ONLINE SUPPLEMENT TO:

Evaporation measurement and modeling of an alpine saline lake influenced by freeze–thaw on the Qinghai–Tibet Plateau

Fangzhong Shi[1,2], Xiaoyan Li[1,2,3,4], Shaojie Zhao[1,2], Yujun Ma[5], Junqi Wei[1,2], Qiwen Liao[1,2], Deliang Chen[6]

[1]State Key Laboratory of Earth Surface Processes and Resource Ecology, Faculty of Geographical Science, Beijing Normal University, Beijing 100875, China;

[2]School of Natural Resources, Faculty of Geographical Science, Beijing Normal University, Beijing 100875, China

[3]Key Laboratory of Tibetan Plateau Land Surface Processes and Ecological Conservation, Ministry of Education, Qinghai Normal University, Xining, China

[4]Academy of Plateau Science and Sustainability, Qinghai Normal University, Xining, China

[5]School of Geography and Planning, Sun Yat–sen University, Guangzhou, China

[6]Regional Climate Group, Department of Earth Sciences, University of Gothenburg, Gothenburg, Sweden.

* To whom the correspondence should be addressed: Xiao–Yan Li, State Key Laboratory of Earth Surface Processes and Resource Ecology, Beijing Normal University, Beijing, China. Emails: xyli@bnu.edu.cn.

Keywords

Lake evaporation and sublimation, saline lakes, flux observation, ice–covered period, Qinghai Lake, Qinghai–Tibet Plateau

Author Contributions

XY Li conceived the idea, FZ Shi performed the analyses. XY Li, FZ Shi, DL Chen and YJ Ma led the manuscript writing. SJ Zhao, YJ Ma, JQ Wei and QW Liao provided analysis of datasets. All contributed to review and revise the manuscript.

This PDF file includes:

Supplementary Fig. S1 to S9

Supplementary Tables S1 to S3

Figures

Fig. S1.

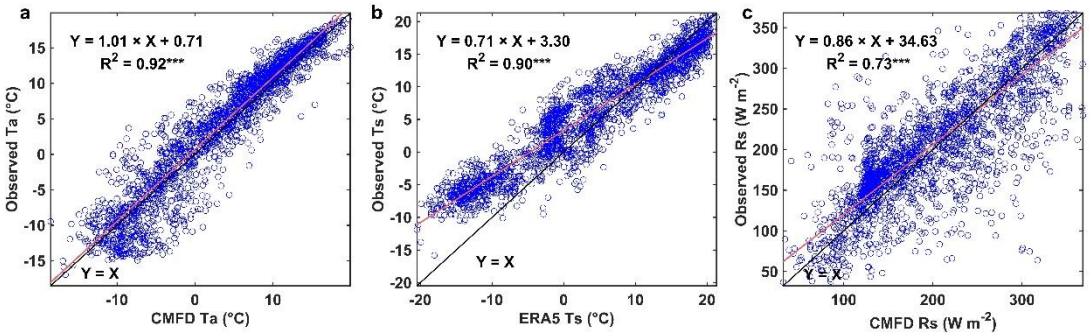


Fig. S1. Relationship between the daily air temperature (Ta) from the China Regional High–Temporal–Resolution Surface Meteorological Elements–Driven Dataset (CMFD), lake surface temperature (Ts) from the interim reanalysis dataset v5 (ERA5) and downward shortwave radiation (Rs) from CMFD with the observed Ta (a), Ts (b) and Rs (c) in Qinghai Lake.

Fig. S2.

