Earth Observation and Space
Department of Meteorology

University of Reading

Modelling lake thermal dynamics under climate change

R. Iestyn Woolway[1]
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Lake water temperature

- Lake surface temperature varies at a range of timescales:

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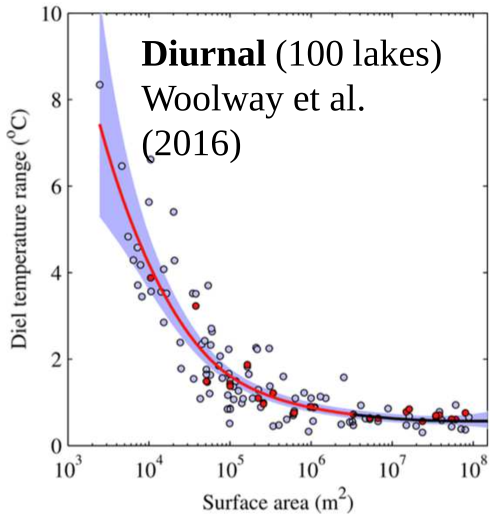

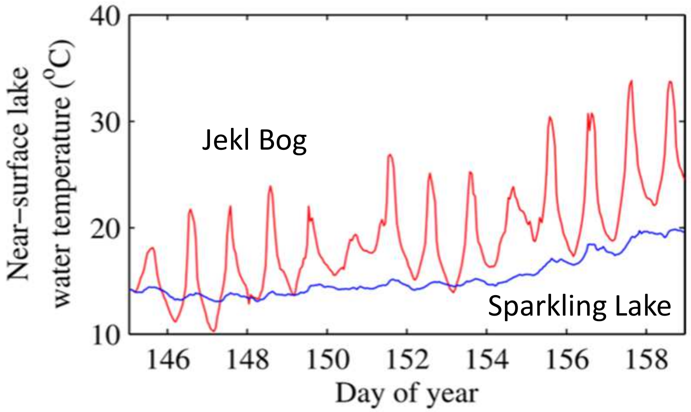

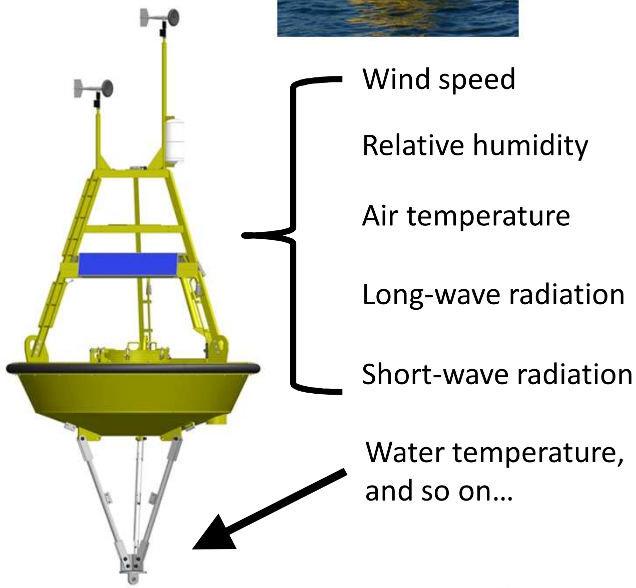

RESEARCH ARTICLE

Diel Surface Temperature Range Scales with Lake Size

R. Iestyn Woolway[1,2,3]*, Ian D. Jones[1], Stephen C. Maberly[1], Jon R. French[2], David M. Livingstone[4], Donald T. Monteith[1], Gavin L. Simpson[5,6], Stephen J. Thackeray[1], Mikkel R. Andersen[7], Richard W. Battarbee[2], Curtis L. DeGasperi[8], Christopher D. Evans[9], Elvira de Eyto[10], Heidrun Feuchtmayr[1], David P. Hamilton[11], Martin Kernan[2], Jan Krokowski[12], Alon Rimmer[13], Kevin C. Rose[14], James A. Rusak[15], David B. Ryves[16], Daniel R. Scott[16], Ewan M. Shilland[2], Robyn L. Smyth[17], Peter A. Staehr[18], Rhian Thomas[19], Susan Waldron[20], Gesa A. Weyhenmeyer[21]

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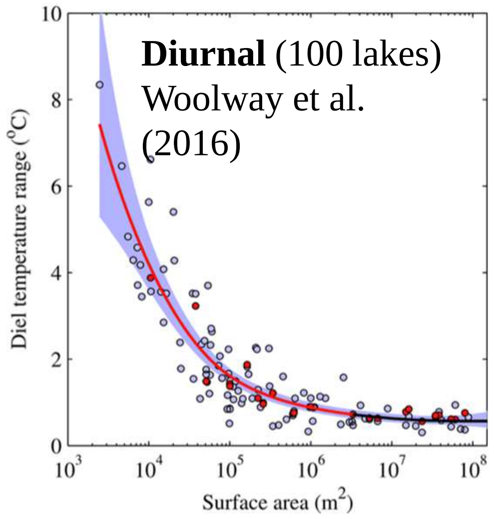
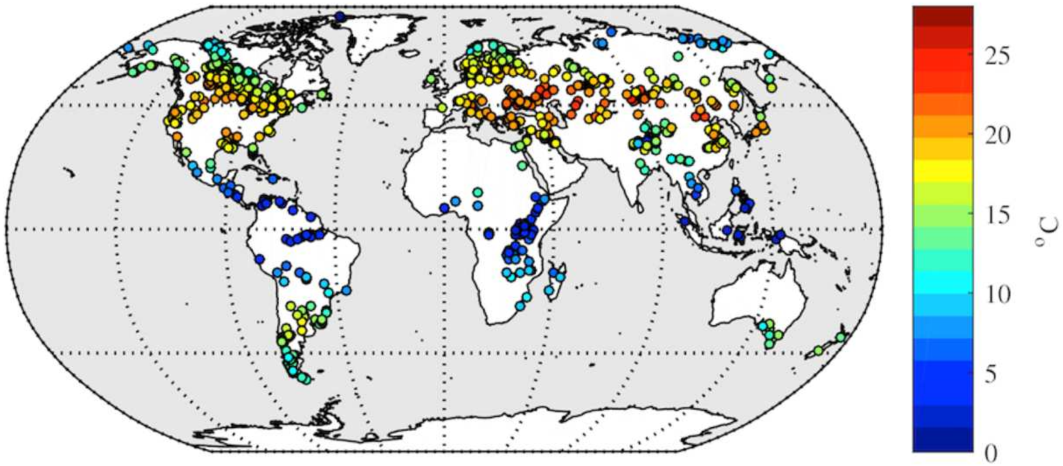


Seasonal (732 lakes; ARC-Lake)



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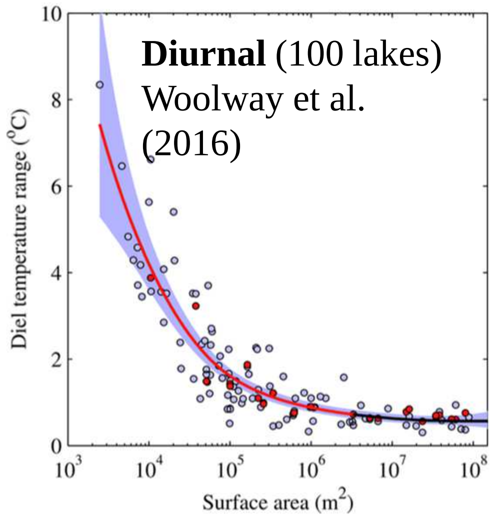

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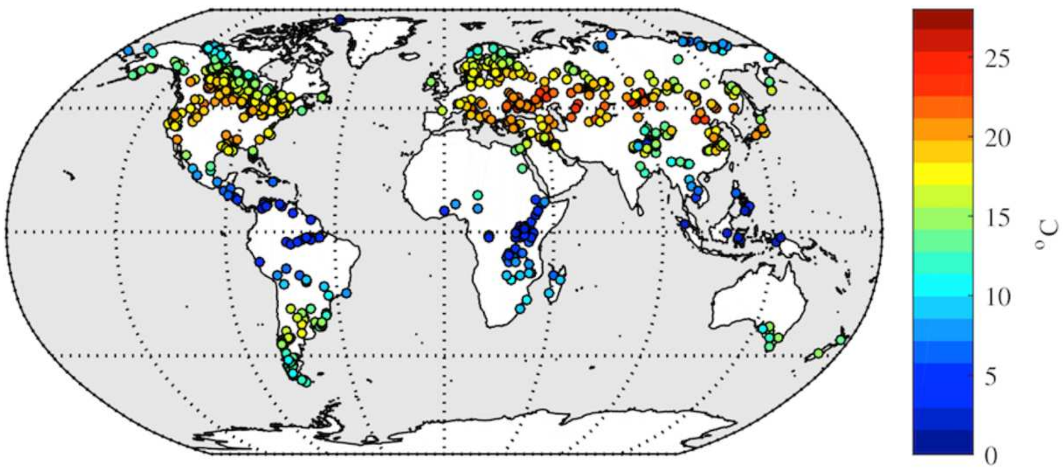

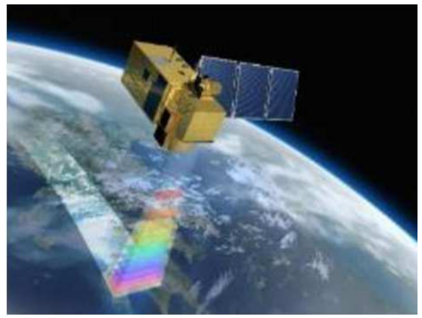

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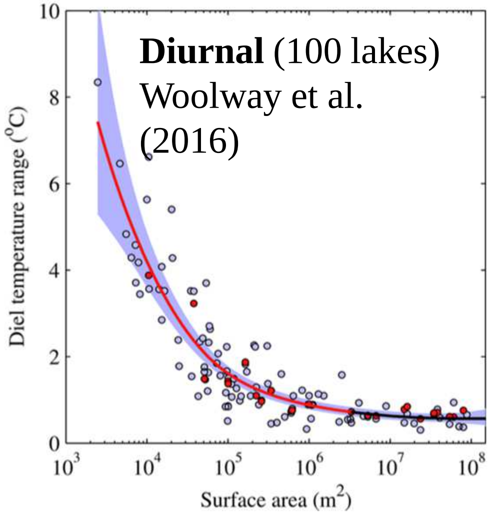

