The impact of climate change on lakes in Central Europe

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EC-projects CLIME & REFLECT

Layout

- Setting the stage
- Describing climatic changes
- Defining the actors
- Indices (NAO, AO, MOI, RI)
- Impacts on temperature, stability and timing
- Regional coherence
- Chemical and biological effects
- Summary
- References

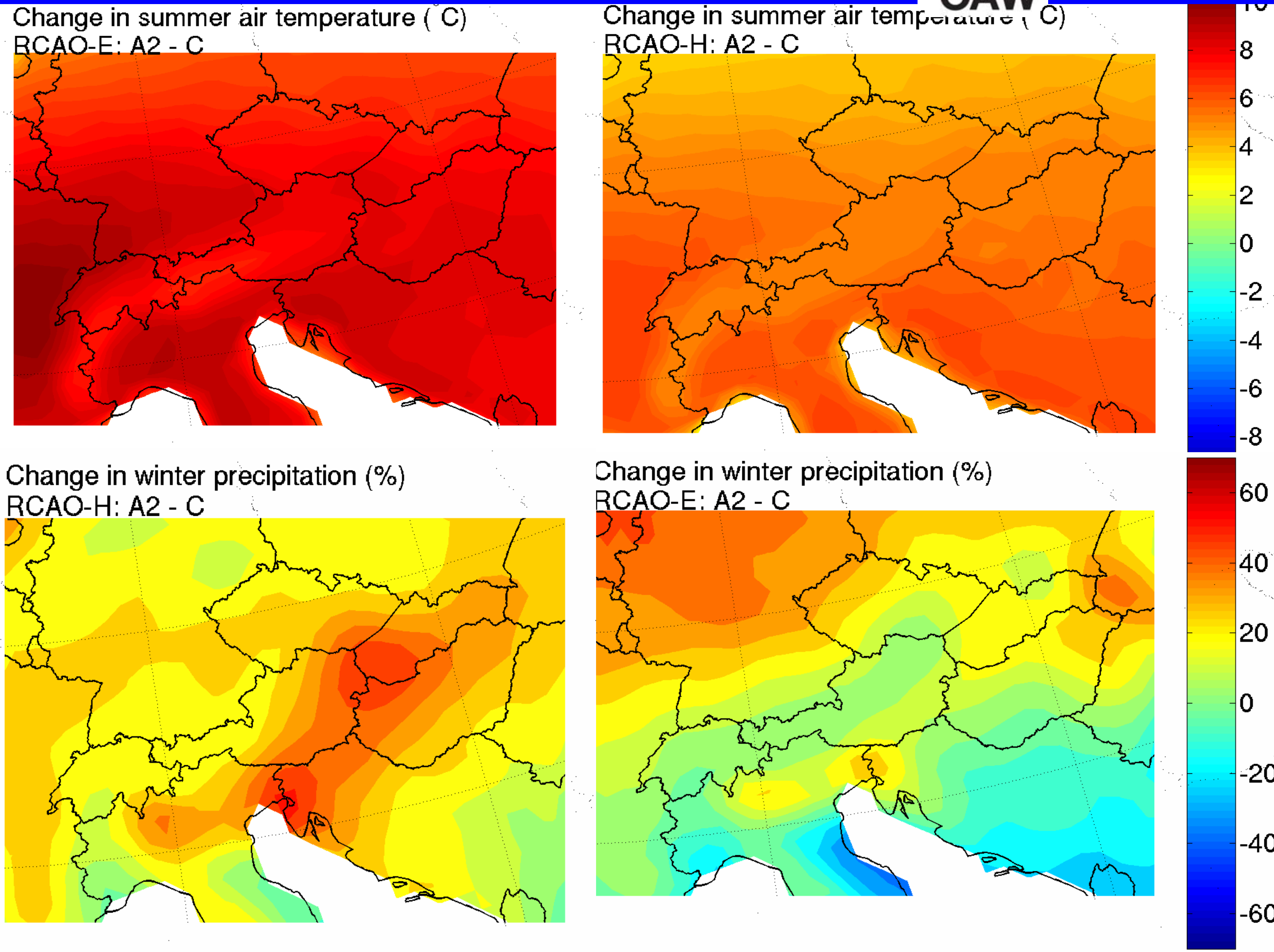
Central Europe

Climate change in progress

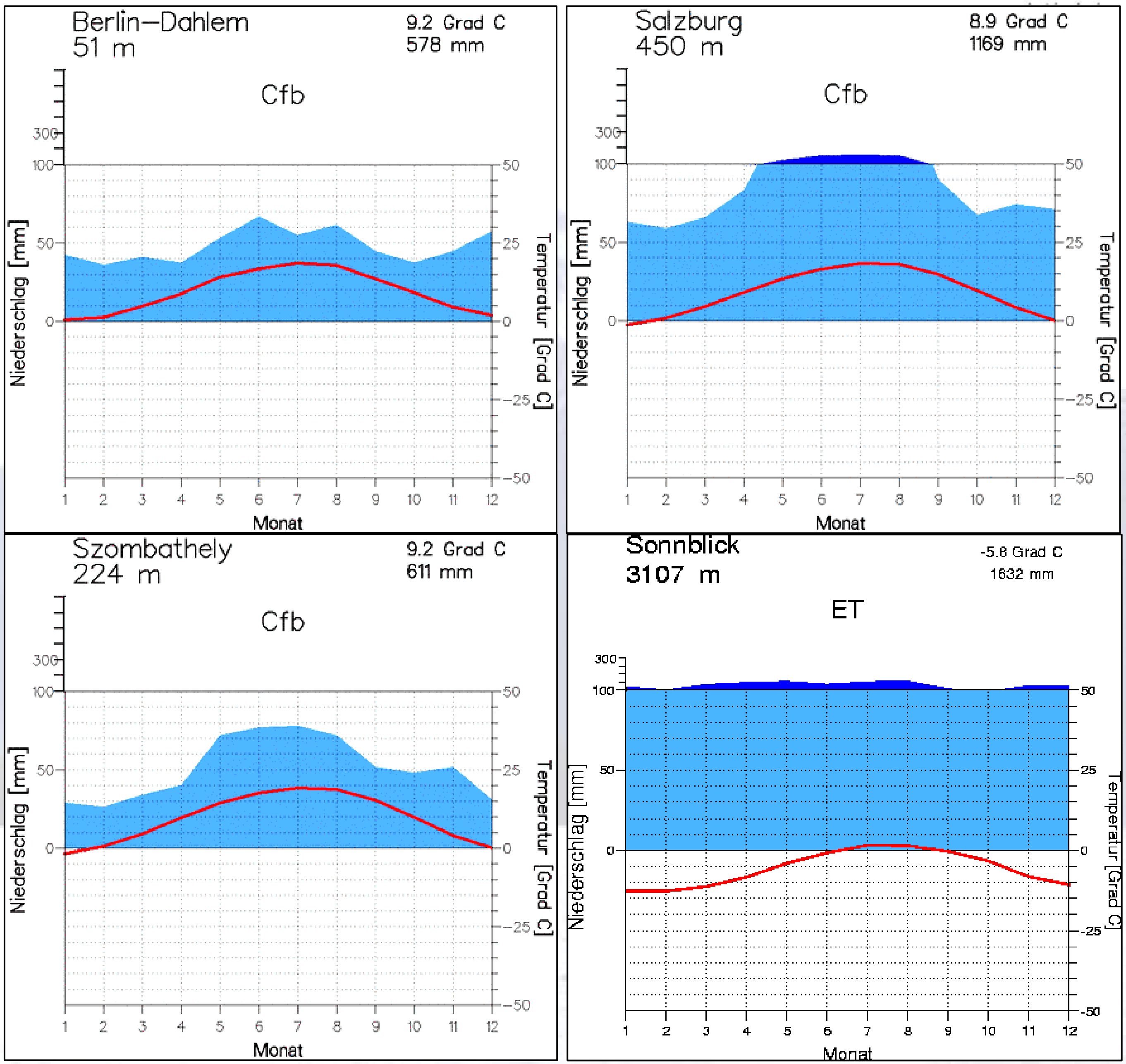
Pasterze and Großglockner Austria

www.gletscherarchiv.de

Climate Scenarios Central Europe



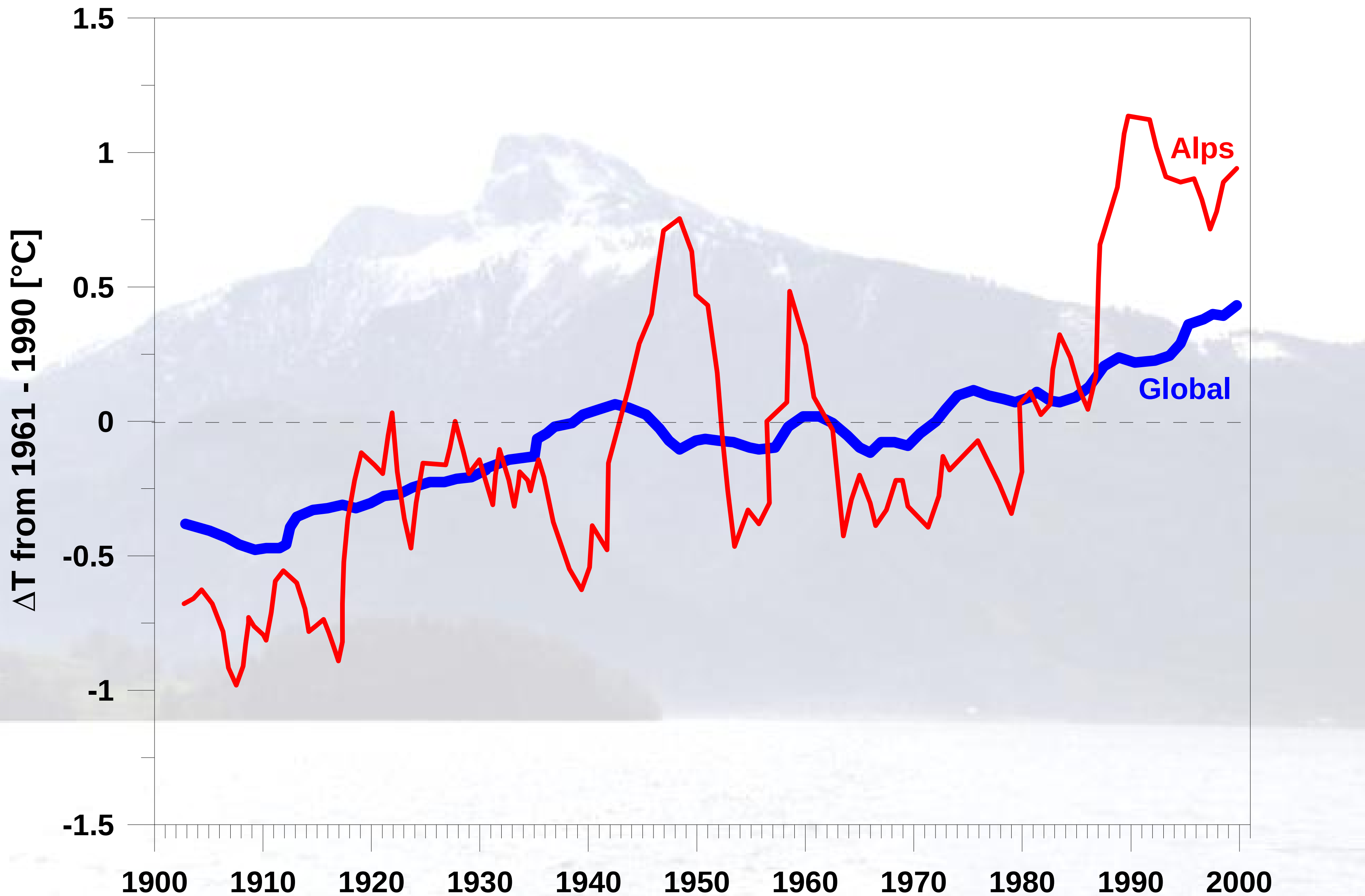
Climate Diagrams



From Mühr (2006)

http://www.klimadiagramme.de

Temperature Anomalies, IPCC BP



Modified from Beniston (1997)