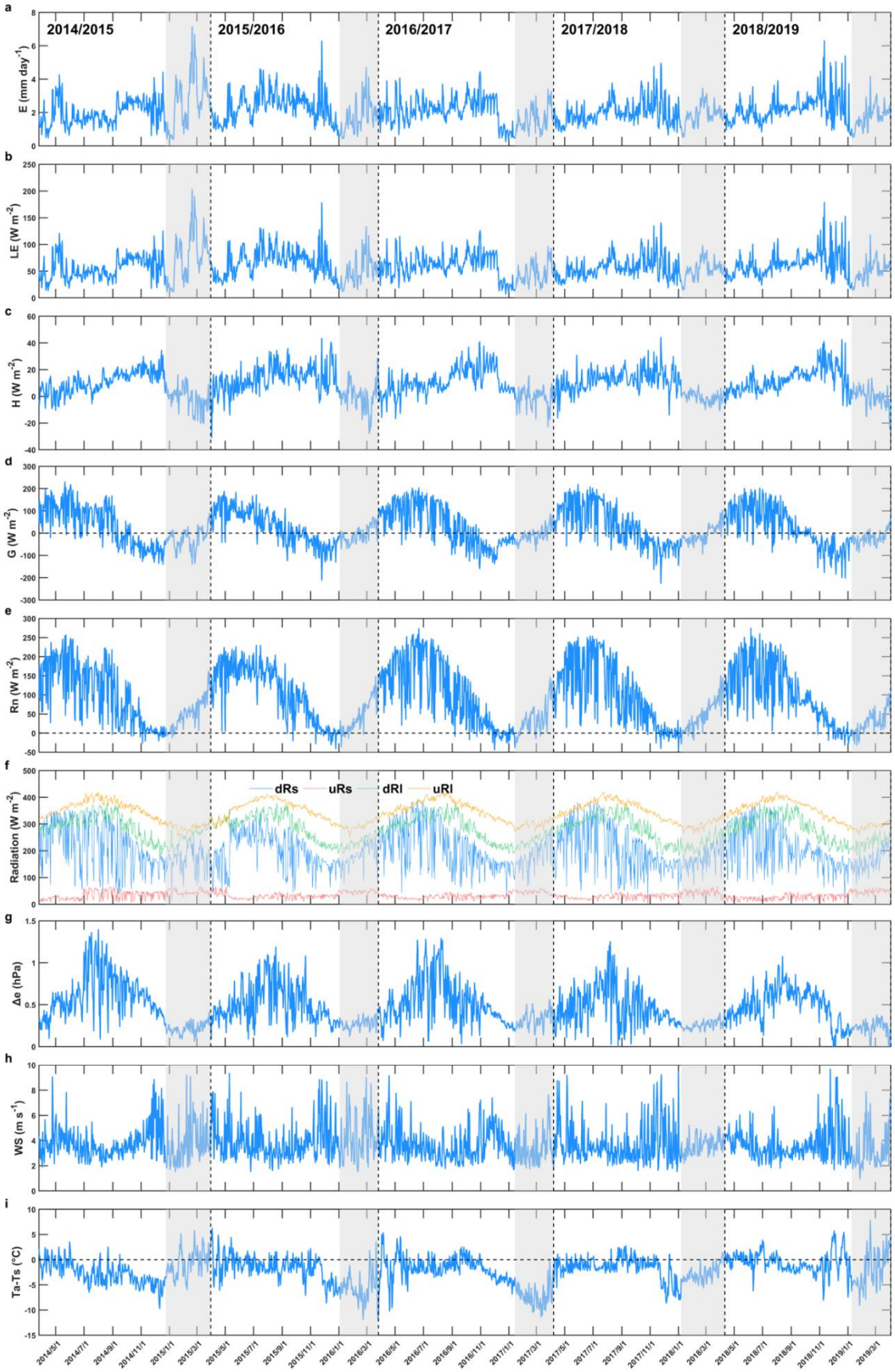

a
2014/2015
2015/2016
2016/2017
2017/2018
2018/2019
E (mm day-1)
b
LE (W m-2)
c
H (W m-2)
d
G (W m-2)
e
Rn (W m-2)
f
dRs
uRs
dRl
uRl
Radiation (W m-2)
g
Δe (hPa)
h
WS (m s-1)
i
Ta-Ts (°C)

Fig. S2. The time series of the daily lake evaporation (E), latent heat (LE), sensible heat (H), heat storage change (G), net radiation (Rn), four radiation components (incoming shortwave: dRs, reflected shortwave: uRs, and incoming and outgoing longwave radiation: dRl and uRl), vapor pressure difference (Δe), wind speed (U), and the difference between air temperature and lake surface temperature (Ta−Ts) of Qinghai Lake (QHL) during the ice–free (IF) and ice–covered (IC) periods from 2014 to 2018. The gray area indicates ice–covered period. The labels 2014/2015, 2015/2016, 2016/2017, 2017/2018 and 2018/2019 indicate the cycle year of freeze–thaw cycling

Fig. S3.