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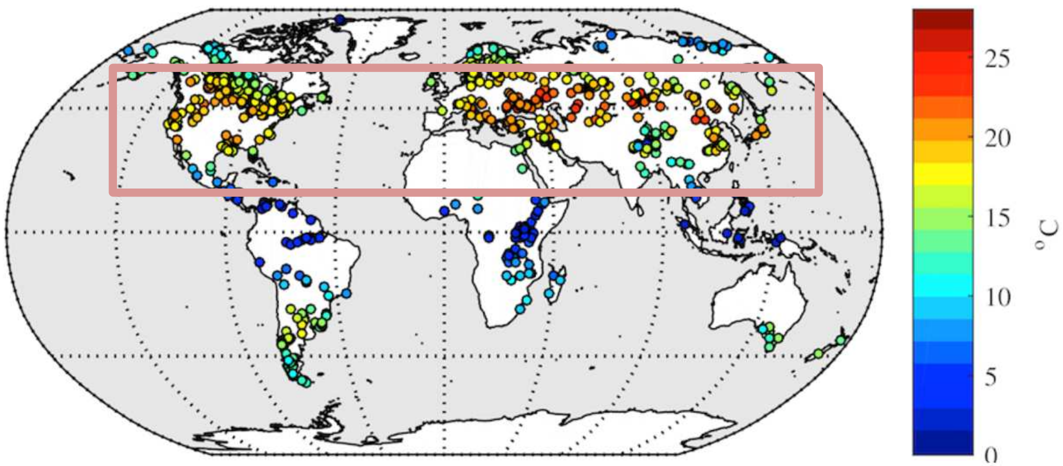

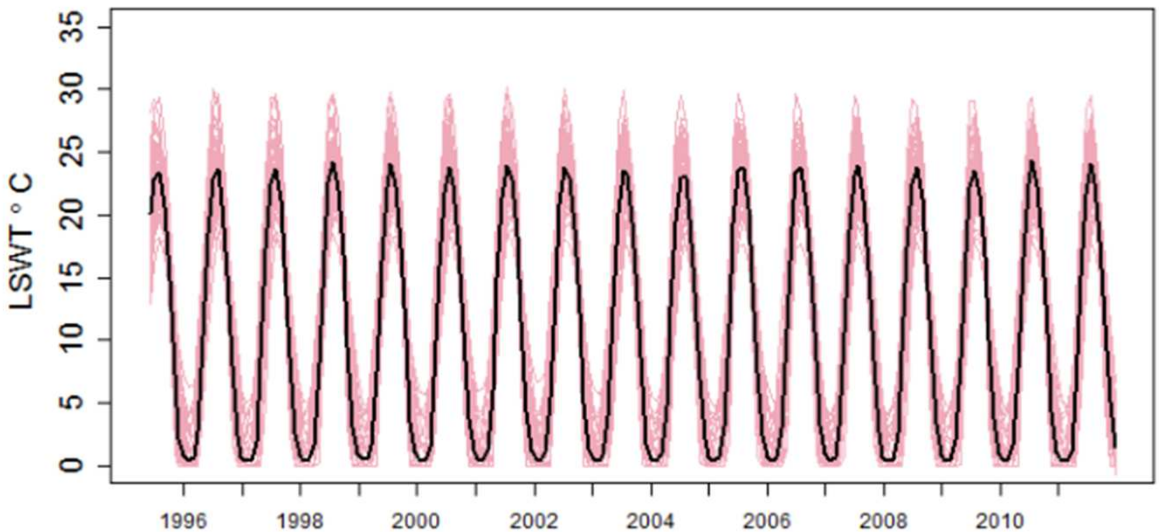

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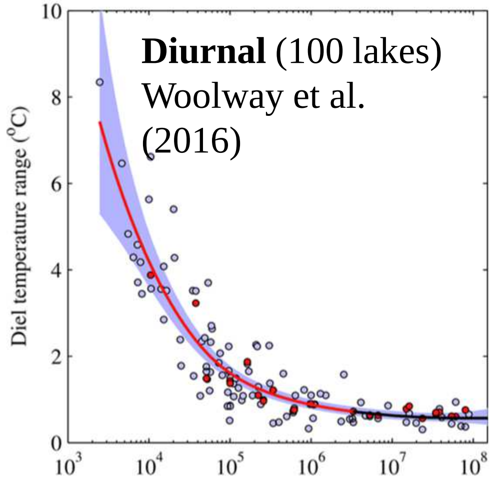

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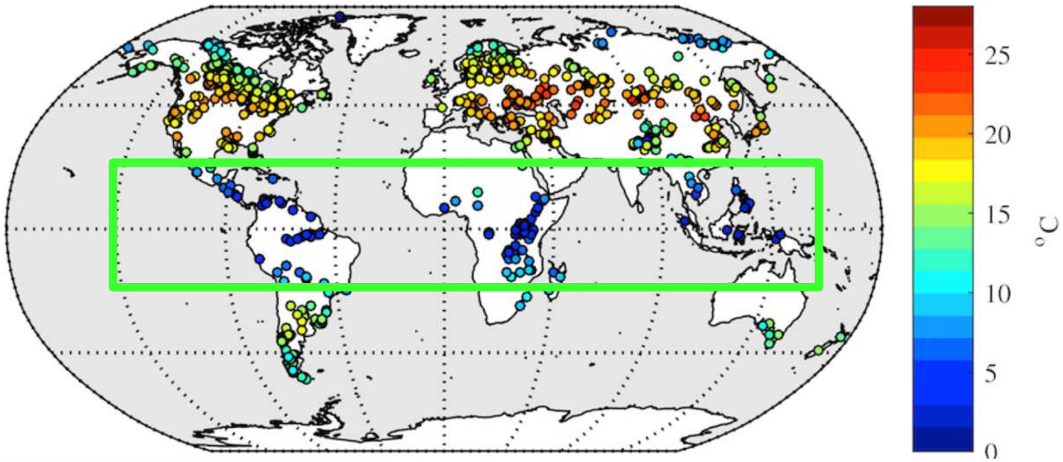

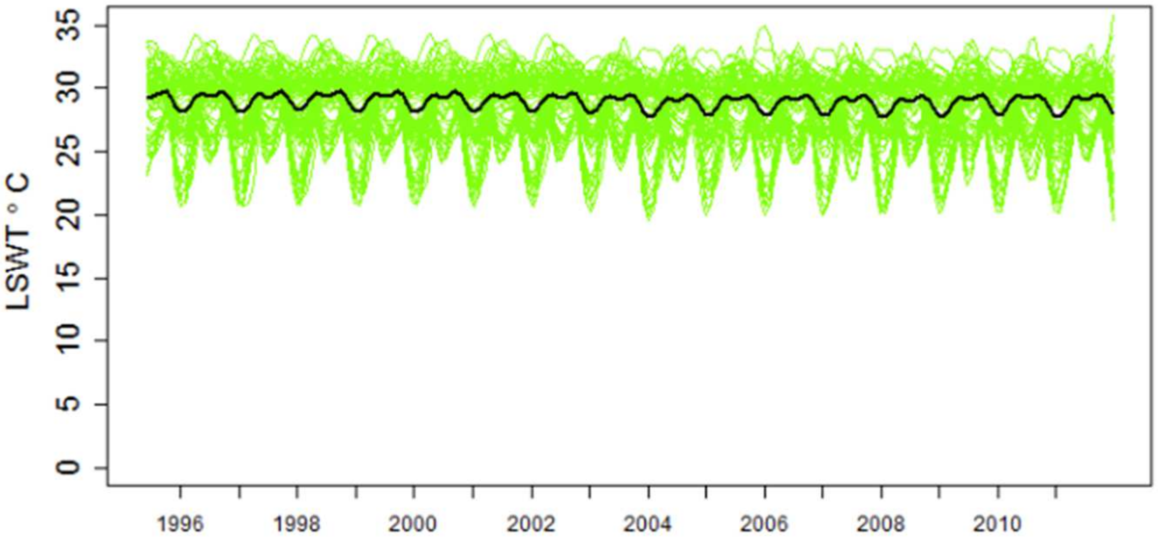

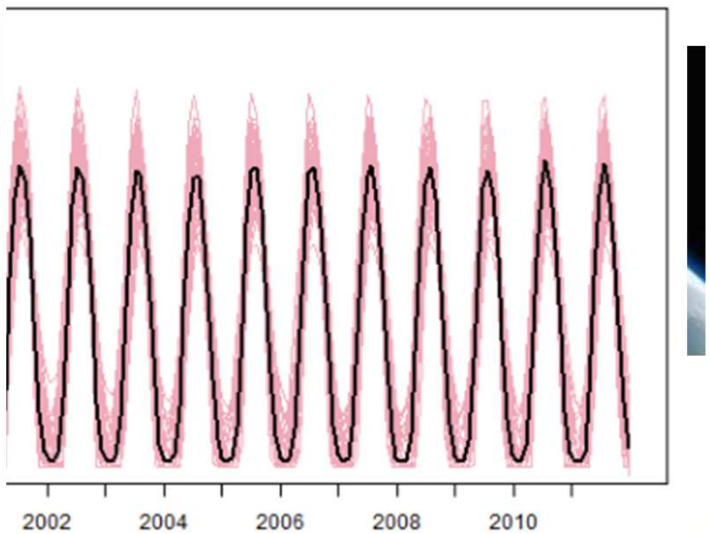

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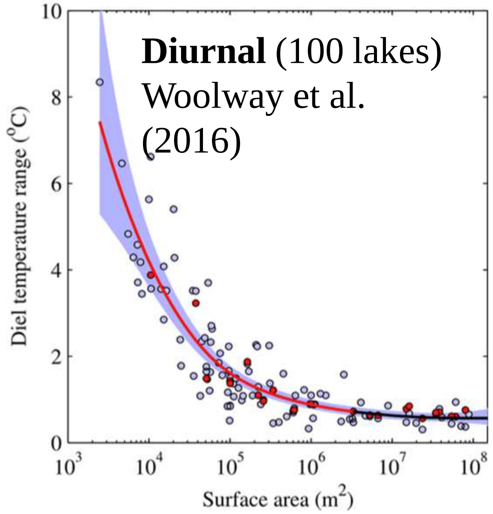

