Combining a weather generator and a one-dimensional lake model to simulate climate change effects on a deep lake

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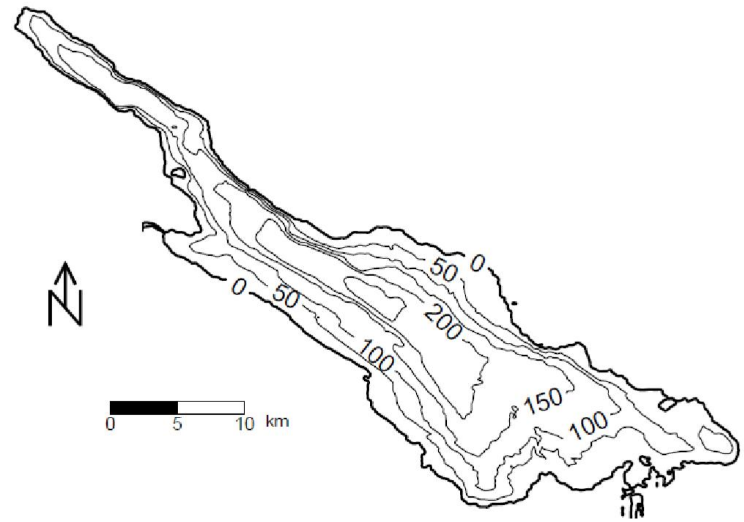
Lake Constance

- mixing type: warm monomictic
- maximum depth: 251 m
- average depth: 100 m
- surface area: 473 km²
- residence time: 5 yr
- phosphorus concentration: < 10 µg/L
- drinking water reservoir for ca. 4 Mio people (125 Mio m³/yr)



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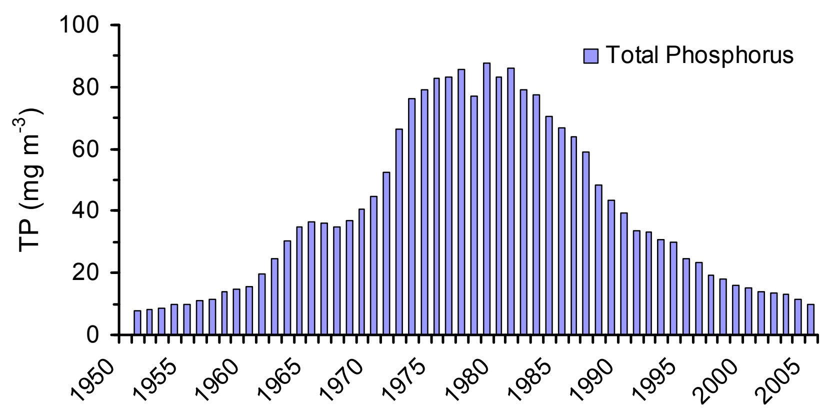

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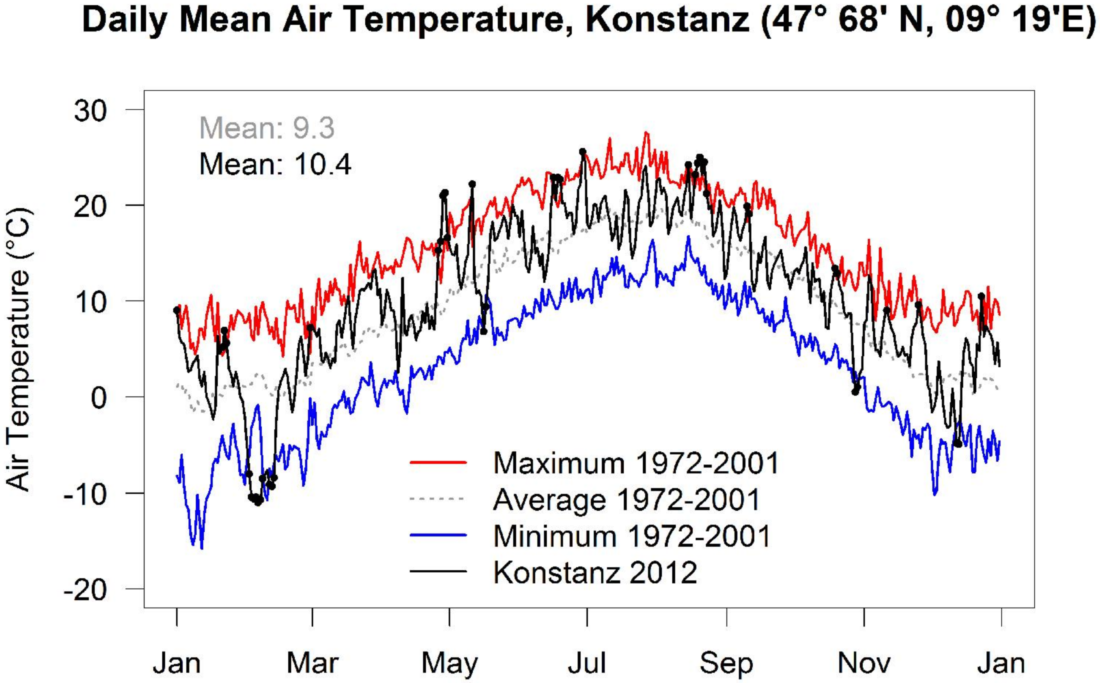
Climate change in deep lakes

- increase in thermal stability ($\Delta T_{epi} > \Delta T_{hyp}$);
  Livingstone, 2003, Climatic Change
- earlier onset of the phytoplankton spring bloom;
  Winder and Schindler, 2004, GCB
- correlation between phytoplankton spring bloom and stratification onset;
  Ocean: *Sverdrup, 1952*
  Lake Constance: *Ollinger and Bäuerle, 1998; Peeters et al., 2007*

Meteorological variability



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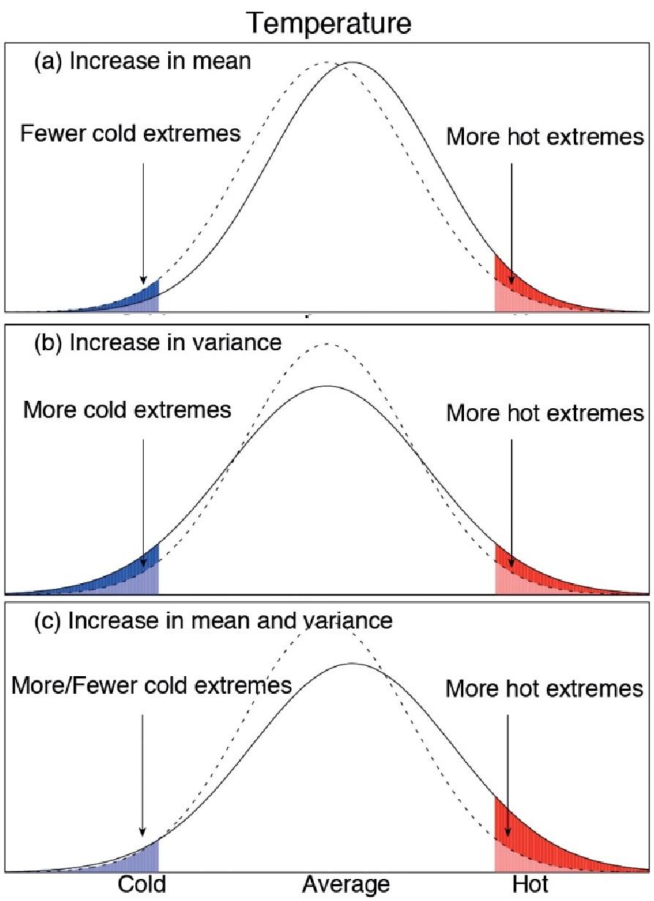

