

Supplementary Materials

Table S1. The 100 monthly circulation indices collected from the National Climate Center of China Meteorological Administration.

Classification	Name	Abbreviation
Atmospheric	Northern Hemisphere Subtropical High Area Index	NHSHA
	North African Subtropical High Area Index	NAHAI
	North African–North Atlantic–North American Subtropical High Area Index	NAASHA
	Western Pacific Subtropical High Area Index	WPSHA
	Eastern Pacific Subtropical High Area Index	EPSHA
	North American Subtropical High Area Index	NASHA
	Atlantic Subtropical High Area Index	NASHAI
	North American–Atlantic Subtropical High Area Index	NAASHAI
	Pacific Subtropical High Area Index	PSHA
	Northern Hemisphere Subtropical High Intensity Index	NHSH
	North African Subtropical High Intensity Index	NASHII
	North African–North Atlantic–North American Subtropical High Intensity Index	NAAASH
	Western Pacific Subtropical High Intensity Index	WPSH
	Eastern Pacific Subtropical High Intensity Index	EPSH
	North American Subtropical High Intensity Index	NASH
	North Atlantic Subtropical High Intensity Index	NASHI
	North American–North Atlantic Subtropical High Intensity Index	NAASH
	Pacific Subtropical High Intensity Index	PSHI
	Northern Hemisphere Subtropical High Ridge Position Index	NHRP
	Pacific Polar Vortex Intensity Index	PPVI
	North American Polar Vortex Intensity Index	NAPV
	Atlantic–European Polar Vortex Intensity Index	AEPVI
	Northern Hemisphere Polar Vortex Intensity Index	NVI
	Northern Hemisphere Polar Vortex Central Longitude Index	NVCL
	Northern Hemisphere Polar Vortex Central Latitude Index	NVCLI
	Northern Hemisphere Polar Vortex Central Intensity Index	NHPVCI
	Eurasian Zonal Circulation Index	EZC
	Eurasian Meridional Circulation Index	EMC
	Asian Zonal Circulation Index	AZC
	Asian Meridional Circulation Index	AMC
	East Asian Trough Position Index	EATP
	East Asian Trough Intensity Index	EATI
	Tibet Plateau Region 1 Index	TPR1
	Tibet Plateau Region 2 Index	TPR2
	India–Burma Trough Intensity Index	IBTI
	Arctic Oscillation	AO
	Antarctic Oscillation	AAO
	North Atlantic Oscillation	NAO

Classification	Name	Abbreviation
	North African Subtropical High Ridge Position Index	NARP
	North African–North Atlantic–North American Subtropical High Ridge Position Index	NANRP
	Western Pacific Subtropical High Ridge Position Index	WWRP
	Eastern Pacific Subtropical High Ridge Position Index	EPRP
	North American Subtropical High Ridge Position Index	NSRP
	South China Sea Subtropical High Ridge Position Index	SSRP
	North American–North Atlantic Subtropical High Ridge Position Index	NNRP
	Pacific Subtropical High Ridge Position Index	PSHRG
	Western Pacific Sub Tropical High Western Ridge Point Index	WHWRP
	Asia Polar Vortex Area Index	APVA
	Pacific Polar Vortex Area Index	PPVA
	North American Polar Vortex Area Index	NAPVA
	Atlantic–European Polar Vortex Area Index	AEPVA
	Northern Hemisphere Polar Vortex Area Index	NHPVA
	Asia Polar Vortex Intensity Index	APVI
	Pacific/North American Pattern	PNA
	East Atlantic Pattern	EA
	West Pacific Pattern	WP
	East Atlantic–West Russia Pattern	EAWR
	Polar–Eurasia Pattern	POL
	Scandinavia Pattern	SCA
	30 hPa Zonal Wind Index	30ZW
	50 hPa Zonal Wind Index	50ZW
	Mid-Eastern Pacific 200mb Zonal Wind Index	MPZW
	West Pacific 850mb Trade Wind Index	WPTW
	Central Pacific 850mb Trade Wind Index	CPTW
	East Pacific 850mb Trade Wind Index	EPTA
	Atlantic–European Circulation W Pattern Index	ACWP
	Atlantic–European Circulation C Pattern Index	ACCP
Sea temperature	NINO 1+2 SSTA Index	NINO1+2
	NINO 3 SSTA Index	NINO3
	NINO 4 SSTA Index	NINO4
	NINO 3.4 SSTA Index	NINO3.4
	NINO W SSTA Index	NINOW
	NINO C SSTA Index	NINOC
	NINO A SSTA Index	NINOA
	Indian Ocean Warm Pool Strength Index	IOWPS
	Western Pacific Warm Pool Area Index	WPWPA
	Western Pacific Warm Pool Strength index	WPWPS
	Atlantic Multi-Decadal Oscillation Index	AMO
	Oyashio Current SST Index	OC
	West Wind Drift Current SST Index	WWDC
	Kuroshio Current SST Index	KC
	NINO B SSTA Index	NINOB