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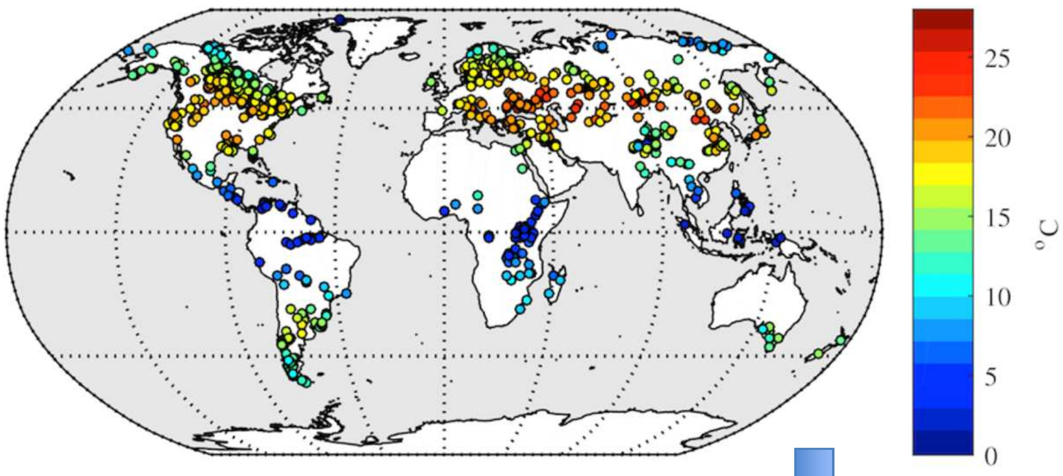
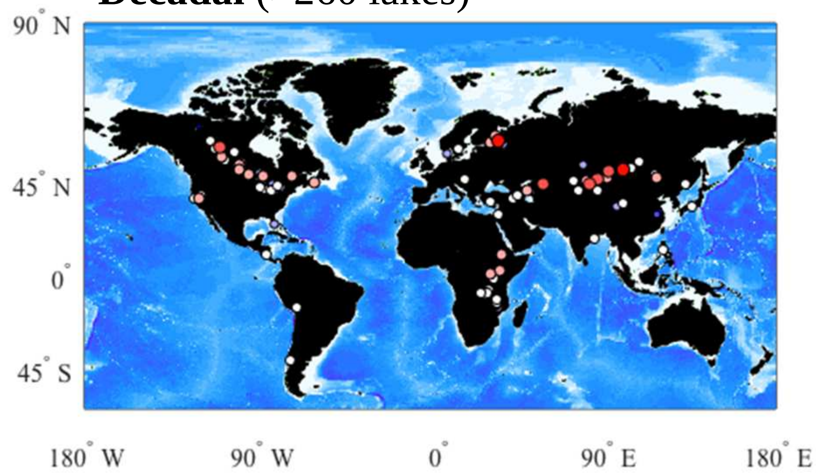


Decadal (>260 lakes)



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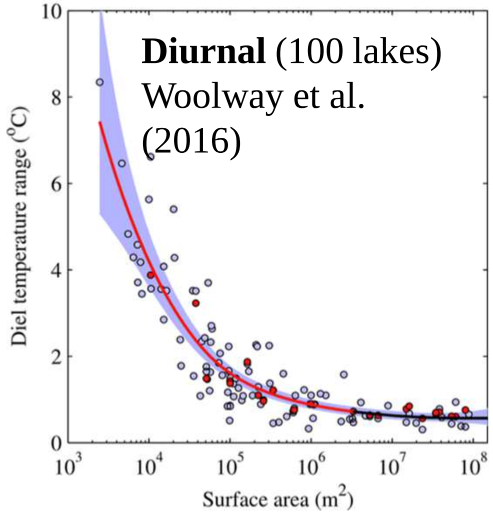

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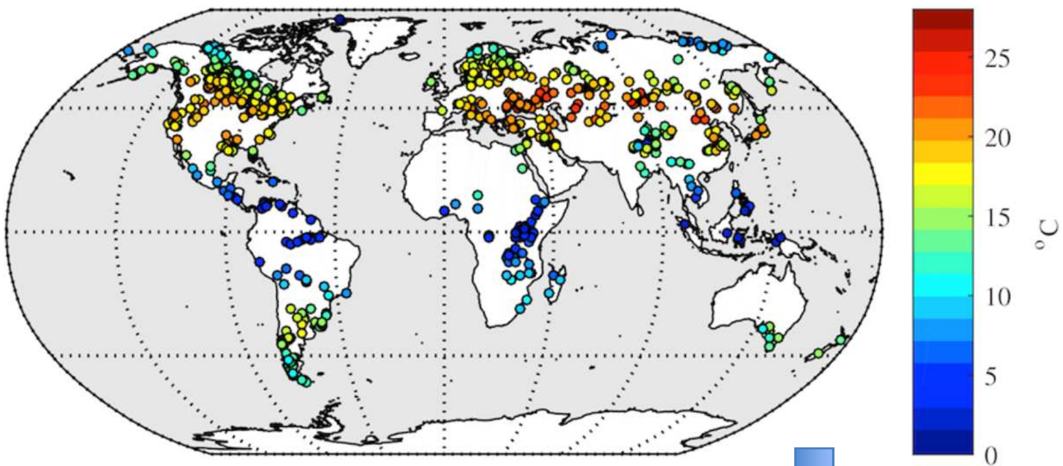

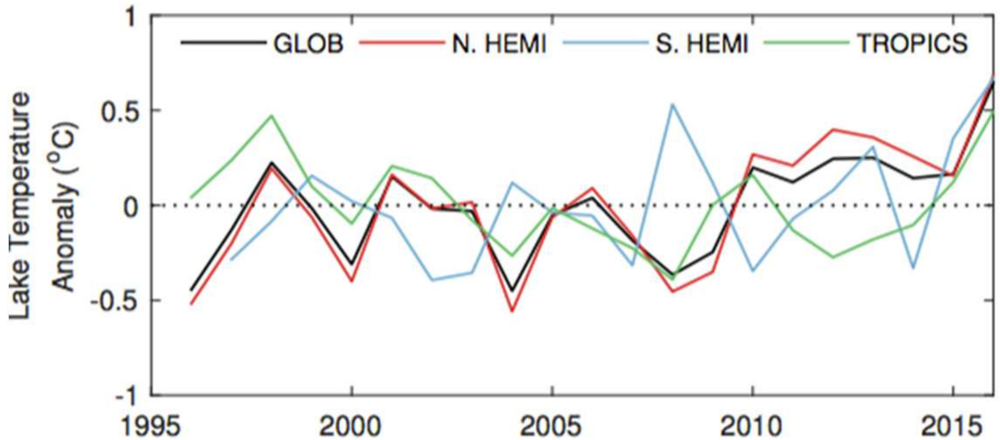

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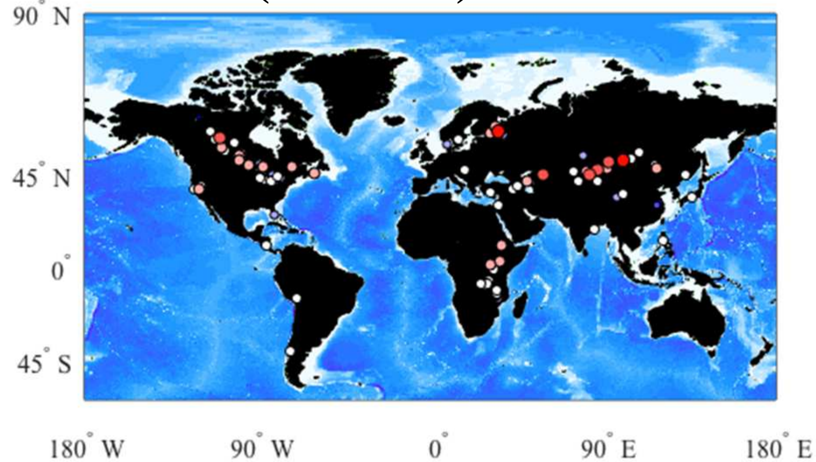

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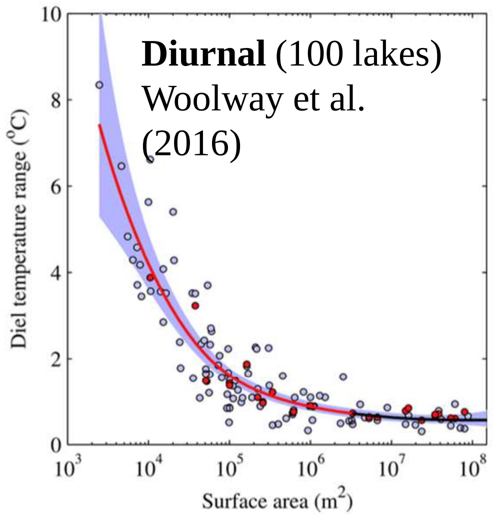

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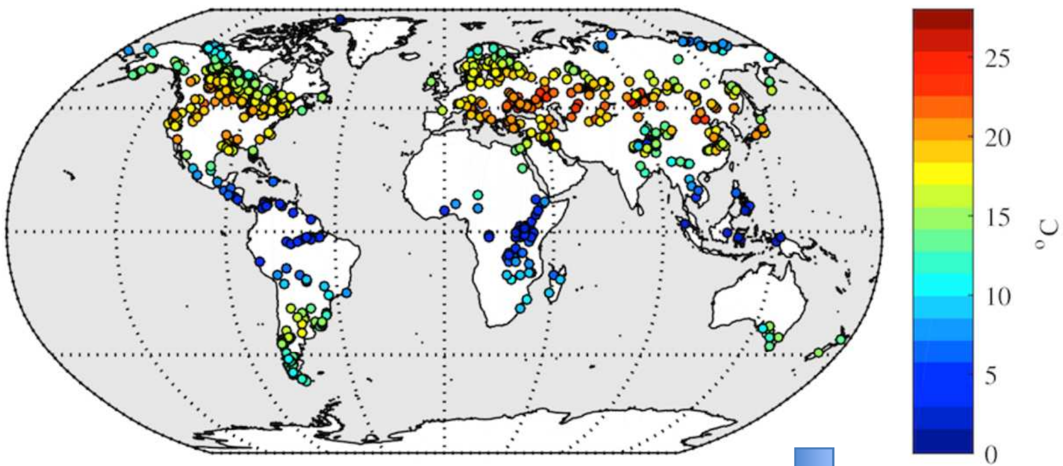

