(06/NEODAAS/14)

Investigating the potential of R/S for long-term limnological analysis at pan-continental scales

Eirini Politi
Environmental Systems Research Group (ESRG)
University of Dundee

1st Globolakes Workshop, 10-12th December 2012, Stirling, Scotland

Background

1. Lakes are **sensitive indicators of climate change** at local to larger spatial scales (e.g. De Stasio et al., 1996; Williamson et al., 2010).
2. Prediction for **non-uniform climatic change** occurrence across the globe (Hardy, 2003) and have different effects on lakes depending on geographic location (Adrian et al., 2009).
3. Lake responsiveness owes much to **site-specific** characteristics such as lake size, lake shape, catchment characteristics (Gerten & Adrian, 2001).

Complex response patterns requiring comprehensive surveillance monitoring programmes to:

- Identify rates of change, and
- The greatest sensitivity within individual systems in terms of ecological response

Key points

1	2	3
Lakes located many kilometres apart & in different climatic regions exhibit similar response to synoptic-scale meteorological forcing [4]:	**Direct response of lake water temperatures at all depths to air temperature fluctuations at regional and synoptic scales has been established (e.g. [3], [4])**	**Lakes have the potential to reveal changes and homogeneous trends even at relatively short (i.e. decadal) temporal scales (e.g. [1], [2]):**
Above suggests a coherent response to the same synoptic-scale climatic phenomena		20-30 year long R/S archives could prove useful in climate studies

[1] Arhonditsis, G. B., Brett, M. T., DeGasperi, C. L., & Schindler, D. E. (2004). Effects of climatic variability on the thermal properties of Lake Washington. Limnology and Oceanography, 49, 256–270

[2] Livingstone, D. M. (2003). Impact of secular climate change on the thermal structure of a large temperate central European lake. Climatic Change, 57, 205–225

[3] Livingstone, D. M., & Dokulil, M. (2001). Eighty years of spatially coherent Austrian lake surface temperatures and their relationship to regional air temperature and the North Atlantic Oscillation. Limnology and Oceanography, 46, 1220-1227

[4] Livingstone, D. M., & Padisák, J. (2007). Large-scale coherence in the response of lake surface-water temperatures to synoptic-scale climate forcing during summer. Limnology and Oceanography, 52, 896–902

Aims

This project investigated the potential to:

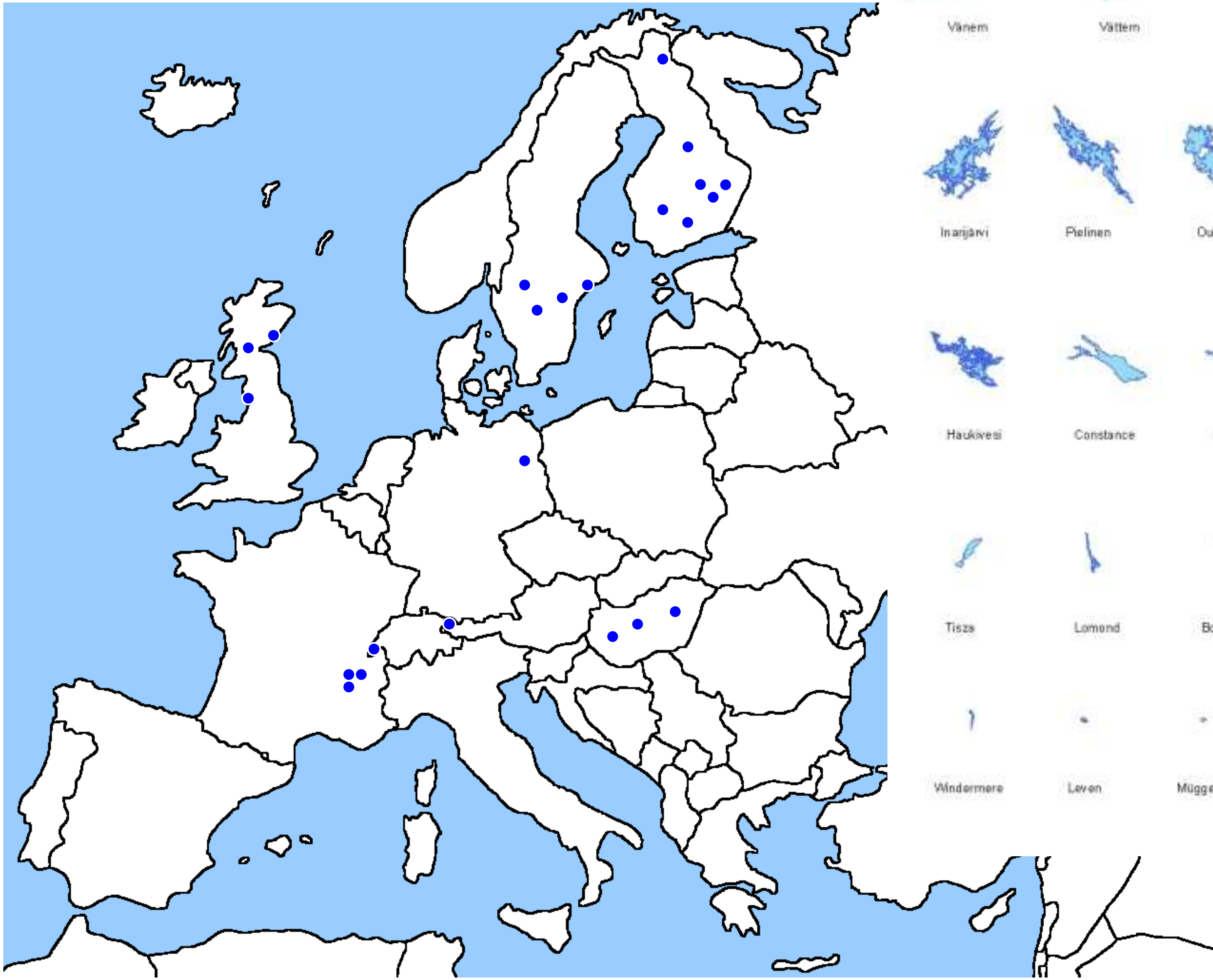
Map
large European lakes
& their water quality

