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*Supplement of*

# Historical modelling of changes in Lake Erken thermal conditions

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# Historical modelling of changes in Lake Erken thermal conditions

**S1. Limitations of GOTM in predicting water temperature during ice cover conditions**

The GOTM model used for the simulation documented here did not have a functioning ice model, but instead cut off surface heat exchange when the simulated surface water temperature became negative. This provided a very simple way to make continuous simulations that include freezing conditions that would normally lead to the formation of ice. However, the temperature profiles during winter were not realistic, and could not be used for model calibration. This can be seen in figures S1-S2 where a comparison between simulated an observed water temperature at 1m and 15 m depth is reported for year 2009. At 1 m depth, simulated and observed temperature are rather similar throughout the entire year. However, at 15 m depth, the model does not take into account the heat loss from sediment during ice-cover, which cause an increase in bottom water temperature. During winter, there is a clear mismatch between simulated and observed water temperature. For this reason, all water temperature data collected between December 1st - March 31st are excluded and only data between April 1st - November 30th are used for model calibration.
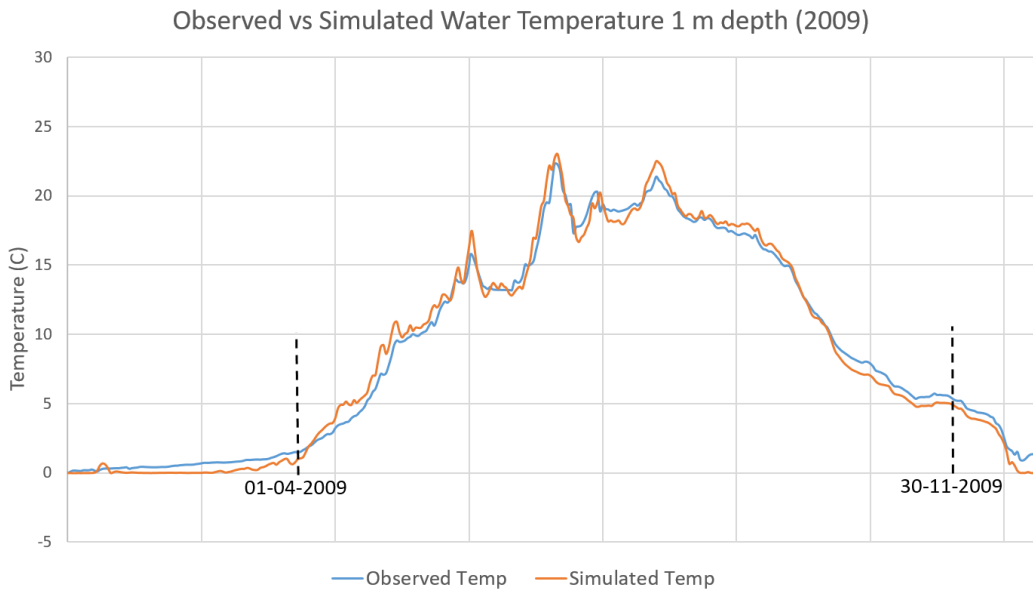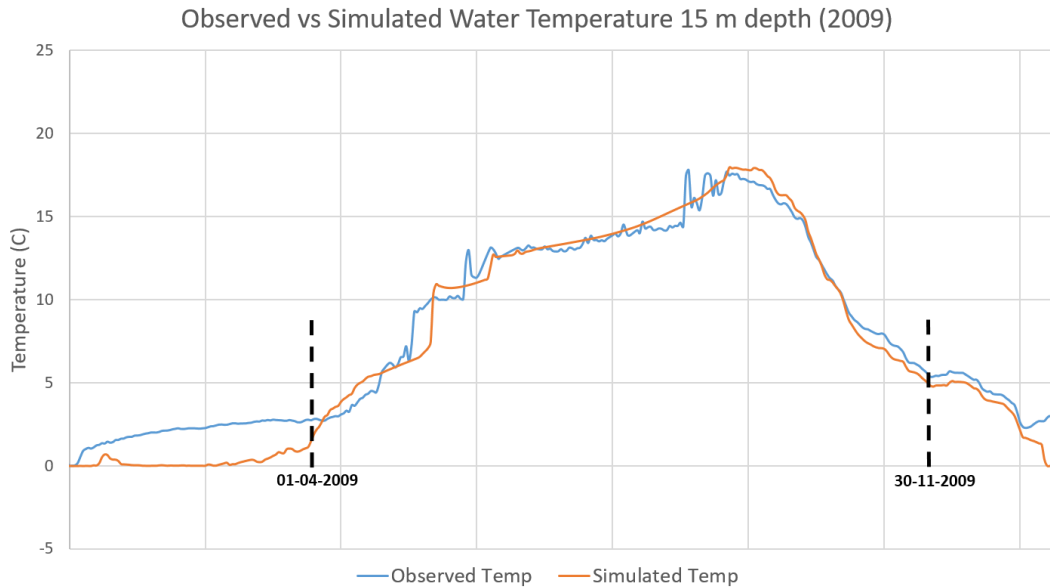


**Figure S1: Comparison between observed and simulated water temperature data at 1m depth in 2009.**

**Figure S2: Comparison between observed and simulated water temperature data at 15m depth in 2009.**

## S2. Data sources of driving parameters and missing data estimation

Since October 12th 1988, the Erken meteorological station on Malma island has collected hourly data of wind speed (WS), air
temperature (Air T) and downwelling short wave radiation (SWR) in digital form using a data logging system. Prior to this,
old paper records of hourly WS data from the Erken station were also available for the years 1964, 1966-1969 and 1972-1973.
Old paper records of total daily SWR from Lake Erken were also available at SMHI archive (Swedish Meteorological and
Hydrological Institute) measured in the periods 1961-1965 and 1969-1983. Hourly CC data were retrieved from Svenska
Hogarna station (59.4445 N, 19.5059 E) for the entire period of study (1961-2017). These data were downloaded from SMHI
website (http://opendata-download-metobs.smhi.se/explore/). Daily precipitation (DP) data were retrieved from Erken
meteorological station paper records (1961-1965) and from several meteorological stations in the vicinity of Lake Erken:
Norrtälje (59.7506 N, 18.7091 E, period 1966-1984), Norrveda (59.8298 N, 18.9524 E, periods Jun-Jul. 1978 and Feb.-Jun.
1979), Rimbo (59.7487 N, 18.3535 E, period 1984-1988), Norrtälje-Vasby (59.8524 N, 18.7296 E, period 1989-1994) and
Svanberga (59.8321 N, 18.6348 E, period 1995-2016). DP data of these stations were downloaded from SMHI website. For
the period 1995-2016, air pressure (Air P) and relative humidity (RH) data were provided by Svanberga meteorological station
(59.8321 N, 18.6348 E), the closest SMHI station to the lake (about 800 m far from the Erken Laboratory meteorological
station). In the following sections (2.1-2.5), a detailed description of how we estimated WS, Air T, RH, Air P and SWR missing
data using Neural Network Analysis is reported. At the end, we obtained a complete hourly dataset of meteorological data

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from January 1$^{st}$ 1961 to December 31$^{st}$ 2017. However, since the observed water temperature data to calibrate the model were available until October 31$^{st}$ 2017 the model simulation period stops on that day.
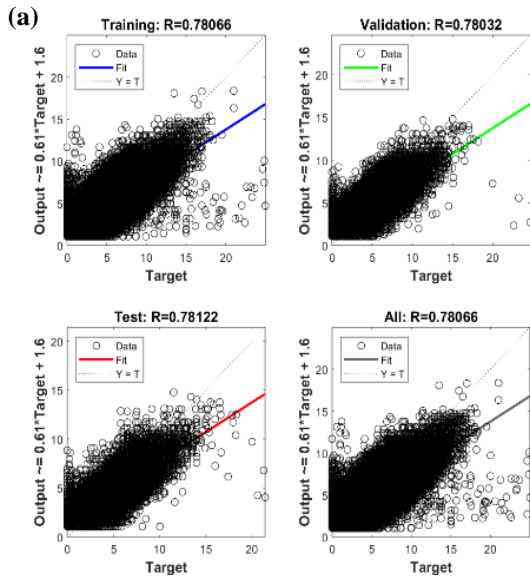
## S2.1 Wind speed estimation

