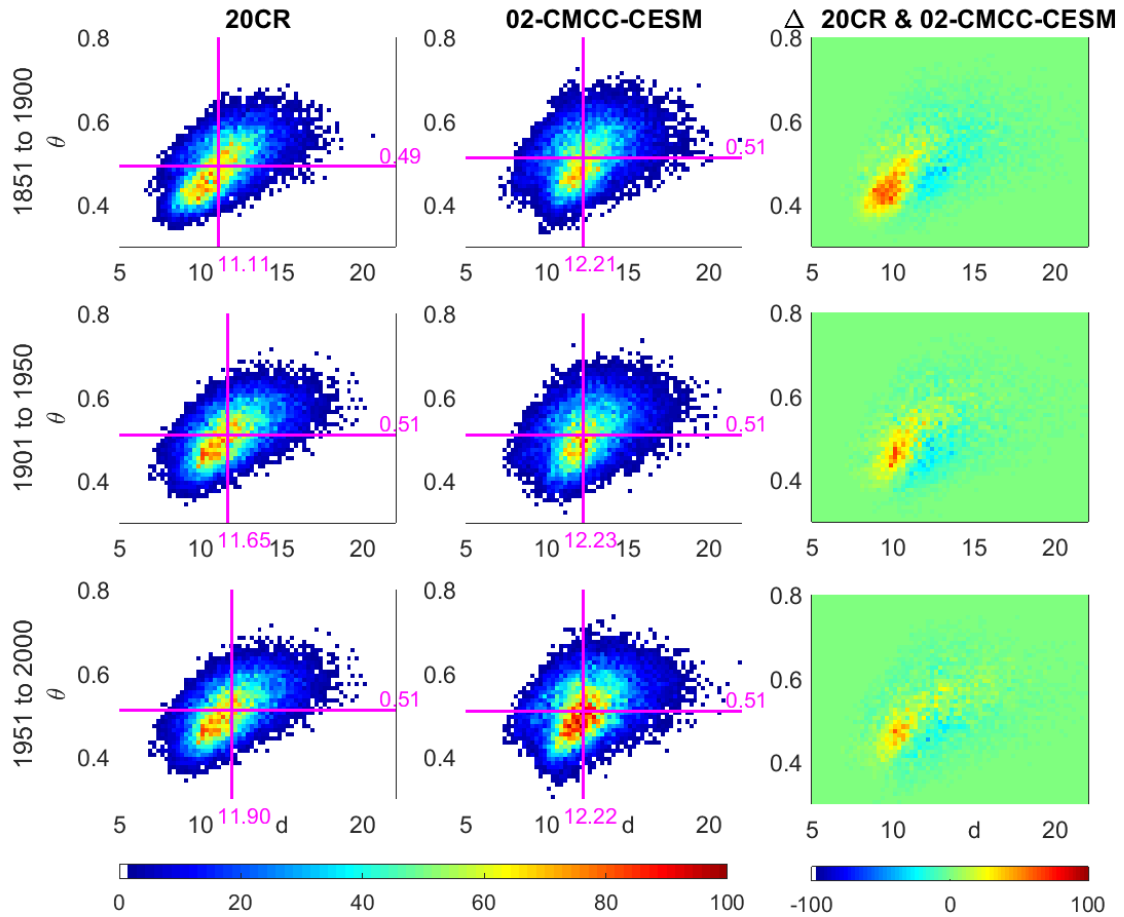
121 **Fig. 18.** Bivariate histograms of (d, θ) for the 20CR (left), the model CNRM-CM5 (centre) and their
122 difference Δ (right) for three periods: 1851-1900 (top), 1901-1950 (centre), 1951-2000 (bot-
123 tom). The violet lines indicate the median values. The colorbar represents the frequency of
124 joint d, θ observations in number of days. 27

125 **Fig. 19.** Bivariate histograms of (d, θ) for the 20CR (left), the model MRI-ESM1 (centre) and their
126 difference Δ (right) for three periods: 1851-1900 (top), 1901-1950 (centre), 1951-2000 (bot-
127 tom). The violet lines indicate the median values. The colorbar represents the frequency of
128 joint d, θ observations in number of days. 28

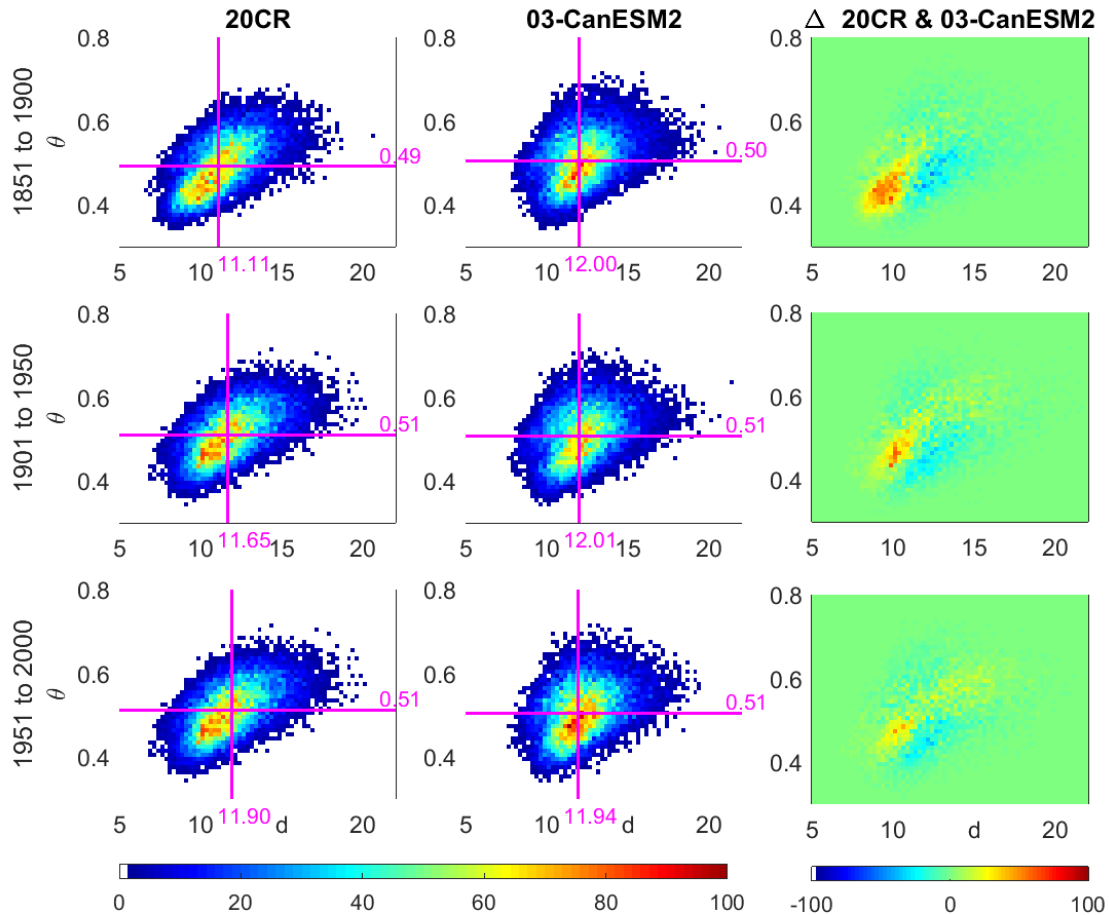
129 **Fig. 20.** Bivariate histograms of (d, θ) for the 20CR (left), the model BCC-CSM1-M (centre) and
130 their difference Δ (right) for three periods: 1851-1900 (top), 1901-1950 (centre), 1951-2000
131 (bottom). The violet lines indicate the median values. The colorbar represents the frequency
132 of joint d, θ observations in number of days. 29

133 **Fig. 21.** Bivariate histograms of (d, θ) for the 20CR (left), the model MRI-GCM3 (centre) and their
134 difference Δ (right) for three periods: 1851-1900 (top), 1901-1950 (centre), 1951-2000 (bot-

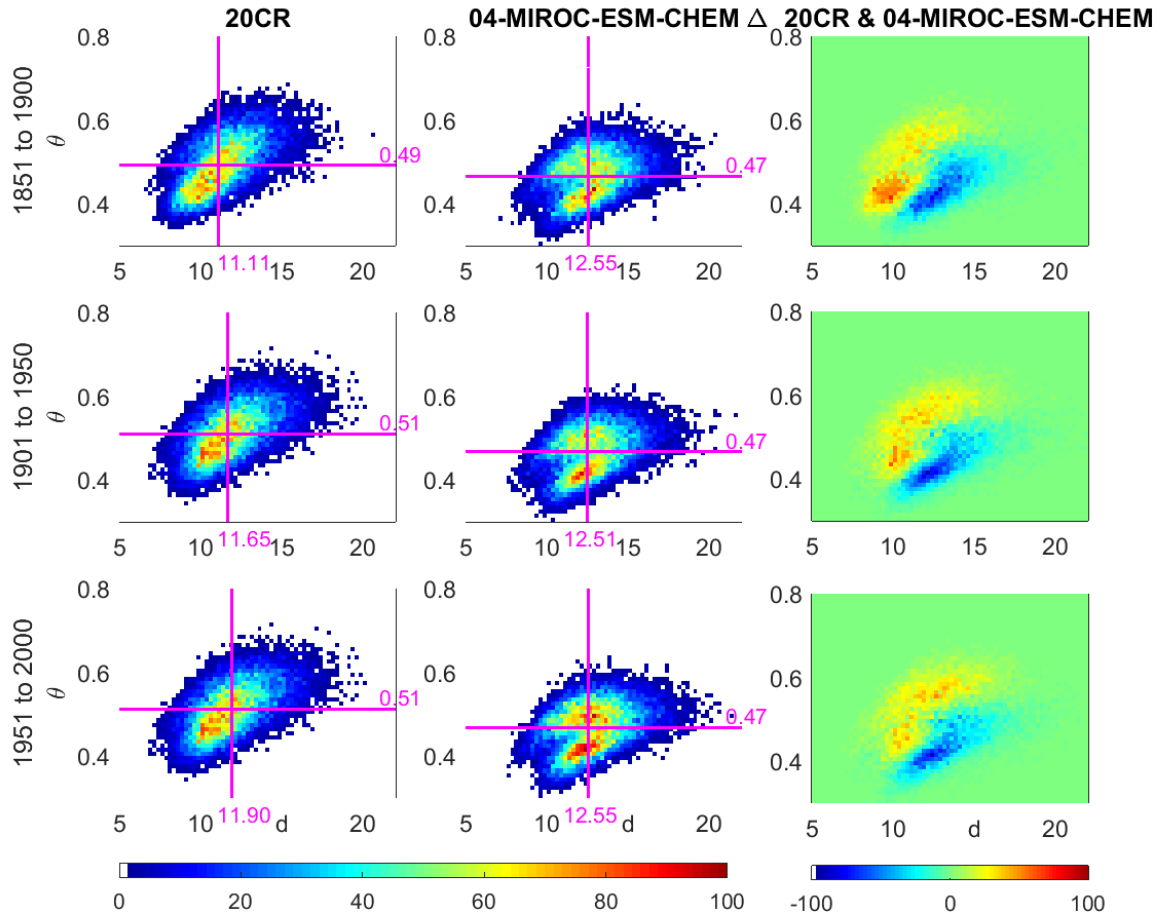
135	tom). The violet lines indicate the median values. The colorbar represents the frequency of	
136	joint d, θ observations in number of days.	30
137	Fig. 22. Bivariate histograms of (d, θ) for the 20CR (left), the model EC-EARTH (centre) and their	
138	difference Δ (right) for three periods: 1851-1900 (top), 1901-1950 (centre), 1951-2000 (bot-	
139	tom). The violet lines indicate the median values. The colorbar represents the frequency of	
140	joint d, θ observations in number of days.	31
141	Fig. 23. Bivariate histograms of (d, θ) for the 20CR (left), the model CESM1-FAST (centre) and	
142	their difference Δ (right) for three periods: 1851-1900 (top), 1901-1950 (centre), 1951-2000	
143	(bottom). The violet lines indicate the median values. The colorbar represents the frequency	
144	of joint d, θ observations in number of days.	32
145	Fig. 24. Bivariate histograms of (d, θ) for the 20CR (left), the model CESM1-CAM5 (centre) and	
146	their difference Δ (right) for three periods: 1851-1900 (top), 1901-1950 (centre), 1951-2000	
147	(bottom). The violet lines indicate the median values. The colorbar represents the frequency	
148	of joint d, θ observations in number of days.	33
149	Fig. 25. Bivariate histograms of (d, θ) for the 20CR (left), the model CESM1-BGC (centre) and	
150	their difference Δ (right) for three periods: 1851-1900 (top), 1901-1950 (centre), 1951-2000	
151	(bottom). The violet lines indicate the median values. The colorbar represents the frequency	
152	of joint d, θ observations in number of days.	34
153	Fig. 26. Bivariate histograms of (d, θ) for the 20CR (left), the model CCSM4 (centre) and their dif-	
154	ference Δ (right) for three periods: 1851-1900 (top), 1901-1950 (centre), 1951-2000 (bot-	
155	tom). The violet lines indicate the median values. The colorbar represents the frequency of	
156	joint d, θ observations in number of days.	35



