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EFFECT OF COARSE CLIMATE MODEL RESOLUTION ON LAKE TEMPERATURE SIMULATION

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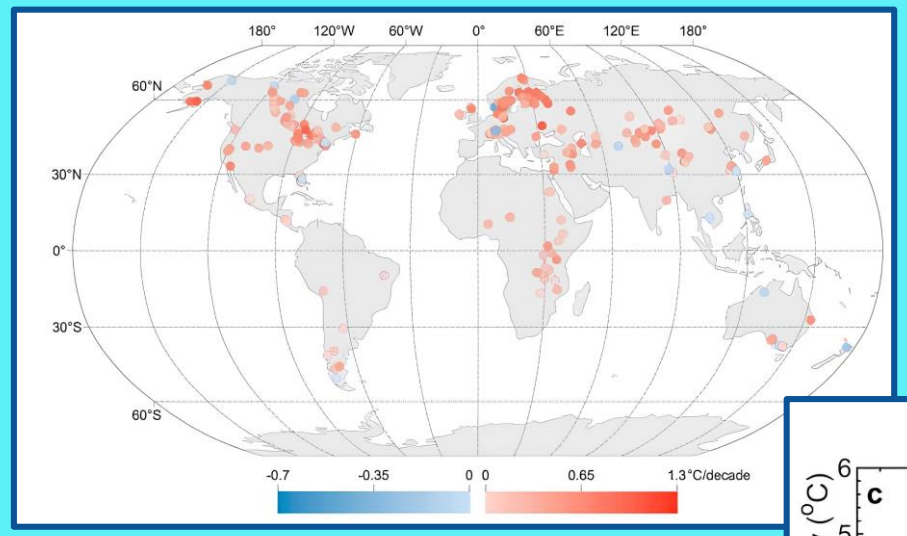
DIPARTIMENTO DI INGEGNERIA CIVILE, ARCHITETTURA, TERRITORIO, AMBIENTE E MATEMATICA

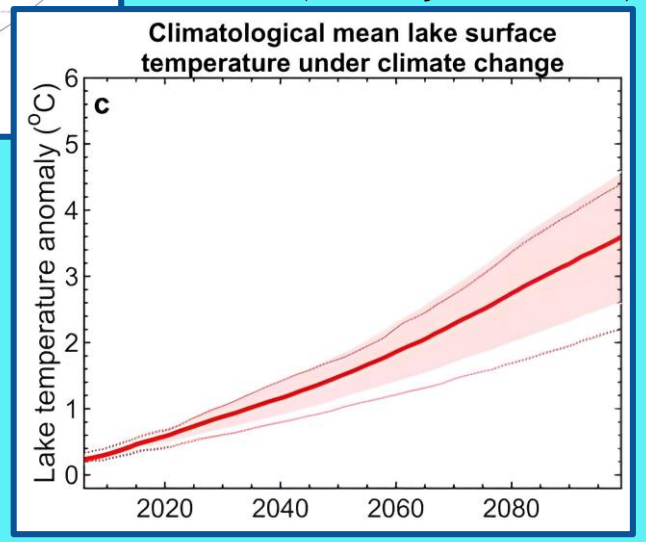
eawag aquatic research



(O'Reilly, C. M., et al. - 2015)

Lake surface temperatures are predicted to increase by 70 to 85 % of the increase in air temperatures (Schmid, Hunziker, and Wüest 2014)

(Woolway et al. - 2021)



...What will be the impact on the ecosystem?

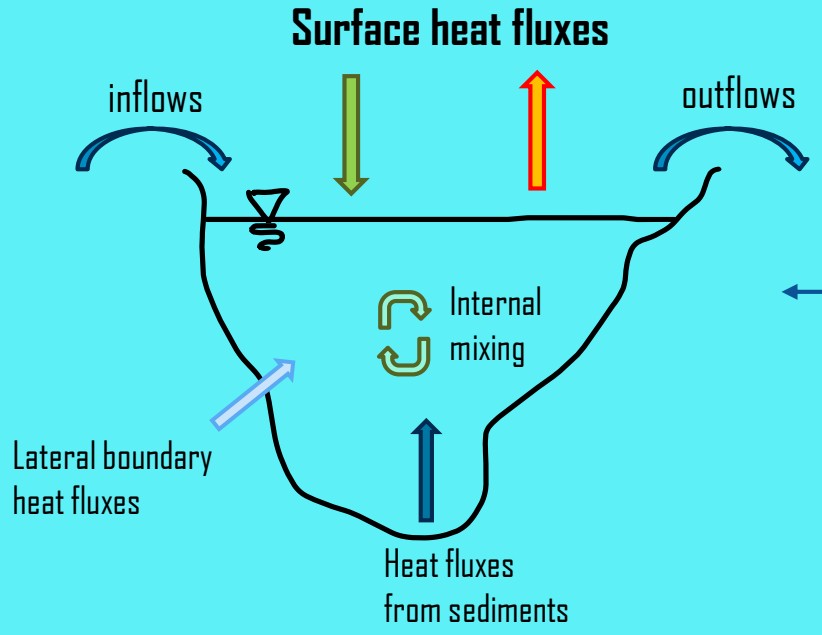
How to evaluate lakes temperature ?

