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Mapping (dis)agreement in hydrologic projections

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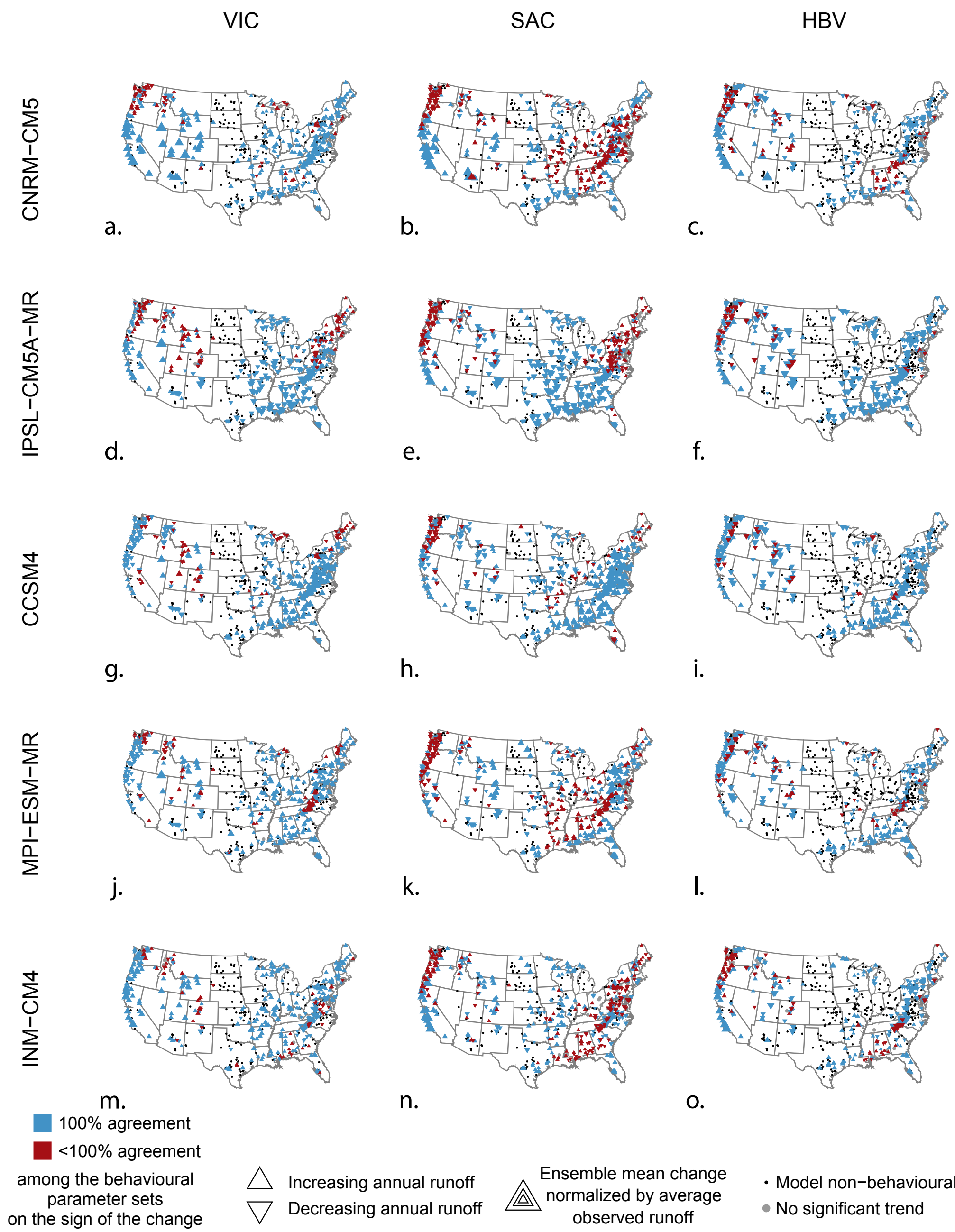