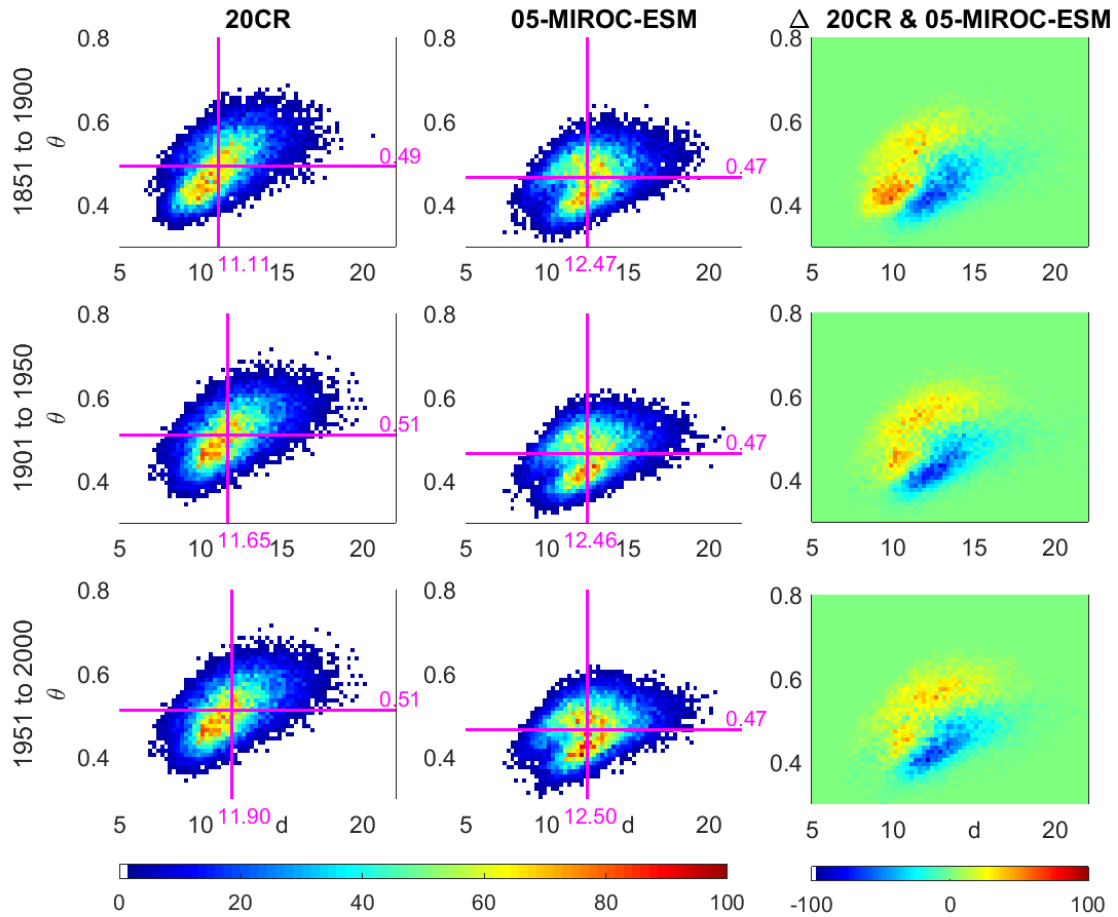
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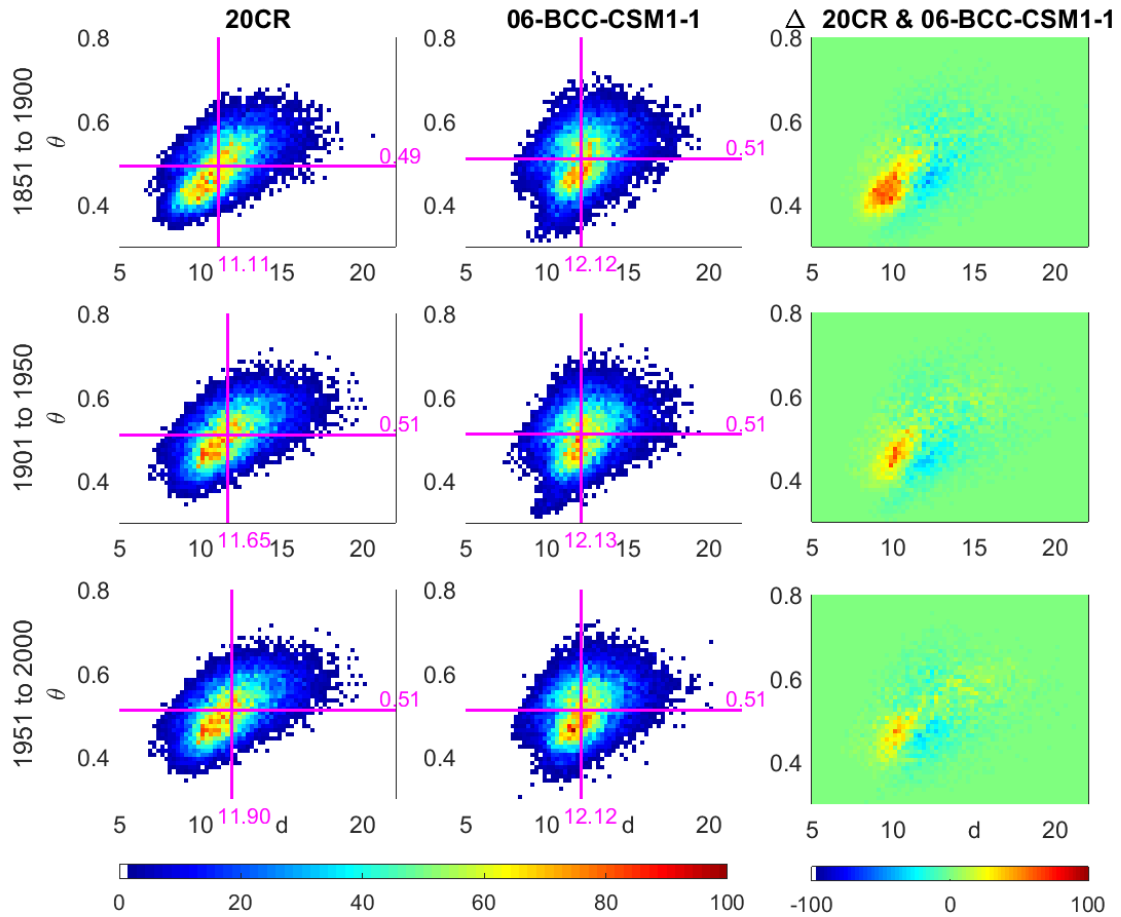
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 161 Δ (right) for three periods: 1851-1900 (top), 1901-1950 (centre), 1951-2000 (bottom). The violet lines indicate
 162 the median values. The colorbar represents the frequency of joint d, θ observations in number of days.



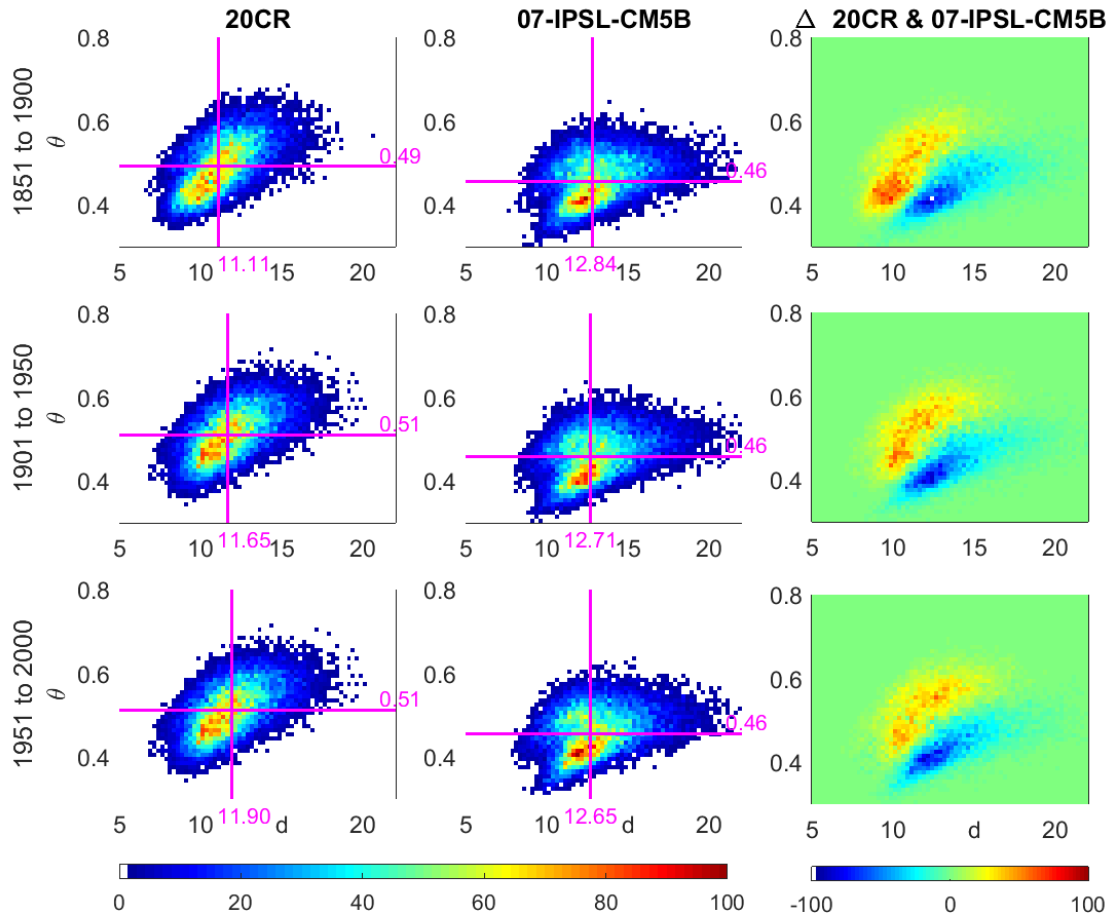
163 FIG. 3. Bivariate histograms of (d, θ) for the 20CR (left), the model MIROC-ESM-CHEM (centre) and their
 164 difference Δ (right) for three periods: 1851-1900 (top), 1901-1950 (centre), 1951-2000 (bottom). The violet
 165 lines indicate the median values. The colorbar represents the frequency of joint d, θ observations in number of
 166 days.