Prognosis for the Alps

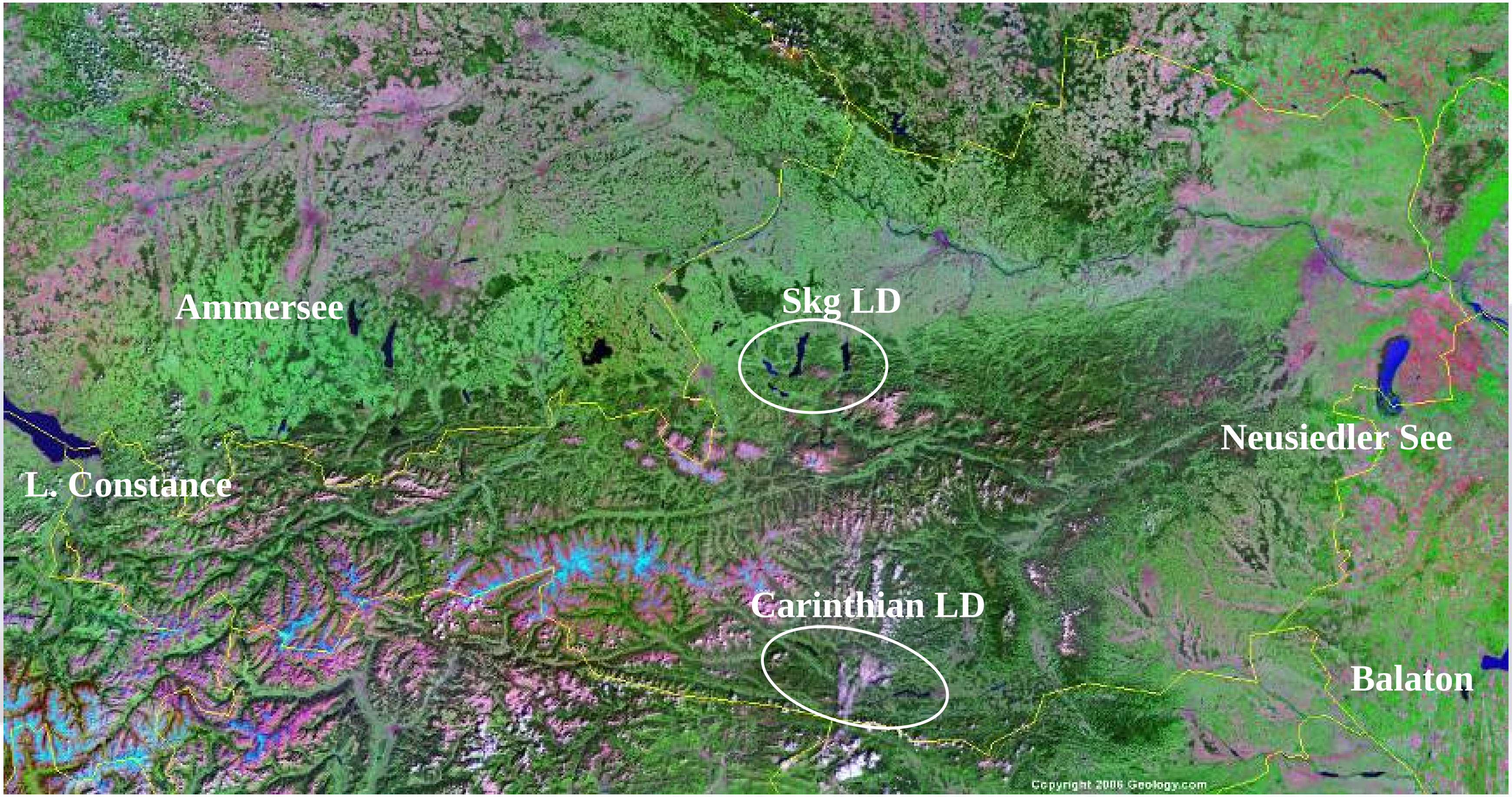
Temperature increase is estimated to range between 2-4°C with higher winter temperatures and more marked increase in summer

From: Kromp-Kolb, H. & Formayer, H. (2001) - Austria
Klimaänderungen in Bayern (1999) - Bavaria
Beniston, M. (2004) - Switzerland

Changes in the pattern of precipitation may have an even greater impact than rising temperatures.
A 10% decline in precipitation in the Alps plus a 1-2°C rise in temperature could produce a 40-70% reduction in runoff.
Ecological zones will tend to move uphill.

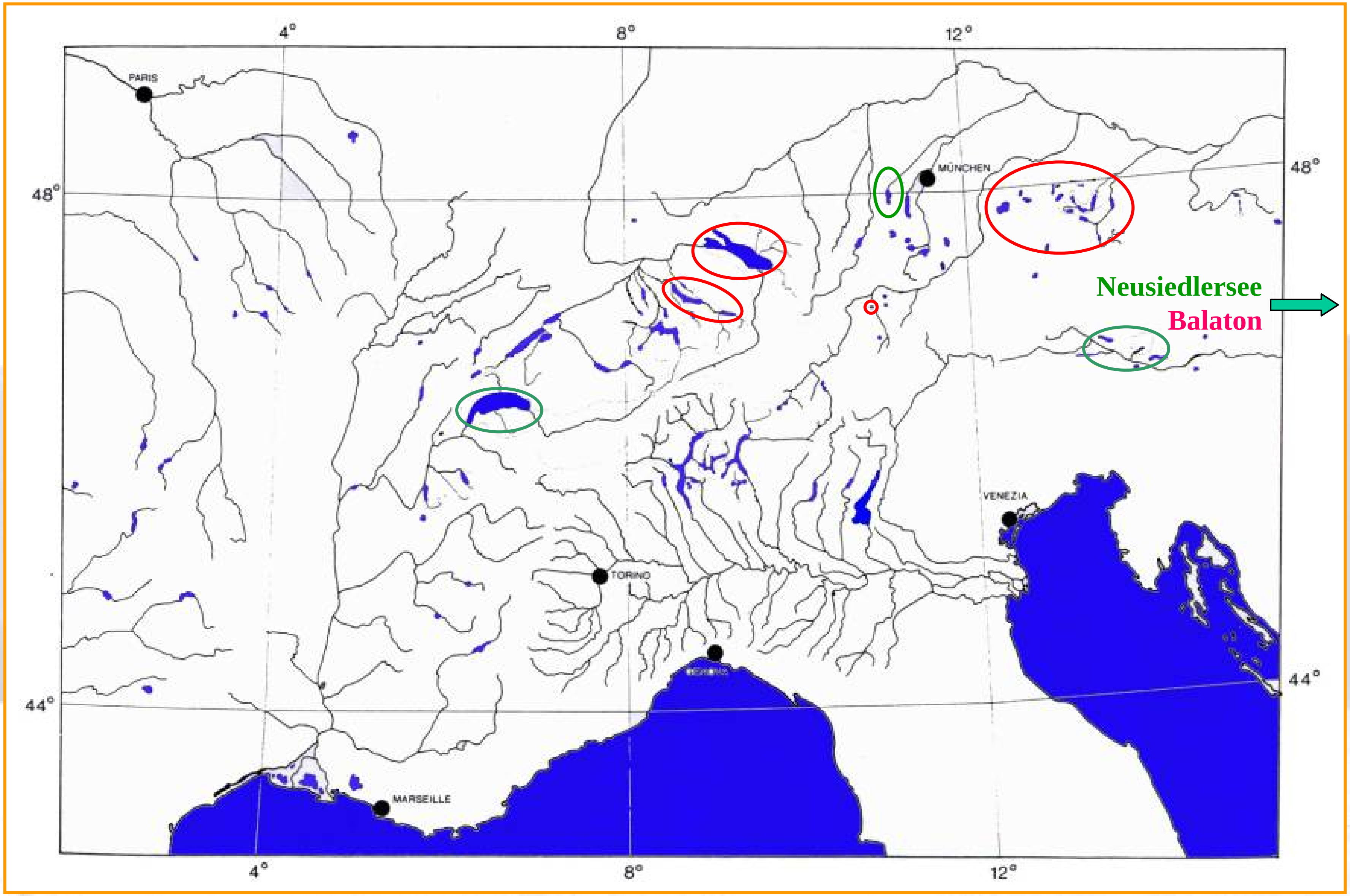
From: Unit on Climate Change (IUCC), UNEP, Switzerland