Missing WS data were predicted using the Erken meteorological station wind speed data as target and wind speed datasets from different SMHI stations (downloaded from SMHI database) as input data (table S1). In Matlab version R2017b (MathWorks Inc. Natick, Massachusetts), five different ANN function fitting analyses (*nftool*) were developed to predict Lake Erken wind speed, using the maximum number of input datasets available for each time period. Once the input-target best fit function was calculated, WS was predicted for the entire time interval of the input datasets for each ANN analysis. WS data above 25 m/s were removed from the analysis. Figure S3 shows the regression plots of the 5 different ANN function fitting analyses developed for the overlapped time periods between input and target datasets and the error histogram associated with every analysis. If different analyses predicted wind speed at the same time point, the prediction with the highest correlation and smallest error between output and target was preferred. If none of the 5 fitting function analyses predicted wind speed data for a certain time point (i.e. none of the input datasets had a wind speed value at that time point) a linear interpolation was used to fill missing data in the final wind speed dataset used in the GOTM model. In this case, 28700 missing data were replaced with a linear interpolation (total no. of data points = 499656). Figure S1 shows the graphical results of ANN *nftool* analysis for predicting wind speed.
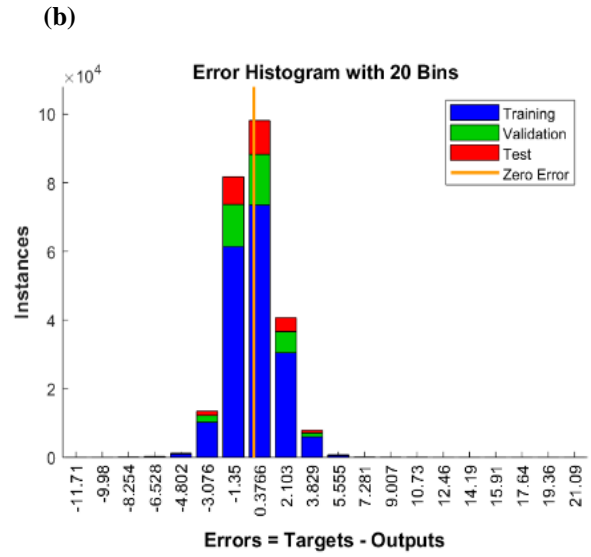
**Table S1: Schematic description of wind speed estimation using ANN analysis**

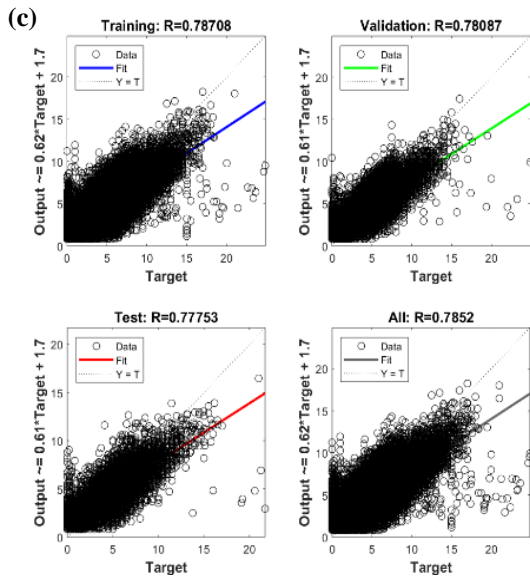| WS ANN analysis no. | WS input data (SMHI stations) * | WS target data (met station) | Compared years between inputs and target | Time interval of predicted data | No. of missing data replaced by predicted WS (% of total data) |
|---|---|---|---|---|---|
| 1 | UF+SB | Erken | 1964, 1966-1969, 1972-1973, 1988-2016 | 1961-2017 | 6900 (1.4 %) |
| 2 | UF+SB+Ar | Erken | 1964, 1966-1969, 1972-1973, 1988-1997 | 1962-1997 | 134199 (26.9 %) |
| 3 | UF+SB+Ar+Sk | Erken | 1988-1997 | 1976-1997 | 20524 (4.1 %) |
| 4 | UF+SB+Ar+Sk+AUT | Erken | 1985-1997 | 1985-1997 | 22526 (4.5 %) |
| 5 | UF+SB+AUT+Sv | Erken | 1995-2016 | 1995-2017 | 4418 (0.9 %) |
| | | | | | **Total 188567 (38.1%)** |

*UF = Uppsala Flygplats (59.8953 N, 17.5935 E), SB = Stockholm-Bromma (59.3537 N, 17.9513 E), Ar = Arlanda (59.6557 N, 17.9462 E), Sk = Skarpö A (59.3455 N, 18.7406 E), AUT = Uppsala Aut (59.8586 N, 17.6253 E), Sv = Svanberga (59.8321 N, 18.6348 E)
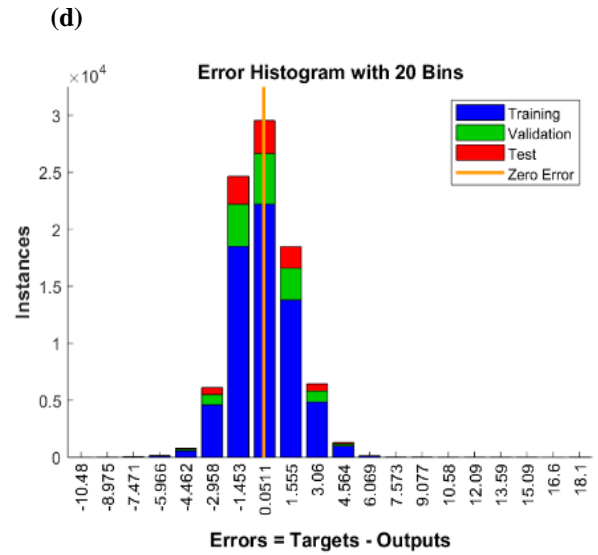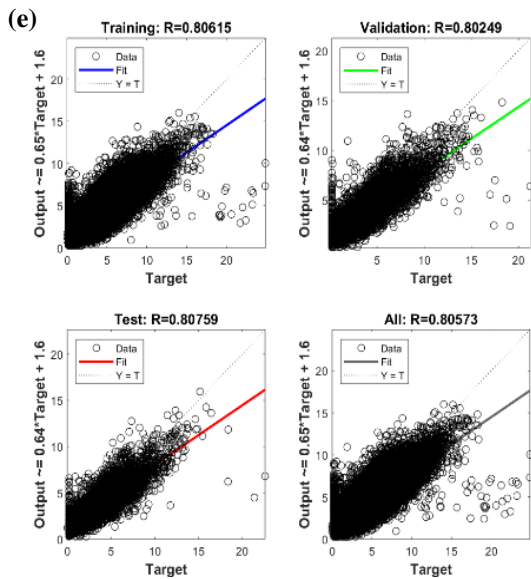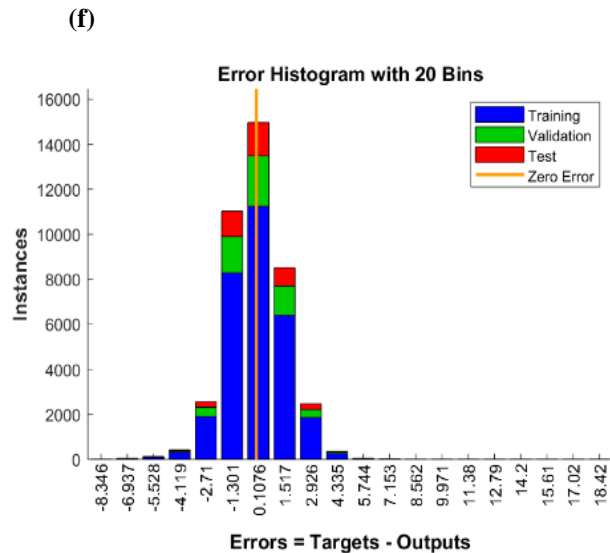
**(a)**



