Using high resolution Climate Model to Evaluate Future Water and Solutes Budgets in the Sea of Galilee

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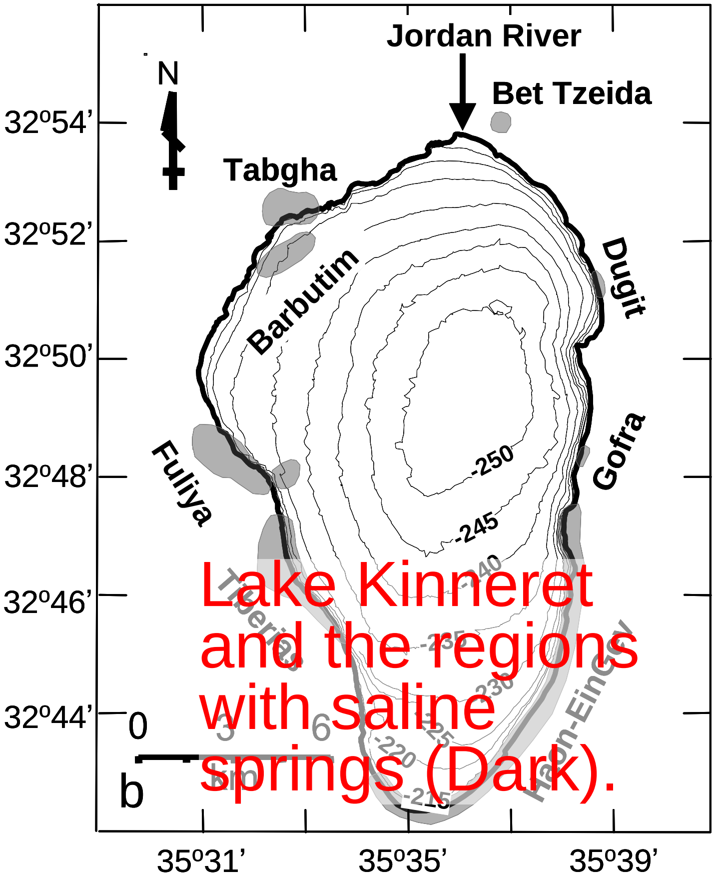
Objectives

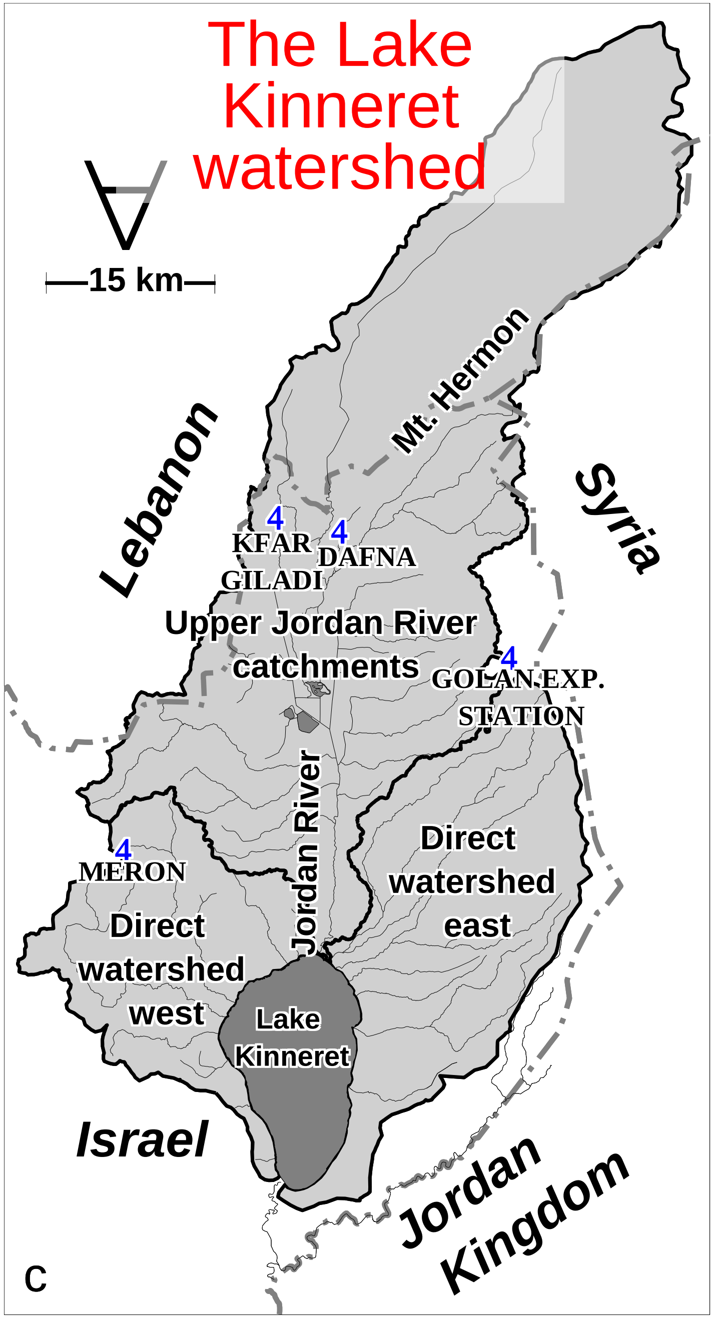
- Combine climate and hydrological models to predict long term patterns of water availability and water quality in the Lake Kinneret (Israel) watershed;
- Explain how these models may contribute to improve the water management of hydrological systems that are affected by climate change.
- Provide a first prediction estimate for expected changes in the region.

Orientation maps

East Mediterranean.



Lake Kinneret and the regions with saline springs (Dark).