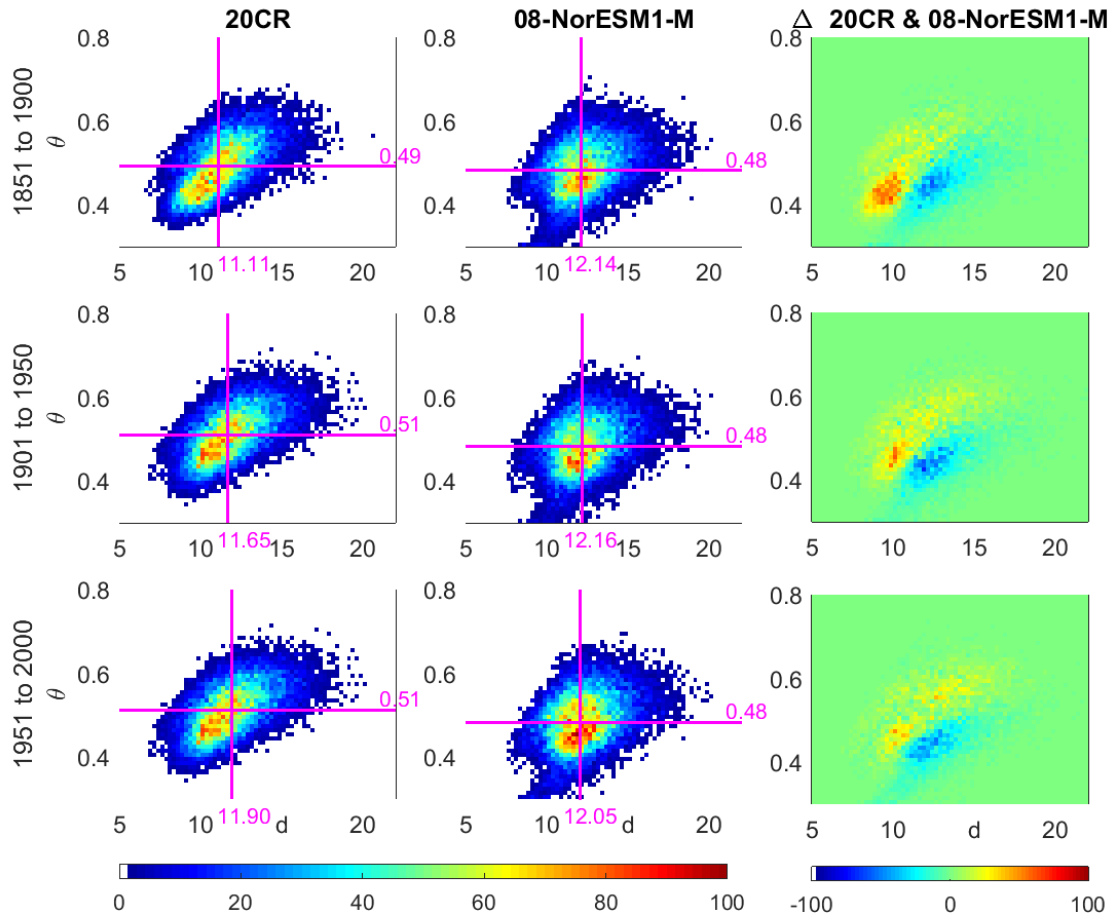
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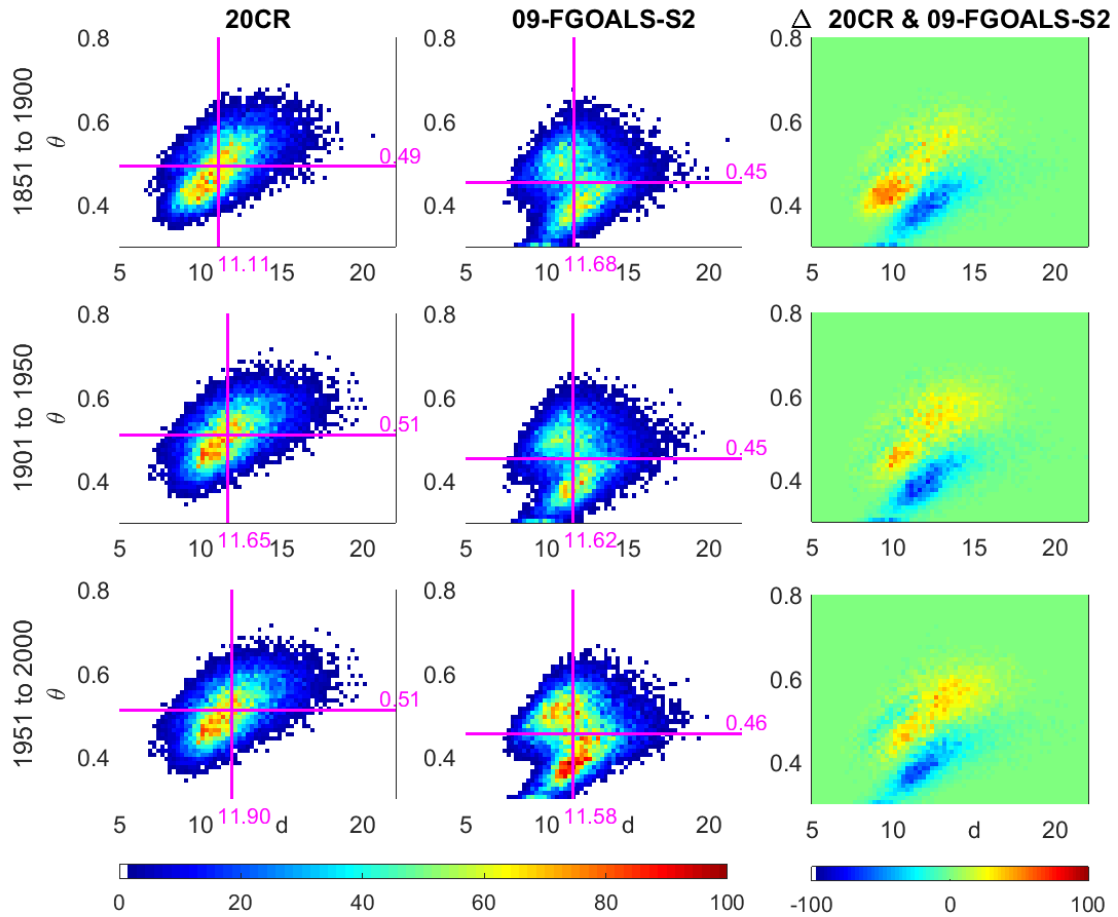
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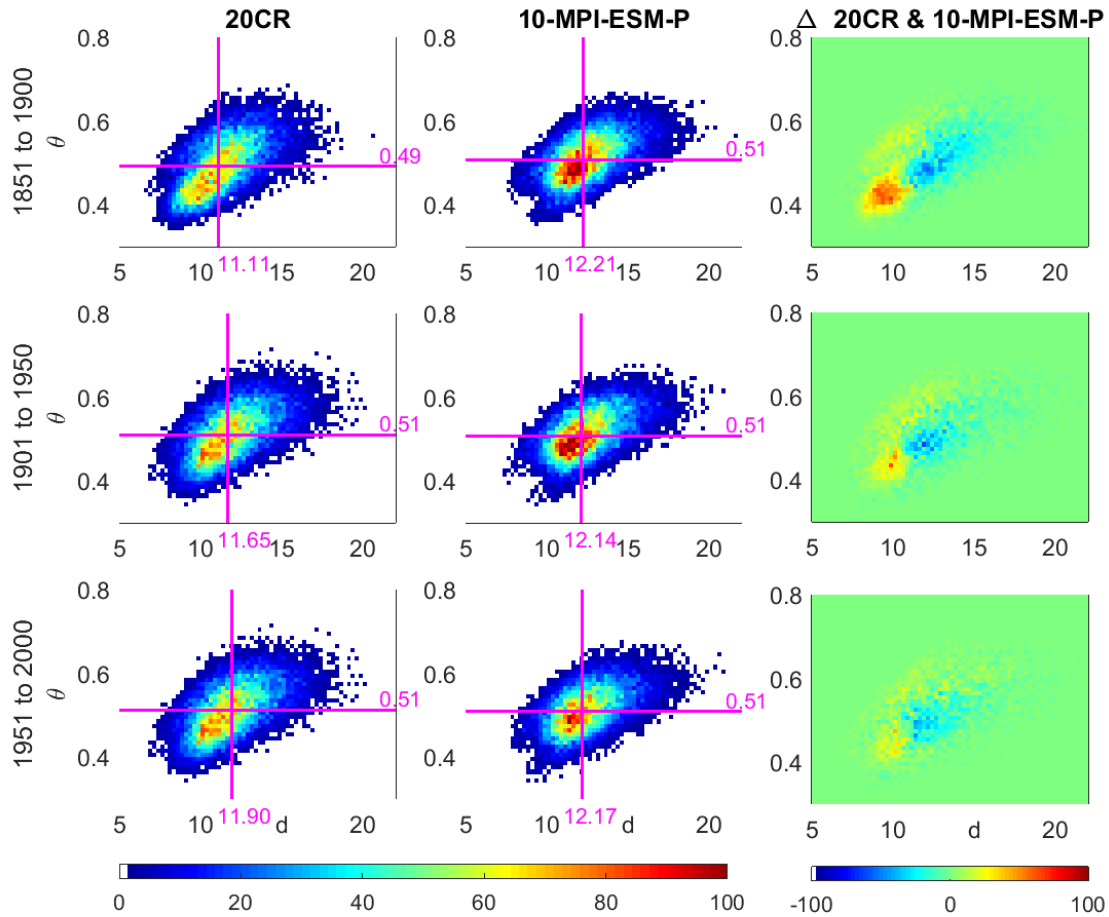
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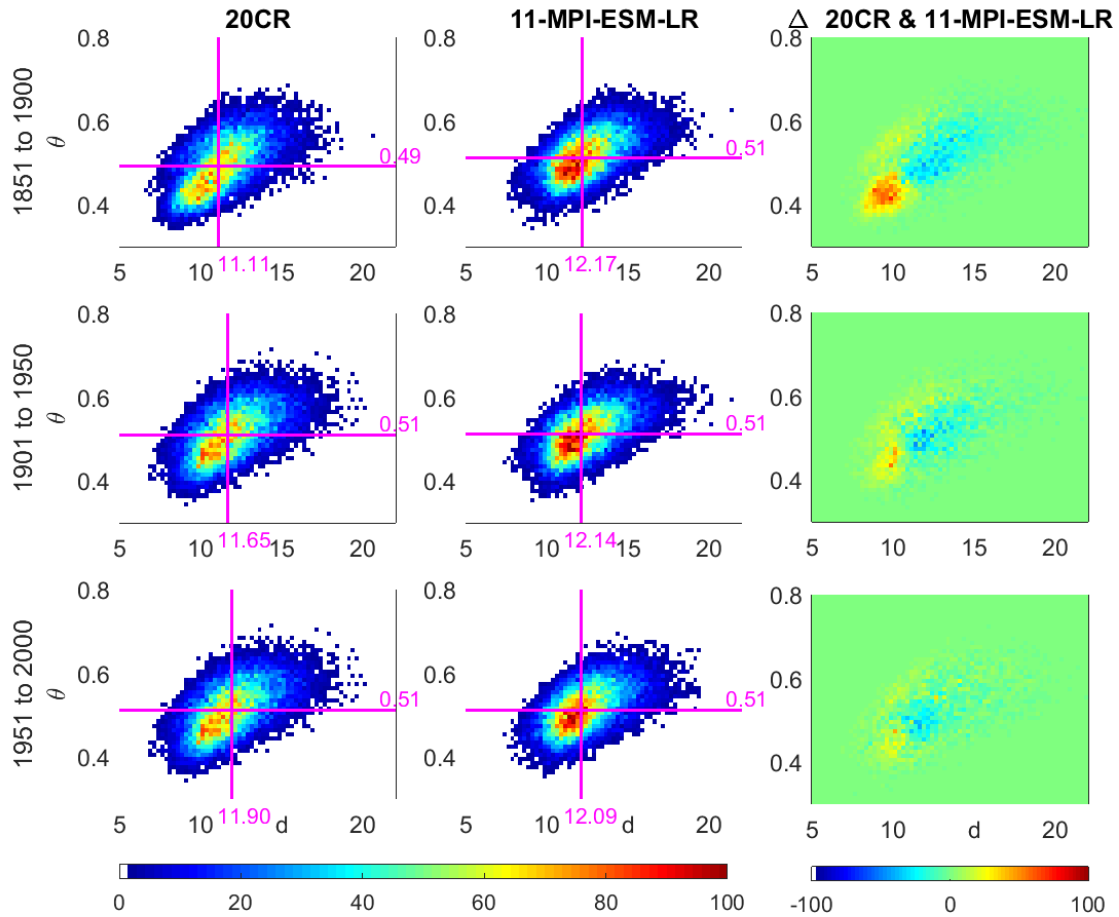
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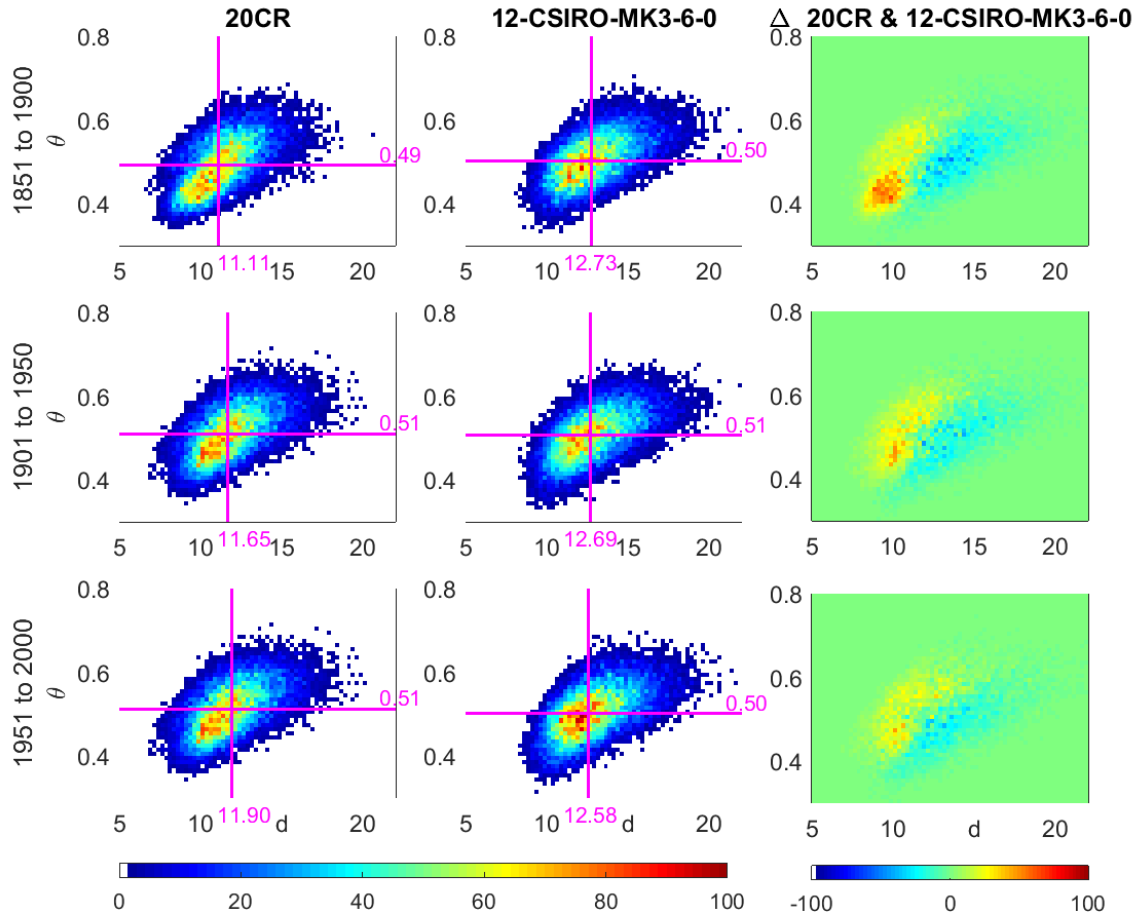
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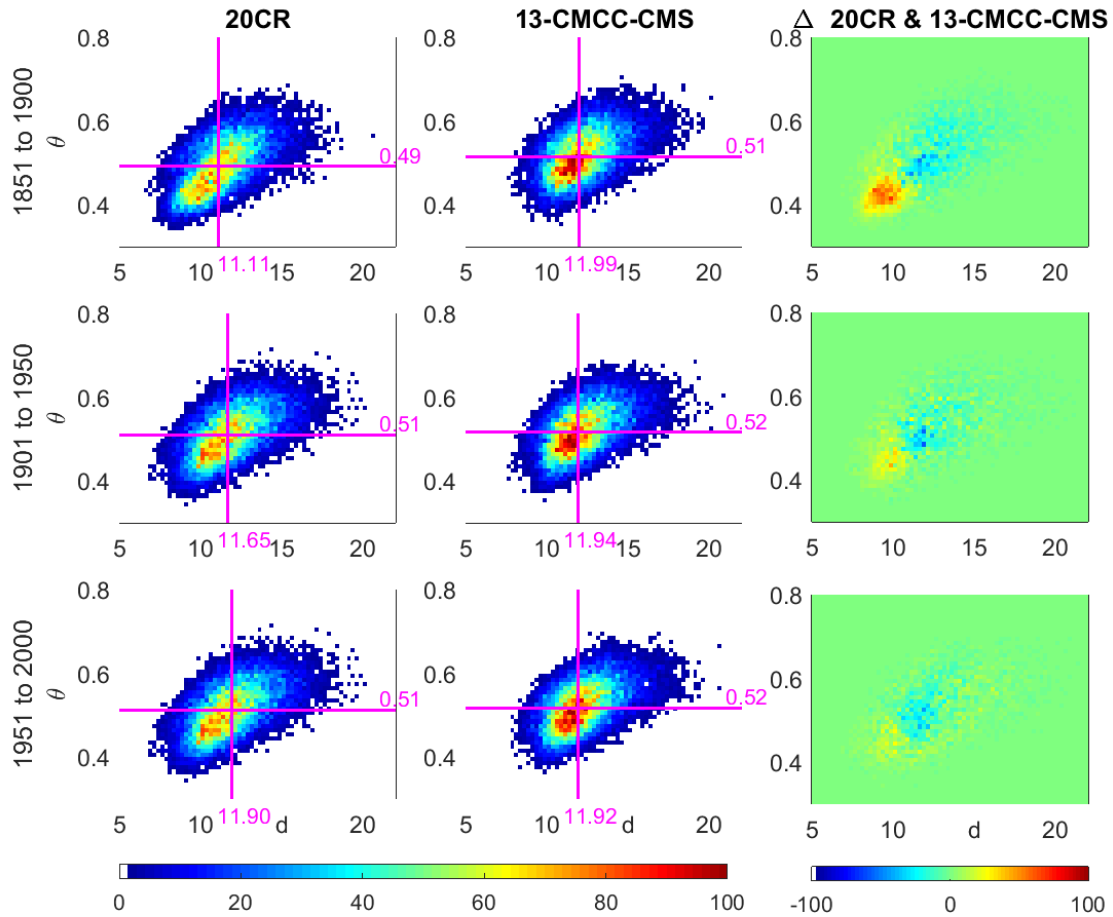
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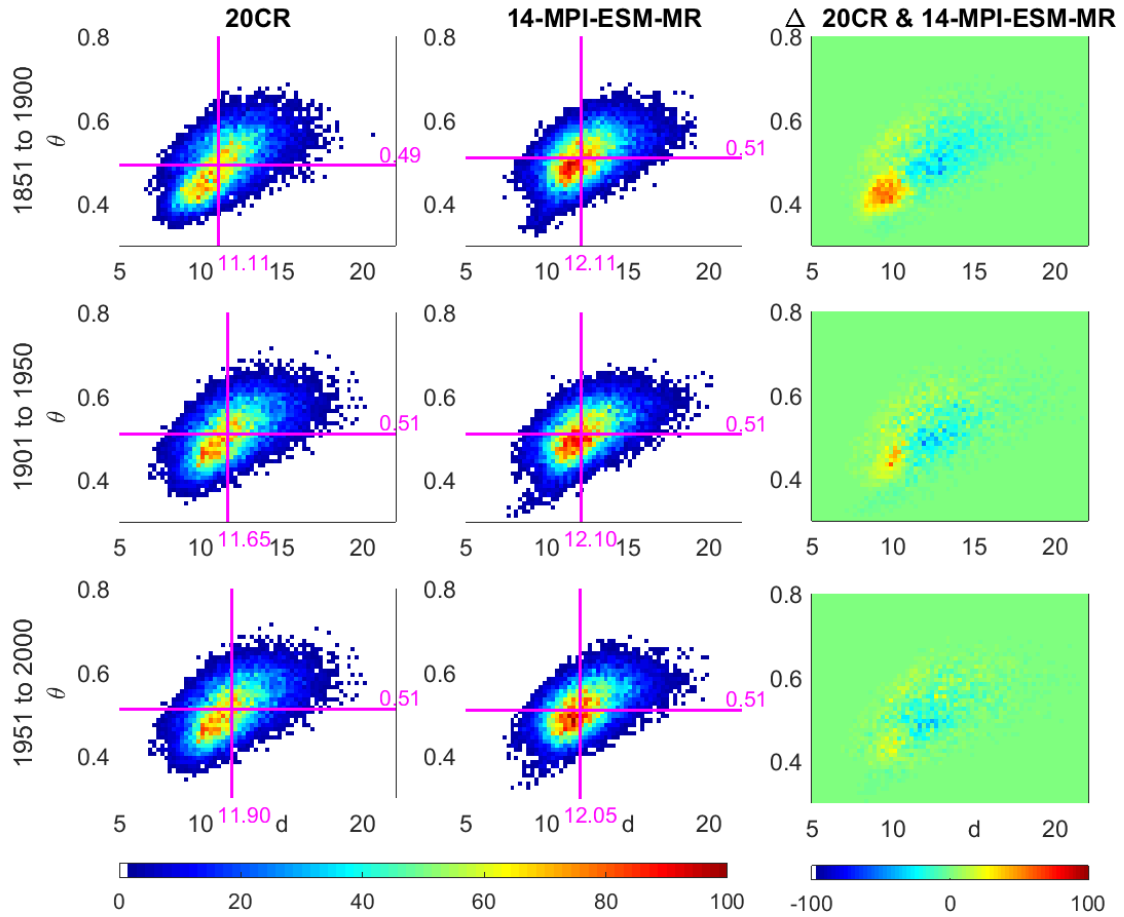
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 186 ference Δ (right) for three periods: 1851-1900 (top), 1901-1950 (centre), 1951-2000 (bottom). The violet lines
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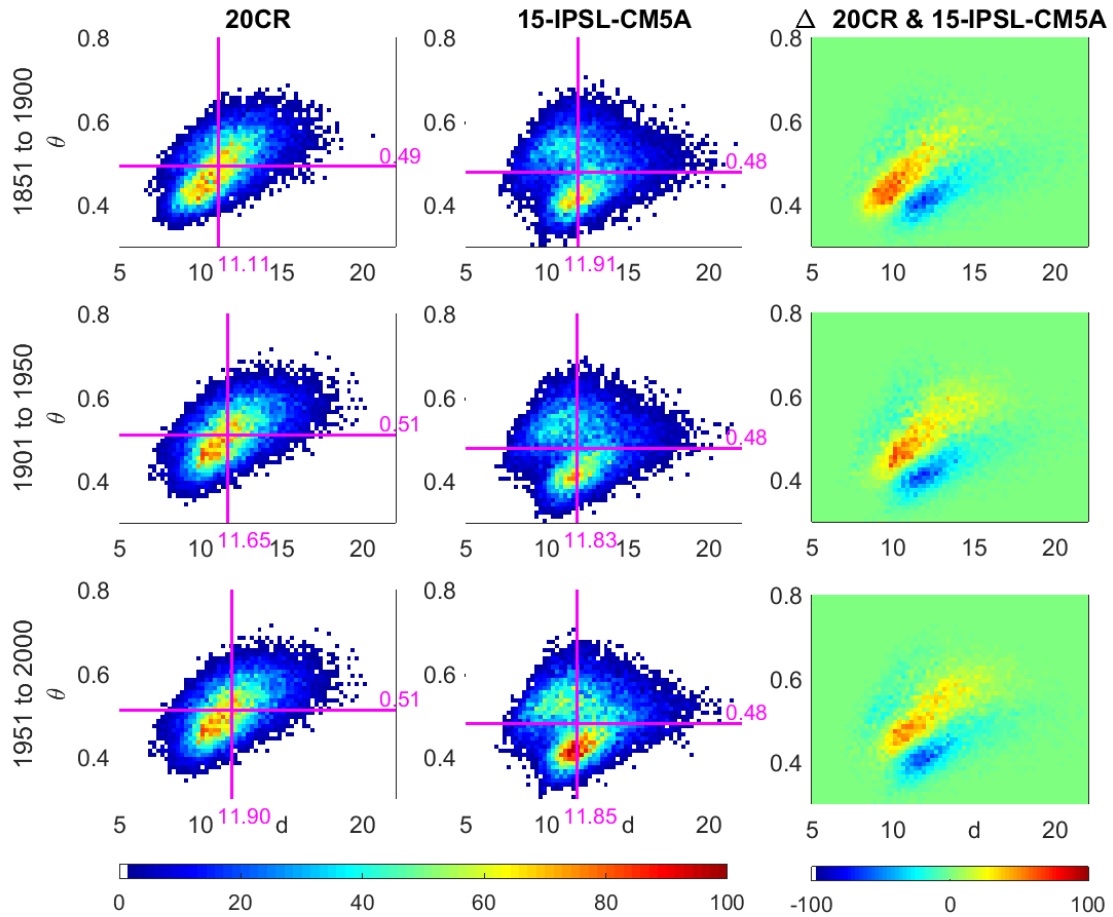
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 190 lines indicate the median values. The colorbar represents the frequency of joint d, θ observations in number of
 191 days.