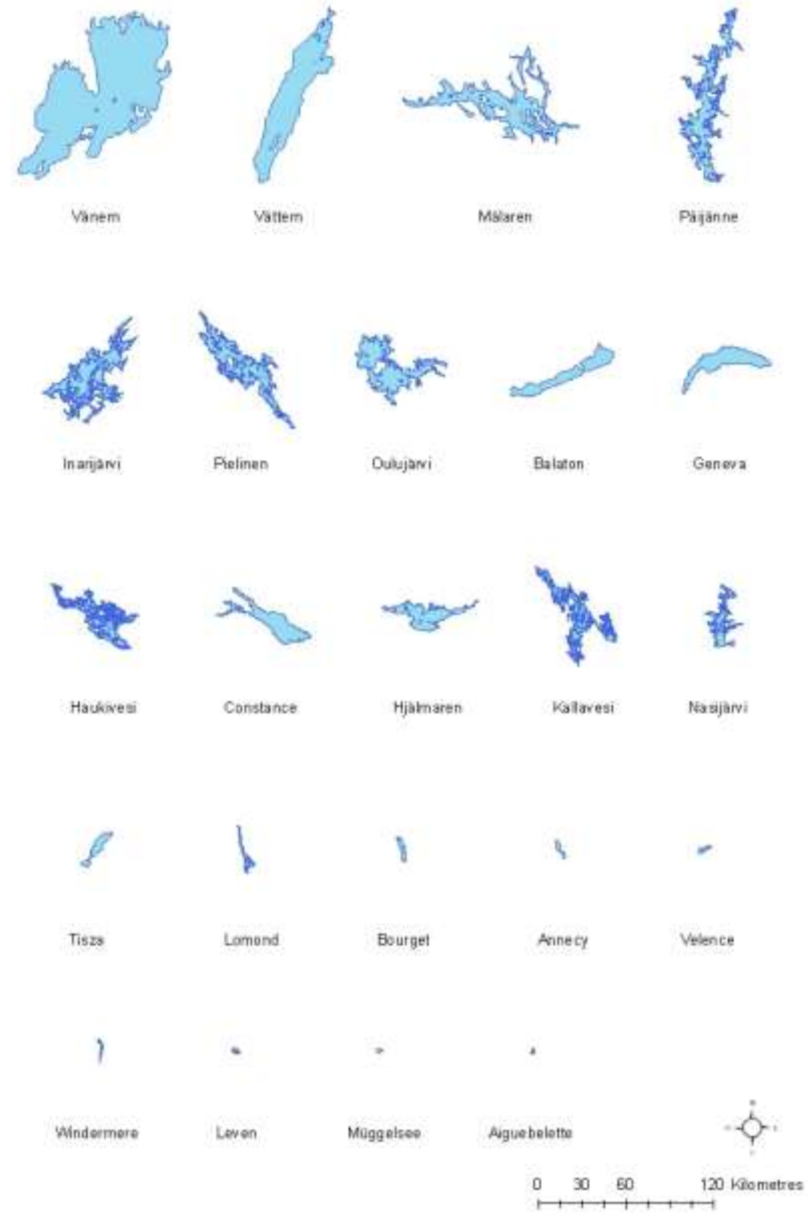
Test
existing algorithms
for the estimation
of lake water quality

Apply
promising algorithms to
past dates & study
spatial-temporal
trends in lake water quality

