Supporting Information

for

Spatial and Temporal Trends in Lake Erie Hypoxia, 1987-2007

Yuntao Zhou[1,2]*, Daniel R. Obenour[2,3], Donald Scavia[2-4], Thomas H. Johengen[5]

and Anna M. Michalak[1]

consisting of 4 sections, 1 equation, 2 tables and 6 figures within 14 pages

1. Department of Global Ecology, Carnegie Institution for Science, Stanford, California 94305, USA
2. Department of Civil & Environmental Engineering, University of Michigan, Ann Arbor, Michigan 48109, USA
3. School of Natural Resources & Environment, University of Michigan, Ann Arbor, Michigan 48109, USA
4. Graham Sustainability Institute, University of Michigan, Ann Arbor, Michigan 48103, USA
5. Cooperative Institute for Limnology and Ecosystems Research, School of Natural Resources & Environment, University of Michigan, Ann Arbor, Michigan 48109, USA

* ytzhou@umich.edu, Phone: (734) 709-3253, Fax: (650) 462-5968.

S1. Locations of regular dissolved oxygen (DO) sampling

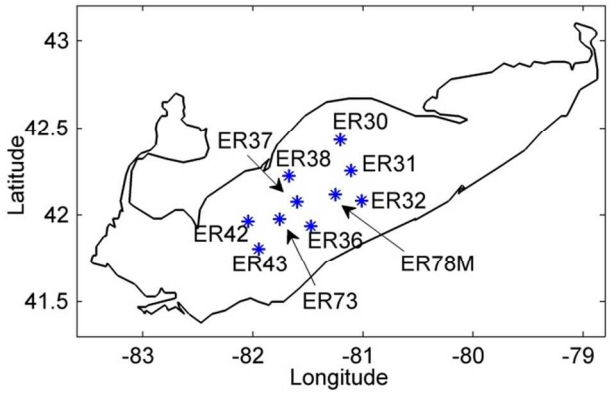


Figure S1 Regular DO measurement locations.

S2. Hypoxic extent for August and September, 1987-2007.