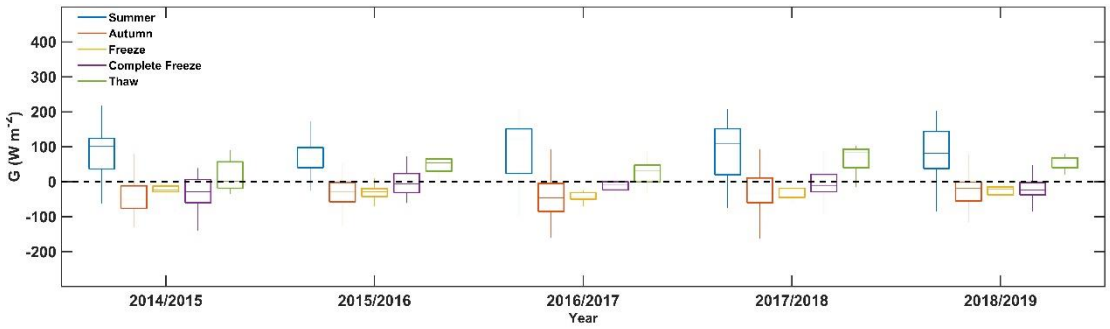


Fig. S3. Heat storage change (G) in Qinghai Lake during summer, autumn, freeze, complete freeze and thaw periods in each year from 2014 to 2018. The whiskers indicate the 1.5 interquartile range. Summer and autumn last from June to August and September to November, respectively. The labels 2014/2015, 2015/2016, 2016/2017, 2017/2018 and 2018/2019 indicate the cycle year of freeze–thaw cycling.

Fig. S4.

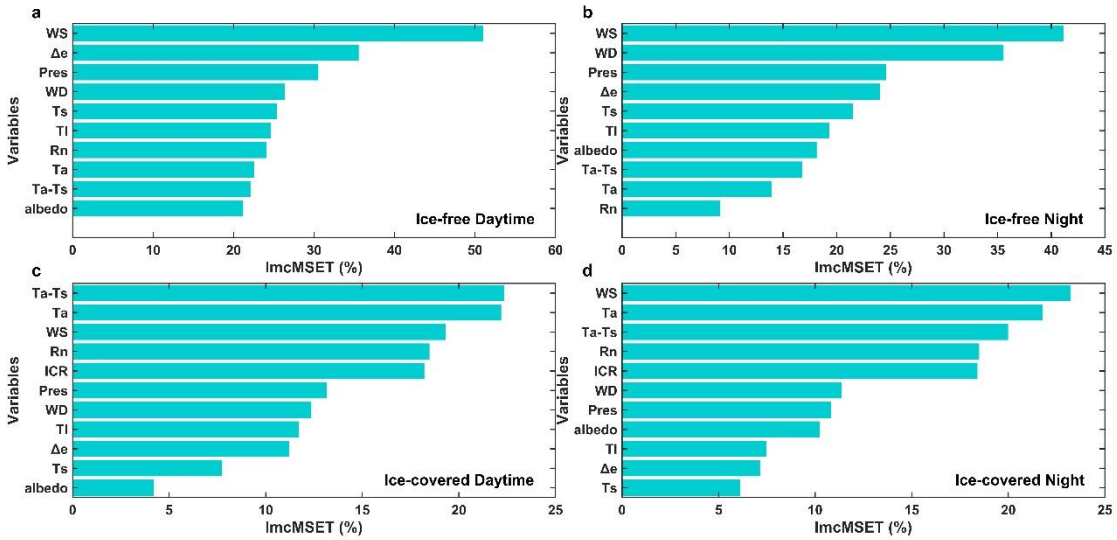
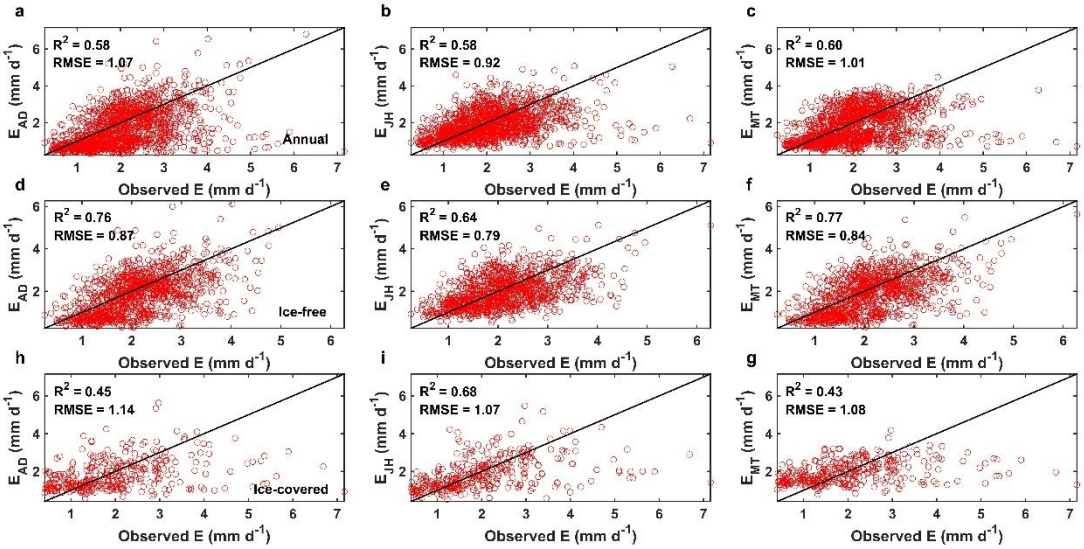


