living planet symposium | BONN 23–27 May 2022

TAKING THE PULSE OF OUR PLANET FROM SPACE

Using Lakes CCI satellite products to detect the influence of heatwave events on chlorophyll-a in Europe

Gary Free, Mariano Bresciani, Monica Pinardi, Giulio Tellina, **Claudia Giardino** - National Research Council of Italy (CNR-IREA)
Prof. Dr. Stefan Simis - Plymouth Marine Laboratory, United Kingdom

26-05-2022

Presentation structure

- The CCI LAKES project
- The study on heatwave and chlorophyll-a response
  - Preliminary investigation in 1-3 shallow lakes
  - Up-scaling to 36 European lakes
- Conclusions

https://climate.esa.int/en/projects/lakes/

Lakes as sentinels of climate change

esa

The influence of climate change is already clearly evident in many of Earth's lakes

nature communications

Article | Published: 31 August 2020

Rapid worldwide growth of glacial lakes since 1990

Dan H. Shugar, Aaron Burr, Umesh K. Haritashya, Jeffrey S. Kargel, C. Scott Watson, Maureen C. Kennedy, Alexandre R. Bevington, Richard A. Betts, Stephan Harrison & Katherine Strattman

Nature Climate Change 10, 939–945(2020) | Cite this article

3975 Accesses | 2 Citations | 1212 Altmetric | Metrics

nature communications

Article | Open Access | Published: 06 March 2020

Global lake thermal regions shift under climate change

Stephen C. Maberly, Ruth A. O'Donnell, R. Iestyn Woolway, Mark E. J. Cutler, Mengyi Gong, Ian D. Jones, Christopher J. Merchant, Claire A. Miller, Eirini Politi, E. Marian Scott, Stephen J. Thackeray & Andrew N. Tyler

Nature Communications 11, Article number: 1232 (2020) | Cite this article

Article

Lake heatwaves under climate change

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Received: 15 April 2020

R. Iestyn Woolway[1,2], Eleanor Jennings[1], Tom Shatwell[3], Malgorzata Golub[4], Don C. Pierson[4] & Stephen C. Maberly[5]

Lakes & Reservoirs
Science, Policy and Management for Sustainable Use

REVIEW ARTICLE

Impacts of water level changes in the fauna, flora and physical properties over the Balkhash Lake watershed

Kuanysh B. Isbekov, Vyacheslav N. Tsoy, Jean-Francois Crétaux, Nikolai V. Aladin, Igor S. Plotnikov, Guillaume Clos, Muriel Berge-Nguyen, Saule Zh. Assylbekova

First published:16 May 2019 | https://doi.org/10.1111/lre.12263 | Citations: 1

Hydrological Processes

Research Article

Recent trends in Canadian lake ice cover

Claude R. Duguay, Terry D. Prowse, Barrie R. Bonsal, Ross D. Brown, Martin P. Lacroix, Patrick Ménard

First published: 27 February 2006 | https://doi.org/10.1002/hyp.6131 | Citations: 144

Science of the Total Environment 693 (2019) 133414

Contents lists available at ScienceDirect

Science of the Total Environment

journal homepage: www.elsevier.com/locate/scitotenv

Effects of climate change and episodic heat events on cyanobacteria in a eutrophic polymictic lake

Maciej Bartosiewicz[a,b,*], Anna Przytulska[b,c], Bethany N. Deshpande[c], Dermot Antoniades[c], Alicia Cortes[d], Sally MacIntyre[d], Moritz F. Lehmann[b], Isabelle Laurion[a]

Contents lists available at ScienceDirect

Remote Sensing of Environment

journal homepage: www.elsevier.com/locate/rse

Changes of water clarity in large lakes and reservoirs across China observed from long-term MODIS

Shenglei Wang[a,b], Junsheng Li[b,c], Bing Zhang[b,c,*], Zhongping Lee[d], Evangelos Spyrakos[e], Lian Feng[f], Chong Liu[g], Hongli Zhao[h], Yanhong Wu[b], Liping Zhu[g], Liming Jia[i], Wei Wan[a], Fangfang Zhang[b], Qian Shen[b], Andrew N. Tyler[e], Xianfeng Zhang[a]

Increasing body of evidence on regional to global climate change in lakes from remote observations

ESA CCI LAKES project: to exploit satellite data to create the largest and longest possible consistent, global record of five lake climate variables:

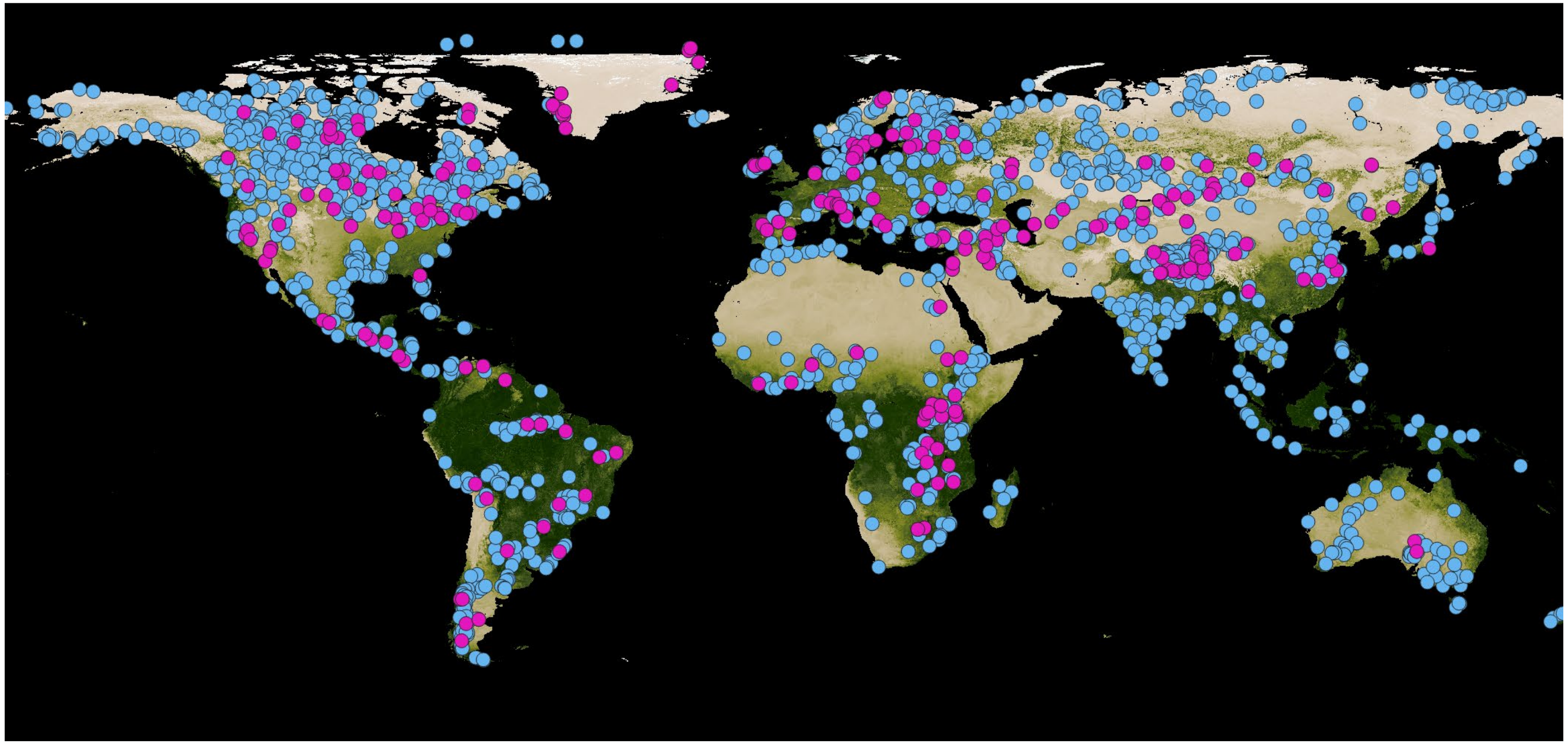
- Lake Water Extent
- Lake Water Level
- Lake Ice Cover
- Lake Surface Water Temperature
- Lake Surface Water Reflectance (chl-a, turbidity)

ESA CCI programme aims to provide stable, long-term, satellite-based ECV data products

Essential Climate Variable (ECV) is a physical, chemical or biological variable or a group of linked variables that critically contributes to the characterization of Earth's climate

CCI LAKES

- V1: ~ 250 lakes (limited coverage of Water Level and Extent)
- V2: ~ 2000 lakes (longer continuous coverage) (NEW!)