Figure A1. The agreement among the different model runs (representing different behavioural parameter sets) on the sign of the ensemble mean change in mean annual runoff for three hydrologic models (columns, VIC = Variable Infiltration Capacity Model, SAC = Sacramento Soil Moisture Accounting Model, HBV = Hydrologiska Byråns Vattenbalansavdelning Model) forced with five different climate models (rows). The direction of the triangle-marker shows the sign of the ensemble mean change, the size of the marker indicates the relative projected change. a) VIC forced with CNRM-CM5. b) SAC forced with CNRM-CM5. c) HBV forced with CNRM-CM5. d) VIC forced with IPSL-CM5A-MR. e) SAC forced with IPSL-CM5A-MR. f) HBV forced with IPSL-CM5A-MR. g) VIC forced with CCSM4. h) SAC forced with CCSM4. i) HBV forced with CCSM4. j) VIC forced with MPI-ESM-MR. k) SAC forced with MPI-ESM-MR. l) HBV forced with MPI-ESM-MR. m) VIC forced with INM-CM4. n) SAC forced with INM-CM4. o) HBV forced with INM-CM4.

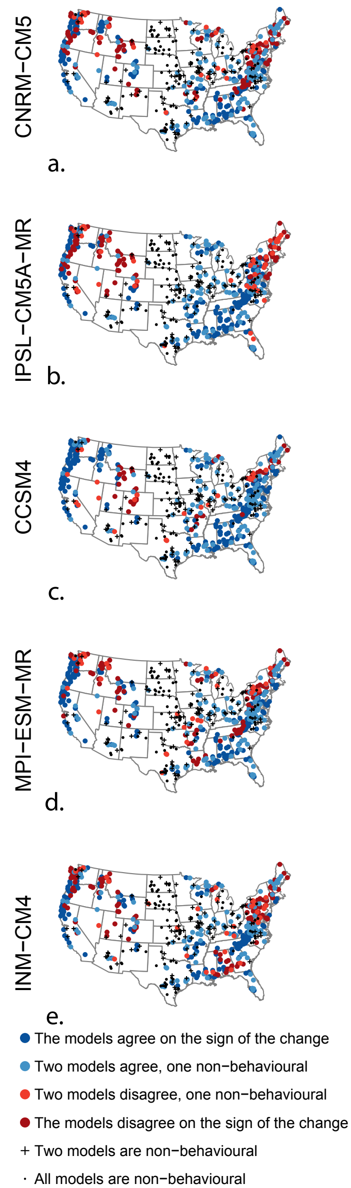

Figure A2. The agreement among the three hydrologic models on the sign of the ensemble mean change in mean annual runoff, forced with five different climate models. a) The three hydrologic models are forced with CNRM-CM5 data. b) The three hydrologic models are forced with IPSL-CM5A-MR data. c) The three hydrologic models are forced with CCSM4 data. d) The three hydrologic models are forced with MPI-ESM-MR data. e) The three hydrologic models are forced with INM-CM4 data.

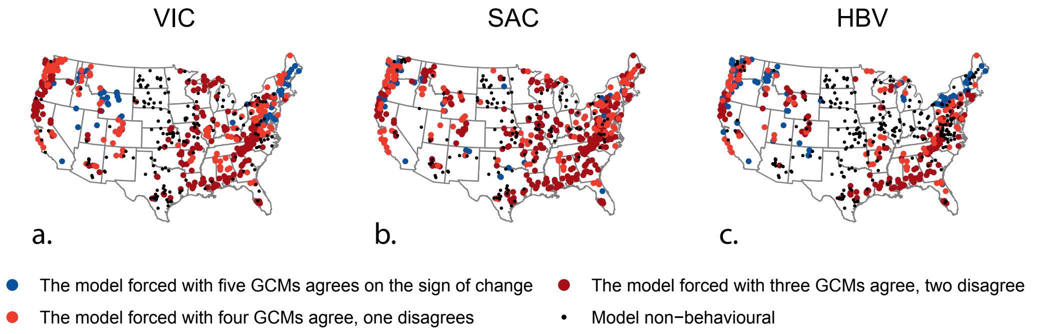

Figure A3. The agreement on the sign of the ensemble mean change in mean annual runoff in the output from the same hydrologic model forced with five different climate models. a) Agreement when the Variable Infiltration Capacity Model (VIC) is forced with data from five different GCMs. b) Agreement when Sacramento Soil Moisture Accounting Model (SAC) is forced with data from five different climate models. c) Agreement when Hydrologiska Byråns Vattenbalansavdelning Model (HBV) is forced with data from five different GCMs.