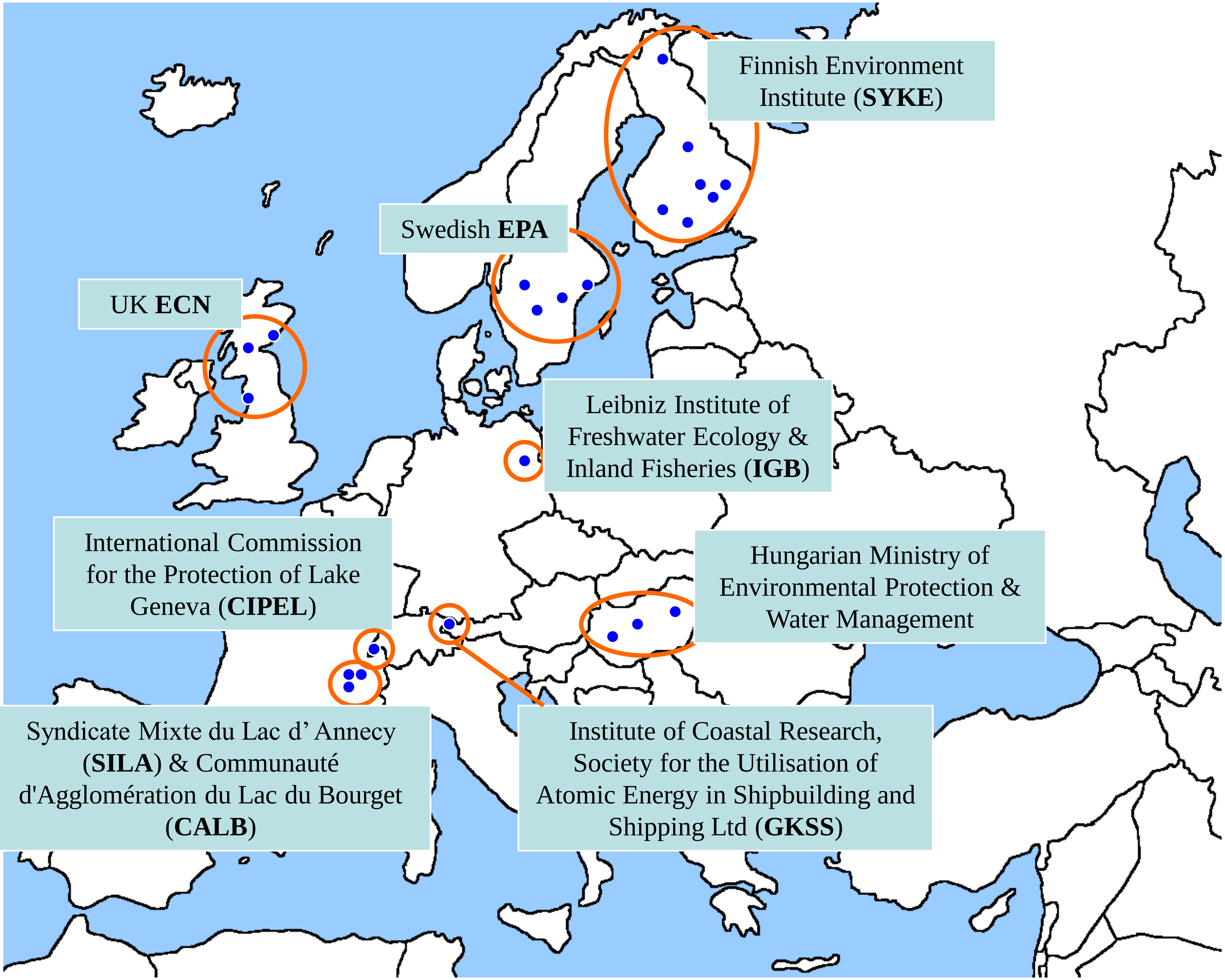
Monitor
lakes in the future
at wide spatial-temporal
scales

Study sites




Vänern
Vättern
Mälaren
Päijänne
Inarijärvi
Pielinen
Oulujärvi
Balaton
Geneva
Haukivesi
Constance
Hjälmaren
Kallavesi
Näsijärvi
Tisza
Lomond
Bourget
Annecy
Velence
Windermere
Leven
Müggelsee
Aiguebelette
0 30 60 120 Kilometres

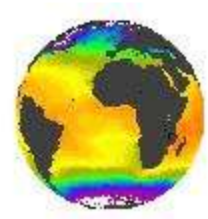
Field data



Finnish Environment Institute (**SYKE**)
Swedish **EPA**
UK **ECN**
Leibniz Institute of Freshwater Ecology & Inland Fisheries (**IGB**)
International Commission for the Protection of Lake Geneva (**CIPEL**)
Hungarian Ministry of Environmental Protection & Water Management
Syndicate Mixte du Lac d' Annecy (**SILA**) & Communauté d'Agglomération du Lac du Bourget (**CALB**)
Institute of Coastal Research, Society for the Utilisation of Atomic Energy in Shipbuilding and Shipping Ltd (**GKSS**)

Case study: LWST using NOAA AVHRR

Politi, E., Cutler, M. E. J. & Rowan, J. S. (2012). Using the NOAA Advanced Very High Resolution Radiometer to characterise temporal and spatial trends in water temperature of large European lakes. Remote Sensing of Environment, 126, 1-11



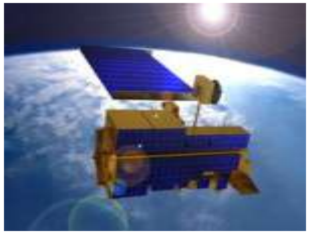
NOAA AVHRR:

- Operational since 1979
- Spatial resolution 1.1 x 1.1 km
- At any time two NOAA satellites; day-time & night-time coverage for thermal data (12hr revisit time)
- NOAA AVHRR TIR bands were designed for SST
- Operational algorithms for SST each calibrated for each satellite
- 30-year long DSRS archive

ERS ATSR, ENVISAT AATSR

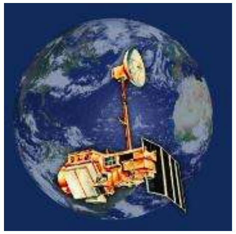
NOAA AVHRR

Terra/Aqua MODIS, Terra ASTER



Nimbus-7 CZCS

Landsat TM/ETM+

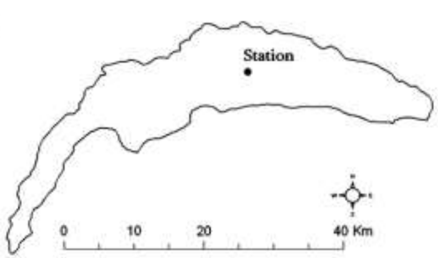


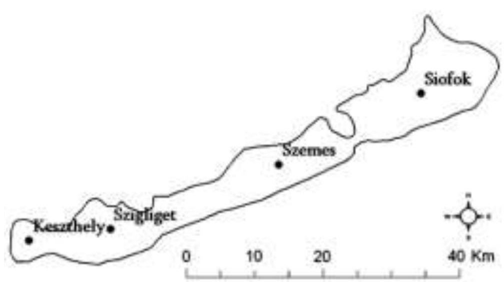
Case study: LWST using NOAA AVHRR

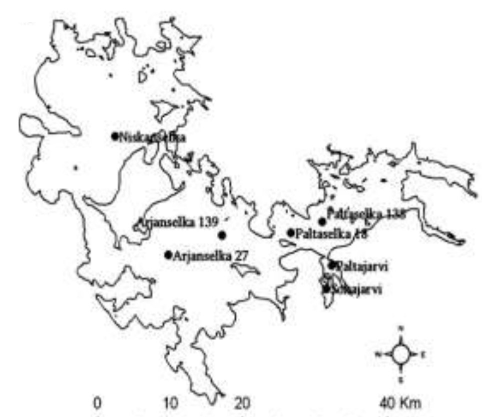
Case study: LWST using NOAA AVHRR

Name	Altitude (m a.s.l.)	Max depth (m)	Mean depth (m)	Volume (km^3)	Surface area (km^2)	Catchment size (km^2)	Ratio C.Size/S.Area	Ecoregion
Geneva (Fra/Switz)	372	310	153	88.9	584	7975	13.66	Alps
Balaton (Hungary)	105	12	3.2	1.9	593	5775	9.74	Hungarian lowlands
Vättern (Sweden)	89	128	40	74	1856	4503	2.43	Central plains
Oulujärvi (Finland)	122	38	7	6.2	887	(n/a)	(n/a)	Fenno-Scandian shield

Politi, E., Cutler, M. E. J. & Rowan, J. S. (2012). Using the NOAA Advanced Very High Resolution Radiometer to characterise temporal and spatial trends in water temperature of large European lakes. Remote Sensing of Environment, 126, 1-11