Classification	Name	Abbreviation
	NINO Z SSTA Index	NINOZ
	Tropical Northern Atlantic SST Index	TNA
	Tropical Southern Atlantic SST Index	TSA
	Western Hemisphere Warm Pool Index	WHWP
	Indian Ocean Warm Pool Area Index	IOWPA
	ENSO Modoki Index	EM
	Nino Eastern Pacific index	NE
	Nino Central Pacific index	NC
	Indian Ocean Basin-Wide Index	IOBW
	Tropic Indian Ocean Dipole Index	TIOD
	South Indian Ocean Dipole Index	SIOD
Other	Western North Pacific Typhoon number	WNPTN
	Number of Landing Typhoon on China	NLTC
	Total Sunspot Number Index	TSN
	Southern Oscillation Index	SOI
	Atlantic Meridional Mode SST Index	AMM
	Quasi-Biennial Oscillation Index	QBO
	North Atlantic Triple index	NAT

Table S2. Model performance measurements (R^2 , $LCCC$, $RMSE$, and MAE) for the calibration period using multi-variable linear regression (MLR) and random forest (RF) at 44 sites in northwestern China.

No. of Site	MLR-Based				RF-Based			
	R^2	$LCCC$	MAE (mm)	$RMSE$ (mm)	R^2	$LCCC$	MAE (mm)	$RMSE$ (mm)
51053	0.863	0.927	17.5	22.4	0.869	0.929	16.5	21.9
51060	0.888	0.941	16.0	20.8	0.897	0.945	14.8	19.9
51068	0.901	0.948	14.5	19.3	0.900	0.946	14.2	19.3
51076	0.874	0.933	17.7	22.7	0.883	0.937	16.9	22.0
51087	0.870	0.931	17.7	23.1	0.873	0.931	17.1	22.9
51133	0.827	0.905	20.6	26.7	0.829	0.906	20.2	26.5
51156	0.816	0.899	15.8	22.0	0.825	0.903	15.4	21.5
51232	0.912	0.954	24.4	31.3	0.920	0.958	22.4	29.8
51238	0.872	0.931	14.4	19.0	0.867	0.928	14.2	19.3
51241	0.786	0.880	19.4	26.5	0.782	0.878	18.8	26.8
51243	0.914	0.955	20.2	26.1	0.925	0.960	17.6	24.4
51334	0.919	0.958	13.6	17.1	0.922	0.958	13.0	16.9
51367	0.897	0.945	17.2	22.6	0.907	0.950	15.7	21.5
51477	0.891	0.942	15.4	21.0	0.899	0.946	14.5	20.2
51526	0.930	0.964	13.7	17.6	0.934	0.965	12.1	17.2
51567	0.895	0.945	12.9	17.4	0.909	0.951	11.5	16.2
51573	0.903	0.949	17.6	21.9	0.932	0.963	14.4	18.5
51628	0.893	0.943	13.1	16.9	0.900	0.945	12.3	16.3
51656	0.910	0.953	14.8	19.1	0.927	0.960	12.8	17.3
51704	0.878	0.935	18.2	23.7	0.898	0.945	15.7	21.7
51705	0.733	0.846	21.7	27.5	0.735	0.847	21.3	27.4
51709	0.883	0.938	16.3	20.6	0.892	0.942	15.4	19.8
51720	0.847	0.917	16.2	21.9	0.867	0.927	14.2	20.5
51730	0.918	0.957	12.7	16.0	0.933	0.964	10.9	14.6
51765	0.929	0.963	13.3	16.9	0.944	0.970	11.1	15.1
51810	0.898	0.946	13.3	17.9	0.911	0.952	12.2	16.8
51811	0.900	0.948	13.4	17.5	0.911	0.952	12.5	16.6
51818	0.893	0.944	12.4	16.9	0.890	0.941	12.3	17.2
51828	0.917	0.957	12.5	16.1	0.920	0.957	12.1	15.8
51839	0.932	0.965	10.5	13.8	0.936	0.966	9.7	13.5