Fig. S4. Importance of the daytime and nighttime climate factors to the evaporation (E) rate of Qinghai Lake during the ice–free (IF) and ice–covered (IC) periods. Rn, Δe. WS, WD, Pres, Ta−Ts, Tl and ICR denote the net radiation, vapor pressure difference, wind speed, wind direction, surface air pressure, difference between the air and lake surface temperatures, average temperature of the lake body from 0 to 300 cm and ice coverage rate, respectively.

63 **Fig. S5.**



64

65 **Fig. S5. Relationship between the observed daily observed and simulated evaporation (E) with**
66 **the atmospheric dynamics model (E_{AD}), mass–transfer model (E_{MT}) and Jensen–Haise model**
67 **(E_{JH}) in the cycle year (annual: AN, a−c), ice–free (IF, d−f) and ice–covered (IC, h–g) periods**
68 **from 2014 to 2018.**

69

70

Fig. S6.

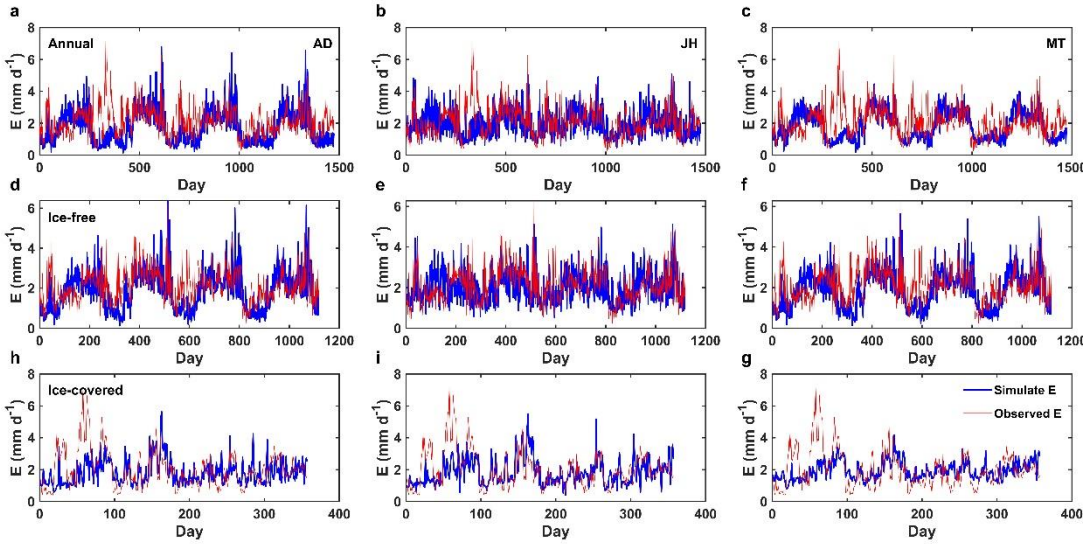


Fig. S6. Daily observed and simulated evaporation (E) with the atmospheric dynamics model (E_{AD}), mass–transfer model (E_{MT}) and Jensen–Haise model (E_{JH}) in the cycle year (annual: AN, a−c), ice–free (IF, d−f) and ice–covered (IC, h−g) periods from 2014 to 2018.

Fig. S7.