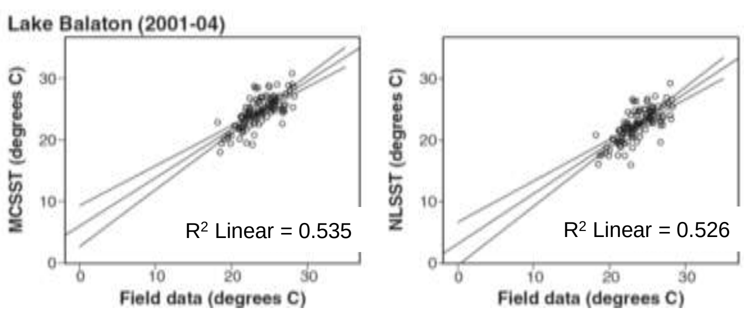


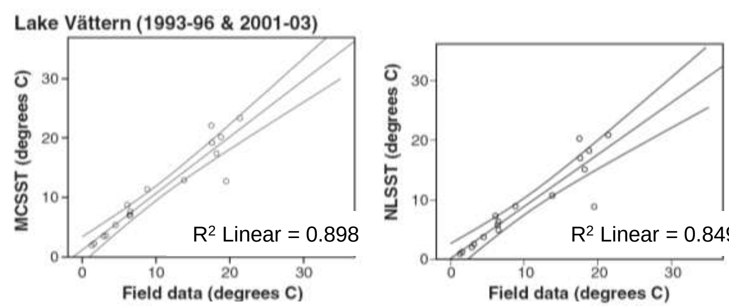


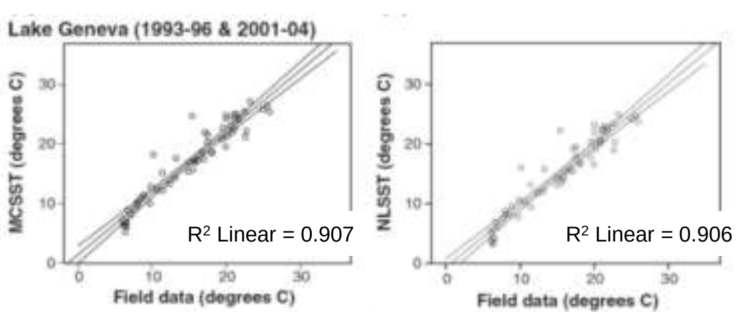
Case study: LWST using NOAA AVHRR

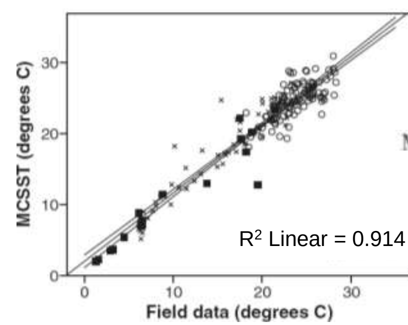
Lake	Period	Number of cloud-free scenes	Number of pairs
Geneva (1)	1993-96; 2001-04	58	58
Balaton (4)	2001-04	34	110
Vättern (2)	1993-96; 2001-04	12	17
Oulujärvi (3*)	2001-04	16	22

* Three (of total seven) central stations were used to avoid mixed pixels





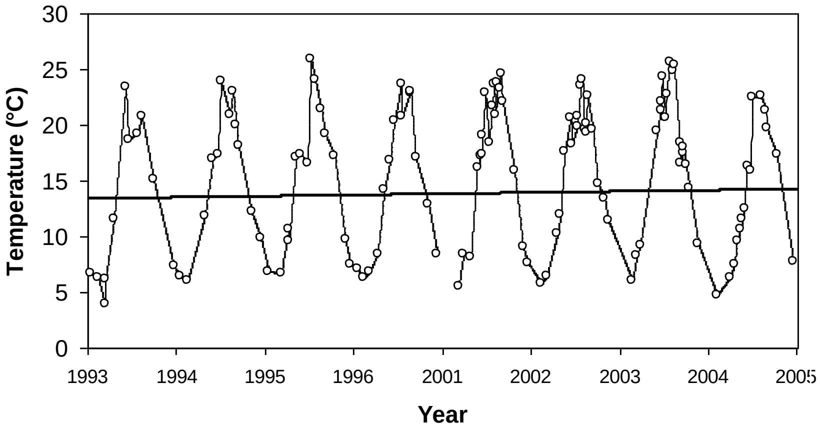




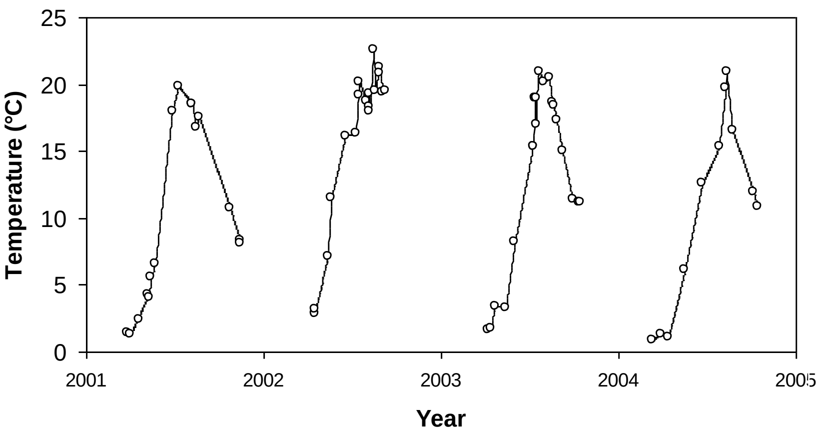
$$MCSSTcal[^{\circ}C] = 0.951(MCSST) - 0.183$$