The mostly adopted solution are **hydrodynamic models**

- **1D-models** → **SIMSTRAT** *(Goudsmit et al. 2002)*
- 2D-models
- 3D-models

Aim to solve a **heat balance**

Simplified to just **surface heat fluxes** + **inflows/outflows**



Accumulation — Inflow

$$V\rho C_p \frac{dT}{dt} = A_s J + Q\rho C_p T_{in} - Q\rho C_p T_{out}$$

Surface heat exchange — Outflow

$$J_{sw} = (1 - r_s) H_s^0 f_s(C)$$

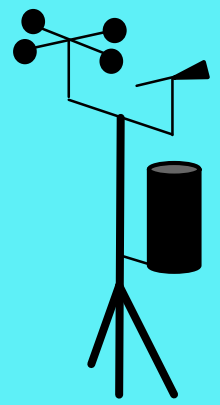
$$J_{lw\_atm} = (1 - r_a) E_a \sigma T_a^4$$

$$J_{lw\_lake} = -E_w \sigma T_w^4$$

$$J_{sensible} = c_s \rho_a c_p U_{wind} (T_a - T_s)$$

$$J_{latent} = min\left[0; \frac{0.622}{P} c_L \rho_a L_e U_{wind} (e_a - e_s(T_s))\right]$$

Weather station



If our goal is the past lake temperature

Time history

- Solar radiation
- Air temperature
- Wind speed
- Vapour pressure
- Total cloud cover
- Precipitation

Atmospheric forcing

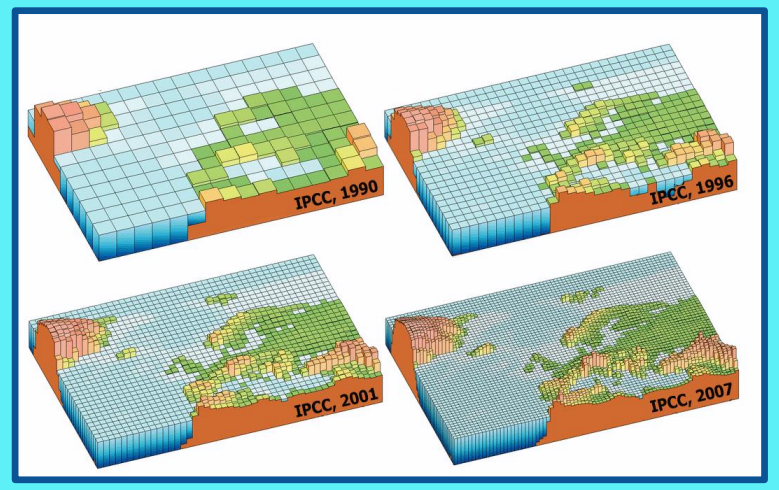
SIMSTRAT

$\frac{dT}{dz}$ in time

Climate Models

If our goal is the future lake temperature

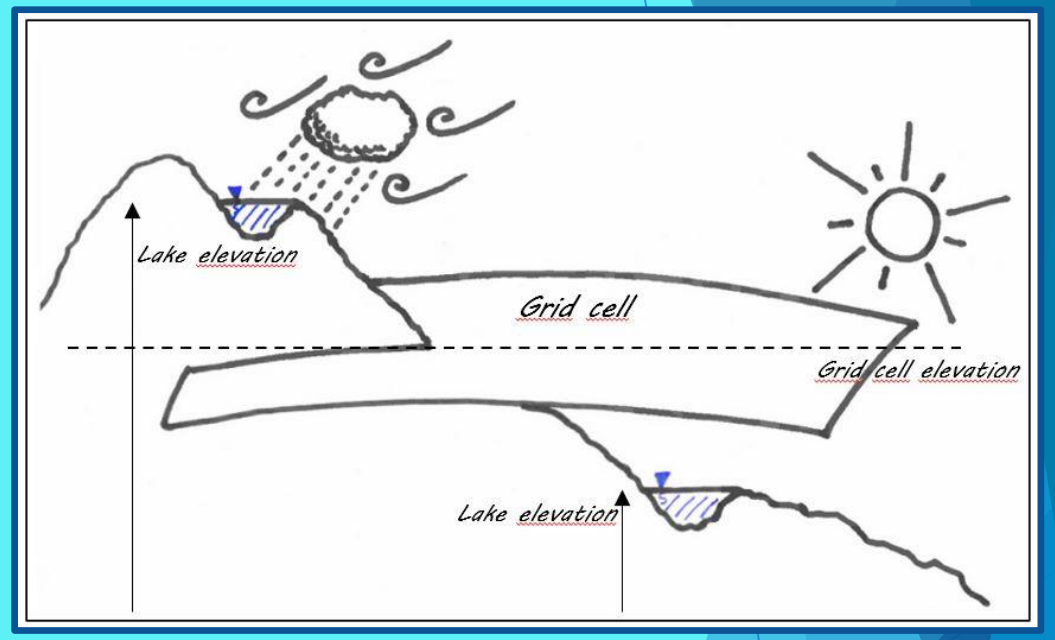
The structure of a climate model



Inside each grid-cell the future weather variables are computed

- AR5: around **70km x 70km**
- ISIMIP: around **50km x 50km**
- ERA5-land: around **9km x 9km**
- COSMO REA6: around **6km x 6km**
- COSMO-1e: around **1.1km x 1.1km**

Issue: grid-cells often larger than lakes scale



- Possible **mismatch between cell and lake elevation**, especially in mountainous areas
- Possible **different meteorological conditions** between the grid-cell and the actual lake atmosphere

Bias in the water temperature estimate

How to assess the effect of such issues ?

