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Sources of skill in lake temperature, discharge and ice-off seasonal forecasting tools

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You can find all the codes and data files related to this manuscript at:
https://github.com/NIVANorge/seasonal_forecasting_watexr

Table S1: Time series of observations available at each case-study. Note: Temperature is lake water temperature and N is the number of seasons with data (out of 91 seasons).

Site	Variable	Start	End	S	Sampling season	Frequency
Norway	Discharge Temperature	1994 2005	2016 2015	91 33	Year-round Apr-Oct	Daily Monthly
Spain	Discharge Temperature	1994 1997	2016 2016	91 72	Year-round Year-round	Daily Weekly-Monthly
Australia	Discharge Temperature	2003 2006	2013 2016	43 20	Year-round Year-round	Daily Daily (irregular)
Germany	Discharge Temperature	1994 1994	2016 2016	91 90	Year-round Year-round	Daily Weekly-biweekly

Table S2: Verification statistics (NSE, R^2, RMSE/sd, bias) for Lake_PO for each case-study for each season. The percentage of seasons (S), months (M) and days (D) covered by observations is also given as “Obs coverage”. Statistics are calculated on daily data. RMSE/sd is the root-mean squared error divided by one standard deviation.

			Obs coverage			NSE	R^2	RMSE/sd	bias
			S	M	D				
Norway	Discharge	WI	100	100	93	0.46	0.47	0.73	0.15
		SP	100	96	93	0.40	0.41	0.77	-1.02
		SU	100	100	96	0.05	0.43	0.97	2.75
		AU	100	100	95	0.57	0.66	0.66	-3.13
	Surface Temperature	WI	0			-	-	-	-
		SP	48	48	5	0.87	0.92	0.36	0.53
		SU	48	48	11	0.67	0.81	0.57	0.38
		AU	48	48	5	0.81	0.99	0.43	-1.03
	Bottom Temperature	WI	0			-	-	-	-
		SP	43	39	4	0.53	0.7	0.68	-0.65
		SU	43	39	10	0.37	0.60	0.79	0.84
		AU	43	39	5	0.80	0.92	0.44	-0.58
	Ice-on		100	-	-	0.97	0.99	0.16	1.8
	Ice-off		100	-	-	0.36	0.76	1.09	-14.7
Spain	Discharge	WI	100	100	99	0.69	0.69	0.56	-0.63
		SP	100	100	99	0.54	0.57	0.38	-3.15
		SU	100	100	98	0.37	0.40	0.80	-1.53
		AU	100	100	98	0.60	0.63	0.63	-0.73
	Surface Temperature	WI	77	45	3	0.76	0.77	0.48	0.12
		SP	83	65	4	0.81	0.88	0.43	-0.90
		SU	78	30	3	0.60	0.66	0.62	-0.45
		AU	87	70	4	0.82	0.92	0.42	-1.28
	Bottom Temperature	WI	27	5	2	0.38	0.40	0.76	0.06
		SP	48	17	3	-0.27	0.26	1.10	0.07
		SU	48	4	2	0.48	0.55	0.70	-0.25
		AU	35	4	3	-0.72	0.00	1.27	-0.38
Germany	Discharge	WI	100	100	100	0.62	0.63	0.62	0.04
		SP	100	100	100	0.61	0.68	0.62	-1.08
		SU	100	100	100	-0.06	0.35	1.03	-0.51
		AU	100	100	100	0.35	0.58	0.80	1.00
	Surface Temperature	WI	95	41	3	-0.22	0.50	1.09	-0.36
		SP	100	96	6	0.92	0.95	0.28	0.61
		SU	100	100	7	0.51	0.89	0.70	1.24
		AU	100	96	6	0.92	0.97	0.27	-0.24
	Bottom Temperature	WI	95	41	3	0.59	0.66	0.64	0.15
		SP	100	96	6	-0.46	0.72	1.20	1.28
		SU	100	100	7	-1.04	0.75	1.42	3.54
		AU	100	96	5	0.50	0.90	0.70	1.01
Australia	Discharge	WI	50	47	97	-1.69	0.01	1.64	-1.02
		SP	48	48	100	-6.22	0.04	2.69	-0.16
		SU	48	43	93	-0.12	0.15	1.06	0.48
		AU	43	43	100	0.02	0.34	0.99	-1.26
	Surface Temperature	WI	23	23	82	-0.04	0.55	1.02	0.62
		SP	22	13	57	0.90	0.94	0.31	0.15
		SU	17	9	47	0.88	0.89	0.34	0.10
		AU	26	13	57	0.88	0.89	0.34	0.21
	Bottom Temperature	WI	23	23	82	0.12	0.40	0.94	1.25
		SP	22	13	57	-0.02	0.28	1.01	0.84
		SU	17	9	46	0.86	0.87	0.38	-0.18
		AU	26	13	48	0.16	0.42	0.92	0.10