IPCC 2013

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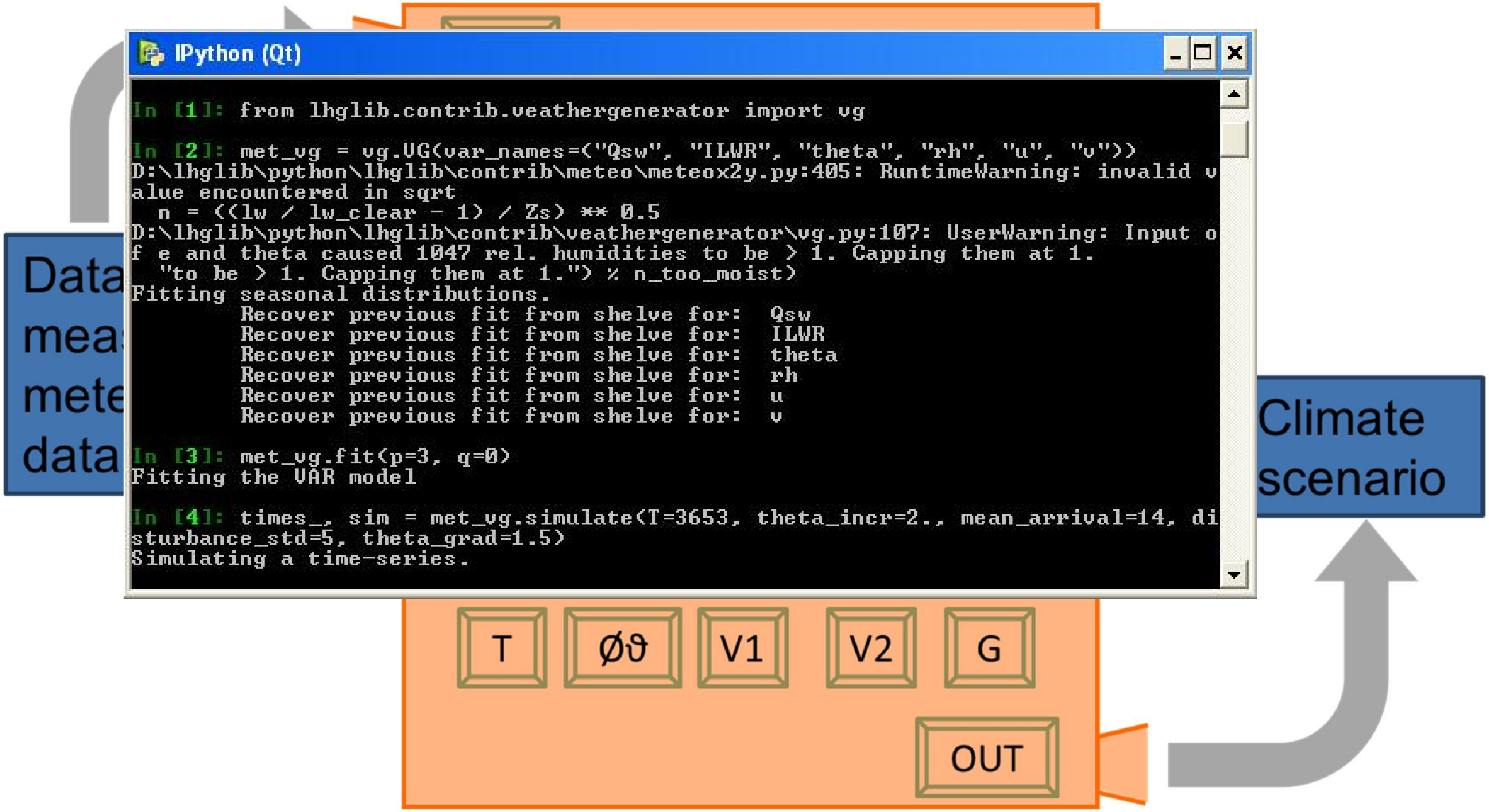
Vector-autoregressive weather Generator VG



Schlabing et al. 2014, EMS

open source: http://bitbucket.org/iskur/vg

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Correlation structure of meteorological variables

Measured

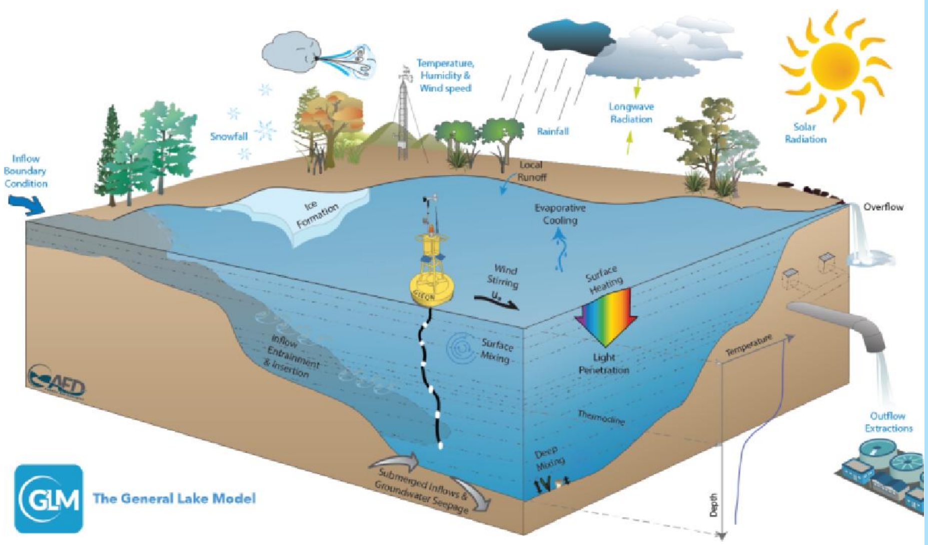
	θ	Q_{sw}	$Q_{lw(i.)}$	ϕ	u	v
θ	1.00	0.72	0.89	-0.48	-0.06	0.02
Q_{sw}	0.72	1.00	0.43	-0.77	-0.26	-0.19
$Q_{lw(i.)}$	0.89	0.43	1.00	-0.19	0.08	0.13
ϕ	-0.48	-0.77	-0.19	1.00	0.14	0.13
u	-0.06	-0.26	0.08	0.14	1.00	0.80
v	0.02	-0.19	0.13	0.13	0.80	1.00

