

Is Air Temperature Enough to Predict Lake Surface Temperature?

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Lake Garda (Italy)
<http://www.tr3ntino.it/>

Prediction of lake surface temperature

- **Deterministic** process-based models:

accurate description of the energy fluxes between the lake and the surrounding system, but are **complex** and require a **large amount** of data.

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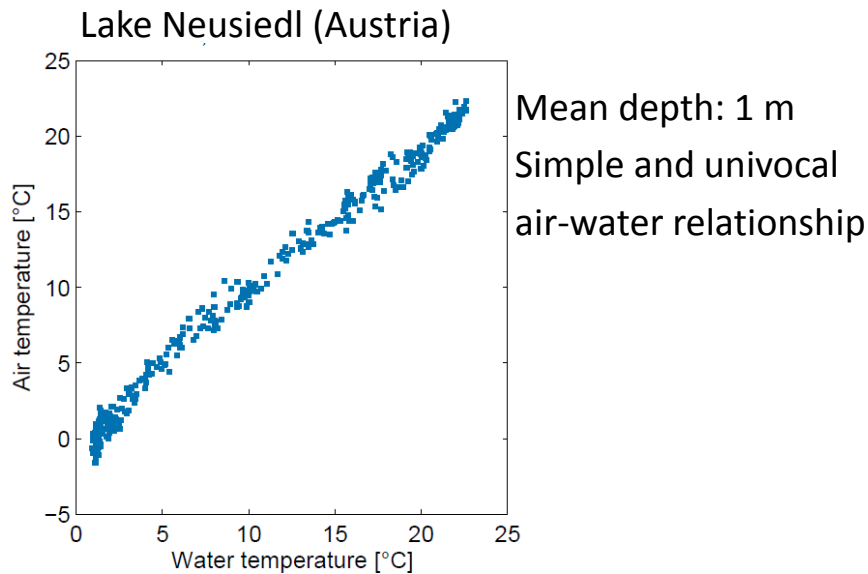
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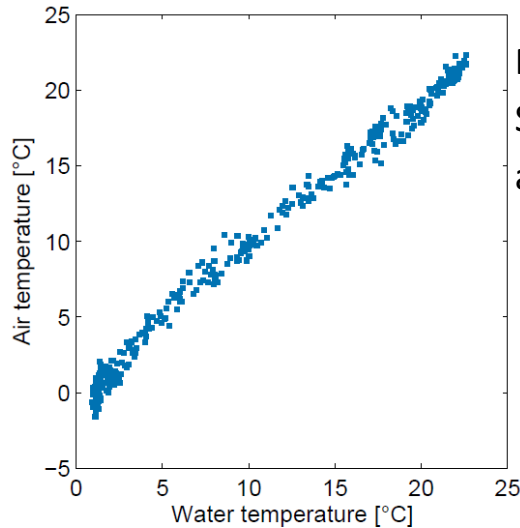
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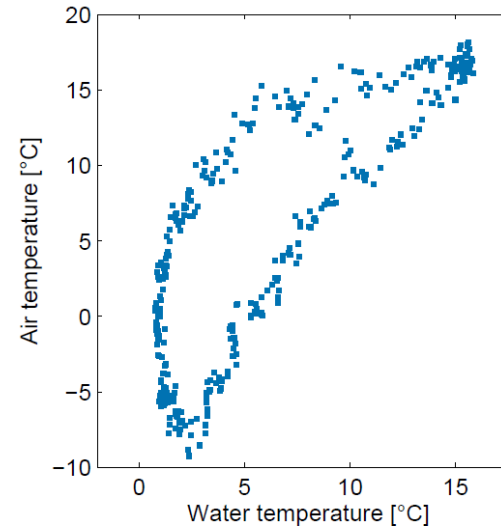
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Lake Neusiedl (Austria)



Mean depth: 1 m
Simple and univocal
air-water relationship

Lake Superior (USA-Canada)



Mean depth: 146 m
Significant air-water
hysteresis cycle

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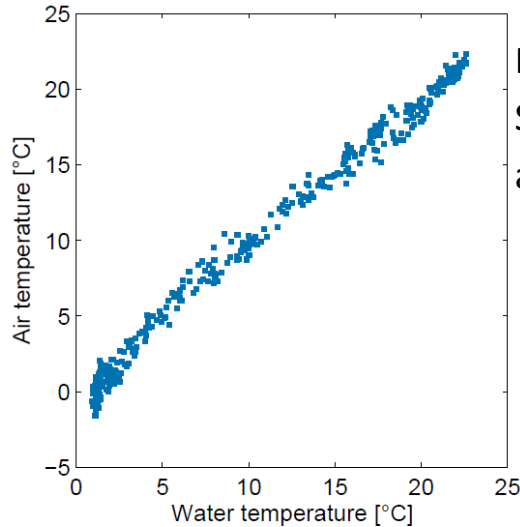
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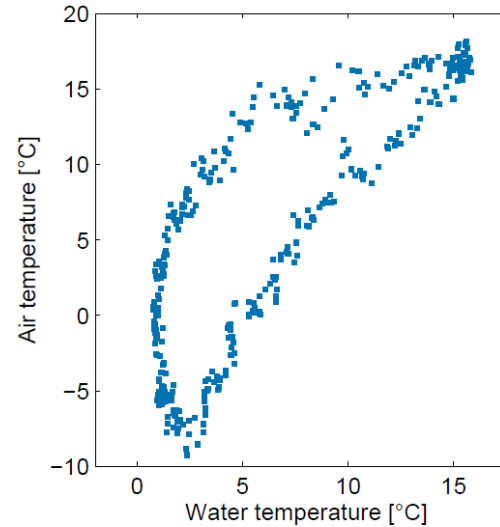
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- **Hybrid** physically-based/statistical models:

Relying on **few input data** (only air temperature), while retaining the same **high performance** of deterministic models.

No!

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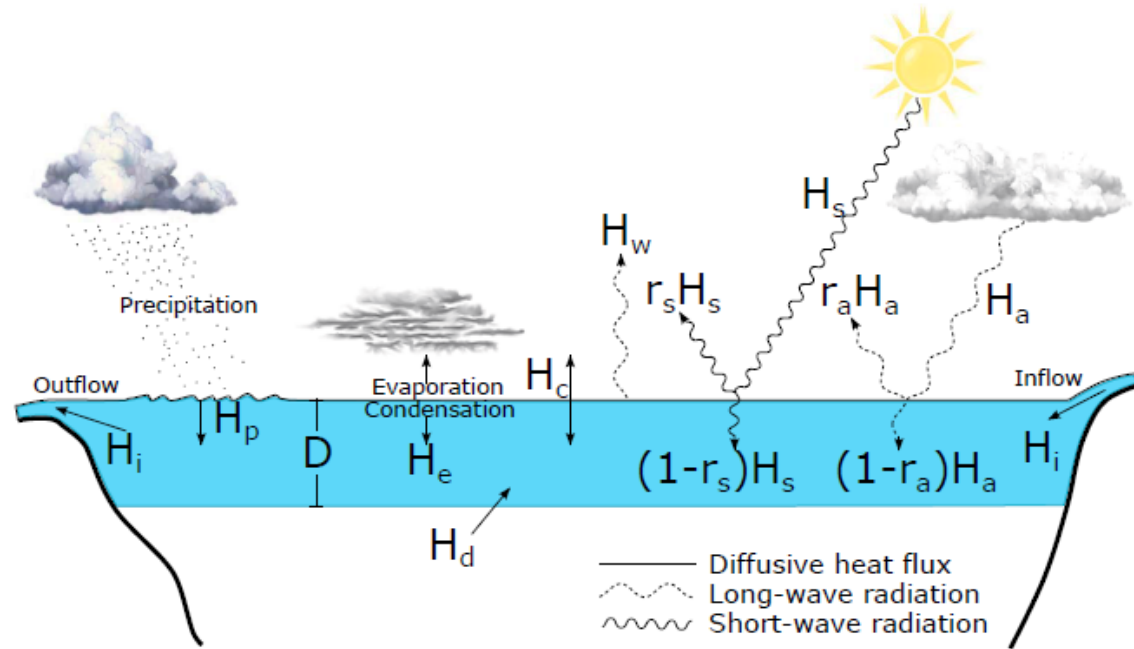
The model: *air2water*

● The key equation

Heat budget in the well-mixed surface layer
(volume integrated)

$$\rho c_p V_s \frac{dT_w}{dt} = \Phi_{\text{net}} A$$

● surface area
 ● surface layer volume
 ● specific heat
 ● water density



T_w **water temperature** of the surface layer

Φ_{net} **net heat flux**: complex balance of different contributions

$$\Phi_{\text{net}} = H_s + H_a + H_w + H_e + H_c + H_p + H_i + H_d$$

● Temporal evolution of LST

In order to keep the formulation of the model as **simple** as possible:

- **linearization** of heat flux terms by Taylor expansion
- **air temperature** T_a as a proxy for the integrated effect of the relevant processes and fluxes (see e.g., Livingstone and Padisák, 2007)

$$\frac{dT_w}{dt} = \frac{1}{\delta} \left\{ a_1 + a_2 T_a - a_3 T_w + a_5 \cos \left[2\pi \left(\frac{t}{t_y} - a_6 \right) \right] \right\}$$

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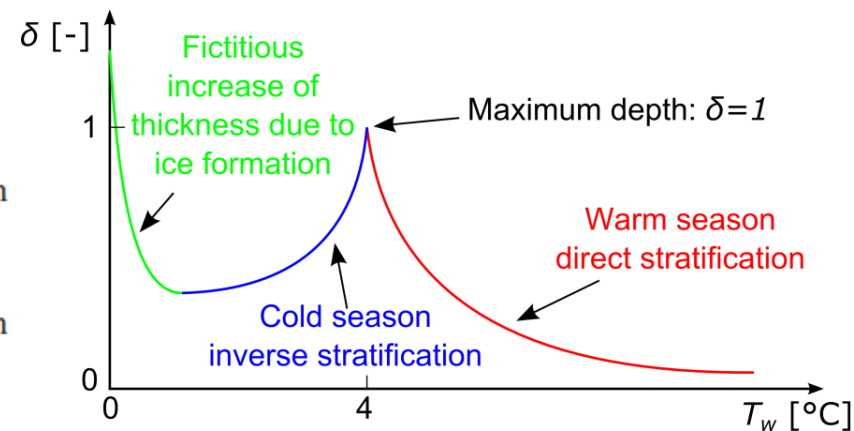
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dimensionless depth of the surface well-mixed layer

$$\delta = \exp \left(- \frac{T_w - T_h}{a_4} \right) \quad \text{for } T_w \geq T_h$$

$$\delta = \exp \left(- \frac{T_h - T_w}{a_7} \right) + \exp \left(- \frac{T_w}{a_8} \right) \quad \text{for } T_w < T_h$$



An application to Lake Superior

Model calibration

Based on the optimization of the **Nash-Sutcliffe efficiency index**, by performing **100'000'000** Monte Carlo realizations with uniform random sampling (GLUE).

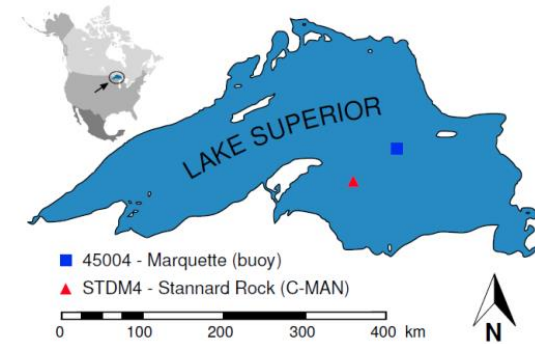
calibration

with 2/3 of the dataset



validation

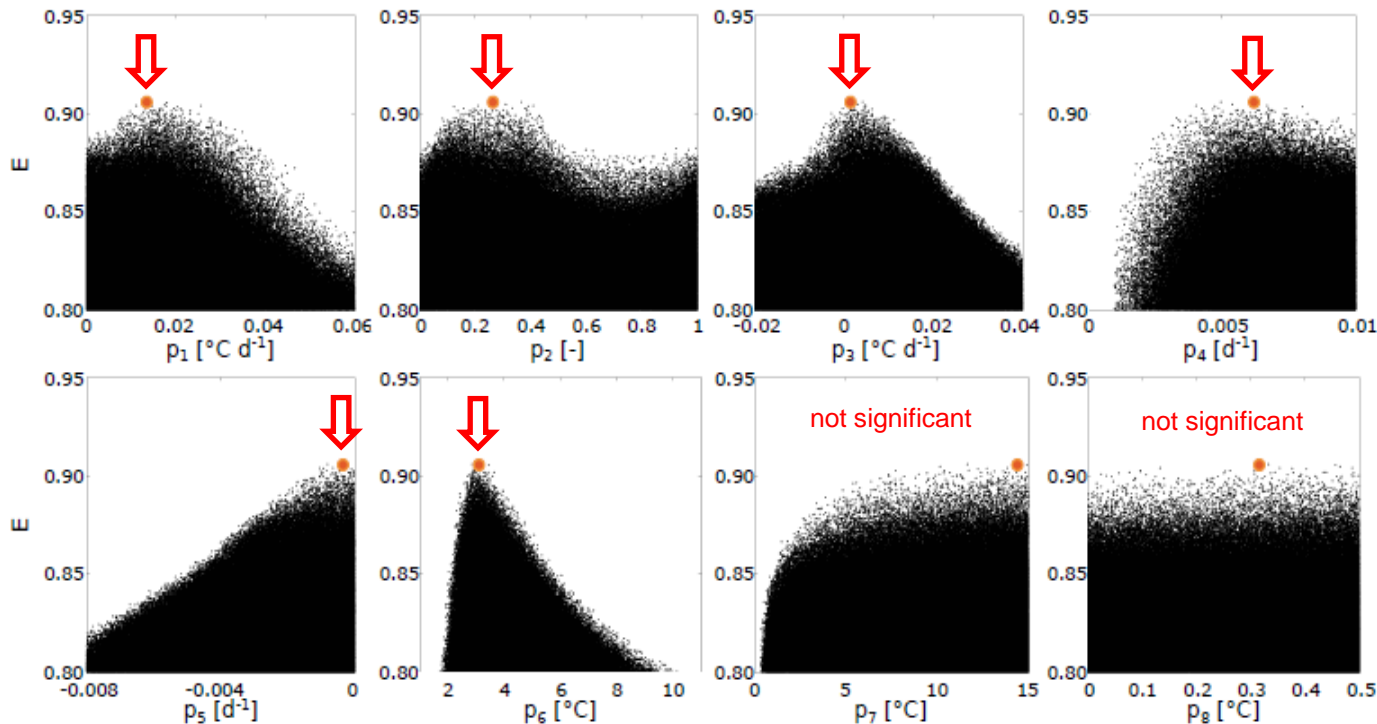
with 1/3 of the dataset



Data provided by: GLERL
Great Lakes Environmental
Research Laboratory, NOAA
National Oceanic and
Atmospheric Administration