Weather station based atmospheric forcing

Climate model based atmospheric forcing

comparison

SIMSTRAT

surface temperature

surface temperature

comparison

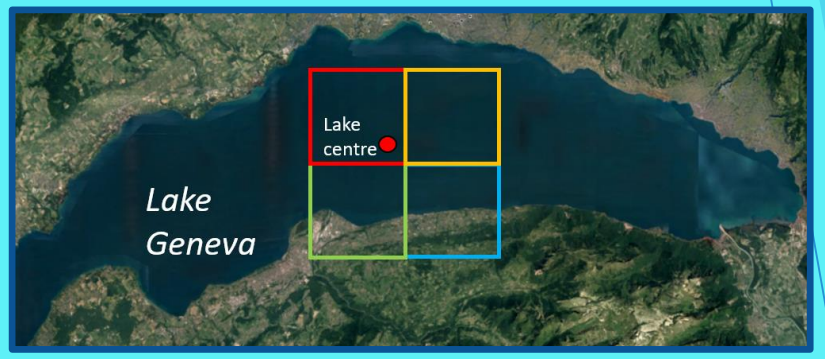
For 68 Swiss lakes

The climate model variables

- **The climate model**: ***COSMO REA6*** *(reanalysis product of COSMO)*

6 x 6 km grid-cells

- **The extraction criteria**: from the closest cell to the lakes center

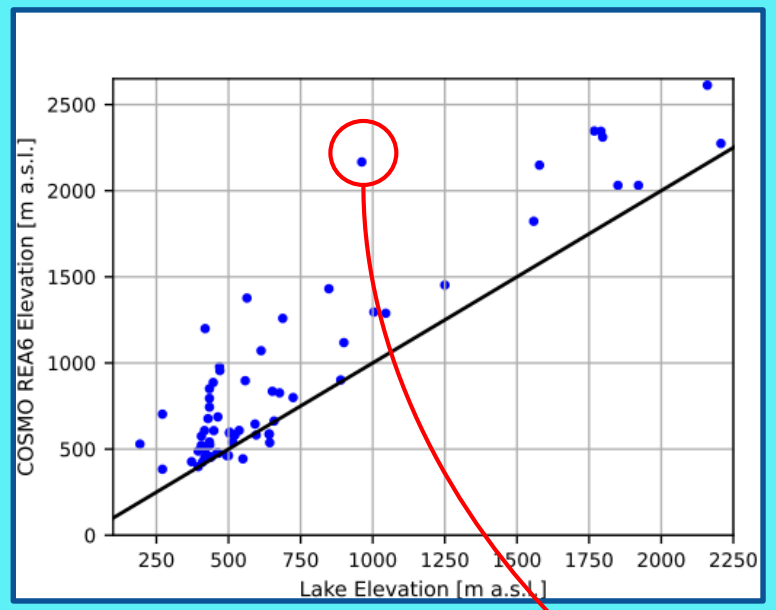


- **Time interval**: from 01/01/1995 to 01/09/2019

- **The extraction tool**: a Python code to automatically extract the model data and create the atmospheric forcing files, for all the lakes

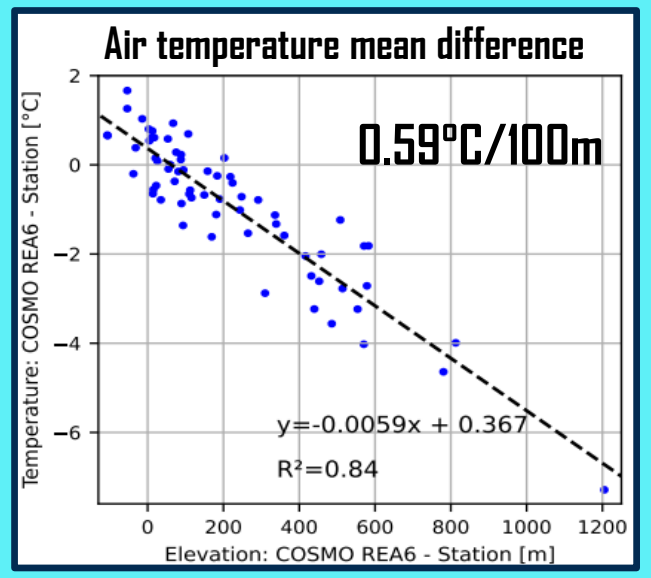
```python
def ch1903_to_latlng(x, y):
    x_aux = (x - 600000) / 1000000
    y_aux = (y - 200000) / 1000000
    lat = 16.9023892 + 3.238272 * y_aux - 0.270978 * x_aux ** 2
    - 0.002528 * y_aux ** 2 - 0.0447 * x_aux ** 2 * y_aux - 0.014 * y_aux ** 3

    lng = 2.6779094 + 4.728982 * x_aux + 0.791484 * x_aux * y_aux + 0.1306 * x_aux * y_aux ** 2
    - 0.0436 * x_aux ** 3

    lat = (lat * 100) / 36
    lng = (lng * 100) / 36
    return lat, lng

def func_coord_near (lat,long,u):
    result_u=[]
    all_coords=[]
    for i in range (len(lat)):
        distance=(((u.latitude-lat[i])**2)+(u.longitude-long[i])**2)**(1/2)
        coords=distance.argmin(dim=['x','y'])
        all_coords.append(coords)
    return(all_coords)
```