Perialpine Lakes

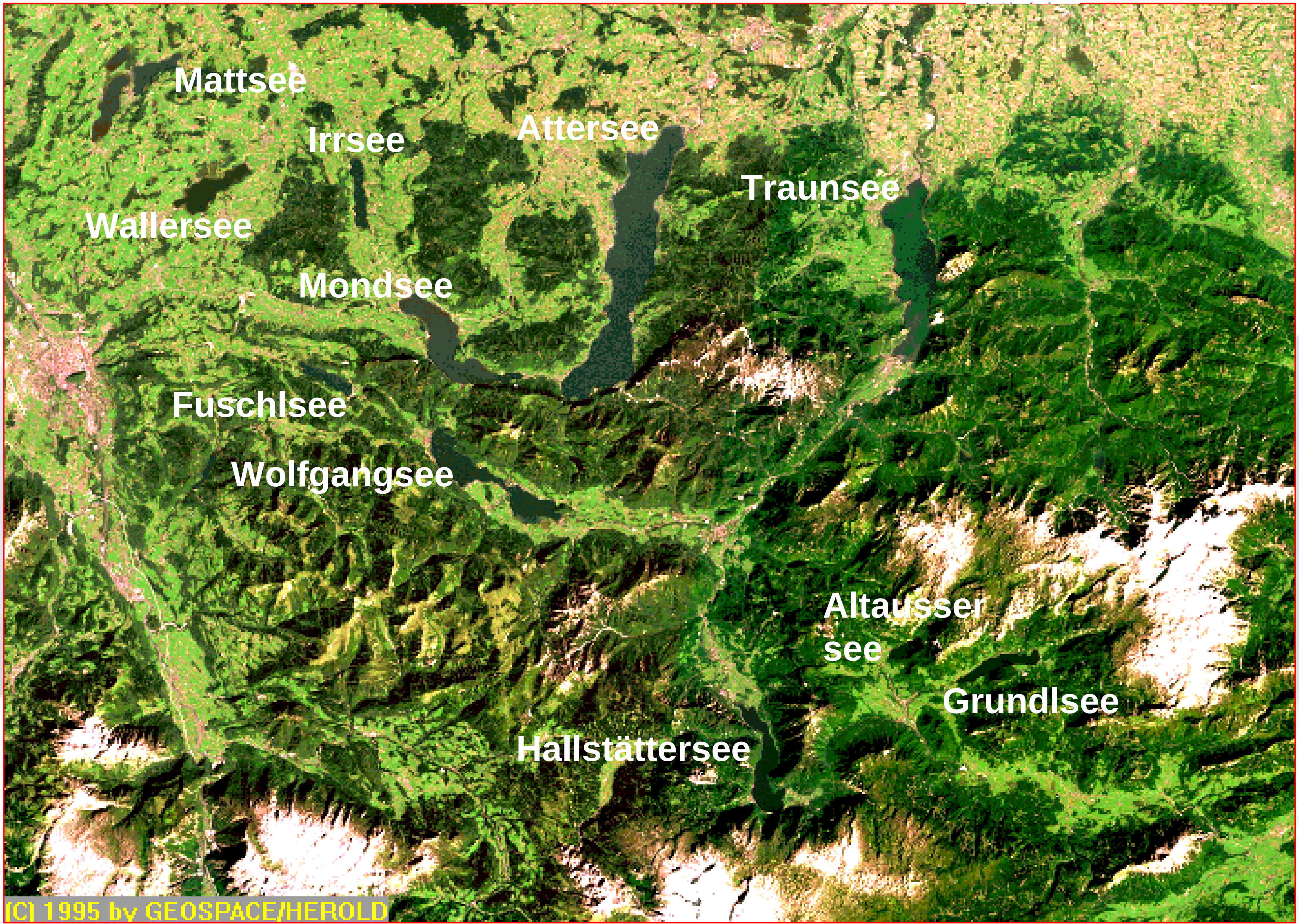


http://visibleearth.nasa.gov

Location of lakes in Central Europe

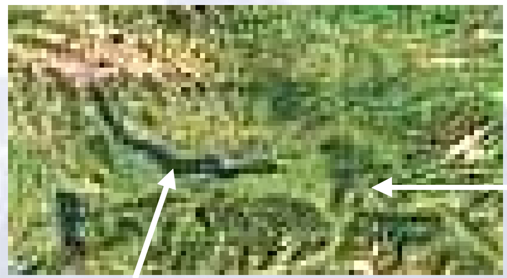


Satellite image of Salzkammergut



Images of lakes

Müggelsee



Walensee

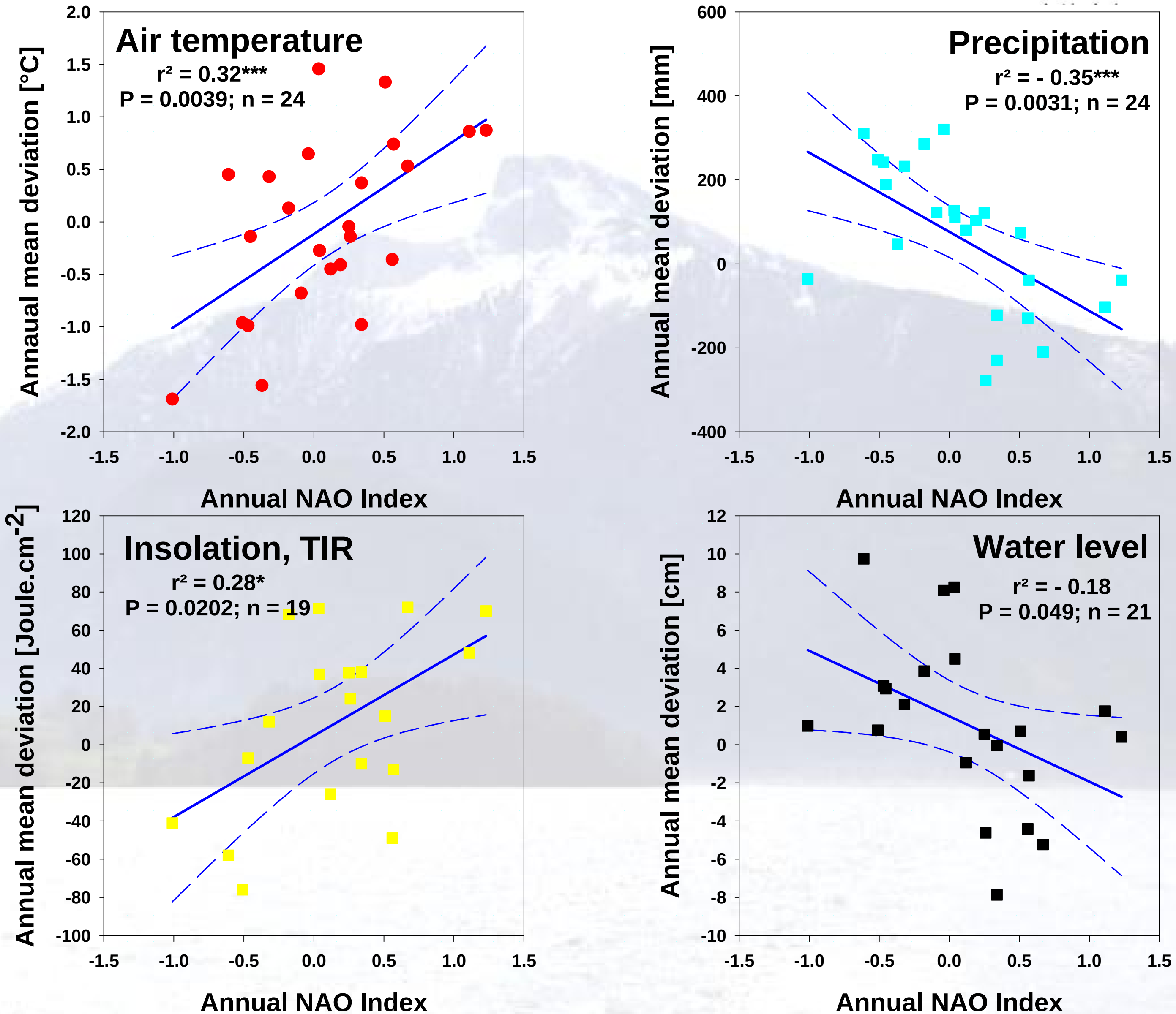
Zürichsee

Not to Scale!

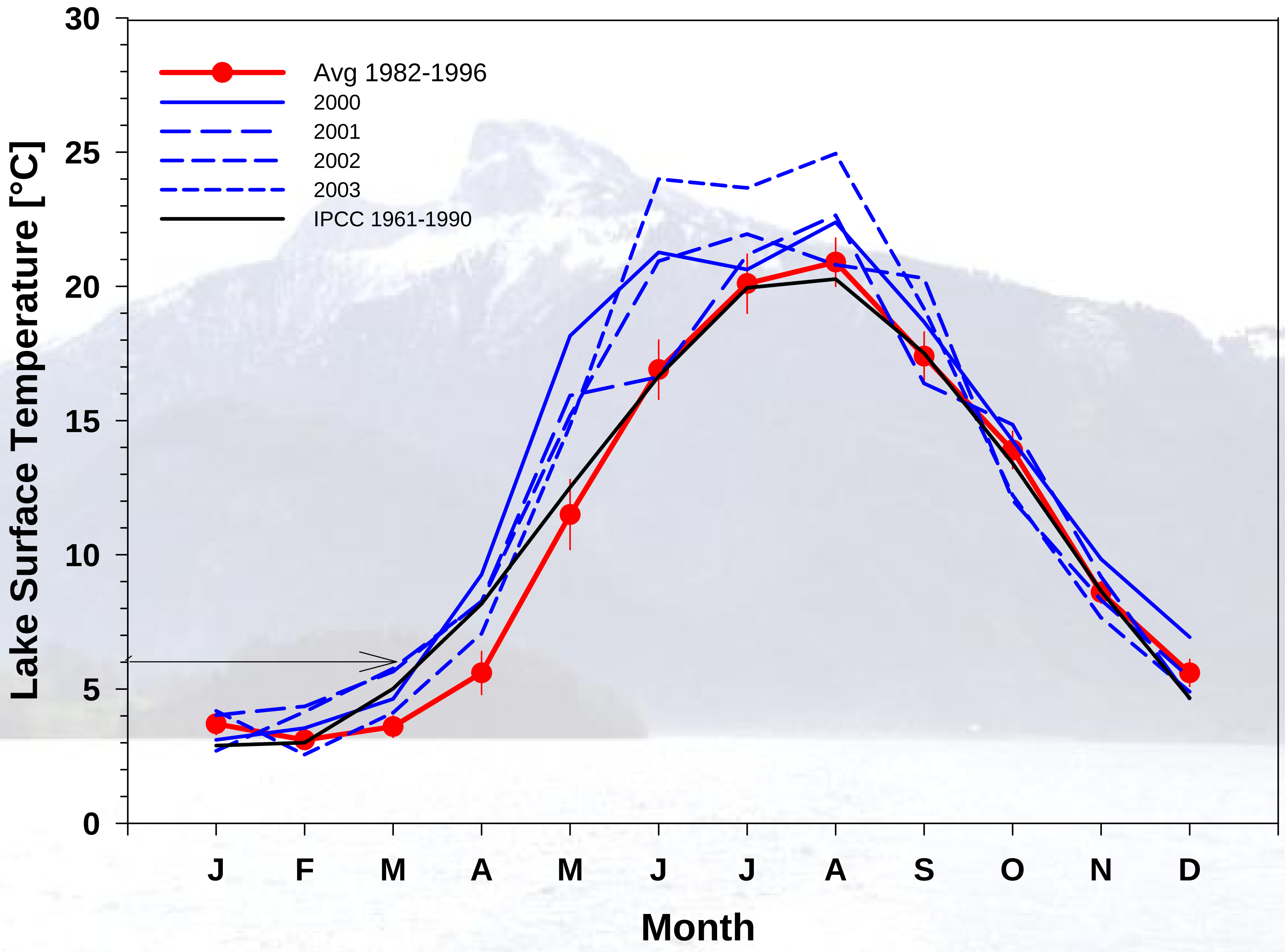
Morphometry of selected Lakes

Lake	Country	Geographical Position	Altitude [m]	Area [km²]	Z_{max} [m]	Z_{avg} [m]	Volume [10^6 m^3]	Tw [y]	Catchment area [km²]
L. Constance, LC	A/CH/D	47.39N/09.18E	395.0	472.00	253.0	101.0	47,600	4.2	11890.0
Zürichsee, LZ	CH	47.20N/08.35E	406.0	67.00	140.0	49.0	29	1.2	1740
Walensee, WS	CH	47.10N/09.15E	419.0	24.00	151.0	105.0	25	1.4	1061.0
L. Geneva, LL	CH/F	46.27N/06.32E	372.0	582.00	309.0	152.0	89,000	11.4	7395.0
Mondsee, MO	A	47.48N/13.24E	481.0	14.21	68.3	36.0	510	1.7	247.0
Attersee, AS	A	47.48N/13.30E	469.2	45.90	170.6	84.2	3,945	7.0	463.5
Hallstättersee, HS	A	47.36N/13.42E	508.0	8.58	125.2	64.9	557	0.5	646.5
Traunsee, TS	A	47.53N/13.48E	422.0	25.60	191.0	89.7	2,302	1.0	1417.0