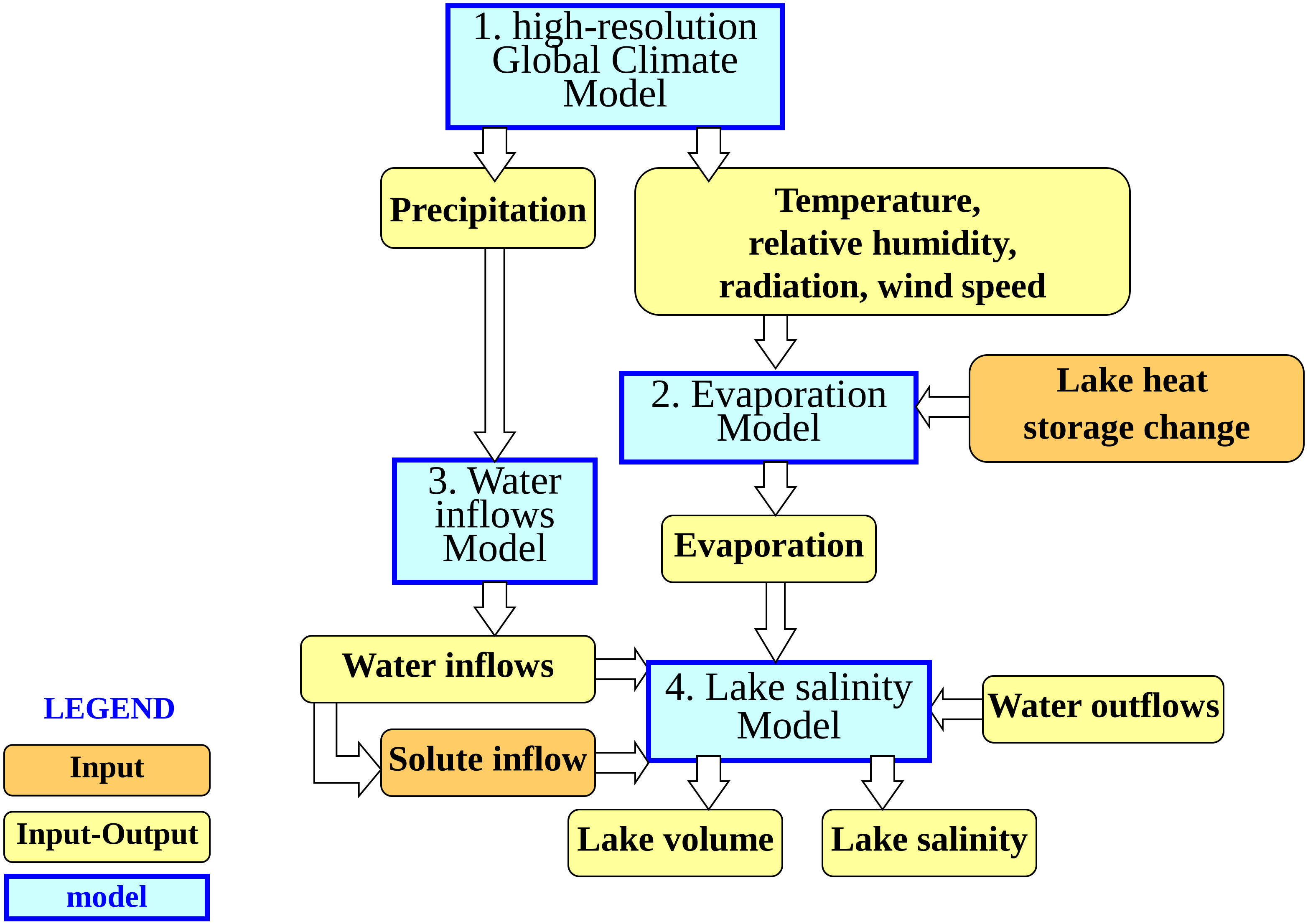
The Lake Kinneret watershed

Introduction

Results from a high resolution global climate model were integrated into hydrological tools to provide a first approximation of climate change impacts on water quantity and quality in the Sea of Galilee (Lake Kinneret), the major freshwater resource in Israel.

- Precipitation data extracted from a climate model were downscaled and used in a hydrological stream flow model
- The precipitation data were used in a multiple regression model to calculate annual incoming water volumes.
- Simultaneously, meteorological data were used in a model based on modified Penman equation, to calculate annual lake evaporation.
- The salinity in the lake was calculated with the results of the previous models, using a system approach lake salinity model, assuming a complete mixing mechanism.

Schematic description of the proposed cascade of models



1. high-resolution Global Climate Model

Precipitation

Temperature, relative humidity, radiation, wind speed

2. Evaporation Model

Lake heat storage change

3. Water inflows Model

Evaporation

Water inflows

4. Lake salinity Model

Water outflows

Solute inflow

Lake volume

Lake salinity

LEGEND

Input

Input-Output

model

Characteristic	1. Climate model	2. LK Evaporation	3. Water inflows	4. LK salinity
[Time interval]	[day]	[day]	[year]	[year]
Input	Climate-model version of the Japan Meteorological Agency's (JMA) operational numerical weather prediction model.	Daily values for temperature (T), relative humidity (RH), global radiation (R_s) and wind speed (U) as extracted from the climate model	Annual precipitation (P) in mm from current and previous year, extracted from the climate model.	Annual long term predictions for inflows (IW) and outflows in Mm^3; Annual evaporation values from the lake (ΣE_D) in Mm^3; Annual solute inflows (S_{in}) to the lake in ton Cl^-.
Output	Climate simulations for past (1979-2007) and future (2015-2034). Daily values for precipitation (P), temperature (T), relative humidity (RH), global radiation (R_s) and wind speed (U)	Daily evaporation values from the lake (E_D) in Mm^3	Annual long term predictions for incoming water to the lake (IW) in Mm^3	Long-term predictions of volume (V) in Mm^3, solute mass (S) in ton, and salinity C in ppm Cl^-.
Objective	To understand evolution of relevant atmospheric variables in the face of climate change	To generate evaporation calculations for use in the water balance and salinity model.	To predict annual water inflows to the lake.	To use the physical mechanism of CM as a tool to predict long-term changes of chloride concentration in LK.
System verification	Precipitation: apply bias correction and compare with historical values of rain gauges in UCJR. Evaporation: compare relevant atmospheric parameters with historic values	Compare monthly averaged modeled values with historical values	Compare predicted vs. observed values of water inflows	Compare predicted vs. observed values of lake volume and salinity from 1964 to 2005
Calibration	For precipitation values, bias correction (Deque, 2006). For evaporation parameters, no calibration required	No calibration required	Based on regression coefficients	No calibration required
References	Mizuta et al (2006), Kitoh et al (2008)	Rimmer et al. (2009).	Givati and Rosenfeld (2007)	Rimmer (2003). Rimmer et al (2006).

Climate model

Model name - A climate model version of the Japan Meteorological Agency’s (JMA) operational numerical weather prediction model

Horizontal grid size - 20 km

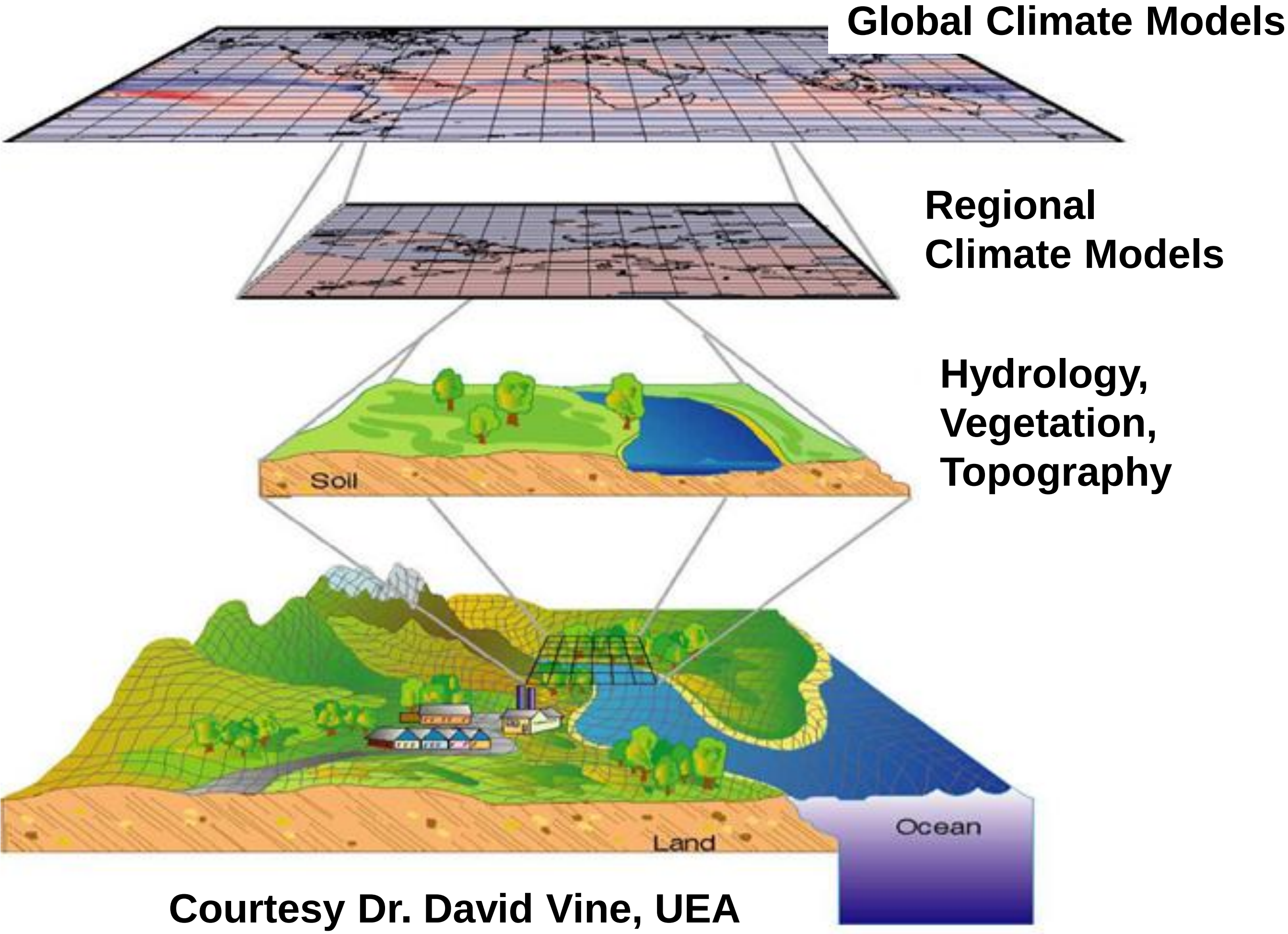
Advantages – 1. The model resolution allows for a more realistic representation of topography. 2. Currently, this is the only GCM available at this resolution. 3. It has been shown to be skillful at showing precipitation changes over the "fertile crescent" and recently has been shown to outperform reanalysis data in the region of the Middle East.