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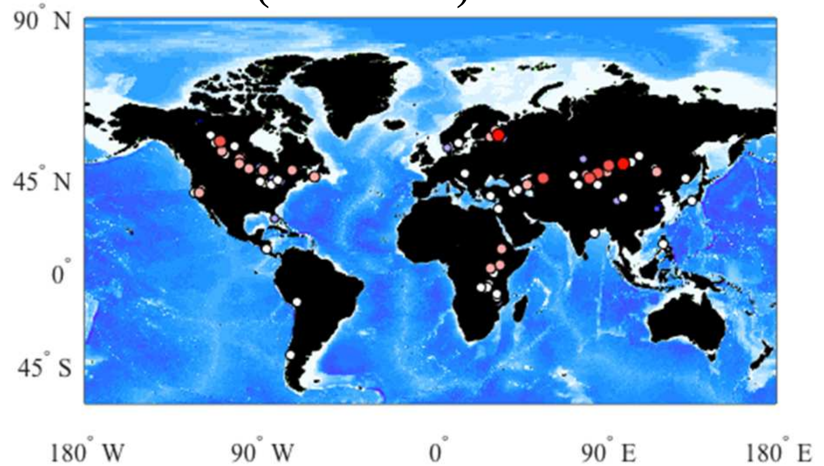
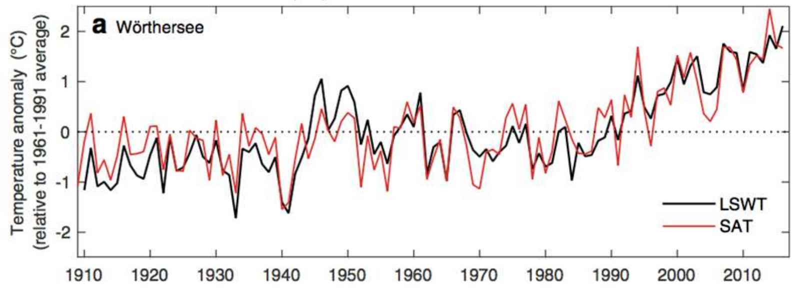
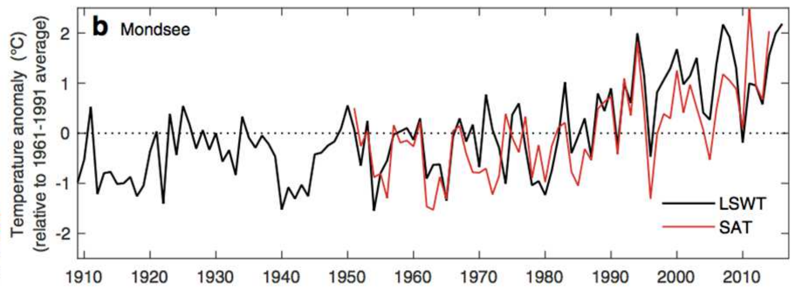


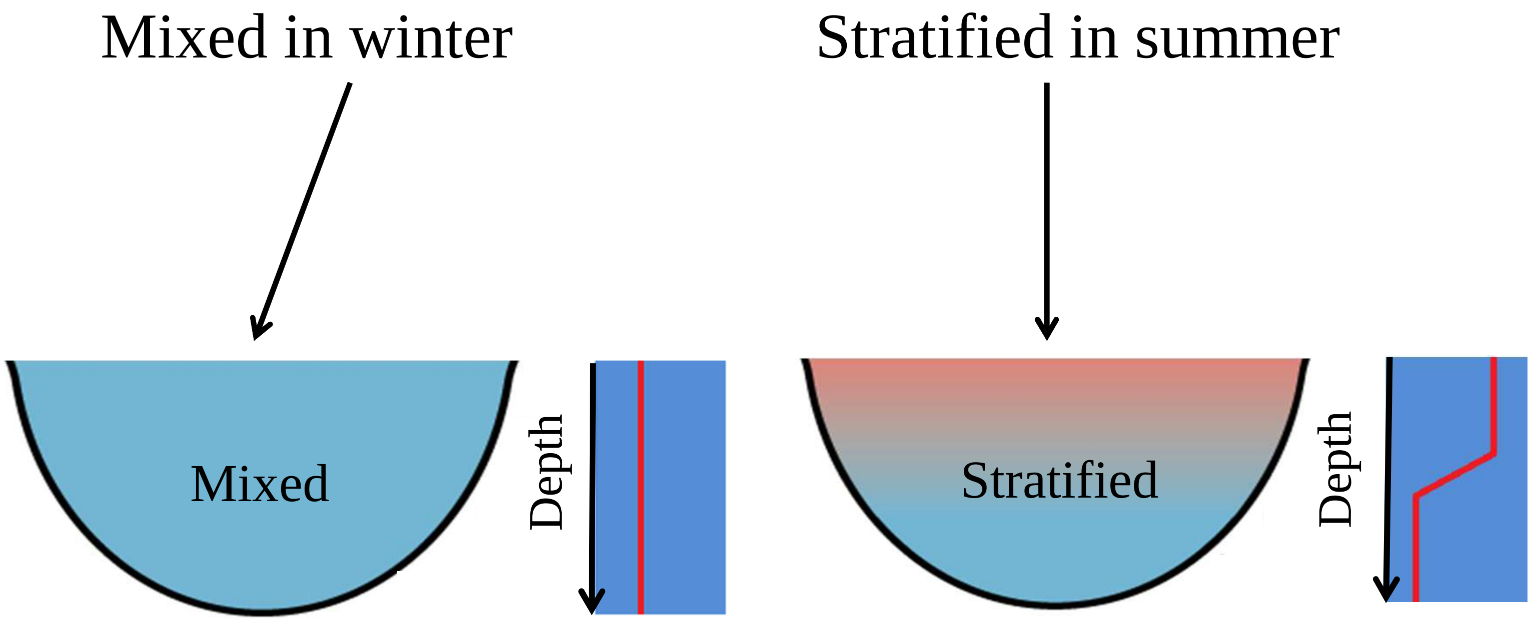


100 years (Woolway et al., 2017)



Lake water temperature

- Lake temperature also varies with depth.
- The temperature structure is one of the most fundamental characteristics of a lake as it determines the physical environment of the ecosystem



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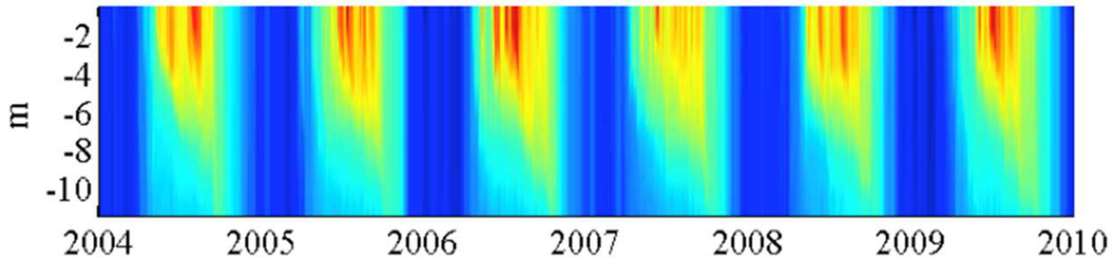
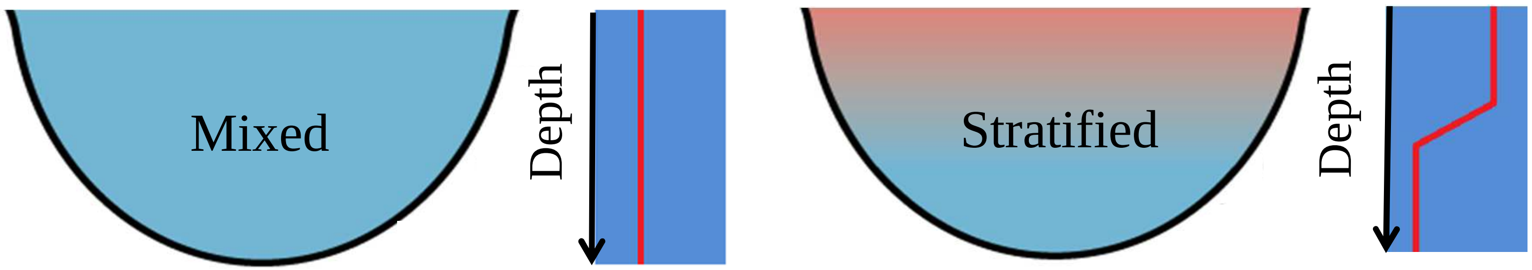
Esthwaite Water, UK.





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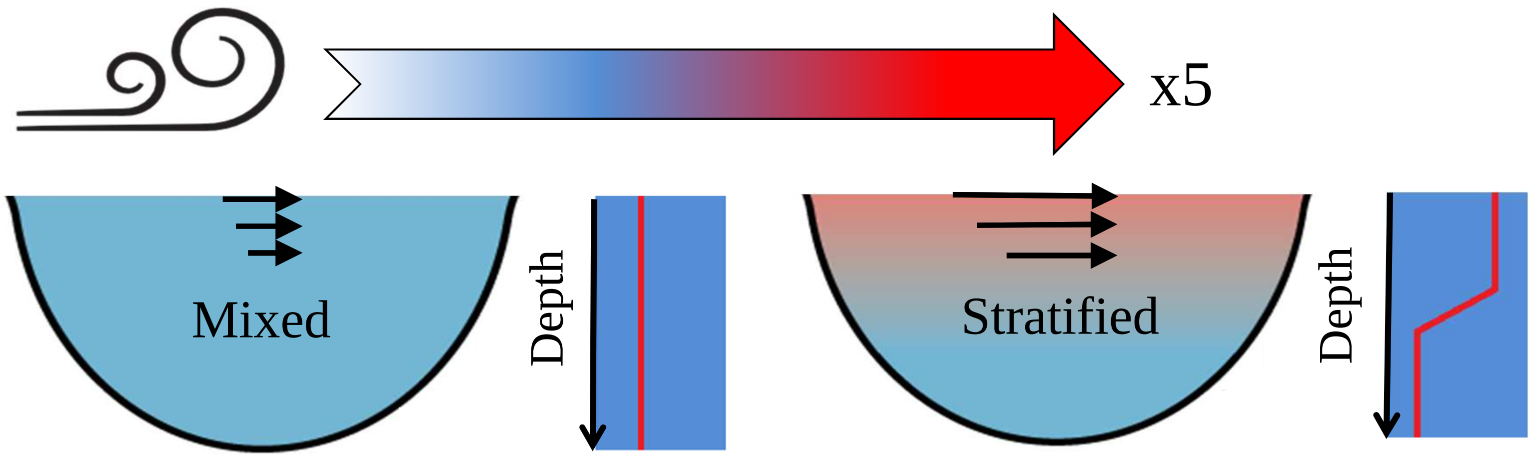
Woolway and Simpson (2017), **Energy input and dissipation in a temperate lake during the spring transition**, *Ocean Dynamics*, doi:10.1007/s10236-017-1072-1

Efficiency of wind energy transfer to a lake increases by a factor of 5 between mixed and stratified regimes



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Why do we need lake models?

If we have data, why do we need lake models? Some examples:

1. Lake models can be used to disentangle the multiple factors which influence the role of climate change on lake thermal dynamics.
2. Models can be used to predict lake temperatures when measurements are not available.
3. Can be used to validate theories of lake temperature response to climatic warming

Here are 2 examples of the value of lake models for understanding the influence of climate change on lakes.