WS ANN 1

**(b)**



WS ANN 1

**(c)**



WS ANN 2

**(d)**



WS ANN 2

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**(e)**



WS ANN 3
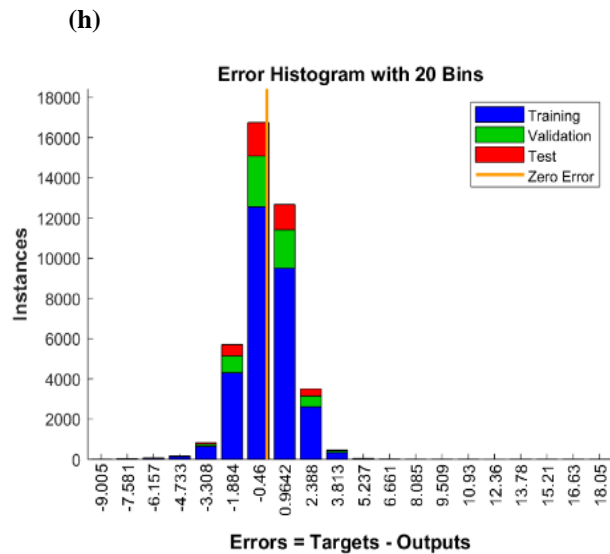
**(f)**



WS ANN 3

**(g)**
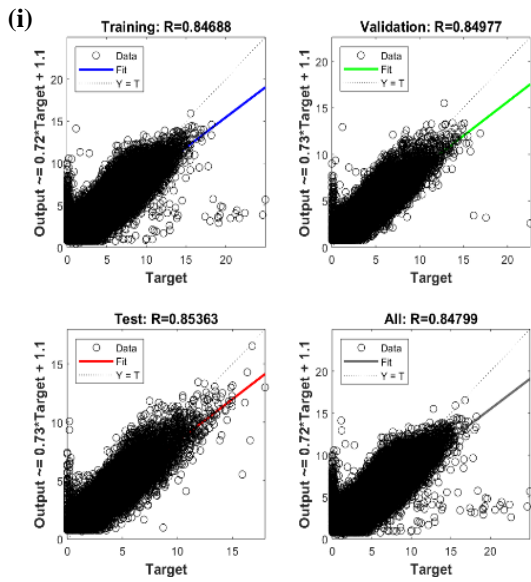


WS ANN 4

**(h)**



WS ANN 4

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**(i)**
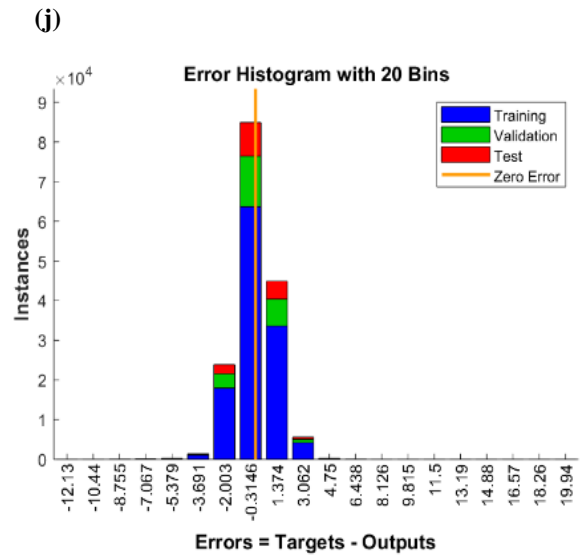


WS ANN 5

**(j)**
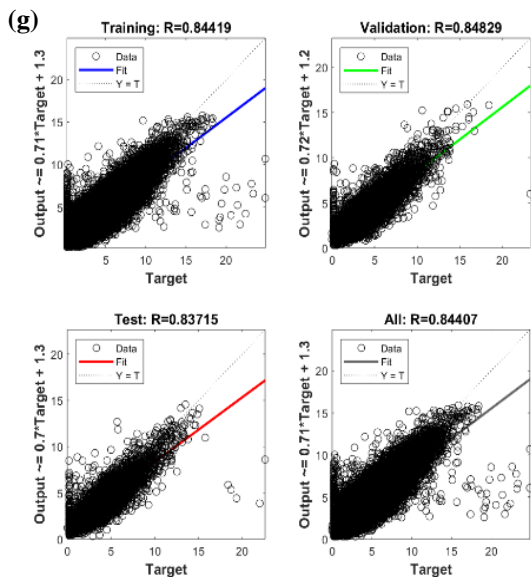


WS ANN 5

**Figure S3: Graphical results of WS ANN 1-5. Panels (a), (c), (e), (g), (i) show the regression plots between target (Erken WS) and output for training, validation, test and overall regression; panels (b), (d), (f), (h), (j) show the error histogram plots of the different WS ANN analyses performed to predict wind speed.**

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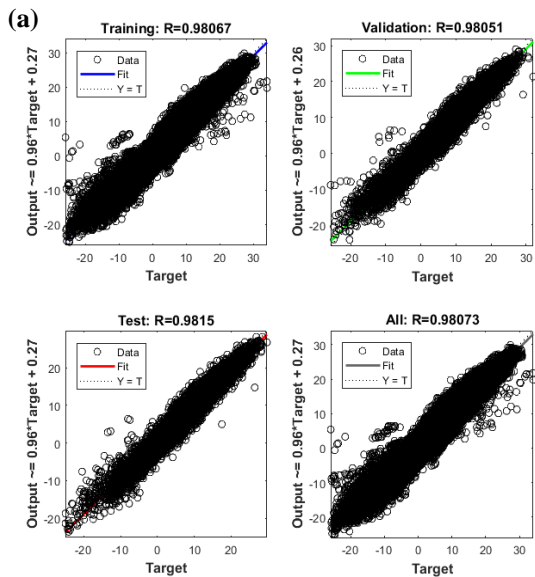
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## S2.2 Air temperature estimation

Hourly air temperature (Air T) have been recorded by the Erken meteorological station starting from October 12th, 1988 and continues today. The number of hourly Air T data recorded by the Erken meteorological station in the period Oct. 1988-Dec. 2017 is 235250. To complete air temperature dataset for the period 1961-1988, Erken Air T was estimated from air temperature

5   of Stockholm-Bromma (SB) and Uppsala Flygplats (UF) stations using ANN function fitting analysis (*nftool*) in Matlab version R2017b (MathWorks Inc. Natick, Massachusetts). To replace missing data in the time interval 1988-2017, Erken Air T was predicted from SB, UF, Arlanda (Ar) and Uppsala AUT for the period 1988-1997. For the period 1998-2000 Erken Air T missing values were predicted from SB, UF, AUT and Söderarm (S). Missing values for the period 2001-2017 were predicted from air temperature of SB, UF, AUT, S and Films Kirkby (FK) stations (table S2). The remaining missing data that were not

10   possible to predict using air temperature data from neighbouring stations were replaced by linear interpolation (missing data replaced by linear interpolation over the period 1961-2017: 29424). Results of Air T ANN function fitting analyses are shown in figure S4.

**Table S2: Schematic description of air temperature prediction using ANN analysis**
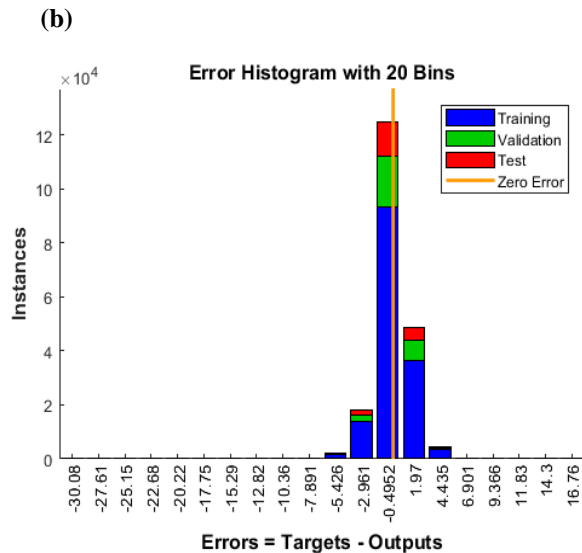
| Air T ANN analysis no. | Air T input data (met stations) * | Air T target data (met station) | Compared years between inputs and target | Time interval of predicted data | No. of missing data replaced by predicted WS (% of total data) |
|---|---|---|---|---|---|
| 1 | UF+SB | Erken | 1988-2016 | 1961-1988 | 224228 (45.2 %) |
| 2 | UF+SB+Ar+AUT | Erken | 1988-1997 | 1988-1997 | 6111 (1.2 %) |
| 3 | UF+SB+AUT+S | Erken | 1998-2000 | 1998-2000 | 66 (0.1 %) |
| 4 | UF+SB+AUT+S+FK | Erken | 2001-2016 | 2001-2017 | 4577 (0.9%) |
|   |   |   |   |   | **Total 234982 (47.0%)** |