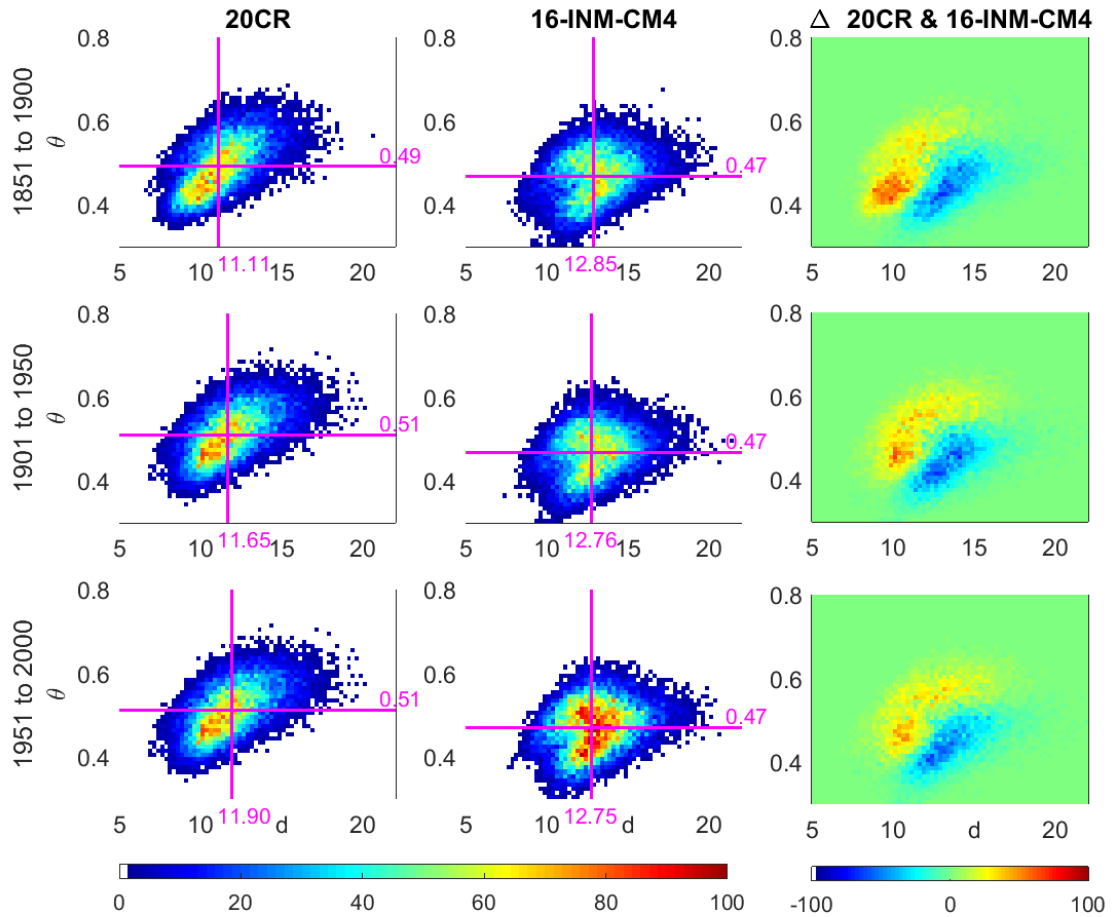
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 193 ference Δ (right) for three periods: 1851-1900 (top), 1901-1950 (centre), 1951-2000 (bottom). The violet lines
 194 indicate the median values. The colorbar represents the frequency of joint d, θ observations in number of days.



