Supplemental Information for

On the predictability of lake surface temperature using air temperature in a changing climate: A case study for Lake Tahoe (USA)

S. Piccolroaz[1,2], N. C. Healey[3], J. D. Lenters[4,5], S. G. Schladow[6,7], S. J. Hook[3], G. B. Sahoo[6], M. Toffolon[1]

[1] Department of Civil, Environmental and Mechanical Engineering, University of Trento, Italy

[2] Institute for Marine and Atmospheric research Utrecht, Department of Physics and Astronomy, Utrecht University, Utrecht, The Netherlands

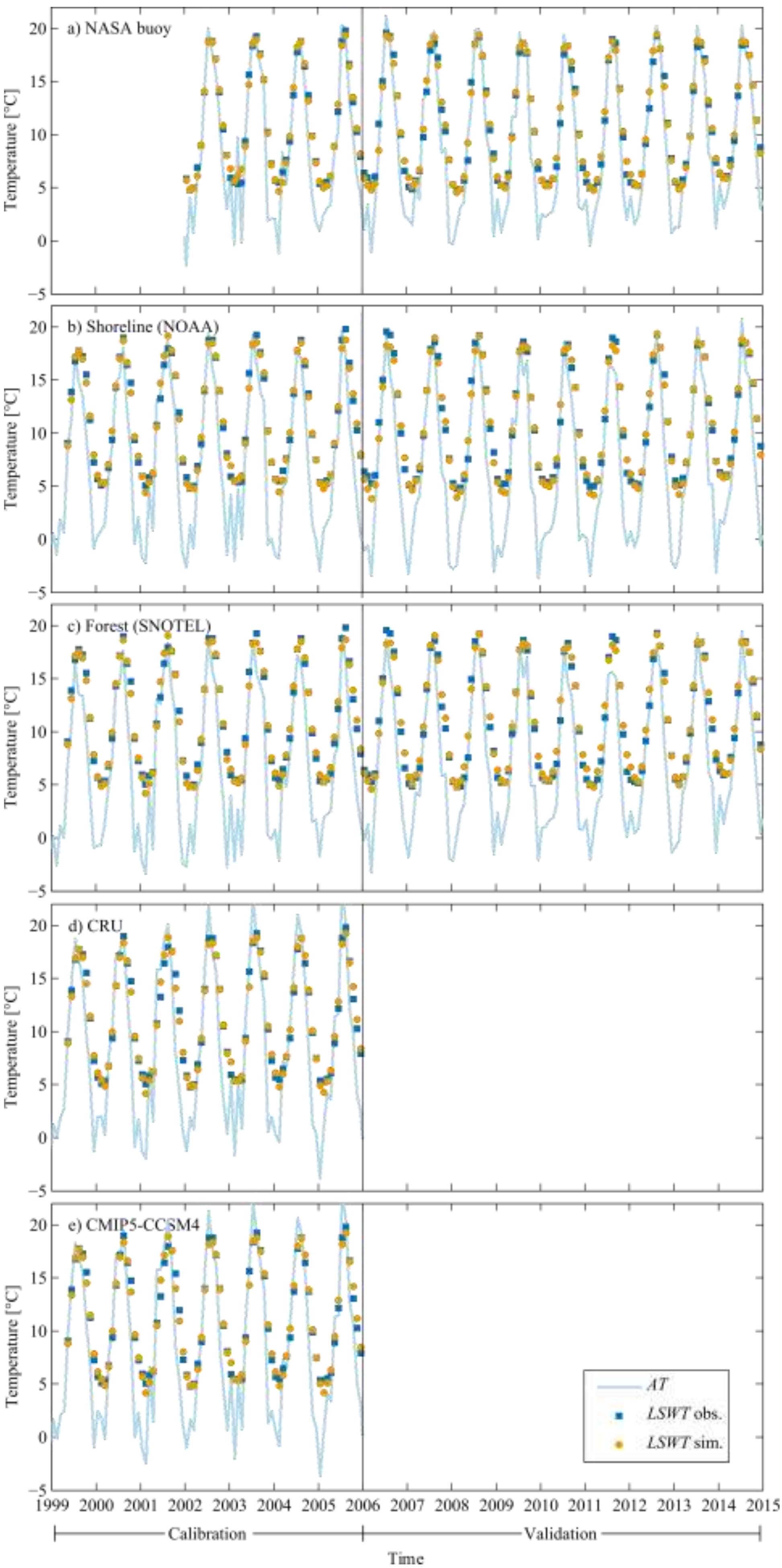
[3] NASA Jet Propulsion Laboratory, California Institute of Technology, USA