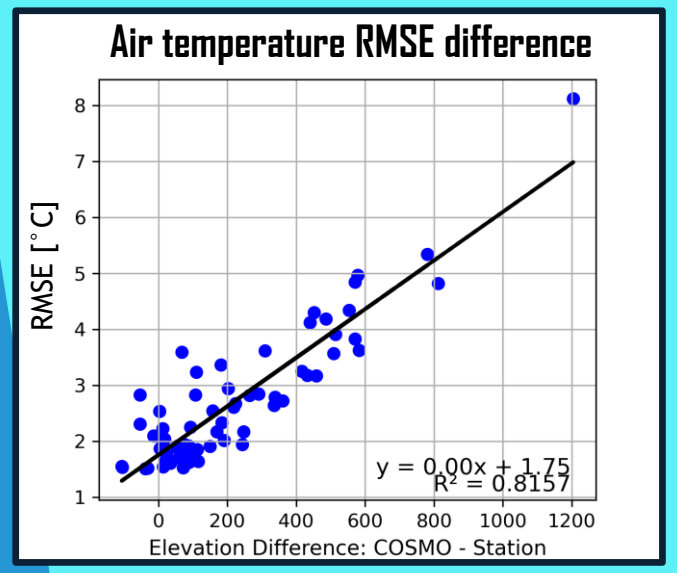
The elevation mismatch

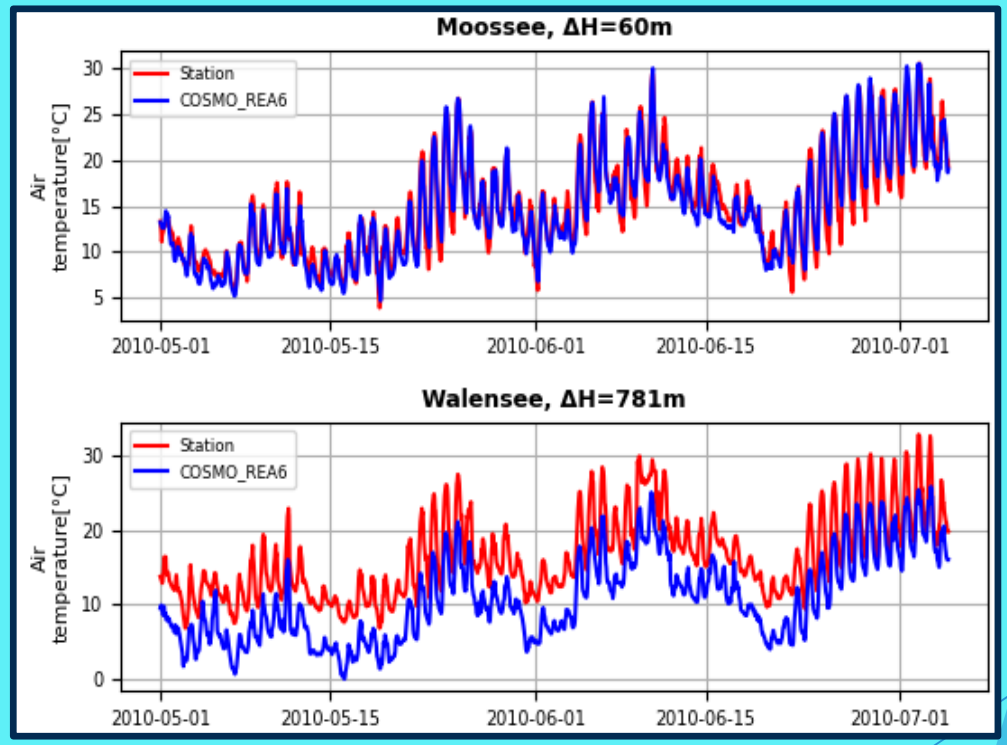


- Most of the times, **the model overestimates** the **elevation**.
- The **greater difference** is present for lakes located in **highly variable topography** environments.
- The mismatch in the elevation reaches values **up to** around **1200 m**.