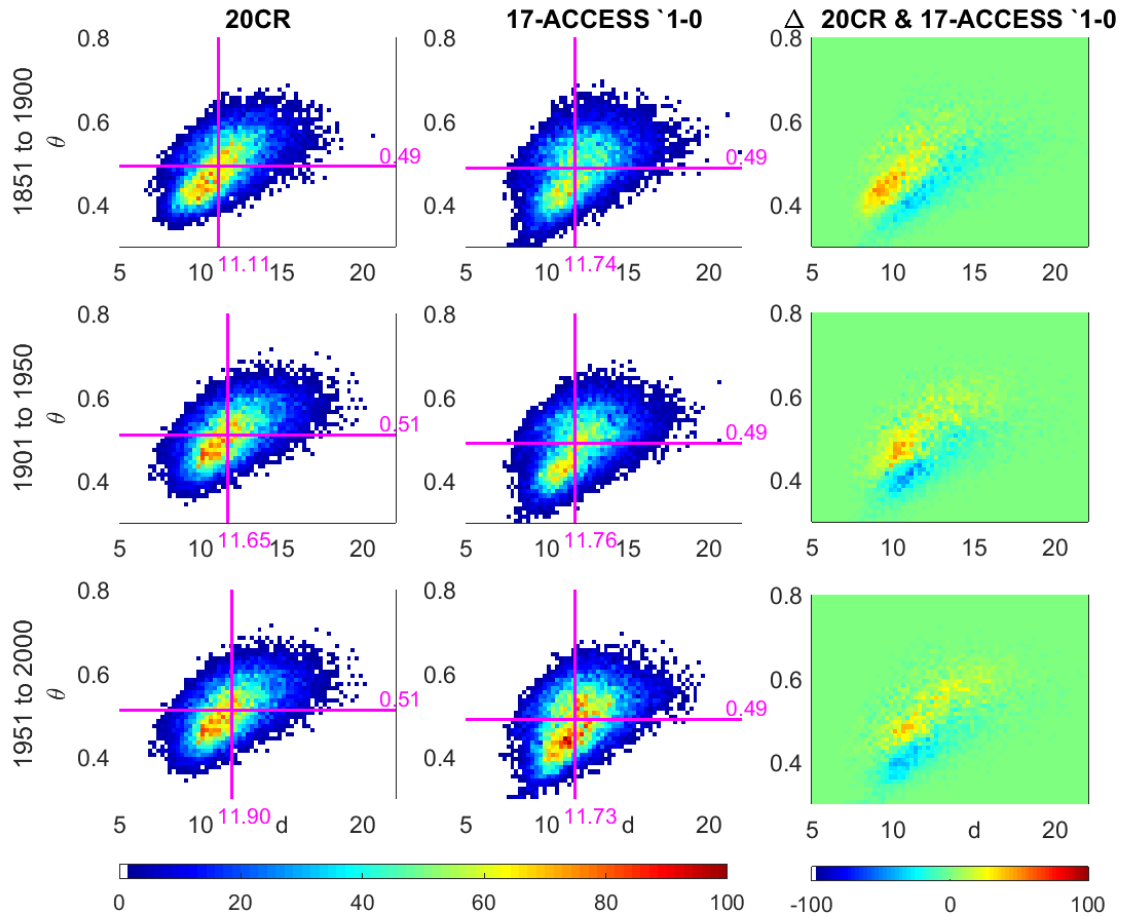
195 FIG. 13. Bivariate histograms of (d, θ) for the 20CR (left), the model MPI-ESM-MR (centre) and their
 196 difference Δ (right) for three periods: 1851-1900 (top), 1901-1950 (centre), 1951-2000 (bottom). The violet
 197 lines indicate the median values. The colorbar represents the frequency of joint d, θ observations in number of
 198 days.



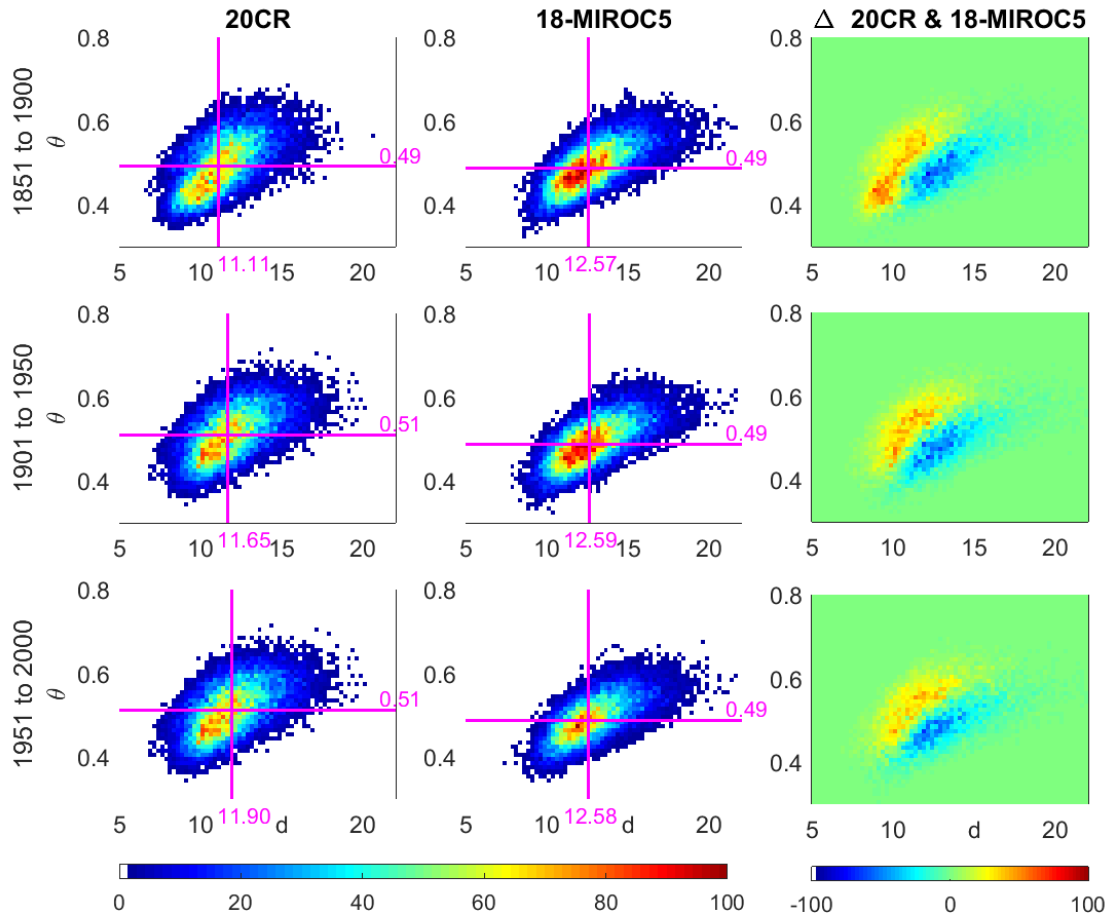
199 FIG. 14. Bivariate histograms of (d, θ) for the 20CR (left), the model IPSL-CM5A (centre) and their differ-
 200 ence Δ (right) for three periods: 1851-1900 (top), 1901-1950 (centre), 1951-2000 (bottom). The violet lines
 201 indicate the median values. The colorbar represents the frequency of joint d, θ observations in number of days.