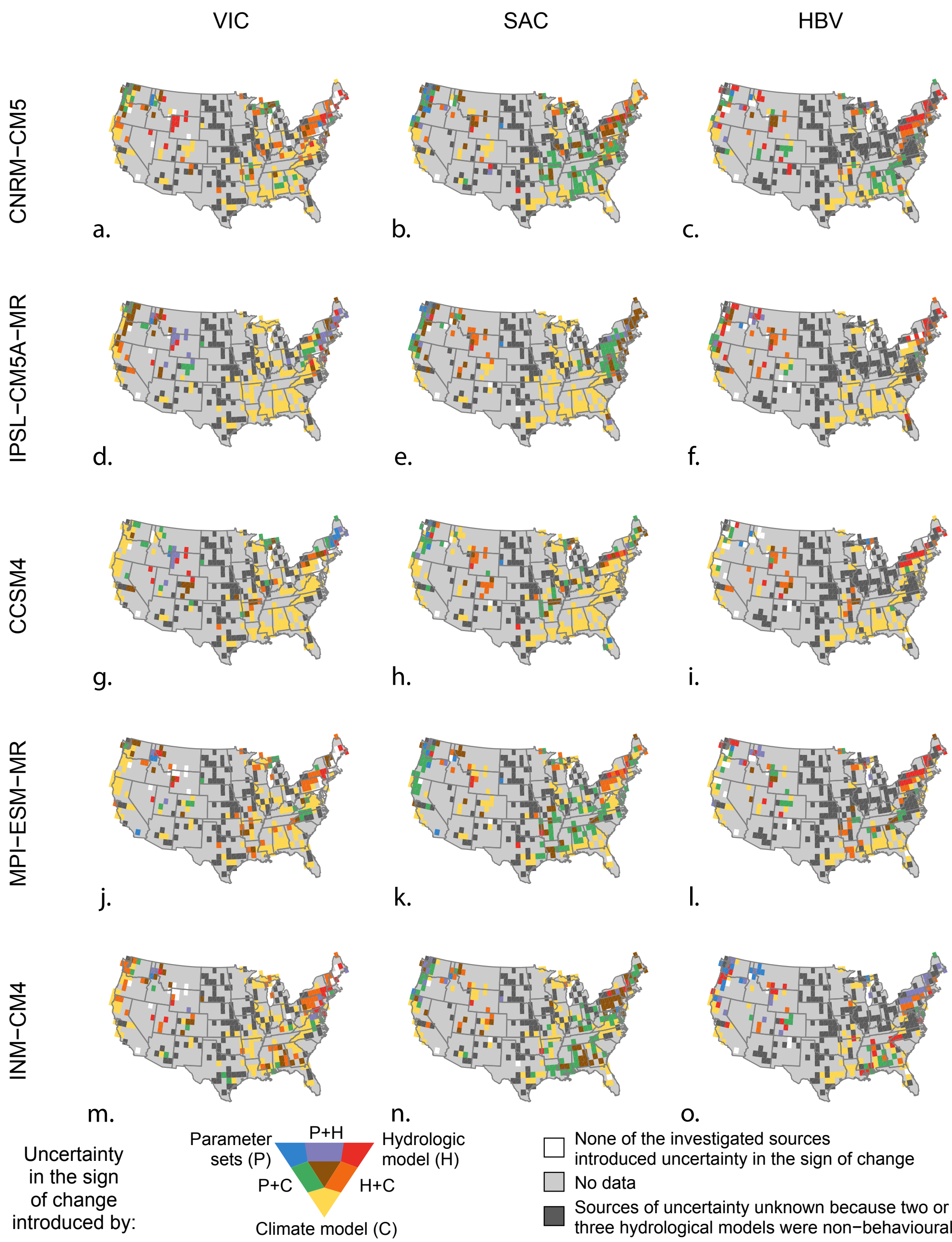

Figure A4. Distribution of the combined investigated sources of uncertainty for mean annual runoff. Spatial coverage is obtained by determining a grid-based maximum likelihood. a) Variable Infiltration Capacity Model (VIC) was used as reference when climate model uncertainty was tested, CNRM-CM5 was used as reference when the hydrologic models were tested. b) Sacramento Soil Moisture Accounting Model (SAC) and CNRM-CM5 as reference options. c) Hydrologiska Byråns Vattenbalansavdelning Model (HBV) and CNRM-CM5 as reference options. d) VIC and IPSL-CM5A-MR as reference options. e) SAC and IPSL-CM5A-MR as reference options. f) HBV and IPSL-CM5A-MR as reference options. g) VIC and CCSM4 as reference options. h) SAC and CCSM4 as reference options. i) HBV and CCSM4 as reference options. j) VIC and MPI-ESM-MR as reference options. k) SAC and MPI-ESM-MR as reference options. l) HBV and MPI-ESM-MR as reference options. m) VIC and INM-CM4 as reference options. n) SAC and INM-CM4 as reference options. o) HBV and INM-CM4 as reference options.