Literature - Mizuta et al. 2006; Kitoh et al. 2008; Jin et al. 2009.

high-resolution
Global Climate
Model

Downscaling the combined climate and hydrological models

“Bridging the scale gap” between climate change models (spatial scale of 50-100s of kilometers) and hydrological and other response models (watershed specific, input spatial scale at local or gauge level) to understand climate change impacts on water sources at the local level.



Courtesy Dr. David Vine, UEA

Downscaling method

- daily values from both the observed data and modeled data for the historical period are ordered sequentially.
- These two time-series are then divided into percentiles and the mean for each percentile is calculated.
- The bias correction factor (bcf) for each percentile i is calculated by subtracting the mean of the modeled data (y) from the mean of the observed data (x) such that.

$$bcf_i = \left(\bar{x}_i - \bar{y}_i\right)$$

- This correction factor is then applied to all the daily values in the modeled time series based on the appropriate percentile.

high-resolution
Global Climate
Model

Downscaling results

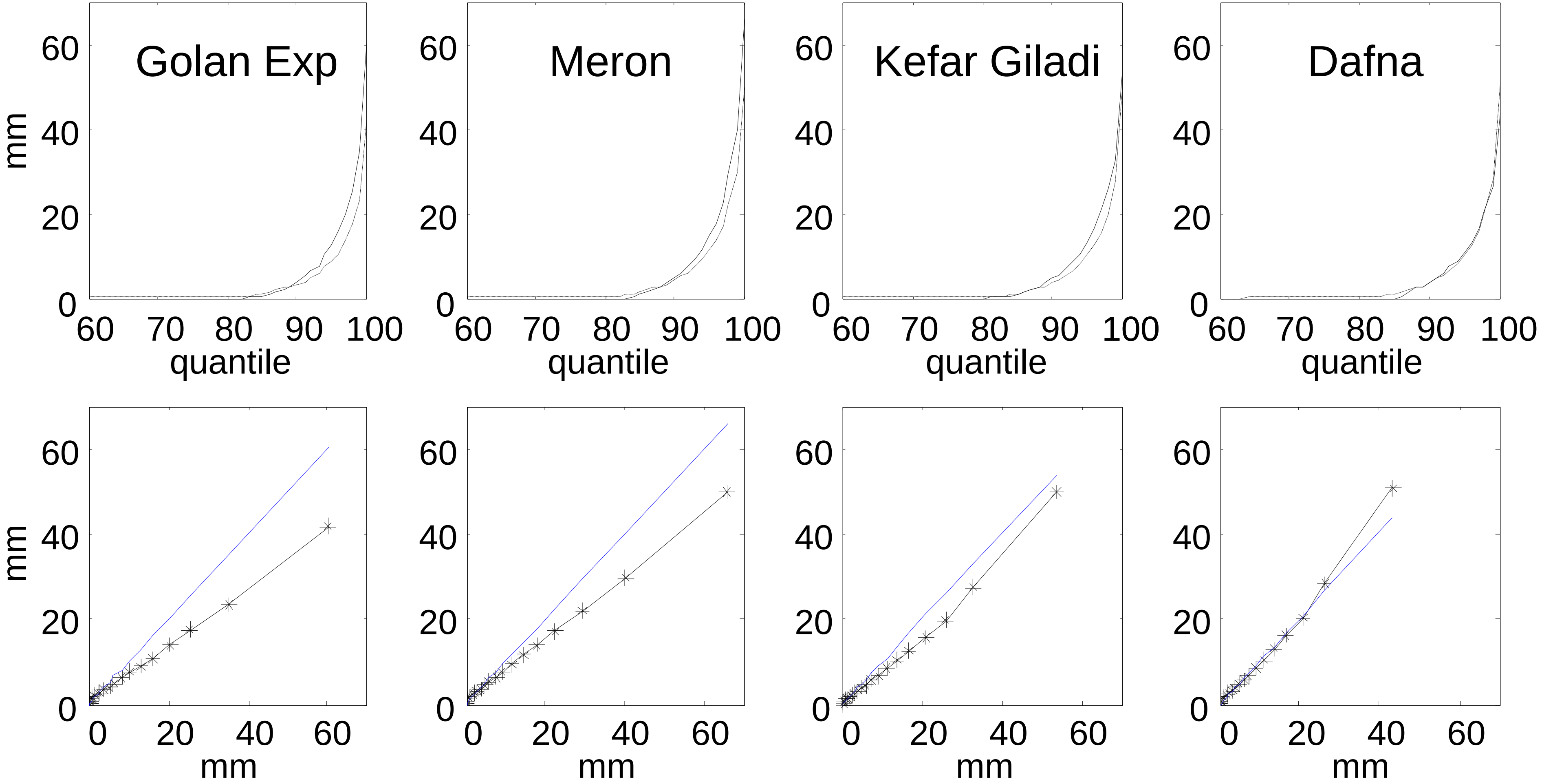
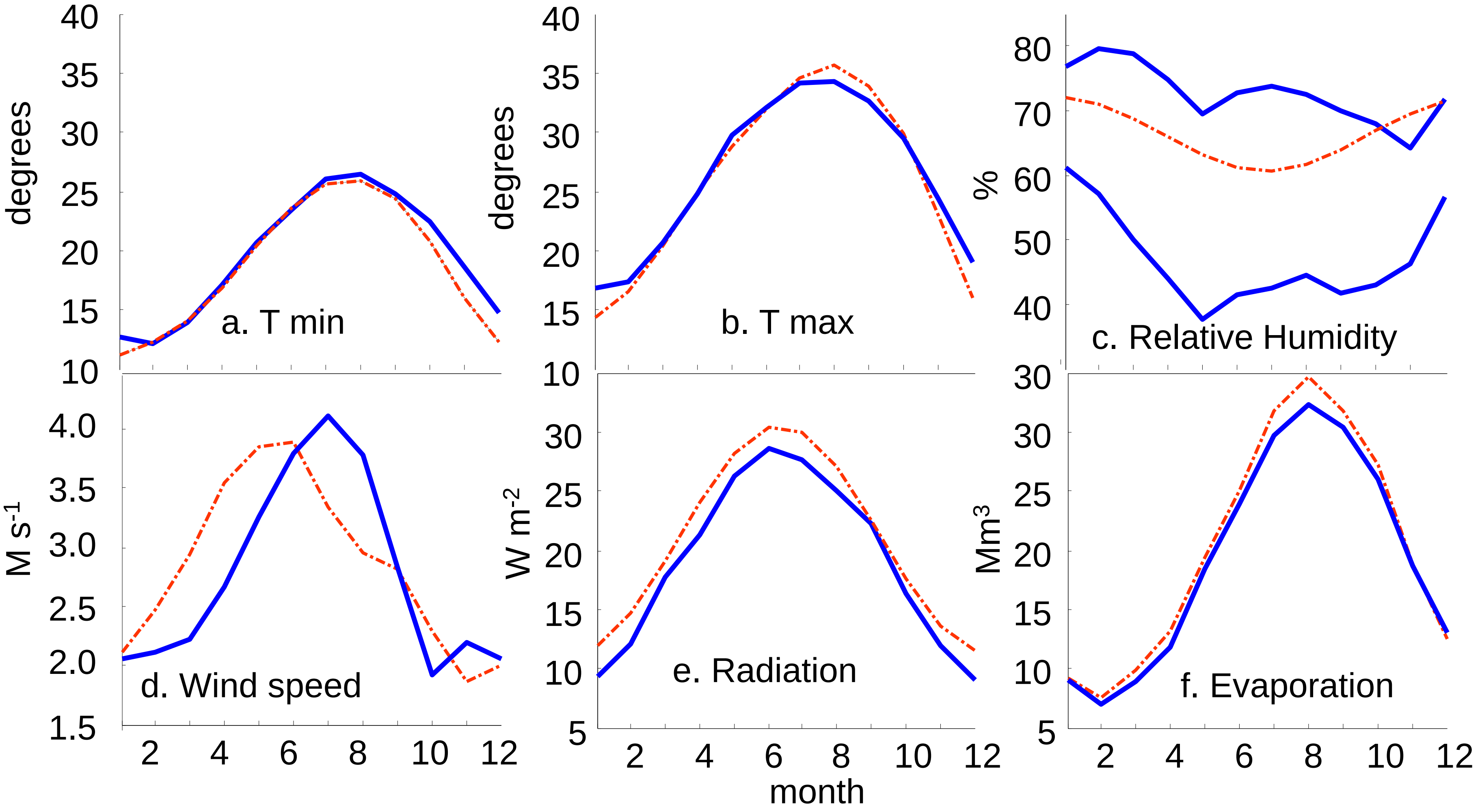