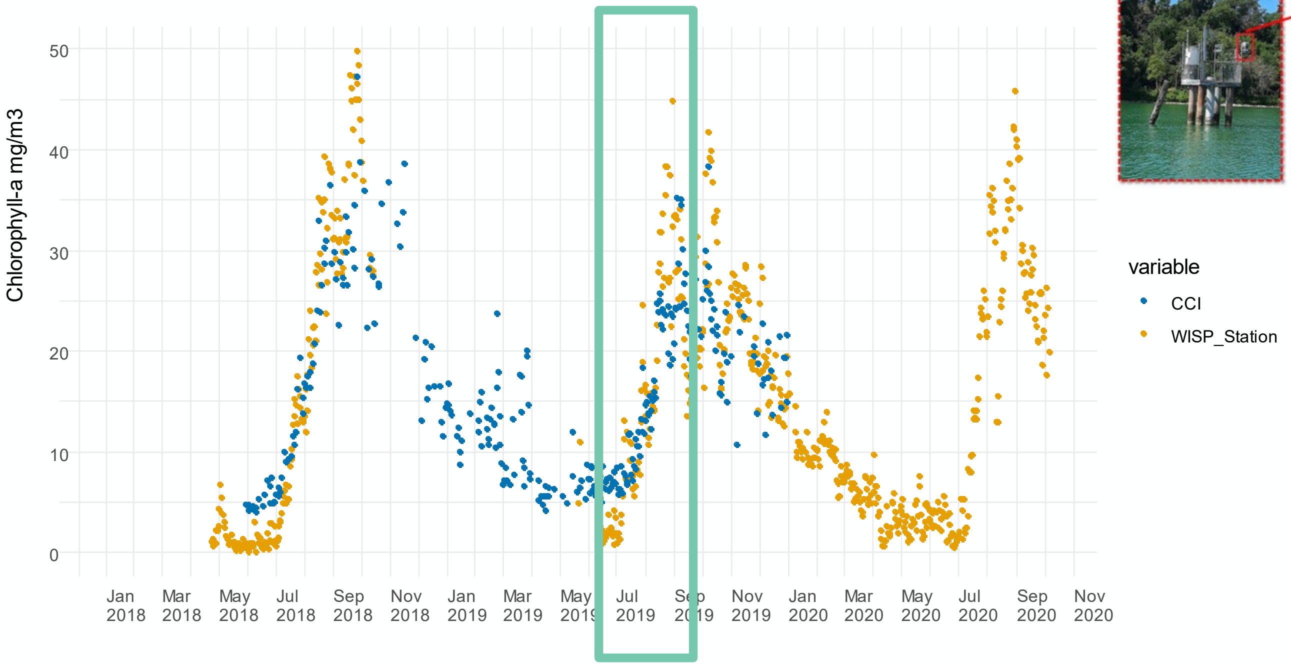


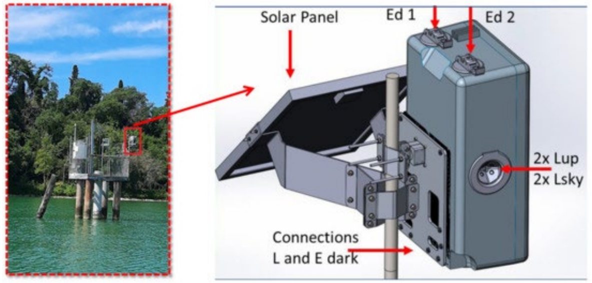
Crétaux, J.-F.; Merchant, C.J.; Duguay, C.; Simis, S.; Calmettes, B.; Bergé-Nguyen, M.; Wu, Y.; Zhang, D.; Carrea, L.; Liu, X.; et al. ESA Lakes Climate Change Initiative (Lakes_cci): Lake Products.

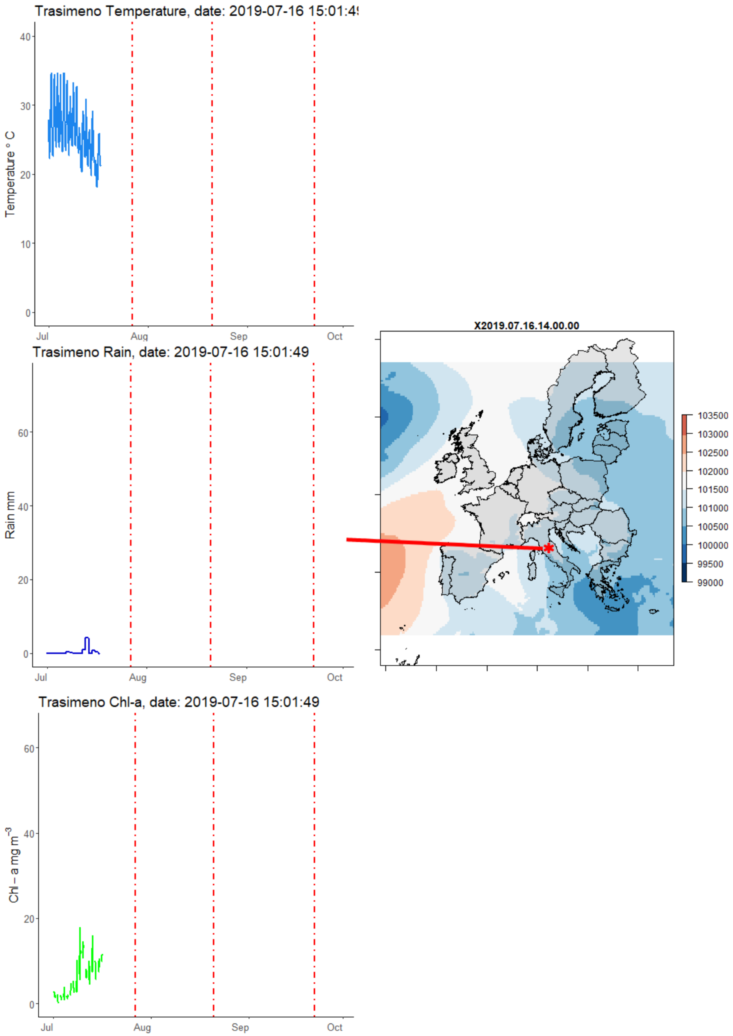
https://catalogue.ceda.ac.uk/uuid/03c935c6890c4b2ebf4aae4d84cd9472

CCI LAKES – First investigation

Lake Trasimeno (Italy)







Estimates of Chl-a from the CCI LAKES (Chla_CCI) and from WISPStation (Chla_WISP) agreed well