Simulated

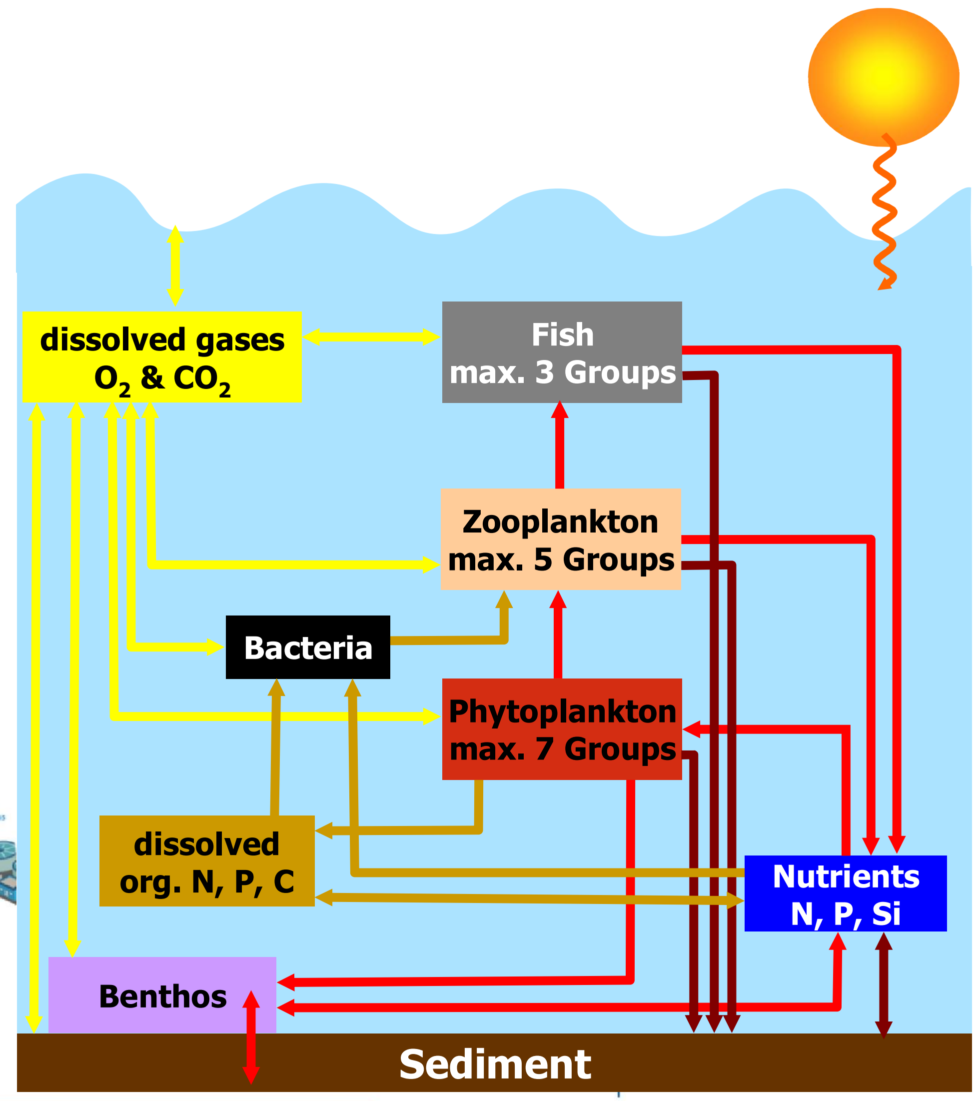
	θ	Q_{sw}	$Q_{lw(i.)}$	ϕ	u	v
θ	1.00	0.69	0.89	-0.47	-0.08	-0.01
Q_{sw}	0.69	1.00	0.43	-0.72	-0.20	-0.13
$Q_{lw(i.)}$	0.89	0.43	1.00	-0.20	0.06	0.11
ϕ	-0.47	-0.72	-0.20	1.00	0.15	0.12
u	-0.08	-0.20	0.06	0.15	1.00	0.77
v	-0.01	-0.13	0.11	0.12	0.77	1.00

Hydrophysical lake model

The general lake model (GLM)