No. of Site	MLR-Based				RF-Based			
	R^2	$LCCC$	MAE (mm)	$RMSE$ (mm)	R^2	$LCCC$	MAE (mm)	$RMSE$ (mm)
51855	0.909	0.952	13.5	17.3	0.920	0.957	11.8	16.2
51931	0.885	0.939	12.2	16.9	0.892	0.942	11.2	16.4
52101	0.801	0.890	14.1	19.6	0.791	0.882	14.5	20.1
52112	0.930	0.964	21.3	26.8	0.947	0.972	17.9	23.4
52118	0.875	0.933	14.2	19.0	0.884	0.937	12.9	18.3
52203	0.905	0.950	15.6	19.8	0.924	0.960	13.6	17.8
52313	0.932	0.965	15.8	20.7	0.933	0.964	14.5	20.5
52323	0.898	0.946	14.8	19.4	0.902	0.947	14.0	19.2
52546	0.880	0.936	12.4	16.9	0.876	0.933	12.3	17.2
52652	0.850	0.919	13.6	17.7	0.850	0.917	13.3	17.7
52674	0.610	0.758	16.8	22.7	0.530	0.715	18.5	25.2
52679	0.750	0.857	14.8	20.0	0.735	0.848	14.9	20.6
52681	0.850	0.919	15.0	19.6	0.848	0.916	14.8	19.8
52797	0.663	0.797	18.1	24.3	0.647	0.792	18.3	24.9

Table S3. Model performance measurements (R^2 , $LCCC$, $RMSE$, and MAE) for the validation period using multi-variable linear regression model (MLR) and random forest model (RF) at 44 sites in northwestern China.

No. of Site	MLR-Based				RF-Based			
	R^2	$LCCC$	MAE (mm)	$RMSE$ (mm)	R^2	$LCCC$	MAE (mm)	$RMSE$ (mm)
51053	0.830	0.908	18.1	24.1	0.857	0.924	16.6	21.9
51060	0.892	0.943	14.8	19.1	0.905	0.950	14.4	17.9
51068	0.904	0.946	15.1	20.4	0.911	0.938	14.7	21.1
51076	0.841	0.913	18.0	24.3	0.860	0.925	17.2	22.5
51087	0.867	0.909	20.8	26.8	0.857	0.920	18.1	24.4
51133	0.796	0.855	23.4	32.5	0.814	0.884	20.6	28.4
51156	0.828	0.900	17.3	22.0	0.822	0.895	16.1	21.6
51232	0.916	0.951	23.1	30.4	0.919	0.958	19.5	27.0
51238	0.840	0.915	17.1	22.2	0.848	0.901	16.3	22.6
51241	0.743	0.850	21.1	28.6	0.746	0.857	19.4	27.8
51243	0.880	0.920	22.7	30.4	0.918	0.951	16.1	22.6
51334	0.923	0.944	16.4	21.2	0.936	0.937	15.8	21.5
51367	0.917	0.954	16.7	21.6	0.898	0.924	19.2	26.4
51477	0.887	0.927	16.0	21.8	0.937	0.961	11.4	15.0
51526	0.928	0.963	13.6	17.7	0.950	0.971	11.2	15.3
51567	0.907	0.932	15.9	19.9	0.913	0.930	14.6	19.6
51573	0.824	0.877	28.8	36.4	0.890	0.881	26.2	34.8
51628	0.864	0.916	16.7	21.6	0.873	0.904	17.2	22.4
51656	0.866	0.910	20.0	26.3	0.886	0.920	17.0	23.8
51704	0.861	0.921	17.8	23.4	0.879	0.931	15.0	21.9
51705	0.622	0.747	25.4	32.2	0.668	0.793	22.6	29.1
51709	0.853	0.915	20.7	24.9	0.867	0.908	20.3	24.8
51720	0.789	0.878	17.4	23.2	0.830	0.910	12.4	18.1
51730	0.894	0.927	16.8	20.4	0.915	0.948	12.9	17.0
51765	0.927	0.943	17.3	21.1	0.943	0.948	14.7	19.3
51810	0.886	0.927	16.8	20.8	0.894	0.923	16.1	20.6
51811	0.898	0.932	16.4	19.6	0.909	0.940	14.1	18.0
51818	0.862	0.923	13.8	20.2	0.872	0.932	12.4	19.1
51828	0.892	0.944	13.7	18.4	0.900	0.947	12.5	17.9
51839	0.895	0.944	12.0	17.2	0.898	0.948	10.3	16.3