Figure 2: Inverse CDF (top row) and Q-Q plots (bottom row) for precipitation based on observed values at four rainfall stations and results from the 20km GCM model for the years 1979-2007 (28 years)

high-resolution Global Climate Model

Climate model verification



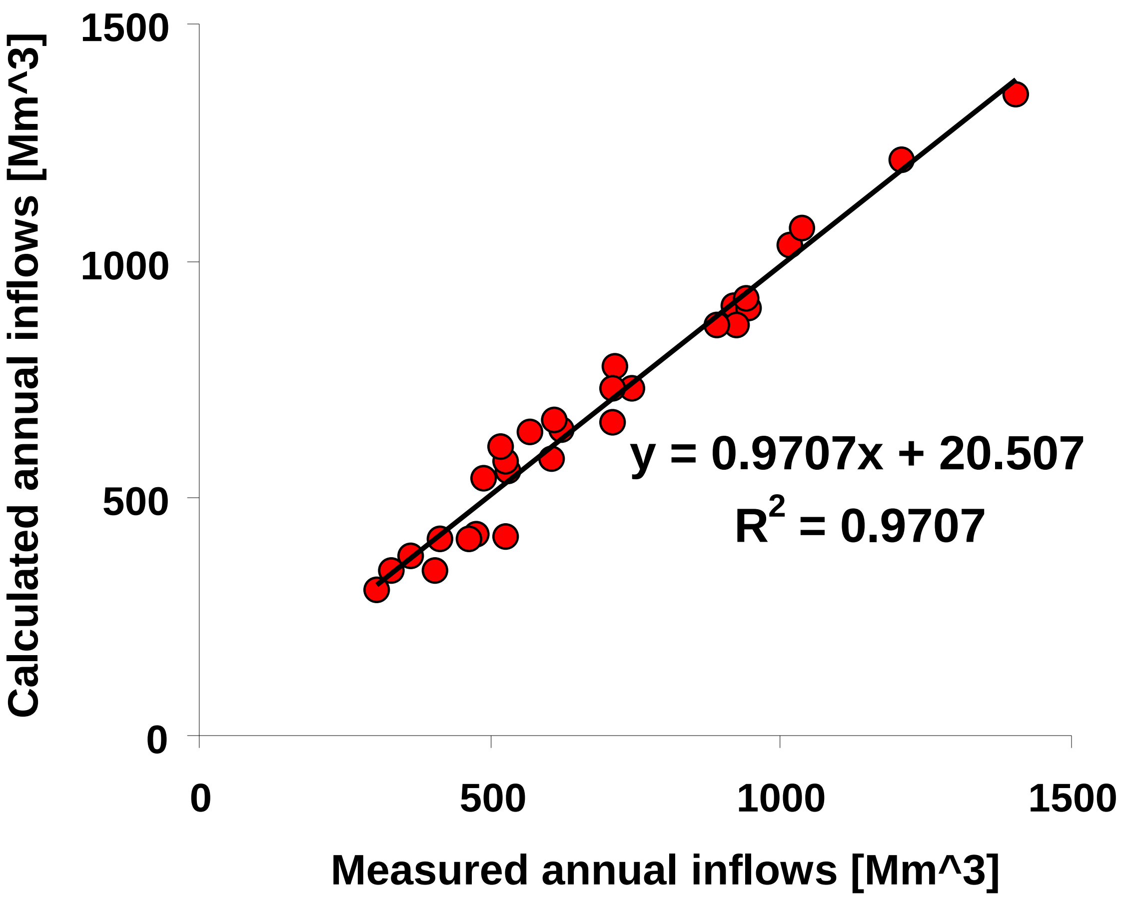
Meteorological parameters used for evaporation calculations (a-e), observed (blue) vs. modeled (red) data for the historical period 1996-2007. Calculated evaporation based on Penman is also shown (f).

Annual inflows - multiple regression model

$$IW_{(i)} = a \times P_{GH(i)} + b \times P_{GH(i-1)} - c$$

- $IW_{(i)}$ is the predicted annual incoming water in the lake (Mm^3),
- $P_{GH(i)}$ is the annual precipitation (mm) on the Golan height,
- $P_{GH(i-1)}$ is the annual precipitation (mm) in the Golan height in previous year.
- The parameters a=1.04, b=0.18, and c=-355 are constants determined by a calibration process.

Verification of annual inflows - multiple regression model



Penman-Monteith (Allen et al. 1998; Valiantzas 2006)

$$\overset{1}{E} = \overset{2}{\frac{\Delta}{\Delta+\gamma}\frac{\left(R_n - \Delta G_L *\right)}{L}} + \overset{3}{\frac{\gamma}{\Delta+\gamma}\frac{f(u)(e_{aS} - e_a)}{L}}$$

1: Evaporation (mm/day)

2: The “Radiation component” - Net radiation R_n, DG_L is all measured heat storage change per area in the lake including inflows and outflows.