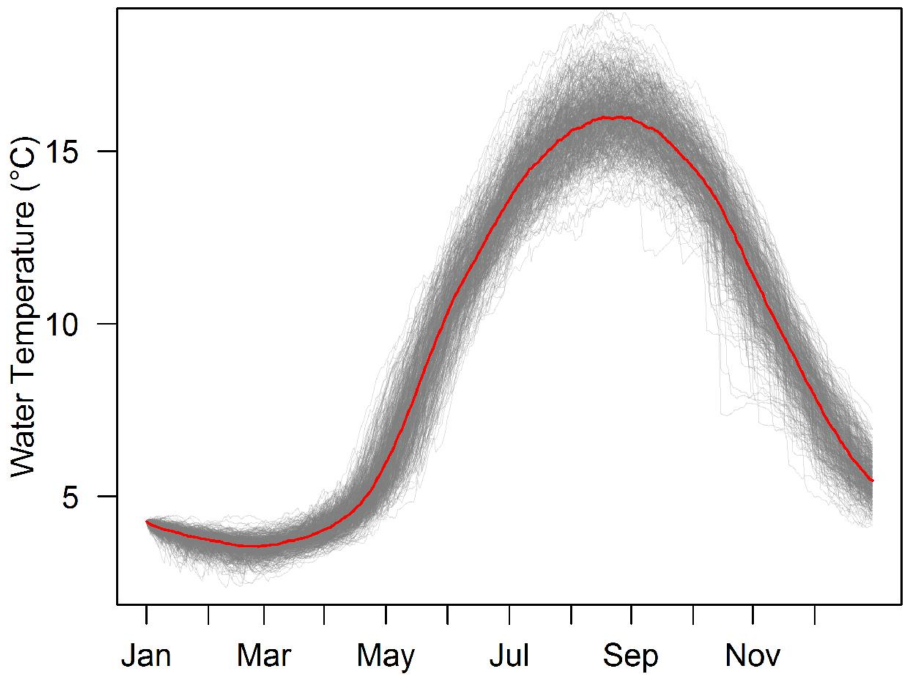


Ecological lake model

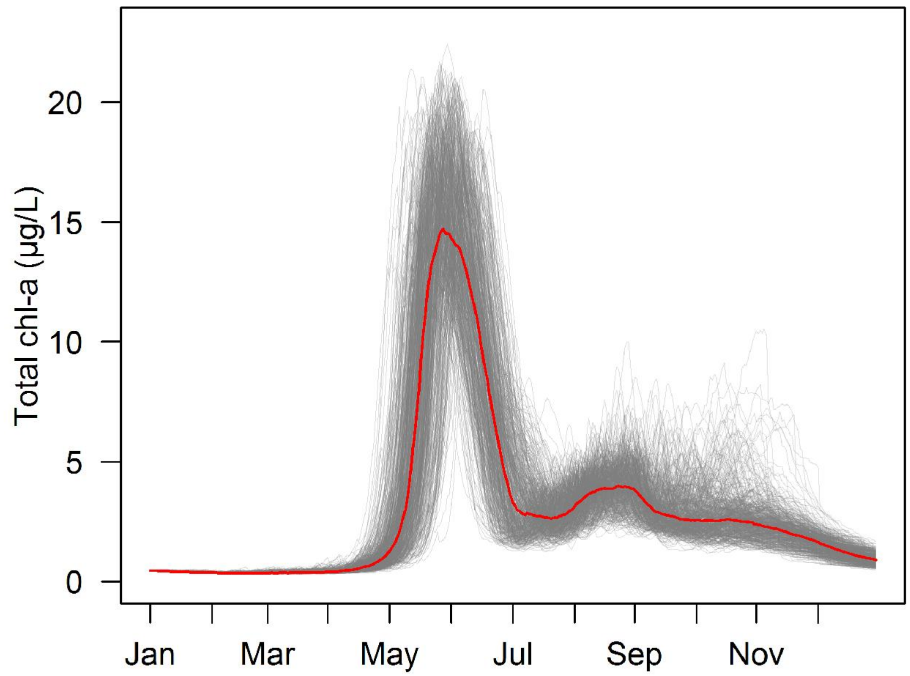


Base Scenario (500 realisations)

Mean Water Temperature 0-20 m



Mean Total Chl-a Conc. 0-20 m



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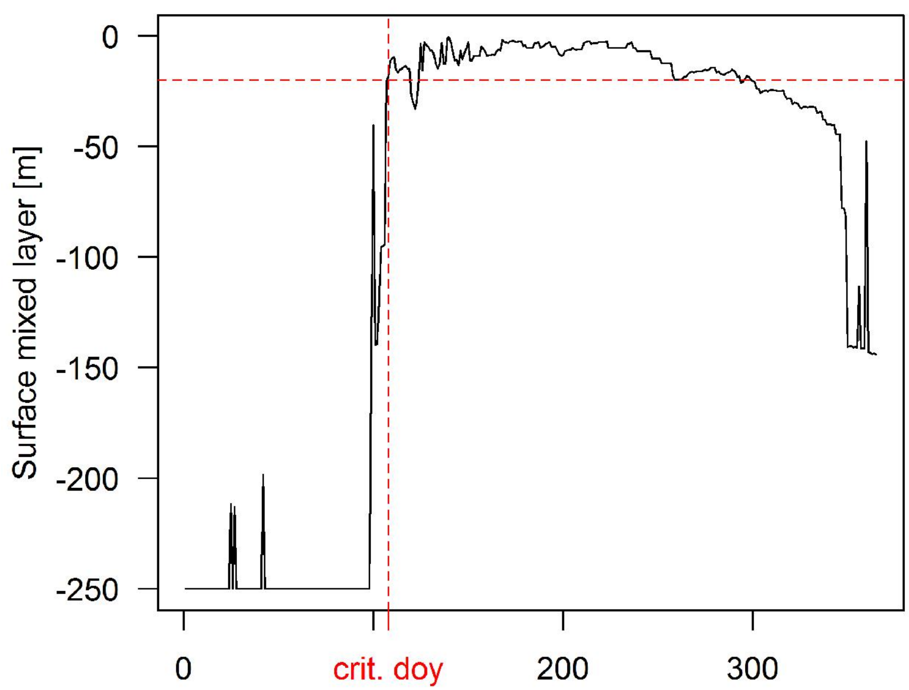
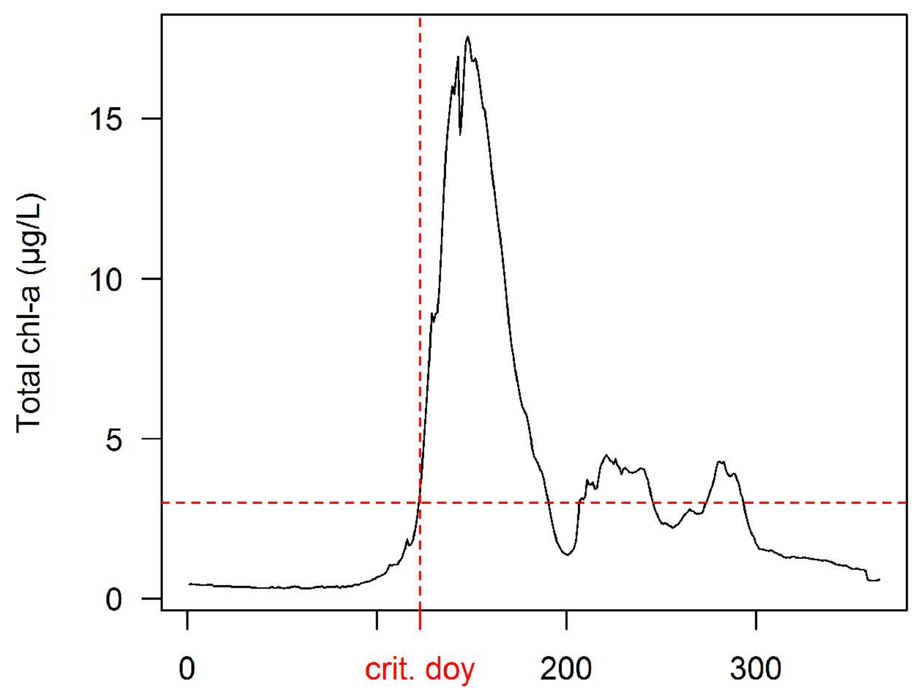
Stratification and bloom onset