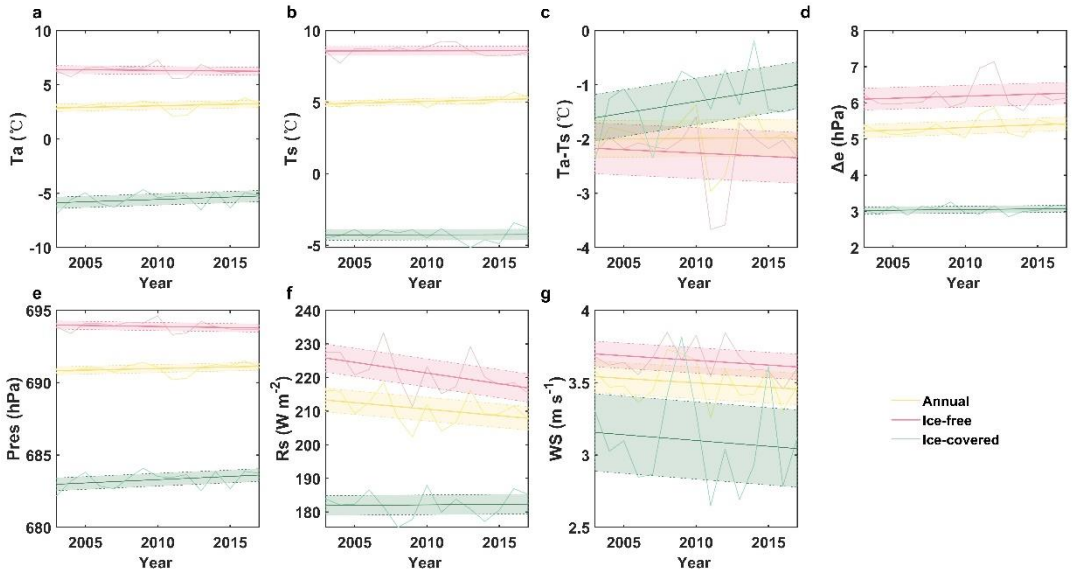


Fig. S7. Interannual variability in the air temperature (Ta), lake surface temperature (Ts), difference between Ta and Ts (Ta−Ts), vapor pressure difference (Δe), air pressure (Pres), downward shortwave radiation (Rs) and wind speed (WS) in the cycle year (annual: AN), ice–free (IF) and ice–covered (IC) periods from 2003 to 2017. The shading indicates the 95% confidence interval of the trend line.

Fig. S8.

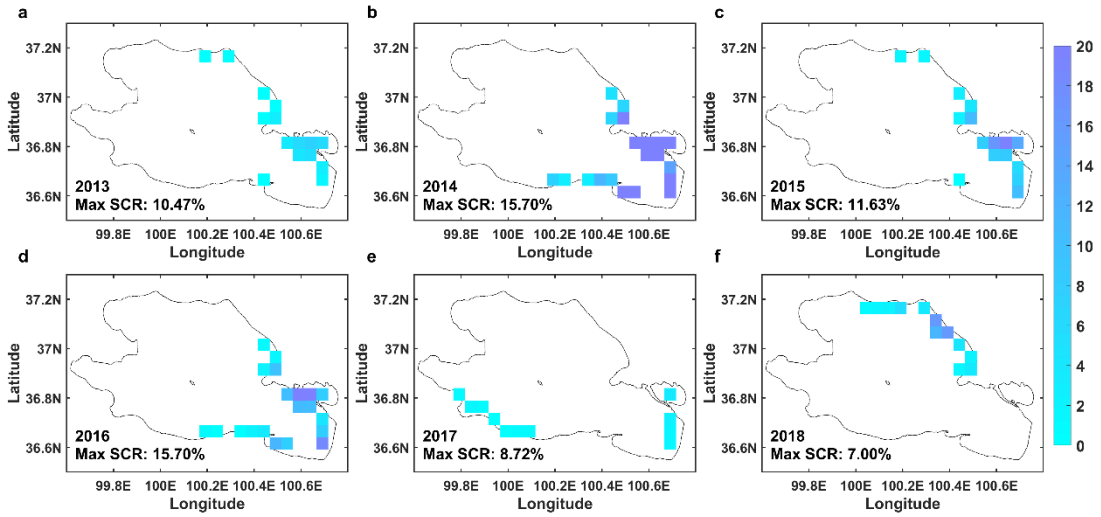


Fig. S8. Spatial distribution of average snow depth (cm) in Qinghai Lake from 2013 to 2018. Max SCR means the maximal snow coverage rate**.**

Fig. S9.