[4] Department of Geography, University of Colorado at Boulder, Boulder, USA

[5] Center for Limnology, University of Wisconsin-Madison, Boulder Junction, USA

[6] Department of Civil and Environmental Engineering, University of California, Davis, USA

[7] Tahoe Environmental Research Center, University of California, Davis, USA



a) NASA buoy
b) Shoreline (NOAA)
c) Forest (SNOTEL)
d) CRU
e) CMIP5-CCSM4
Temperature [°C]
AT
LSWT obs.
LSWT sim.
1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015
Calibration
Validation
Time

Figure S1. Time series of modeled (*air2water*) and observed (NASA buoy) *LSWT*, with *air2water* forced by a variety of *AT* datasets: (a) NASA buoy, (b) shoreline (NOAA), (c) forest (SNOTEL), (d) CRU, and (e) CMIP5-CCSM4. A vertical line separates calibration and validation periods.

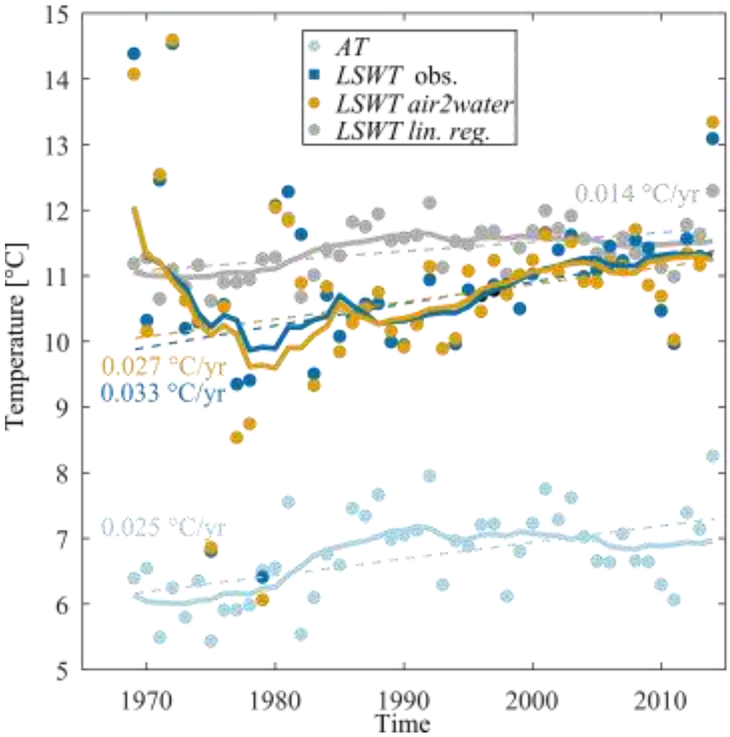


Figure S2. Comparison of mean annual *AT* and *LSWT* (observed at the off-shore station maintained by the University of California, Davis and simulated by the *air2water* model and by a linear regression model) during the period 1969-2014. Also shown are the 10-year moving averages (solid lines) and long-term trends (linear regression; dashed lines).

Note that, as with Figure 4 in the main text, the averaged values of *LSWT* should not be considered as annual means in a strict sense: *LSWT* observations are spot measurements available at monthly frequency thus *LSWT* annual means are evaluated by only averaging over the days when observed *LSWT* is available (i.e., 12 values per year). Differently, due to the higher day-by-day fluctuation of *AT*, the annual averages of *AT* are evaluated considering the whole year (i.e., 365 values per year).