Text S1: Inflow-outflow linear regression for Wupper Reservoir (Germany)

For each simulation at Wupper Reservoir (Germany), a linear regression was trained to obtain the best possible linear model to predict outflow from inflow. For Lake pseudo-observations, i.e., when models were forced with ERA5 meteorological data, over the training (1994-2016) and validation (2017-2019) periods the linear model had performance measures as follow:

Training period – Nash-Sutcliffe efficiency: 0.67 and Kling-Gupta efficiency: 0.79

Validation period – Nash-Sutcliffe efficiency: 0.78 and Kling-Gupta efficiency 0.82

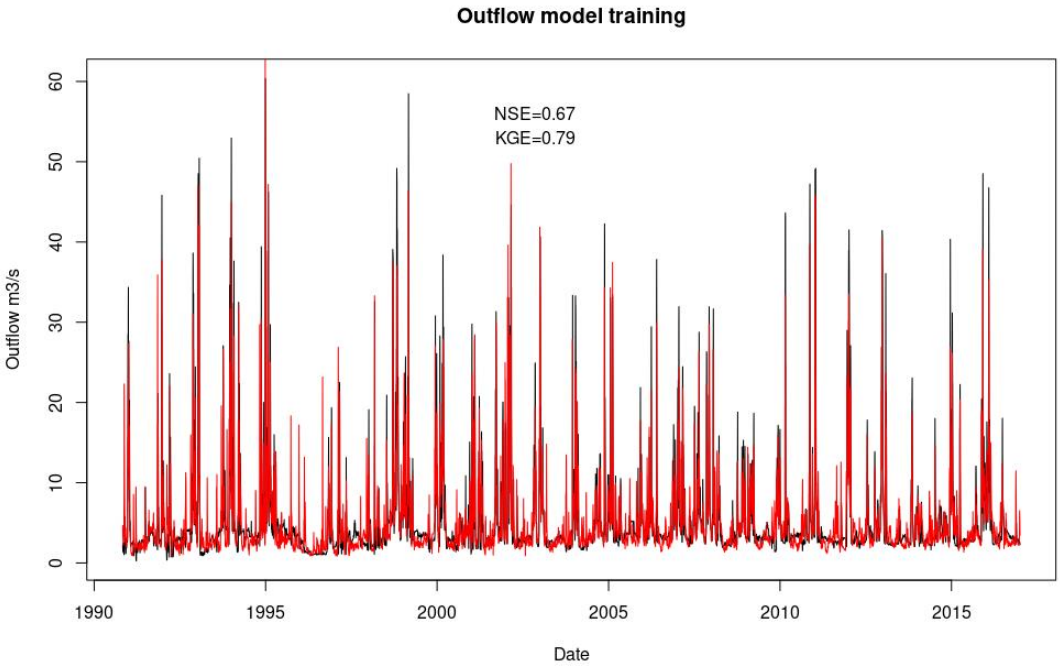

Figure S1: Comparison of modeled (red) and observed (black) outflow over the model training period.