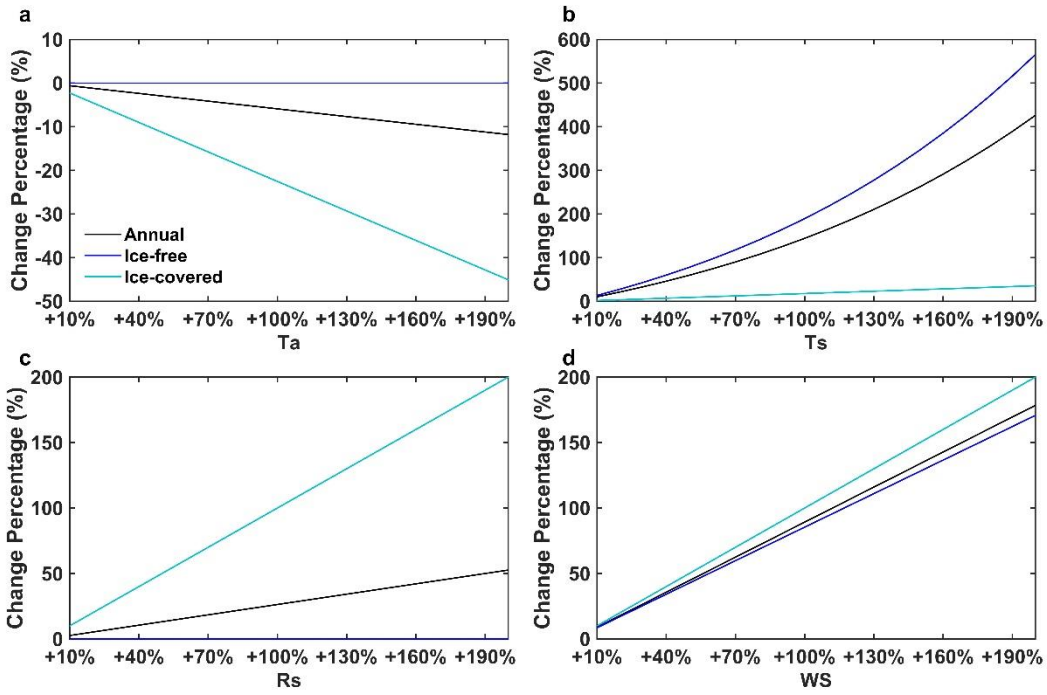


Fig. S9. Sensitivity of E to air temperature (Ta), lake surface temperature (Ts), downward shortwave radiation (Rs) and wind speed (WS) to the simulated evaporation (E) of Qinghai Lake (QHL) in the cycle year (annual: AN), ice–free (IF) and ice–covered (IC) periods from 2003 to 2017.

TABLES

Table S1. Daily mean evaporation of Qinghai Lake (QHL) in the cycle year (annual: AN), ice–free (IF) and ice–covered (IC) periods from 2014 to 2018.

Daily mean evaporation (mm d^{-1})					
Periods	2014	2015	2016	2017	2018
AN	2.16 ± 1.07	2.21 ± 0.93	2.02 ± 0.81	1.96 ± 0.69	2.10 ± 0.81
IF	1.96 ± 0.73	2.34 ± 0.89	2.15 ± 0.79	1.99 ± 0.70	2.24 ± 0.81
IC	2.71 ± 1.55	1.77 ± 0.93	1.57 ± 0.72	1.85 ± 0.62	1.72 ± 0.67
Daytime mean evaporation (mm d^{-1})					
AN	1.21 ± 0.60	1.30 ± 0.62	1.11 ± 0.46	1.11 ± 0.43	1.18 ± 0.48
IF	1.10 ± 0.44	1.36 ± 0.61	1.18 ± 0.44	1.12 ± 0.45	1.23 ± 0.49
IC	1.52 ± 0.83	1.08 ± 0.59	0.87 ± 0.45	1.09 ± 0.37	1.01 ± 0.41
Night mean evaporation (mm d^{-1})					
AN	0.95 ± 0.56	0.91 ± 0.45	0.91 ± 0.48	0.84 ± 0.36	0.93 ± 0.42
IF	0.87 ± 0.38	0.98 ± 0.43	0.97 ± 0.49	0.87 ± 0.37	1.00 ± 0.42
IC	1.18 ± 0.85	0.69 ± 0.46	0.70 ± 0.38	0.77 ± 0.32	0.72 ± 0.36

Table S2. Multiyear average contributions of the changes in air temperature (Ta), lake surface temperature (Ts), downward shortwave radiation (Rs) and wind speed (WS) to the simulated evaporation of Qinghai Lake in the cycle year (annual: AN), ice–free (IF) and ice–covered (IC) periods from 2003 to 2017.