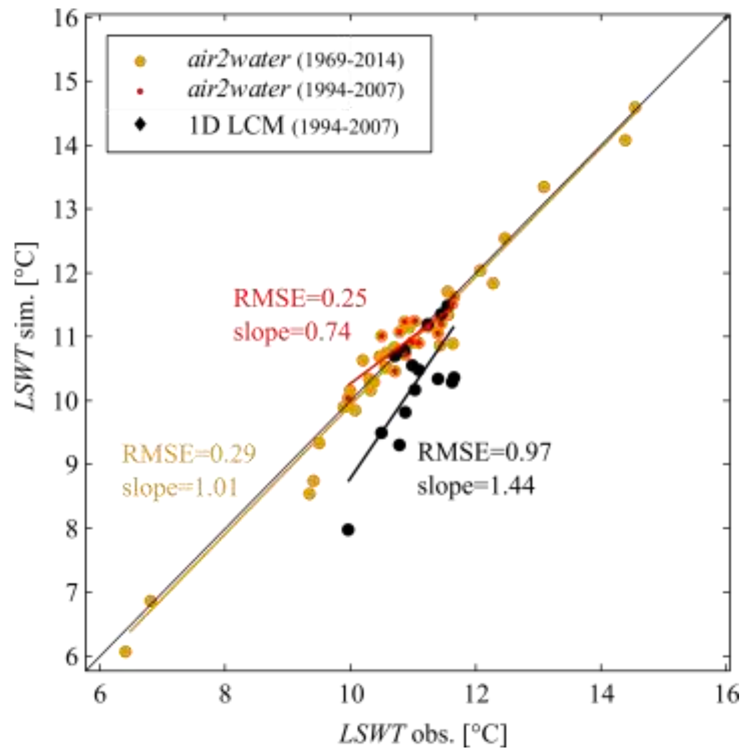


Figure S3. Scatterplot between mean annual observed *LSWT* (off-shore UC Davis) and *LSWT* simulated using the *air2water* and the 1D Lake Clarity Model (1D LCM, Sahoo et al. 2013). Continuous lines identify linear regressions. Dashed lines identify perfect agreement (1:1 line).

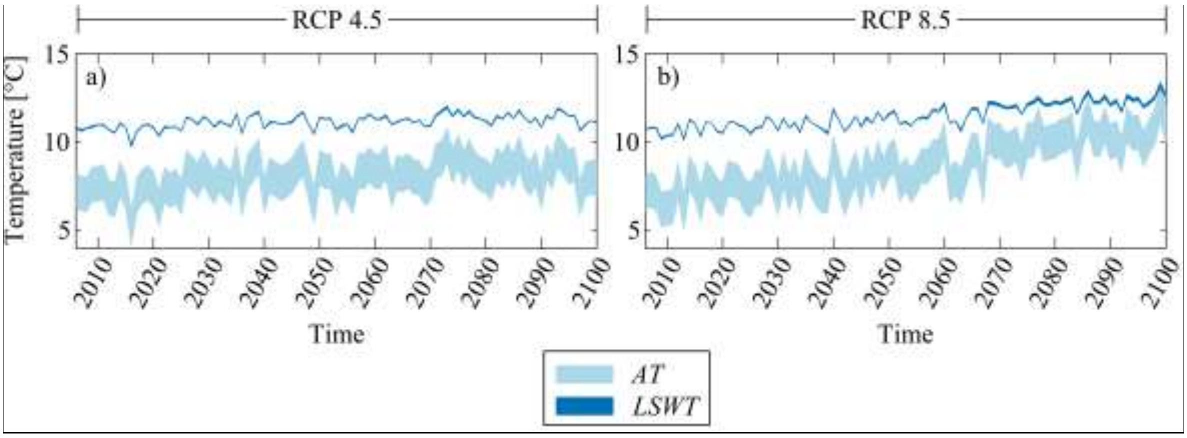


Figure S4. Projected annual averages of *AT* and *LSWT* for the period 2006-2100 under the scenarios RCP 4.5 (a) and RCP 8.5 (b). Thickness of the curves represents the interval of variability of *AT* and *LSWT* corresponding to the different air temperature data sets: NASA buoy, shoreline (NOAA), forest (SNOTEL), CRU, and CMIP5-CCSM4.