15   *UF = Uppsala Flygplats (59.8953 N, 17.5935 E), SB = Stockholm-Bromma (59.3537 N, 17.9513 E), Ar = Arlanda (59.6557 N, 17.9462 E), AUT = Uppsala Aut (59.8586 N, 17.6253 E), S = Söderarm (59.7538 N, 19.4089 E), FK = Films Kirkby (60.2363 N, 17.9078 E)
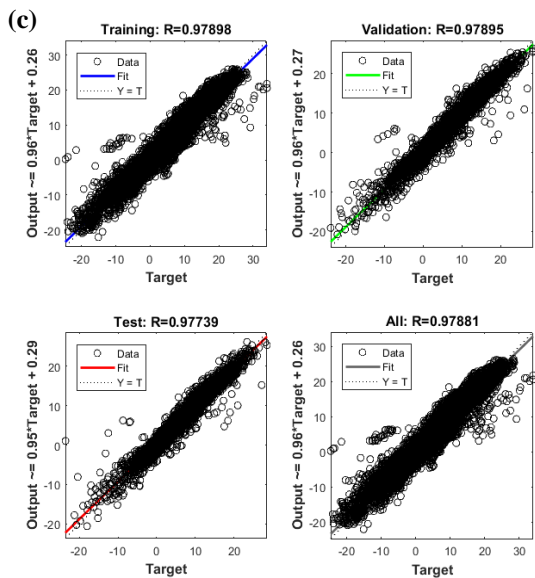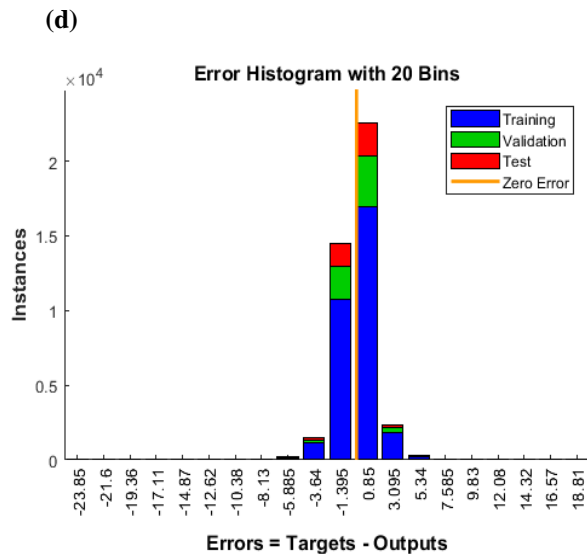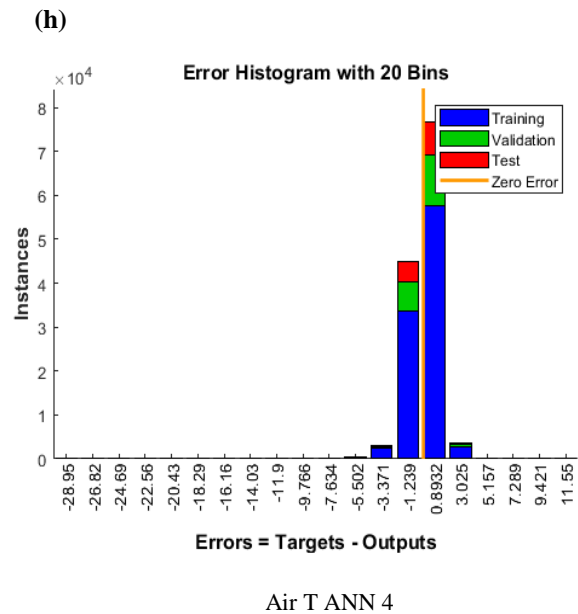
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**(a)**



Air T ANN 1

**(b)**



Air T ANN 1

**(c)**



Air T ANN 2

**(d)**



Air T ANN 2

**(e)**

Training: R=0.98981

Validation: R=0.98949

Test: R=0.98972

All: R=0.98975

Air T ANN 3

**(f)**

Error Histogram with 20 Bins

Air T ANN 3



**(g)**

Training: R=0.9909

Validation: R=0.99096

Test: R=0.99104

All: R=0.99092

Air T ANN 4

**(h)**

Error Histogram with 20 Bins
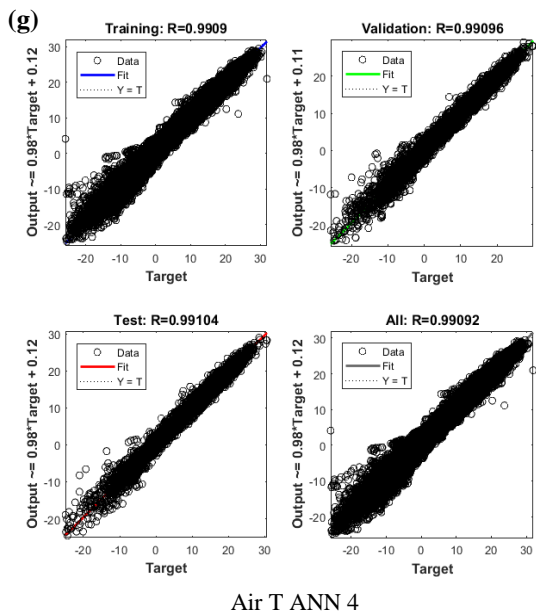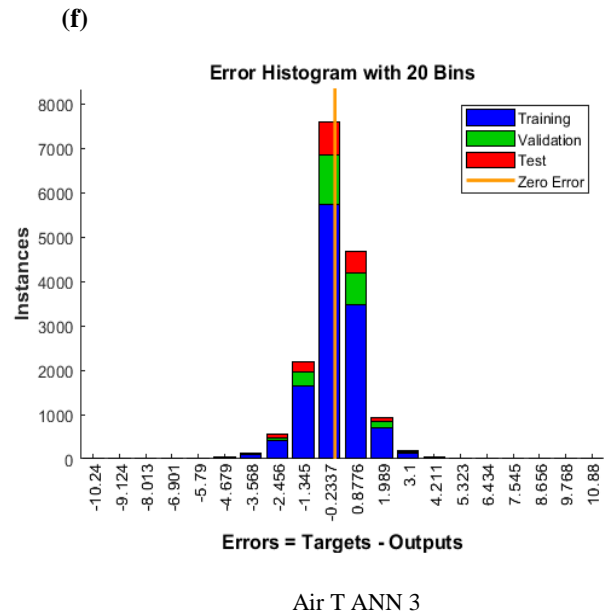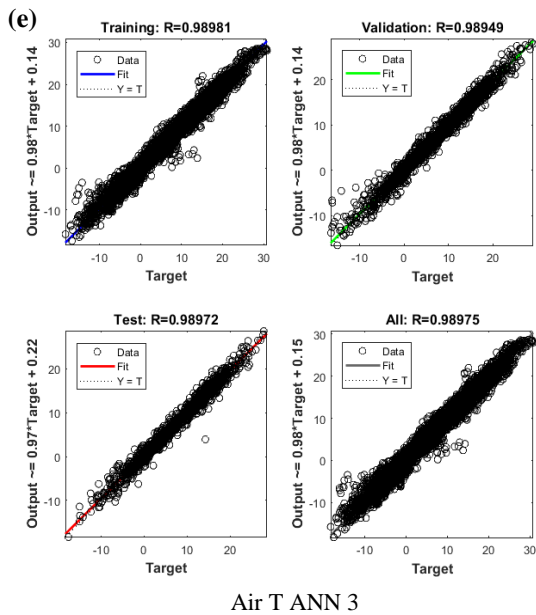
Air T ANN 4

**Figure S4: Graphical results of AirT ANN 1-4. Panels (a), (c), (e), (g) show the regression plots between target (Erken AirT) and output for training, validation, test and overall regression; panels (b), (d), (f), (h) show the error histogram plots of the different AirT ANN analyses performed to predict Air Temperature.**

**S2.3 Relative humidity estimation**

Hourly relative humidity (RH) from the Svanberga station was used as the target dataset in ANN analysis, since no humidity data have been collected from Erken meteorological station. Svanberga relative humidity records start on August 1st 1995 and continue to present days. The number of RH data collected from Svanberga station during the period August 1995-December

5   2017 is 191678. To predict relative humidity for the period 1961-1995, relative humidity from UF was used as input data in ANN best fit function analysis. Missing data between 1995-2017 have been predicted from UF and AUT relative humidity (Table S3). These humidity data were retrieved from SMHI database (Thomas Carlund, personal communication). Output-target correlation and related error of ANN analyses are shown in figure S5. Missing data that could not be predicted from ANN function fitting analyses have been replaced using linear interpolation (number of missing data replaced by linear

10   interpolation over the period 1961-2017: 13886).