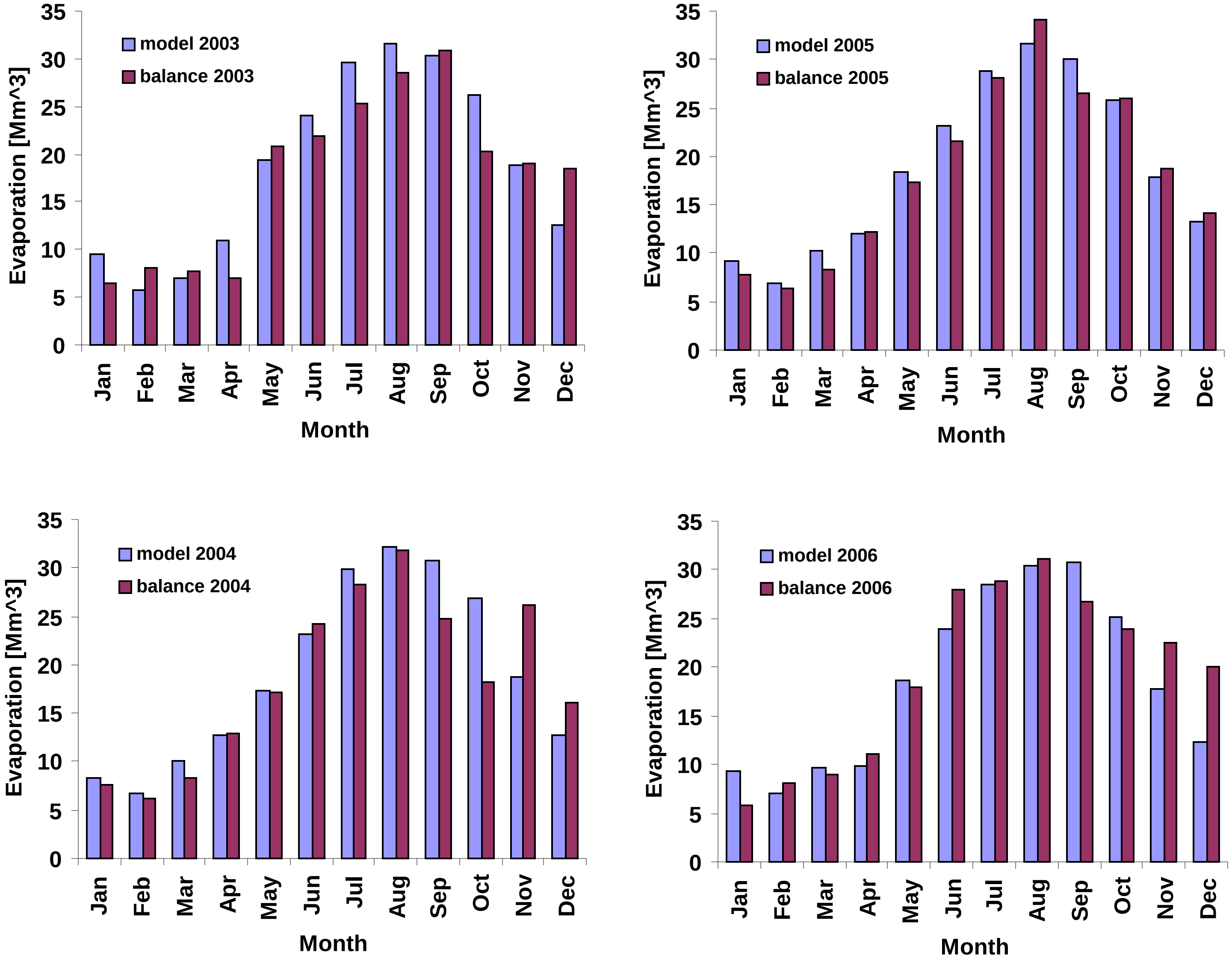
3: The “Wind component” where f(u) is the wind function, e_{aS} and e_a are the saturated and dry vapor pressure of the air respectively.

D -The slope of the saturation vapor pressure temperature curve.

γ-Psychrometric constant.

L- Latent heat of vaporization.