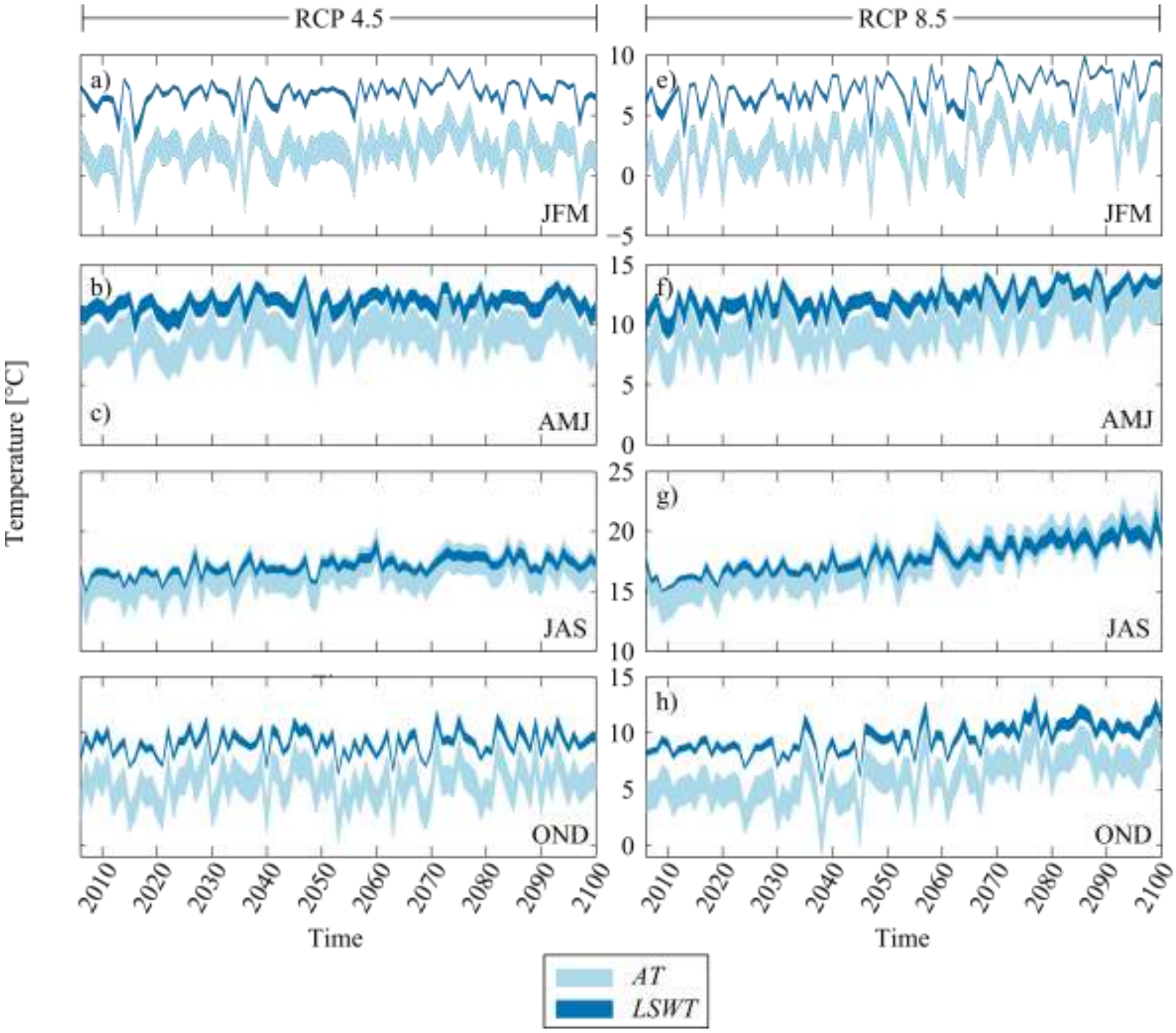


Figure S5. Projected annual averages of *AT* and *LSWT* for the period 2006-2100 under the scenarios RCP 4.5 (a-d) and RCP 8.5 (e-h), using a linear regression model. Thickness of the curves represents the interval of variability of *AT* and *LSWT* corresponding to the different air temperature data sets: NASA buoy, shoreline (NOAA), forest (SNOTEL), CRU, and CMIP5-CCSM4. Compared to Figure 6 in the main text, it is possible to notice a significant thickening of the interval of variability of *LSWT* during all seasons and for both scenarios (especially for AMJ), and a progressive widening of the band with time (especially for JAS and OND). This suggests that simple regression models (e.g., the linear regression model) provide non-univocal *LSWT* predictions depending on the *AT* dataset used as input, with an increase of the error as *AT* goes beyond the limits of the time series used for model calibration (compare also Table S2 with Table 3 in the main text). These model predictions do not provide a robust and reliable description of the future evolution of *LSWT* in Lake Tahoe.