Consequences of the altitude mismatch







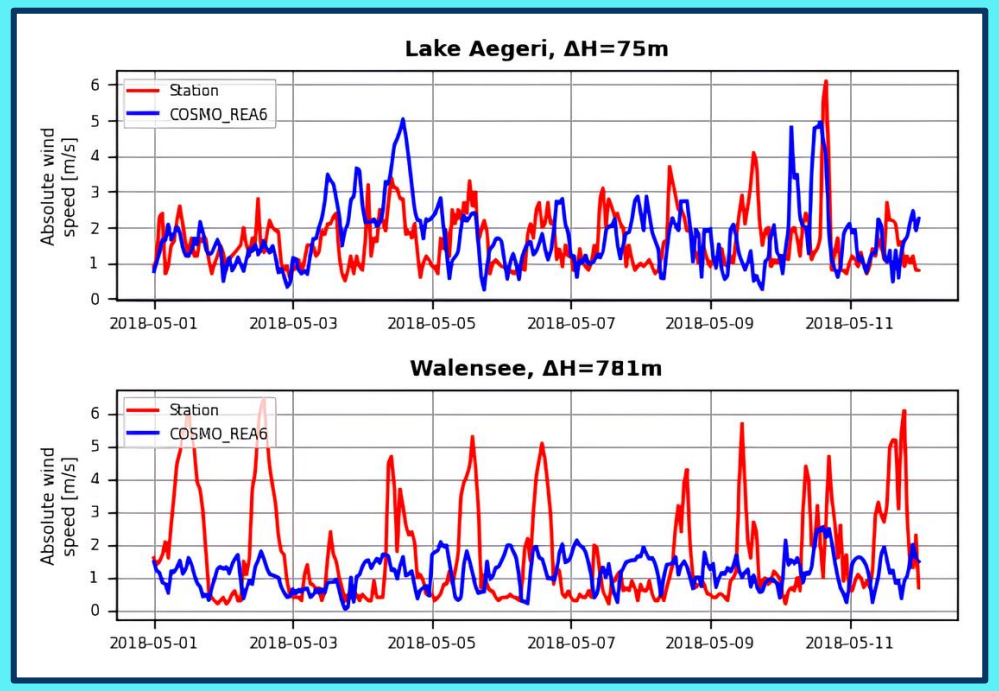
$\Delta T_{mean} = 0.04°C$

$RMSE = 1.71°C$

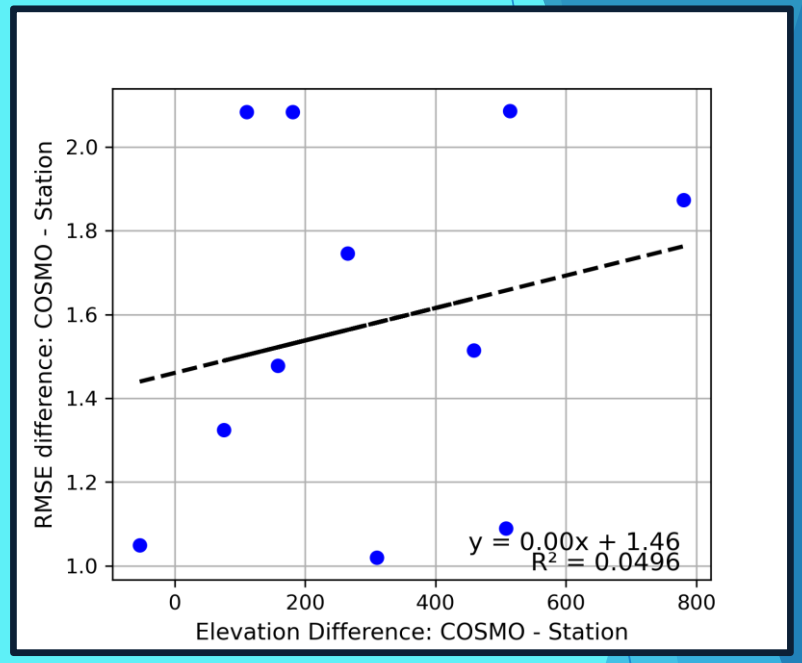
$\Delta T_{mean} = 4.64°C$

$RMSE = 5.34°C$

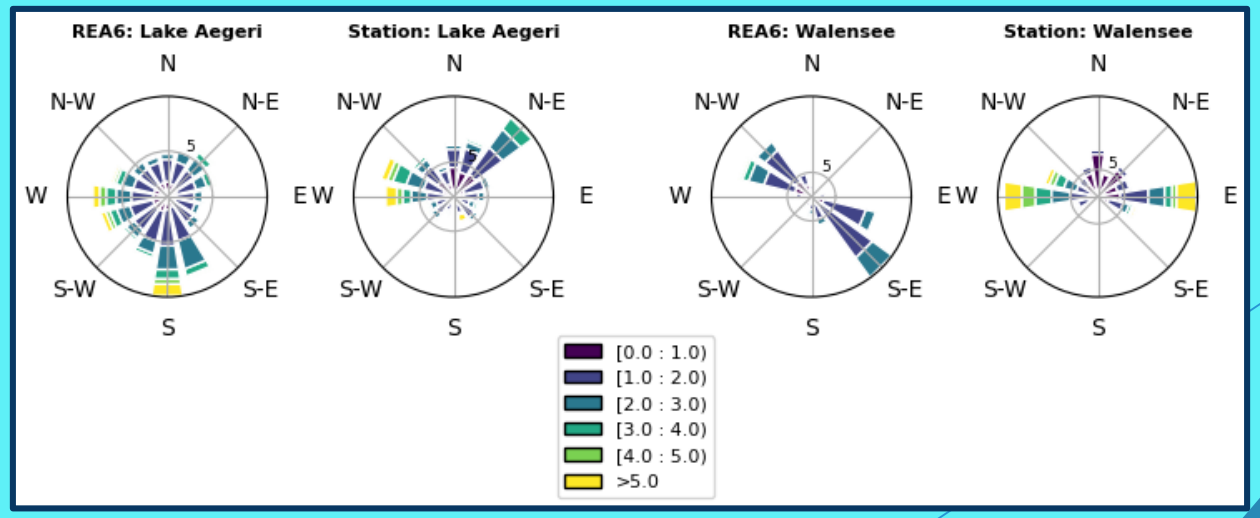
The issues in the wind speed



Slight **correlation** with **elevation gap**

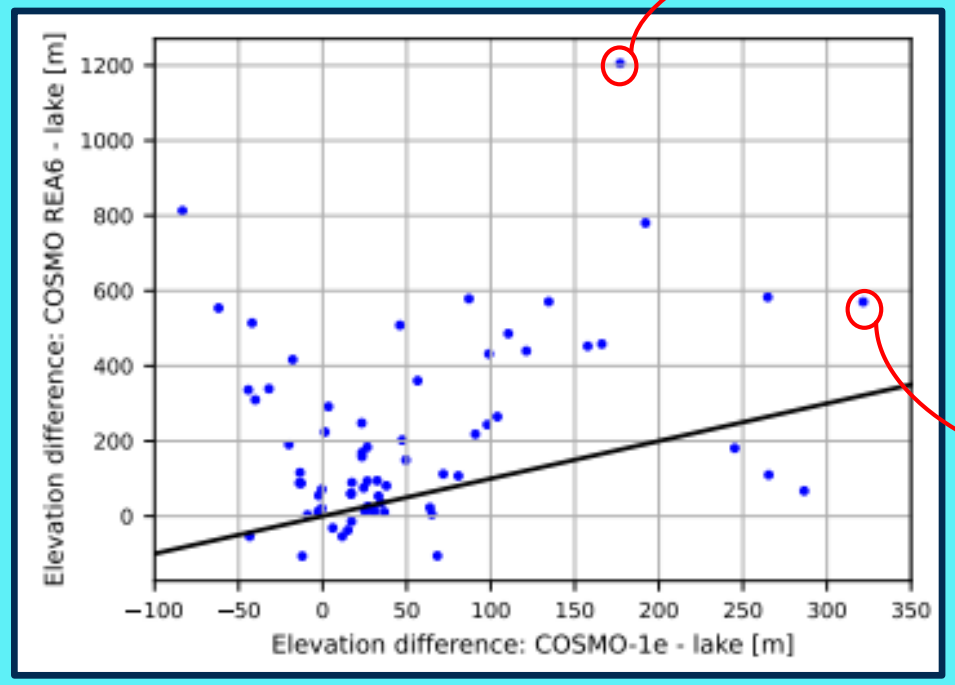


Problems also in the **direction**



What about a model with higher resolution ?