Bias = 0.2 ºC **RMSE = 1.64 ºC**

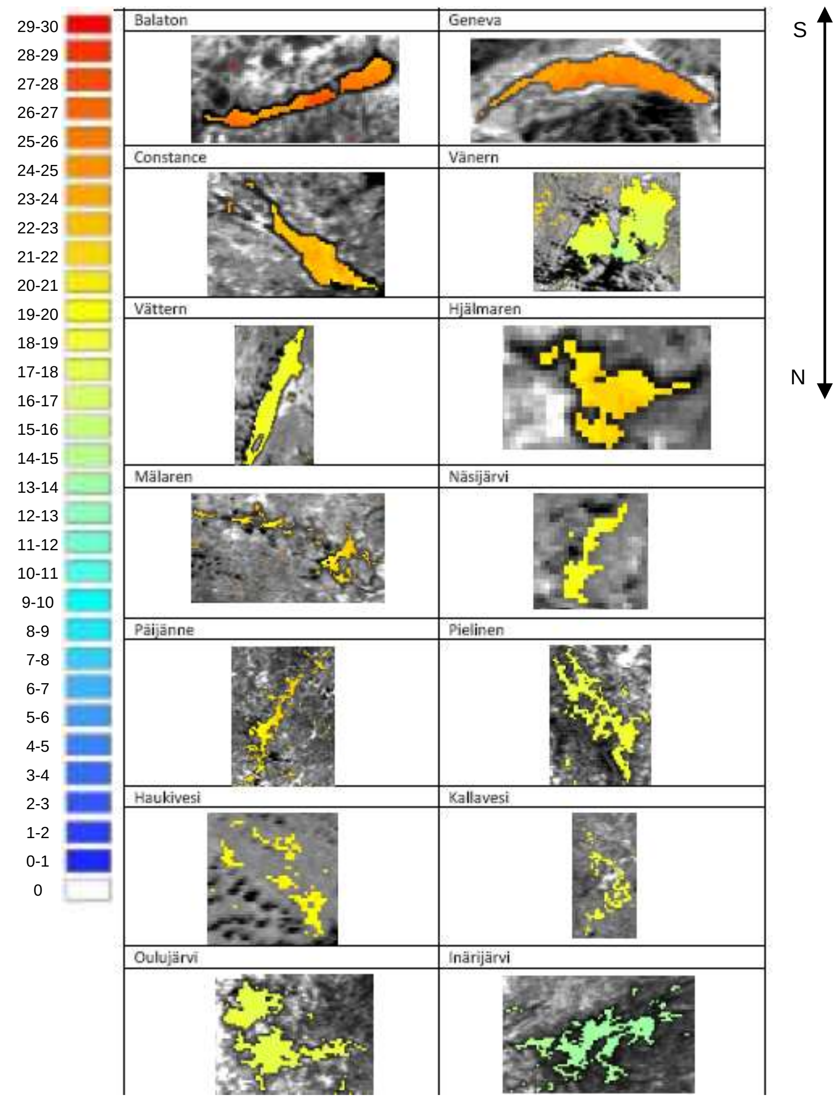
Results



Temporal patterns of LWST in Lake Geneva in 1993-96 and 2001-04 using interpolated NOAA AVHRR MCSSTcal estimates. The trend line was determined by linear regression. Notice the break in time between the years 1996 and 2001.

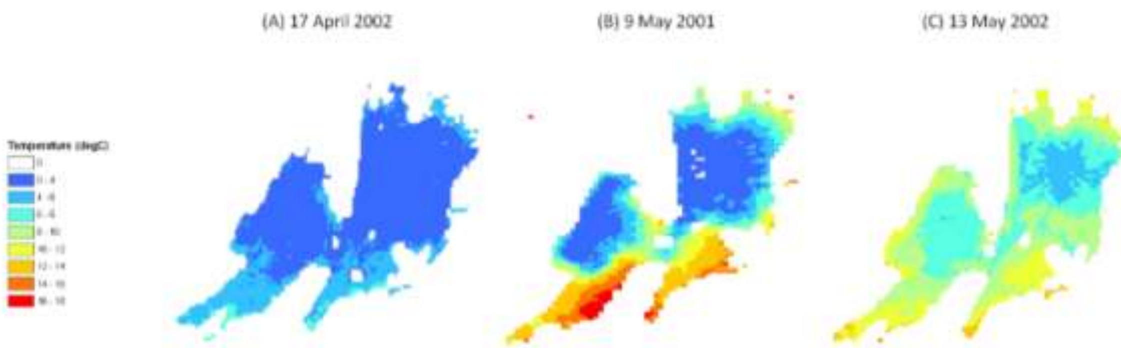


Temporal patterns of LWST in Lake Vättern (Station Jungfrun) in 1993-96 using interpolated NOAA AVHRR MCSSTcal estimates.

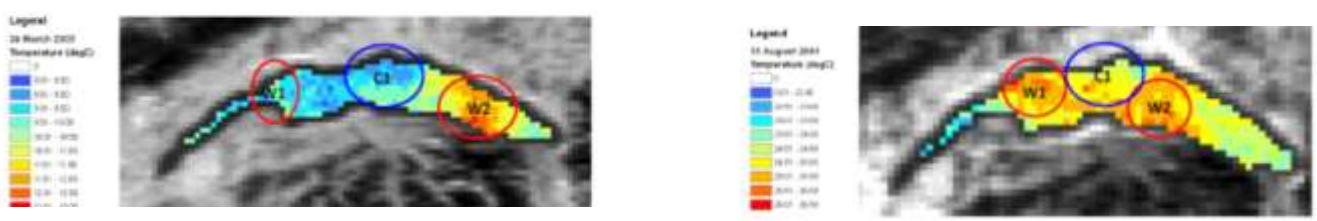


Spatial distibution of LSWT in fourteen large European lakes from NOAA AVHRR images acquired on various dates in August 2001.

Results



The evolution of the spring thermal bar in Lake Vänern. Dates from different years were used. The NOAA AVHRR MCSSTcal algorithm was used for the estimation of LWST.



Spatial distribution of LWST in Lake Geneva: early spring (March) and late summer (August); C1, W1-2 are permanent cold and warm cores (Oesch *et al*., 2008)

Challenges

The scale issue:

1. Point *vs.* X-pixel mean

Assumption that a point measurement from the sampling station is representative of the average value of the parameter studied for a X km^2 area containing the sample, but clearly this depends upon the intrinsic scale of variation of the parameter under consideration.