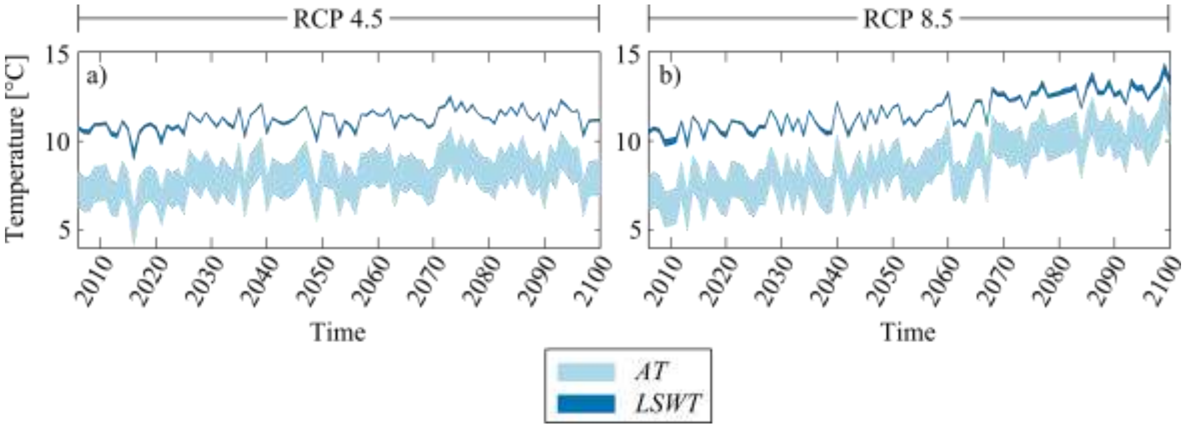


Figure S6. Projected annual averages of *AT* and *LSWT* for the period 2006-2100 under the scenarios RCP 4.5 (a) and RCP 8.5 (b), using a linear regression model. Thickness of the curves represents the interval of variability of *AT* and *LSWT* corresponding to the different air temperature data sets: NASA buoy, shoreline (NOAA), forest (SNOTEL), CRU, and CMIP5-CCSM4. Compared to Figure S4, it is possible to notice the widening of the interval of variability of *LSWT* for both scenarios, although it is not as significant as in Figure S5, thus suggesting the existence of a compensation effect among the different seasons (compare also Table S2 with Table 3 in the main text). These model predictions do not provide a robust and reliable description of the future evolution of *LSWT* in Lake Tahoe.