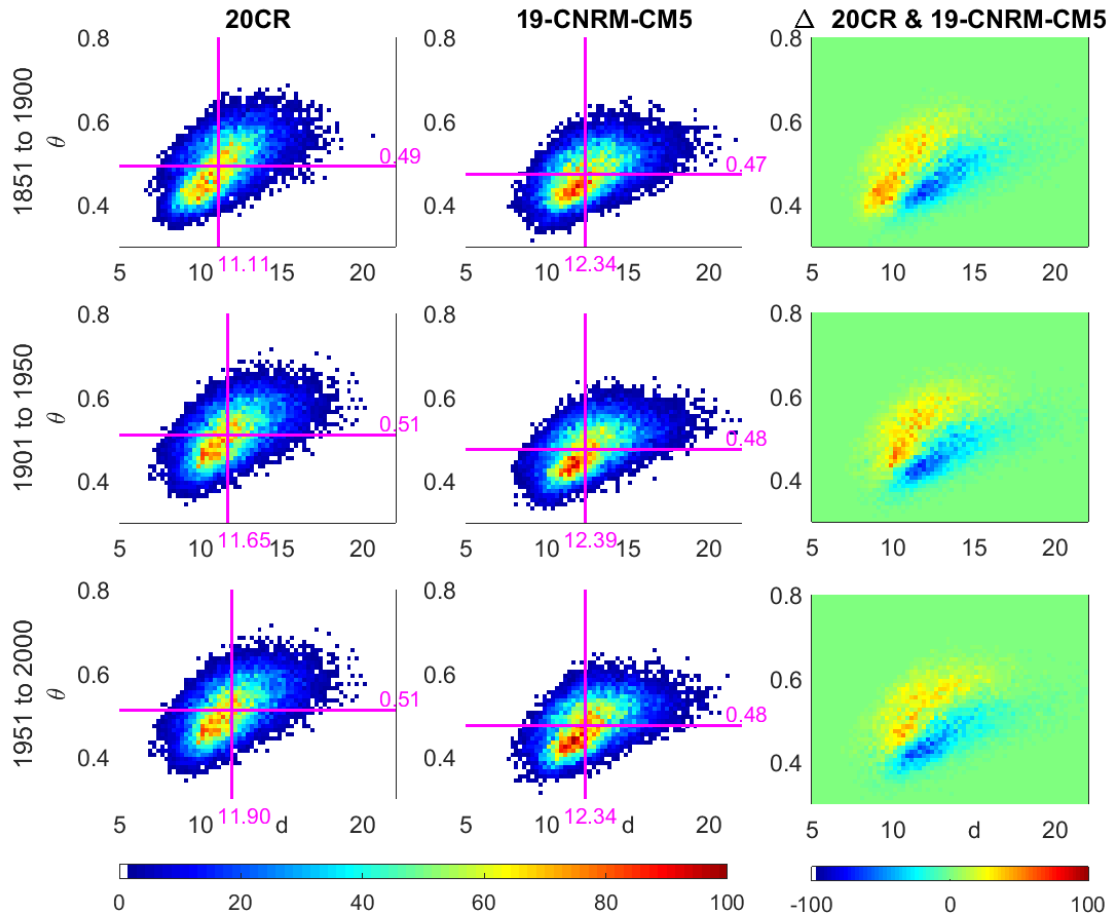
202 FIG. 15. Bivariate histograms of (d, θ) for the 20CR (left), the model INM-CM4 (centre) and their difference
 203 Δ (right) for three periods: 1851-1900 (top), 1901-1950 (centre), 1951-2000 (bottom). The violet lines indicate
 204 the median values. The colorbar represents the frequency of joint d, θ observations in number of days.



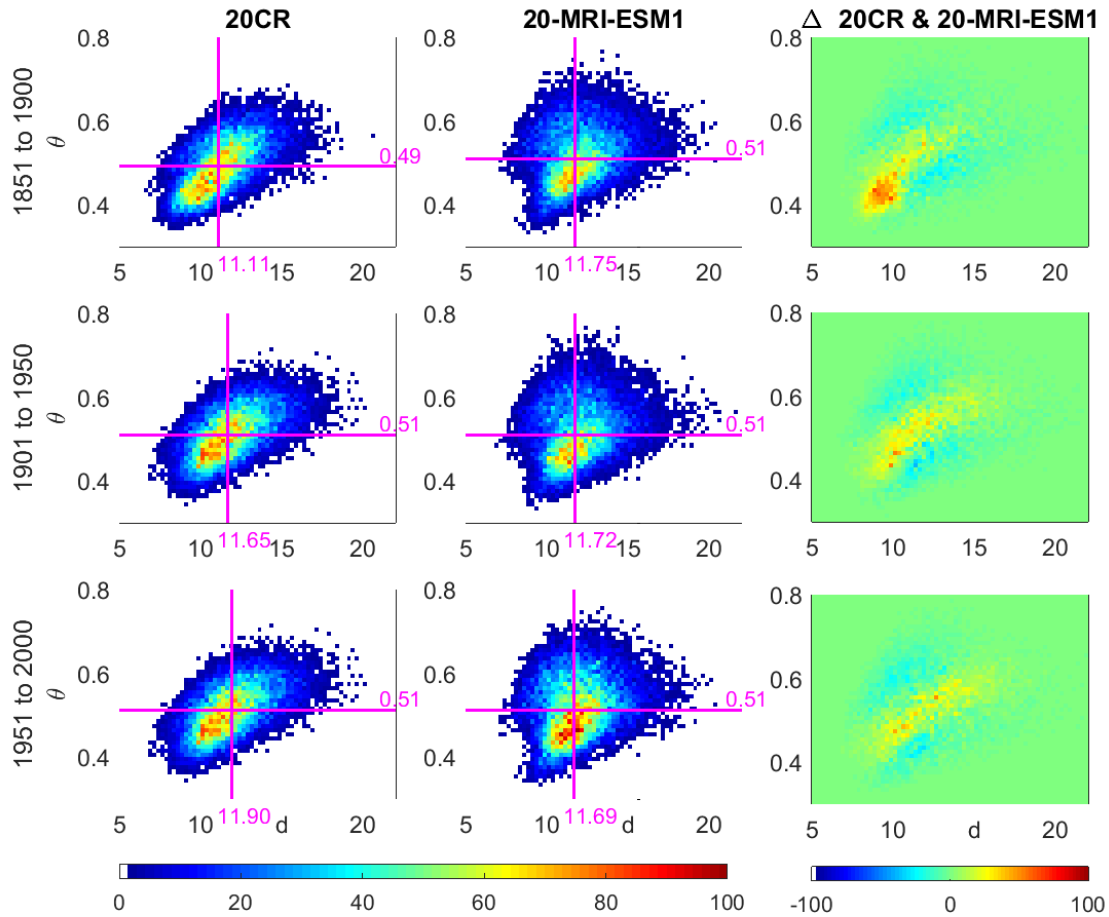
205 FIG. 16. Bivariate histograms of (d, θ) for the 20CR (left), the model ACCESS-1-0 (centre) and their dif-
 206 ference Δ (right) for three periods: 1851-1900 (top), 1901-1950 (centre), 1951-2000 (bottom). The violet lines
 207 indicate the median values. The colorbar represents the frequency of joint d, θ observations in number of days.



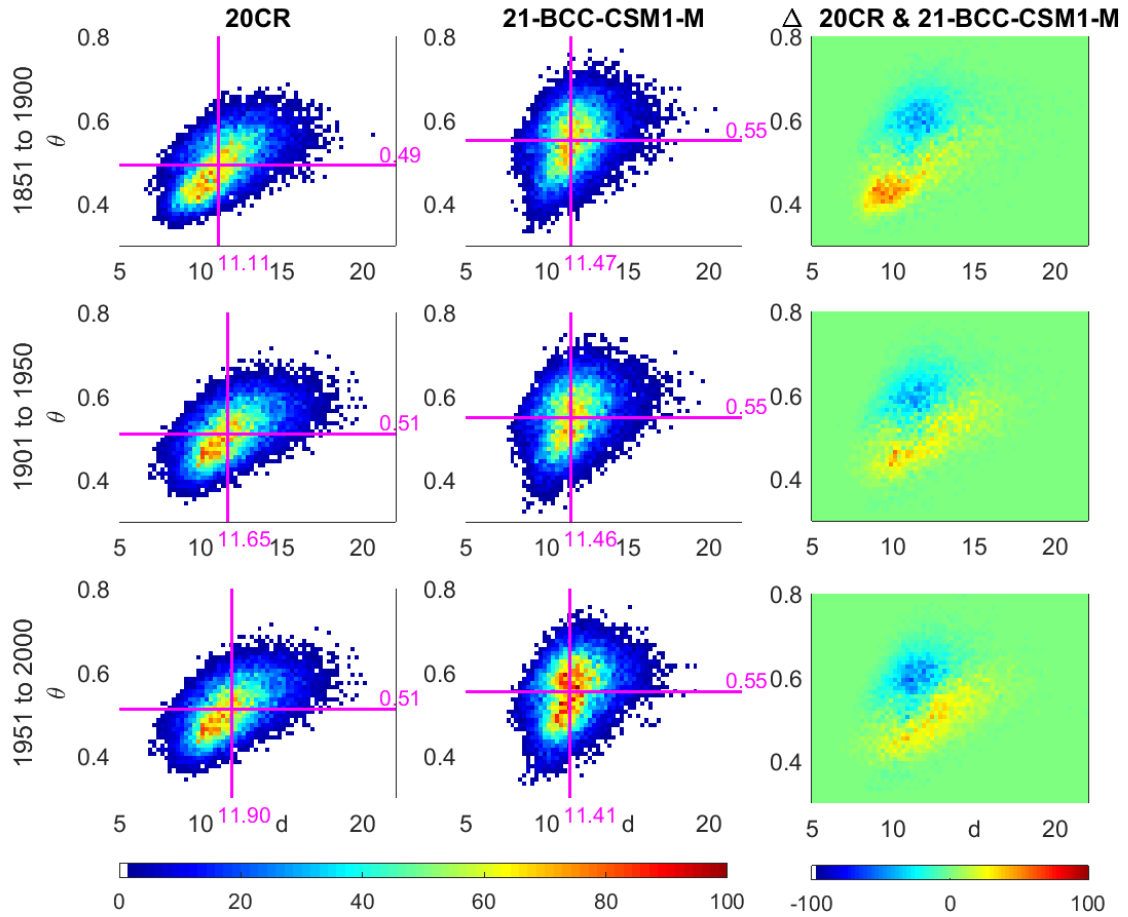
208 FIG. 17. Bivariate histograms of (d, θ) for the 20CR (left), the model MIROC5 (centre) and their difference
 209 Δ (right) for three periods: 1851-1900 (top), 1901-1950 (centre), 1951-2000 (bottom). The violet lines indicate
 210 the median values. The colorbar represents the frequency of joint d, θ observations in number of days.