No. of Site	MLR-Based				RF-Based			
	R^2	$LCCC$	MAE (mm)	$RMSE$ (mm)	R^2	$LCCC$	MAE (mm)	$RMSE$ (mm)
51855	0.906	0.873	26.1	30.5	0.926	0.873	21.9	28.4
51931	0.864	0.908	16.1	20.9	0.889	0.914	13.9	19.2
52101	0.748	0.859	16.5	22.1	0.725	0.843	16.7	22.9
52112	0.943	0.964	19.4	25.3	0.951	0.971	16.7	22.8
52118	0.854	0.919	16.1	20.9	0.880	0.936	13.0	18.4
52203	0.927	0.936	18.7	22.3	0.936	0.956	13.1	18.0
52313	0.932	0.965	15.8	20.3	0.953	0.976	12.6	16.6
52323	0.906	0.944	17.0	21.0	0.912	0.948	15.6	19.6
52546	0.847	0.878	20.0	24.7	0.853	0.887	18.4	23.5
52652	0.820	0.874	19.1	23.6	0.835	0.873	18.3	23.4
52674	0.535	0.699	19.8	24.9	0.488	0.677	20.3	26.2
52679	0.635	0.778	18.7	25.9	0.644	0.772	18.4	25.6
52681	0.836	0.907	17.3	21.6	0.862	0.915	15.8	20.0
52797	0.555	0.716	19.3	27.0	0.587	0.749	17.8	25.4

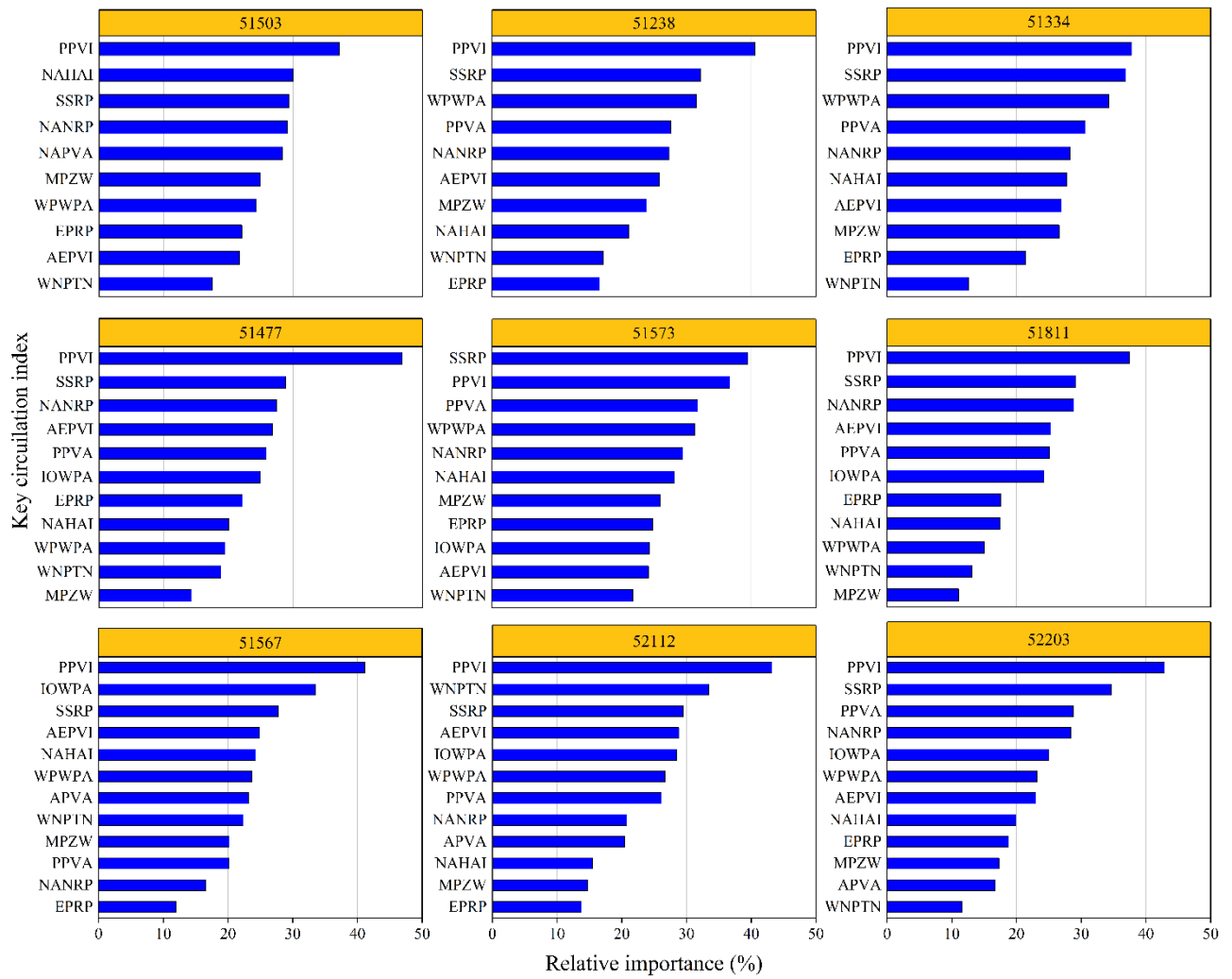


Figure S1. The importance of different predictor variables used in the RF model to predict monthly *D* at 9 representative sites in northwestern China.