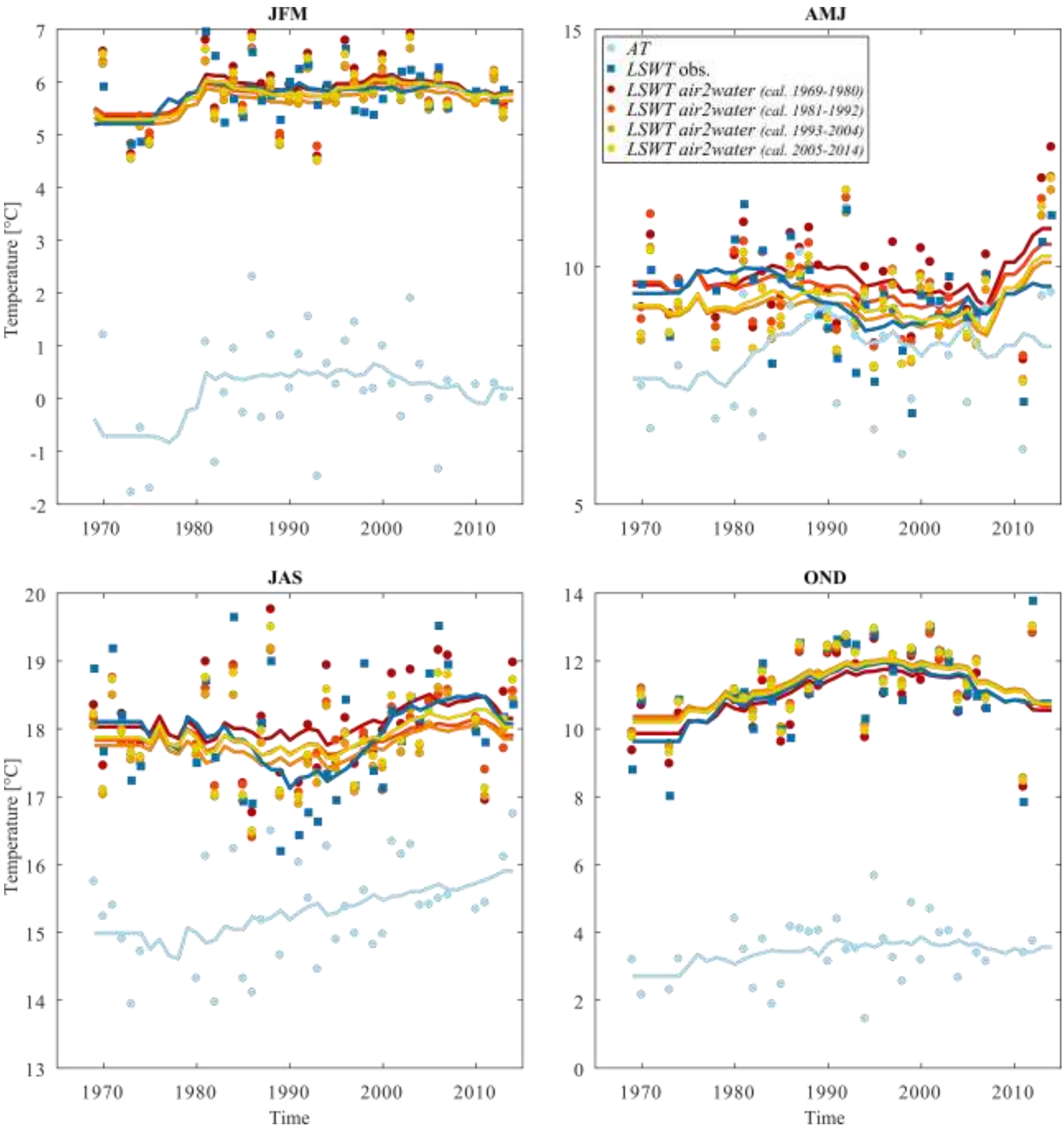


Figure S7. Comparison of mean JFM, AMJ, JAS, and OND *AT* and *LSWT* observed at the off-shore station maintained by the University of California, Davis and simulated by the *air2water* model considering four different 12-year calibration windows: 1969-1980, 1981-1992, 1993-2004, and the shorter 2005-2014. Also shown are the 10-year moving averages (solid lines) and long-term trends (linear regression; dashed lines).