Verification of evaporation model



Complete mixing equations

Solute mass conservation

$$\frac{dS(t)}{dt}+S_{out}(t)=S_{in}(t)$$

The definition of S_{out} and q

$$S_{out}(t)=Q_{out}(t)C_{lake}(t)$$

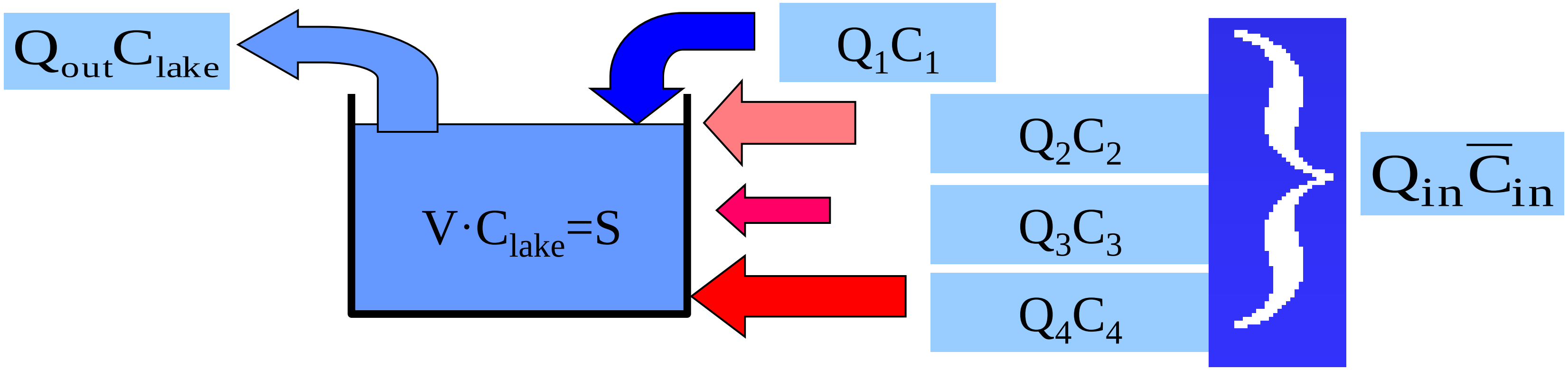
$$C_{lake}(t)=\frac{S(t)}{V(t)}$$

$$S_{out}(t)=\frac{Q_{out}(t)}{V(t)}S(t)=q(t)S(t)$$

The definition of S_{in}

$$\overline{C}_{in}(t)=\frac{\sum_i Q_i(t)C_i(t)}{\sum_i Q_i(t)}$$

$$S_{in}(t)=Q_{in}(t)\overline{C}_{in}(t)$$



Complete mixing – general solution

Solute mass conservation equation

$$\frac{dS(t)}{dt} + q(t)S(t) = S_{in}(t)$$

Initial conditions

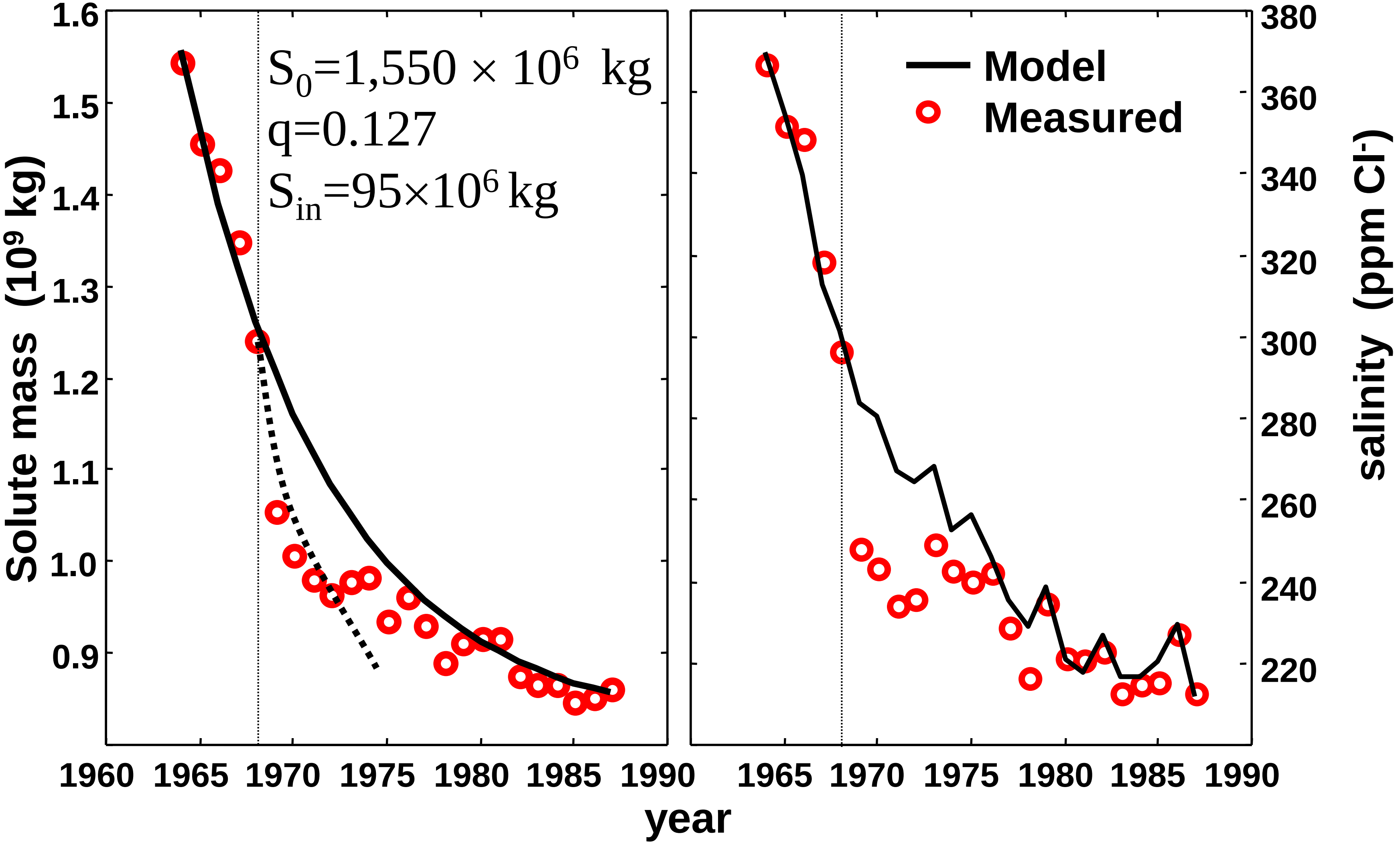
$$S\big|_{t=0} = S_0$$

General solution of the solute mass conservation equation

$$S(t) = \exp\left(-\int_0^t q(t')dt' \right) \cdot \left[\int_0^t \exp\left(\int_0^{t'} q(t'')dt'' \right) S_{in}(t')dt' + S_0 \right]$$

Verification of salinity model: result for 1964-87

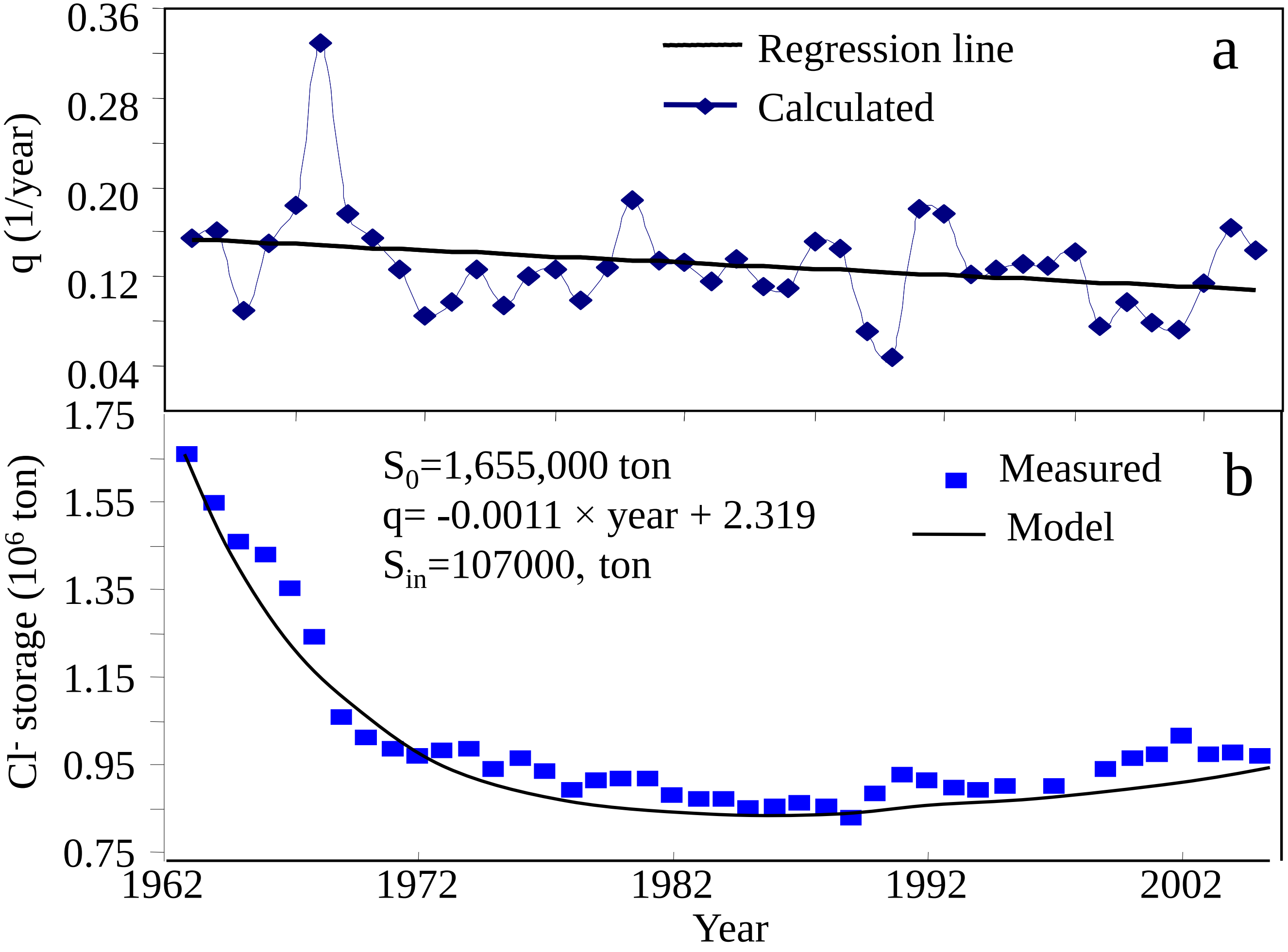
The reduction in solute mass and salinity between 1964 and 1987 is an obvious result of the operation of the SWC in 1964



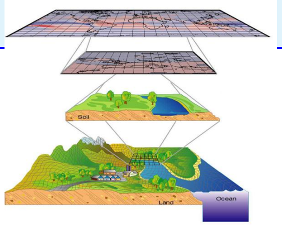
Lake salinity
Model

Verification of salinity model: result for 1964-2005

Combined effect of the operation of the SWC in 1964 and the reduction in fresh water inflows from the Jordan River and the local streams.