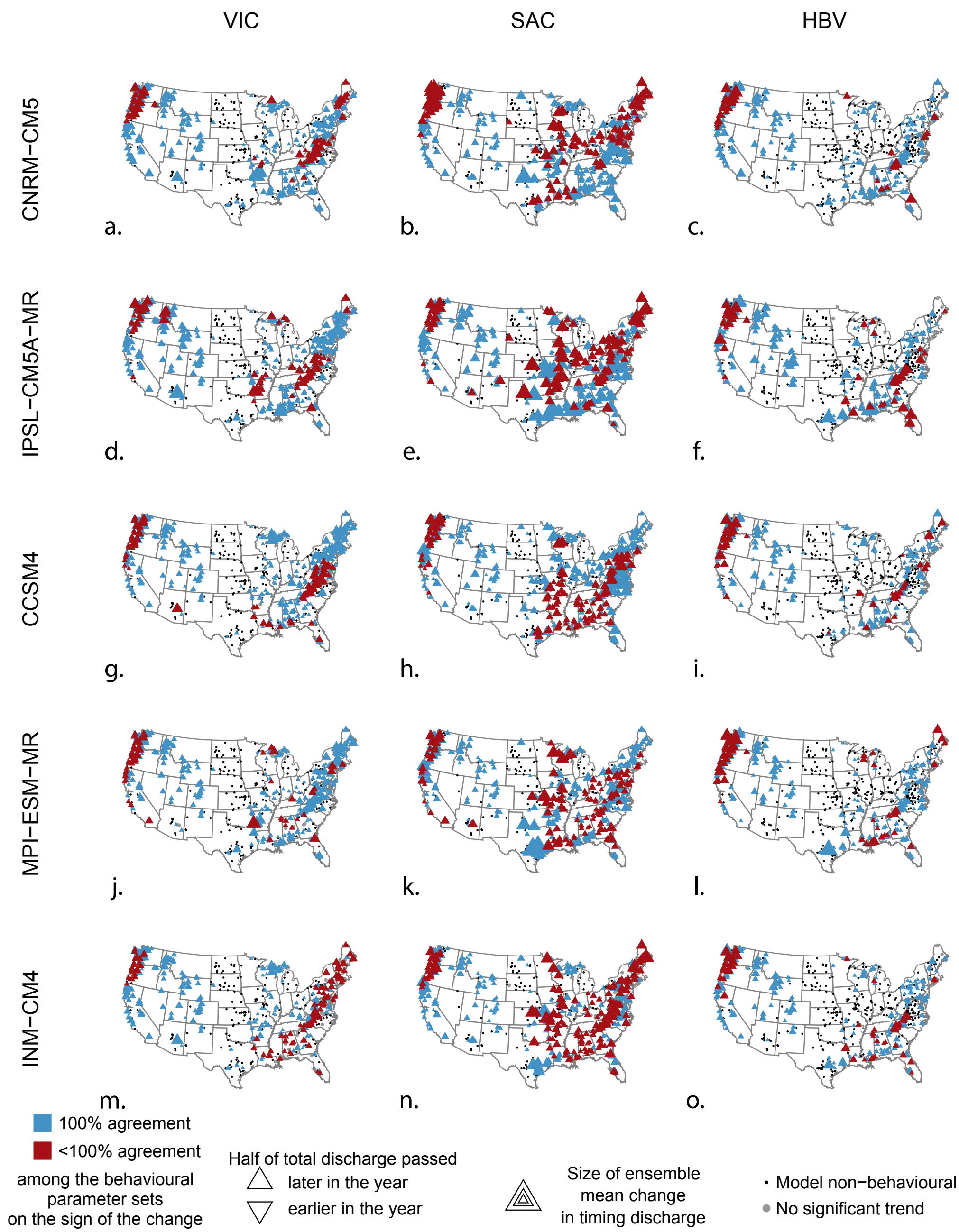

Figure B1. The agreement among the different model runs (representing different behavioural parameter sets) on the sign of change in discharge timing for three hydrologic models (columns, VIC = Variable Infiltration Capacity Model, SAC = Sacramento Soil Moisture Accounting Model, HBV = Hydrologiska Byråns Vattenbalansavdelning Model) forced with five different General Circulation Models (GCMs, rows). The direction of the triangle-marker shows the sign of the ensemble mean change, the size of the marker indicates the relative projected change. a) VIC forced with CNRM-CM5. b) SAC forced with CNRM-CM5. c) HBV forced with CNRM-CM5. d) VIC forced with IPSL-CM5A-MR. e) SAC forced with IPSL-CM5A-MR. f) HBV forced with IPSL-CM5A-MR. g) VIC forced with CCSM4. h) SAC forced with CCSM4. i) HBV forced with CCSM4. j) VIC forced with MPI-ESM-MR. k) SAC forced with MPI-ESM-MR. l) HBV forced with MPI-ESM-MR. m) VIC forced with INM-CM4. n) SAC forced with INM-CM4. o) HBV forced with INM-CM4.

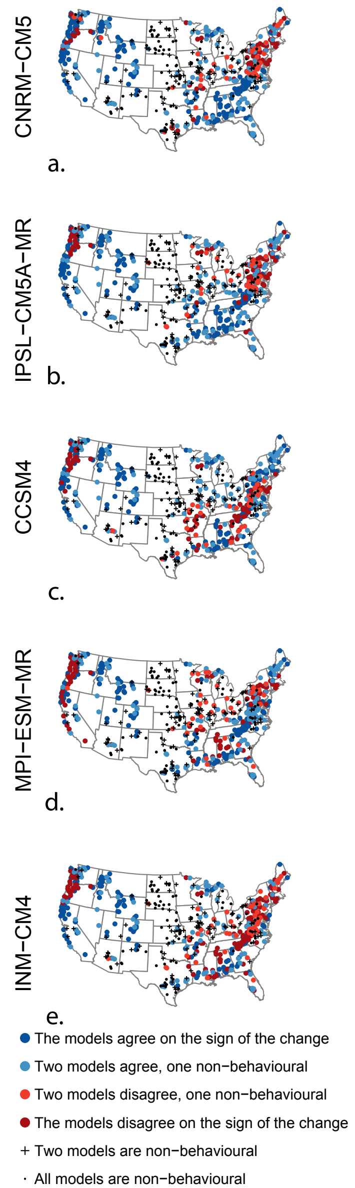