2. What is an environmentally meaningful scale of measurement?

Point measurement(s) *vs.* lake-mean

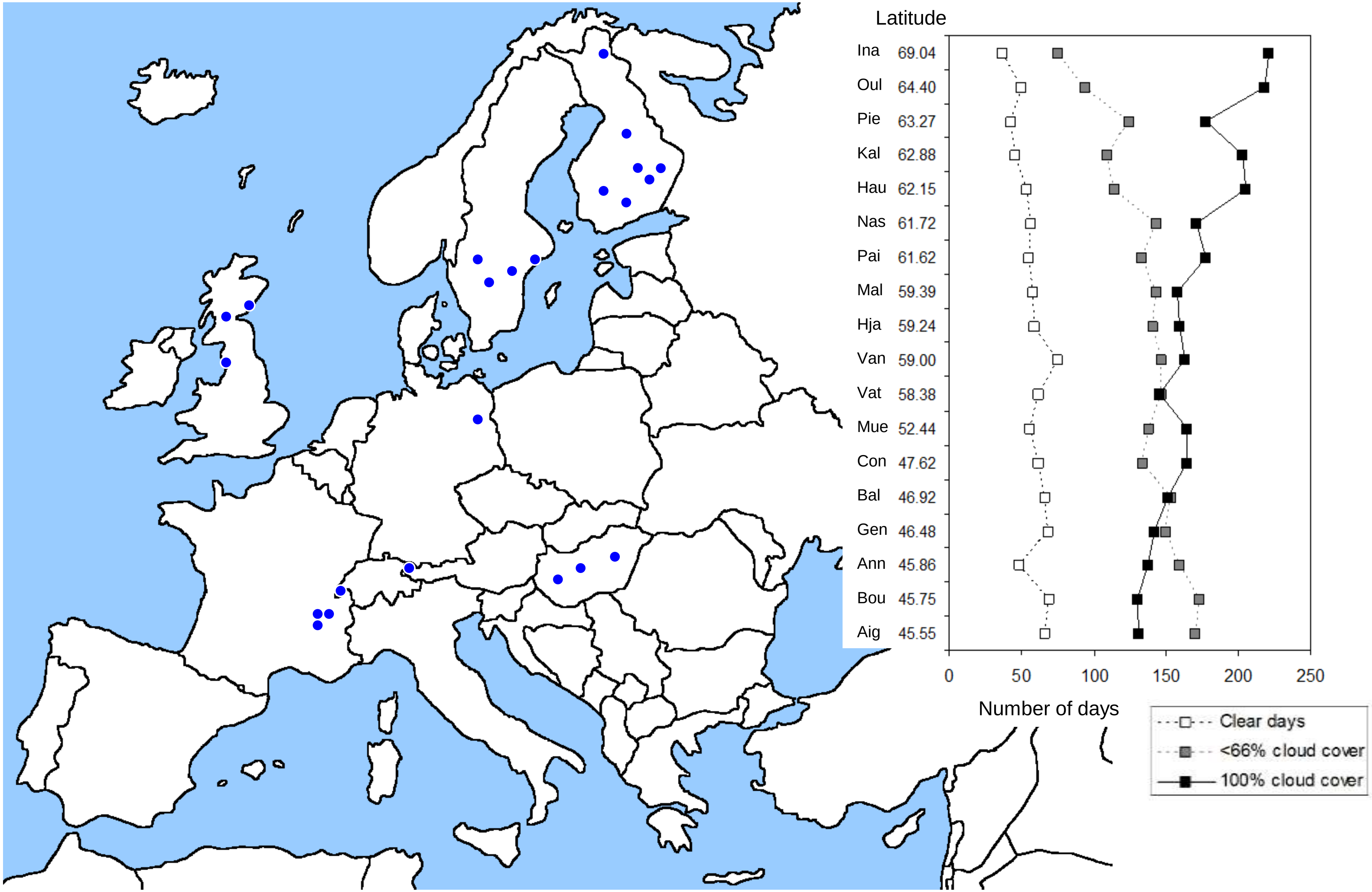
Frequency: Daily *vs.* seasonal/annual measurements

Estimating uncertainty: Quality of field data and coherence in field sampling methods

Cloud: Undetected cloud and frequent cloud cover

Adjacency effect

Challenges



Latitude
Ina 69.04
Oul 64.40
Pie 63.27
Kal 62.88
Hau 62.15
Nas 61.72
Pai 61.62
Mal 59.39
Hja 59.24
Van 59.00
Vat 58.38
Mue 52.44
Con 47.62
Bal 46.92
Gen 46.48
Ann 45.86
Bou 45.75
Aig 45.55
0
50
100
150
200
250
Number of days
Clear days
<66% cloud cover
100% cloud cover