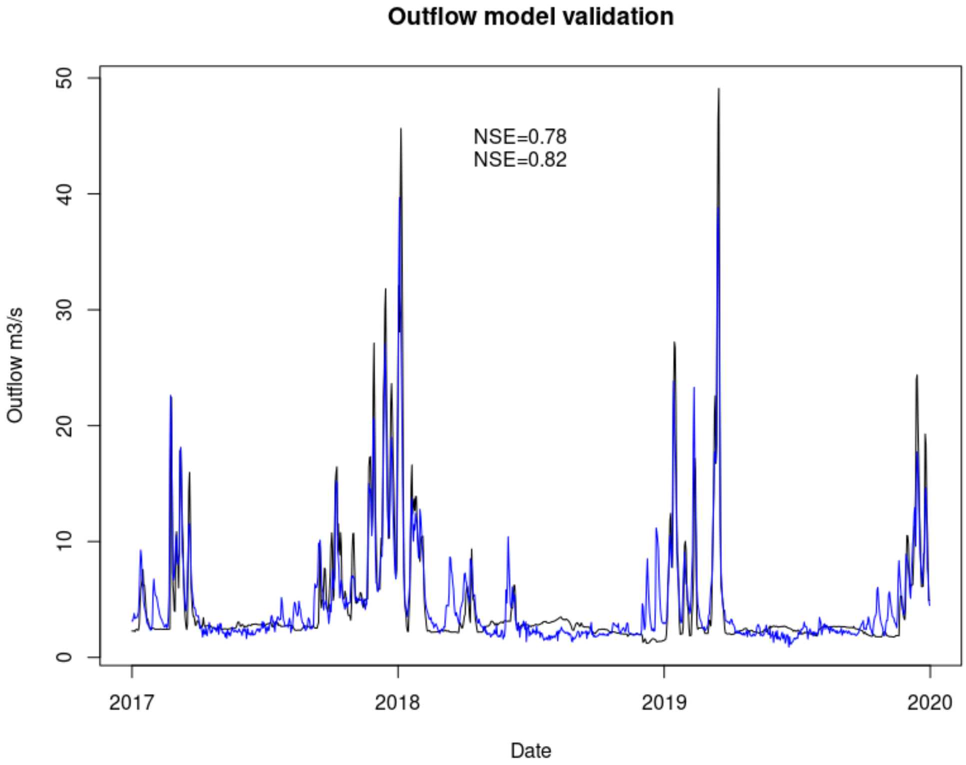

Figure S2: Comparison of modeled (blue) and observed (black) outflow over the model validation period.

Text S2: Validation of inflow water temperature model at Wupper Reservoir (Germany)

The linear model of the form (A +B*AirTemperature) used to predict inflow water temperature at Wupper Reservoir was validated against observation over 2004-2014 (Figure S3) with performance measures as follow: Nash-Sutcliffe efficiency: 0.97, Kling-Gupta efficiency: 0.79 and Pearson’s correlation of 0.98.