NAO vs. Met data



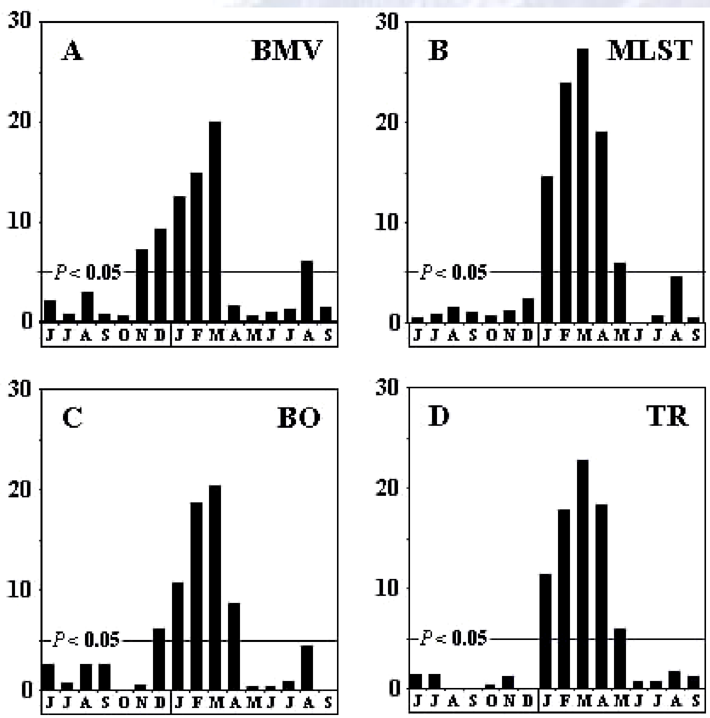
LST in Mondsee

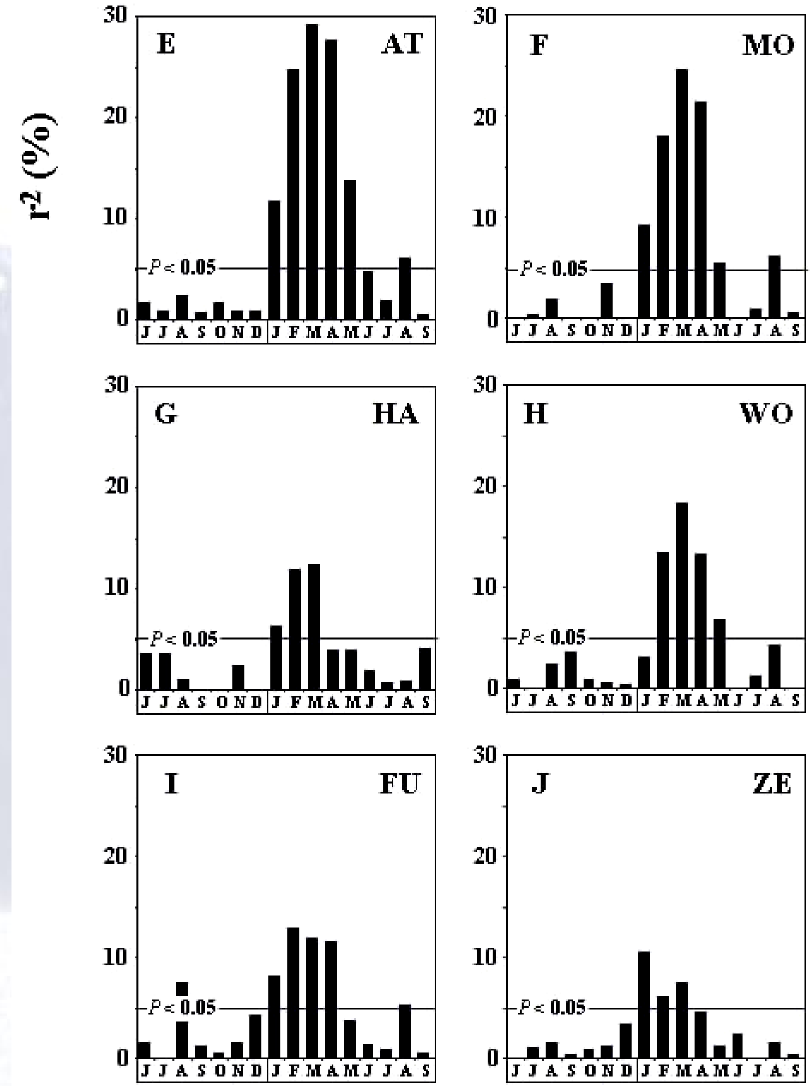


NAO$_{Winter}$ vs. Air & LST

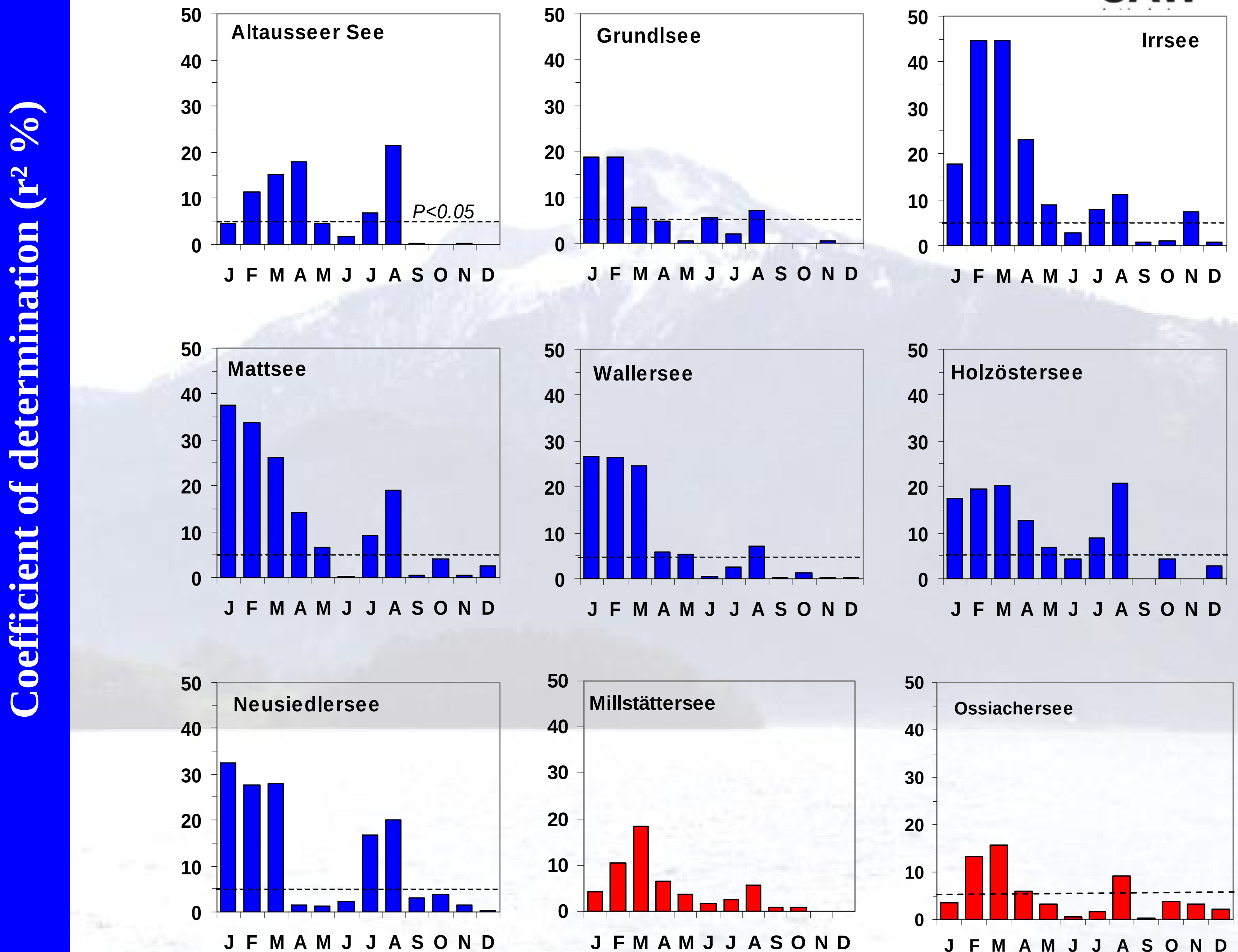
From
Livingstone & Dokulil (2001)
L & O 46, 1220-1227

Coefficient of determination (r^2 %)



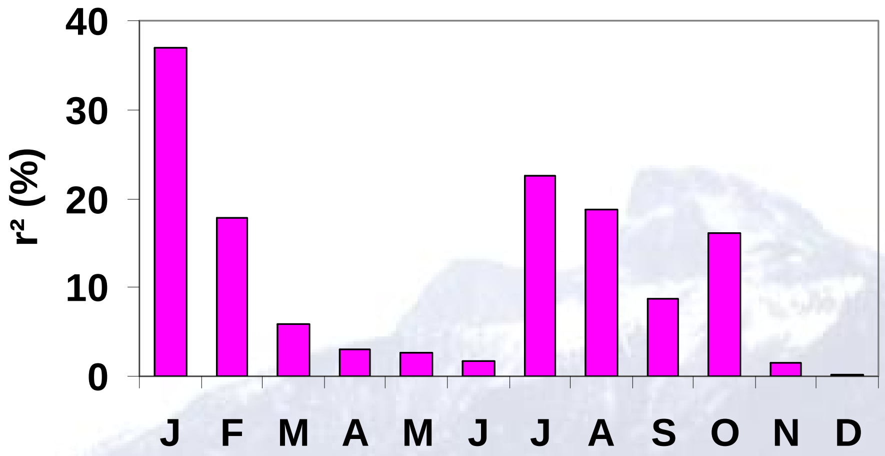


NAO_{Winter} vs. LST



MOI_{Winter} vs. LST & Ice cover

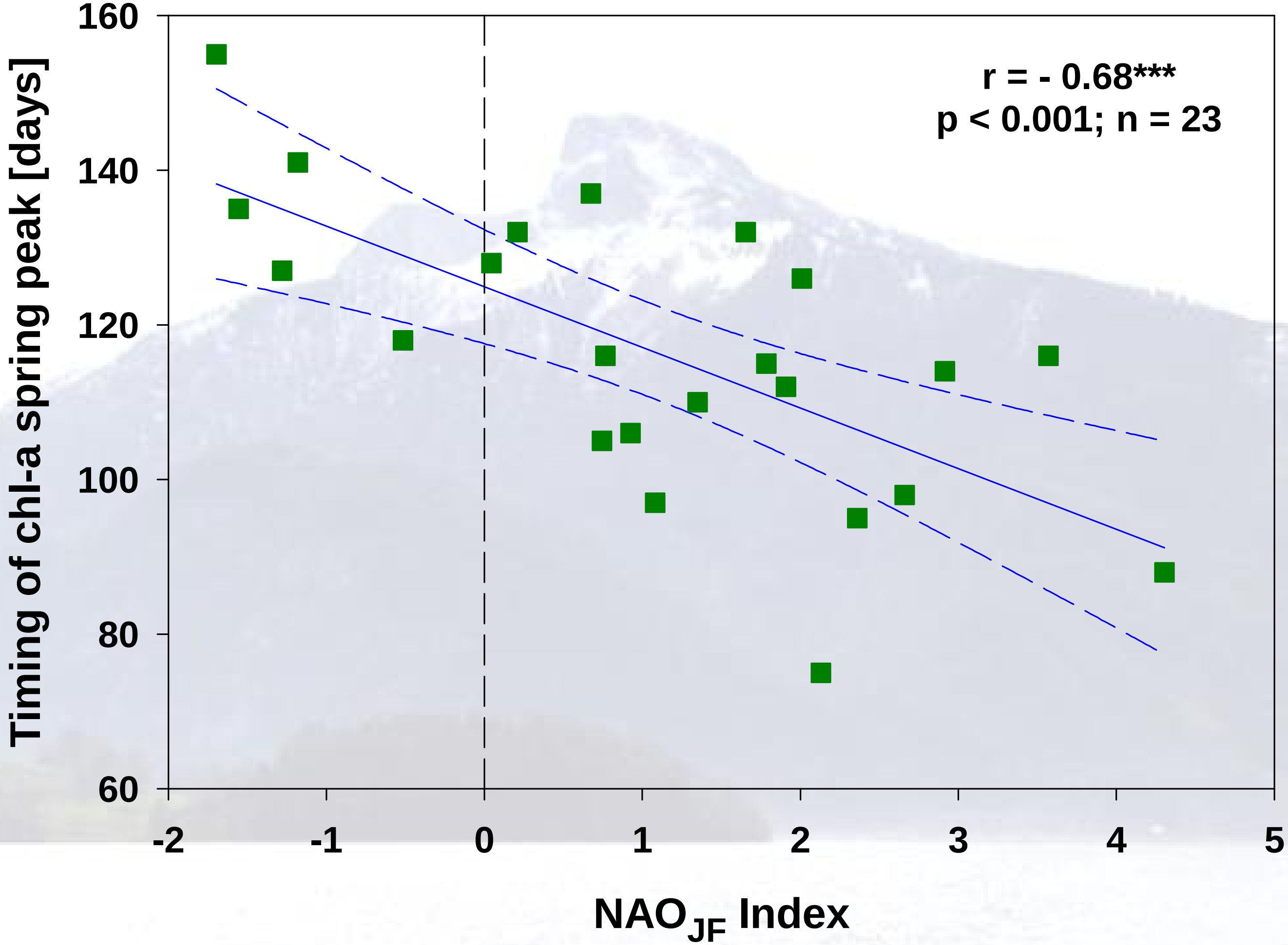
Mediterranean Oscillation Index



Lake	Ice	NAO	AO	MOI
Müggelsee	Duration	-0.762***	-0.612***	n.s.
	Ice-off	-0.609***	-0.504*	n.s.
Irrsee	Duration	-0.494***	-0.410***	n.s.
	Ice-off	-0.671***	-0.330*	n.s.
Mondsee	Duration	-0.570**	-0.443*	n.s.
	Ice-off	-0.724**	-0.774**	n.s.
Neusiedler See	Duration	-0.451*	n.s.	-0.503*
	Ice-off	-0.511**	-0.461*	-0.650**
Balaton	Duration	-0.261*	n.s.	-0.381*
	Ice-off	-0.528***	-0.323**	-0.486**

NAO vs Chl-a spring peak

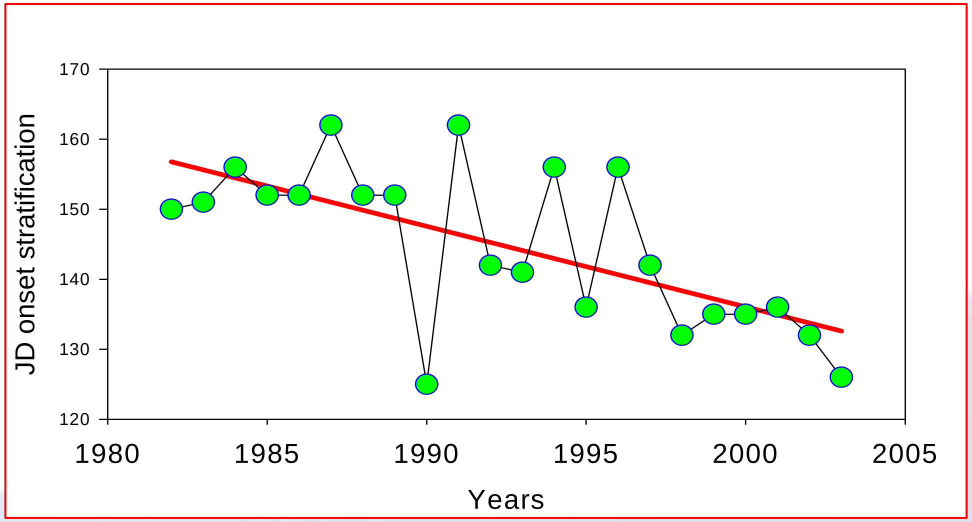
Mondsee



On average, the chlorophyll-a spring peak has shifted earlier by about 48 days

Onset of stratification

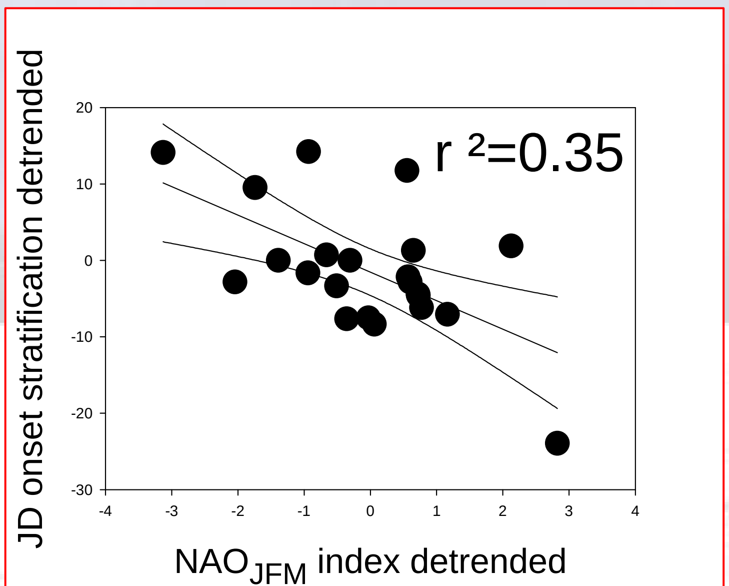
Mondsee



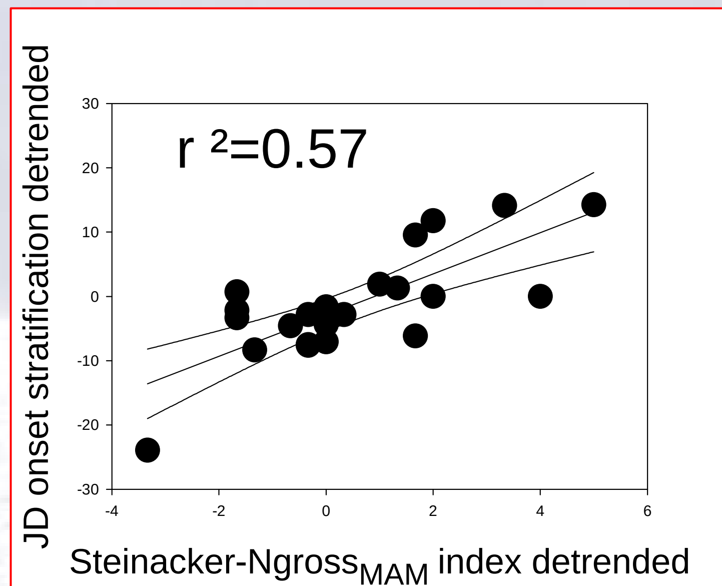
data are detrended

From
Teubner et al., in prep.