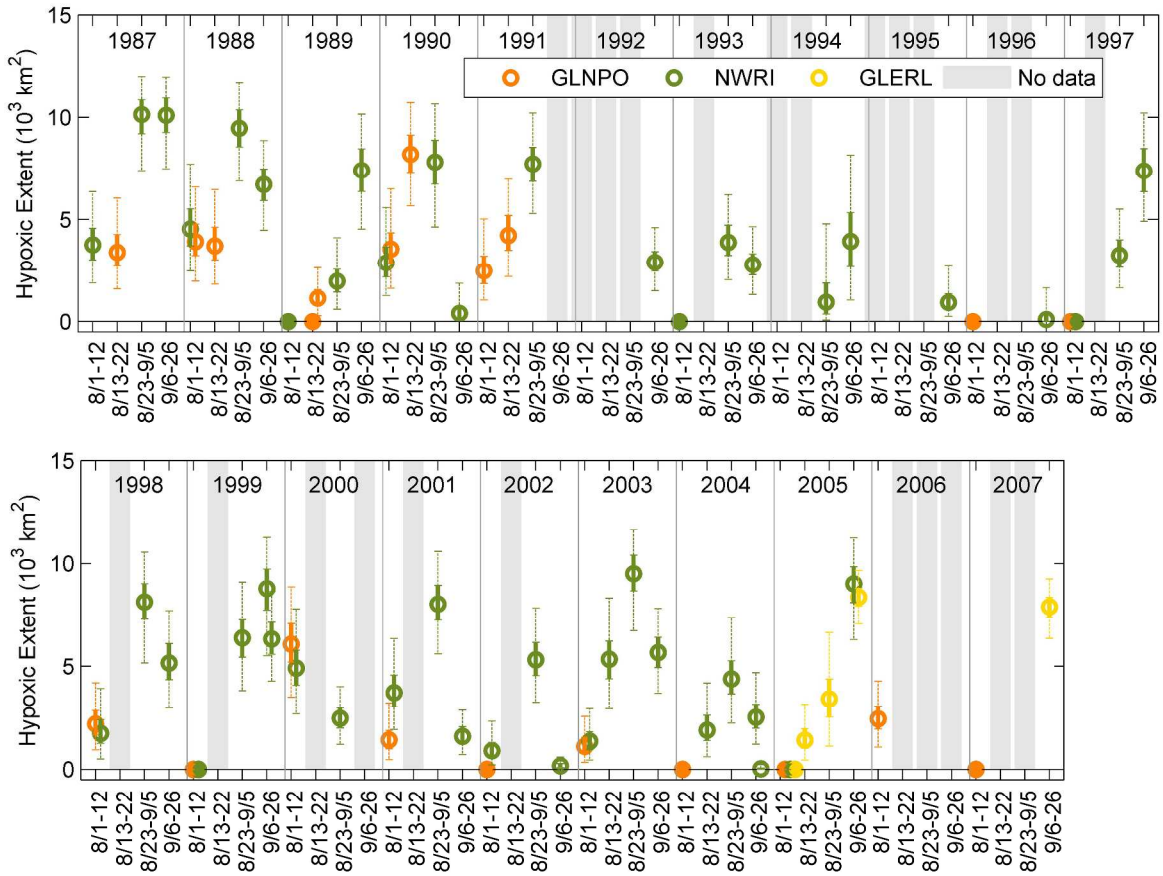


Figure S2 Plot of the median (circle), interquartile range (solid line), and 95% confidence intervals (dashed line) of the estimated hypoxic extent in early August (8/1-12), mid-August (8/13-22), late August and early September (8/23-9/5), and mid-September (9/6-26) from all available cruises with observed hypoxia from GLNPO, NWRI and GLERL for 1987-2007. The hypoxic extents of zero shown in solid circle represent cruises for which no hypoxia was observed, and periods shaded in grey represent times during which no data were available.

Table S1 Median (50th percentile), interquartile range (25th and 75th percentiles), and 95% confidence intervals (2.5th and 97.5th percentiles) of estimated hypoxic extent from all available GLNPO, NWRI and GLERL cruises for 1987-2007. This table presents the same information as that in Figure S2, but in tabular form.