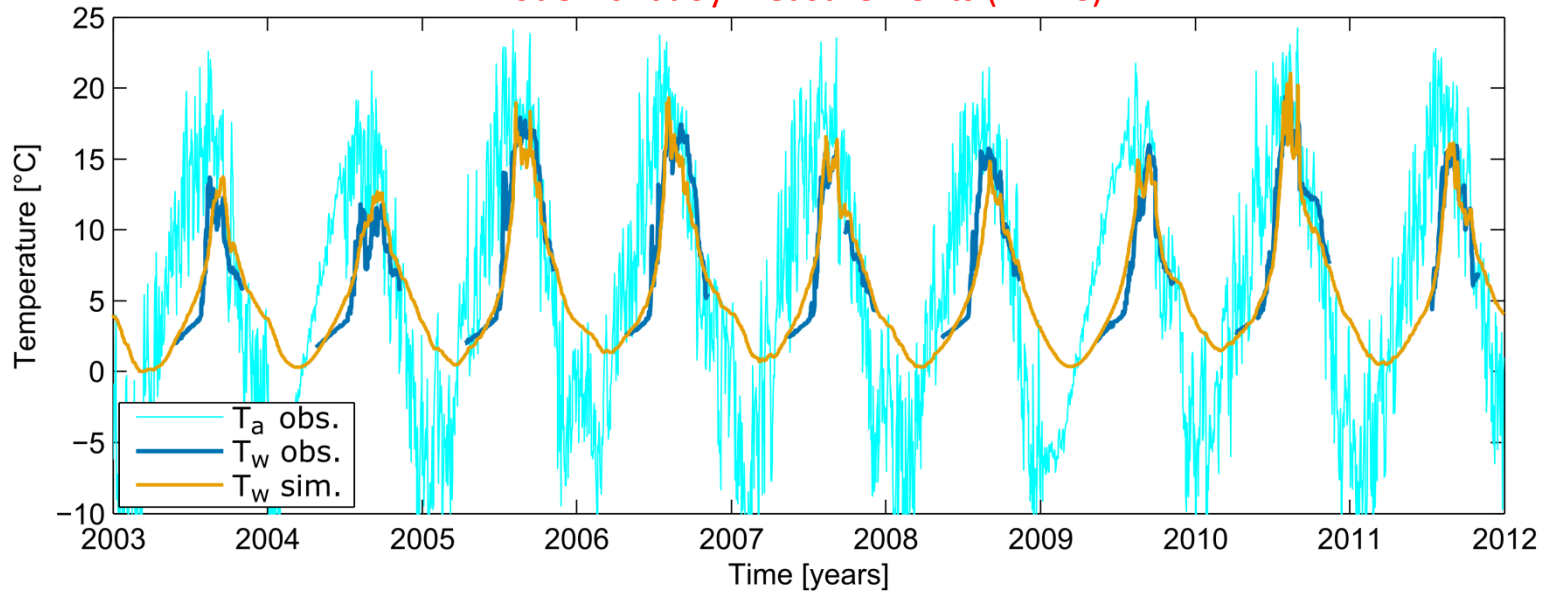


Water temperature:
offshore buoy (27 years),
satellite (18 years).
Air temperature:
C-MAN station (27 years).



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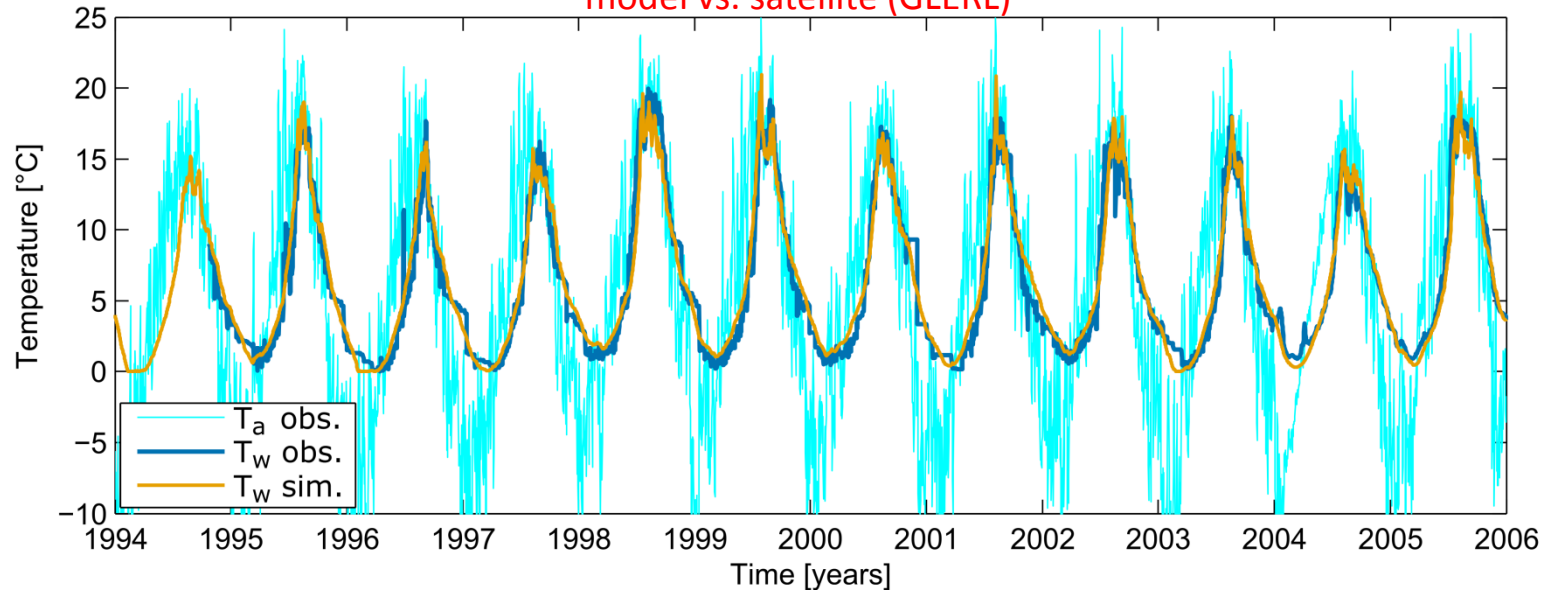
model vs. buoy measurements (NDBC)



Calibration:
RMSE = 1.40 °C
NSE=0.91

Validation:
RMSE = 1.71 °C
NSE=0.90

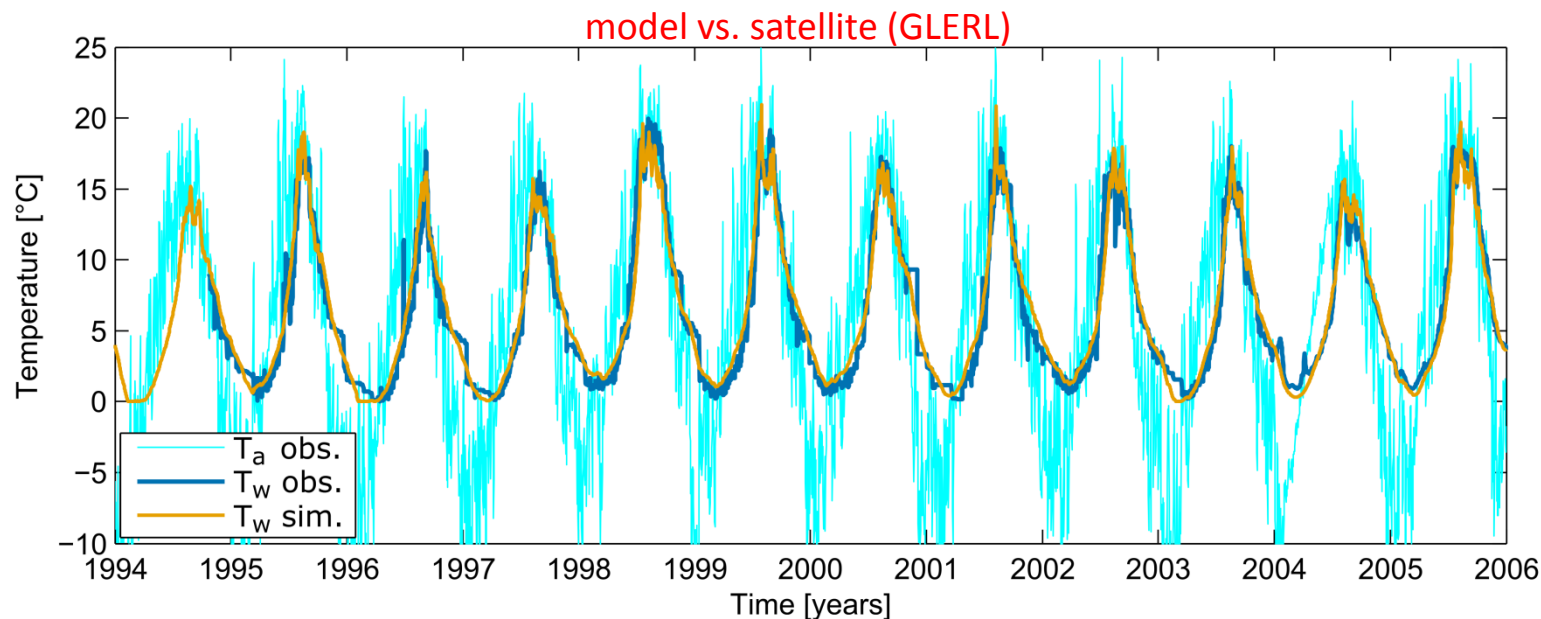
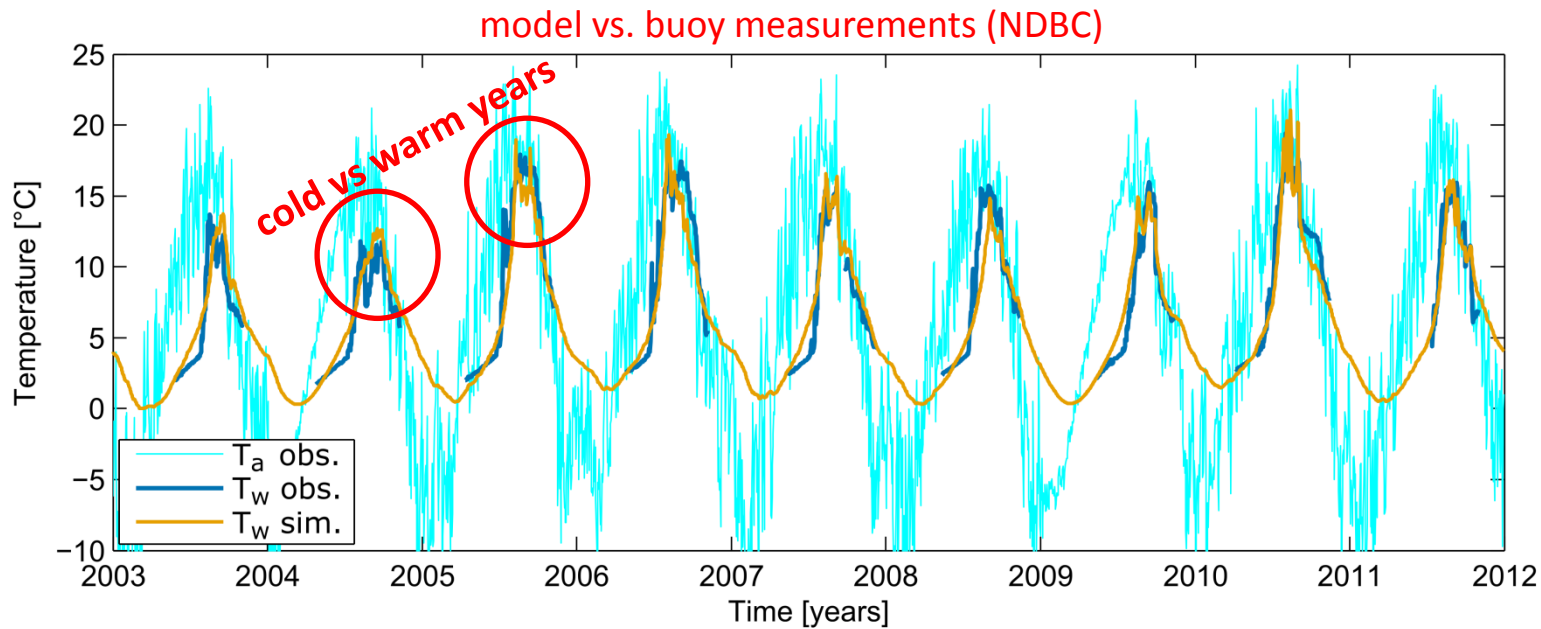
model vs. satellite (GLERL)