- **The climate model**: *COSMO-1e*
- **Grid-cell dimension**: **1.1km x1.1km**
- **The extraction criteria**: from the closest cell to the lakes center
- **Time interval**: from 01/01/2017 to 31/12/2022



Lago di Poschiavo

1205 m → **177 m**

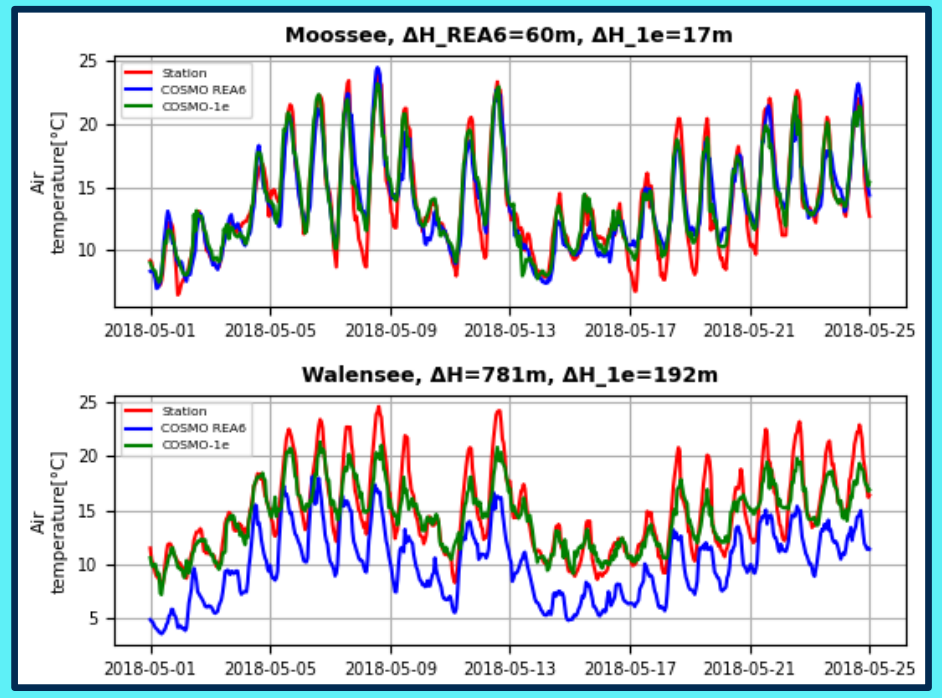
Max elevation gap with *COSMO-1e* : **322 m**

Expected consequences:

- Air temperatures closer to measured values
- General improvement of the variables estimate, especially for the wind speed

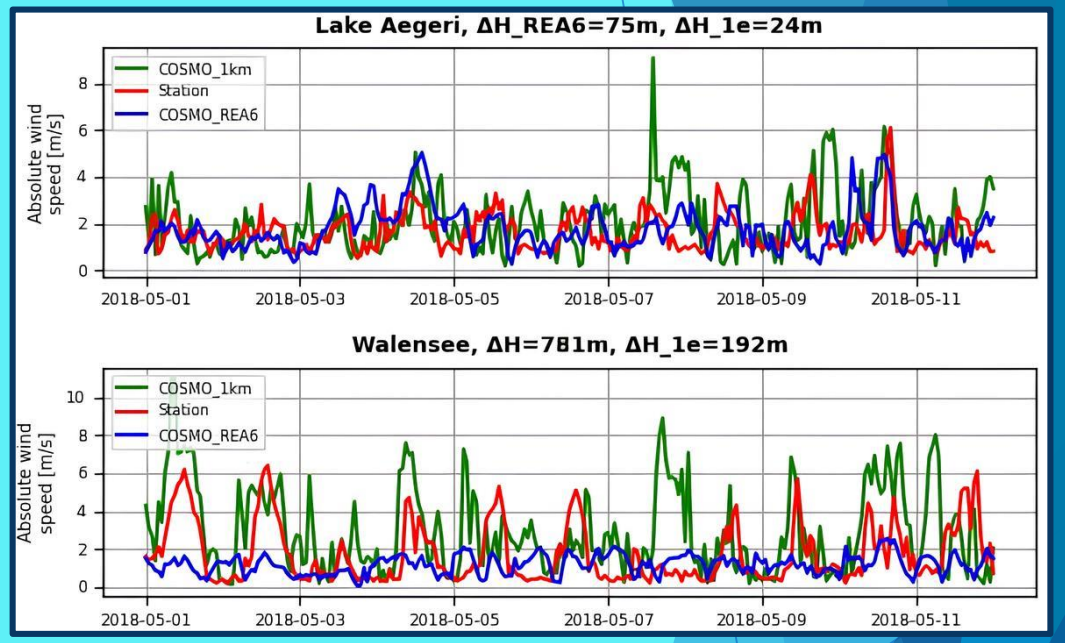
Consequences of adopting COSMO-1e (1km x 1km)