**Table S3: Schematic description of relative humidity prediction using ANN analysis**

| RH ANN analysis no. | RH input data (met stations)* | RH target data (met station) | Compared years between inputs and target | Time interval of predicted data | No. of missing data replaced by predicted RH (% of total data) |
|---|---|---|---|---|---|
| 1 | UF | Svanberga | 1995-2017 | 1961-2017 | 228757 (45.8%) |
| 2 | UF+AUT | Svanberga | 1995-2017 | 1986-2017 | 65335 (13.1%) |
| | | | | | **Total 294092 (58.9%)** |

*UF = Uppsala Flygplats (59.8953 N, 17.5935 E), AUT = Uppsala Aut (59.8586 N, 17.6253 E)

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RH ANN 1

RH ANN 1
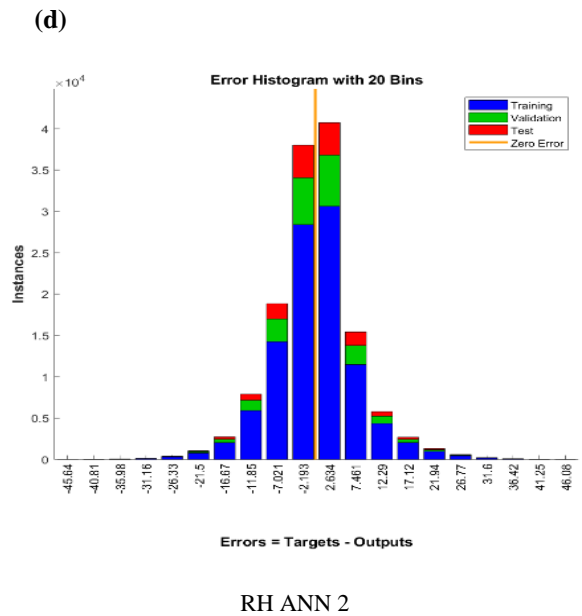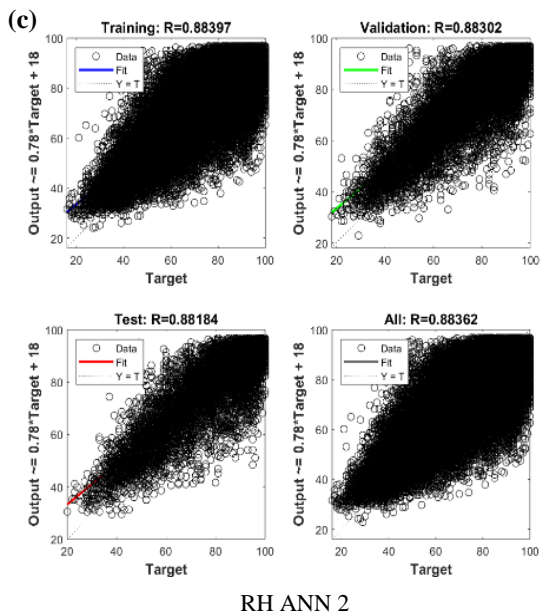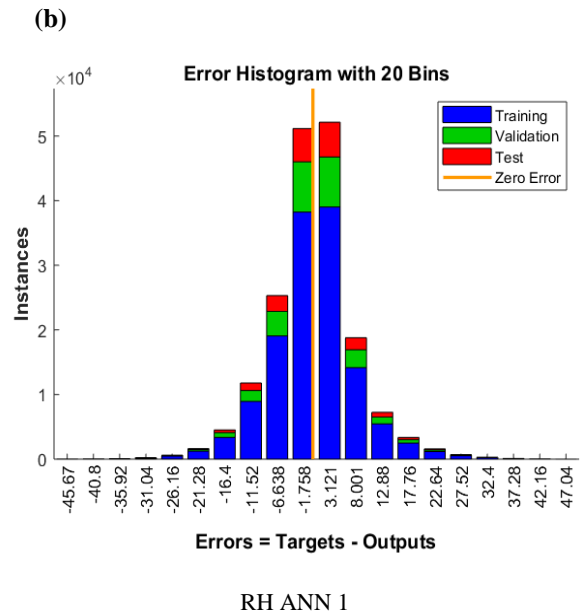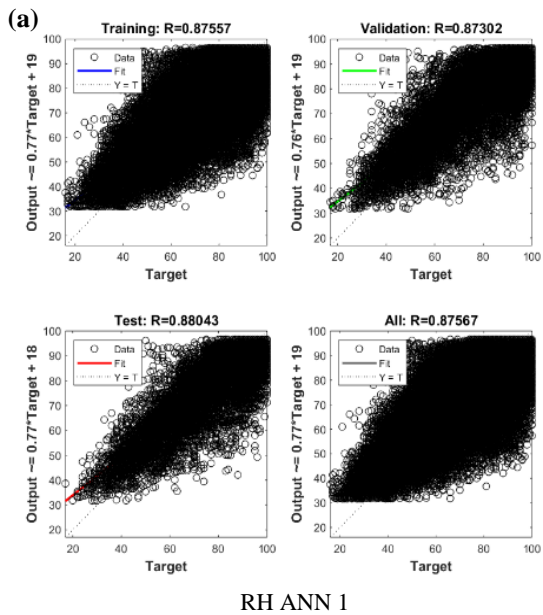
RH ANN 2

RH ANN 2

**Figure S5: Graphical results of RH ANN 1-2. Panels a, c show the regression plots between target (Svanberga RH) and output for training, validation, test and overall regression; panels b, d show the error histogram plots of the different RH ANN analyses performed to predict relative humidity.**

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## S2.4 Air pressure estimation

Since air pressure (Air P) data from Malma island were available only between Nov 2016-Dec 2017, hourly air pressure prediction with ANN was performed using Svanberga Air P dataset (185026 data points) as target and air pressure datasets from UF and SB as inputs data for predicting Air P missing data over the period 1961-2016 (table S4). Air P from Erken meteorological station were used to complete the dataset between Nov. 2016-Dec. 2017. Missing data that could not be predicted by ANN function fitting analysis were replaced by linear interpolation (missing data replaced by linear interpolation: 45212). Output-target regression plots and errors are shown in figure S6.

**Table S4: Schematic description of air pressure prediction using ANN analysis**
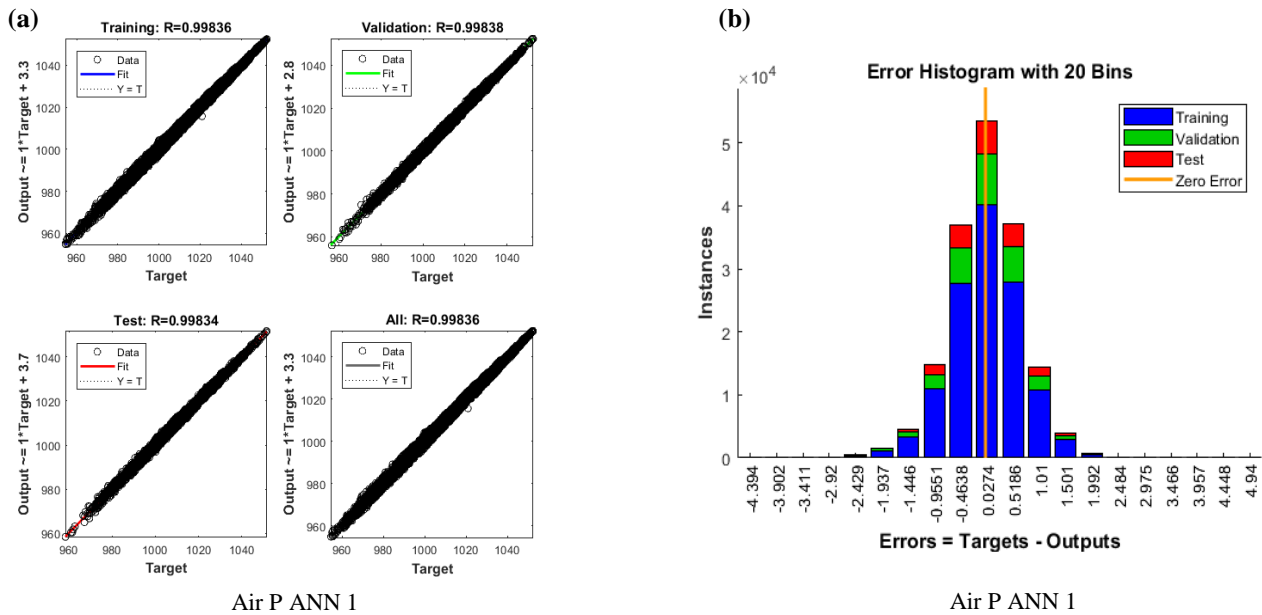
| Air P ANN analysis no. | Air P input data (met station)* | Air P target data (met station) | Compared years between inputs and target | Time interval of predicted data | No. of missing data replaced by predicted WS (% of total data) |
|---|---|---|---|---|---|
| 1 | UF+SB | Svanberga | 1995-2016 | 1961-2016 | 259563 |
| | | | | | **Total 259563 (53.0 %)** |