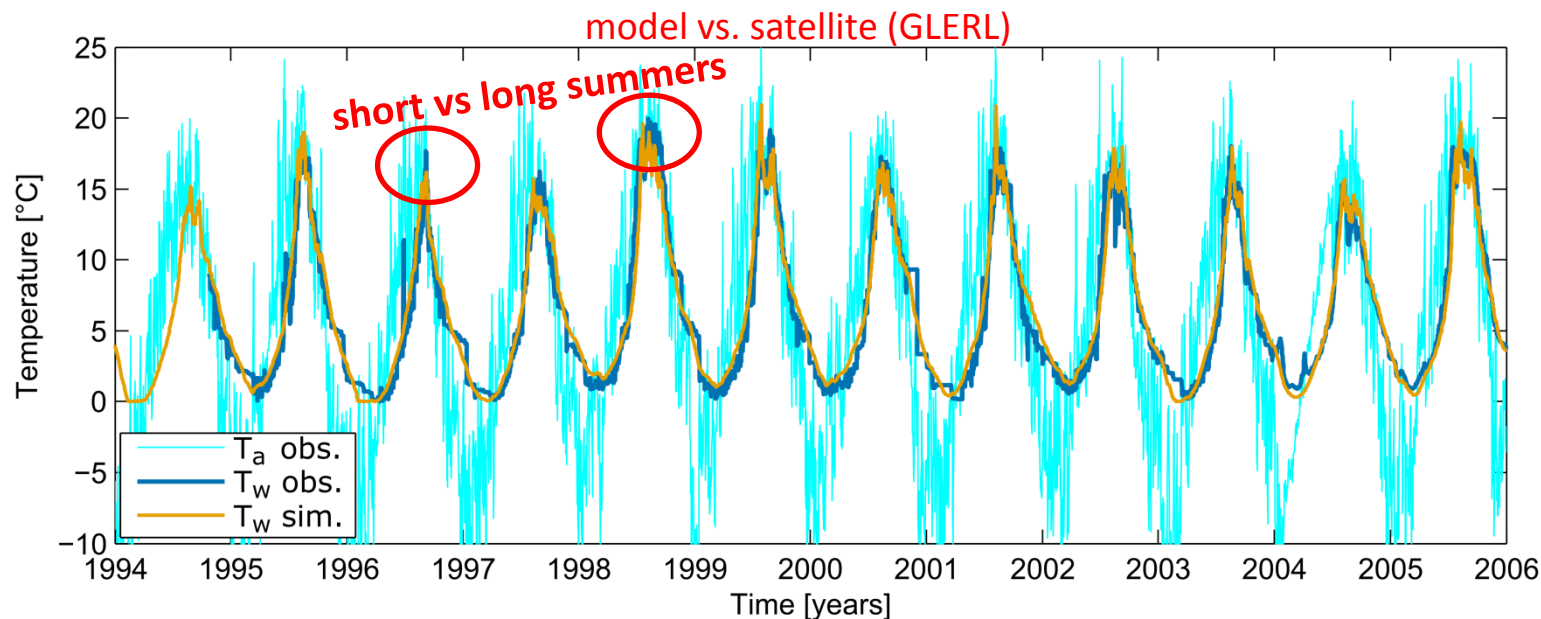
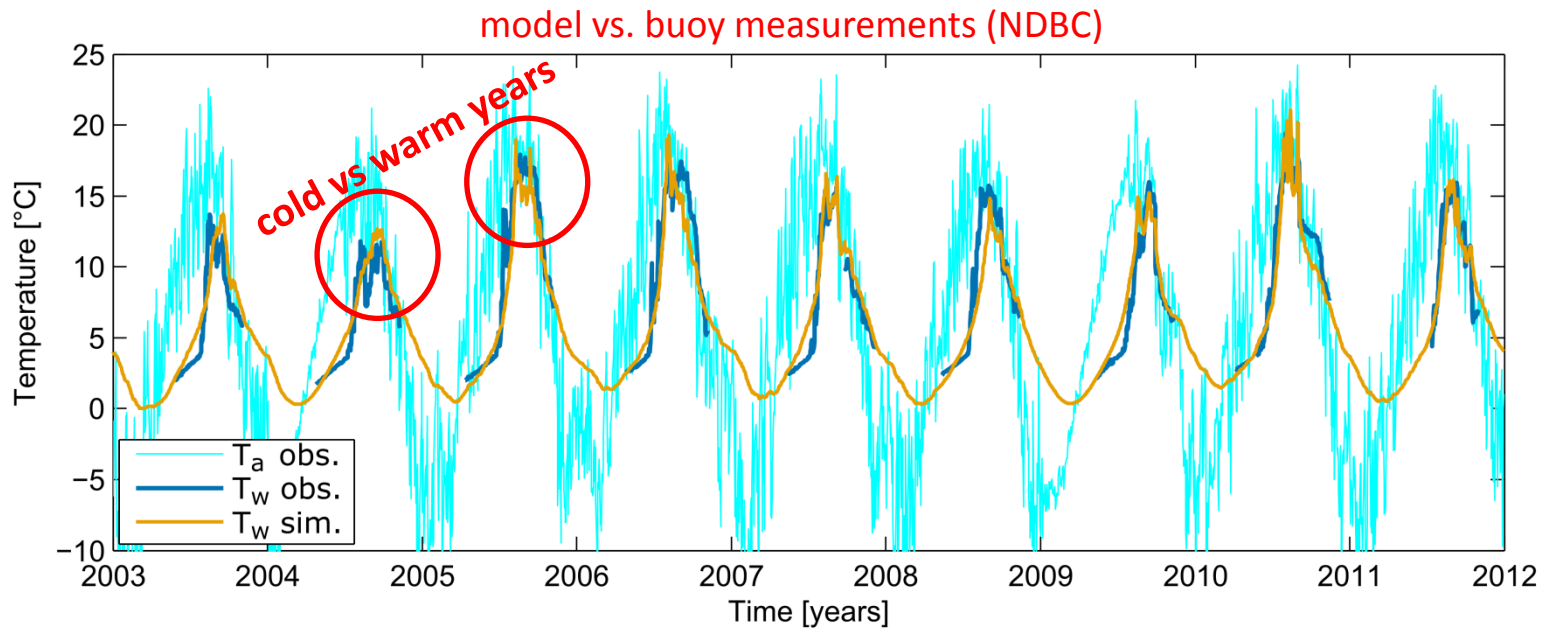
Calibration:
RMSE = 1.17 °C
NSE=0.95

Validation:
RMSE = 1.02 °C
NSE=0.97

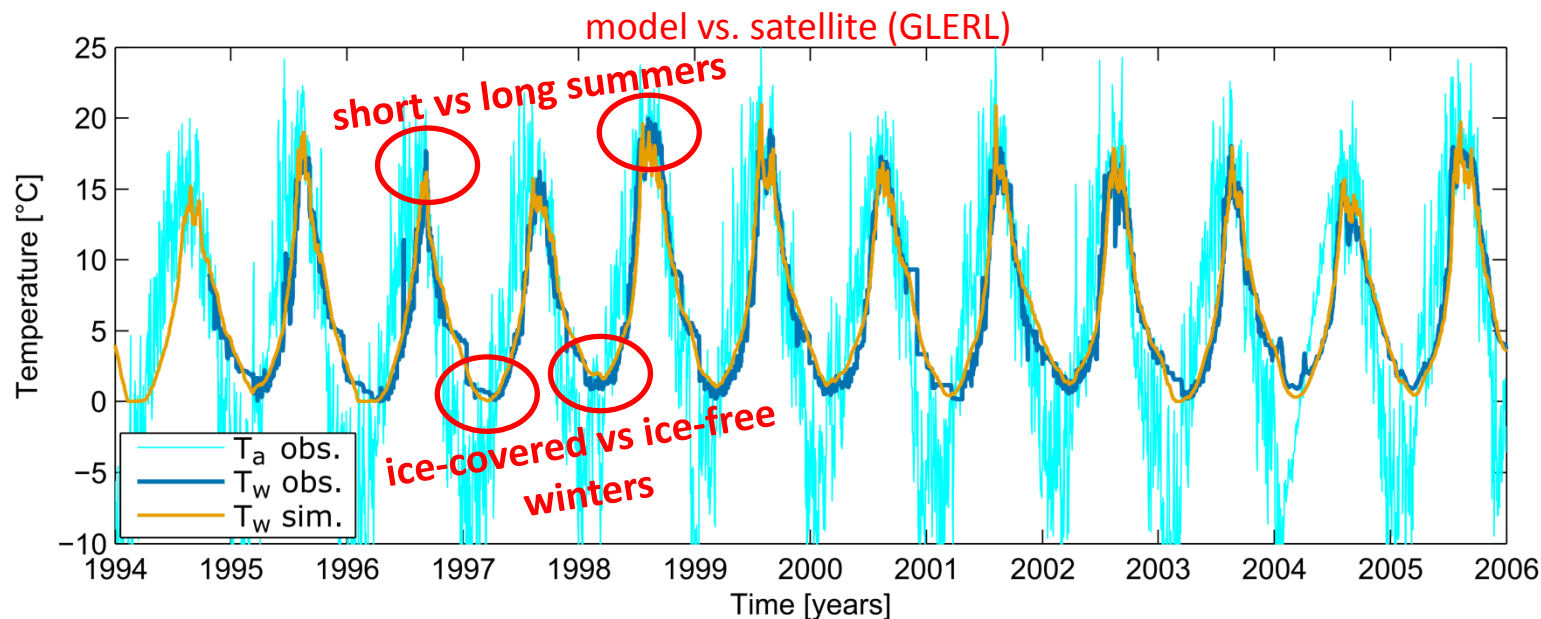
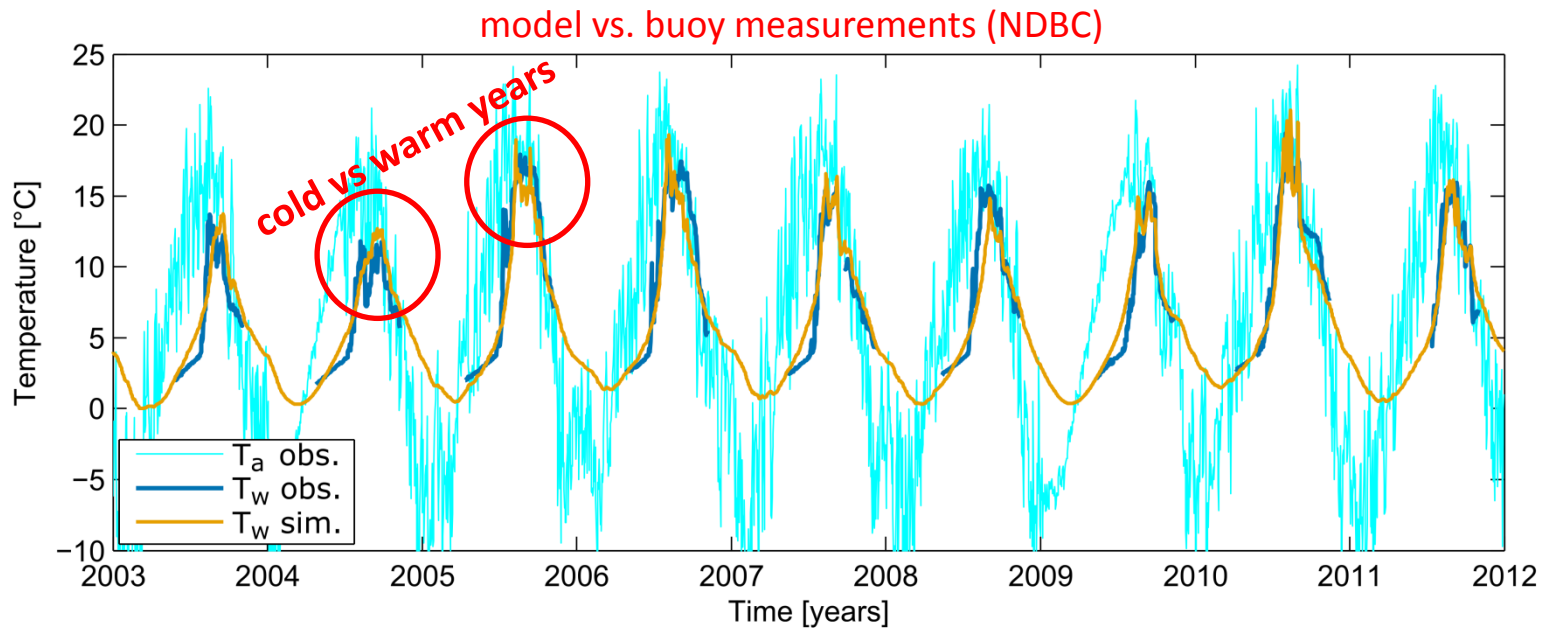
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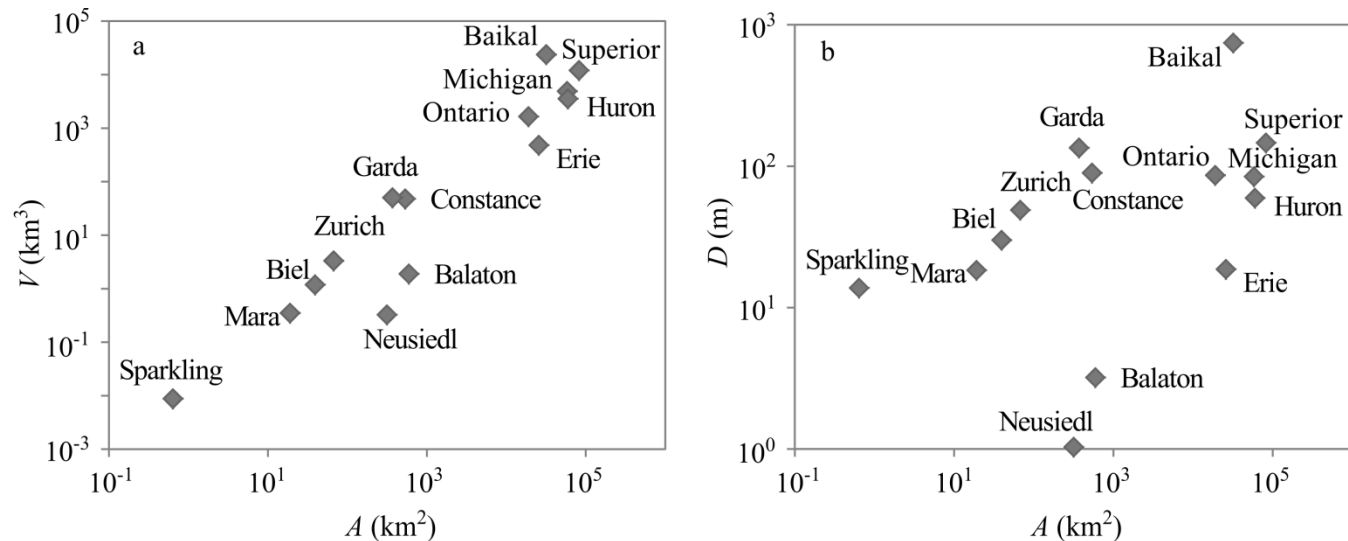
An application to Lake Superior



Application to different lakes

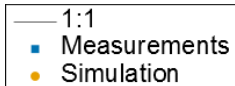
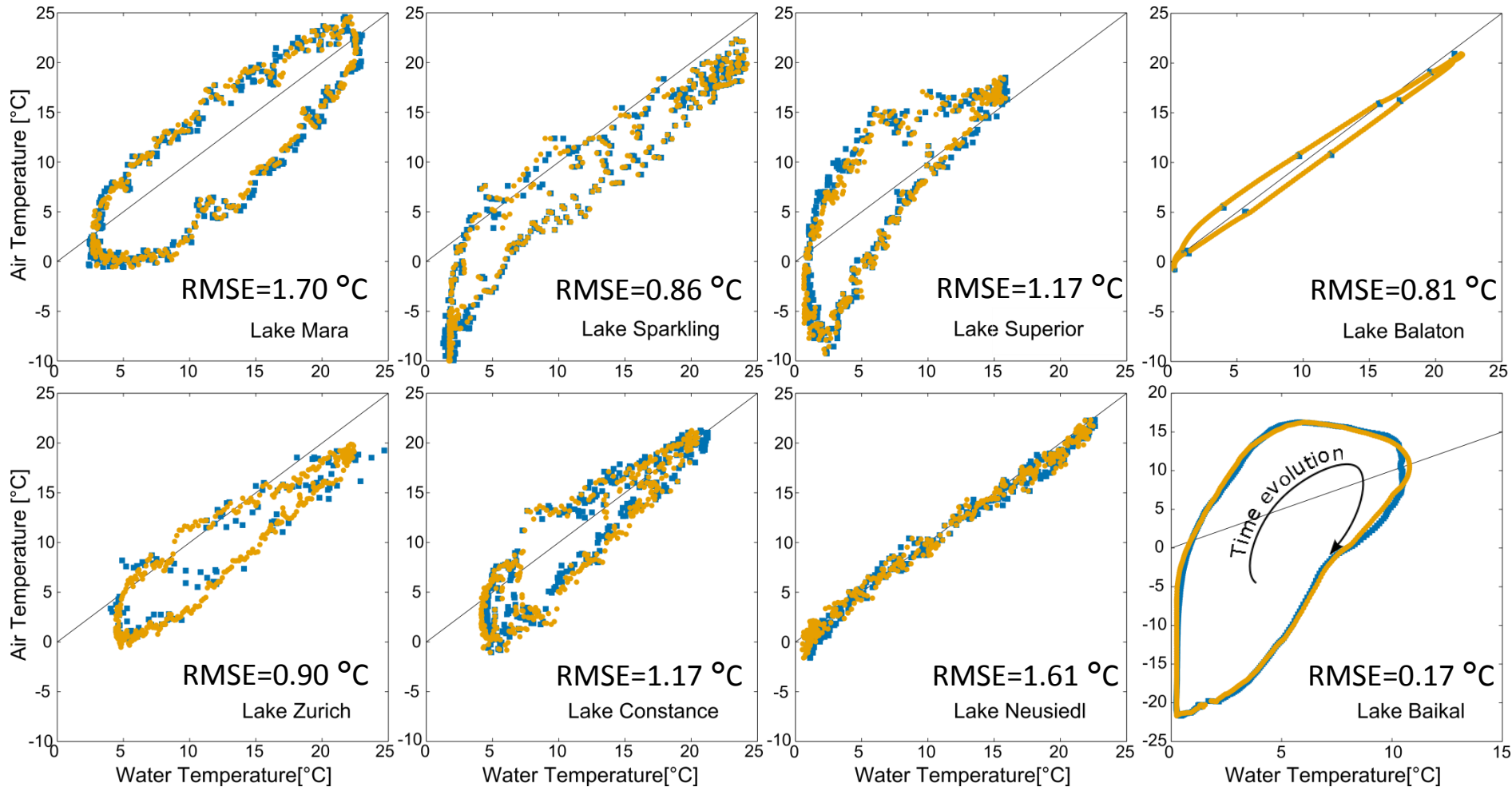


Air2water has been tested on **14 temperate lakes** within the North Temperate Zone, having **different morphological** characteristics.