For shallow lakes, its often the low pressure system after the heatwave that increases Chl-a

Bresciani et al., in press 2022

CCI LAKES – First investigation

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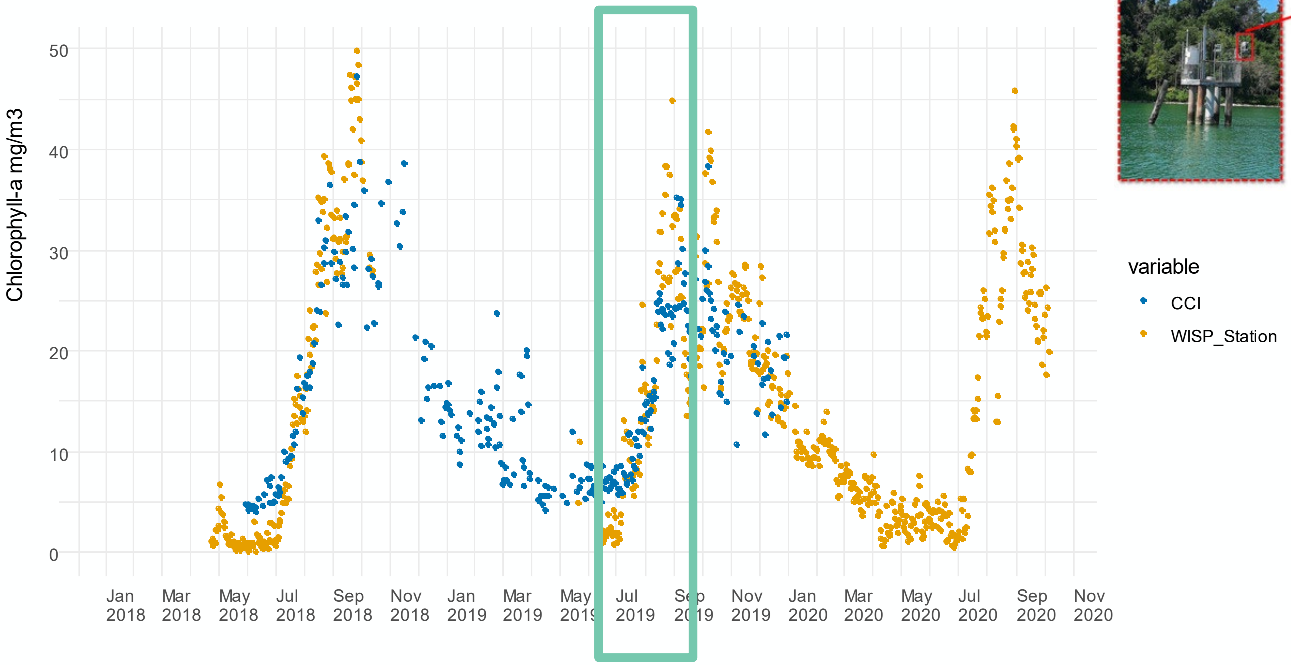

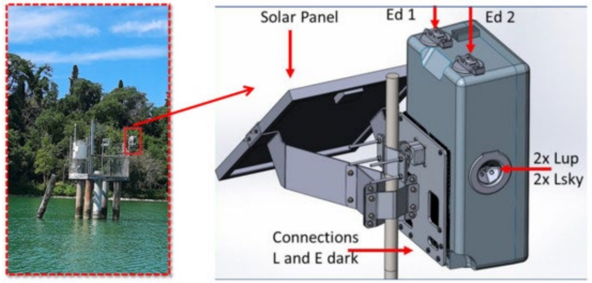

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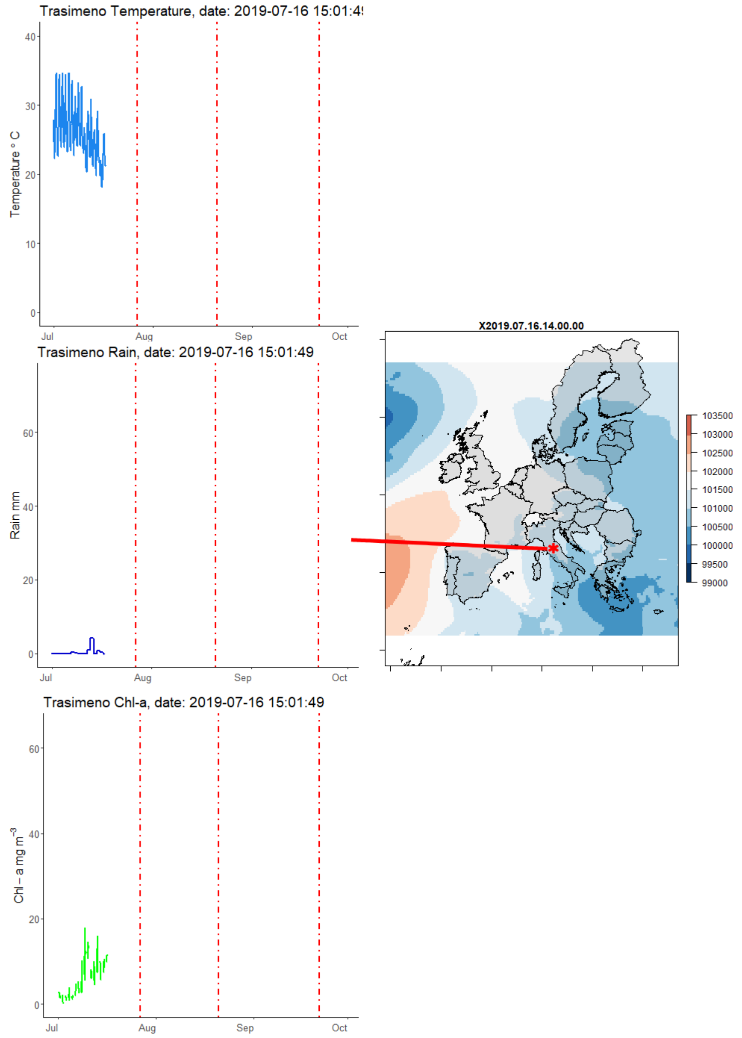


Bresciani et al., in press 2022

CCI LAKES – First investigation

esa

From 1 to 3 lakes (all shallow)

Examined response of high-frequency chlorophyll-a estimated from 3 WISPstations in Europe (summer 2019)

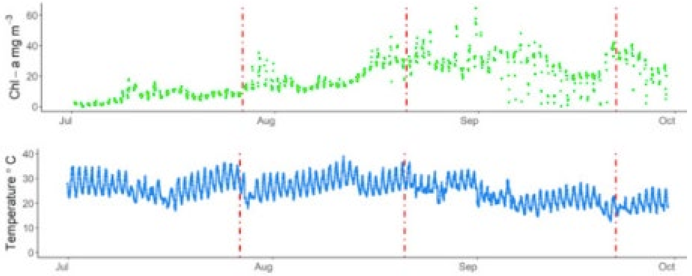
Table 1. Main features of Lake Trasimeno, Curonian Lagoon and Lake Võrtsjärv.