Here we show two figures comparing air temperature projections for the CCSM4 model and other CMIP5 models, for RCP 4.5 and RCP 8.5 scenarios, respectively.

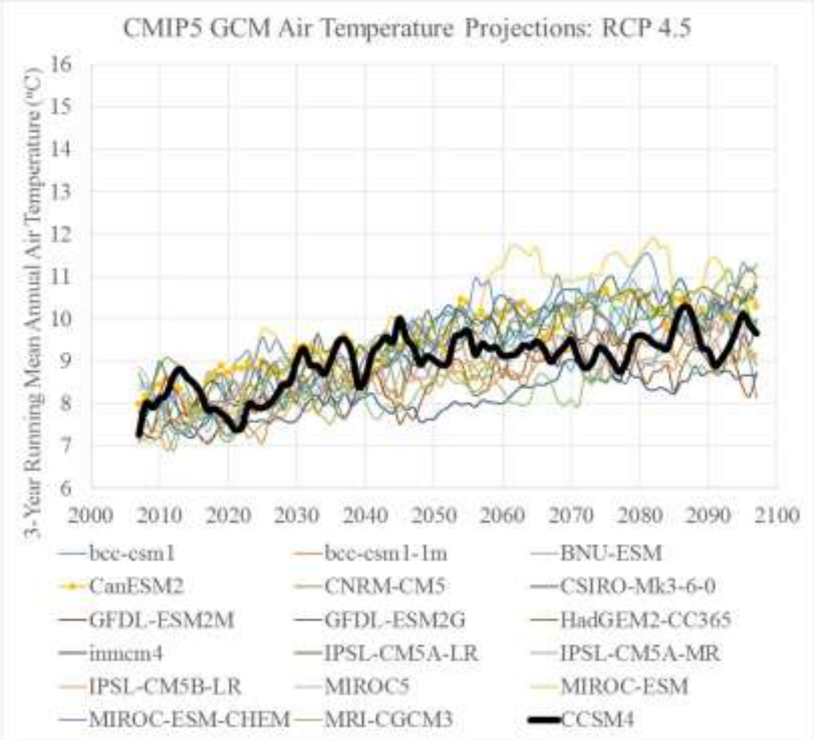


Figure S8. CMIP5 GCM projections of air temperature at Lake Tahoe under the Representative Concentration Pathway (RCP) 4.5. CCSM4 has been made thick/bold for emphasis.