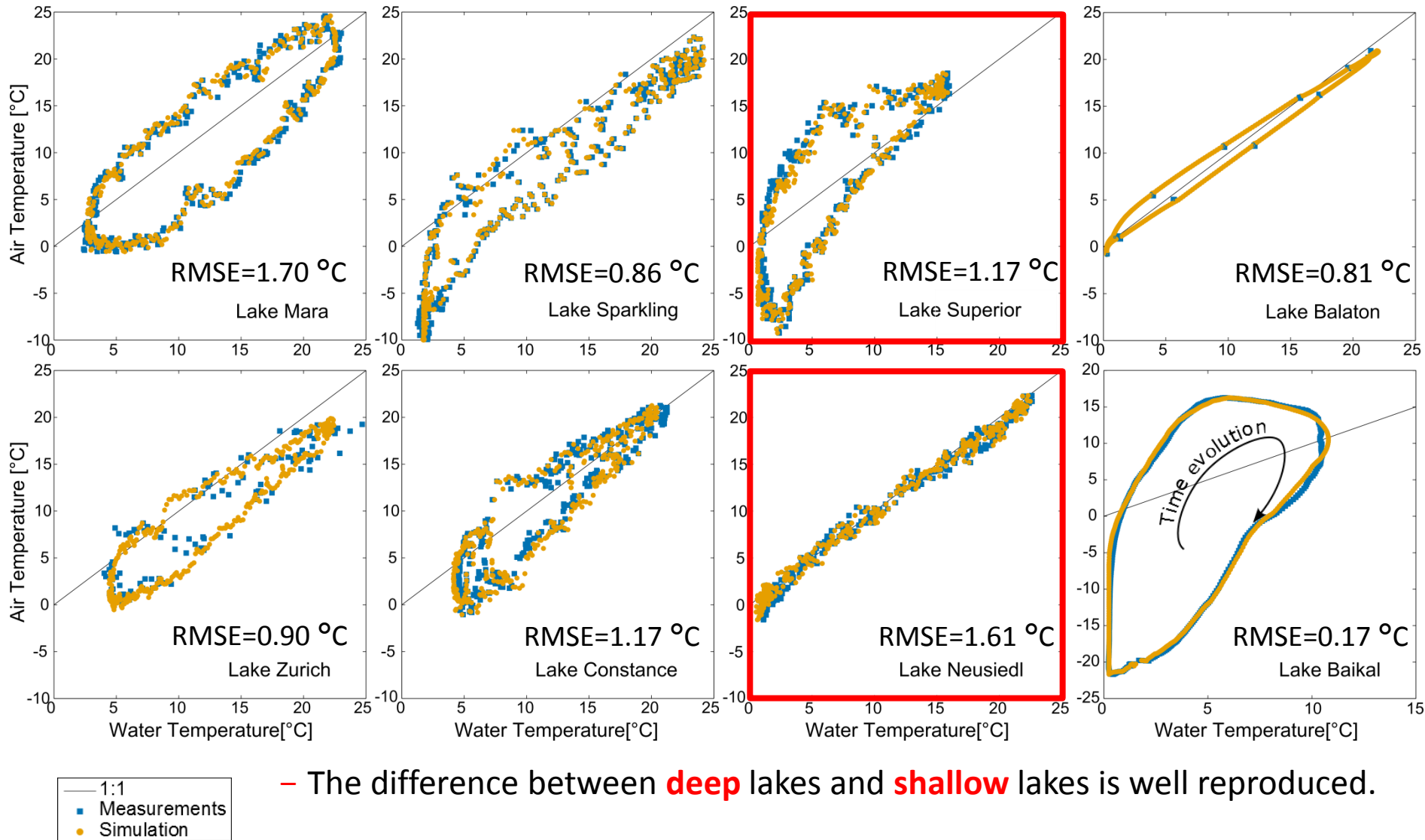


- Toffolon, M., S. Piccolroaz, B. Majone, An.M. Soja, F. Peeters, M. Schmid, and A. Wüest (2014), **Prediction of surface temperature in lakes with different morphology using air temperature**, *Limnology and Oceanography*, 59(6), p. 2185-2202.

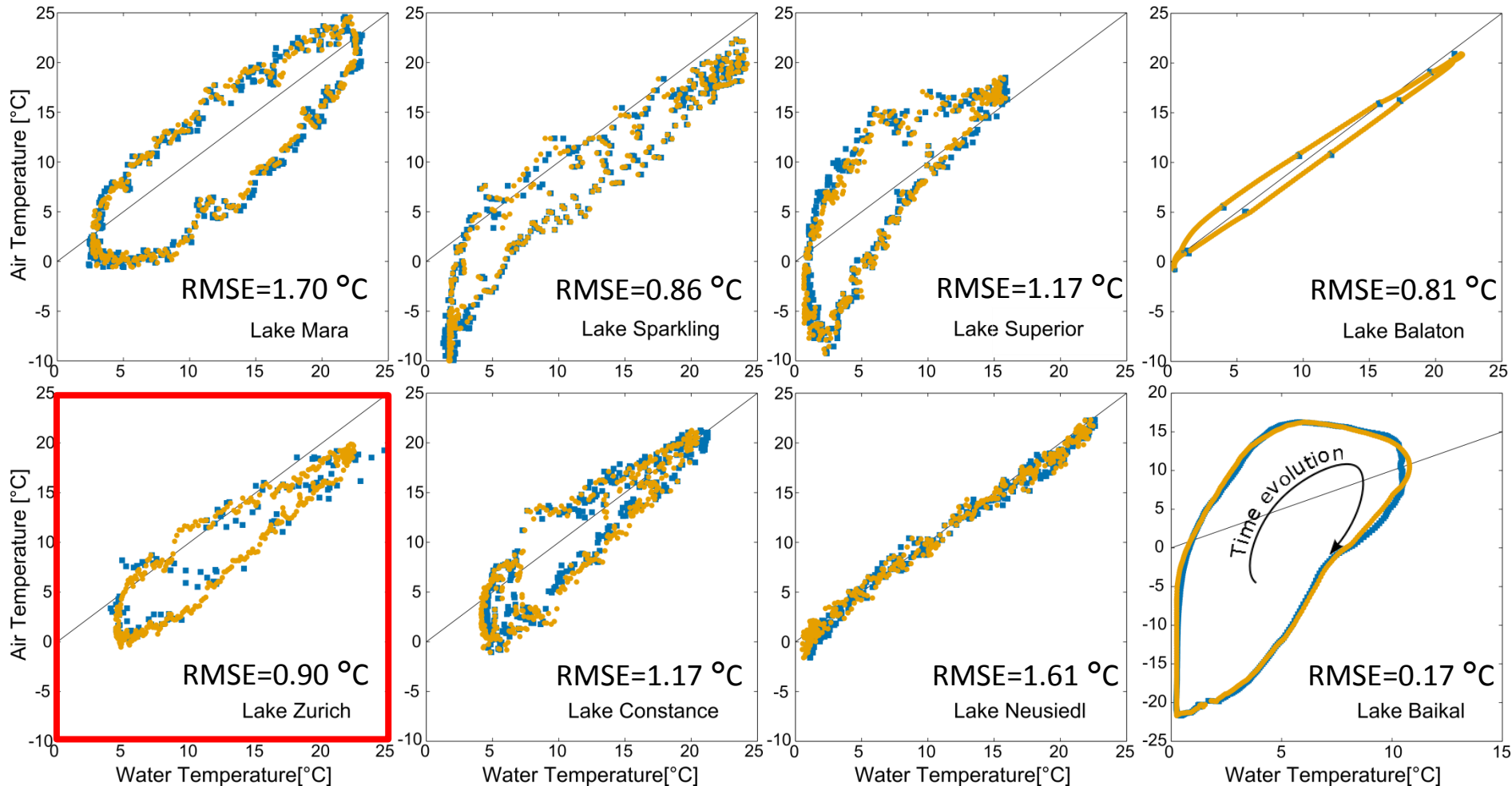
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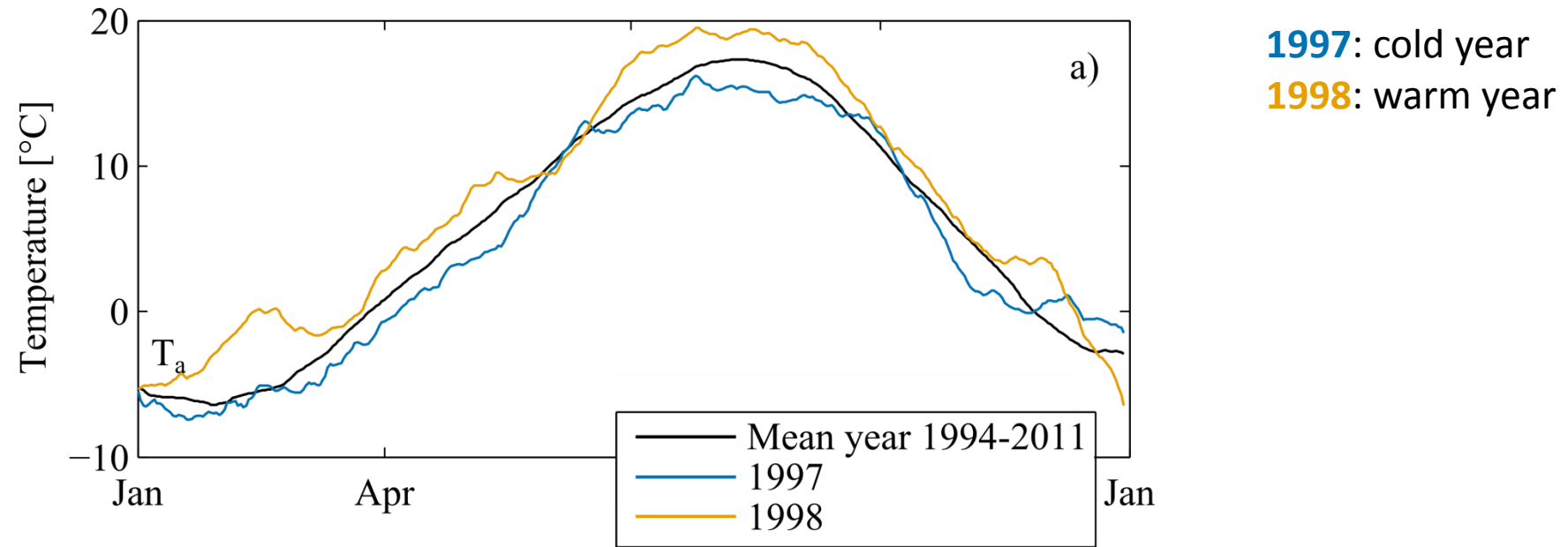


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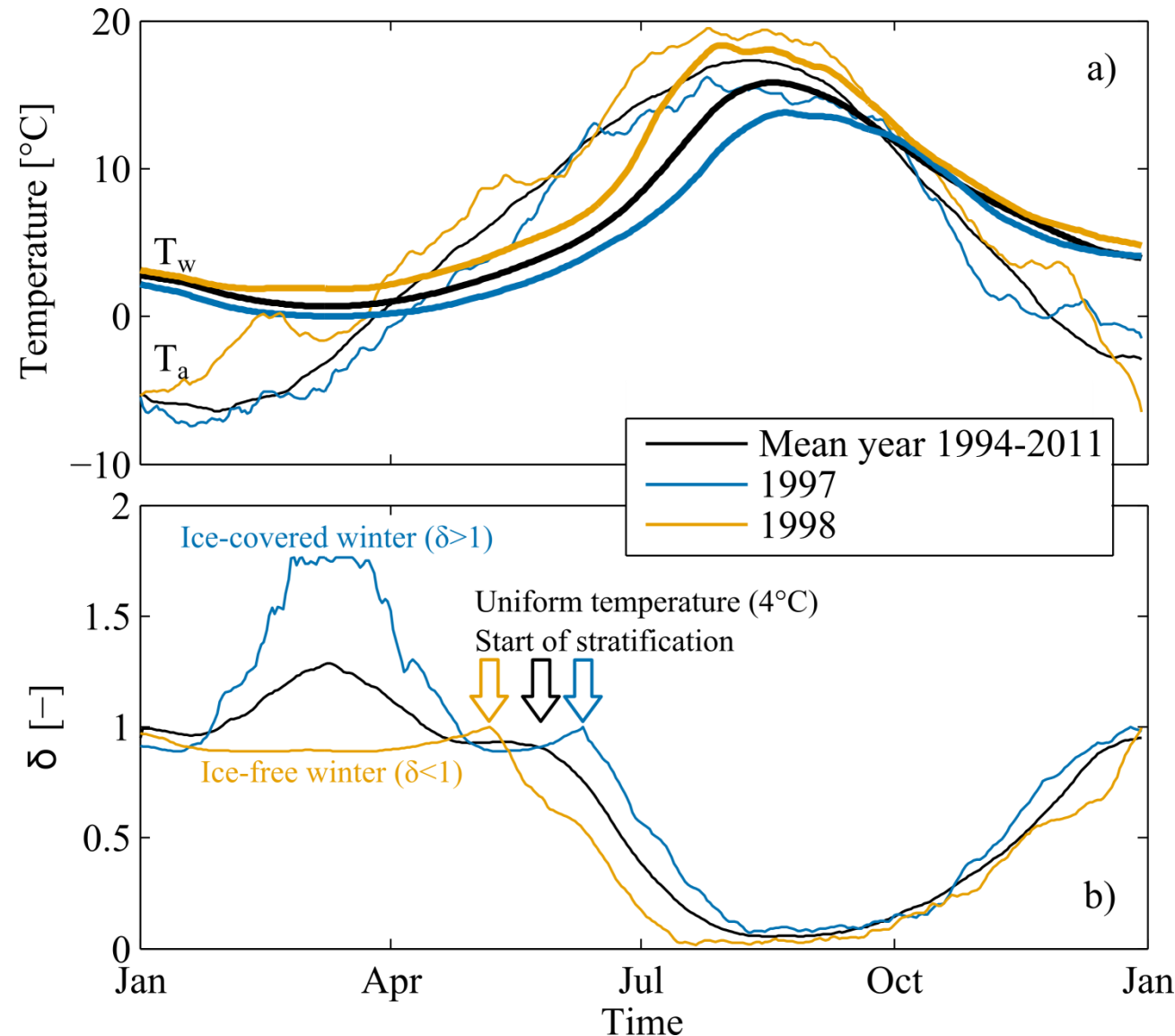


- The difference between **deep** lakes and **shallow** lakes is well reproduced.
- RMSEs are **comparable** with those obtained by using process based models:
SimStrat (Peeters et al., 2002) → **0.77°C**
air2water (Toffolon et al., 2014) → **0.90°C**

What is the role of stratification?