Characteristics	Trasimeno	Võrtsjärv	Curonian Lagoon
Catchment area (km^2)	383	3100	97928
Lake surface area (km^2)	121	270	1584
Maximum depth (m)	5.5	6	5.8 *
Average depth (m)	4.0	2.8	3.8
Water residence time	>20 years	~1 year	10–100 days
Total phosphorous ($\mu g\ L^{-1}$)	27	40	108

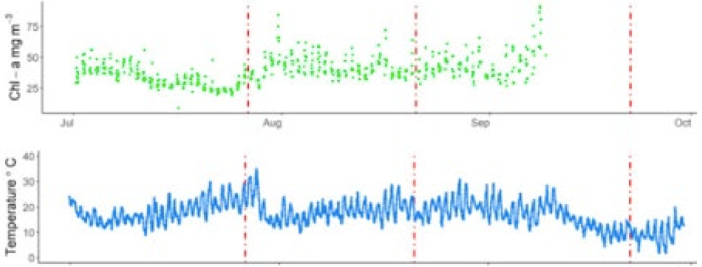
* The artificially deepened Klaipeda Strait for harbor activities is 8–15 m in depth.

Free et al., Sensors 2021

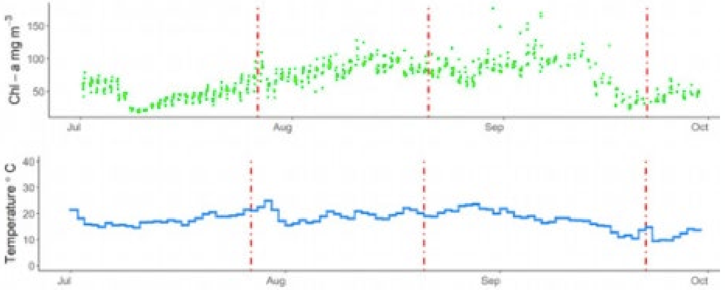
Trasimeno



Võrtsjärv



Curonian lagoon



CCI LAKES – First investigation

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sensors

MDPI

Article

Detecting Climate Driven Changes in Chlorophyll-a Using High Frequency Monitoring: The Impact of the 2019 European Heatwave in Three Contrasting Aquatic Systems

Gary Free [1,*], Mariano Bresciani [1], Monica Pinardi [1], Claudia Giardino [1], Krista Alikas [2], Kersti Kangro [2,3], Eva-Ingrid Rõõm [3], Diana Vaičiūtė [4], Martynas Bučas [4], Edvinas Tiškus [4], Annelies Hommersom [5], Marnix Laanen [5] and Steef Peters [5]

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Citation: Free, G.; Bresciani, M.; Pinardi, M.; Giardino, C.; Alikas, K.; Kangro, K.; Rõõm, E.-I.; Vaičiūtė, D.; Bučas, M.; Tiškus, E.; et al. Detecting Climate Driven Changes in Chlorophyll-a Using High Frequency Monitoring: The Impact of the 2019 European Heatwave in Three Contrasting Aquatic Systems. *Sensors* **2021**, *21*, 6242. https://doi.org/10.3390/s21186242

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Abstract: The frequency of heatwave events in Europe is increasing as a result of climate change. This can have implications for the water quality and ecological functioning of aquatic systems. We deployed three spectroradiometer WISPstations at three sites in Europe (Italy, Estonia, and Lithuania/Russia) to measure chlorophyll-a at high frequency. A heatwave in July 2019 occurred with record daily maximum temperatures over 40 °C in parts of Europe. The effects of the resulting storm that ended the heatwave were more discernable than the heatwave itself. Following the storm, chlorophyll-a concentrations increased markedly in two of the lakes and remained high for the duration of the summer while at one site concentrations increased linearly. Heatwaves and subsequent storms appeared to play an important role in structuring the phenology of the primary producers, with wider implications for lake functioning. Chlorophyll-a peaked in early September, after which a wind event dissipated concentrations until calmer conditions returned. Synoptic coordinated high frequency monitoring needs to be advanced in Europe as part of water management policy and to improve knowledge on the implications of climate change. Lakes, as dynamic ecosystems with fast moving species-succession, provide a prism to observe the scale of future change.

Free et al., Sensors 2021

A heatwave in July 2019 occurred with record daily maximum temperatures over 40 °C in parts of Europe.

Essentially, in these three shallow water bodies – the main response was observed at the end of the heatwave with an increase in chlorophyll-a.

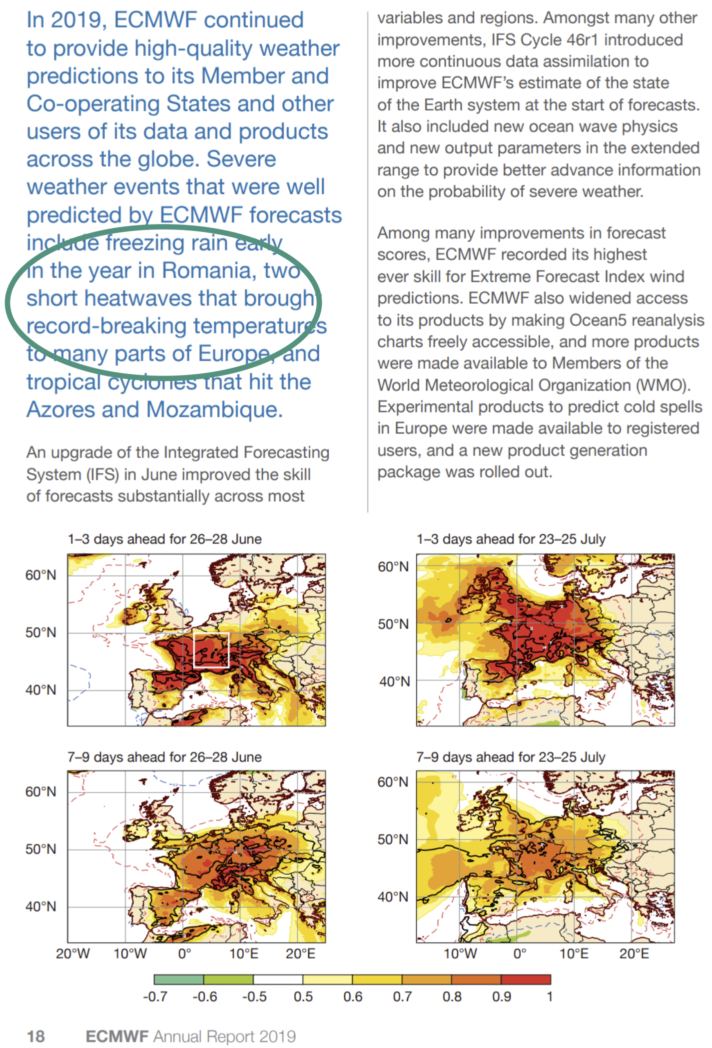
CCI LAKES – Heatwave: up scaling to Europe

Compounded weather events affecting summer 2019 in Europe

Compounded weather events, whereby multiple climatic drivers or hazards can produce higher risk of significant impact has received more attention.