Example 1: Atmospheric Stilling leads to prolonged thermal stratification

Woolway et al., (2017a), **Atmospheric stilling leads to prolonged thermal stratification in a large shallow polymictic lake**, *Clim. Change*, doi:10.1007/s10584-017-1909-0

Example 2: Response of lake temperatures to a climate regime shift

Woolway et al., (2017b), **Warming of Central European lakes and their response to the 1980s climate regime shift**, *Clim. Change*, doi:10.1007/s10584-017-1966-4

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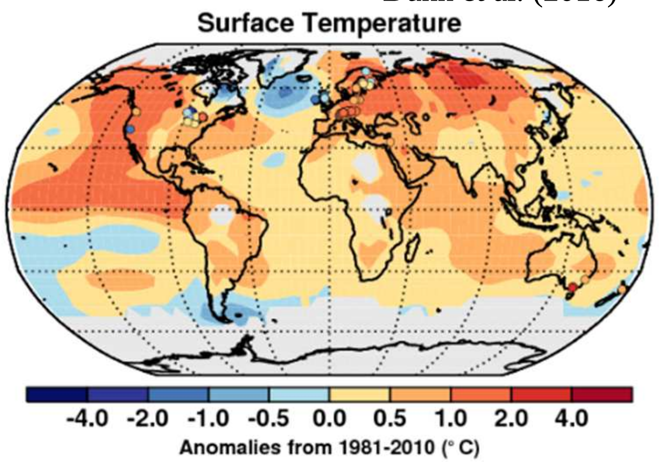
Example 1: Atmospheric stilling leads to prolonged thermal stratification

Atmospheric stilling leads to prolonged thermal stratification in a large shallow polymictic lake

R. Iestyn Woolway[1] • Pille Meinson[2] • Peeter Nõges[2] •
Ian D. Jones[3] • Alo Laas[2]

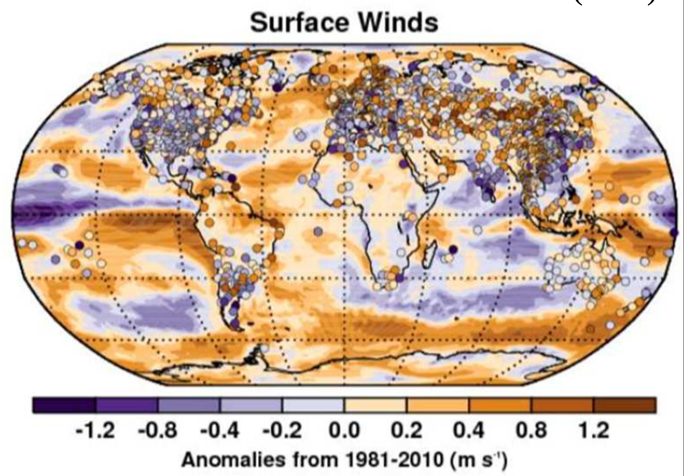
Strengthening of lake stratification:
a matter of increasing temperature
or weakening wind?

Dunn et al. (2016)



NOAA NCEI surface temperatures (contoured), and lake temperatures(circles)

Dunn et al. (2016)

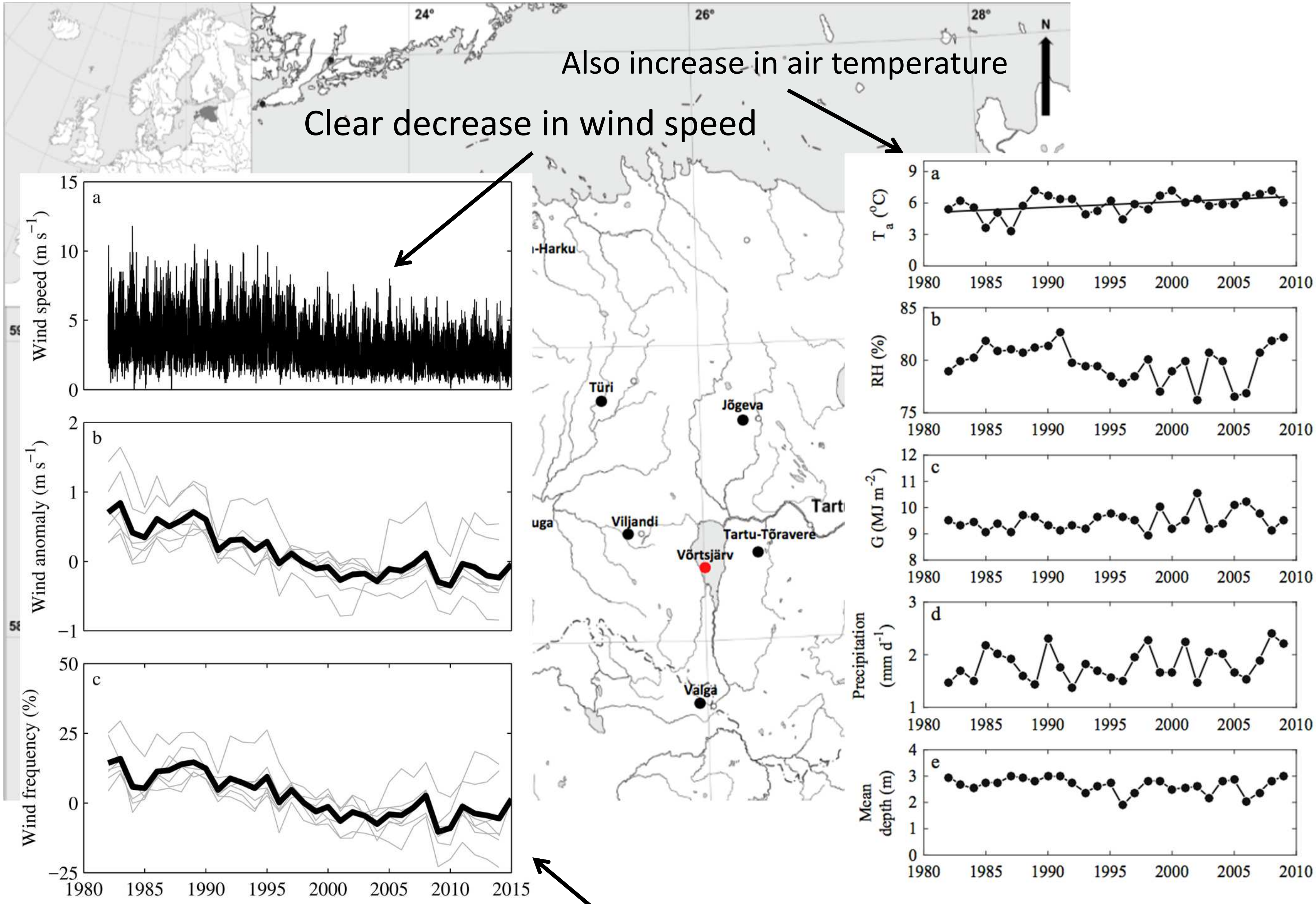


ERA_Interim (worldwide grids) and HadISD (points) surface wind speed


24°
26°
28°
N
Tallinn
Tallinn-Harku
59°
Türi
Jõgeva
Tartu
Pärnu
Pärnu-Sauga
Viljandi
Tartu-Tõravere
Võrtsjärv
58°
Valga
50 Km

Also increase in air temperature

Clear decrease in wind speed



Frequency of winds > 3 m/s

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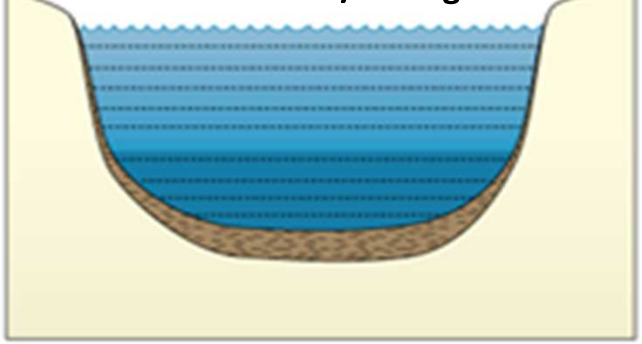
Example 1: Atmospheric stilling leads to prolonged thermal stratification

1D: stratification/mixing model



- One-dimensional lake model capable of simulating the vertical temperature structure of lakes.
- Flexible vertical grid structure
- Study site: Lake Vortsjarv, Estonia
- Mean depth: 2.8 m
- Lake area: 270 km^2

Input data (2 sources)

- Solar radiation
- Air temperature
- Wind speed
- Relative humidity
- Precipitation
- Lake bathymetry

Lake station (3 years)

Land station (28 years)

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Modelling lake surface temperatures: 1982-2010