NAO_{JFM}

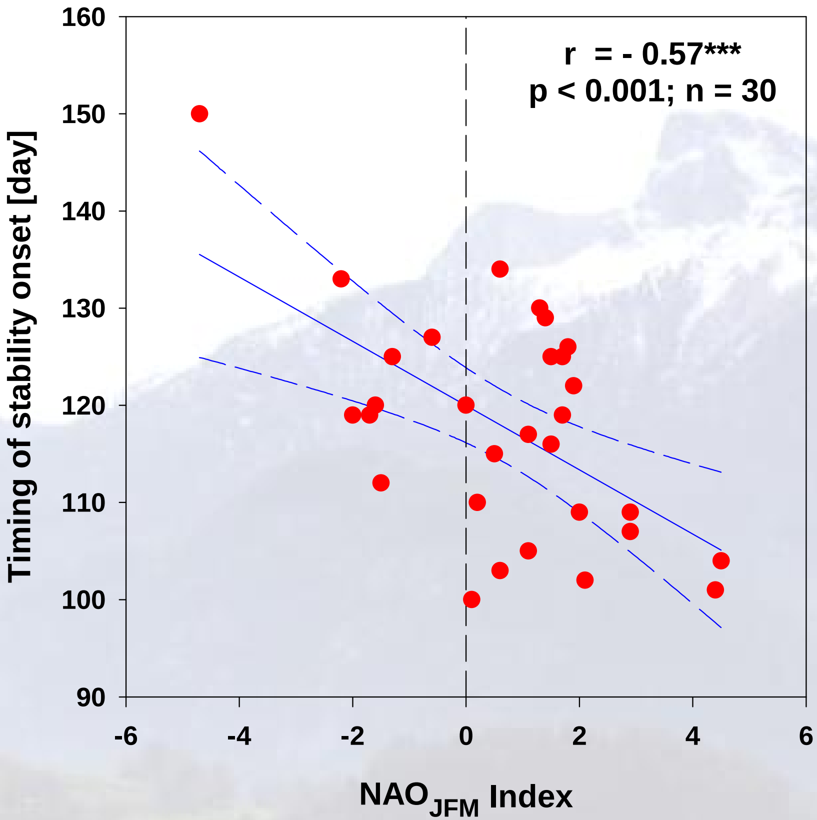


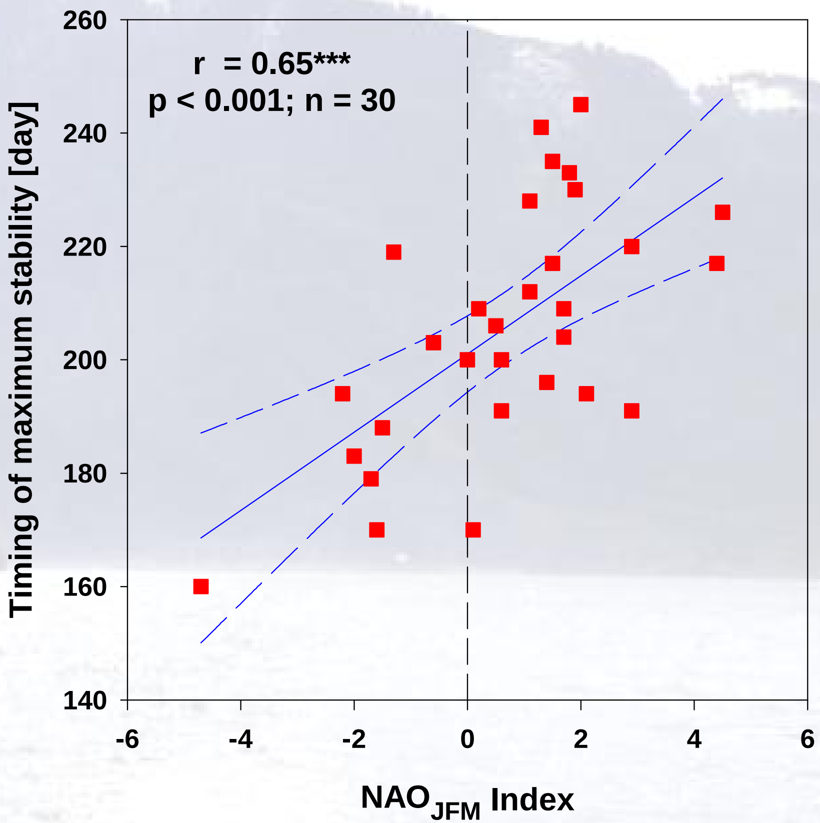
Steinacker-N_{MAM}



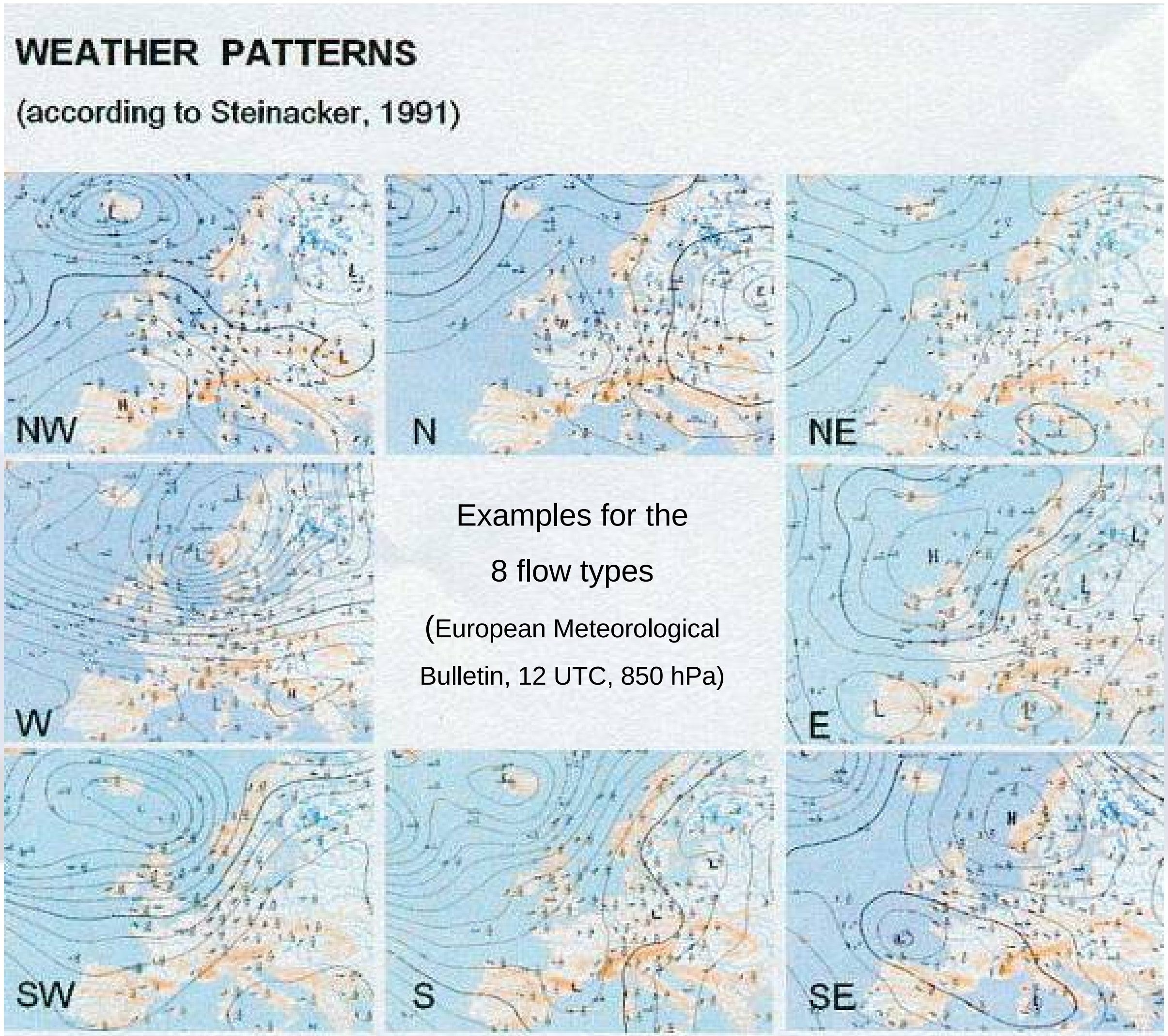
Thermal stability

Mondsee





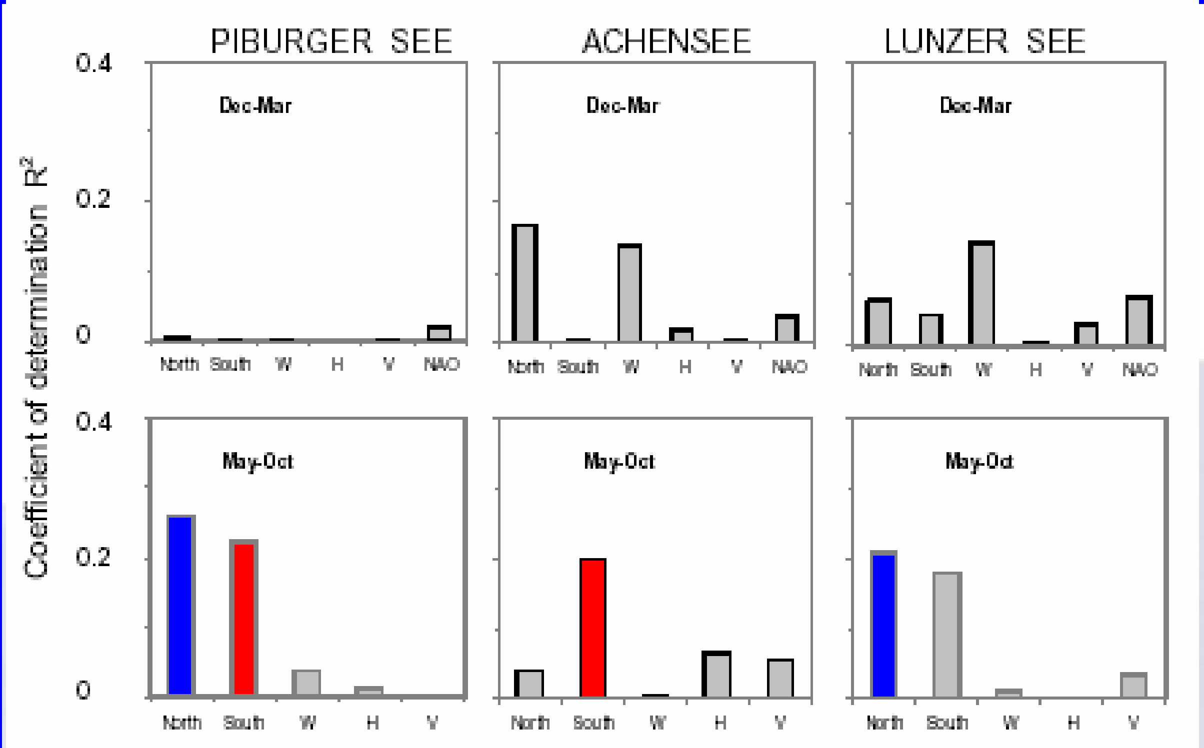
Regional Index (RI)