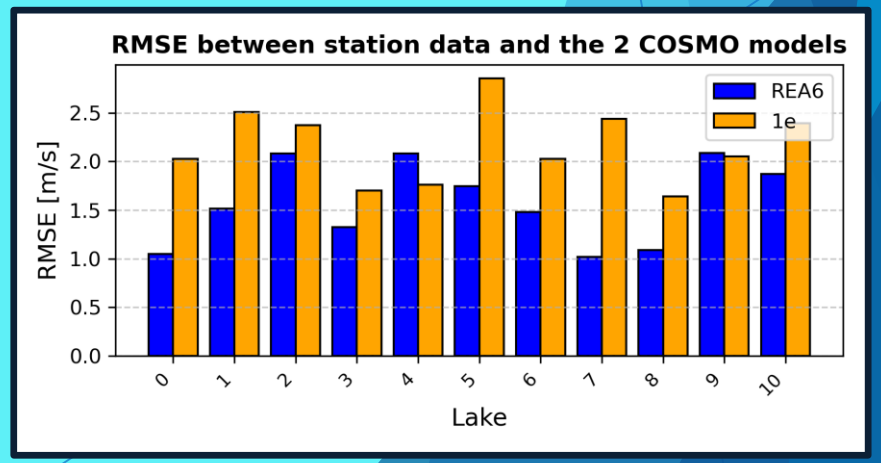
Air Temperature



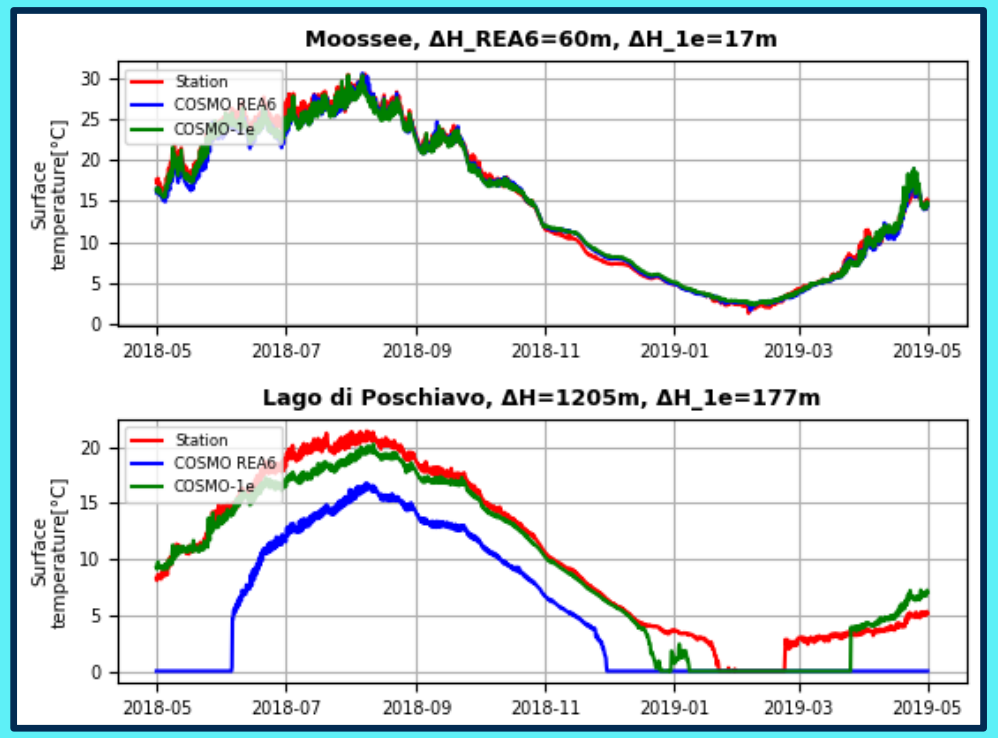
lake	mean difference station - REA6 [°C]	mean difference station - 1e [°C]	RMSE REA6	RMSE 1e
Moossee	0	-0.13	1.71	1.71
Walensee	4.16	0.09	4.88	4.55

Wind Speed



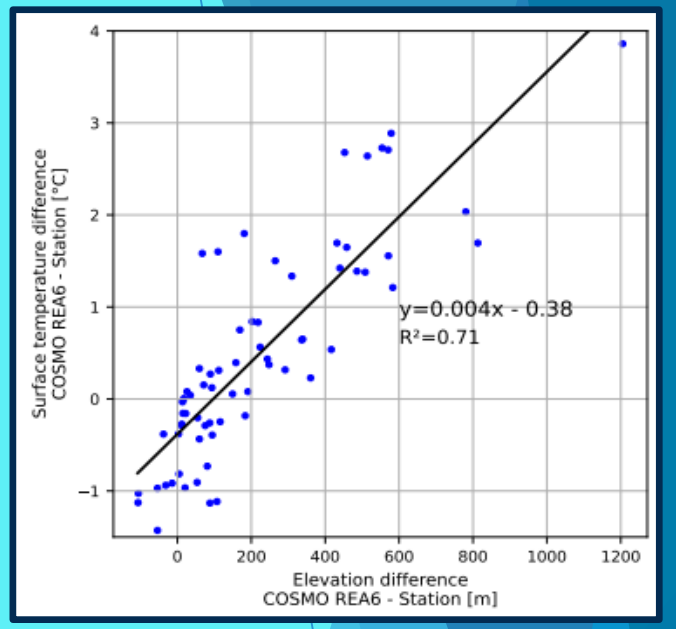


Result of the Simstrat simulations



lake	station surface T [°C]	COSMO REA6 surface T [°C]	COSMO-1e surface T [°C]
Moossee	14.43	14.26	14.34
Lago di Poschiavo	9.50	5.15	9.04

- The **greater the elevation gap**, **the greater** the surface **water temperature difference**
- Adopting **COSMO-1e can lead to improvements** in the surface temperature estimate, but this is true mainly **if the elevation gap is sufficiently reduced** (Lago di Poschiavo)
- The elevation overestimation can lead to a **lengthening** of the **freezing period**, if the lake is supposed to freeze.



100m of altitude mismatch leads to approximately **0.4°C** of difference in the water surface temperature

Air temperature correction

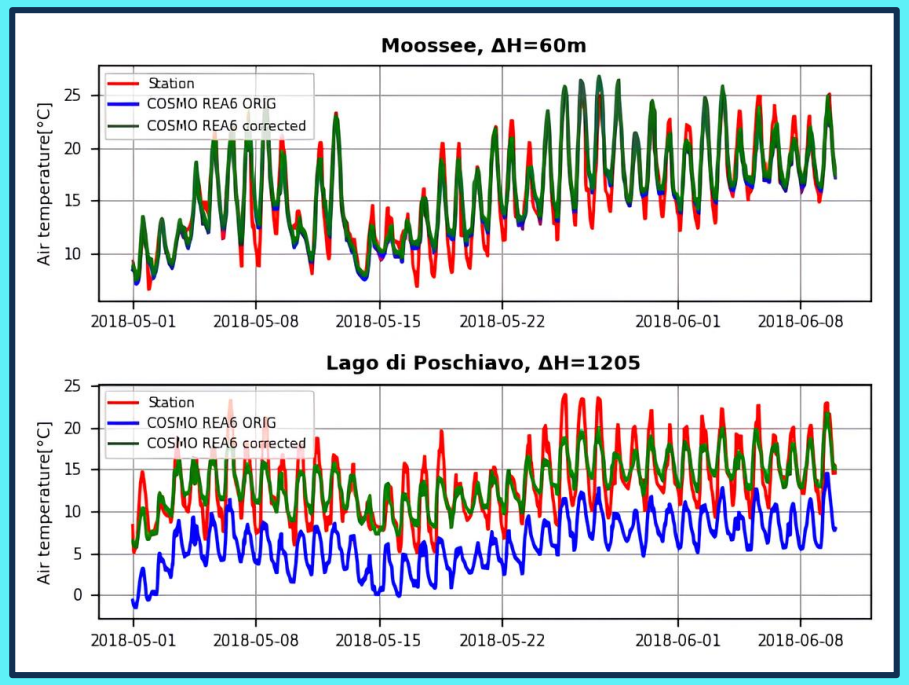
- Air temperature takes into account a vertical thermal gradient of **0.65°C/100m**