Figure B2. The agreement among the three hydrologic models on the sign of the ensemble mean change in discharge timing, forced with five different climate models. a) The three hydrologic models are forced with CNRM-CM5 data. b) The three hydrologic models are forced with IPSL-CM5A-MR data. c) The three hydrologic models are forced with CCSM4 data. d) The three hydrologic models are forced with MPI-ESM-MR data. e) The three hydrologic models are forced with INM-CM4 data.

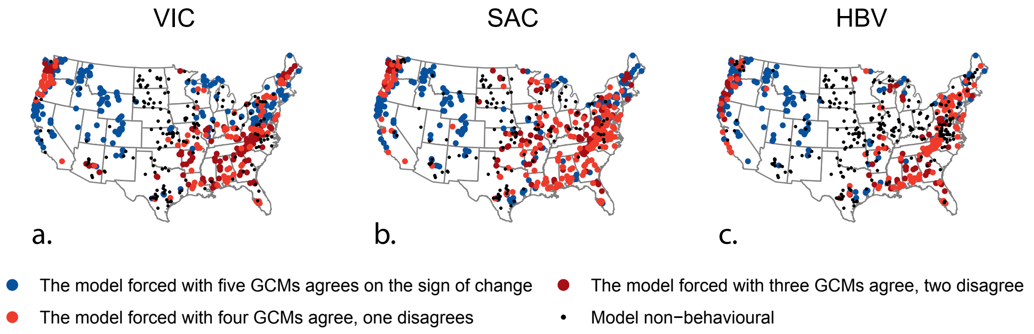

Figure B3. The agreement on the sign of the ensemble mean change in discharge timing in the output from the same hydrologic model forced with five different climate models. a) Agreement when Variable Infiltration Capacity Model (VIC) is forced with data from five different GCMs. b) Agreement when Sacramento Soil Moisture Accounting Model (SAC) is forced with data from five different climate models. c) Agreement when Hydrologiska Byråns Vattenbalansavdelning Model (HBV) is forced with data from five different GCMs.