Surface mixed layer depth



Mean Total Chl-a Conc. 0-20 m



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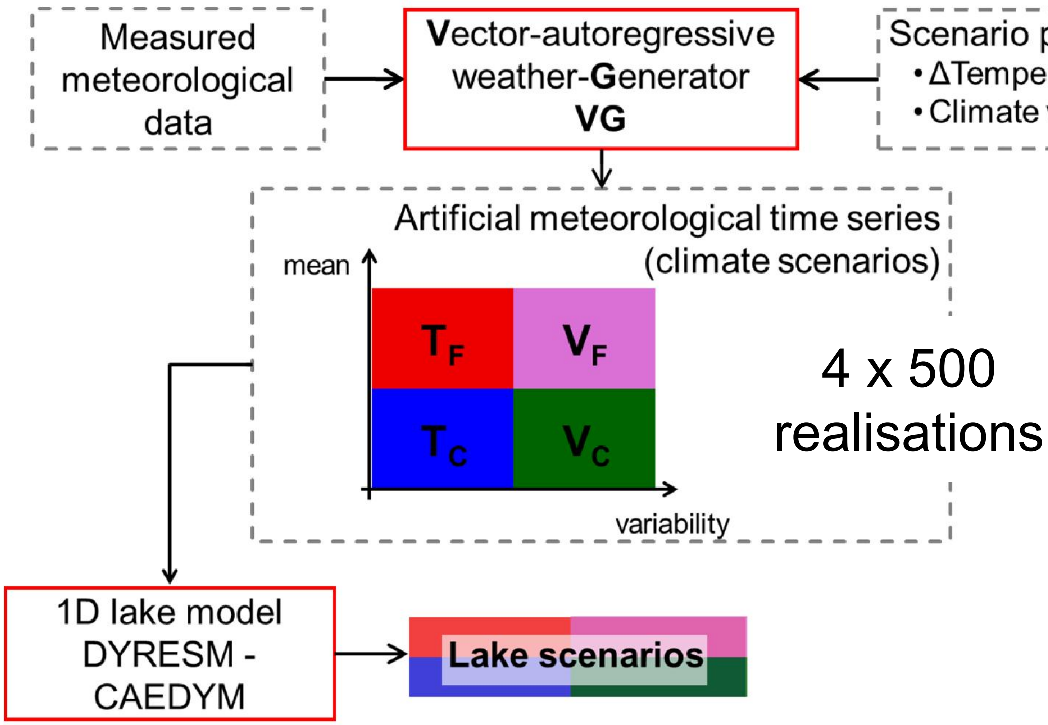
Use of a weather generator for simulating climate change effects on ecosystems: A case study on Lake Constance

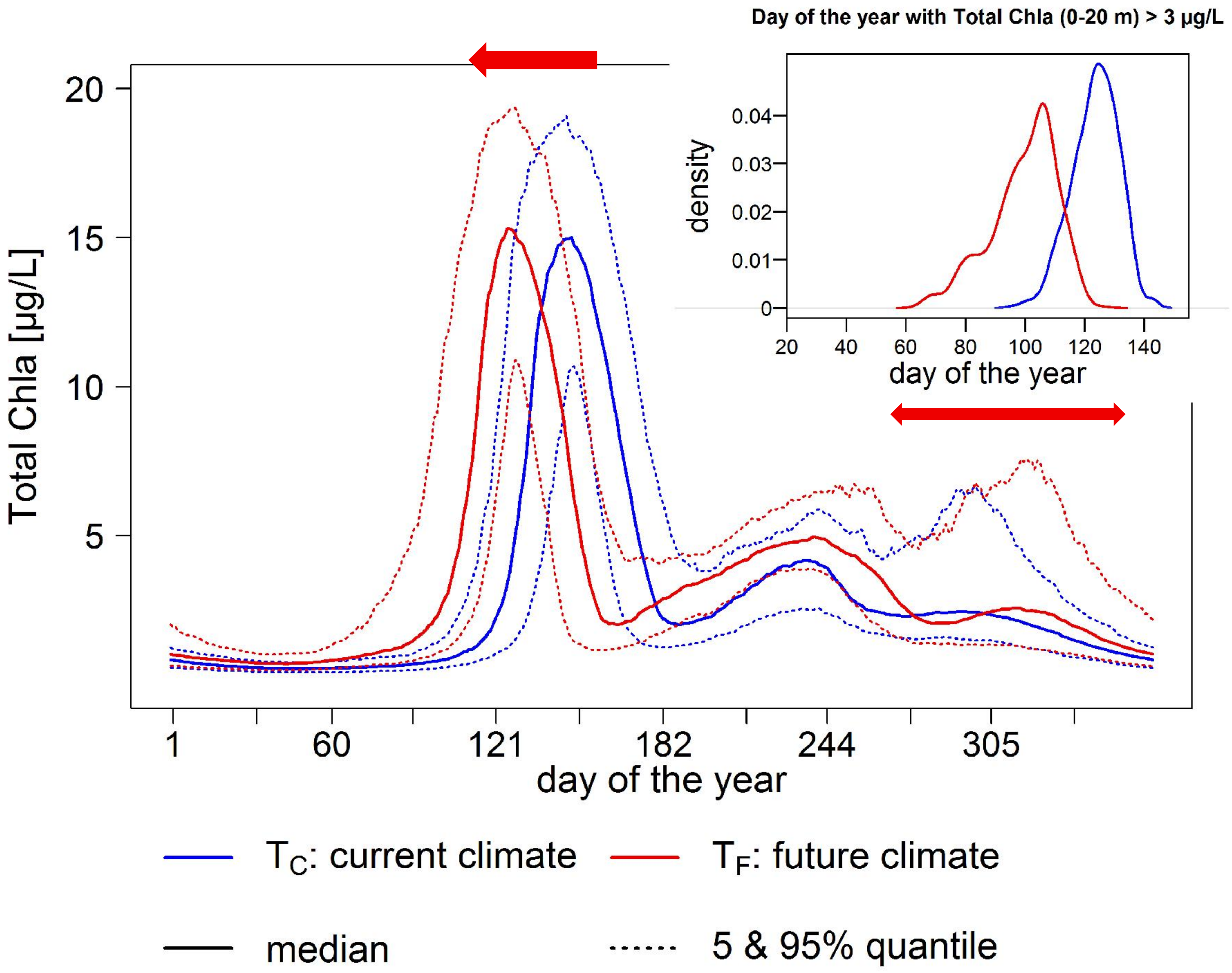
D. Schlabing, M.A. Frassl, M.M. Eder, K. Rinke and A. Bárdossy
Environmental Modelling & Software,
doi: 10.1016/j.envsoft.2014.06.028