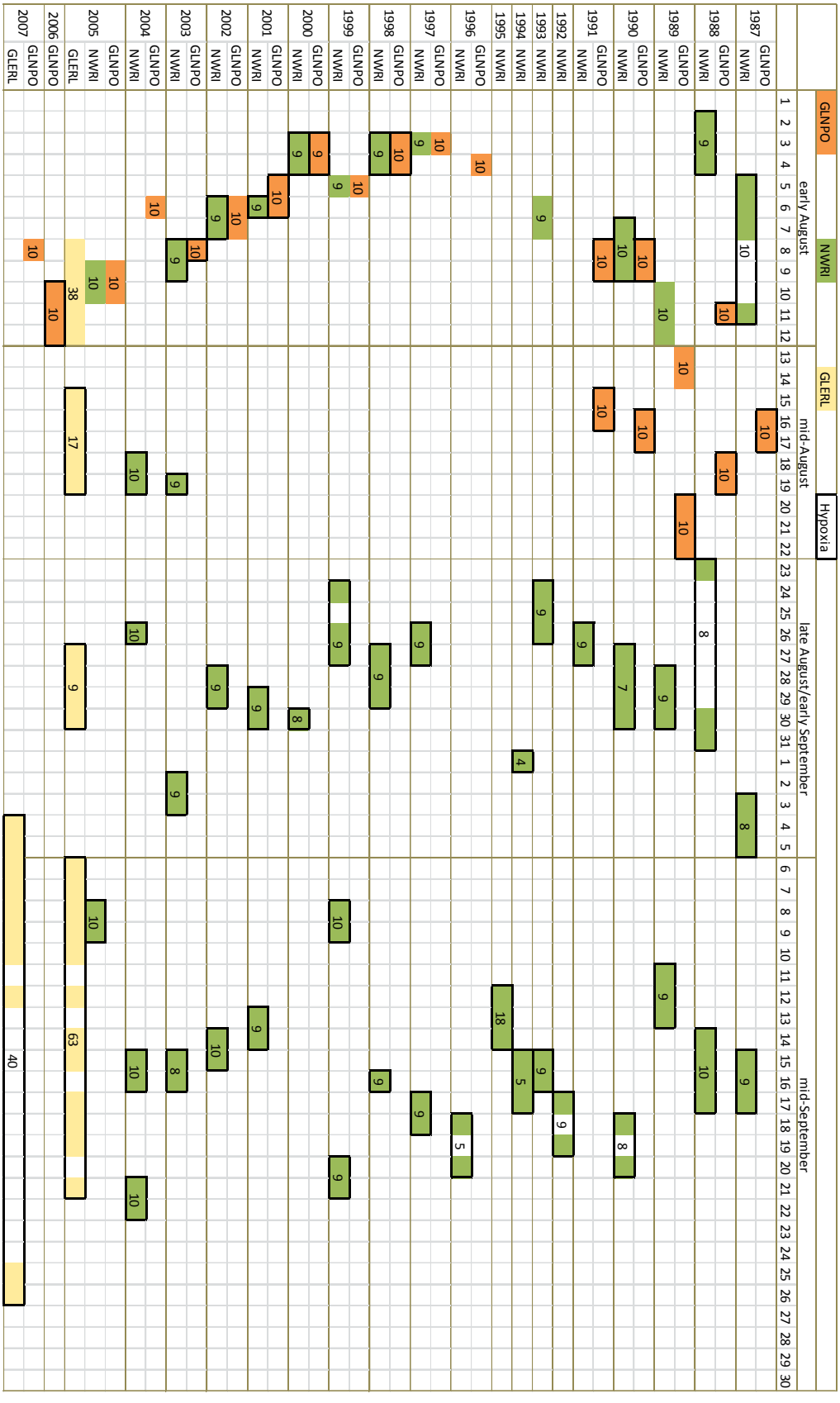
Source	Year	Month	Date	Hypoxic extent (10^3 km^2)				
				2.5%	25%	50%	75%	97.5%
NWRI	1987	Aug	5-7,11	1.90	3.02	3.77	4.56	6.34
GLNPO	1987	Aug	16-17	1.59	2.71	3.41	4.26	6.02
NWRI	1987	Sep	3-5	7.38	9.19	10.13	10.85	12.02
NWRI	1987	Sep	15-17	7.47	9.25	10.09	10.94	11.99
NWRI	1988	Aug	2-4	2.48	3.72	4.53	5.51	7.70
GLNPO	1988	Aug	11	1.97	3.23	3.93	4.77	6.57
GLNPO	1988	Aug	18-19	1.83	3.02	3.72	4.61	6.45
NWRI	1988	Aug	23,30-31	6.86	8.53	9.46	10.35	11.73
NWRI	1988	Sep	14-17	4.47	5.91	6.69	7.46	8.84
NWRI	1989	Aug	10-12	No observed hypoxia				
GLNPO	1989	Aug	13-14	No observed hypoxia				
GLNPO	1989	Aug	20-22	0.28	0.79	1.15	1.55	2.64
NWRI	1989	Aug	28-30	0.59	1.45	1.98	2.56	4.10
NWRI	1989	Sep	11-13	4.52	6.35	7.39	8.45	10.14
NWRI	1990	Aug	7-9	1.27	2.19	2.89	3.66	5.58
GLNPO	1990	Aug	8-9	1.63	2.86	3.56	4.34	6.48

Source	Year	Month	Date	Hypoxic extent (10^3 km^2)				
				2.5%	25%	50%	75%	97.5%
GLNPO	1990	Aug	16-17	5.66	7.29	8.19	9.13	10.70
NWRI	1990	Aug	27-30	4.63	6.70	7.81	8.86	10.65
NWRI	1990	Sep	18,20	0.04	0.17	0.40	0.77	1.87
GLNPO	1991	Aug	8-9	1.05	1.86	2.48	3.20	5.02
GLNPO	1991	Aug	15-16	2.20	3.49	4.23	5.18	6.95
NWRI	1991	Aug	26-27	5.29	6.85	7.71	8.52	10.20
NWRI	1992	Sep	17,19	1.51	2.47	2.91	3.43	4.59
NWRI	1993	Aug	6-7	No observed hypoxia				
NWRI	1993	Aug	24-26	2.05	3.24	3.88	4.72	6.20
NWRI	1993	Sep	15-16	1.33	2.28	2.79	3.33	4.64
NWRI	1994	Sep	1	0.06	0.37	0.95	1.88	4.78
NWRI	1994	Sep	15-17	1.05	2.69	3.94	5.33	8.13
NWRI	1995	Sep	12-15	0.24	0.62	0.94	1.36	2.72
GLNPO	1996	Aug	4	No observed hypoxia				
NWRI	1996	Sep	18,20	0.00	0.02	0.11	0.36	1.65
GLNPO	1997	Aug	3	No observed hypoxia				
NWRI	1997	Aug	3	No observed hypoxia				
NWRI	1997	Aug	26-27	1.66	2.66	3.27	4.01	5.50
NWRI	1997	Sep	17-18	4.90	6.34	7.37	8.45	10.20
GLNPO	1998	Aug	3-4	0.93	1.65	2.18	2.83	4.18