$$Tair = {}^{0.65°C}/_{100m} \cdot \Delta H$$

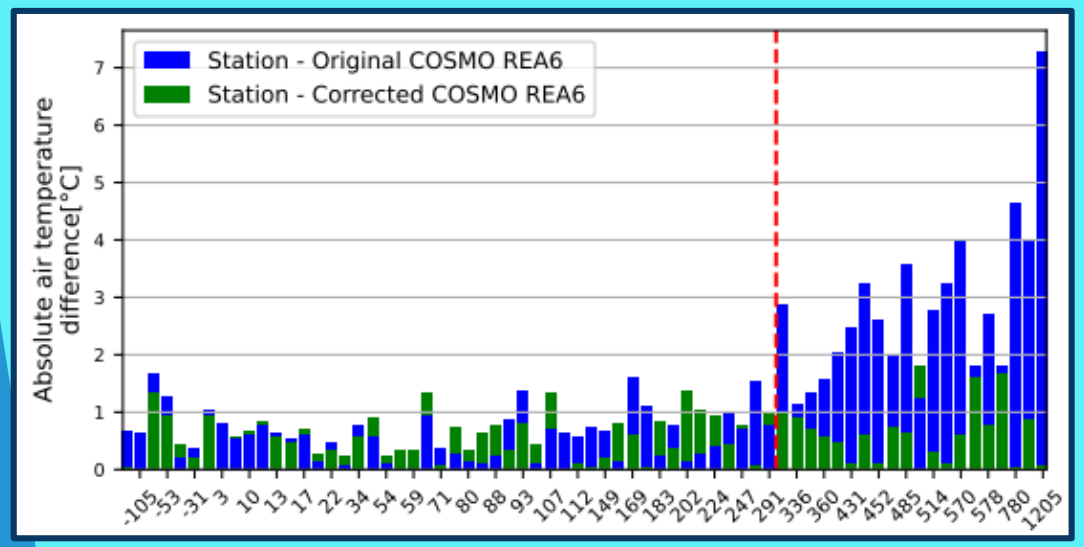
- The vapour pressure needs to be corrected too

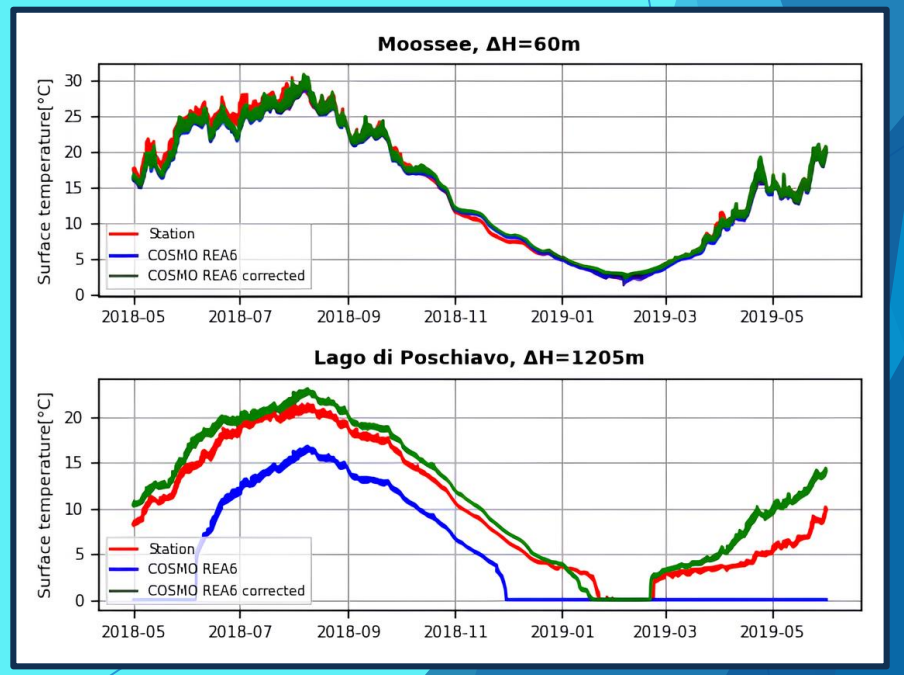
$$Pvap = h \cdot Pvap_{sat}$$

$$Pvap_{sat} = 10 \cdot exp\left(\frac{0.7859 + 0.3477(Tair)}{1 + 0.00412(Tair)}\right)$$



300m





Final comments

- **Lakes temperature forecasts** are **affected by model resolution**, in a way and with a magnitude that varies **case by case**
- The effect of the **altitude overestimation** by the model may have relevant **impact** on the **variables estimate**. This is true the more the topography is irregular
- The **increment** of the model **resolution** most of the times leads to **better surface temperature** estimates.
- For surface temperature forecasts, a simple **correction** of the model **air temperature** based on the altitude gap **is suggested** if the model highly overestimates the lake altitude

Thank you for your attention

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