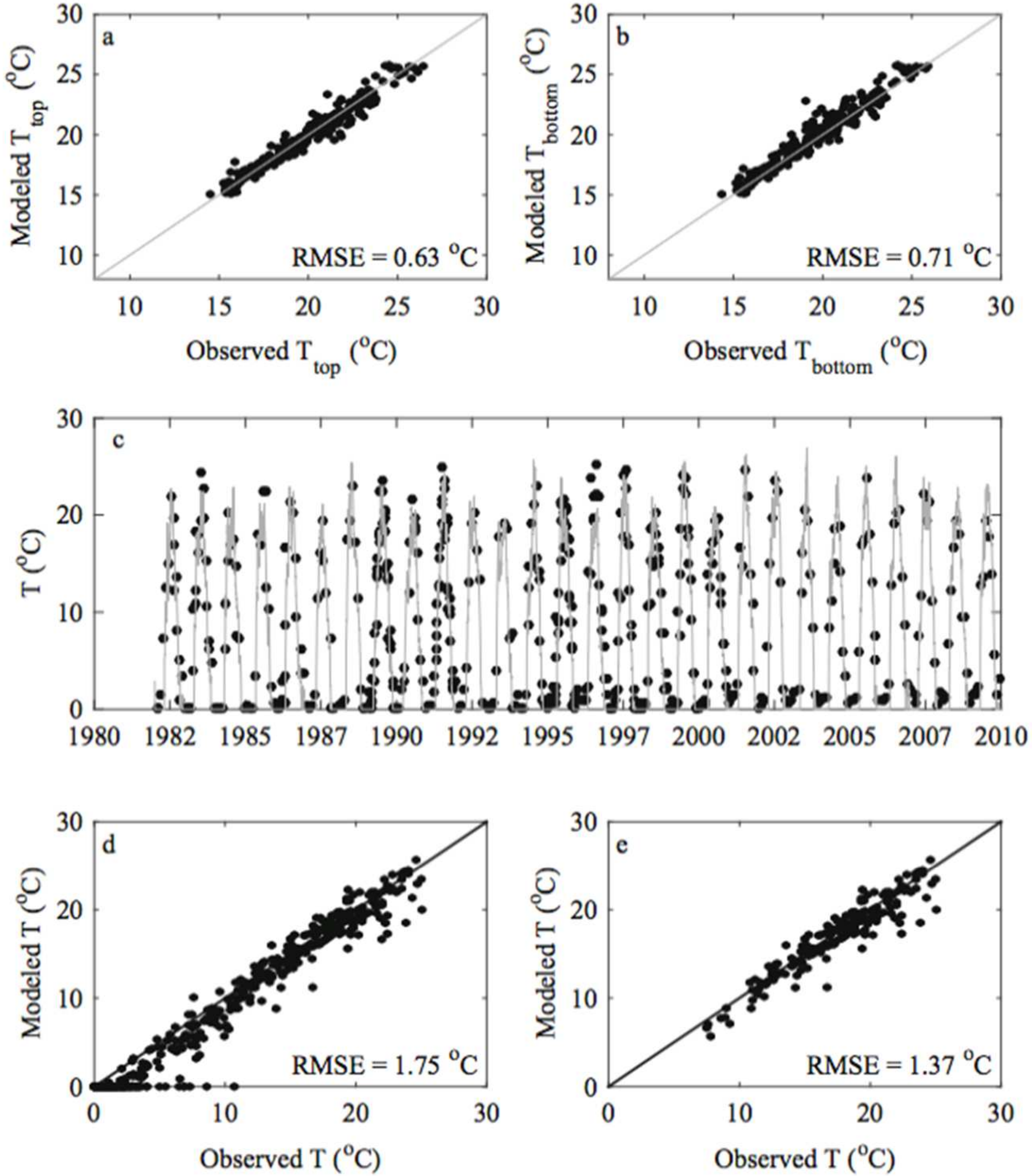

Fig. 3 Comparison of modelled and observed **a** surface and **b** bottom water temperatures for 2013–2015. **c** Comparison of long-term modelled (*grey line*) and observed (*black dots*) lake surface water temperature, showing a comparison **d** throughout the year and **e** during spring/summer (MJJA)

Woolway et al., (2017a), **Atmospheric stilling leads to prolonged thermal stratification in a large shallow polymictic lake**, *Clim. Change*, doi:10.1007/s10584-017-1909-0

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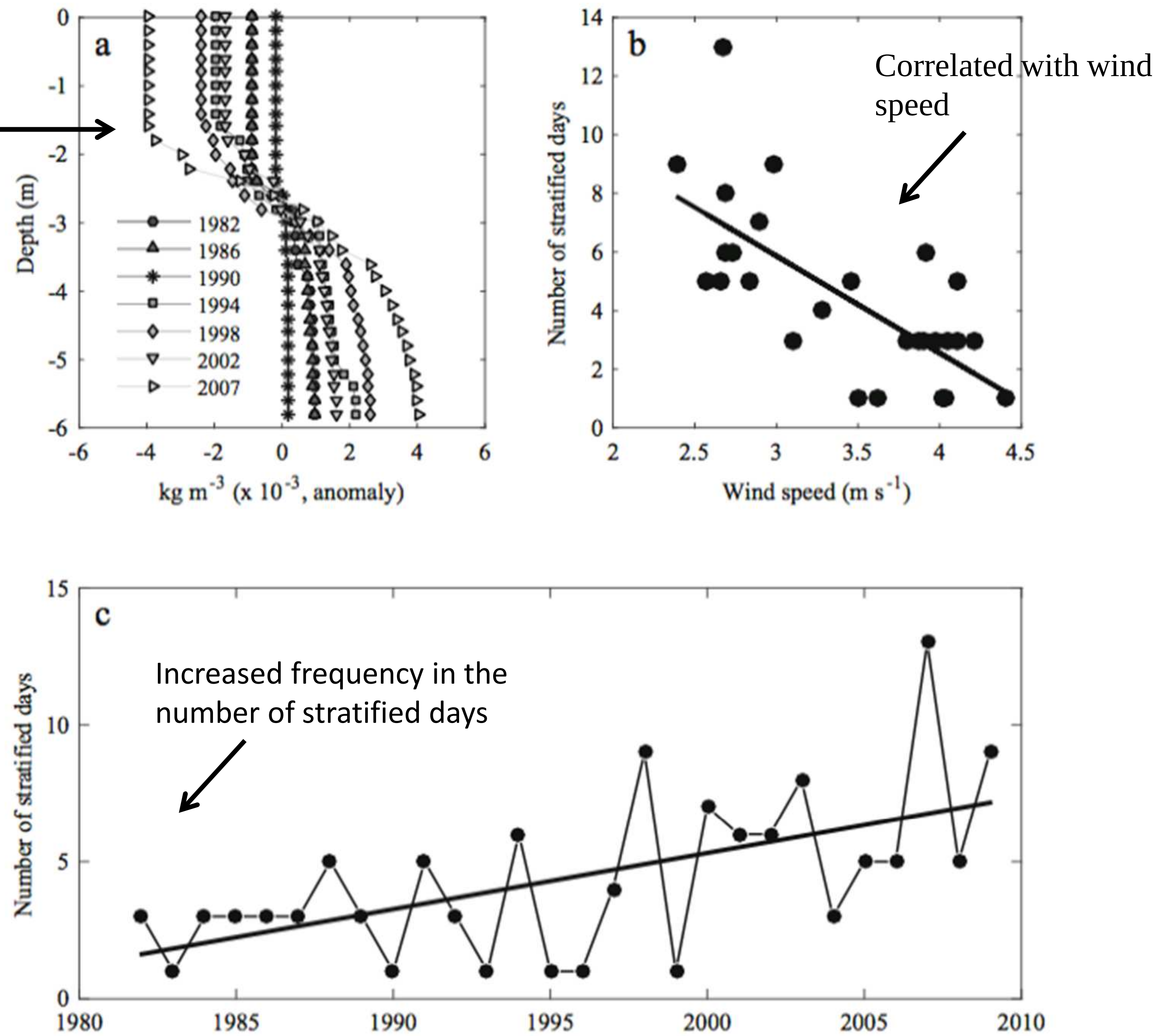
Clear changes in the vertical temperature in recent years. Why?



Woolway et al., (2017a), **Atmospheric stilling leads to prolonged thermal stratification in a large shallow polymictic lake**, *Clim. Change*, doi:10.1007/s10584-017-1909-0

Fig. 4 **a** Simulated water column density profiles averaged for 4 months during spring/summer (MJJA) for selected example years. Shown are the density profile anomalies relative to the 1982 to 2010 average density profile. **b** Relationship between the average wind speeds measured at Tartu-Tõravere meteorological station and the simulated number of stratified days from model runs with observed meteorological data. **c** Time series of the simulated number of stratified days from model runs with observed meteorological data

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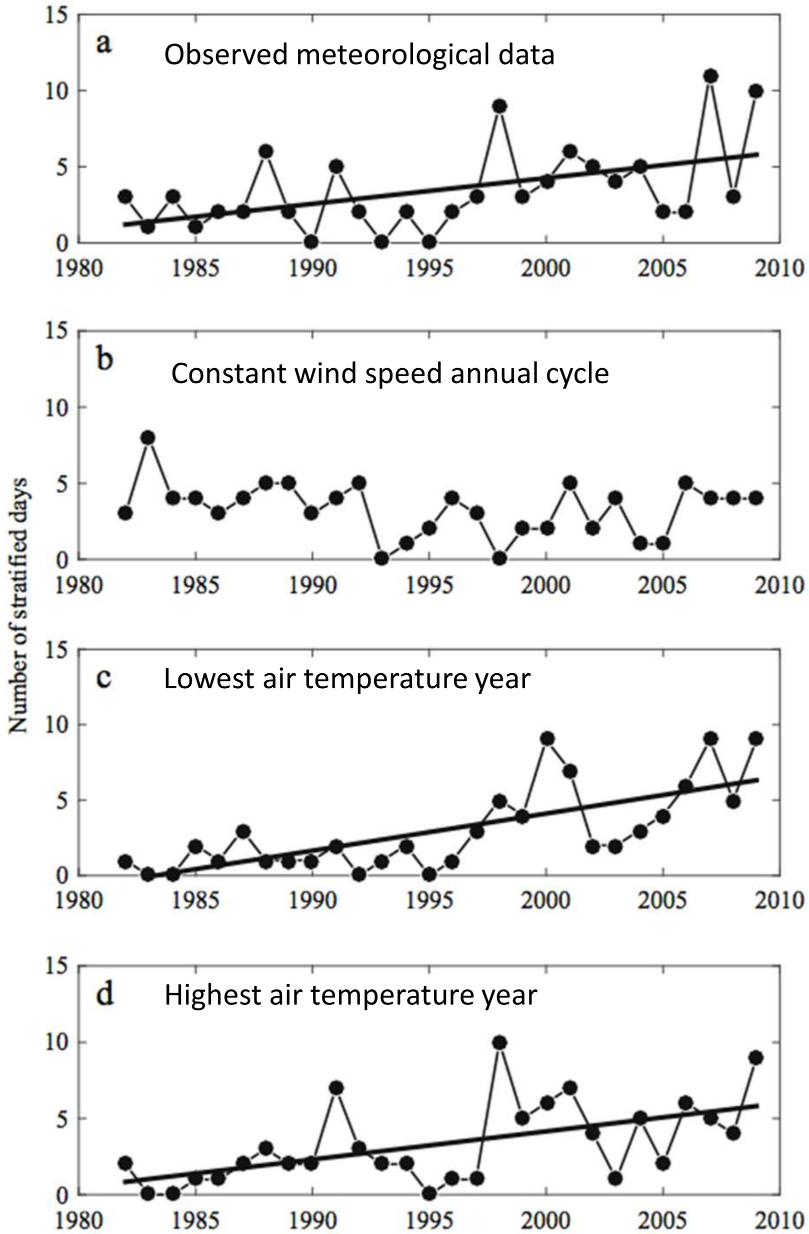
Modelling sensitivity analysis



The only time our model showed no increase in the number of stratified days per year was in the model run with a constant wind speed

Fig. 5 Comparisons of the number of stratified days from model runs with **a** constant 1982 air temperature annual cycle; **b** constant 1982 wind speed annual cycle; **c** constant 1987 air temperature annual cycle; and **d** constant 2009 air temperature annual cycle. Linear regressions of the statistically significant ($p < 0.05$) relationships are shown

Woolway et al., (2017a), **Atmospheric stilling leads to prolonged thermal stratification in a large shallow polymictic lake**, *Clim. Change*, doi:10.1007/s10584-017-1909-0