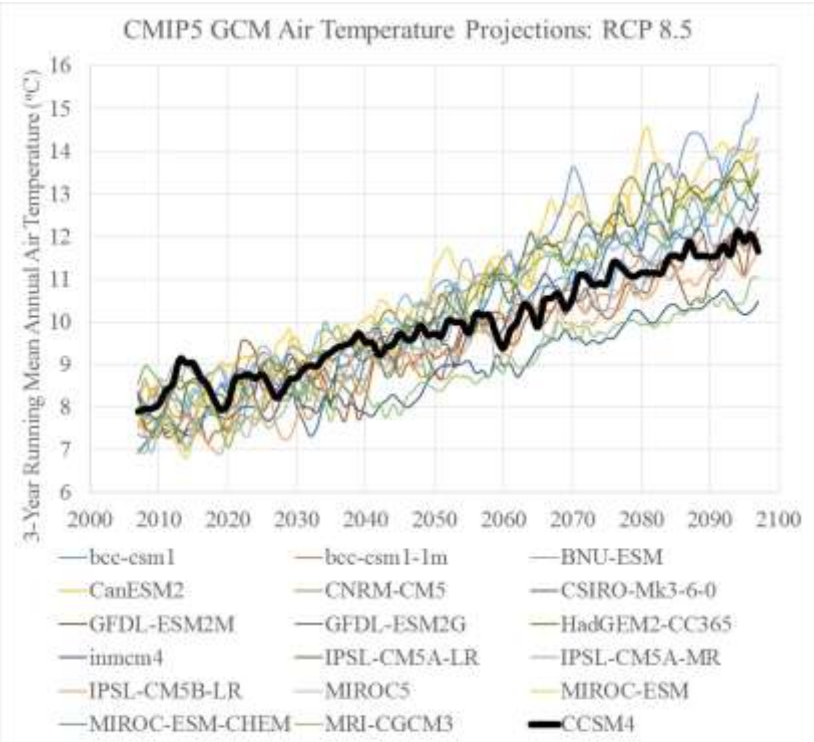


Figure S9. CMIP5 GCM projections of air temperature at Lake Tahoe under the Representative Concentration Pathway (RCP) 8.5. CCSM4 has been made thick/bold for emphasis.

Water temperature data source	Air temperature data source	*m*	*q*	Calibration				Validation			
				RMSE (°C)	NSE (-)	ME (°C)	Max AE (°C)	RMSE (°C)	NSE (-)	ME (°C)	Max AE (°C)
NASA buoy	NASA buoy	0.78	4.19	1.49	0.91	3.44E-2	4.36	1.45	0.91	0.14	3.97
	Shoreline (NOAA)	0.70	6.04	1.94	0.84	1.27E-2	3.56	1.92	0.85	-0.05	4.21
	Forest (SNOTEL)	0.72	6.17	1.84	0.86	-2.44E-3	3.85	1.88	0.86	0.41	4.12
	CRU	0.63	5.77	2.23	0.79	-3.17E-3	4.36	n.a.	n.a.	n.a.	n.a.
	CMIP5-CCSM4	0.65	5.48	2.03	0.83	9.67E-3	4.07	n.a.	n.a.	n.a.	n.a.
UC Davis off-shore	Shoreline (NOAA)	0.59	7.39	2.69	0.72	1.81E-2	6.46	2.53	0.74	0.44	5.98

Table S1. Parameters of the linear regression model ($LSWT = m\ AT + q$) and statistics of model performance at monthly scale (daily for the last case: off-shore UC Davis) obtained in calibration and in validation considering different sources of observed air and water temperature. The table shows a general, significant worsening of model performance in both calibration and validation compared to the results of *air2water* (see Table 2 in the main text).
RMSE: Root Mean Square Error; NSE: Nash-Sutcliffe Efficiency index; ME: Mean Error (i.e., bias); MaxAE: Maximum Absolute Error.

Scenario	Period	*wAT* [°C]	*wLSWT* [°C]	*tAT* [°C decade^{-1}]	*tLSWT* [°C decade^{-1}]
RCP 4.5	JFM	2.30	0.42	0.10	0.07
	AMJ	2.79	1.16	0.12	0.09
	JAS	2.46	0.59	0.23	0.16
	OND	2.52	0.64	0.09	0.06
	Year	1.97	0.13	0.14	0.10
RCP 8.5	JFM	2.30	0.41	0.35	0.24
	AMJ	2.79	1.09	0.39	0.27
	JAS	2.46	0.74	0.62	0.43
	OND	2.52	0.73	0.42	0.29
	Year	1.97	0.19	0.45	0.31

Table S2. Average width of the interval of variability of *AT*(*wAT*) and *LSWT* (*wLSWT*) projected using a linear regression model for the period 2006-2100 under the two climate change scenarios (RCP 4.5 and RCP 8.5) and shown in Figure S5 and Figure S6. *wAT* and *wLSWT* are evaluated for the four seasons and for the whole year. Linear trends of *AT* (*tAT*) and *LSWT* (*tLSWT*) are also reported. Compared to Table 3 in the main text, it is possible to appreciate a significant widening of the interval of variability of *LSWT* (nearly the double for the mean annual *LSWT*, on average three times for the mean seasonal *LSWT*, with peaks of more than four times for the AMJ and JAS mean *LSWT*), and a general increase of the long-term trends of *LSWT* (especially for the RCP 8.5 scenario). Given the large errors and low model performance of the linear regression model (Table S1), and the relatively wide interval of variability of predicted *LSWT*, these model predictions do not provide a robust and reliable description of the future evolution of *LSWT* in Lake Tahoe.