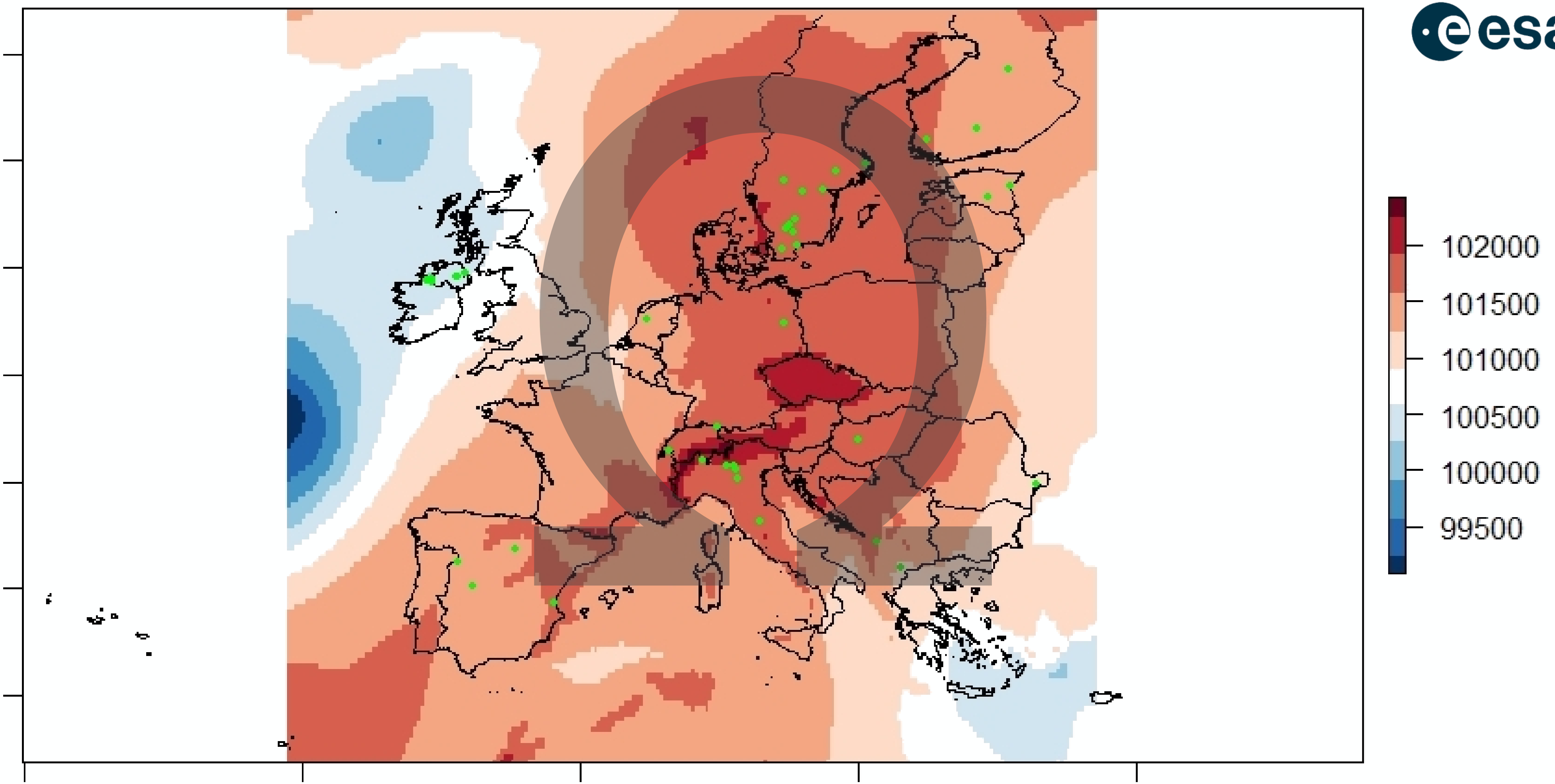
An atmospheric block producing a sequence of heatwaves is an example of a temporally compounding event and can have multiple impacts (Zscheischler et al. 2020).

https://www.ecmwf.int/sites/default/files/elibrary/2020/19546-annual-report-2019.pdf

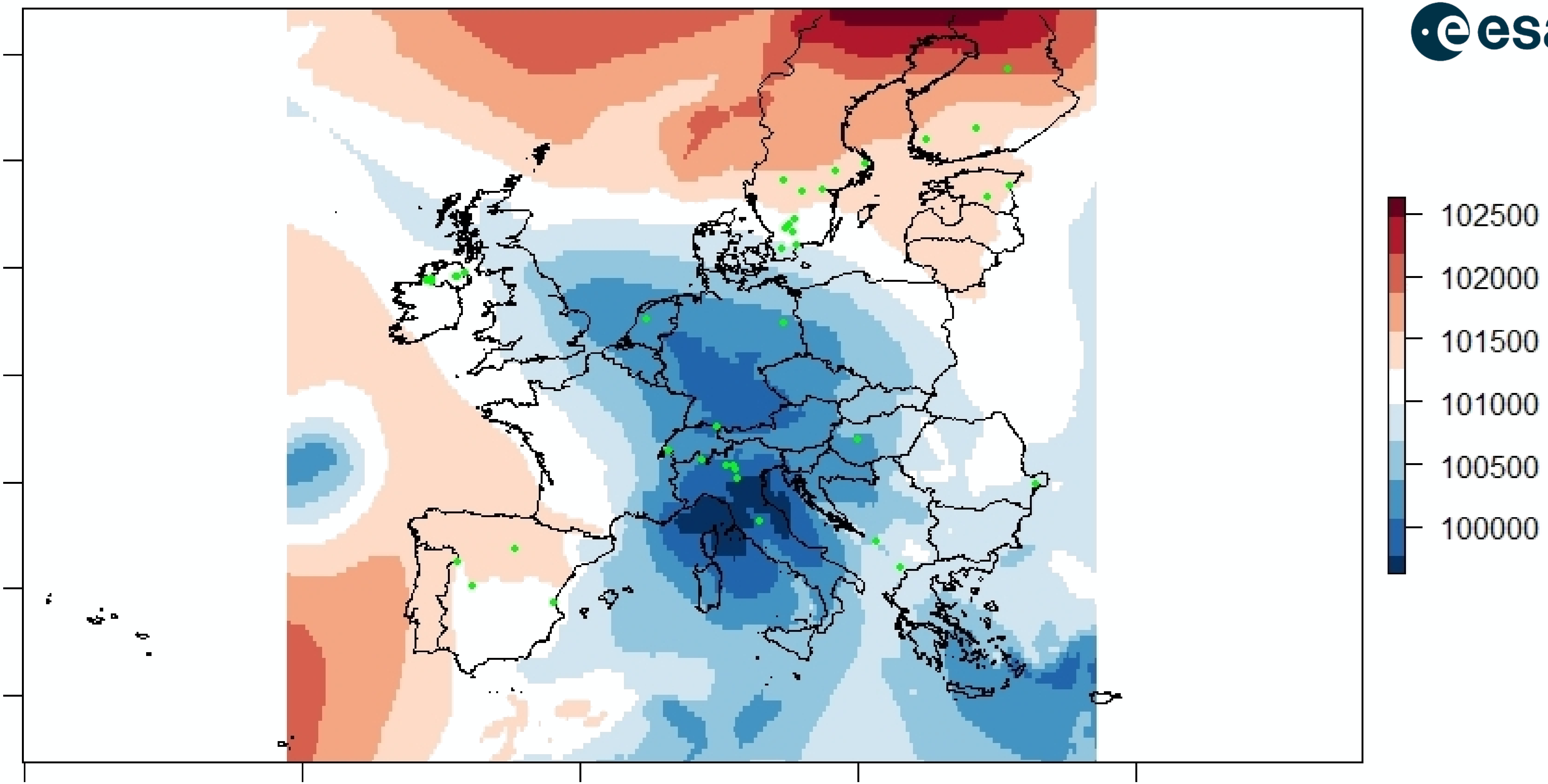

In 2019, ECMWF continued to provide high-quality weather predictions to its Member and Co-operating States and other users of its data and products across the globe. Severe weather events that were well predicted by ECMWF forecasts include freezing rain early in the year in Romania, two short heatwaves that brought record-breaking temperatures to many parts of Europe, and tropical cyclones that hit the Azores and Mozambique.

An upgrade of the Integrated Forecasting System (IFS) in June improved the skill of forecasts substantially across most variables and regions. Amongst many other improvements, IFS Cycle 46r1 introduced more continuous data assimilation to improve ECMWF's estimate of the state of the Earth system at the start of forecasts. It also included new ocean wave physics and new output parameters in the extended range to provide better advance information on the probability of severe weather.