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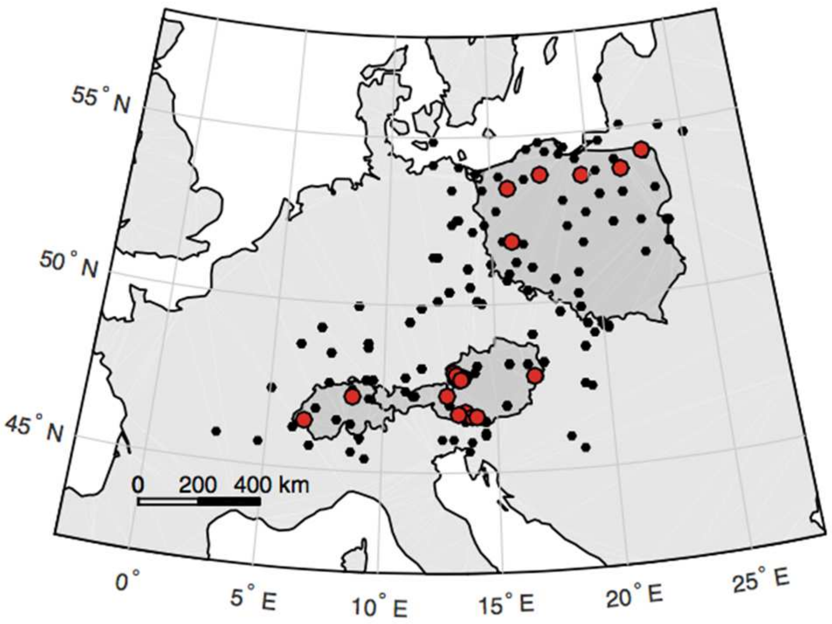
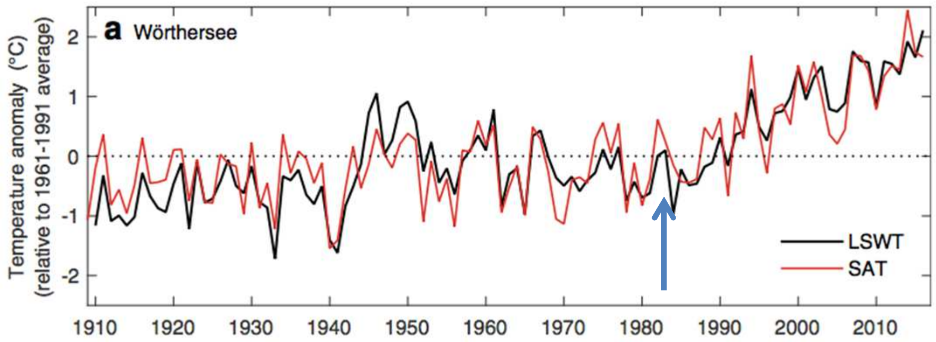
Example 2: Response of lake temperatures to a climate regime shift



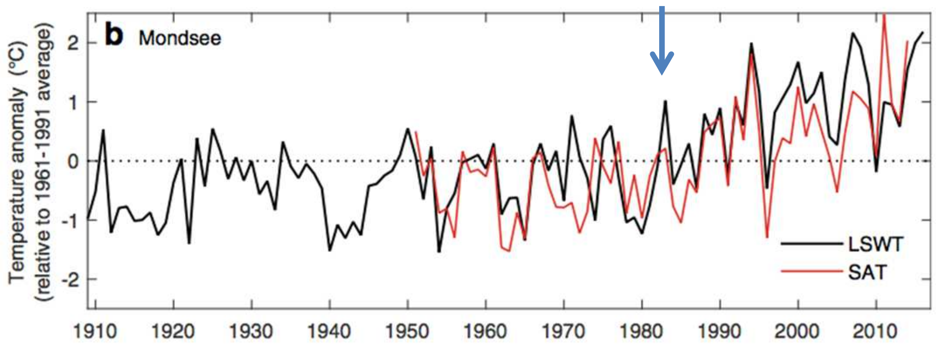
20 lakes in Central Europe

Warming of Central European lakes and their response to the 1980s climate regime shift

R. Iestyn Woolway[1] · Martin T. Dokulil[2] · Wlodzimierz Marszelewski[3] · Martin Schmid[4] · Damien Bouffard[4] · Christopher J. Merchant[1]



Rapid increase in LSWT during the 1980s



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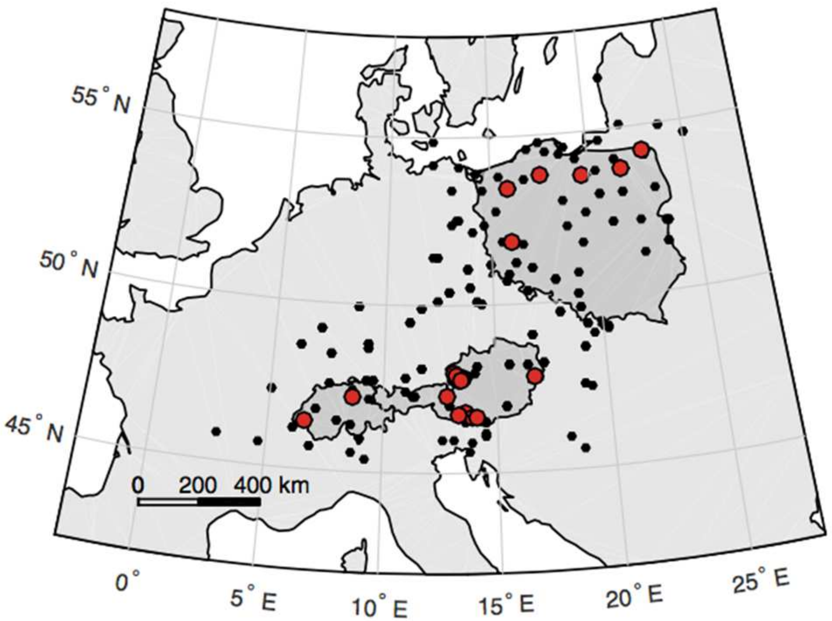

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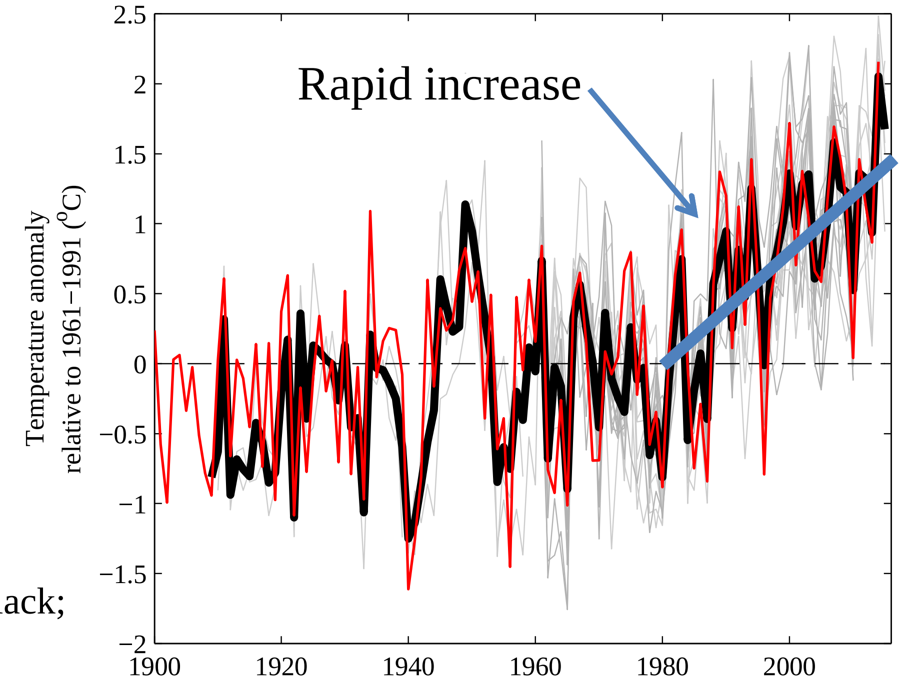

T_{air} in red; regional average T_w in black; Individual T_w in grey.

Can the Freshwater Lake Model, FLake, predict the 1980s regime shift?

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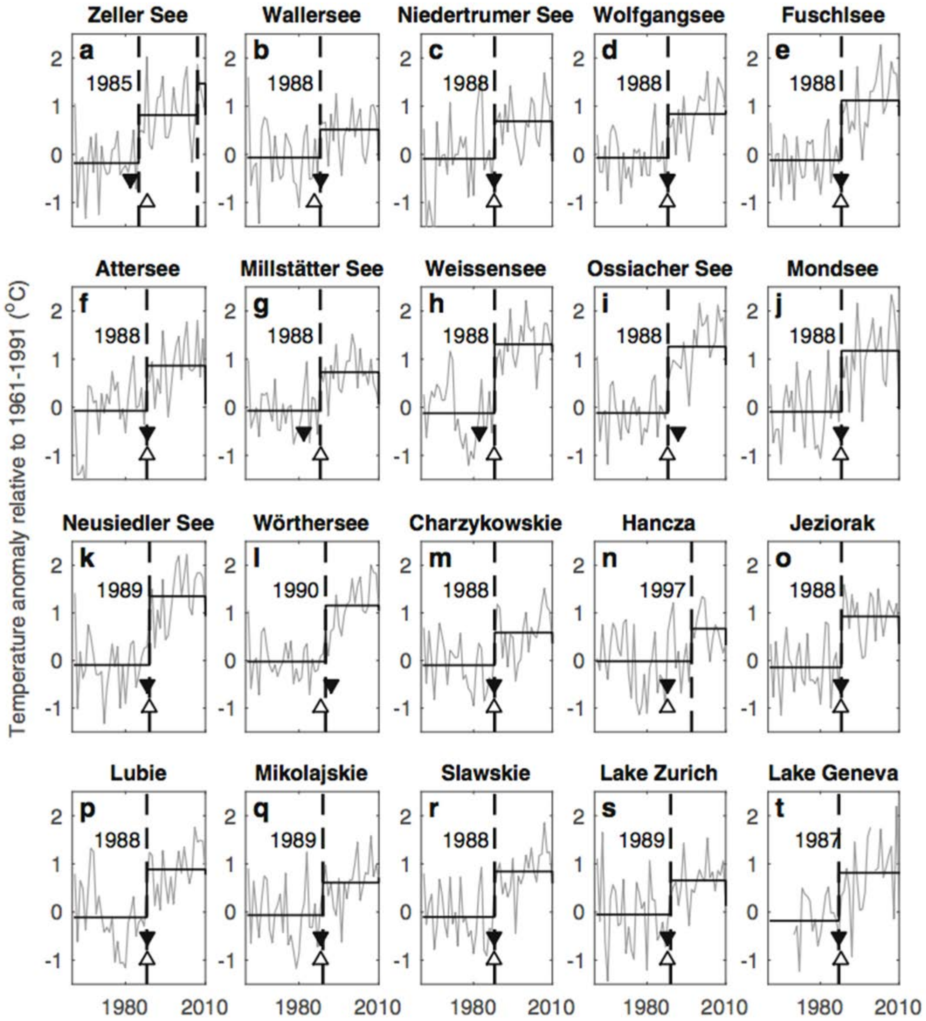
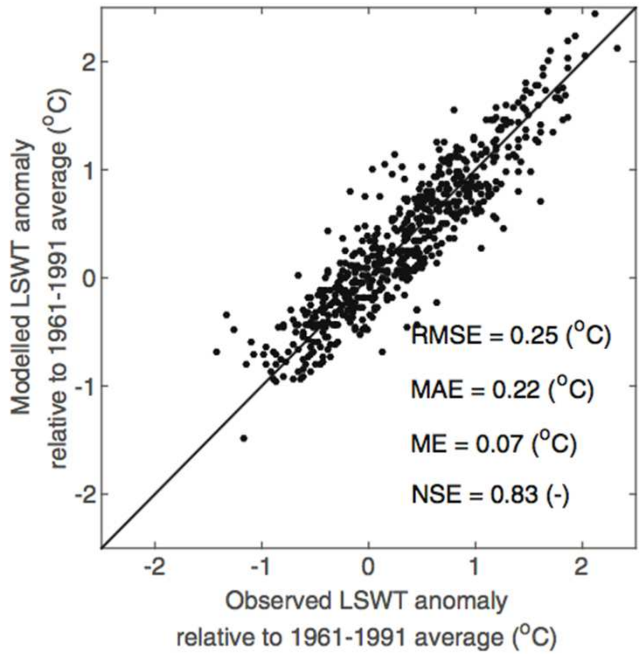