	Ta	Ts	Rs	WS
E Rate in AN (mm)	0.01 ± 0.02	0.01 ± 0.05	−0.02 ± 0.01	−0.05 ± 0.08
E Rate in IF (mm)	0.00 ± 0.00	0.04 ± 0.07	0.00 ± 0.00	−0.01 ± 0.05
E Rate in IC (mm)	0.05 ± 0.06	−0.06 ± 0.04	−0.06 ± 0.04	−0.16 ± 0.21
Sum E in AN (mm)	4.90 ± 6.14	4.35 ± 19.29	−6.17 ± 4.77	−18.92 ± 27.55
Sum E in IF (mm)	0.00 ± 0.00	10.19 ± 19.00	0.00 ± 0.00	−2.69 ± 12.99
Sum E in IC (mm)	4.90 ± 6.14	−5.84 ± 3.54	−6.17 ± 4.77	−16.23 ± 20.79
Percentage in AN (%)	0.92 ± 0.00	2.03 ± 2.20	0.89 ± 0.65	3.75 ± 2.66
Percentage in IF (%)	0.00 ± 0.00	3.11 ± 3.19	0.00 ± 0.00	1.90 ± 1.62
Percentage in IC (%)	3.52 ± 2.46	3.37 ± 1.27	3.19 ± 2.30	11.14 ± 6.23

Table S3. Lake ice phenology of Qinghai Lake from 2002 to 2018.

	IFS	FUS	FUE	BES	BUE	LIF	LIC	LCY
2002		2002/12/25	2003/1/4	2003/3/26	2003/3/30		96	
2003	2003/3/31	2003/12/25	2004/1/3	2004/3/13	2004/3/28	270	95	365
2004	2004/3/29	2004/12/27	2005/1/8	2005/3/14	2005/3/30	274	94	368
2005	2005/3/31	2005/12/16	2005/12/24	2006/3/28	2006/4/6	261	112	373
2006	2006/4/7	2006/12/26	2007/1/11	2007/3/30	2007/4/3	264	99	363
2007	2007/4/4	2007/12/27	2008/1/17	2008/3/31	2008/4/11	268	107	375
2008	2008/4/12	2008/12/22	2009/1/1	2009/3/20	2009/3/30	255	99	354
2009	2009/3/31	2009/12/24	2010/1/1	2010/3/20	2010/4/2	269	100	369
2010	2010/4/3	2010/12/16	2010/12/31	2011/4/5	2011/4/15	258	121	379
2011	2011/4/16	2011/12/21	2012/1/6	2012/4/1	2012/4/14	250	116	366
2012	2012/4/15	2012/12/12	2012/12/27	2013/3/24	2013/4/3	242	113	355
2013	2013/4/4	2013/12/20	2014/1/8	2014/3/3	2014/3/25	261	96	357
2014	2014/3/26	2014/12/23	2015/1/4	2015/3/14	2015/3/29	273	97	370
2015	2015/3/30	2015/12/31	2016/1/22	2016/3/12	2016/3/22	277	83	360
2016	2016/3/23	2017/1/9	2017/1/23	2017/3/18	2017/4/1	293	83	376
2017	2017/4/2	2017/12/31	2018/1/10	2018/3/29	2018/4/3	274	94	368
2018	2018/4/4	2018/12/31	2019/1/10	2019/3/29	2019/4/3	272	94	366

Note: IFS, FUS, FUE, BUS and BUE show the dates of ice–free start, freeze–up start, freeze–up end, break–up start and break–up end, respectively. LIF, LIC and LCY means the length of the ice–free period, ice–covered period and the cycle year (annual: AN), respectively. The ice–covered rate data are from the National Tibetan Plateau Data Center (https://data.tpdc.ac.cn/zh–hans/data/c242394c–fe1a–4840–9beb–0bf4a95d1231/?q=%E6%B9%96%E5%86%B0%E7%89%A9%E5%80%99).