Among many improvements in forecast scores, ECMWF recorded its highest ever skill for Extreme Forecast Index wind predictions. ECMWF also widened access to its products by making Ocean5 reanalysis charts freely accessible, and more products were made available to Members of the World Meteorological Organization (WMO). Experimental products to predict cold spells in Europe were made available to registered users, and a new product generation package was rolled out.



24th July 2019 DOY 205



28th July 2019 DOY 209

CCI LAKES – Heatwave: up scaling to Europe

How the European heatwave in June and July 2019 affected lakes?

36 lakes within Europe to be examined for influence of double heatwave event in 2019

Lake	Country	Lat	Lon	$\bar{z}$ m	Area km^2	TP $mg\ l^{-1}$
Skadar	AL	42.19	19.29	5.0	381	20
Võrtsjärv	EE	58.30	26.03	2.8	260	46
Peipus	EE/RU	58.82	27.42	8.4	3578	49
Päijänne	FI	61.50	25.40	15.2	937	14
Pyhajarvi	FI	60.99	22.31	5.5	153	17
Muggelsee	DE	52.44	13.65	4.9	7	60
Constance	DE/CH	47.54	9.51	85.0	47	8
Balaton	HU	46.98	18.07	3.2	584	47
Garda	IT	45.53	10.65	133.0	369	8
Idro	IT	45.78	10.51	77.0	11	28
Iseo	IT	45.74	10.07	123.0	66	23
Mantua	IT	45.16	10.78	3.5	6	97
Trasimeno	IT	43.15	12.10	4.7	121	42
Maggiore	IT/CH	45.99	8.68	177.0	216	4
Ohrid	MK	41.03	20.72	155.0	359	6
Ijsselmeer	NL	52.54	5.23	4.4	1139	72
Melvin	IE/UK	54.42	-8.13	8.3	23	17
Razim	RO	44.91	28.95	1.7	511	60
Albufera	ES	39.34	-0.36	2.0	26	155
Almendra	ES	41.26	-6.28	30.6	55	32
Cuerda del Pozo	ES	41.85	-2.75	10.0	16	12
Rosarito	ES	40.10	-5.31	6.2	10	97
Bolmen	SE	56.87	13.70	6.2	169	45
Erken	SE	59.85	18.58	9.0	22	34
Glan	SE	58.62	15.97	9.9	71	30
Ivösjön	SE	56.07	14.40	10.7	50	8
Mälaren	SE	59.49	16.76	11.9	1310	30
Moeckeln	SE	56.66	14.21	4.0	46	20
Östra Ringsjön	SE	55.86	13.55	4.7	25	38
Rusken	SE	57.29	14.35	3.5	35	15
Vättern	SE	58.55	14.71	39.0	1888	2
Vänern	SE	59.05	13.59	27.0	5501	6
Vidöstern	SE	57.01	13.98	4.4	42	15
Geneva/ Leman	CH/FR	46.46	6.58	153.0	581	48
Erne	UK	54.49	-7.81	11.9	116	60
Neagh	UK	54.59	-6.42	8.9	382	124

CCI LAKES – Heatwave: materials and methods

The chlorophyll-a concentrations for summer 2019 were extracted from satellite data from the CCI LAKES project database (Crétaux et al. 2020).

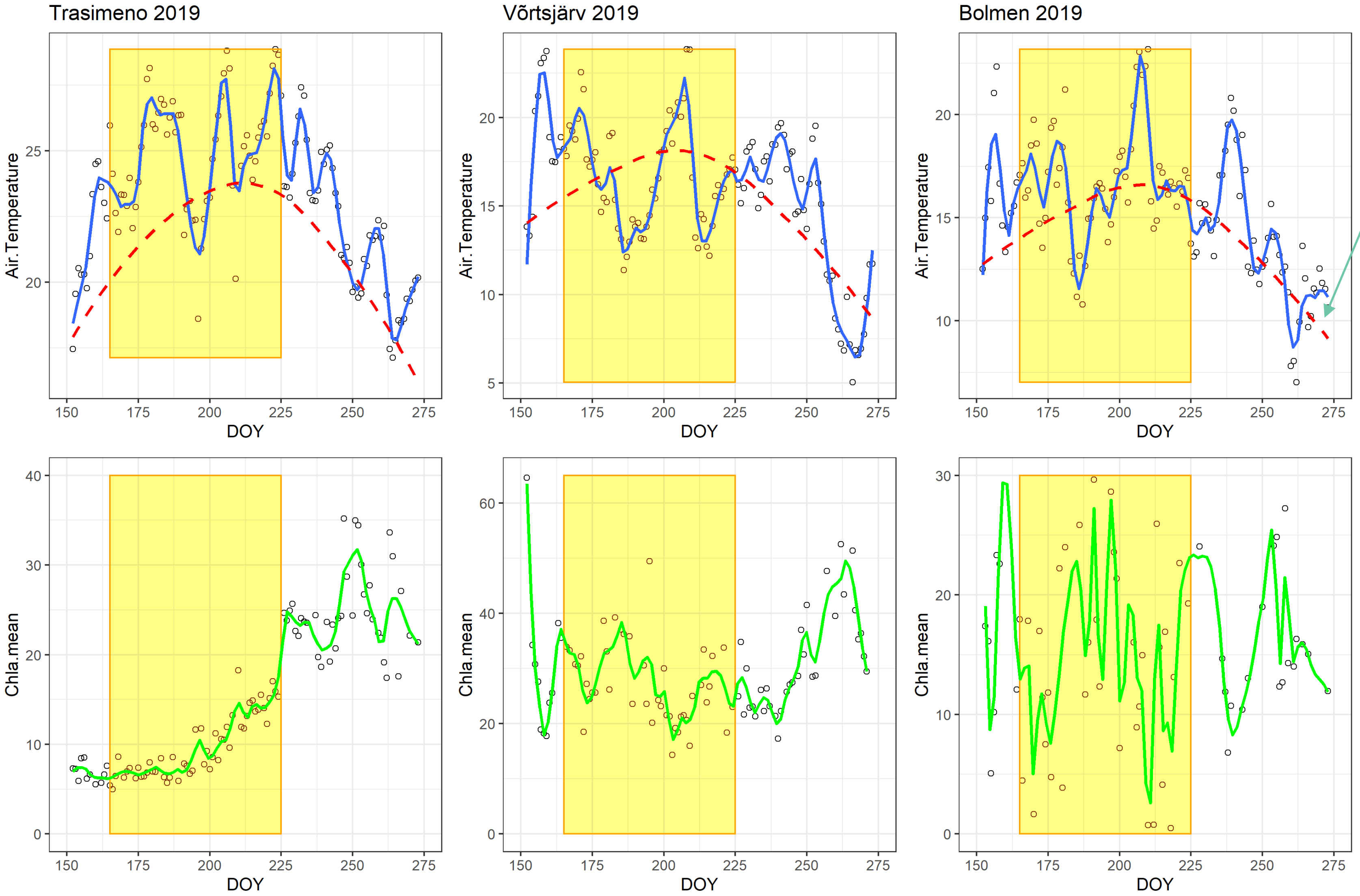
Data on total phosphorus and lake mean depth were obtained from Waterbase (European Environment Agency)

Climatic data were obtained from (ERA5)

Graphing and statistical analysis (regression, correlation, ANOVA) and of thee data was carried out (through R)

The timing and peaks for air temperature and chl-a were identified by fitting a lowess line (a locally weighted non-parametric smoothing method)