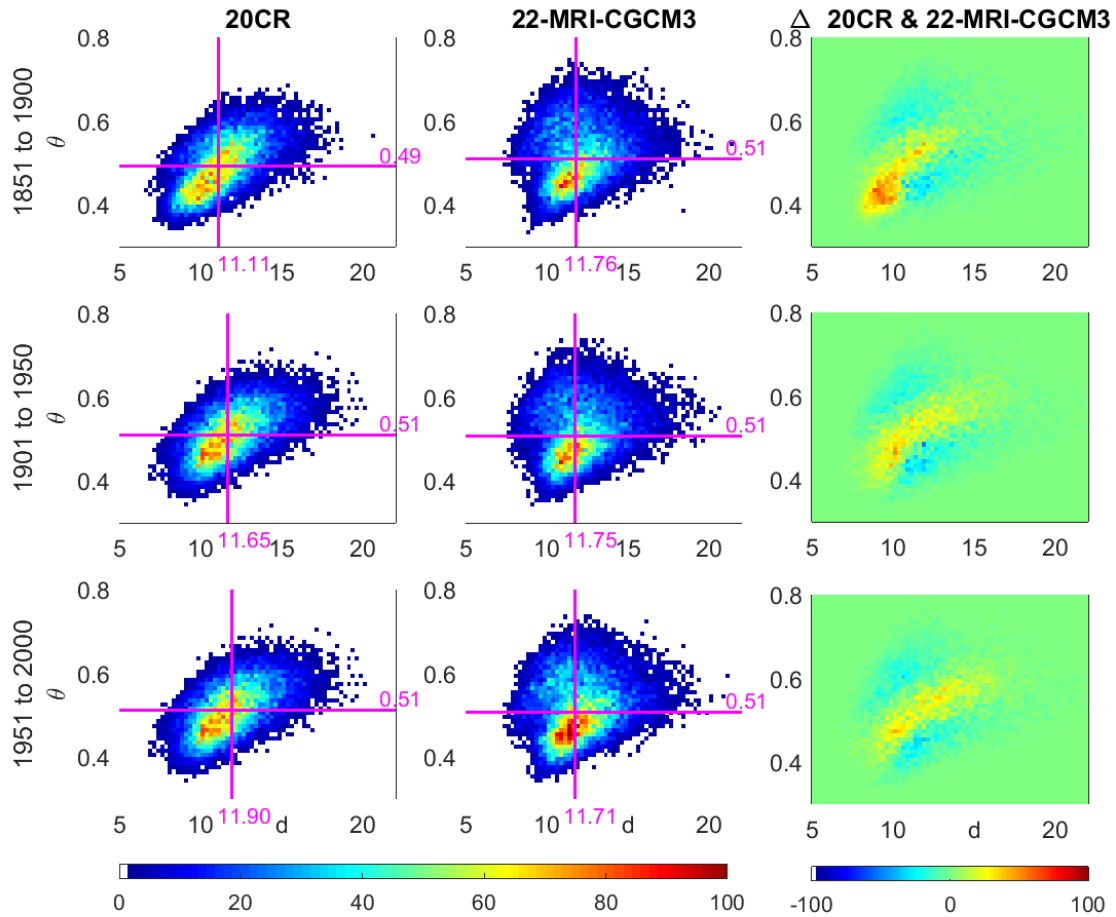
211 FIG. 18. Bivariate histograms of (d, θ) for the 20CR (left), the model CNRM-CM5 (centre) and their dif-
 212 ference Δ (right) for three periods: 1851-1900 (top), 1901-1950 (centre), 1951-2000 (bottom). The violet lines
 213 indicate the median values. The colorbar represents the frequency of joint d, θ observations in number of days.



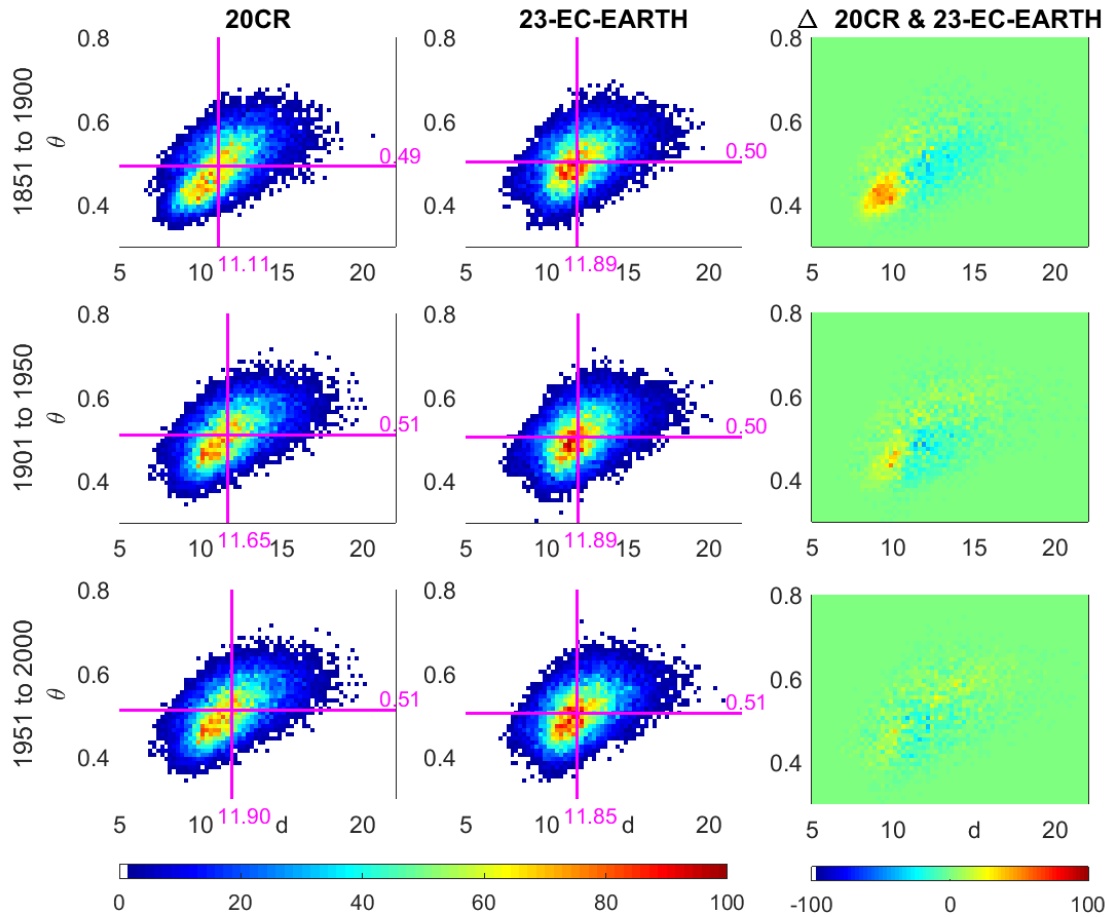
214 FIG. 19. Bivariate histograms of (d, θ) for the 20CR (left), the model MRI-ESM1 (centre) and their difference
 215 Δ (right) for three periods: 1851-1900 (top), 1901-1950 (centre), 1951-2000 (bottom). The violet lines indicate
 216 the median values. The colorbar represents the frequency of joint d, θ observations in number of days.



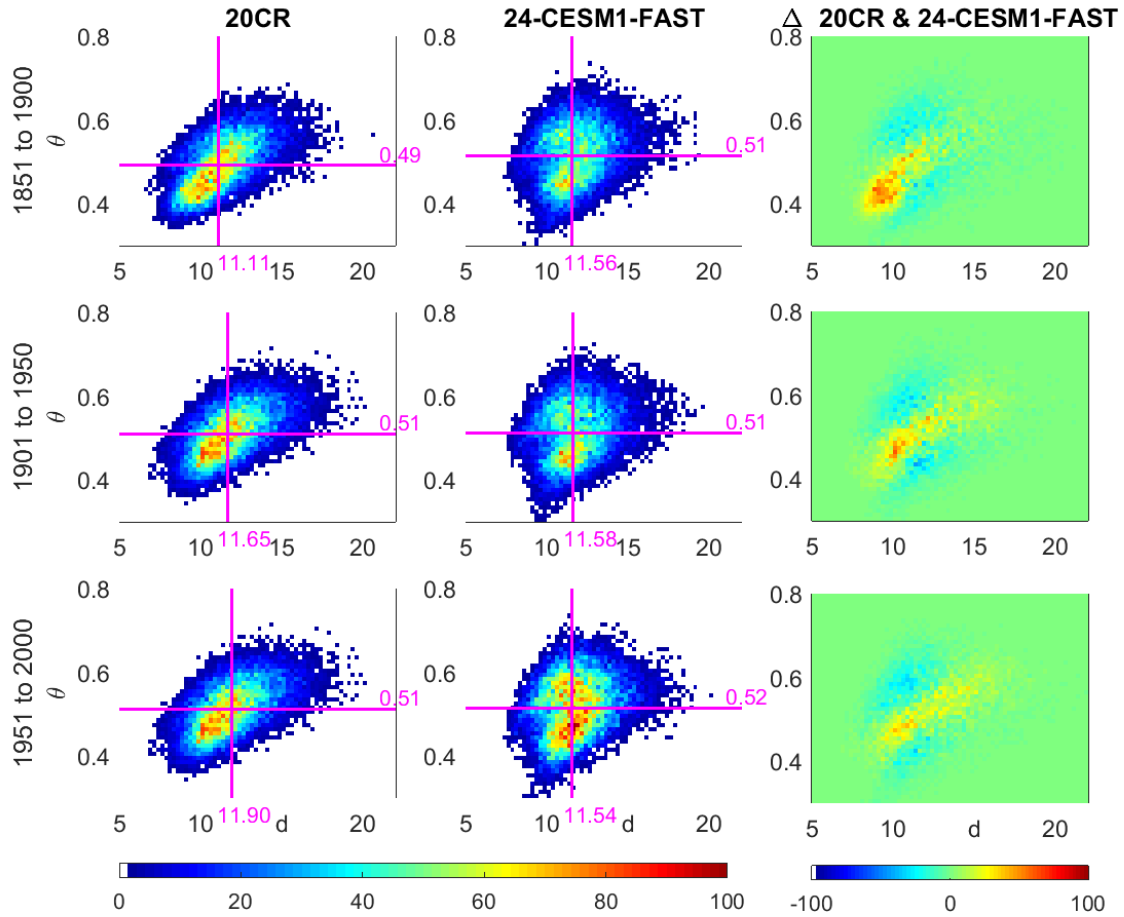
217 FIG. 20. Bivariate histograms of (d, θ) for the 20CR (left), the model BCC-CSM1-M (centre) and their
 218 difference Δ (right) for three periods: 1851-1900 (top), 1901-1950 (centre), 1951-2000 (bottom). The violet
 219 lines indicate the median values. The colorbar represents the frequency of joint d, θ observations in number of
 220 days.