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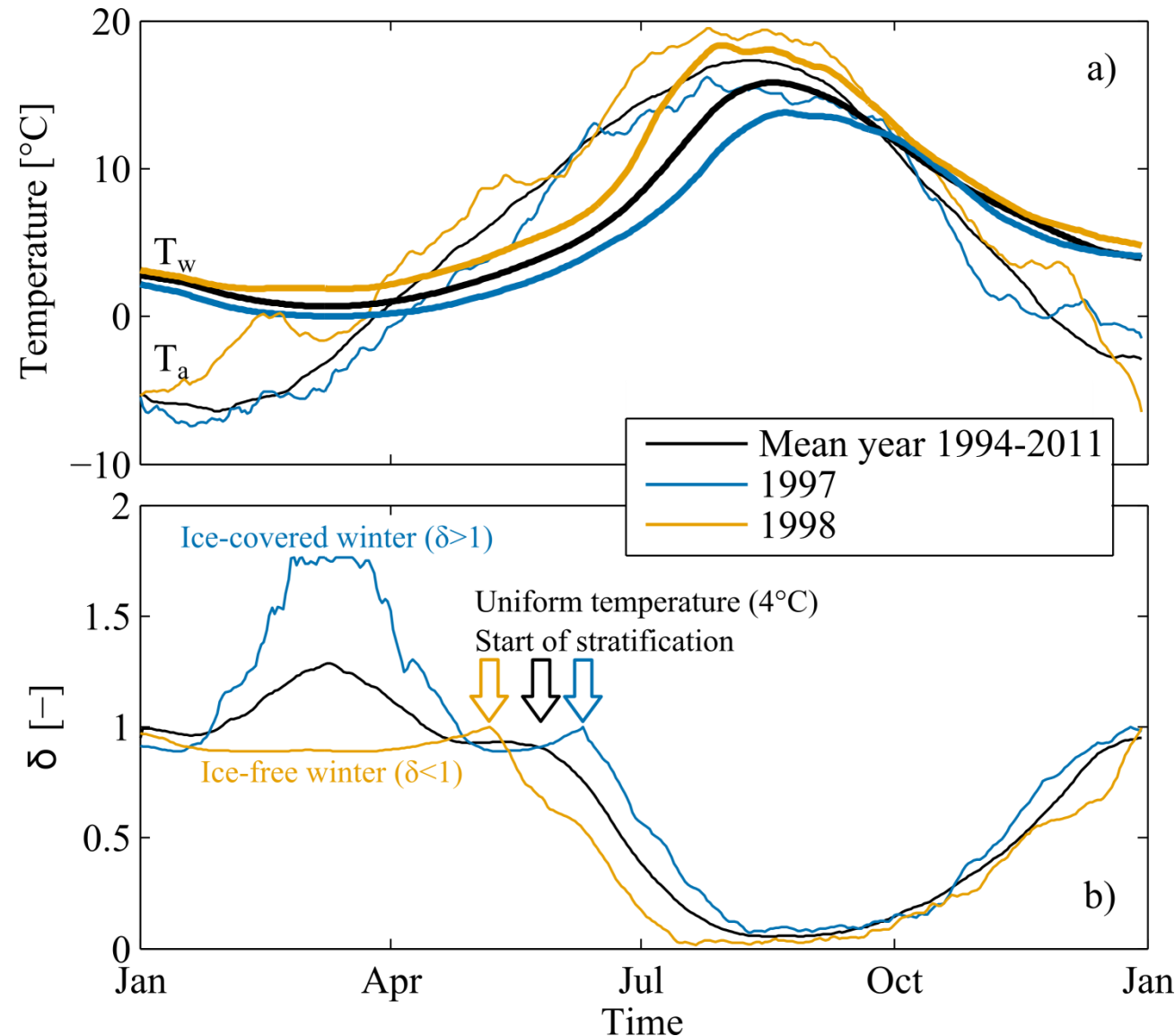
1997: cold year

1998: warm year

Anticipated onset of stratified conditions due to a nearly ice-free winter.

Earlier reduction of the surface volume and a **faster** increase of LST, which in turn contributed to further **decrease** δ during summer months.

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Positive feedback between LST annual cycle and stratification dynamics.

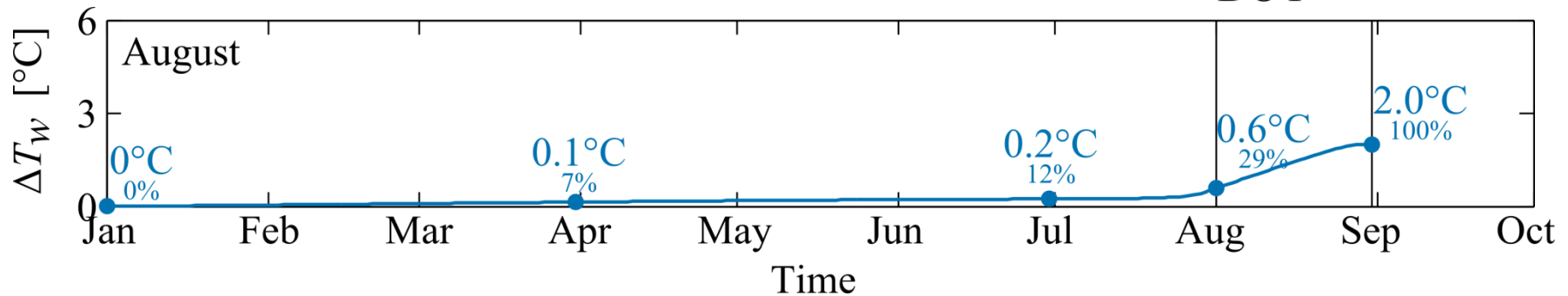
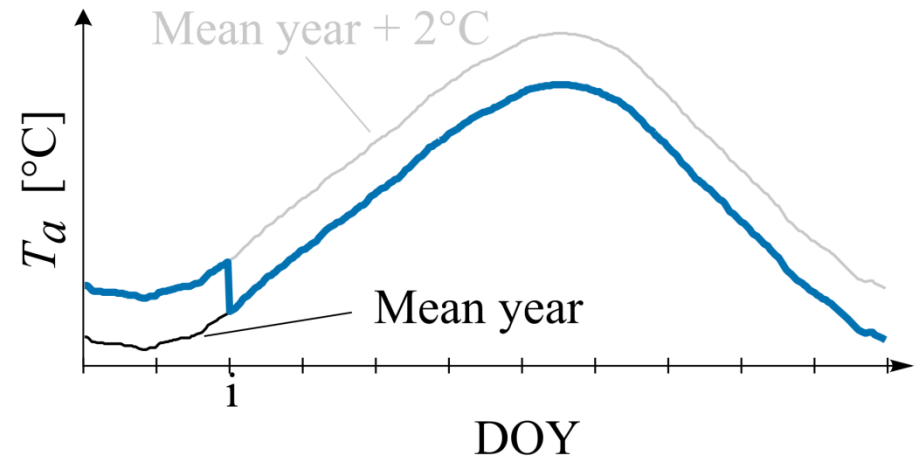
Thermal inertia \rightarrow historical memory of past conditions.

What is the role of stratification?

● The historical memory of the system

365 air temperature cycles **dynamically reconstructed** on the basis of two reference years, progressively delaying of one day the transition between the two years.

ΔT_w = difference between period-averaged LST of the scenario and of the mean year.

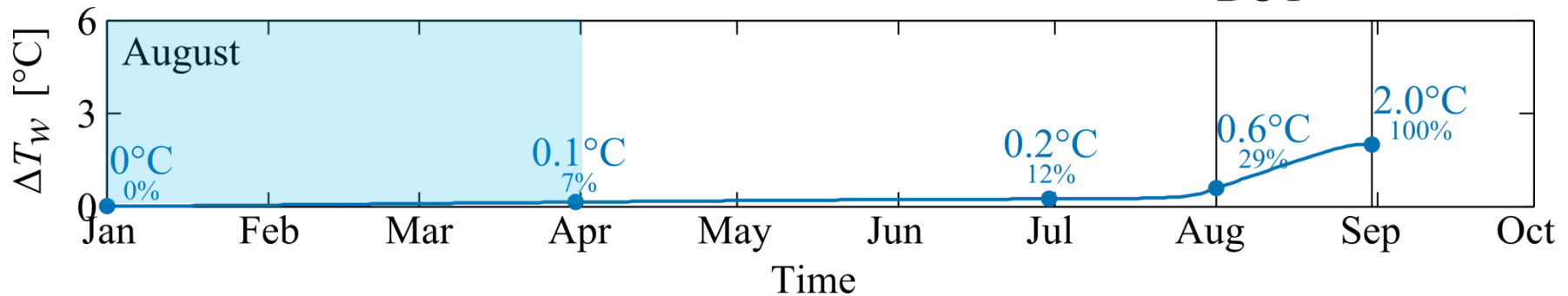
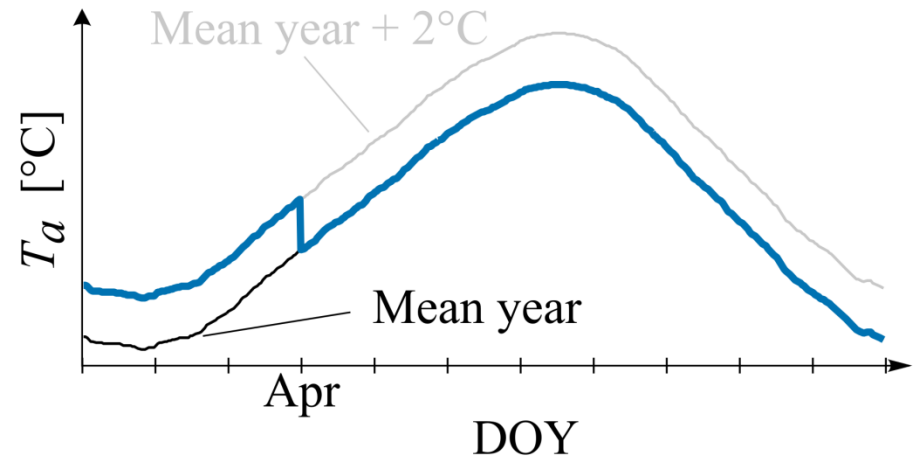


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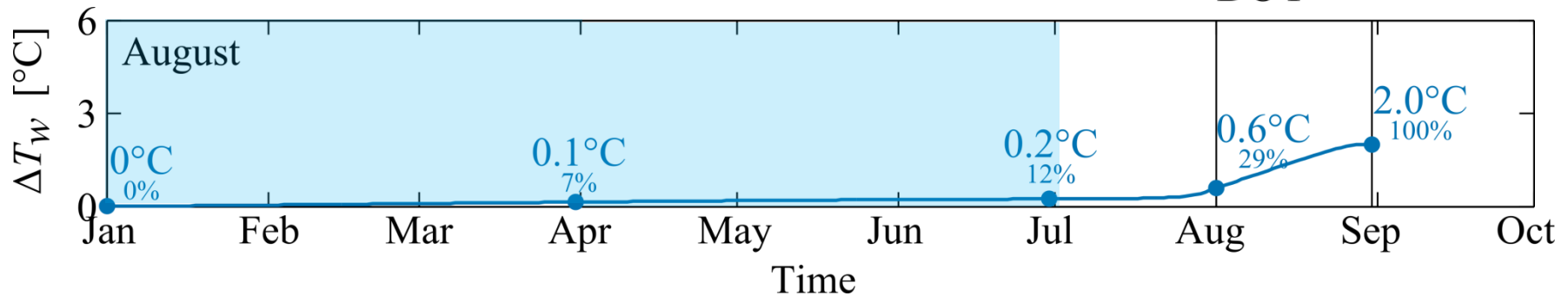
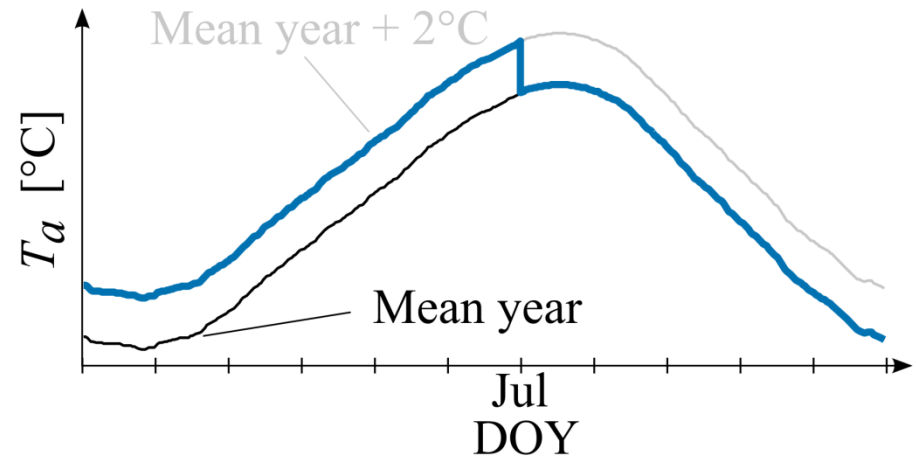


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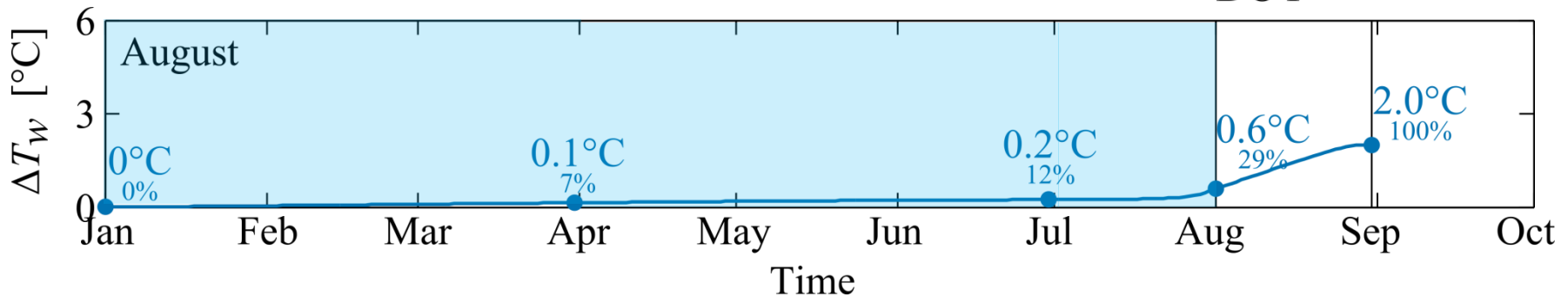
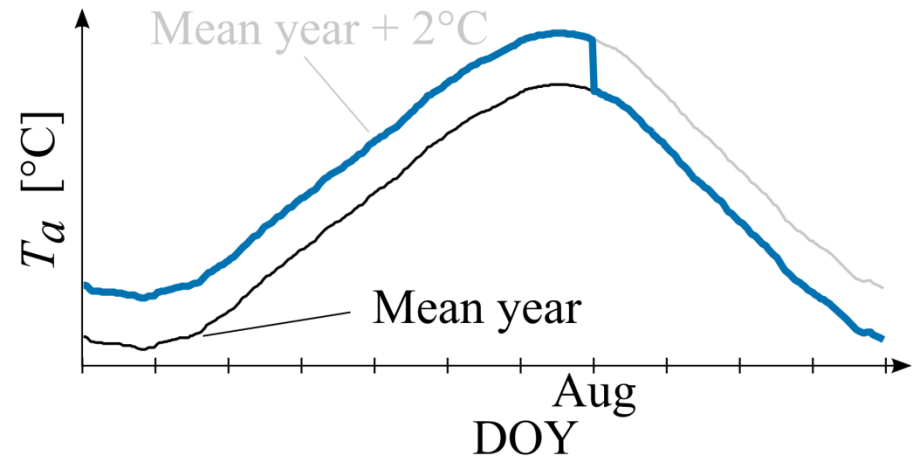