CCI LAKES – Heatwave: results in shallow lakes

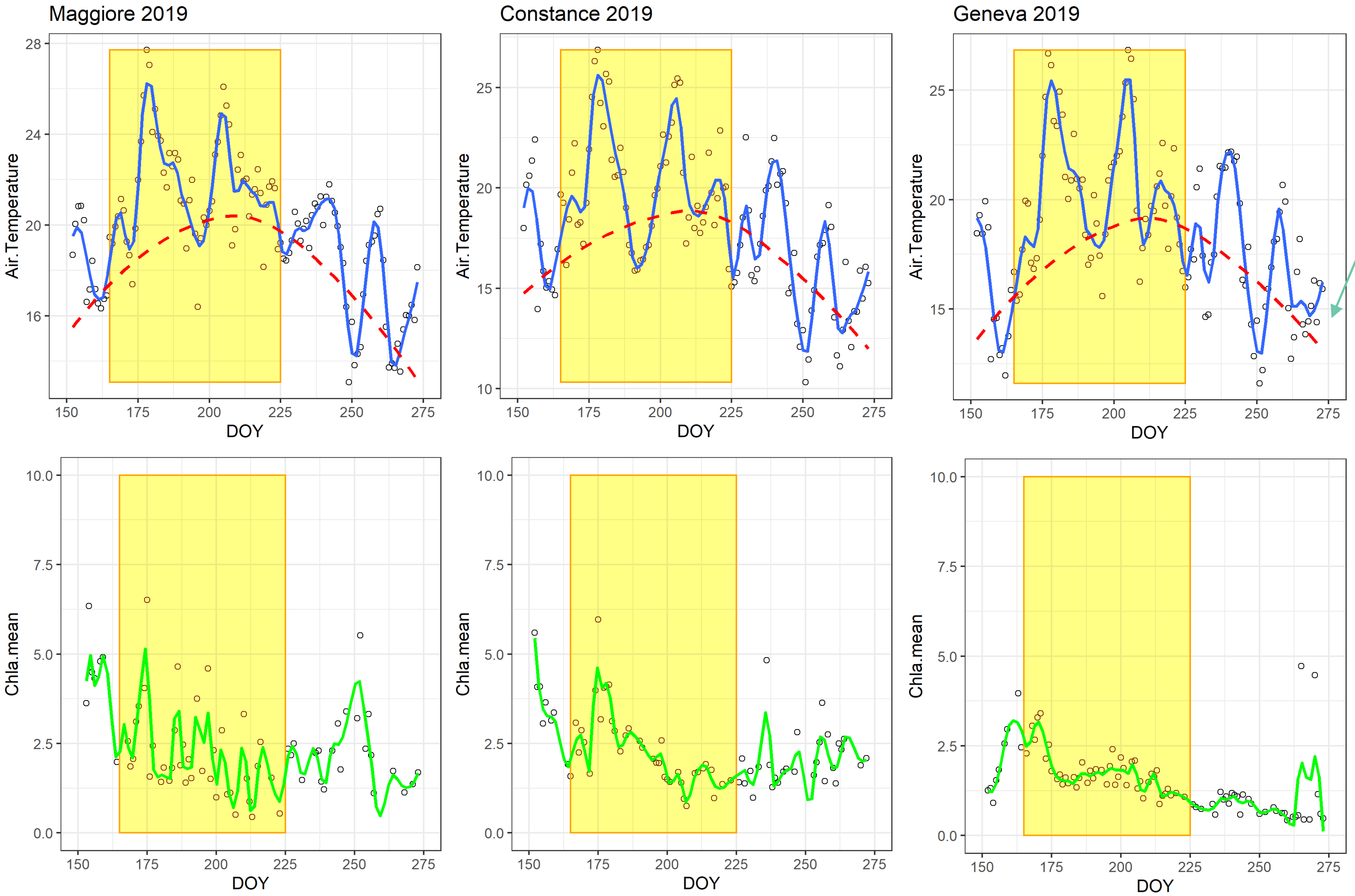


average air temperature (1981-2010)

Yellow box highlights 14 June – 13 August

For shallow lakes, it appeared that peak temperatures during a heatwave event coincided with a decline in chl-a before increasing again following the storm event

CCI LAKES – Heatwave: results in deep lakes



average air temperature (1981-2010)

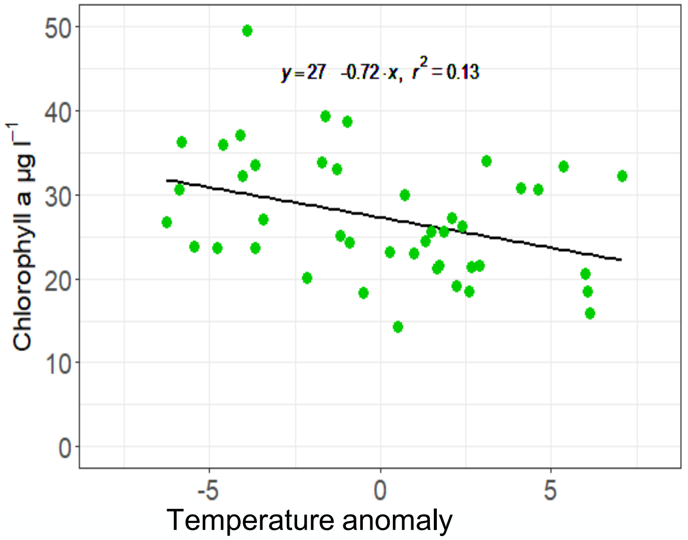
Yellow box highlights 14 June – 13 August

In the deeper nutrient-poorer lakes, the chl-a was always relatively low but nonetheless an increase was visible in synchrony with rising temperatures from the first but not the second heatwave in 2019