Optimal lake morphology

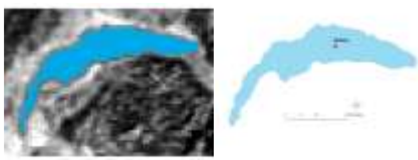
Shape

Size

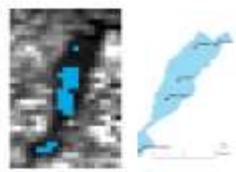
Enclosed bays

Islands

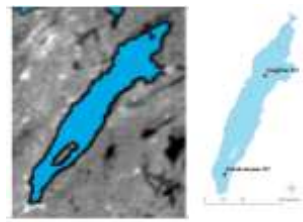
>100 km^2



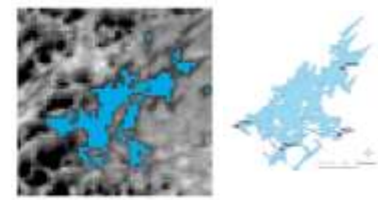
Geneva (584 km^2)



Tisza (127 km^2)

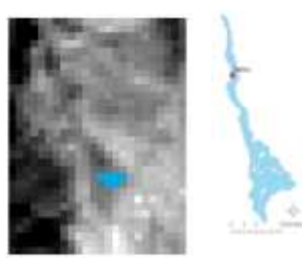


Vättern (1,856 km^2)

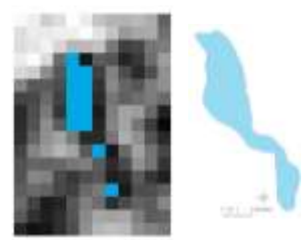


Inärijärvi (1,040 km^2)

<100 km^2



Lomond (71 km^2)



Annecy (27 km^2)

Summary - Conclusions

- Lake responsiveness owes much to **site-specific** characteristics such as lake size, lake shape, catchment characteristics

- Previous studies suggest a coherent lake response to the same synoptic-scale climatic phenomena for certain lakes

- Lakes have the potential to reveal changes and homogeneous trends even at relatively short (i.e. decadal) temporal scales

- Factors complicating linkages between water quality and climate: changes in land cover and land use, diffuse and point pollution, invasion of alien species, *etc*. (EUROPA WFD, 2011; UNEP, 2000).

- The scale issue is an important consideration in R/S studies of lakes

- Cloud cover may limit frequency of R/S observations, but what is the time frequency we actually need?

Thank you for your attention

…and

Mr. Malin Kanth (Swedish EPA)

Dr. Antton Keto (Finnish Environment Institute SYKE)

The International Commission for the Protection of Lake Geneva (CIPEL)

The Hungarian Ministry of Environmental Protection & Water Management, and Ministry of Health

… for the kind offer of field data

Mr. Rory Hutson (PML, NEODAAS)

Mr. Andrew Brooks (DSRS)

… for the pre-processing of and help with the satellite data

References

Adrian, R., O'Reilly, C. M., Zagarese, H., Baines, S. B., Hessen, D. O., Keller, W., et al. (2009). Lakes as sentinels of climate change. Limnology and Oceanography, 54, 2283–2297

Arhonditsis, G. B., Brett, M. T., DeGasperi, C. L., & Schindler, D. E. (2004). Effects of climatic variability on the thermal properties of Lake Washington. Limnology and Oceanography, 49, 256–270

De Stasio, B. T., Hill, D. K., Kleinhans, J. M., Nibbelink, N. P., & Magnuson, J. J. (1996). Potential effects of global climate change on small north-temperate lakes: Physics, fish and plankton. Limnology and Oceanography, 41, 1136–1149

EEA (2010). European Environment Agency. http://www.eea.europa.eu/themes/water/european-waters/lakes

EUROPA WFD (2011). European CommissionWater Framework Directive. http://ec.europa.eu/environment/water/water-framework/index_en.html

Gerten, D., & Adrian, R. (2001). Differences in the persistency of the North Atlantic Oscillation signal among lakes. Limnology and Oceanography, 46, 448–455

Hardy, J. T. (2003). Climate change: Causes, effects and solutions. UK: Wiley

Livingstone, D. M. (1997). Temporal structure in the deep-water temperature of four Swiss lakes: A short-term climatic change indicator?, Verh. Internat. Verein. Limnol., 25, 75-81

Livingstone, D. M. (2003). Impact of secular climate change on the thermal structure of a large temperate central European lake. Climatic Change, 57, 205–225

Livingstone, D. M., & Dokulil, M. (2001). Eighty years of spatially coherent Austrian lake surface temperatures and their relationship to regional air temperature and the North Atlantic Oscillation. Limnology and Oceanography, 46, 1220-1227

Livingstone, D. M., & Padisák, J. (2007). Large-scale coherence in the response of lake surface-water temperatures to synoptic-scale climate forcing during summer. Limnology and Oceanography, 52, 896–902

Oesch, D. C., Jaquet, J. M., Klaus, R. & Schenker, P. (2008). Multi-scale thermal pattern monitoring of a large lake (Lake Geneva) using a multi-sensor approach. International Journal of Remote Sensing, 29, 5785-5808

UNEP (2000). Lakes and reservoirs: Similarities, differences and importance. Short Report, 1, : United Nations Environment Programme (UNEP) International Environmental Technology Centre (IETC) 63 pp

Williamson, G. E., Saros, J. E., & Schindler, D. W. (2010). Sentinels of change. Science, 323, 887–888