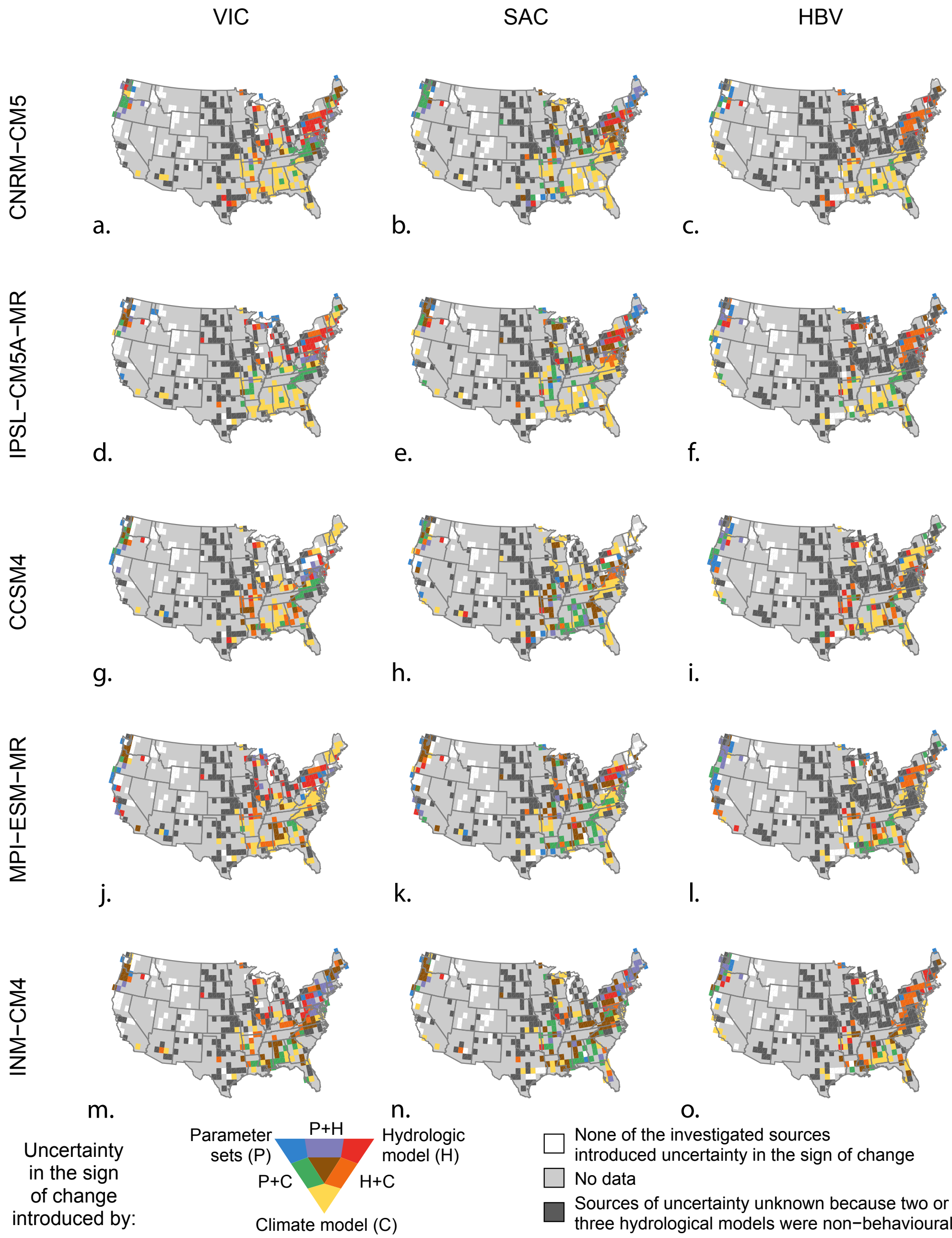

Figure B4. Distribution of the combined investigated sources of uncertainty for the discharge timing. Spatial coverage is obtained by determining a grid-based maximum likelihood. a) Variable Infiltration Capacity Model (VIC) was used as reference when climate model uncertainty was tested, CNRM-CM5 was used as reference when the hydrologic models were tested. b) Sacramento Soil Moisture Accounting Model (SAC) and CNRM-CM5 as reference options. c) Hydrologiska Byråns Vattenbalansavdelning Model (HBV) and CNRM-CM5 as reference options. d) VIC and IPSL-CM5A-MR as reference options. e) SAC and IPSL-CM5A-MR as reference options. f) HBV and IPSL-CM5A-MR as reference options. g) VIC and CCSM4 as reference options. h) SAC and CCSM4 as reference options. i) HBV and CCSM4 as reference options. j) VIC and MPI-ESM-MR as reference options. k) SAC and MPI-ESM-MR as reference options. l) HBV and MPI-ESM-MR as reference options. m) VIC and INM-CM4 as reference options. n) SAC and INM-CM4 as reference options. o) HBV and INM-CM4 as reference options.

Table C1. Selected parameters and their boundaries for the Variable Infiltration Capacity Model (VIC) model (see Methods). Parameter 1 to 7 were shown to be the most sensitive parameters based on Demaria et al. (2007); Chaney et al. (2015) and Melsen et al. (2016). Parameter 8 to 14 were selected for their impact on snow and/or evapotranspiration processes. Parameter 15 - 17 are usually hard-coded in the VIC model, but were shown to be highly sensitive in Mendoza et al. (2015) and are therefore included in the sampling. LB = lower boundary, UB = upper boundary.