10 weather types:

- 8 flow patterns (NW, N, NE, E, SE, S, SW, W): based on the prevailing air flow across the Central Eastern Alps
- 'High pressure' type (H): weak pressure gradient, wind velocity < 15 knots
- 'Variable' type days with a marked change of flow direction (generally due to frontal passage)

Regional Index (RI)



$R^2 > 0.2$ coloured:

\+ correlation **RED**

\- correlation **BLUE**

From Nickus & Thies (2004)

- **Winter (Dec to Mar)**

-No significant signal of NAO in LST

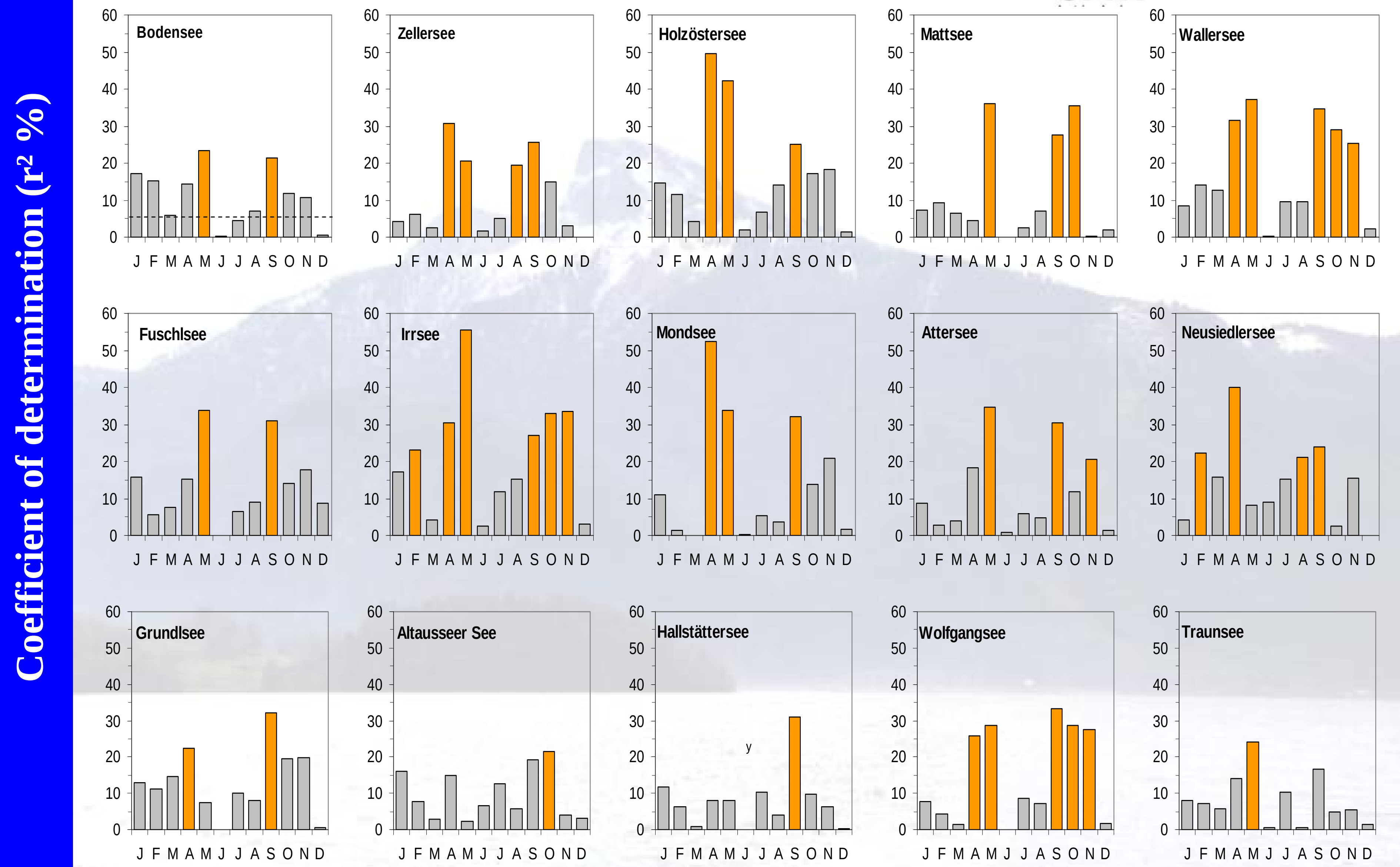
-Weak correlation of distinct weather patterns with LST

-No correlation at Piburger See due to ice cover

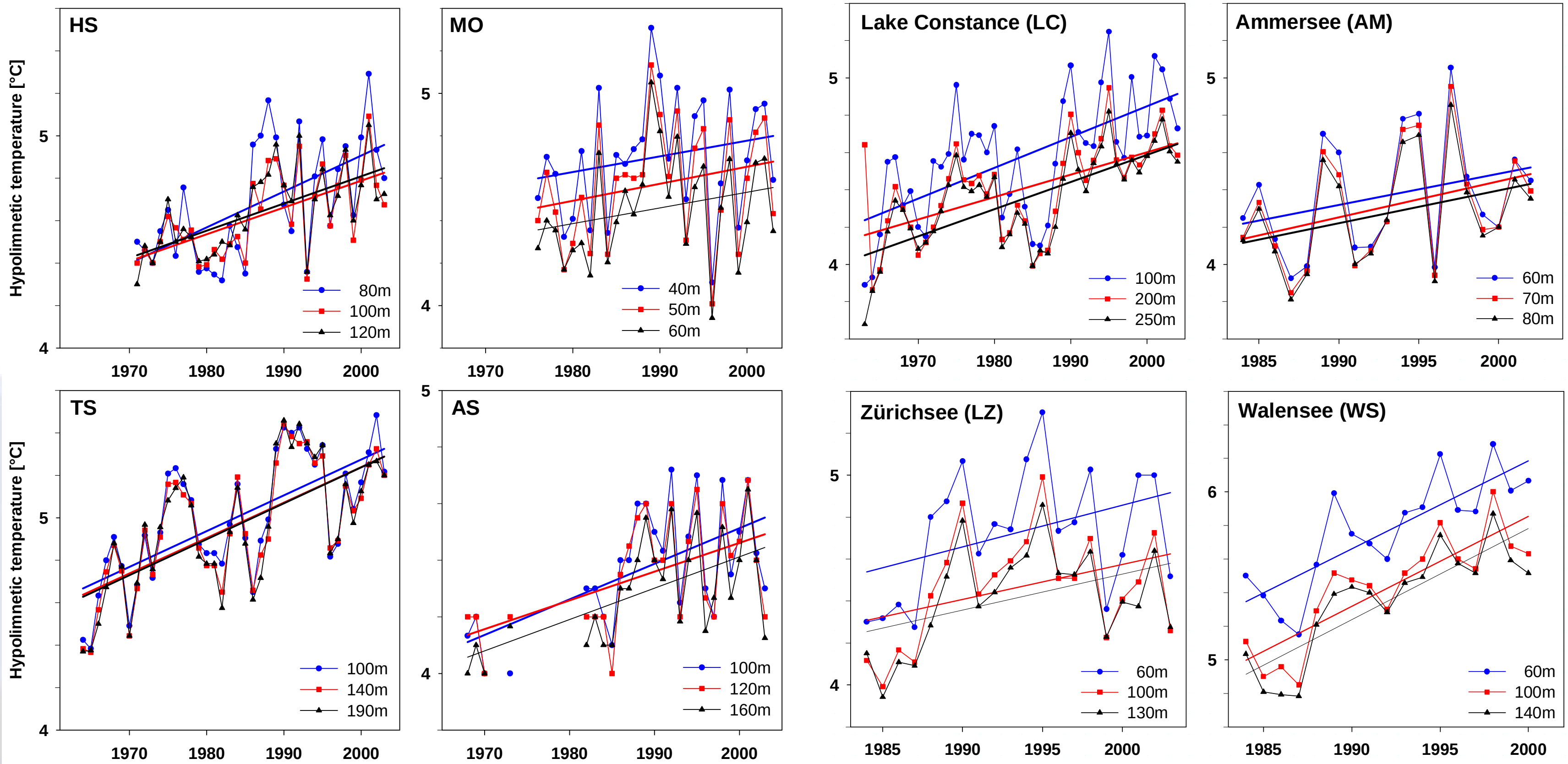
- **Summer (May to Oct)**

-Significant correlation between weather patterns (North and South) and LST ($p < 0.001$)

Northerly vs. LST



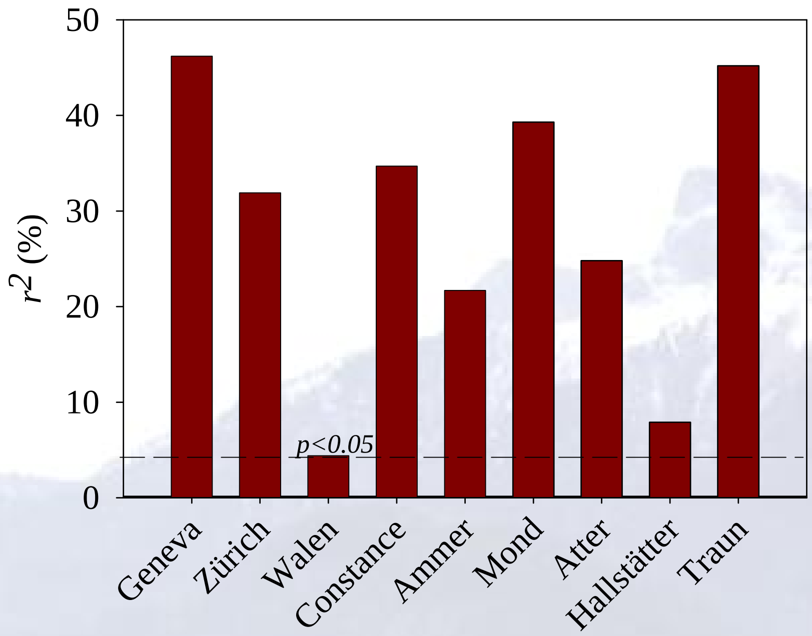
Deep water temperatures

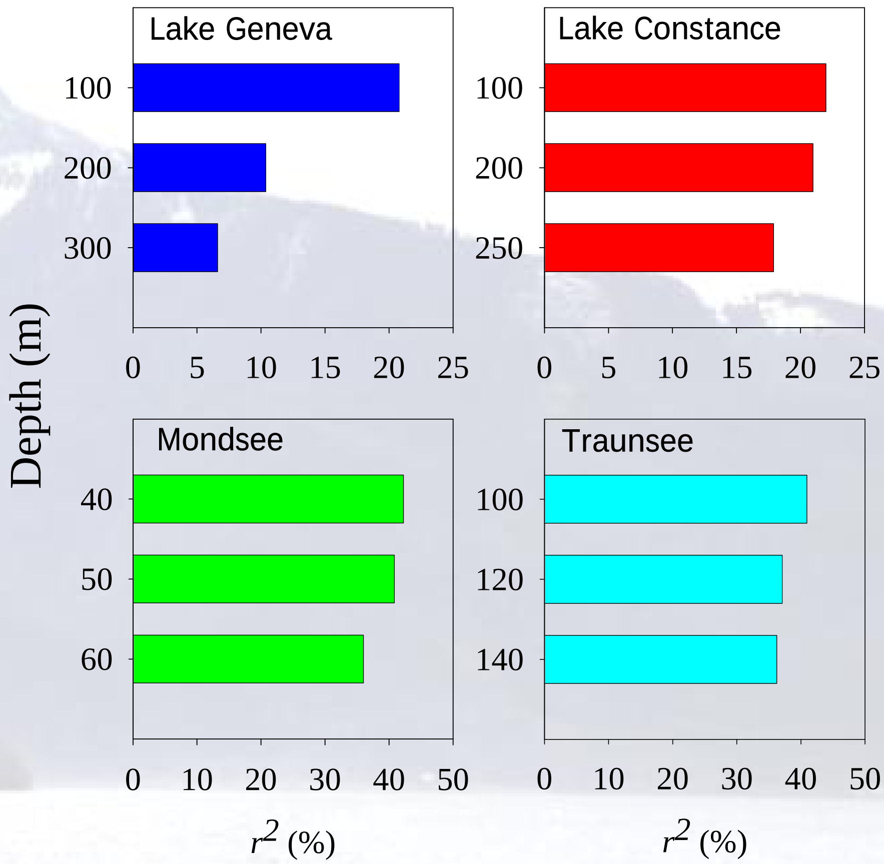


From Dokulil et al.(2006)