Climate-model version of the Japan Meteorological Agency's (JMA) operational numerical weather prediction model



Precipitation

Temperature, relative humidity, radiation, wind speed

Lake heat storage change

Annual inflows- multiple regression model

$$IW_{(i)} = a \times P_{GH(i)} + b \times P_{GH(i-1)} + c$$

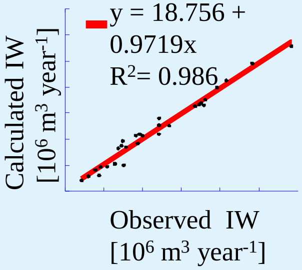
IW : Annual incoming water

$P_{GH(i)}$: Annual precipitation

$P_{GH(i-1)}$: Precipitation in previous year.

a, b, c: Constants determined by a calibration process.

IW calibration



Lake Evaporation model- Penman approach

$$E = \frac{\Delta}{\Delta+\gamma}\frac{(R_n - \Delta G)}{L} + \frac{\gamma}{\Delta+\gamma}\frac{f(u)(e_{aS} - e_a)}{L}$$

E: Evaporation [mm/day]

R_n : Net radiation;

ΔG : Lake heat storage change

f(u): The wind function,

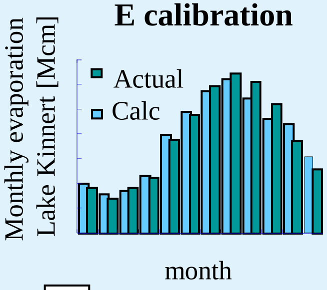
e_{aS} , ea Saturated and dry vapor pressure

Δ: Slope of saturation vapor pressure temp curve

γ-Psychrometric constant. ;

L- Latent heat of vaporization.

E calibration



Water outflows

Lake Evaporation

Water inflows

Solute inflow

Lake salinity model- Complete mixing

$$S(t) = \exp\left(-\int_0^t q(t')dt'\right)\cdot\left[\int_0^t \exp\left(\int_0^{t'} q(t'')dt''\right)S_{in}(t')dt' + S_0\right]$$