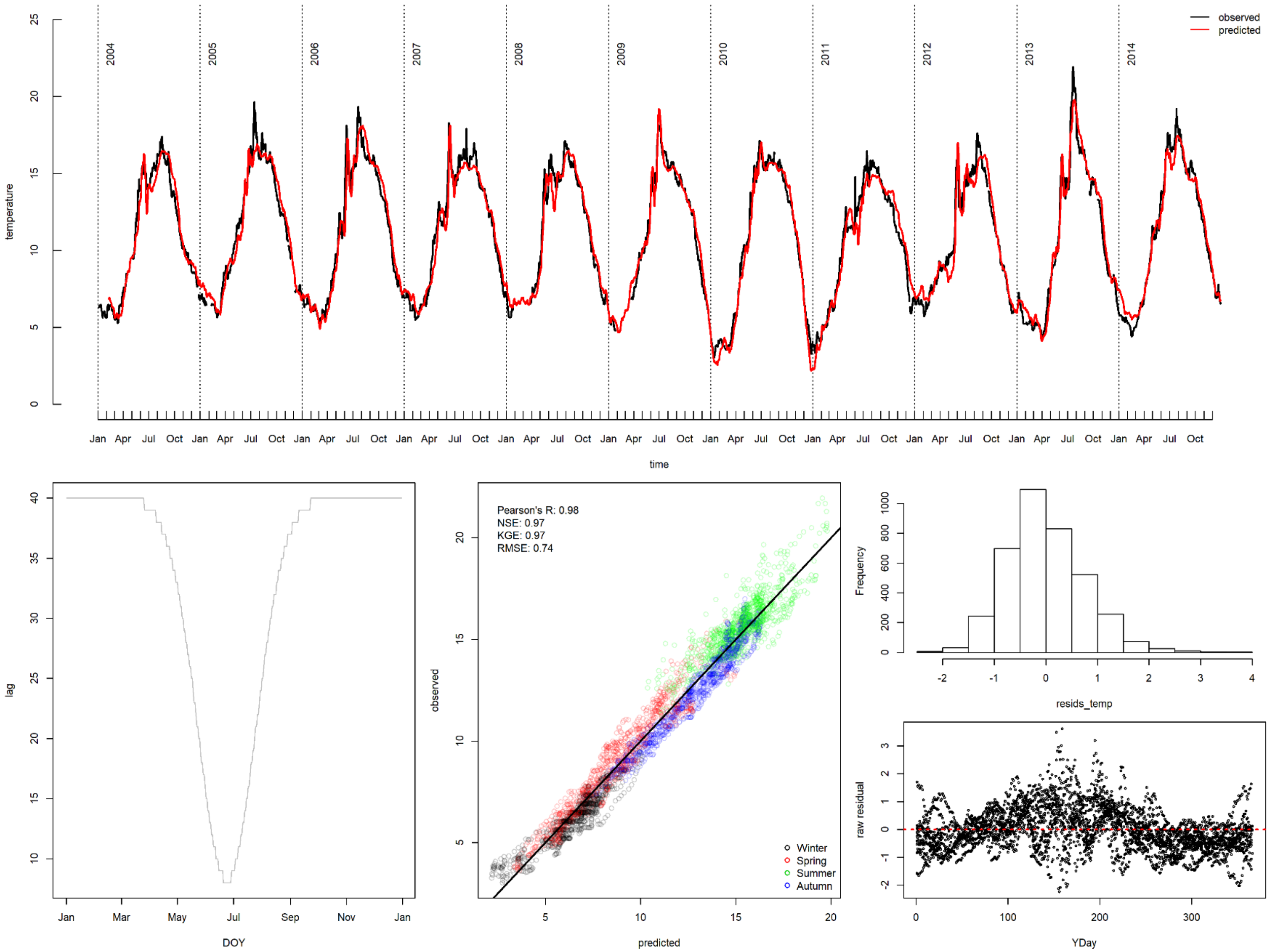

Figure S3: Comparison of modelled and observed inflow temperature and residuals.

Text S3: Lake seasonal heat budget at the four case studies.

The lake energy budget includes exchanges through the air-water interface, i.e., downward short-wave radiation, downward and upward long-wave radiation, latent and sensible heat fluxes, and by lateral fluxes of water, i.e., inflow and outflow of water (Schmid & Read, 2022). The energy fluxes at the air-water interface were calculated with the HeatFluxAnalyzer (Woolway et al., 2015). The net heat flux HF (W m^{-2}) caused by an inflow with discharge Q_{in} and temperature T_{in} is given by Livingstone & Imboden (1989):

$$H_F = \frac{C_p \rho}{A} Q_{in} (T_{in} - T_{Lake})$$

where C_p and ρ are the heat capacity and density of water, respectively; and T_{Lake} is the outflow temperature, which is assumed to be the lake surface temperature (Schmid and Read 2022).

Table S3 below displays the contribution of each heat flux to the total heat fluxes for each case-study and each season.

Table S3: Contributions (%) of each discrete heat flux to the total lake heat fluxes at each case study by season.

		Spring Mar-May	Summer Jun-Aug	Autumn Sep-Nov	Winter Dec-Feb
Lake Vansjø Norway	Short-wave	77	60	56	30
	Long-wave	8	9	10	18
	Latent	13	21	23	18
	Sensible	2	5	7	17
	Throughflow	0	5	4	17
Sau Reservoir Spain	Short-wave	62	66	47	42
	Long-wave	22	23	31	38
	Latent	5	8	12	8
	Sensible	1	1	4	4
	Throughflow	10	2	6	7
Wupper Reservoir Germany	Short-wave	55	45	34	25
	Long-wave	25	21	28	35
	Latent	14	19	20	10
	Sensible	4	6	8	5
	Throughflow	2	9	10	25
Mt Bold Reservoir Australia	Short-wave	50	44	60	54
	Long-wave	22	25	20	15
	Latent	20	13	17	23
	Sensible	5	2	3	5
	Throughflow	3	16	0	2

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