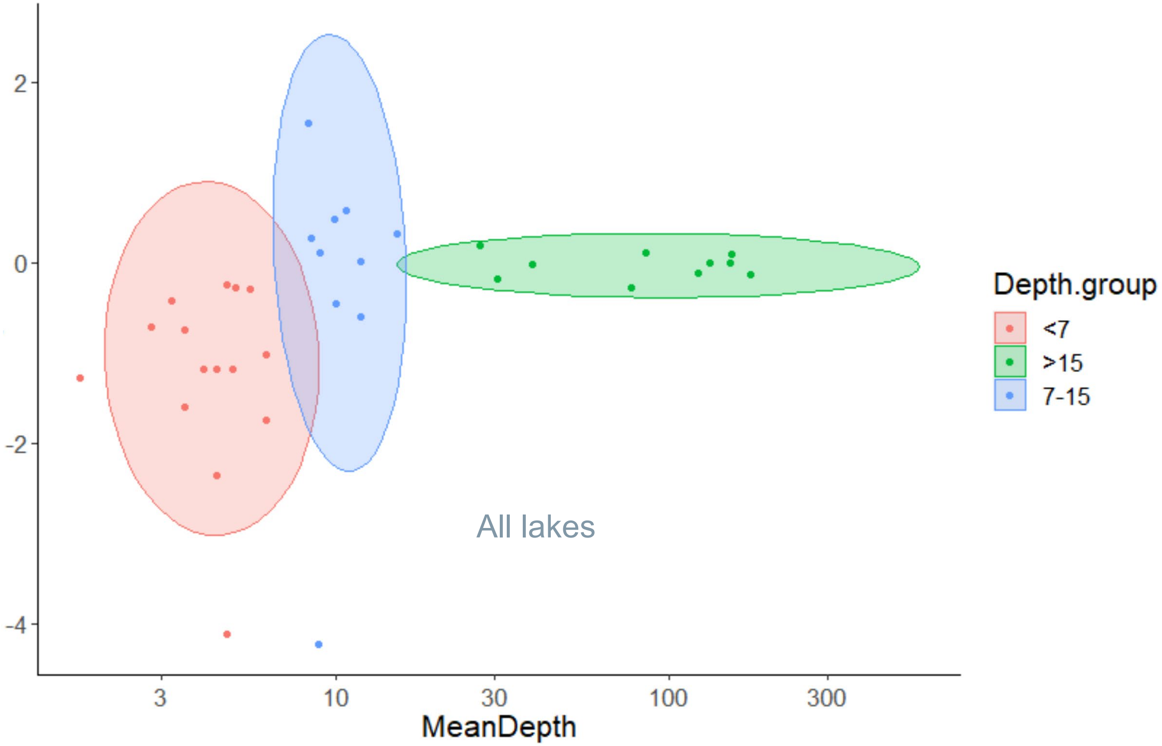
CCI LAKES – Heatwave: results

To generalize the response to heatwaves and subsequent low pressure systems (storms) chlorophyll-a for each lake was regressed against the temperature anomaly

Negative slopes indicates a decrease in chl-a with an increase in temperature anomaly whereas a positive slope indicates an increase with temperature anomaly



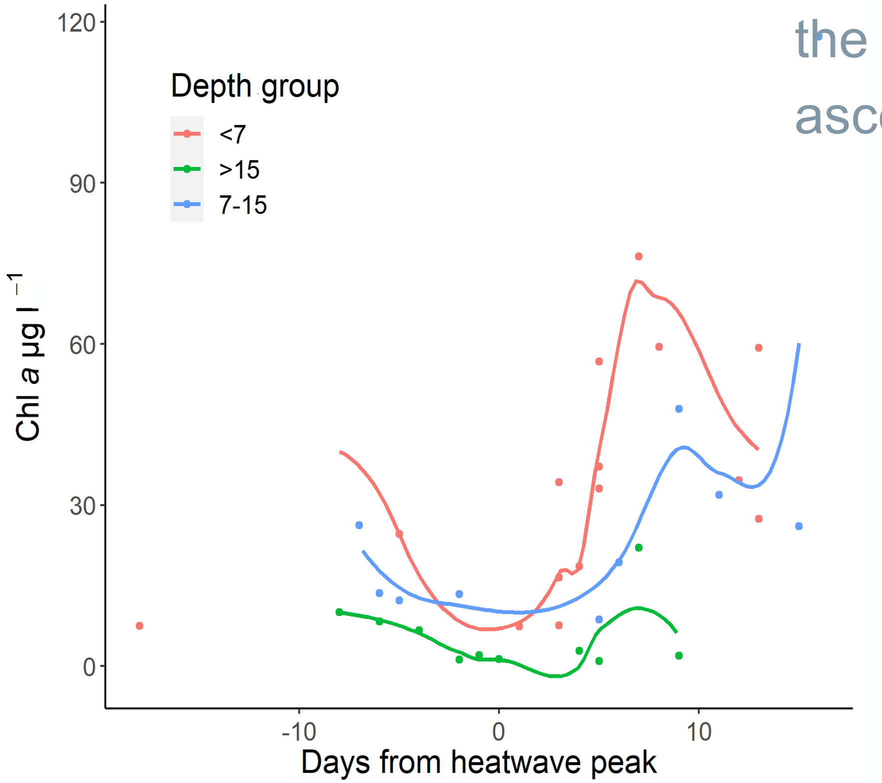
Lake Võrtsjärv



- shallow lakes were typically negative
- medium depth lakes were mixed between negative and positive
- deep lakes showed little response (slope close to zero)

CCI LAKES – Heatwave: results

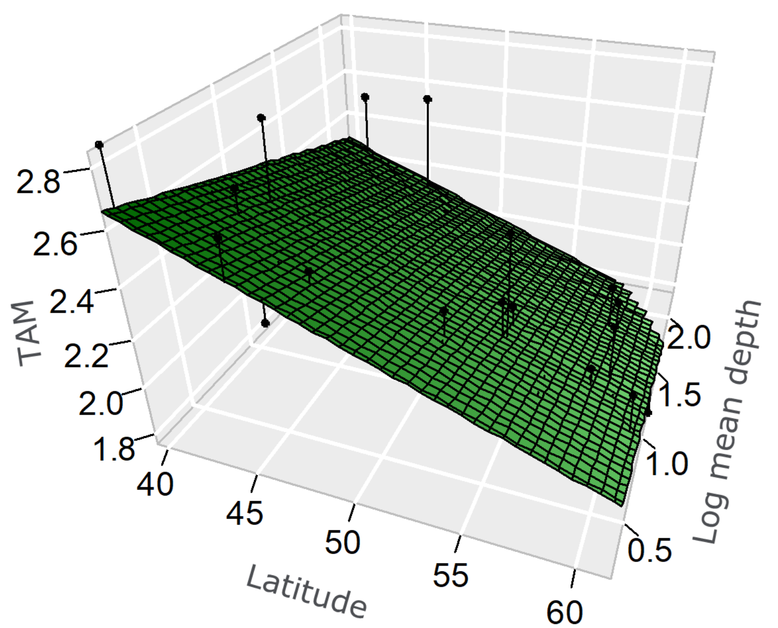
When its hotter than normal, is the Chl-a peak appearing soon or later?



Timing and concentration of the chl-a peak that occurred closest to the air temperature peak during the heatwave, either on the ascending or descending limb of the heatwave

- Shallow lakes - stronger response, delayed by 5 days after heatwave typically
- Deep lakes – Majority have chl-a peak on ascending limb of heatwave

CCI LAKES – Heatwave: results



- Time Alignment Measurement (TAM) values were calculated to indicate temporal alignment between temperature and chl-a (0 indicating perfect alignment and 3 indicating completely out of temporal alignment)
- Predicted TAM surface (on temperature and chl-a) from a multiple regression that included latitude and log mean depth

The regression indicated that shallower lakes at lower (warmer) latitudes tended to be more out of phase than deeper lakes at higher (colder) latitudes

Deep	Northern lakes	synchrony	Chl-a & Temp
Shallow	southern lakes	asynchrony	Chl-a & Temp

CCI LAKES – Heatwave: conclusions

Heatwaves and subsequent storms appeared to play an important role in structuring the phenology of the primary producers, with wider implications for lake functioning

Deep lakes respond sooner – probably higher temperature promotes stratification and ends light limitation leading to more rapid response (though limited nutrients mean only small peak)

Shallow lakes respond later – probably some photo-inhibition and / or greater response to subsequent nutrient impulse (internal / external loading) from low pressure event

Timing of response to HW depends on depth / Trophic status

… (Free et al in preparation)

CCI LAKES: Summary

- This study is part of research activities developed in the first phase of the ESA CCI LAKES project (2019-2022)
- Phase 2 (2022-2025) of the project starts next month
    - 2000 lakes, most variables included daily
    - 1km daily gridded resolution (sub/super-sampled)
    - Level/Extent as one value per lake
    - netCDF files, conformant climate vocabularies
    - Per-pixel product uncertainties
- This opens to new research opportunities to understand the role of lakes as sentinels, integrators, and regulators of climate change

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- This opens to new research opportunities to understand the role of lakes as sentinels, integrators, and regulators of climate change
- To best to support the studies which could benefit from the CCI LAKES dataset we have prepared a survey

ESA CCI LAKES: Summary

Thanks!

https://climate.esa.int/en/projects/lakes/