*UF = Uppsala Flygplats (59.8953 N, 17.5935 E), SB = Stockholm-Bromma (59.3537 N, 17.9513 E)

**(a)**

Training: R=0.99836

Validation: R=0.99838

Test: R=0.99834

All: R=0.99836

Air P ANN 1

**(b)**

Error Histogram with 20 Bins

Air P ANN 1

**Figure S6: Graphical results of Air P ANN 1. Panel (a) shows the regression plots between target (Svanberga Air P) and output for training, validation, test and overall regression; panels (b) shows the error histogram plots of the Air P ANN analysis performed to predict Air P.**

## S2.5 Shortwave radiation prediction

Daily shortwave radiation (SWR) data from the Swedish Agricultural University (SLU) Ultuna weather station were used to predict missing data of Erken SWR using ANN function fitting analysis (table S5). Daily SWR data from Ultuna station

5   were available from 1973-1999. Early records of SWR measured on Erken meteorological station were also available from SMHI. Since the SWR data from both SLU and SMHI were only available as total daily SWR, the total daily SWR was predicted for Erken using ANN function fitting analysis instead of hourly SWR. Output-target regression plots and errors are shown in figure S7. Missing data for which SWR could not be predicted by ANN function fitting analysis (258 points over the period 1961-2016) were replaced by averaging SWR daily values measured at the same date of the missing value but in

10  different years. To estimate hourly SWR values from total daily SWR, we used the method described by Martin and McCutcheon (1999, see section 2.5.1). The measured daily total solar inputs were distributed over a daily cycle based on the idealized hourly variations in solar radiation. Hourly SWR data in the interval Nov.2016-Dec.2017 from Erken meteorological station were attached on a second moment and were not used in the ANN function fitting analysis. In this interval, only 7 datapoints were missing, and they were linearly interpolated. Finally, as a quality check the obtained values

15  of hourly shortwave solar radiation were compared with the theoretical values. From this it became apparent that the measured shortwave radiation of the years 1970, 1971,1973,1974 were overestimated. To correct for this these data were

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reduced by 15.27 %, 28.38%, 15.82% and 10.19 % respectively, due to a probable overestimation of solar radiation throughout the entire year (see section 2.5.2, fig. S8-S11).

**Table S5: Schematic description of shortwave radiation prediction using ANN analysis**

| Daily SWR ANN analysis no. | Daily SWR input data (met station)* | Daily SWR target data (met station) | Compared years | Predicted years | Missing data replaced by predicted daily SWR (% of total data) |
|---|---|---|---|---|---|
| 1 | Ultuna | Erken | 1973-1999 | 1961-2016 | 3972 |
| | | | | | **Total** **3972 (19.1 %)** |

*Ultuna (59.8175 N, 17.6536 E)
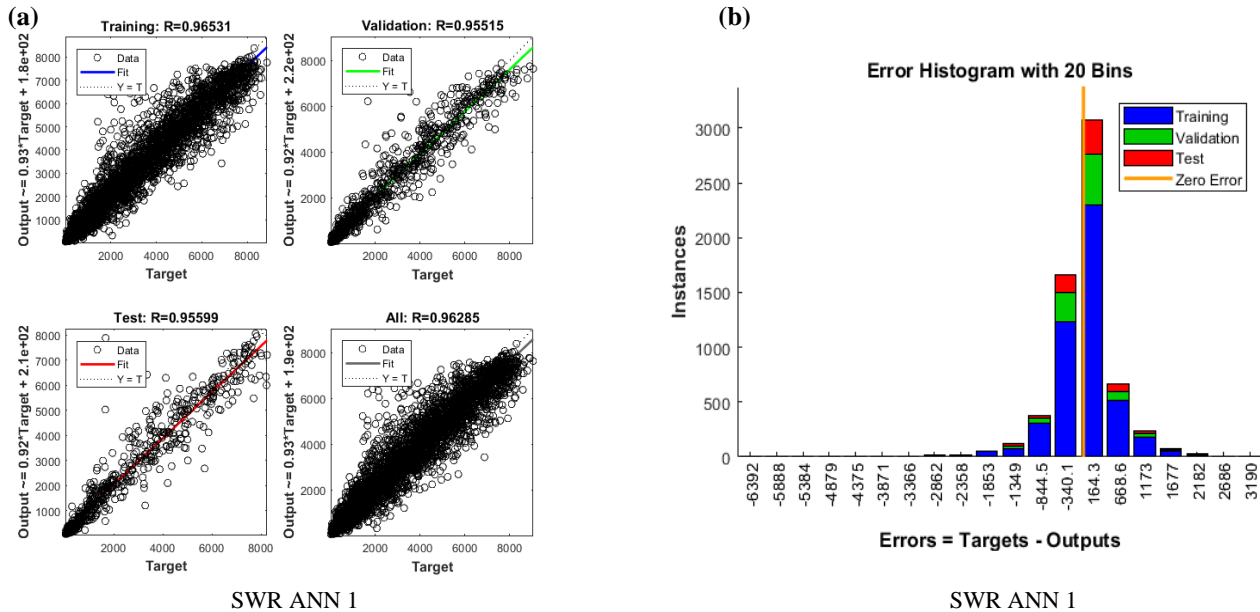


Figure S7: Graphical results of SWR ANN 1. Panel (a) shows the regression plots between target (Erken SWR) and output for training, validation, test and overall regression; panel (b) shows the error histogram plots of the SWR ANN analysis performed to predict short-wave solar radiation.

**S2.5.1 Calculation of theoretical shortwave radiation**

The equations for calculating the theoretical shortwave radiation $H_{sw}$ that reaches the Earth surface according to Martin and McCutcheon (1999) are here presented for Lake Erken. $H_{sw}$ is defined in Eq. (1):

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$$H_{sw} = H_0 * a_t * (1 - R_s) * C_a, \tag{1}$$

where:

$H_{sw}$: short-wave radiation (W/m$^2$)

$H_0$: radiation that reaches the outer atmosphere (W/m$^2$)

5  $a_t$: atmospheric transmission term

$R_s$: reflection coefficient

$C_a$: fraction of solar radiation not absorbed by clouds.

Equation (2) shows how $H_0$ is calculated:

$$H_0 = \frac{H_{sc}}{r^2} * \left\{ \sin\left(\frac{\pi*\theta}{180}\right) * \sin(\delta) + \frac{12}{\pi} * \cos\left(\frac{\pi*\theta}{180}\right) * \cos(\delta) * [\sin(h_e) - \sin(h_b)] \right\} * \Gamma, \tag{2}$$

10  where:

$H_{sc}$: solar constant (1390 W/m$^2$)

$r$: Earth-Sun relative distance

$\theta$: latitude (degrees)

$\delta$: declination

15  $h_e$: solar hour angle (radians) at the end of time interval in which $H_0$ is estimated

$h_b$ solar hour angle (radians) at the beginning of time interval in which $H_0$ is estimated

$\Gamma$: correction factor for diurnal radiation exposure

Equation (3) describe how to estimate $r$:

$$r = 1 + 0.017 * \cos\left[\frac{2\pi}{365} * (186 - D_y)\right], \tag{3}$$

20  where:

$D_y$: day of the year (1-365,366)

$\delta$ is defined in Eq. (4):

$$\delta = \frac{23.45}{185} * \cos\left[\frac{2\pi}{365} * (172 - D_y)\right], \tag{4}$$

$h_e$ and $h_b$ are calculated according to Eq. (5) and Eq. (6) respectively:

25  $$h_e = \left[\frac{\pi}{12} * (h_r - \Delta t_s + a * \pi)\right] + b * (2\pi), \tag{5}$$

$$h_b = \left[\frac{\pi}{12} * ((h_r - 1) - \Delta t_s + a * \pi)\right] + b * (2\pi), \tag{6}$$

where:

$h_r$: hour of the day between 1-24

$a = 1$ if $h_r \leq 12$, $a = -1$ if $h_r > 12$

$b$: coefficient that varies according to the value within the square brackets [] of equation (5) and (6). $b = -1$ if $[] > 2\pi$, $b = 1$ if $[] < 0$ and $b = 0$ in all the other cases.