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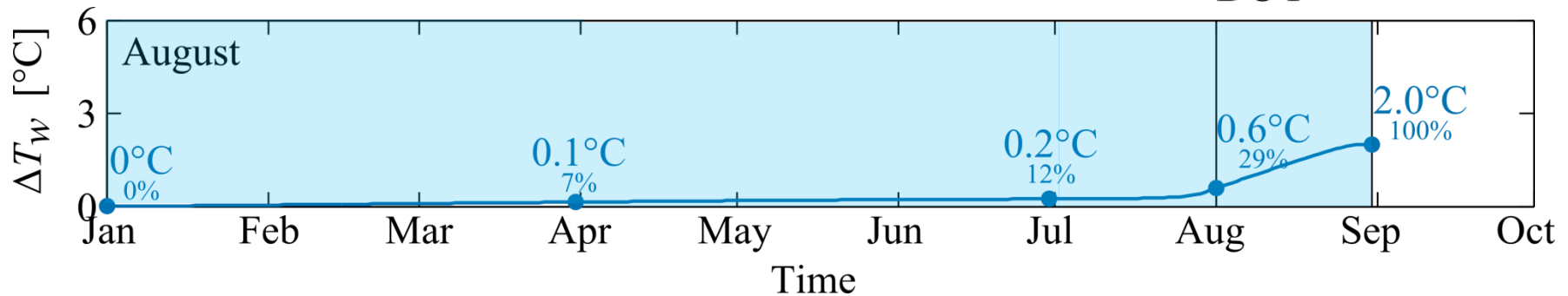
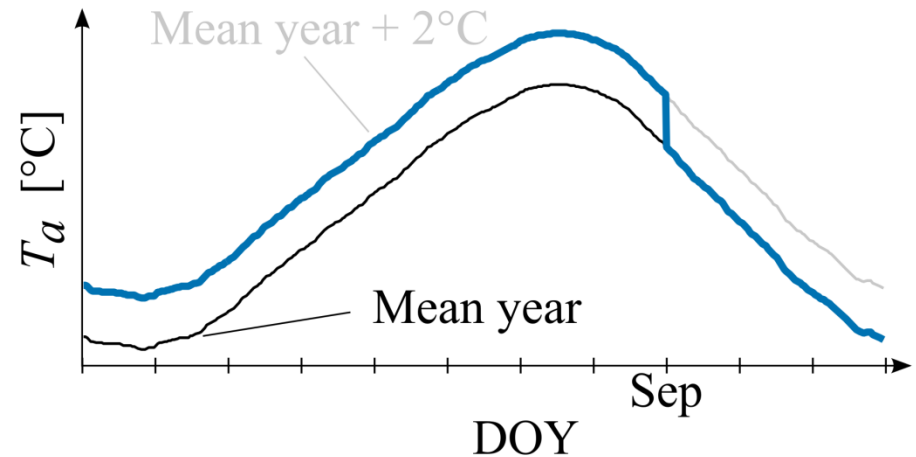


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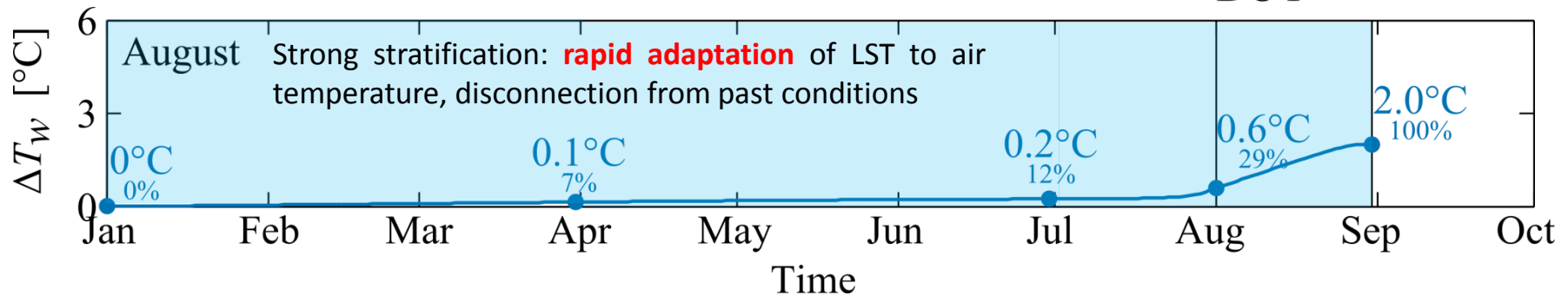
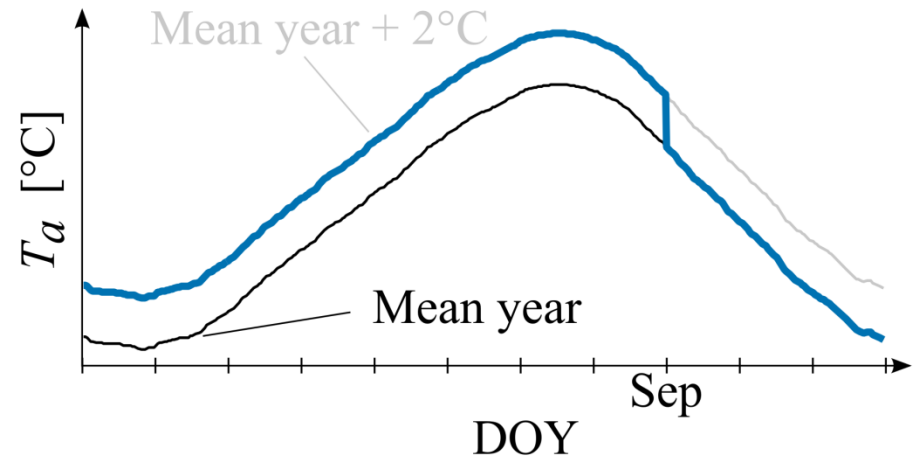


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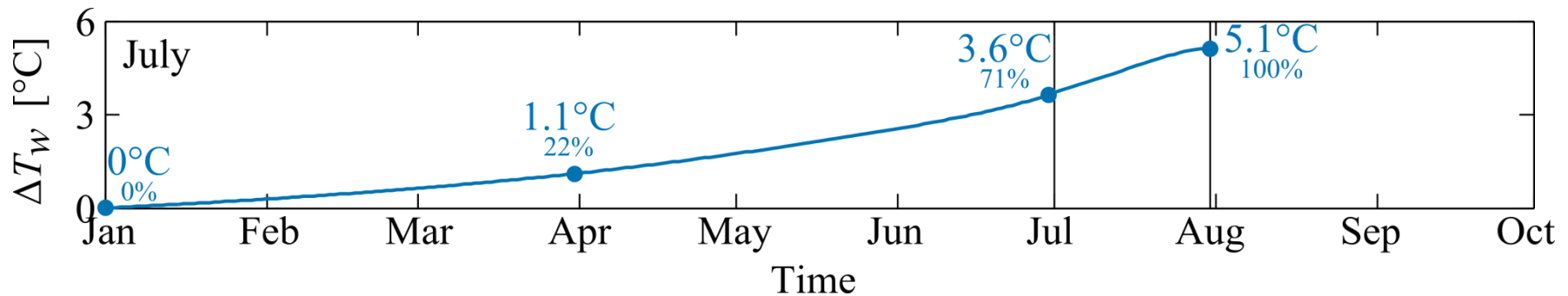
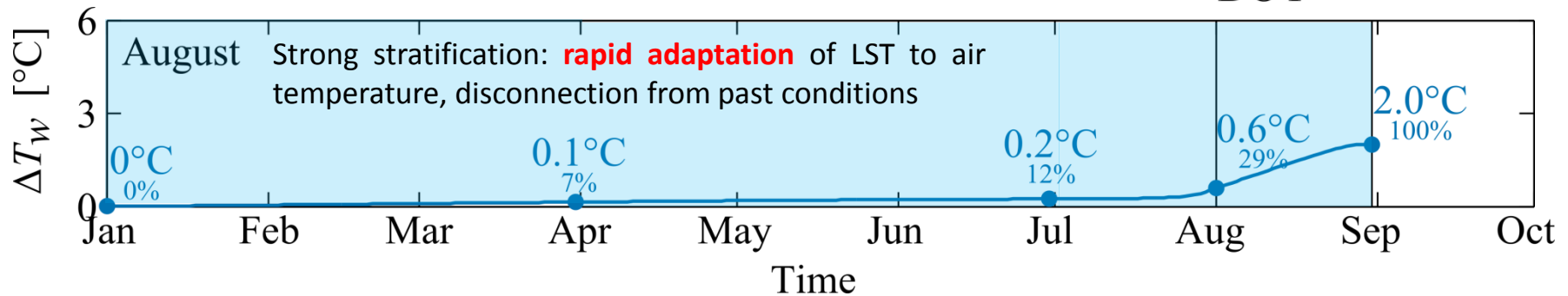
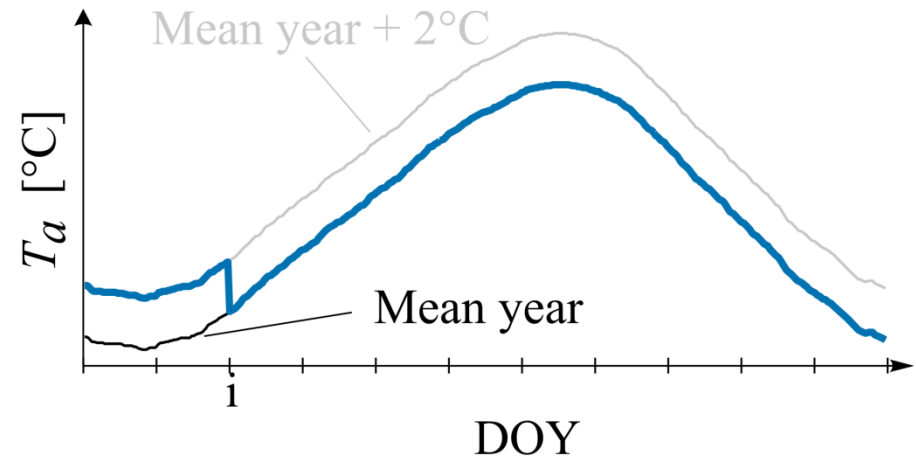


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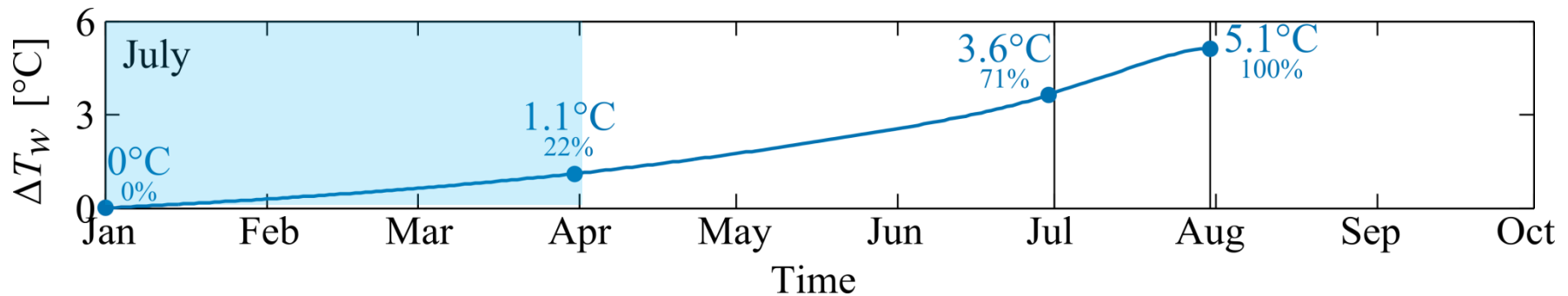
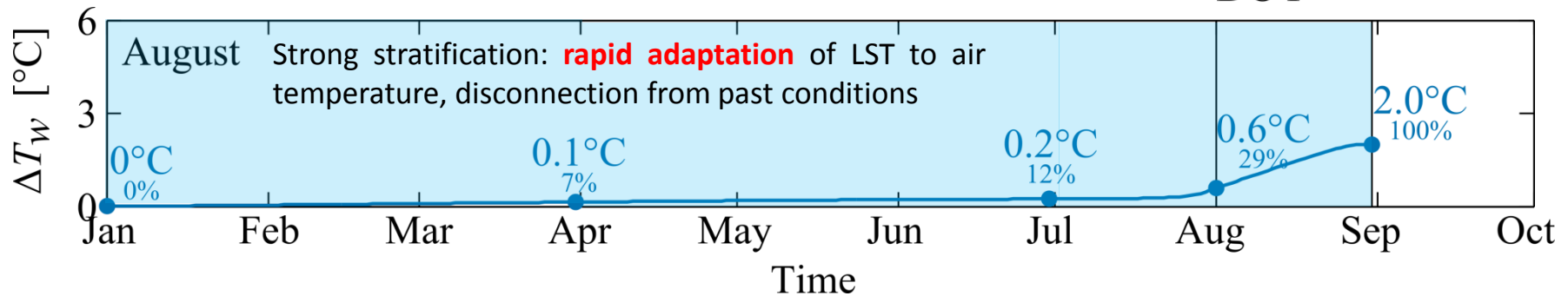
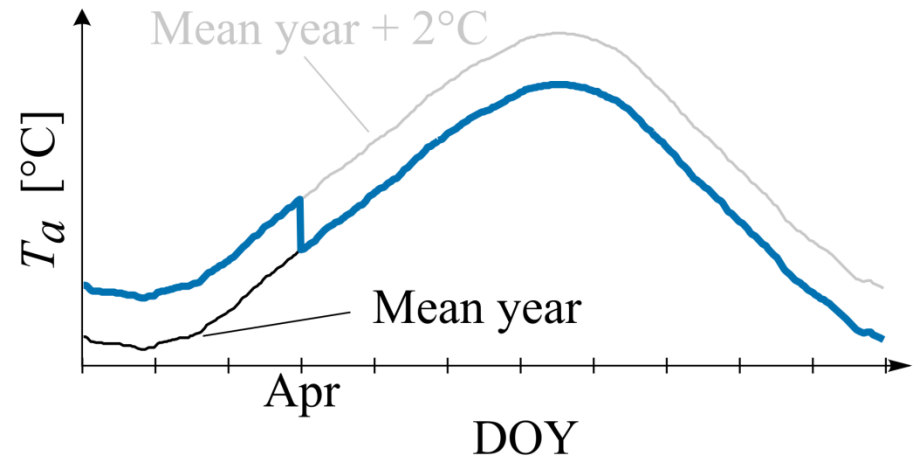