	Name	Unit	LB	UB	Description
1	B_i	-	10^{-5}	0.4	Infiltration shape parameter
2	D_s	-	10^{-4}	1.0	Fraction of $D_{s,max}$ where non-linear baseflow starts
3	$D_{s,max}$	$mm\,d^{-1}$	0.1	50	Max velocity of the baseflow
4	W_s	-	0.2	1.0	Fraction of $W_{s,max}$ where non-linear baseflow starts
5	$Expt_2$	-	4.0	30	Exponent of the Brooks-Corey relation
6	$Depth_2$	m	0.1	3.0	Depth of soil layer 2
7	$Depth_3$	m	0.1	3.0	Depth of soil layer 3
8	Ts_{max}	°C	0.0	3.0	Max temperature where snowfall can occur
9	Ts_{min}	°C	Ts_{max}-0.01	Ts_{max}-3.0	Min temperature where rainfall can occur
10	SR	-	5^{-5}	0.5	Surface roughness of the snow pack
11	RZT_1	-	0.5	2	Multiplication factor for rootzone thickness layer 1
12	RZT_2	-	0.5	2	Multiplication factor for rootzone thickness layer 2
13	RZT_3	-	0.5	2	Multiplication factor for rootzone thickness layer 3
14	R_{min}	-	0.1	10	Multiplication factor for minimum stomatal resistance of the vegetation
15	newalb	-	0.7	0.99	New snow albedo
16	albaa	-	0.88	0.99	Base in snow albedo function for accumulation
17	albtha	-	0.66	0.98	Base in snow albedo function for melt

Table C2. Selected parameters and their boundaries for the Sacramento Soil Moisture Accounting Model (SAC) model (see Methods). The parameter boundaries are based on Newman et al. (2015), the Priestley-Taylor parameter (number 18) has been adapted based on Lhomme (1997). LB = lower boundary, UB = upper boundary.