▲SAT step change △Modelled LSWT step change

Most lakes experienced an increase in LSWT during the 1980s

Using the FLake model, we showed that the regime shift could also be modelled from reanalysis data, thus not a result of lake specific changes.



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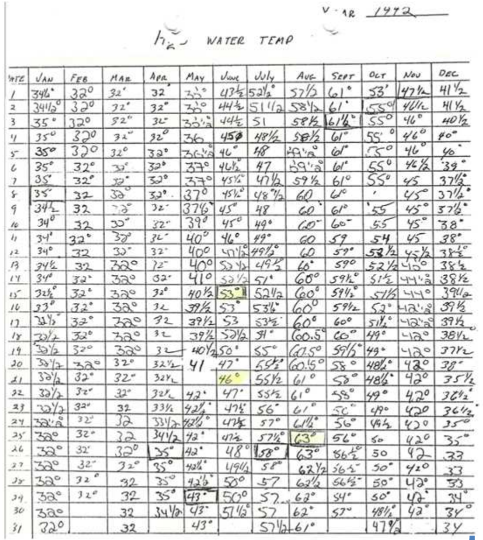
Modelling lakes globally - Datasets



Hydrological yearbooks of in situ measurements

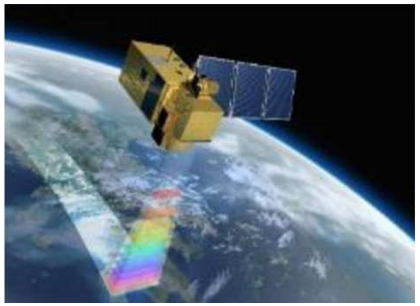
Land-based weather stations

High-resolution lake monitoring buoys

Climate reanalysis data

ECMWF

Lake bathymetry information



Satellite observations

CMIP5 Climate projections

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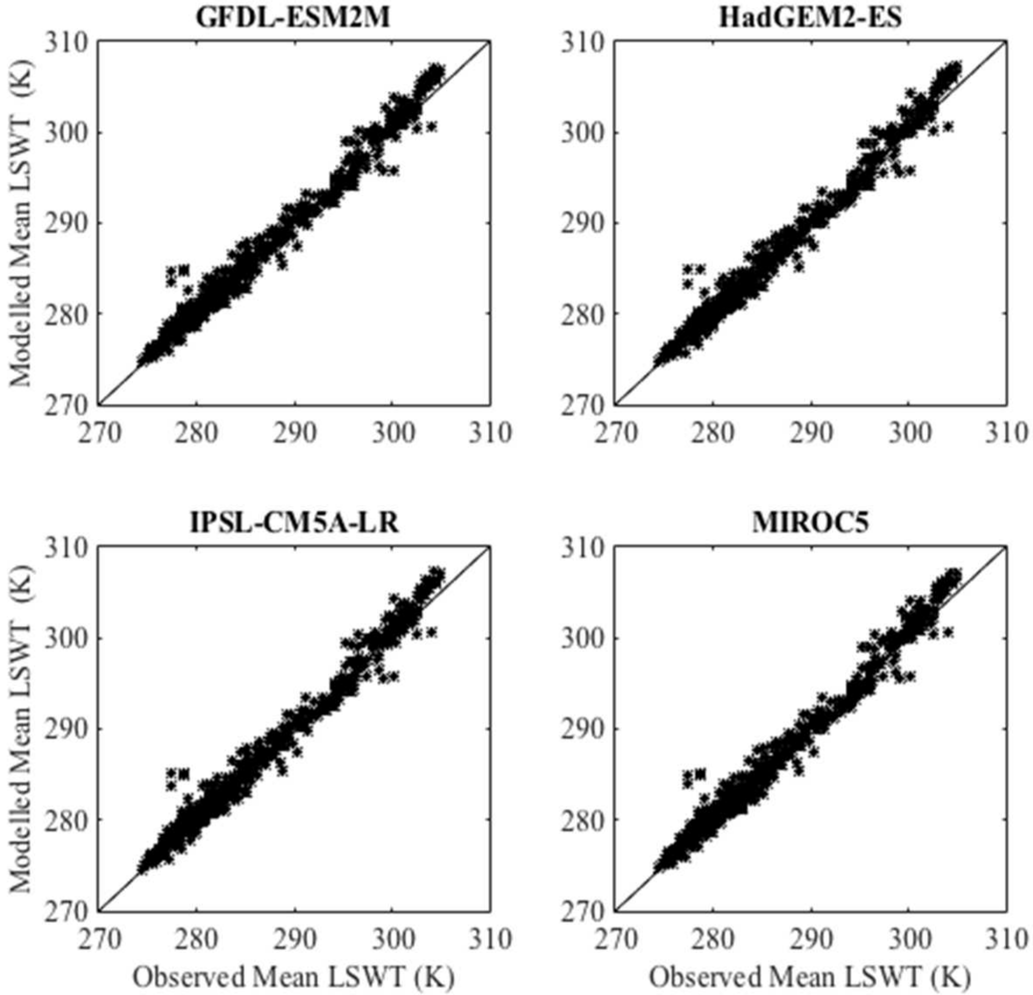
Modelling lakes globally – Results

- ARC-Lake v3, 732 lakes
- Lake average data
- Data reconstructed twice a month
- Dates from June 1995 to Dec 2011
- Over-lake meteorological data from 4 climate projection models



Modelled accurately during historic period

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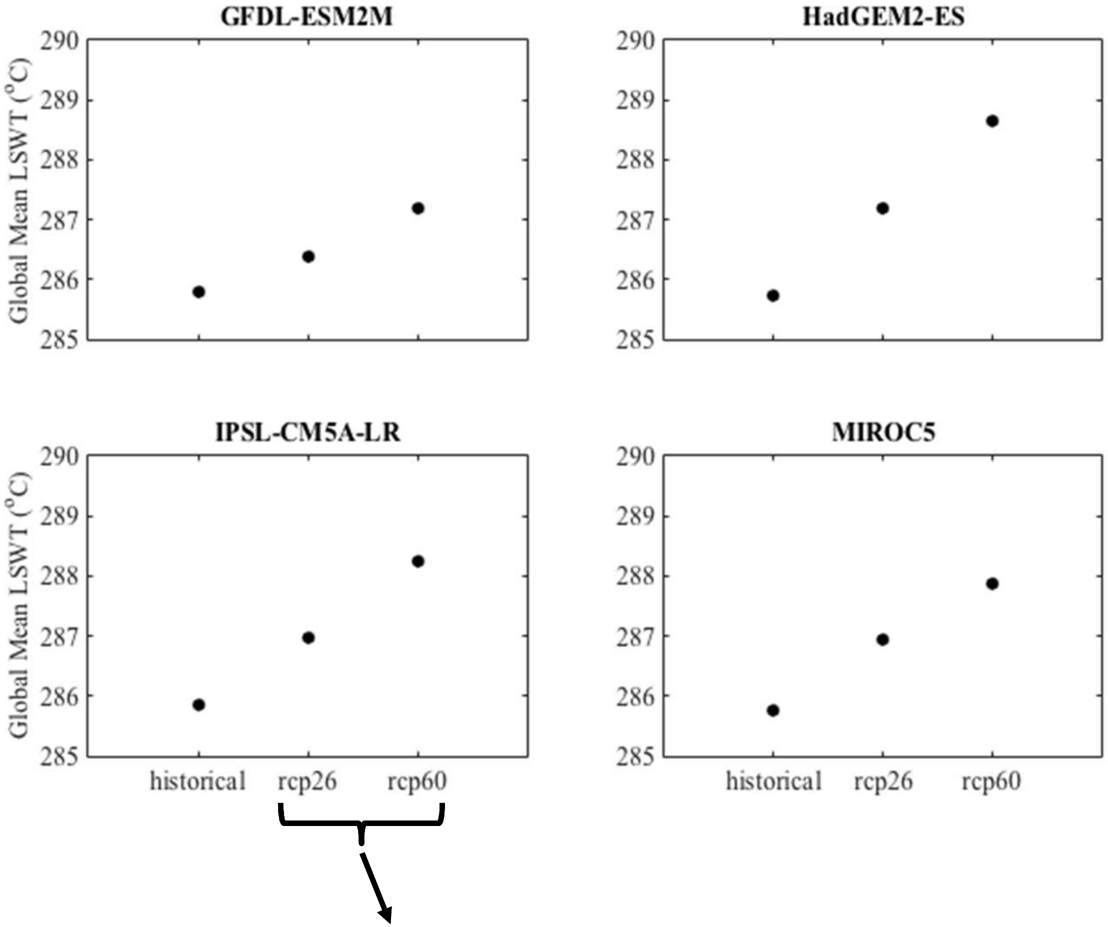
Modelling lakes globally – Results



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Representative Concentration Pathway (RCP) scenarios by 2100 (RCP 2.6 = best case; RCP 6.0 = one of worst cases) – these consider how much greenhouse gases will be released in future.

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Acknowledgements

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NERC SCIENCE OF THE ENVIRONMENT

GloboLakes

esa

ARC Lake

Thank you

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