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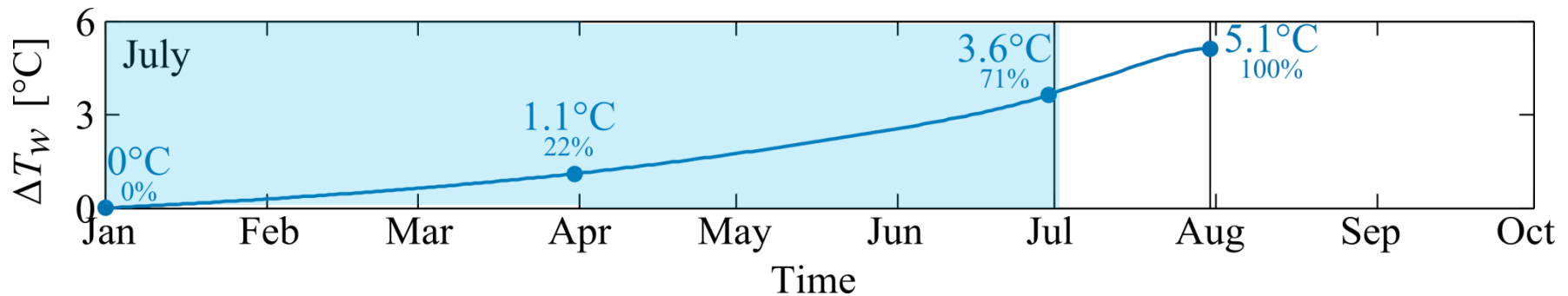
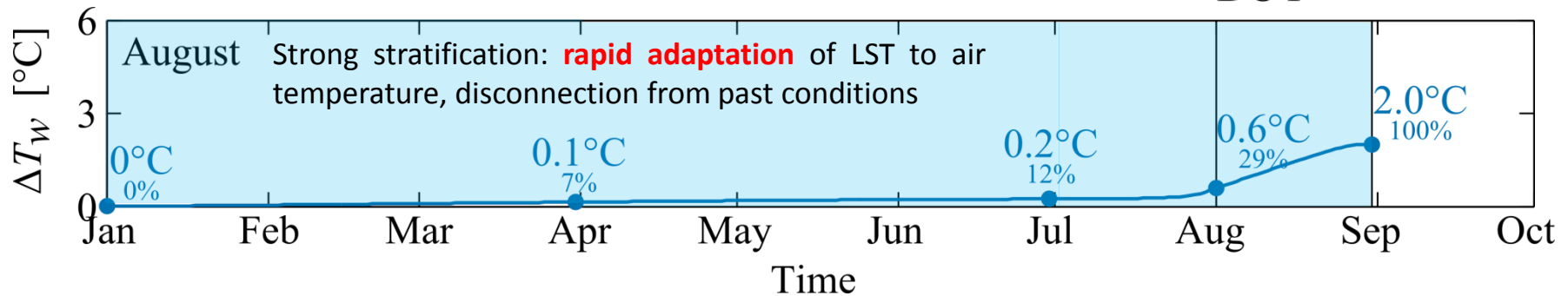
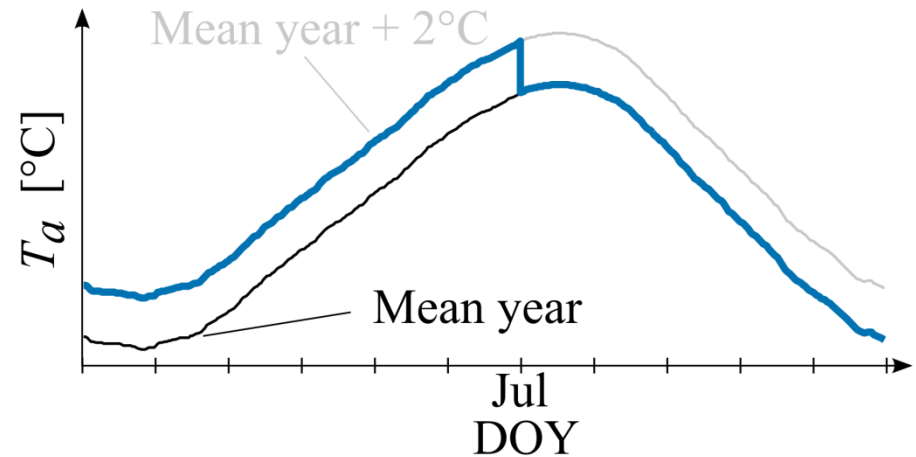


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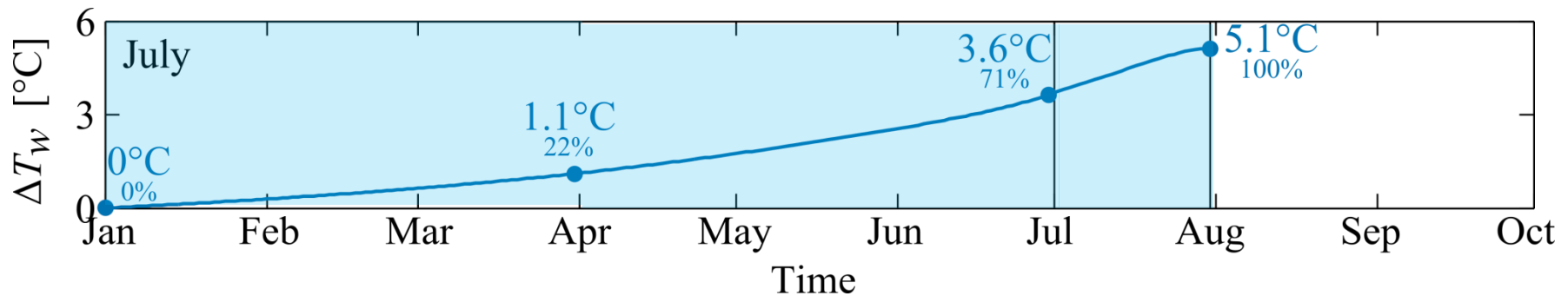
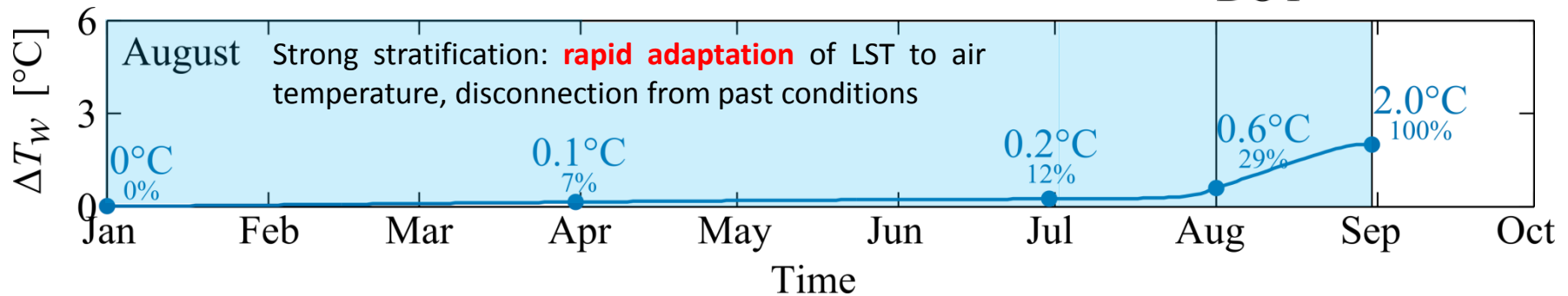
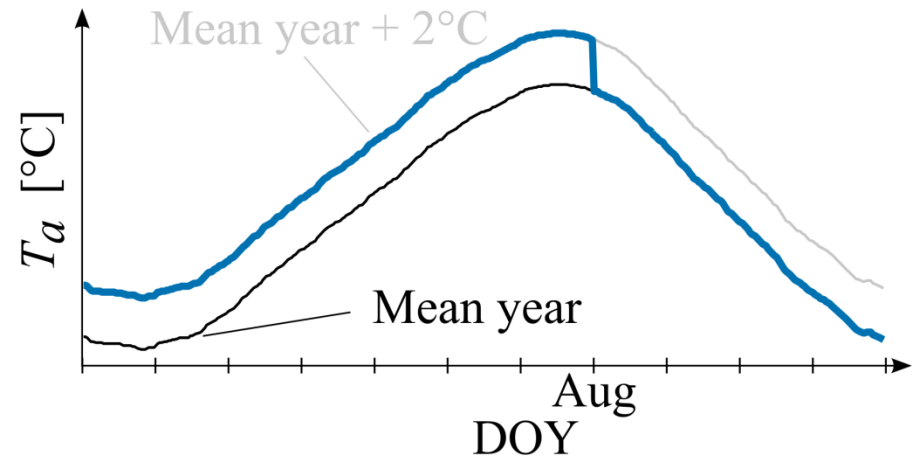


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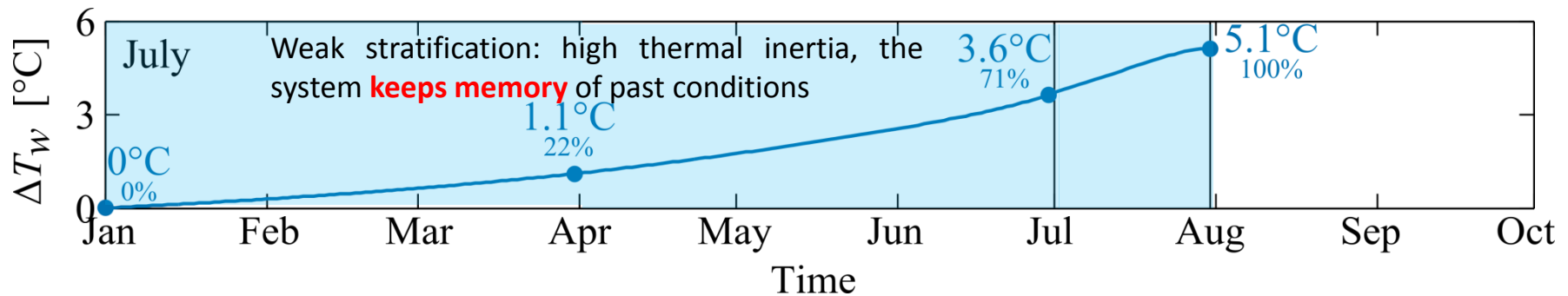
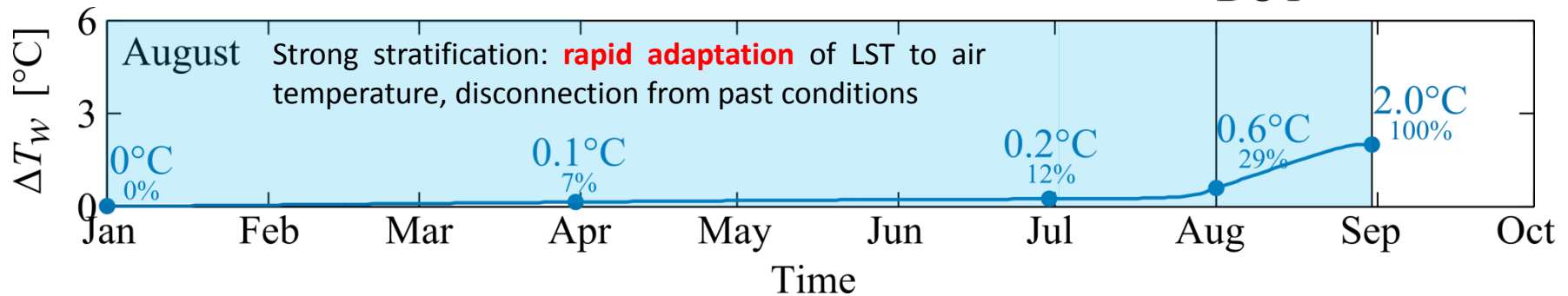
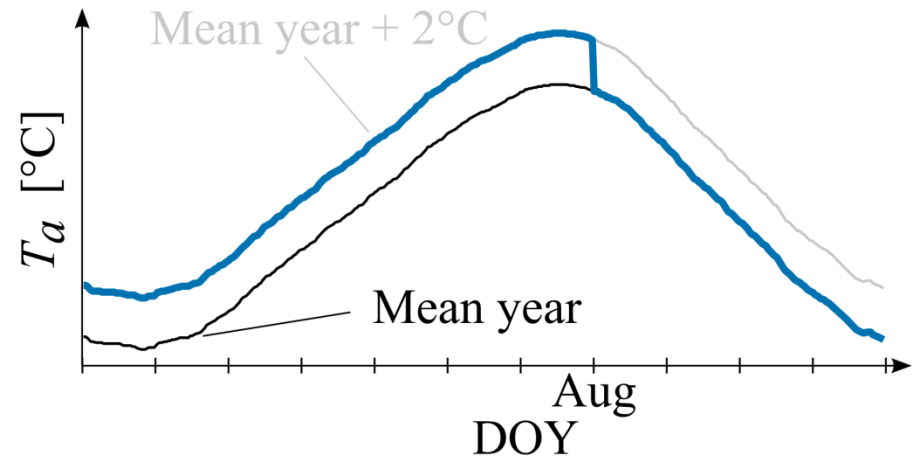