	Name	Unit	LB	UB	Description
1	MFAX	mm $^{\circ}C^{-1}$ $6h^{-1}$	0.8	3.0	Max melt factor
2	MFMIN	mm $^{\circ}C^{-1}$ $6h^{-1}$	0.01	0.79	Min melt factor
3	UADJ	km $6h^{-1}$	0.01	0.40	Wind adjustment factor for rain on snow
4	SI	mm	1.0	3500	snow water equivalent for 100% snow area
5	SCF	-	0.1	5.0	Undercatch correction factor
6	PXTEMP	$^{\circ}C$	-3.0	3.0	Temperature for rain/snow transition
7	UZTWM	mm	1.0	800	Upper zone max storage of tension water
8	UZFWM	mm	1.0	800	Upper zone max storage of free water
9	LZTWM	mm	1.0	800	Lower zone max storage of tension water
10	LZFPM	mm	1.0	800	Lower zone max storage of free water
11	LZFSM	mm	1.0	1000	Lower zone max storage of secondary free water
12	UZK	day^{-1}	0.1	0.7	Upper zone free water lateral depletion rate
13	LZPK	day^{-1}	1^{-5}	0.025	Lower zone primary free water depletion rate
14	LZSK	day^{-1}	1^{-3}	0.25	Lower zone secondary free water depletion rate
15	ZPERC	-	1.0	250	Max percolation rate
16	REXP	-	0.0	6.0	Exponent of the percolation equation
17	PFREE	-	0.0	1.0	Fraction percolating from the upper to the lower zone
18	P-T	-	1.0	1.74	Priestley-Taylor coefficient

Table C3. Selected parameters and their boundaries for the Hydrologiska Byråns Vattenbalansavdelning Model model (see Methods). The selected parameters are based on Parajka et al. (2007), the parameter boundaries have been widened based on Uhlenbrook et al. (1999) and Abebe et al. (2010). The Priestley-Taylor parameter (number 15) is based on Lhomme (1997). LB = lower boundary, UB = upper boundary.

	Name	Unit	LB	UB	Description
1	SCF	-	0.1	5.0	Snow correction factor
2	DDF	mm $^{\circ}C^{-1}$ day^{-1}	0.04	12	Degree day factor
3	Tr	$^{\circ}C$	0.0	3.0	Temperature above which precipitation is rain
4	Ts	$^{\circ}C$	Tr-0.01	Tr-3	Temperature below which precipitation is snow
5	Tm	$^{\circ}C$	-3.0	3.0	Temperature where melt starts
6	LP	-	0.0	1.0	Evaporation reduction threshold
7	FC	mm	0.0	2000	Max soil moisture storage
8	BETA	-	0.0	20	Non-linear shape coefficient
9	K0	day	0.0	2.0	Storage coefficient of very fast response
10	K1	day	2.0	30	Storage coefficient of fast response
11	K2	day	30	250	Storage coefficient of slow response
12	L	mm	0.0	100	Reservoir threshold
13	PERC	mm day^{-1}	0.0	100	Percolation rate
14	BMAX	day	0.0	30	Max baseflow of low flows
15	P-T	-	1.0	1.74	Priestley-Taylor coefficient

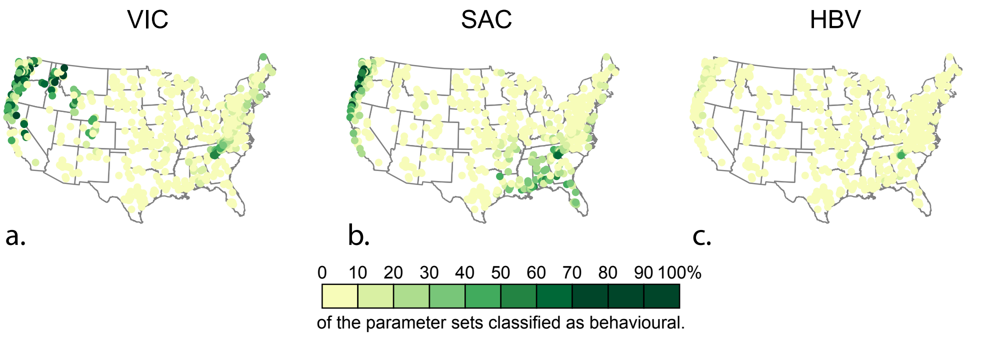

Figure C1. The percentage of parameter sets that have been classified as behavioural based on the Kling-Gupta criterion. a) for the Variable Infiltration Capacity Model (VIC), for a total parameter sample of 1800. b) for the Sacramento Soil Moisture Accounting Model (SAC), with a total parameter sample of 1900. c) for the Hydrologiska Byråns Vattenbalansavdelning Model (HBV) with a total parameter sample of 1600.

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