Deep water temperatures

From Dokulil et al.(2006)



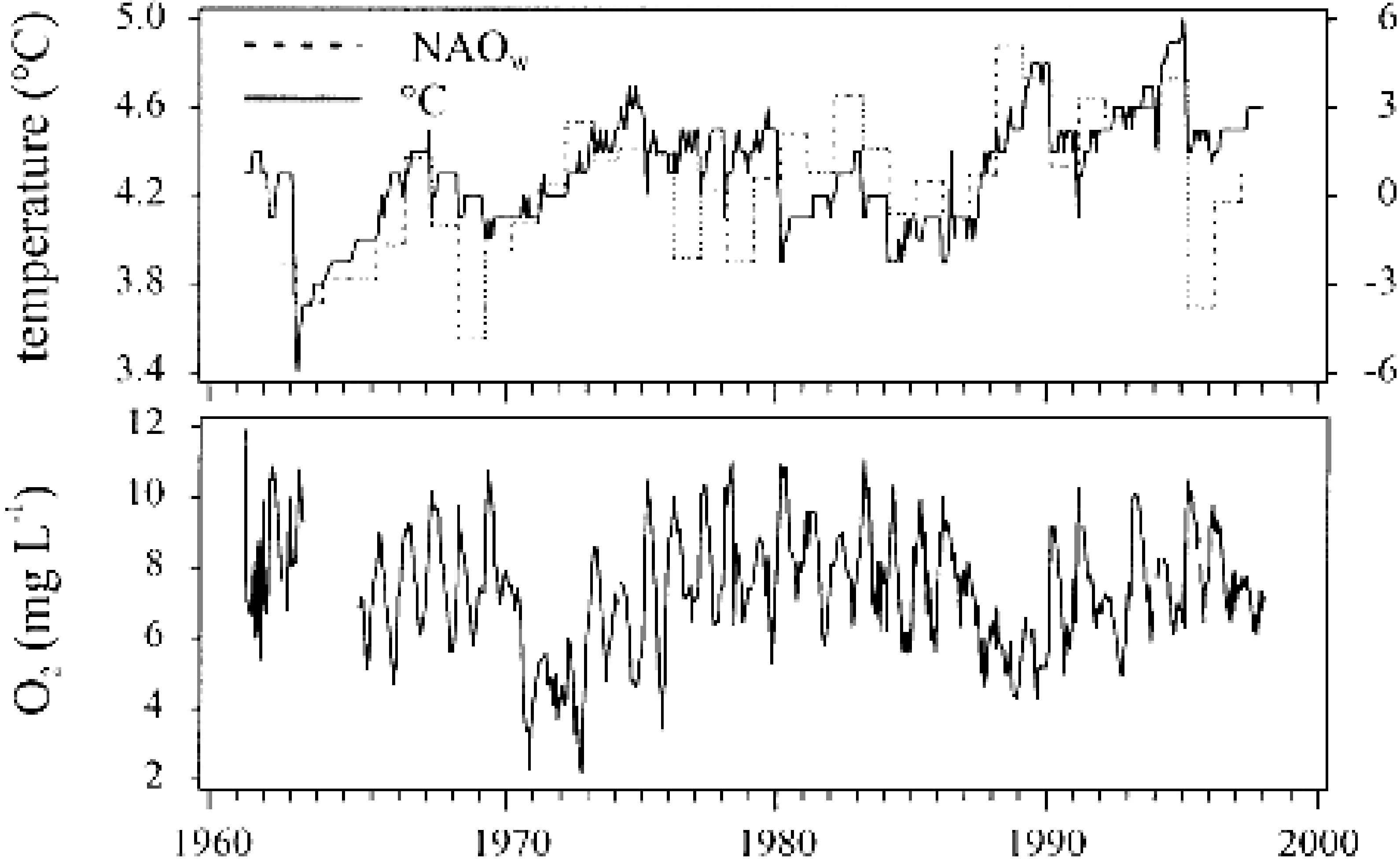


Increase in deep water temperature related to the mean NAO Jan - May

The signal fades with depth

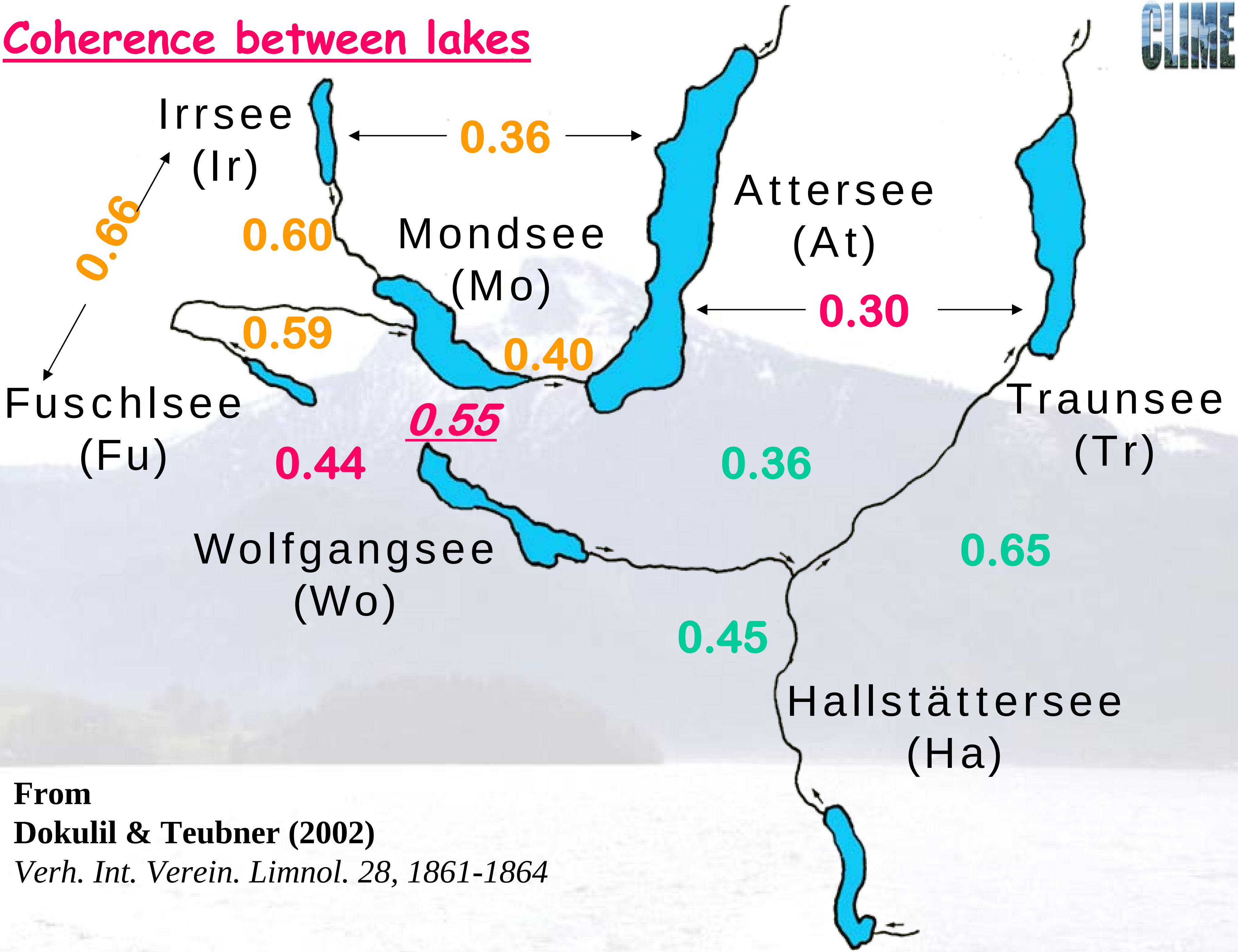
Deep water temperature and oxygen

Lake Constance



From Straile et al. (2003)