5   $\Delta t_s$: fraction of local meridian west of the standard meridian.

$\Delta t_s$ is defined for Lake Erken in Eq. (7):

$$\Delta t_s = \frac{E_a}{15}(L_{sm} - L_{lm}), \tag{7}$$

where:

$L_{sm}$: local standard meridian (15°)

10   $L_{lm}$: local meridian (18.63°)

$E_a = 1$ for east longitude.

Before the calculation of correction factor $\Gamma$ that appears in Eq. (2), it is essential to set solar radiation to 0 before the sunrise and after the sunset. The standard time of sunset $t_{ss}$ and the standard time of sunrise $t_{su}$ are defined in Eq. (8) and Eq. (9) respectively:

15   $$t_{ss} = \frac{12}{\pi} * cos^{-1}\left(-\frac{sin\left(\frac{\pi*\theta}{180}\right)*sin(\delta)}{cos\left(\frac{\pi*\theta}{180}\right)*cos(\delta)}\right) + \Delta t_s + 12, \tag{8}$$

$$t_{su} = -t_{ss} + 2 * \Delta t_s + 24, \tag{9}$$

Therefore, the correction factor $\Gamma$ is equal to 1 when $t_{su} < h_r < t_{ss}$ and 0 otherwise.

Eeuation (10) defines the atmospheric transmission term $a_t$:

$$a_t = \frac{a_2 + 0.5*(1 - a_1 - c_d)}{1 - 0.5*R_g*(1 - a_1 - c_d)}, \tag{10}$$

20   where:

$c_d$: dust coefficient (0.06)

$R_g = 0.045$: ground reflection coefficient of catchment area (extended mixed forest)

$a_1$ and $a_2$: atmospheric transmission coefficients dependent on air moisture content and optical air mass.

$a_1$ and $a_2$ are defined according to Eq. (11) and Eq. (12):

25   $$a_1 = exp[-(0.465 + 0.134 * P_{wc}) * (0.129 + 0.171 * exp(-0.88 * \vartheta_{am}))] * \vartheta_{am}, \tag{11}$$

$$a_2 = exp[-(0.465 + 0.134 * P_{wc}) * (0.179 + 0.421 * exp(-0.721 * \vartheta_{am}))] * \vartheta_{am}, \tag{12}$$

where:

$P_{wc}$: mean daily precipitable water content

$\vartheta_{am}$: optical mass

$P_{wc}$ is defined in Eq. (13):

$$P_{wc} = 0.85 * exp(0.11 + 0.0614 * T_d), \tag{13}$$

5    where:

$T_d$: dewpoint temperature (°C)

The dewpoint is calculated in Eq. (14) according to Lawrence (2005) using the relative humidity (RH) and air temperature (AirT) used to drive the GOTM model:

$$T_d = \frac{243.04 * \left[ ln\left(\frac{RH}{100}\right) + \frac{17.625 * AirT}{243.04 + AirT} \right]}{17.625 - ln\left(\frac{RH}{100}\right) - \frac{17.625 * AirT}{243.044 + AirT}}, \tag{14}$$

10    The optical mass $\vartheta_{am}$ is defined in Eq. (15):

$$\vartheta_{am} = \frac{\left(\frac{288 - 0.0065 * Z}{288}\right)^{5.256}}{sin(\alpha) + 0.15 * \left(\frac{\alpha * 180}{\pi} + 3.855\right)^{-1.253}}, \tag{15}$$

where:

$Z = 11$: altitude of Lake Erken (m)

$\alpha$: solar altitude (radians)

15    The solar altitude is defined in Eq. (16):

$$\alpha = tan^{-1}\left(\frac{\alpha_1}{\sqrt{1 - \alpha_1^2}}\right), \tag{16}$$

where $\alpha_1$ is defined in Eq. (17):

$$\alpha_1 = \left| sin\left(\frac{\pi * \theta}{180}\right) * sin(\delta) + cos\left(\frac{\pi * \theta}{180}\right) * cos(\delta) * cos\left(\frac{h_e + h_b}{2}\right) \right|, \tag{17}$$

The reflection factor, or albedo, ($R_s$) is defined in Eq. (18):

20    $$R_s = a * \left(\frac{180}{\pi} * \alpha\right)^b, \tag{18}$$

where:

$\alpha$: solar altitude (radians)

$a$ and $b$: coefficients dependent on cloud cover ($CC$). In particular:

If $CC > 0.9, a = 0.33, b = -0.45$

25    If $0.5 < CC < 0.9, a = 0.95, b = -0.75$

If $0.1 < CC < 0.5, a = 2.20, b = -0.97$

If $CC < 0.1, a = 1.18, b = -0.77$

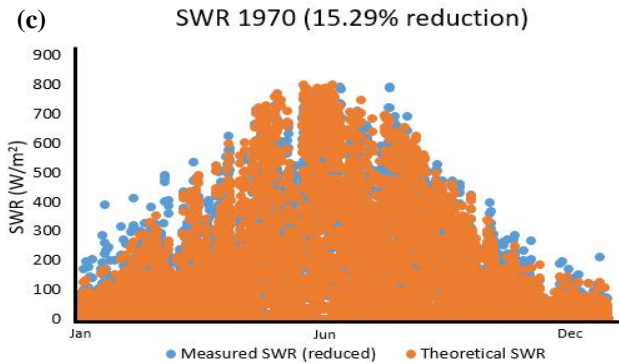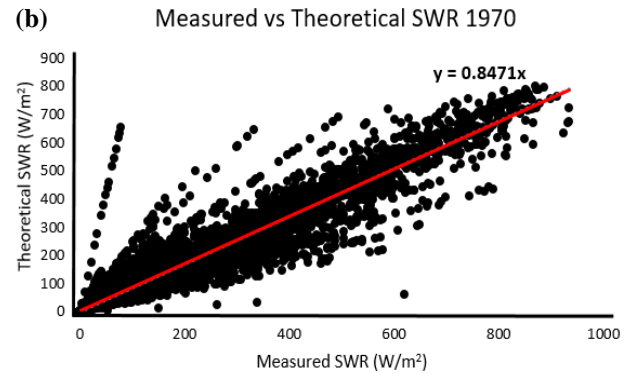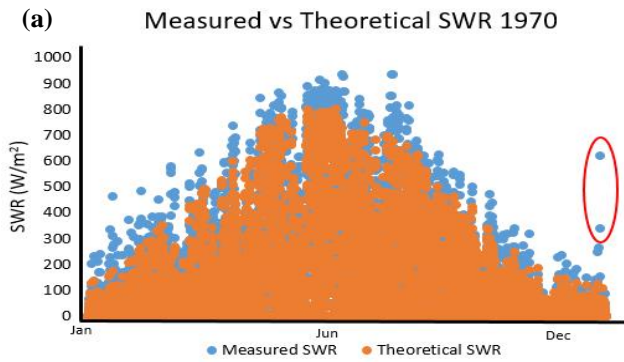The fraction of solar radiation not absorbed by clouds ($c_a$) is defined in Eq. (19):
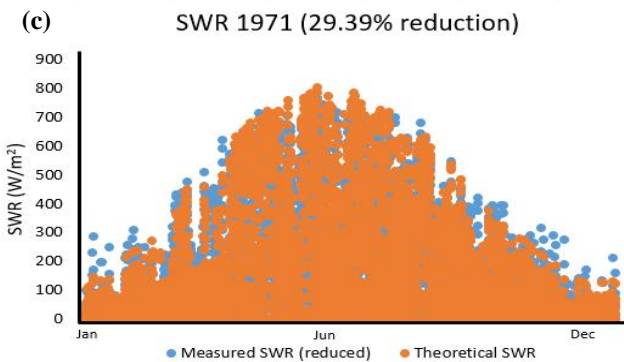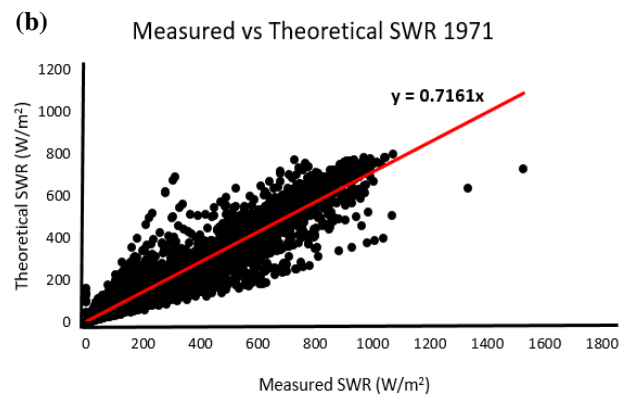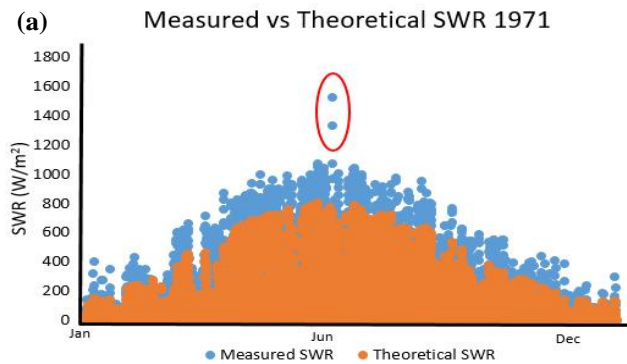
$$C_a = 1 - 0.65 * CC^2, \tag{19}$$