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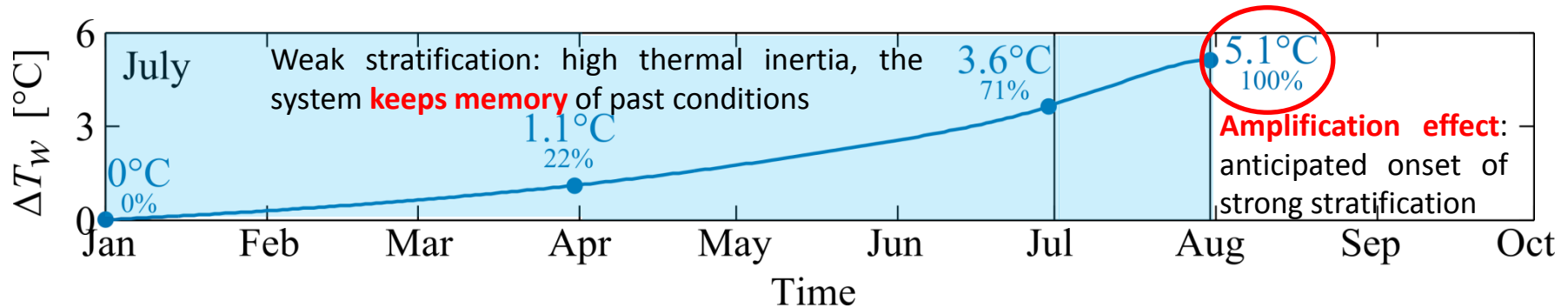
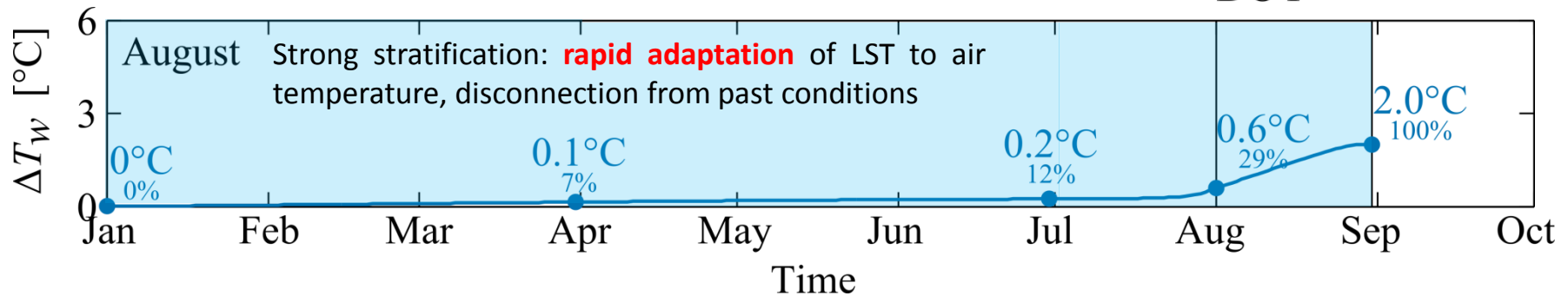
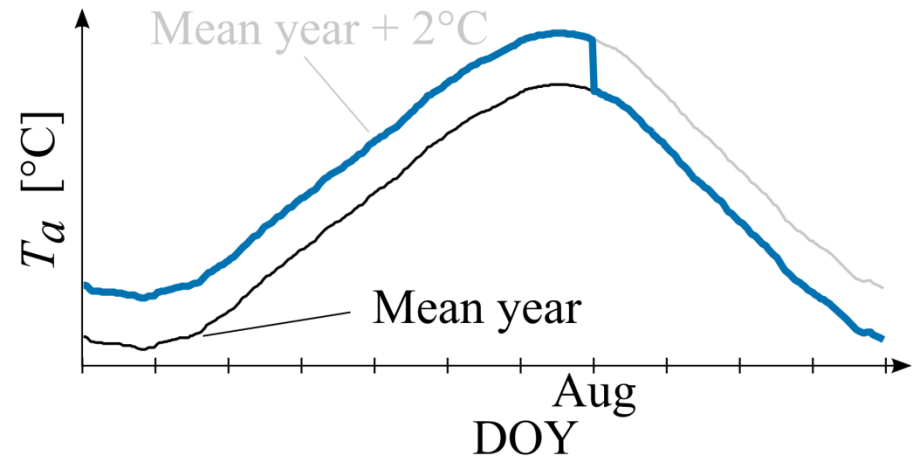


What is the role of stratification?

• The historical memory of the system

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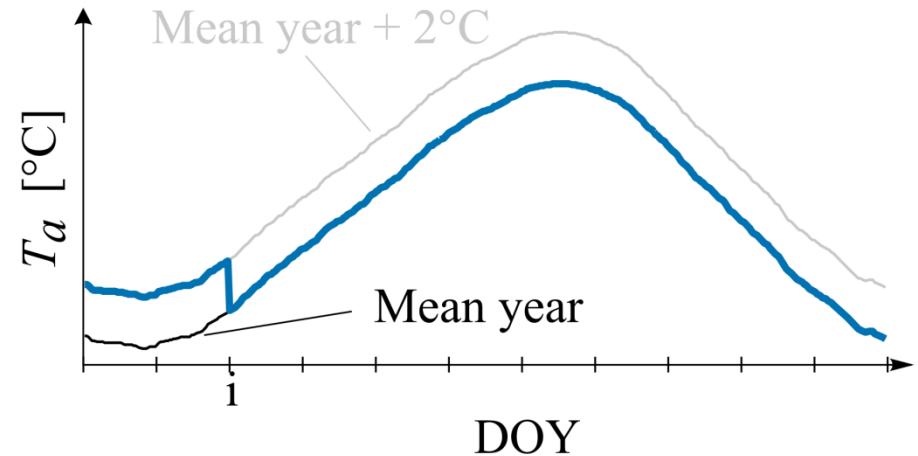


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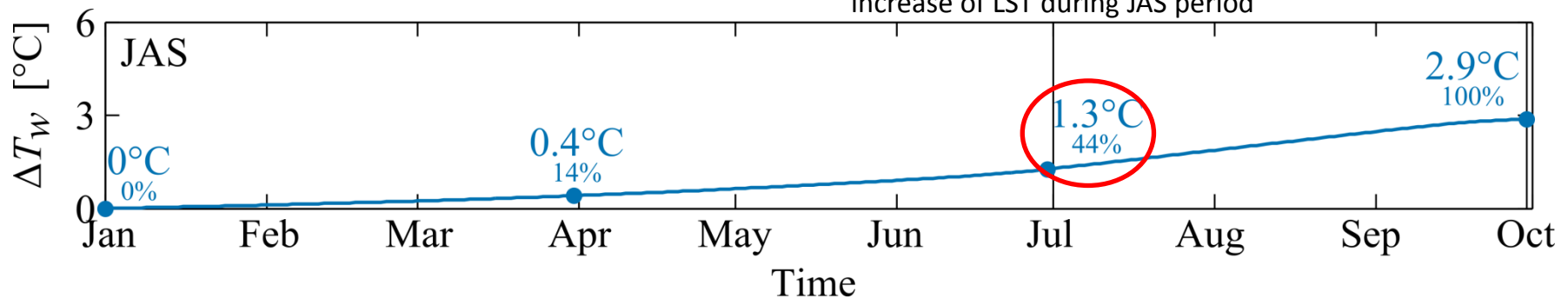
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The two periods January-June and JAS contribute **almost equally** to the increase of LST during JAS period

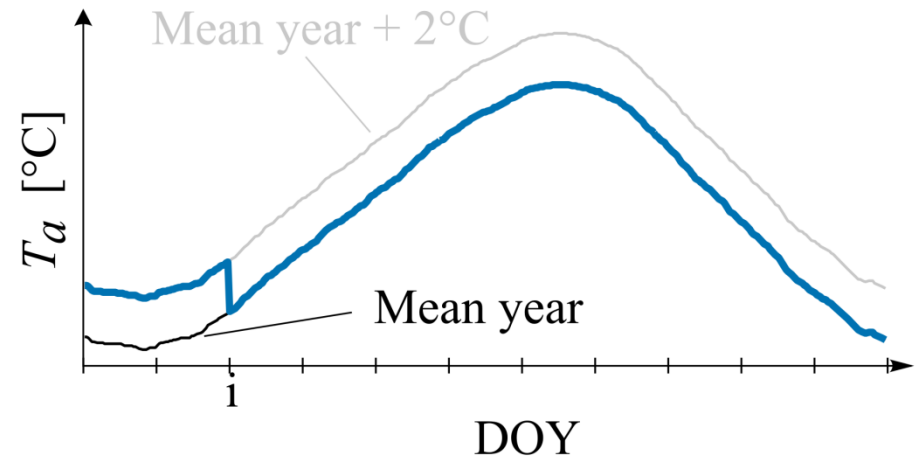


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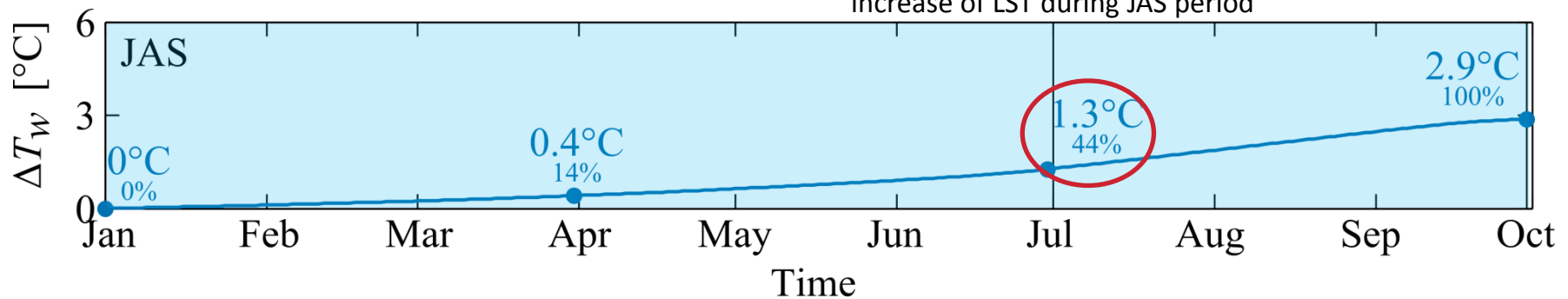
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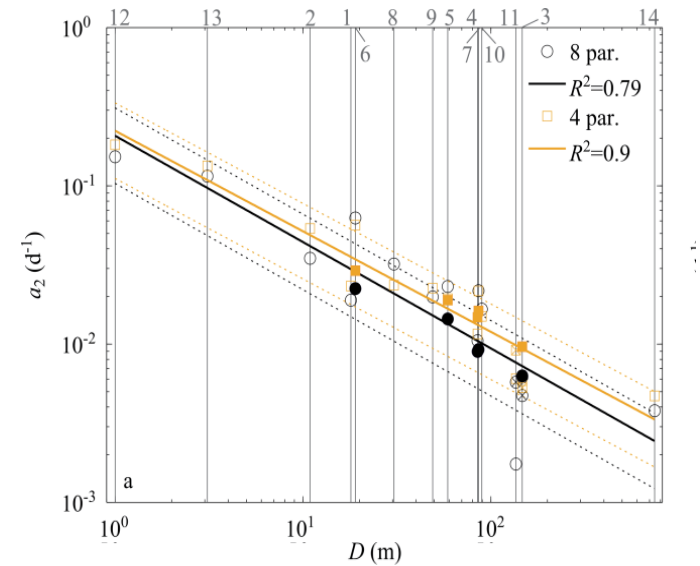


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Parameters regionalization

definition of **regionalization** relationships between model parameters and morphological characteristics of lakes → possibility to apply *air2water* to **ungauged** lakes.

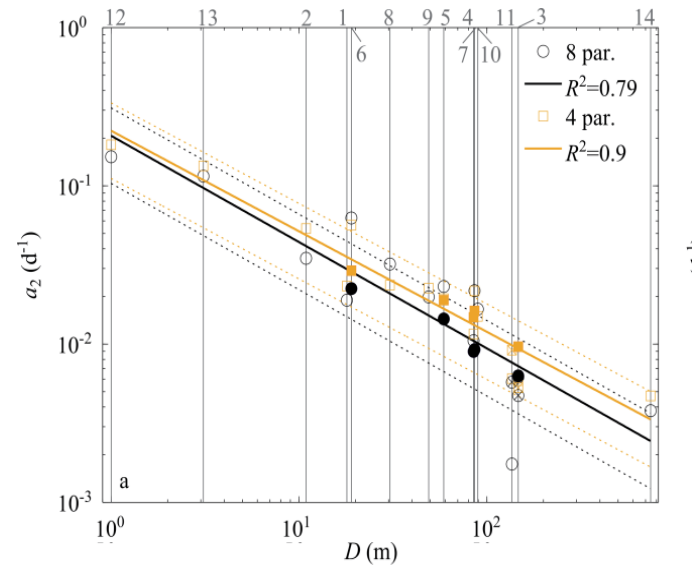


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Application under climate change conditions

comparison between **LST predictions** obtained with *air2water* and more complex physically-based models.



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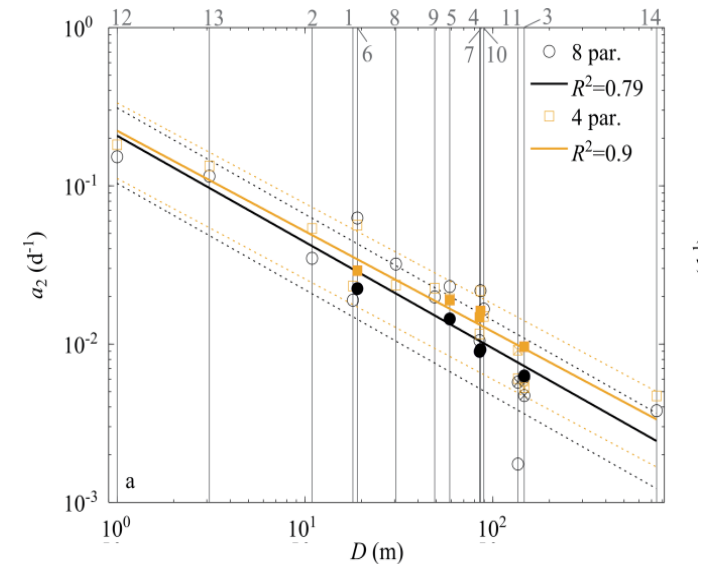
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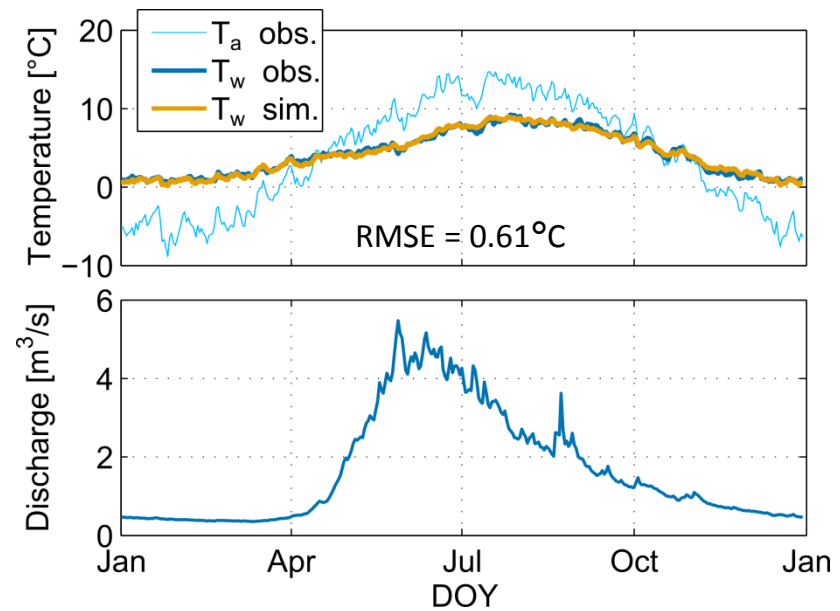
air2stream

a simple model to predict water temperature in **streams** based on air temperature and **discharge**.

We are currently testing the model on 29 Swiss rivers characterized by different hydrological regimes (glacia, nival, pluvial, ...).



River Dischmabach - mean year: 2003-2009



Thank you

s.piccolroaz@unitn.it



Lake Resia (Italy)

<http://poietes.wordpress.com/>