S(t): Solute mass in the lake as function of time

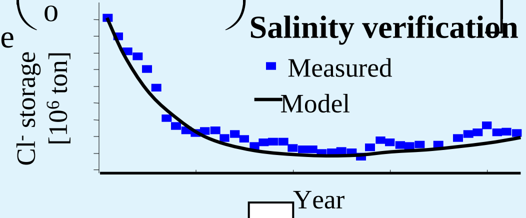
S_0: Initial Solute mass in the lake

S_{in}: Solute inflows to the lake

q: Ratio of water outflows/lake volume

t: time

Salinity verification



LEGEND

Input

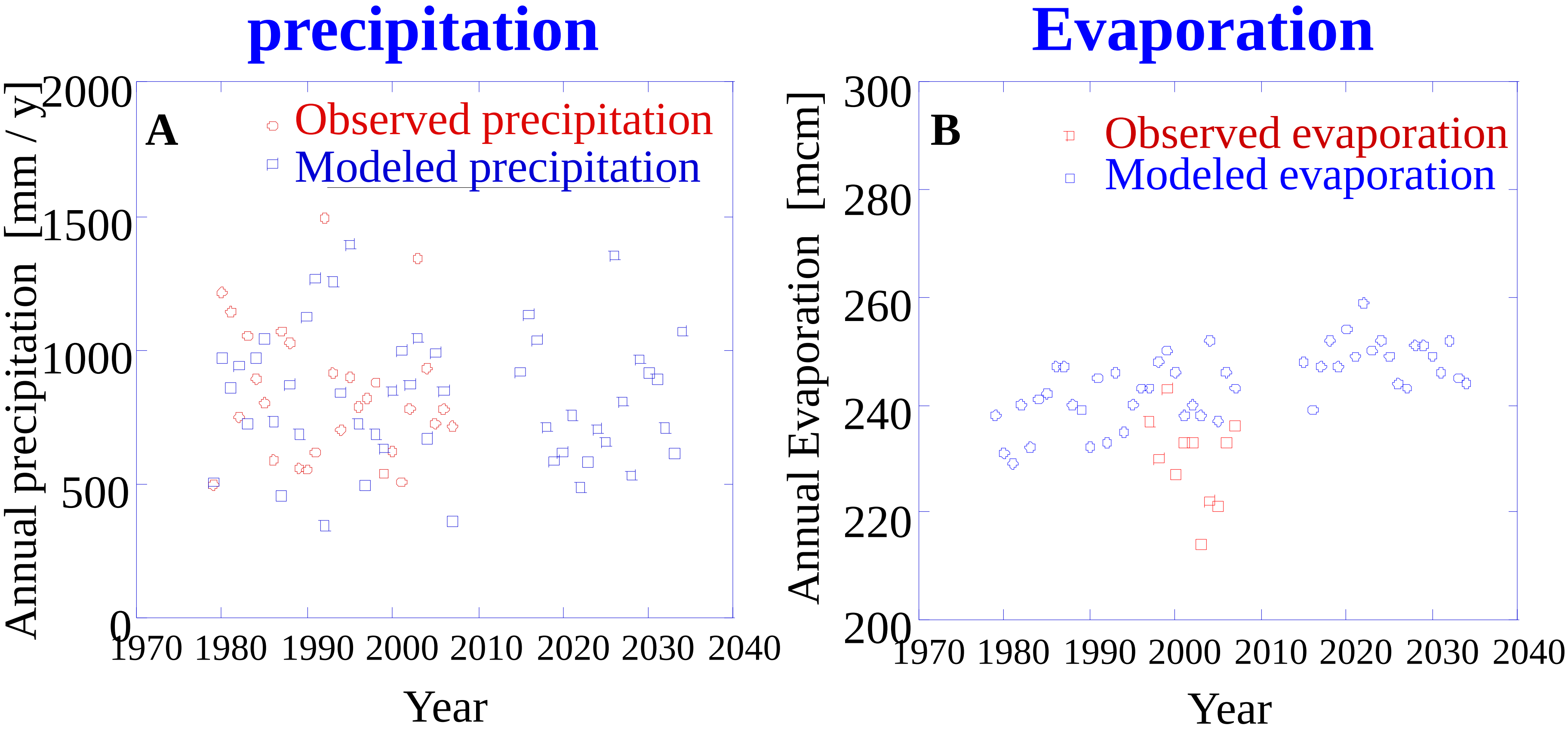
Input-Output

model

Lake volume

Lake salinity

Results of GCM predictions

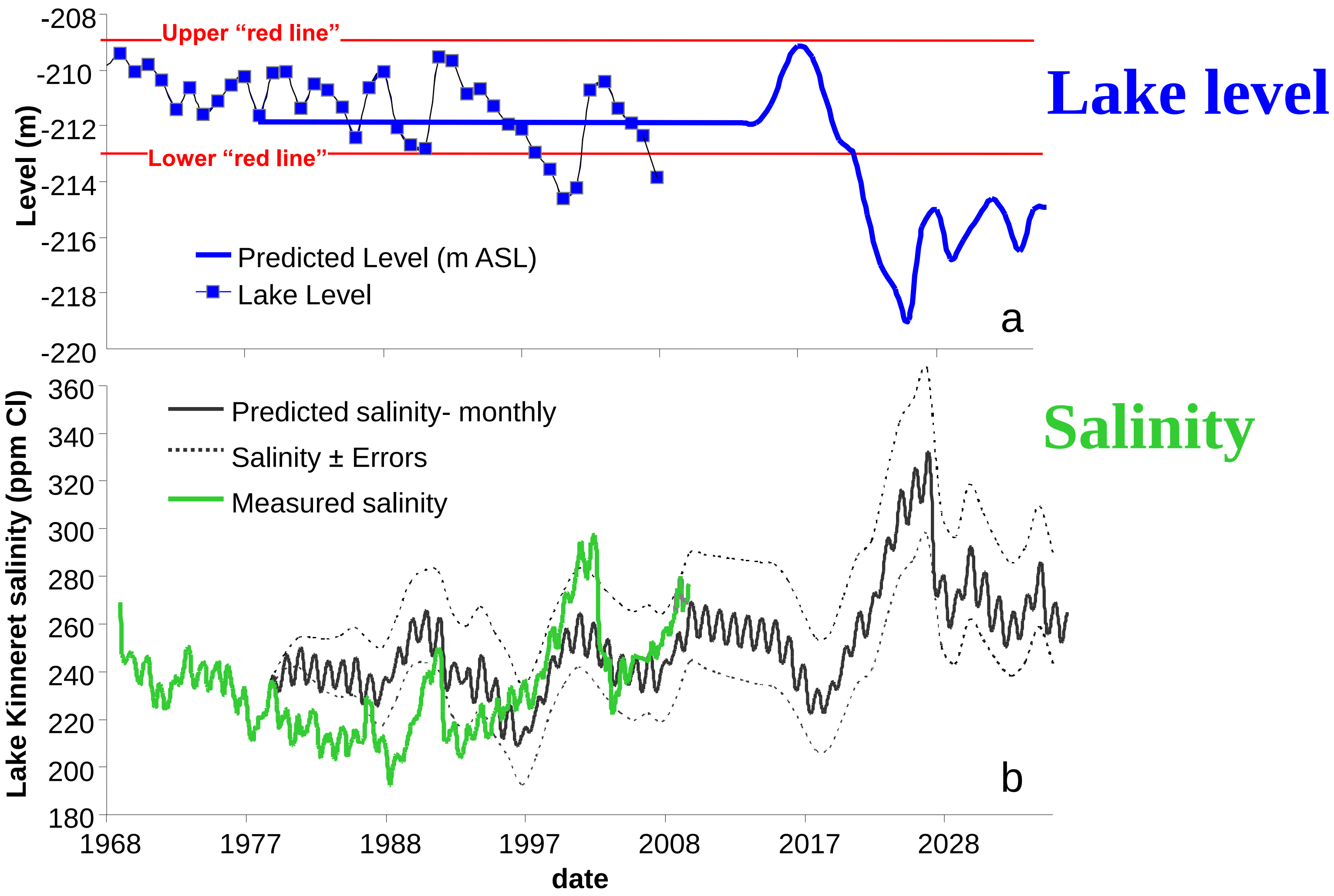


precipitation

Evaporation

Calculated precipitation (A) and evaporation (B) from the models for both the historical time period (1979-2007) and the future (2015-2034) as well as observed values.

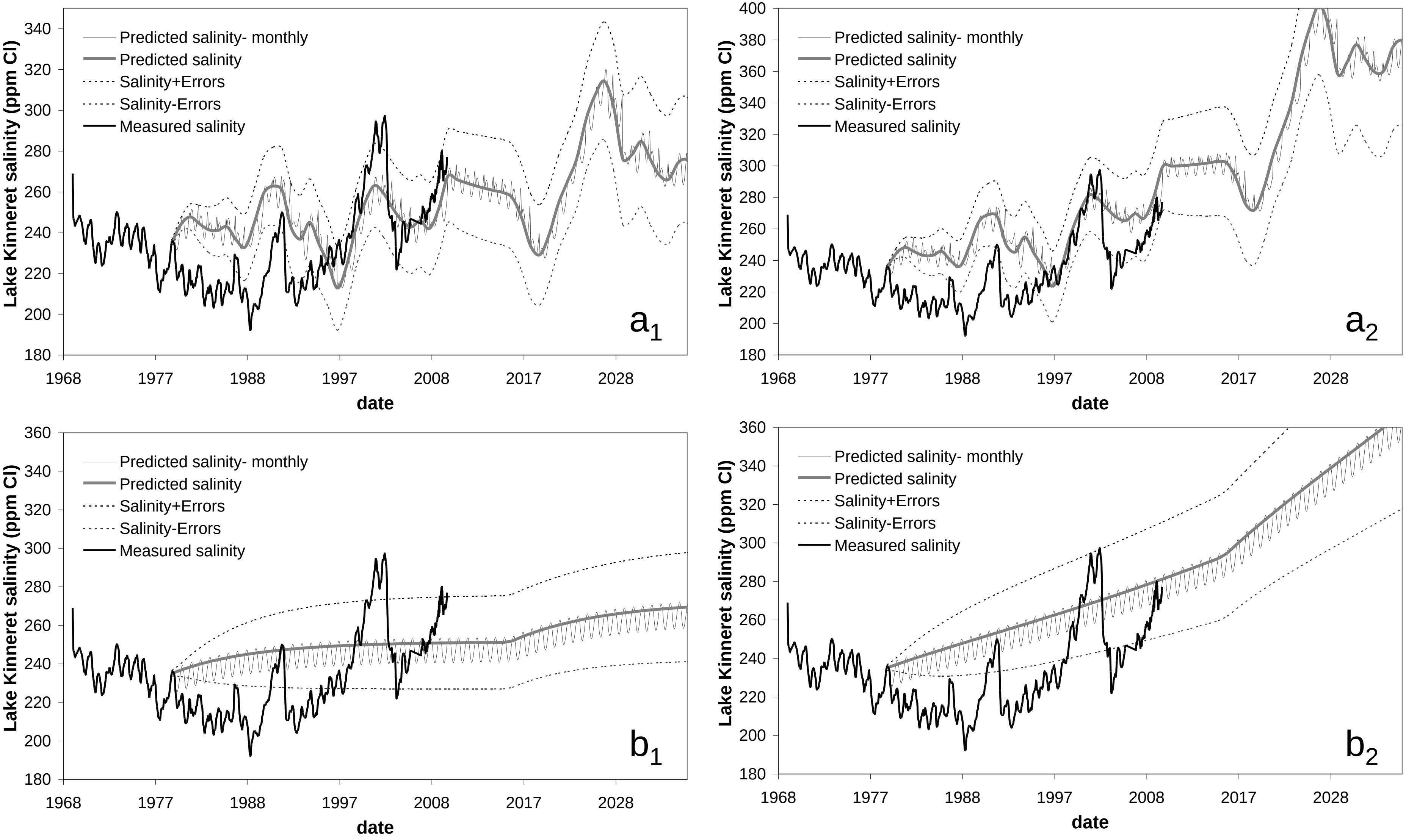
Results of GCM predictions



Typical model results: **a.** Historical Lake Kinnert level for the period 1968-2008; Modeled lake level: In 2009-2015 outflow = available water, and in 2015-2035 we allowed outflow = available water + 10 Mm3 annually. **b.** Actual salinity in lake Kinneret (1968-2009) and expected salinity using inflow from the hydrological model and outflows were 10 Mm^3 above the annual available water

Summary

- The results of a global climate model were integrated into a water availability, evaporation and salinity model in order to determine the impact of climate change on water quality and quantity in Lake Kinneret.
- The analysis we demonstrated is based on a single scenario from a single climate model.
- Given that it is only a single potential representation of future climate, these results should be viewed as a first estimation which must be compared to results of other climate models and additional scenarios.
- In future research we plan to build ensembles from multiple climate models in order to get a more robust and reliable estimation of expected changes in rainfall and evaporation which in turn can be used to better inform planners regarding lake water change and salinity.
- While this study focuses on a particular region, the methodologies presented are general and can be applied to other water bodies as well.


Predicted salinity- monthly
Predicted salinity
Salinity+Errors
Salinity-Errors
Measured salinity
Lake Kinneret salinity (ppm Cl)
date
1968
1977
1988
1997
2008
2017
2028
180
200
220
240
260
280
300
320
340
360
380
400
a1
a2
b1
b2