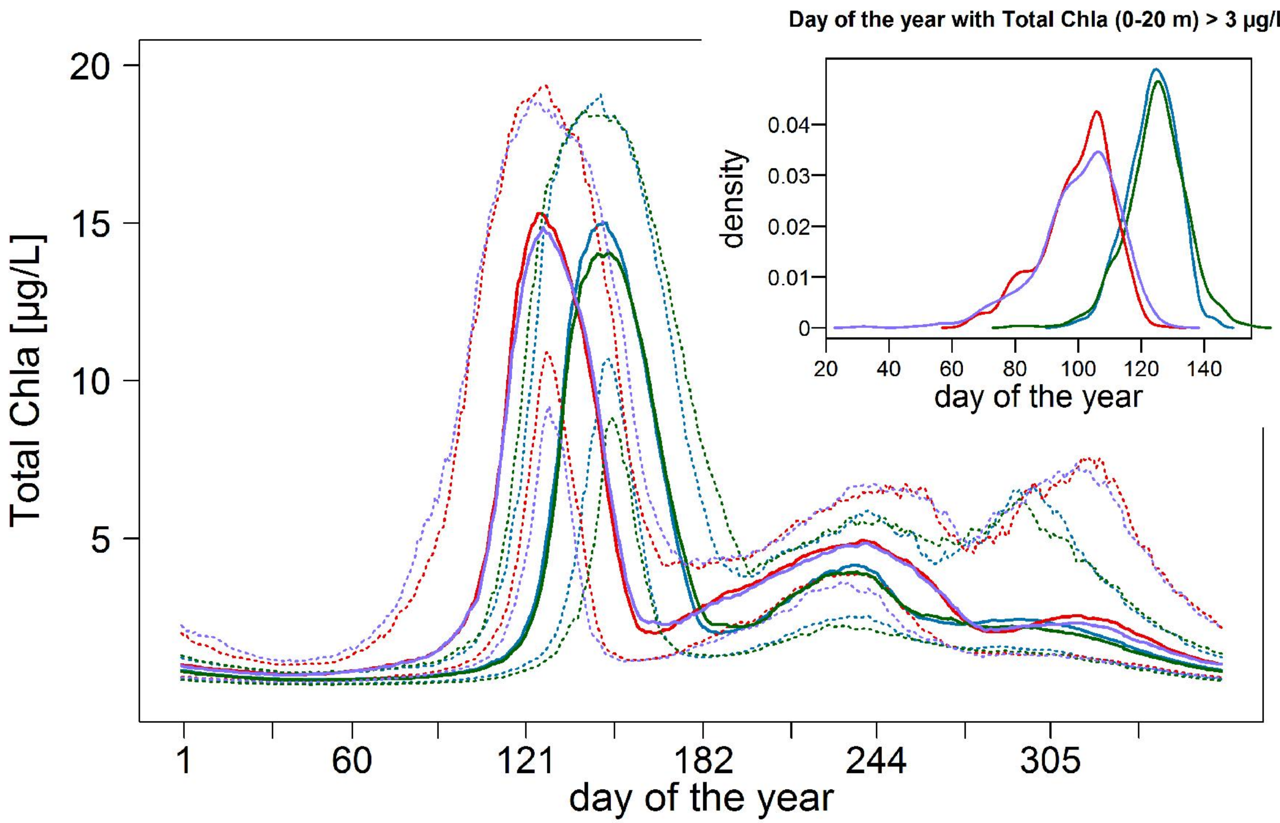
How sensitive is the phytoplankton spring bloom to

1. *a change in mean air temperature*
2. *an increased climate variability*
3. *a combination of both*

Mean Chlorophyll Concentration 0-20 m



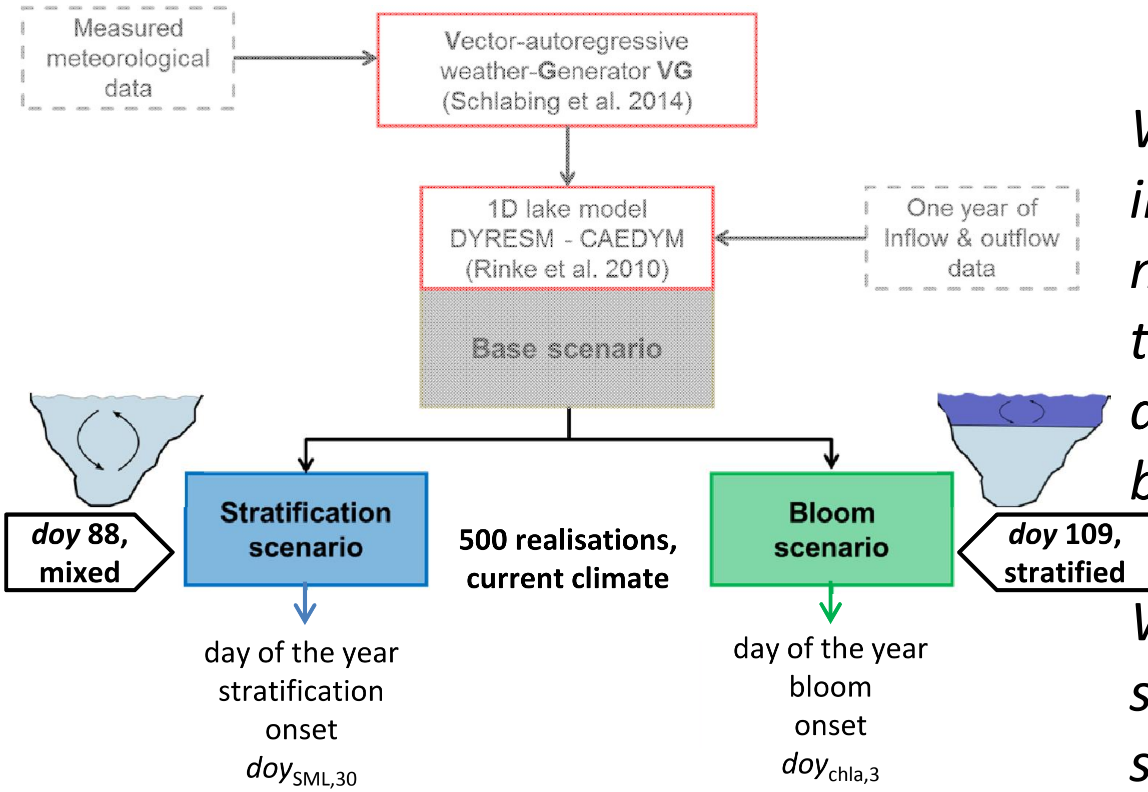
Mean Chlorophyll Concentration 0-20 m



T_C: current climate
V_C: current climate, higher variability
median
T_F: future climate
V_F: future climate,
5 & 95% quantile