where:
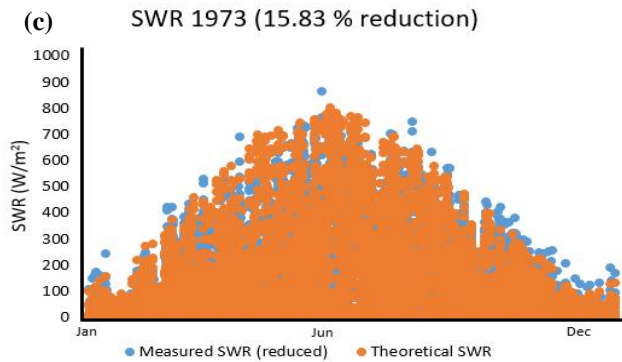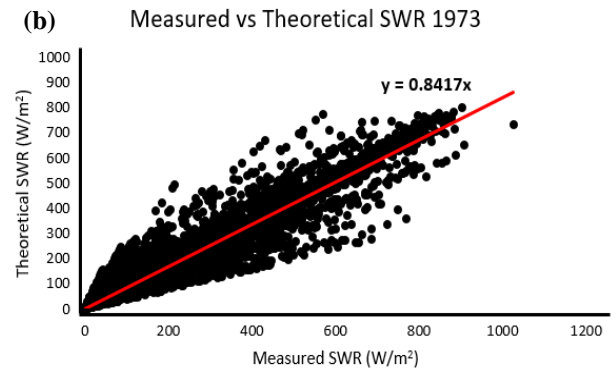
$CC$: cloud cover.
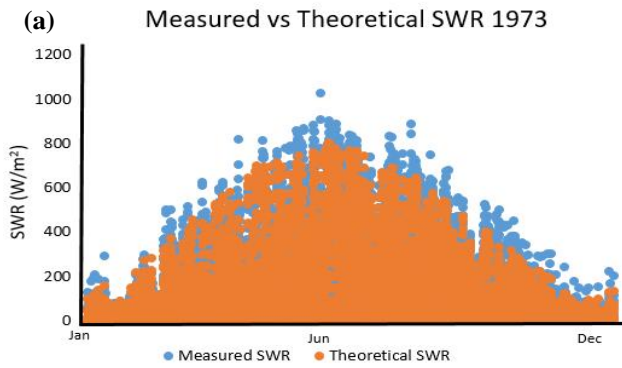
## S2.5.2 Shortwave radiation reduction

The comparison graphs (fig. S8-S11) between measured and theoretical SWR are shown for the years 1970, 1971, 1973 and 1974. A simple linear regression was performed to compare measured and theoretical SWR. The slope of the regression hwas used to calculate the percentage of reduction of the overestimated SWR for the year, 1970, 1971, 1973 and 1974.
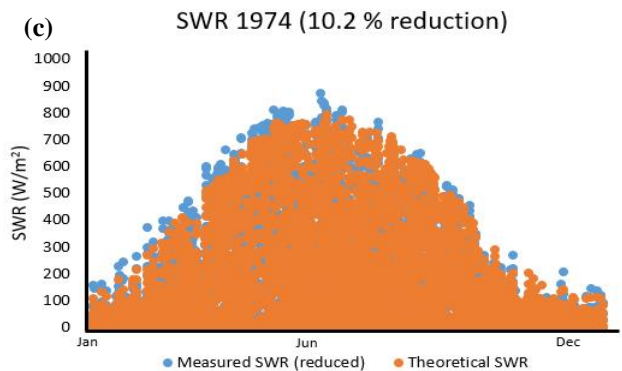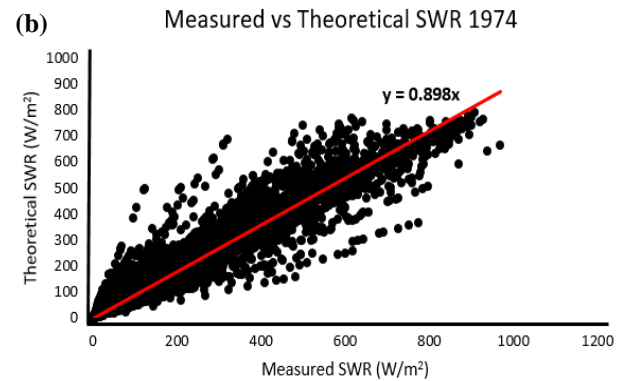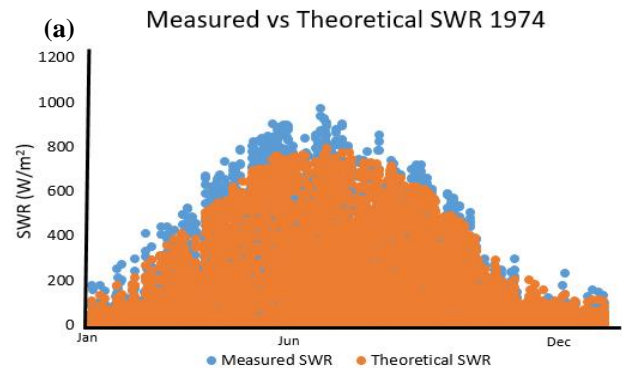
**(a)** Measured vs Theoretical SWR 1970

**(b)** Measured vs Theoretical SWR 1970

y = 0.8471x

**(c)** SWR 1970 (15.29% reduction)

**Figure S8: Overview of the SWR reduction for the years 1970. Panel (a) shows the comparison between measured and theoretical SWR before reduction. The outliers (red circle) were removed and substituted with the corresponding theoretical value of SWR. Panel (b) shows the regression line slopes between measured and theoretical SWR. Panel (c) shows the comparison between measured and theoretical SWR after reduction.**

**(a)** Measured vs Theoretical SWR 1971

**(b)** Measured vs Theoretical SWR 1971

y = 0.7161x

**(c)** SWR 1971 (29.39% reduction)

**Figure S9: Overview of the SWR reduction for the years 1971. Panel (a) shows the comparison between measured and theoretical SWR before reduction. The outliers (red circle) were removed and substituted with the corresponding theoretical value of SWR. Panel (b) shows the regression line slopes between measured and theoretical SWR. Panel (c) shows the comparison between measured and theoretical SWR after reduction.**

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**(a)** Measured vs Theoretical SWR 1973

**(b)** Measured vs Theoretical SWR 1973

y = 0.8417x

**(c)** SWR 1973 (15.83 % reduction)

**Figure S10: Overview of the SWR reduction for the years 1973. Panel (a) shows the comparison between measured and theoretical SWR before reduction. Panel (b) shows the regression line slopes between measured and theoretical SWR. Panel (c) shows the comparison between measured and theoretical SWR after reduction.**

**(a)** Measured vs Theoretical SWR 1974

**(b)** Measured vs Theoretical SWR 1974

y = 0.898x

**(c)** SWR 1974 (10.2 % reduction)

**Figure S11: Overview of the SWR reduction for the years 1974. Panel (a) shows the comparison between measured and theoretical SWR before reduction. Panel (b) shows the regression line slopes between measured and theoretical SWR. Panel (c) shows the comparison between measured and theoretical SWR after reduction.**

20

## References

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