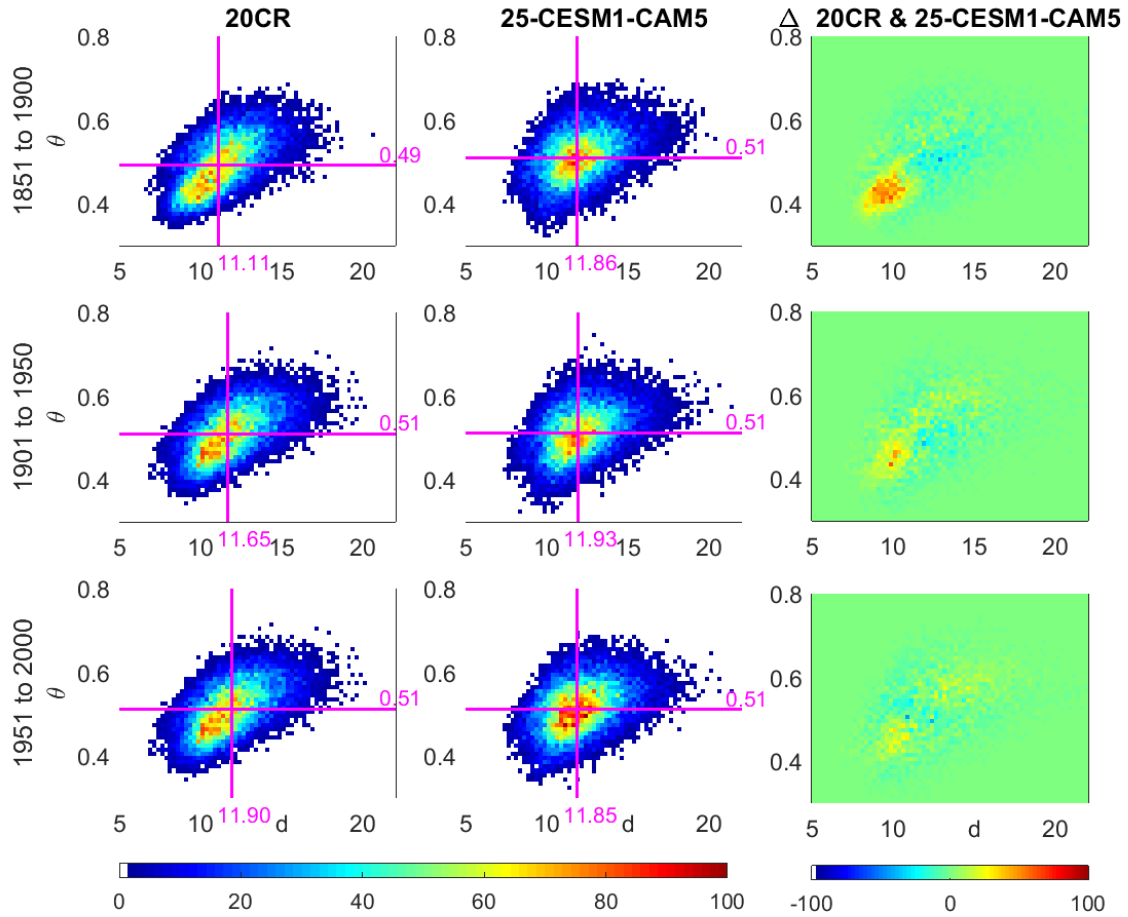
221 FIG. 21. Bivariate histograms of (d, θ) for the 20CR (left), the model MRI-GCM3 (centre) and their difference
 222 Δ (right) for three periods: 1851-1900 (top), 1901-1950 (centre), 1951-2000 (bottom). The violet lines indicate
 223 the median values. The colorbar represents the frequency of joint d, θ observations in number of days.



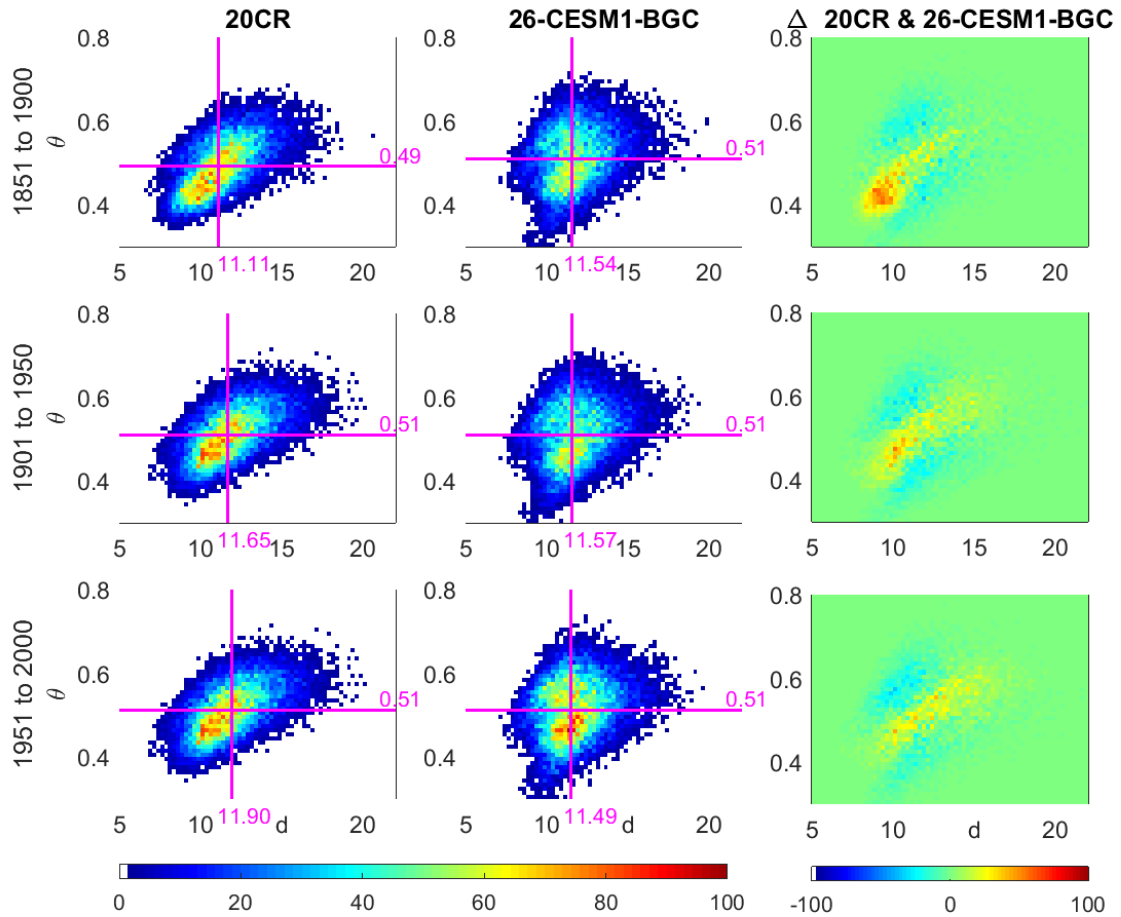
224 FIG. 22. Bivariate histograms of (d, θ) for the 20CR (left), the model EC-EARTH (centre) and their difference
 225 Δ (right) for three periods: 1851-1900 (top), 1901-1950 (centre), 1951-2000 (bottom). The violet lines indicate
 226 the median values. The colorbar represents the frequency of joint d, θ observations in number of days.



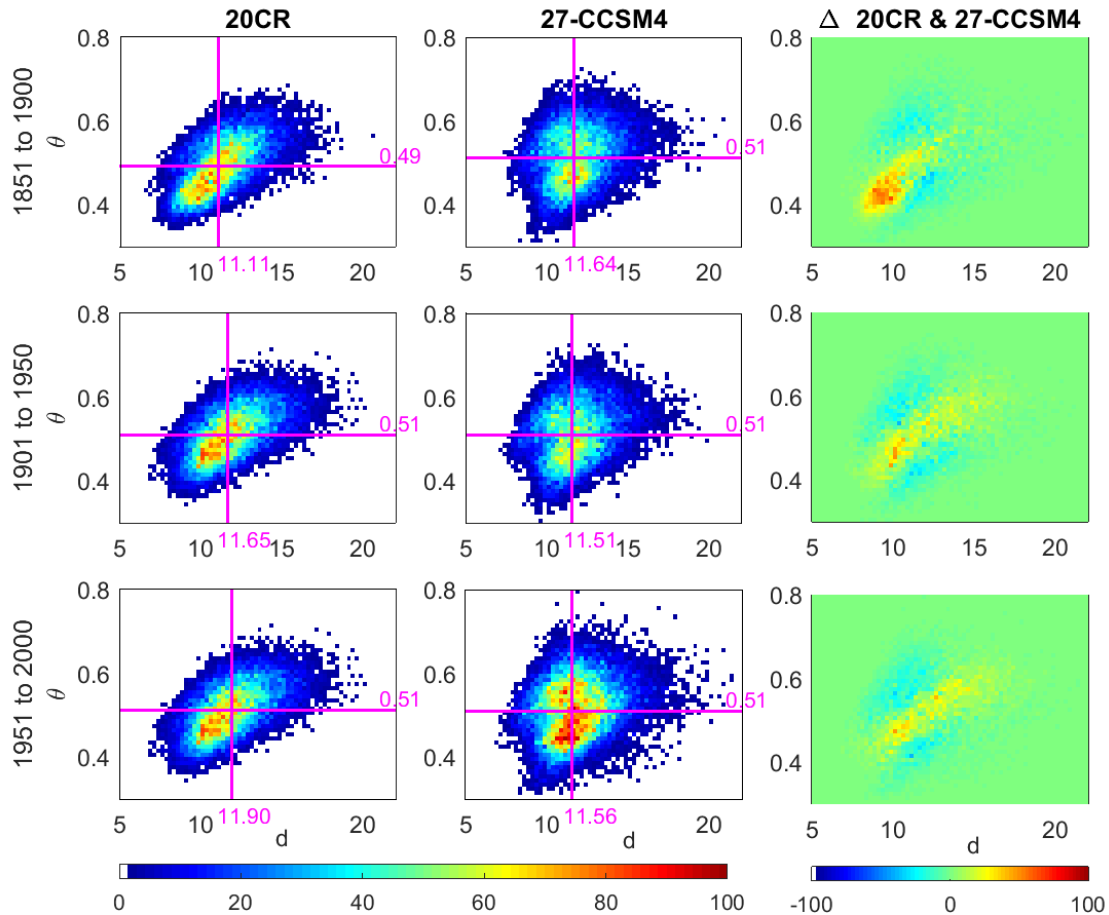
227 FIG. 23. Bivariate histograms of (d, θ) for the 20CR (left), the model CESM1-FAST (centre) and their
 228 difference Δ (right) for three periods: 1851-1900 (top), 1901-1950 (centre), 1951-2000 (bottom). The violet
 229 lines indicate the median values. The colorbar represents the frequency of joint d, θ observations in number of
 230 days.



231 FIG. 24. Bivariate histograms of (d, θ) for the 20CR (left), the model CESM1-CAM5 (centre) and their
 232 difference Δ (right) for three periods: 1851-1900 (top), 1901-1950 (centre), 1951-2000 (bottom). The violet
 233 lines indicate the median values. The colorbar represents the frequency of joint d, θ observations in number of
 234 days.



235 FIG. 25. Bivariate histograms of (d, θ) for the 20CR (left), the model CESM1-BGC (centre) and their dif-
 236 ference Δ (right) for three periods: 1851-1900 (top), 1901-1950 (centre), 1951-2000 (bottom). The violet lines
 237 indicate the median values. The colorbar represents the frequency of joint d, θ observations in number of days.



238 FIG. 26. Bivariate histograms of (d, θ) for the 20CR (left), the model CCSM4 (centre) and their difference
 239 Δ (right) for three periods: 1851-1900 (top), 1901-1950 (centre), 1951-2000 (bottom). The violet lines indicate
 240 the median values. The colorbar represents the frequency of joint d, θ observations in number of days.