Meteorological control of lake ecosystems: The (un)importance of air temperature

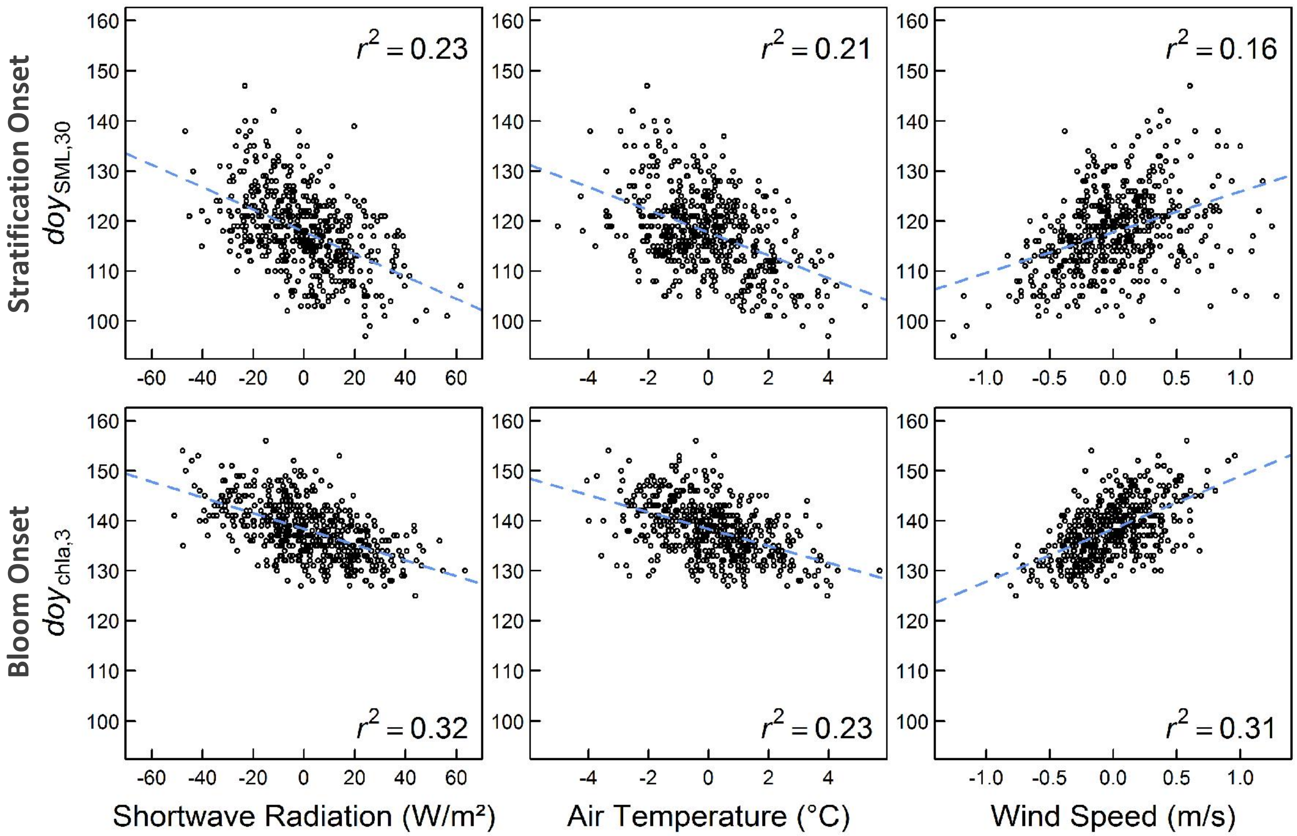
M.A. Frassl, D. Schlabing, M.M. Eder, K.-O. Rothhaupt and K. Rinke
(submitted)



What is the relative importance of different meteorological variables for the timing of stratification and the phytoplankton spring bloom?

What are the relevant time scales for stratification and spring bloom onset?

Relevant meteorological variables



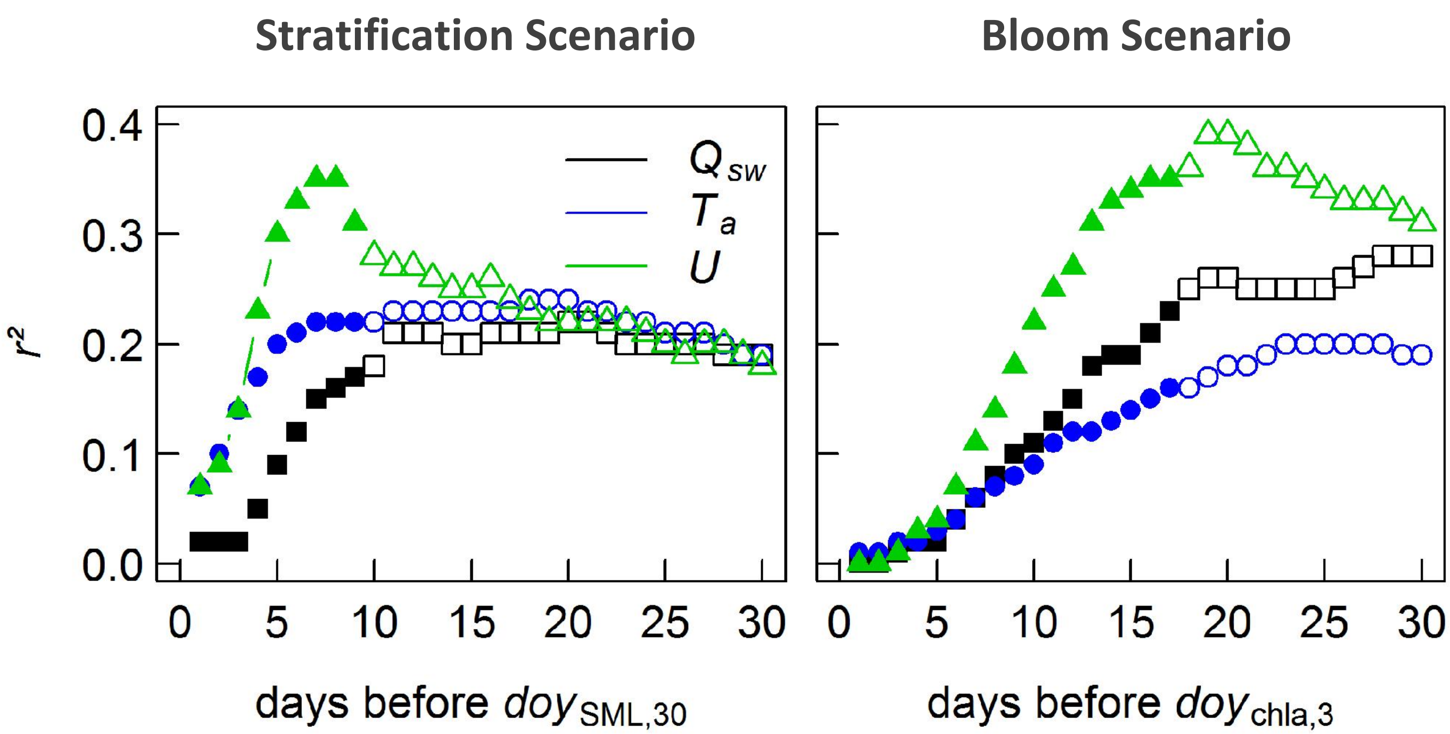
Stratification onset:

$doy_{\mathrm{SML,30}} = 117.68 - 0.14\,\overline{Qsw} - 1.68\,\overline{T} + 7.07\,\overline{U}$, r^2 = 0.436, RI_{QSW} = 0.144, RI_{AT} = 0.155, RI_U = 0.137

Bloom onset:

$doy_{\mathrm{chla,3}} = 138.55 - 0.11\,\overline{Qsw} - 0.95\,\overline{T} + 8.92\,\overline{U}$, r^2 = 0.607, RI_{QSW} = 0.232, RI_{AT} = 0.109, RI_U = 0.266

Relevant time scales



Stratification onset:

$doy_{SML,30} = 118.44 - 0.11\ \overline{Qsw}_{20} - 1.62\ \bar{T}_{18} + 7.79\ \bar{U}_{7}$, r^2 = 0.672, RI_{QSW} = 0.119, RI_{AT} = 0.207, RI_{U} = 0.346