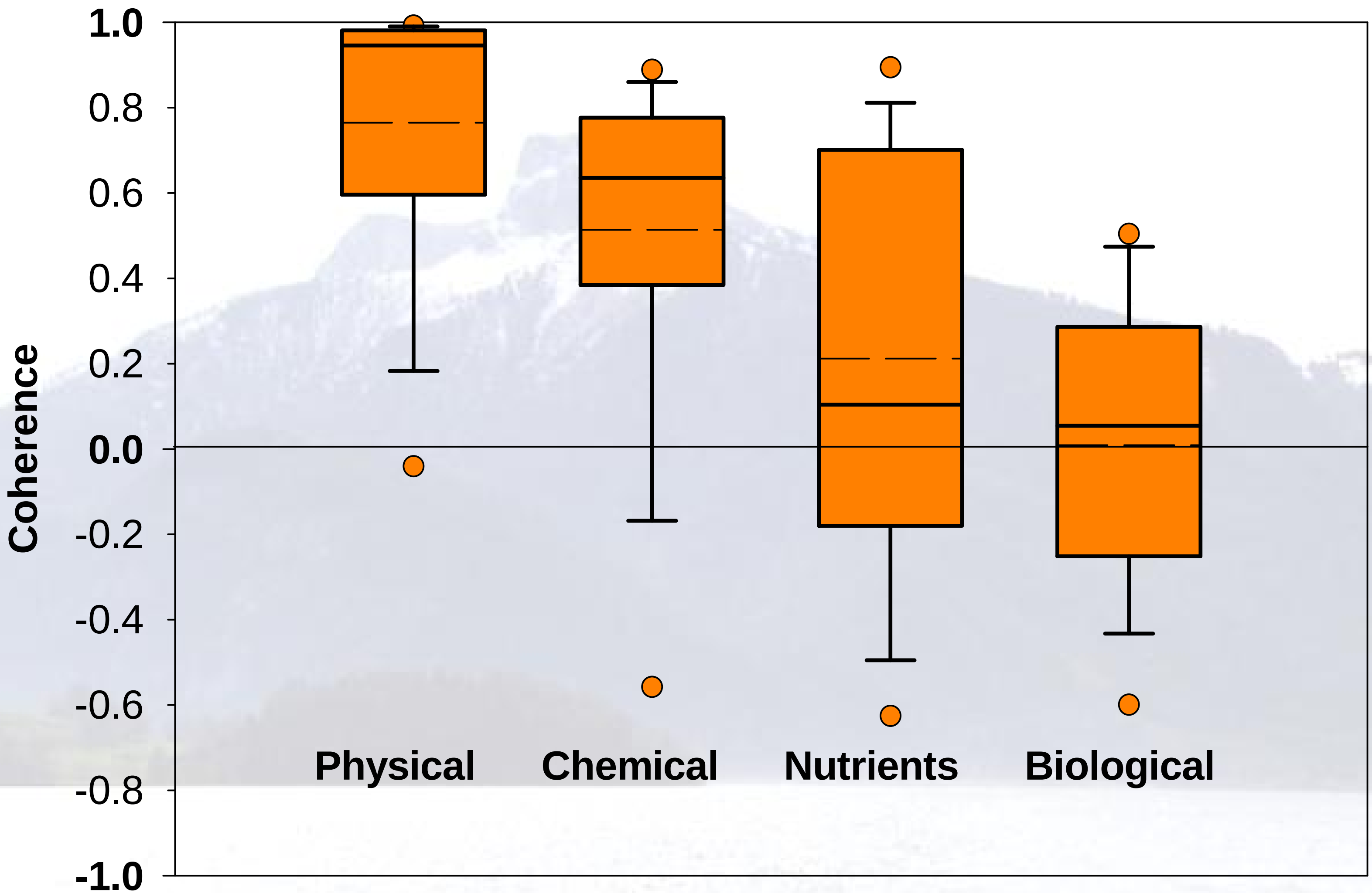
Coherence between lakes



From
Dokulil & Teubner (2002)
Verh. Int. Verein. Limnol. 28, 1861-1864

Coherence: Cascading effect

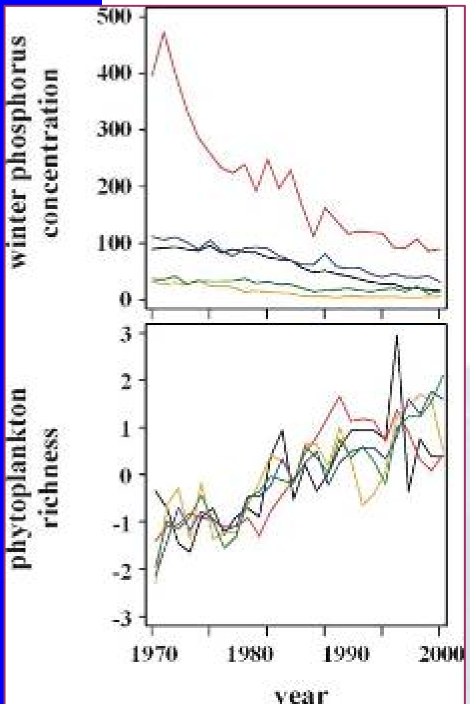
Coherence



From: Dokulil & Teubner (2002) *Verh. Int. Verein. Limnol. 28, 1861-1864*

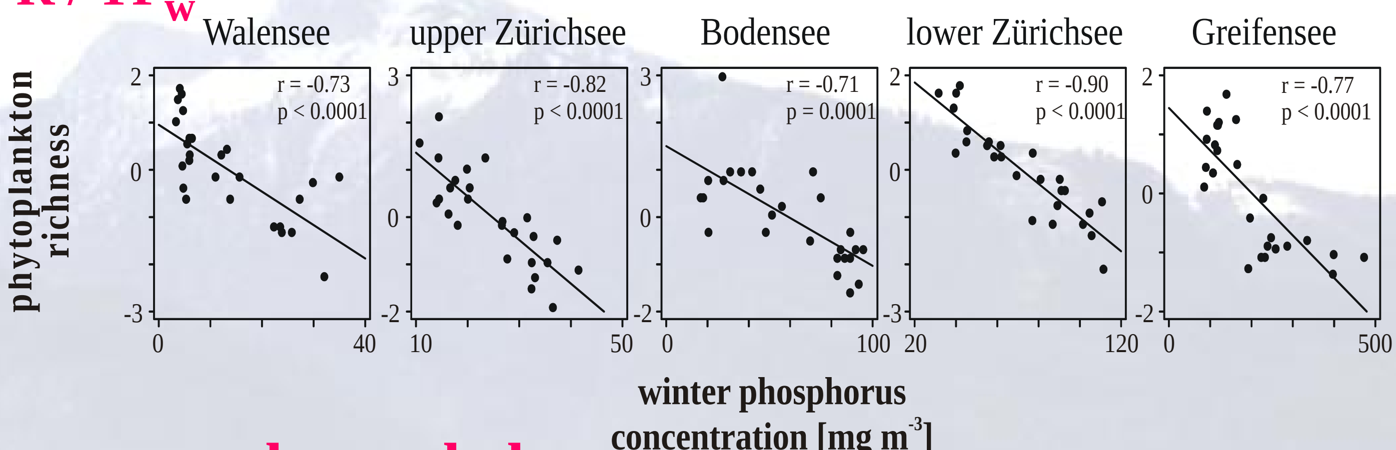
TP & Phytoplankton richness

Swiss lakes

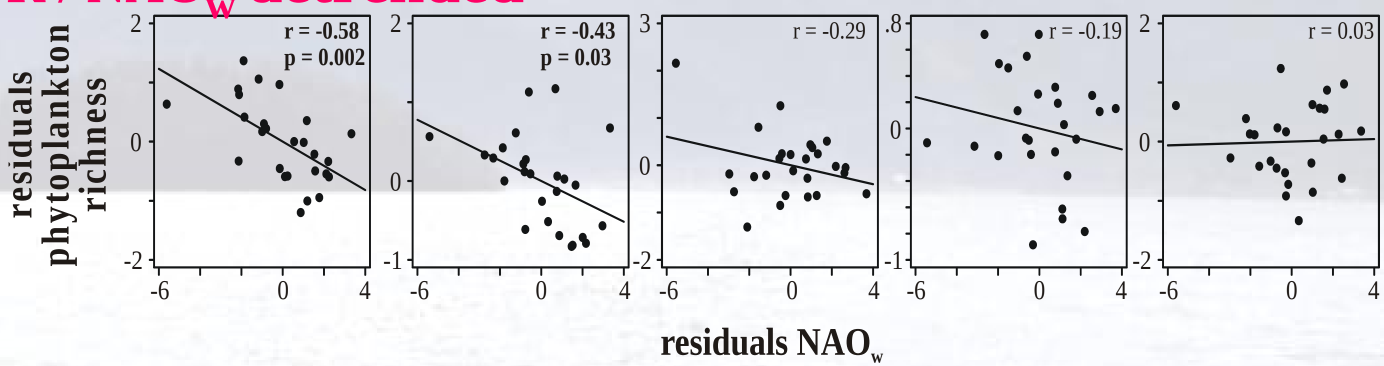


From Jankowski, subm.

R / TP_w



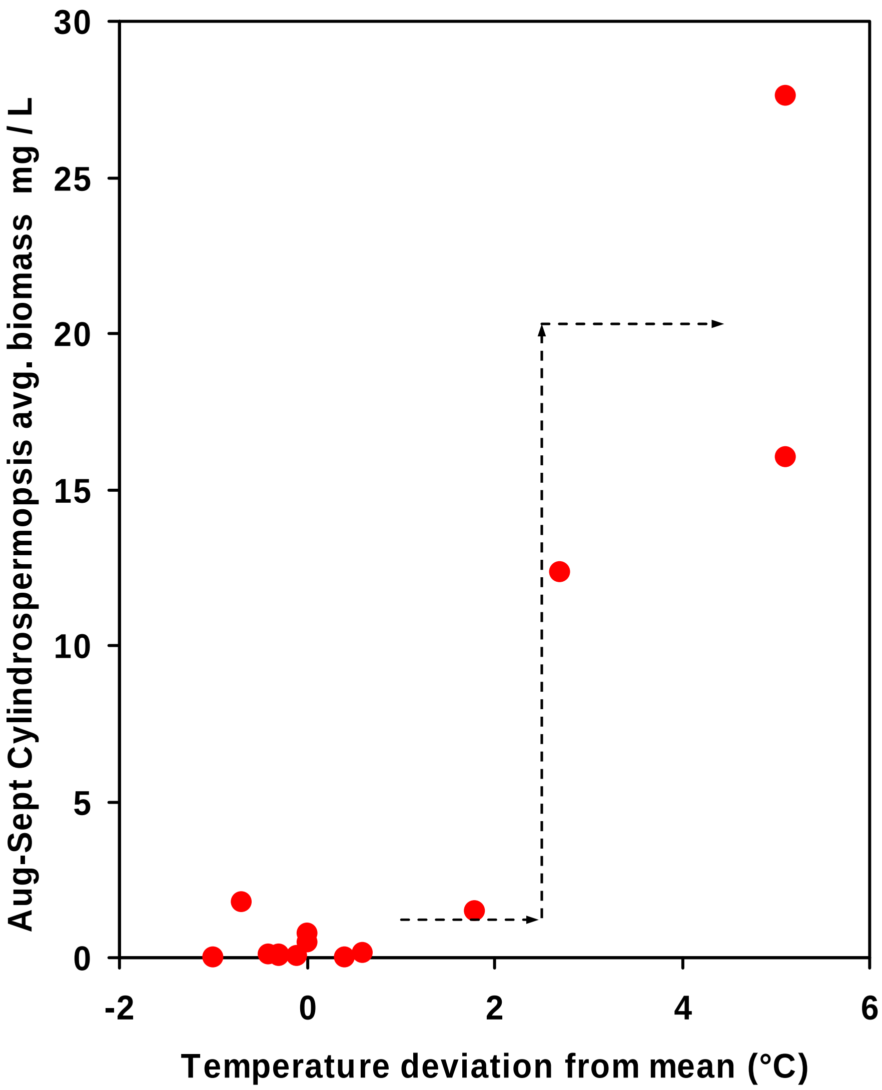
R / NAO_w detrended



Phytoplankton growth

From Padisák (1998)

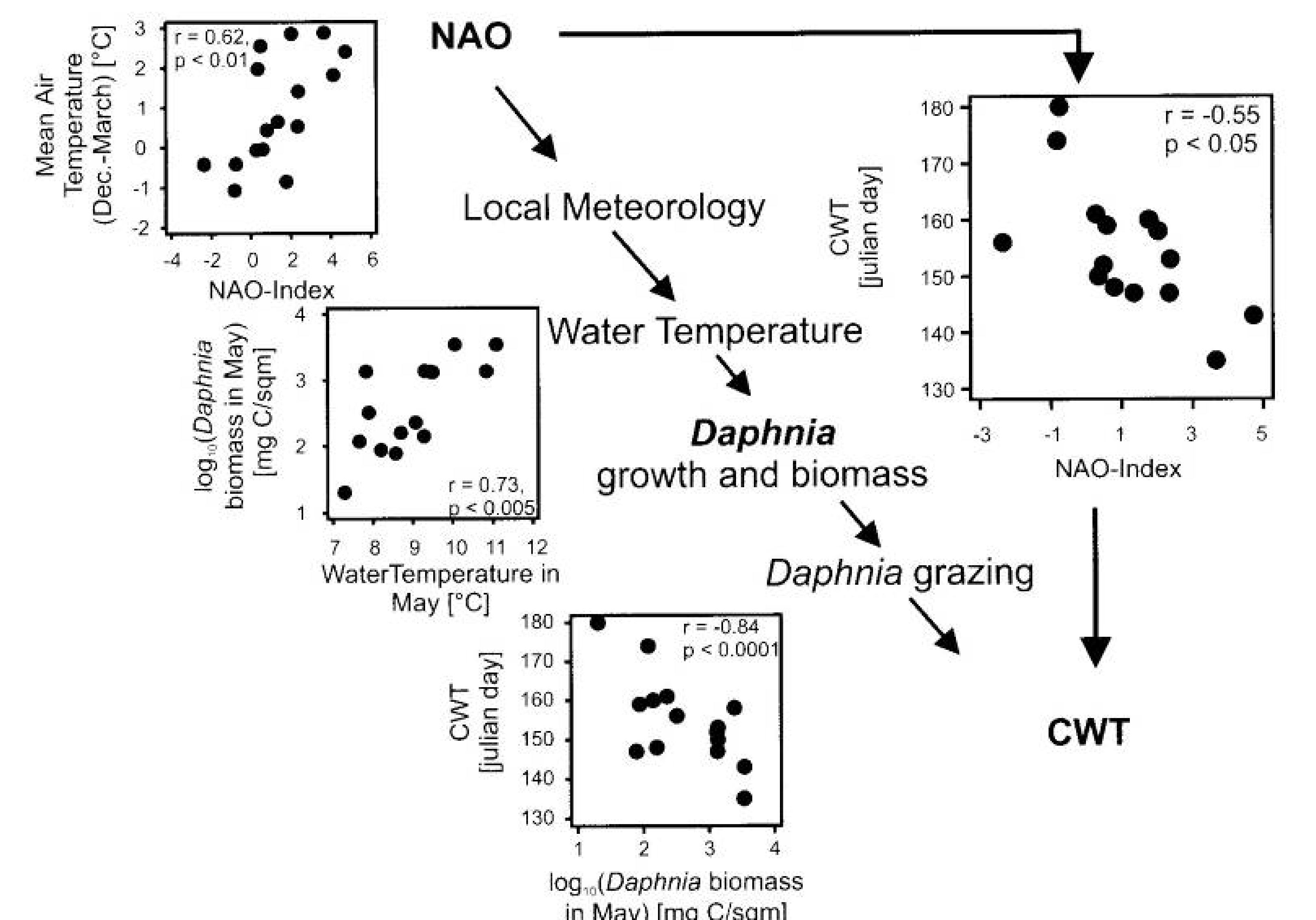
Balaton



Cascading effect

Limnologie
ÖAW

Ecosystem level



From: Straile (2000) Oecologia 122

Summary 1

Limnologie ÖAW

CLIME

- **Air temperature will drastically increase during summer**
- **Precipitation will decrease → wet now, dry in the future**
- **More run-off during winter**
- **Number of extreme events will increase**
- **Earlier ice off and shorter duration**
- **Lake surface temperature (LST) will increase by about 4°C**
- **Deep water temperatures (DWT) increase by about 0.1-0.2°C per decade (PROBE modeled HCA2 ~ 0.5°C)**
- **Higher DWT → lower O_2 concentrations, higher P release**
- **Length of stratification will increase**
- **Central Europe affected mainly by the NAO but also from the AO and, in more continental situations by the MO**

Summary 2

Limnologie ÖAW

CLIME

high NAO

increased air temperature

higher insolation

lower precipitation

water level decrease

Biological Effects

earlier phytoplankton spring peak

mismatch between chla and TP

later peak of TP

reduced species diversity

disruption of the linkage between Phyto- and zooplankton

fish larvae prone to mismatch the dynamics of their food

Selected References

Limnologie ÖAW

CLIME

Dokulil, M.T., Jagsch, A., George, G.D., Anneville, A., Jankowski, T., Wahl, B., Lenhart, B., Blenckner, T. & Teubner, K., 2006. Twenty years of spatially coherent deep-water warming in lakes across Europe related to the North Atlantic Oscillation, *Limnology & Oceanography* 51, 2787-2793.

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