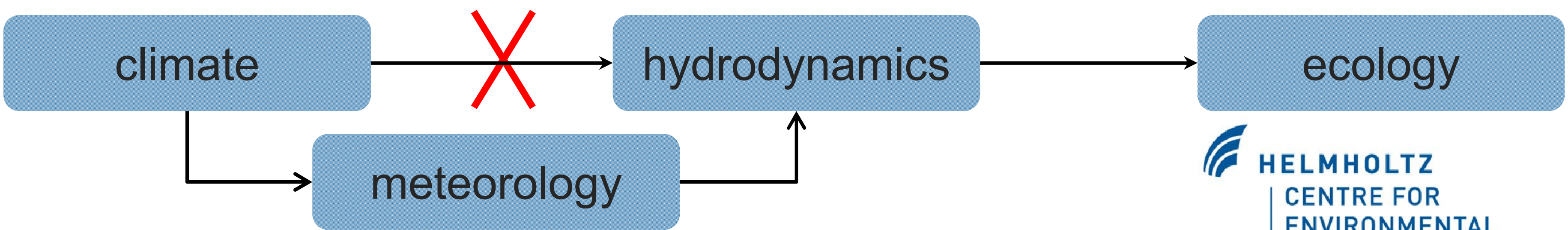
Bloom onset:

$doy_{chla,3} = 138.58 - 0.11\ \overline{Qsw}_{28} - 0.91\ \bar{T}_{23} + 9.67\ \bar{U}_{19}$, r^2 = 0.702, RI_{QSW} = 0.217, RI_{AT} = 0.112, RI_{U} = 0.373

Summary – Weather generator

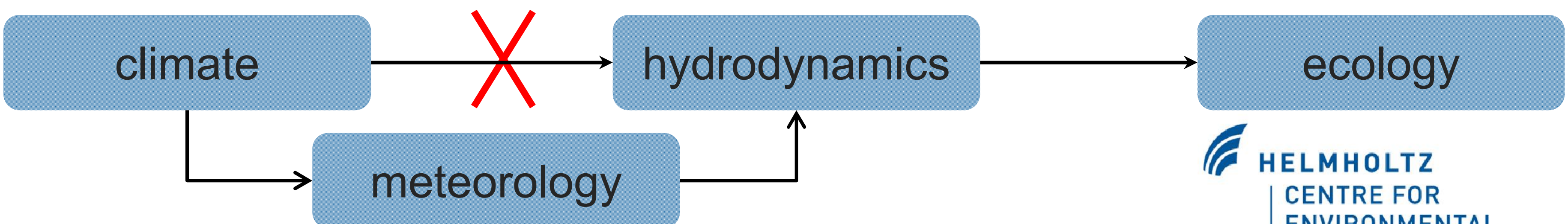
The coupling of statistical (VG) and mechanistic (DYCD) model is a powerful approach:

- process understanding by hand-tailored scenarios (e.g. mean vs. variability)
- VG enables a probabilistic approach
- analysing extreme events



Summary – Lake Ecosystem

- Phytoplankton spring bloom timing depends on the interaction between meteorological variables.
- Increased variability showed only a slight effect.
- Meteorological variables acted at different time scales.
- Wind had the largest influence on the timing.



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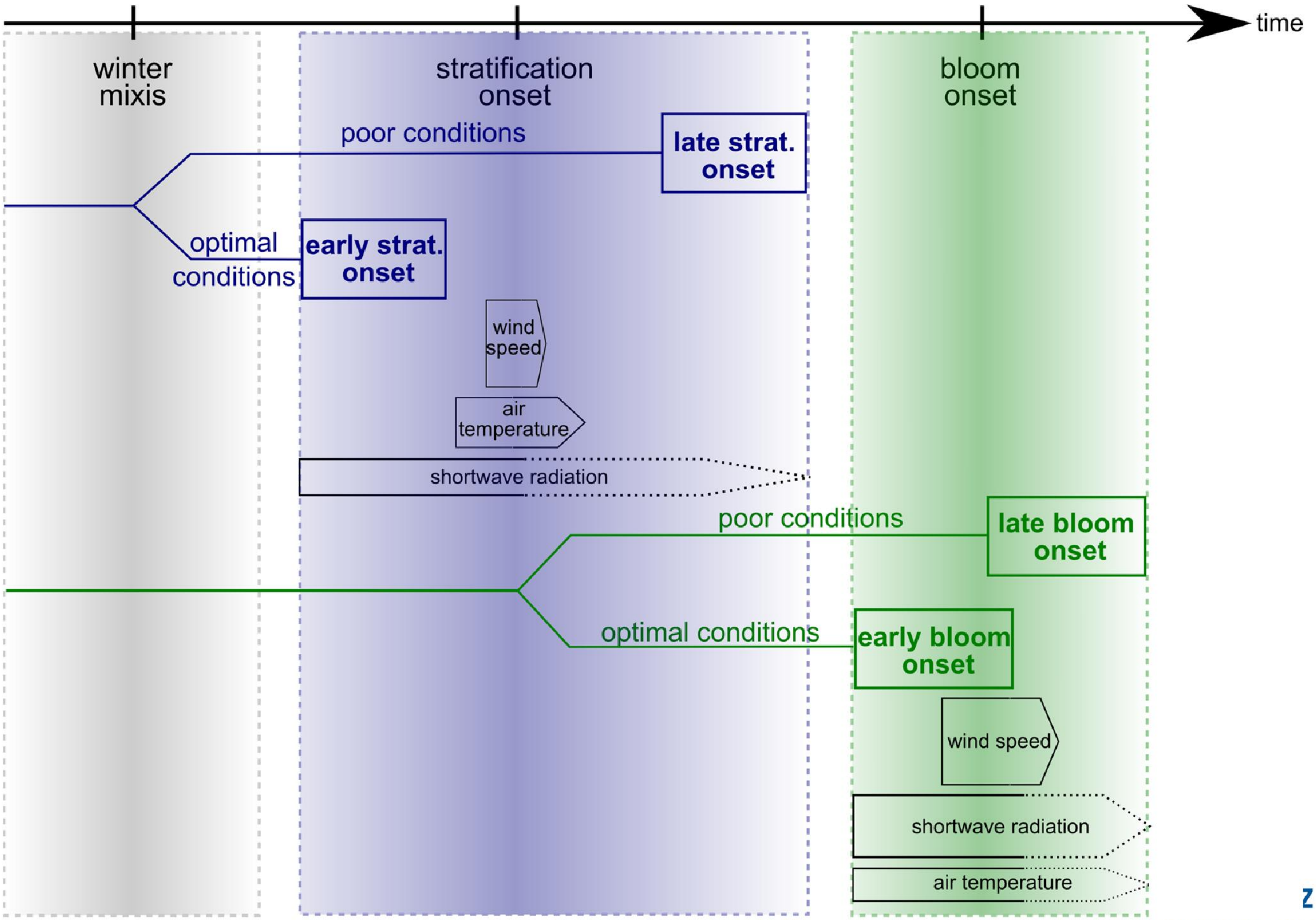
Summary – Lake Ecosystem



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