Source	Year	Month	Date	Hypoxic extent (10^3 km^2)				
				2.5%	25%	50%	75%	97.5%
NWRI	1998	Aug	3-4	0.49	1.24	1.73	2.38	3.91
NWRI	1998	Aug	27-29	5.15	7.27	8.12	9.00	10.53
NWRI	1998	Sep	16	2.97	4.34	5.15	6.09	7.70
GLNPO	1999	Aug	5	No observed hypoxia				
NWRI	1999	Aug	5	No observed hypoxia				
NWRI	1999	Aug	24, 26-27	3.81	5.42	6.35	7.22	9.09
NWRI	1999	Sep	8-9	5.50	7.71	8.77	9.72	11.25
NWRI	1999	Sep	20-21	4.27	5.56	6.30	7.11	8.63
GLNPO	2000	Aug	3-4	3.49	5.19	6.06	7.04	8.85
NWRI	2000	Aug	3-4	2.68	4.07	4.90	5.76	7.77
NWRI	2000	Aug	30	1.20	1.98	2.46	2.96	4.01
GLNPO	2001	Aug	5-6	0.47	0.99	1.41	1.88	3.21
NWRI	2001	Aug	6	1.91	3.02	3.72	4.56	6.31
NWRI	2001	Aug	29-30	5.59	7.21	8.02	8.92	10.57
NWRI	2001	Sep	13-14	0.71	1.26	1.59	2.05	2.86
GLNPO	2002	Aug	6-7	No observed hypoxia				
NWRI	2002	Aug	6-7	0.20	0.57	0.89	1.29	2.31
NWRI	2002	Aug	28-29	3.24	4.53	5.30	6.13	7.82
NWRI	2002	Sep	14-15	0.02	0.09	0.16	0.27	0.59
GLNPO	2003	Aug	8	0.32	0.77	1.10	1.54	2.55

Source	Year	Month	Date	Hypoxic extent (10^3 km^2)				
				2.5%	25%	50%	75%	97.5%
NWRI	2003	Aug	8-9	0.45	0.94	1.35	1.81	2.92
NWRI	2003	Aug	19	2.92	4.38	5.33	6.20	8.31
NWRI	2003	Sep	2-3	6.70	8.65	9.50	10.39	11.67
NWRI	2003	Sep	15-16	3.69	4.92	5.65	6.38	7.79
GLNPO	2004	Aug	6	No observed hypoxia				
NWRI	2004	Aug	18-19	0.59	1.38	1.89	2.59	4.16
NWRI	2004	Aug	26	2.22	3.65	4.38	5.25	7.35
NWRI	2004	Sep	15-16	1.21	1.98	2.51	3.14	4.67
NWRI	2004	Sep	21-22	0.00	0.01	0.03	0.07	0.22
GLNPO	2005	Aug	9-10	No observed hypoxia				
NWRI	2005	Aug	9-10	No observed hypoxia				
GLERL	2005	Aug	8-12	No observed hypoxia				
GLERL	2005	Aug	15-19	0.45	1.02	1.41	1.95	3.15
GLERL	2005	Aug	27-30	1.12	2.52	3.42	4.36	6.61
NWRI	2005	Sep	8-9	6.27	8.08	9.00	9.84	11.24
GLERL	2005	Sep	6-21	7.02	7.91	8.36	8.78	9.66
GLNPO	2006	Aug	10-12	1.07	1.94	2.43	3.05	4.26
GLNPO	2007	Aug	8	No observed hypoxia				
GLERL	2007	Sep	4-26	6.33	7.35	7.89	8.34	9.24

45 **Table S2** Dates and total number of central basin DO measurements for all available GLNPO,
46 NWRI, and GLERL cruises. The shading indicates the data source and the date(s) when
47 sampling occurred in the central basin. The number for each cruise represents the number of
48 observations in the central basin. Cruises that observed hypoxia (i.e. that had at least one
49 observation below 2 mg/l) are outlined in black.


GLNPO
NWRI
GLERL
Hypoxia
early August
mid-August
late August/early September
mid-September
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30
1987 GLNPO NWRI
1988 NWRI GLNPO
1989 NWRI GLNPO
1990 GLNPO NWRI
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2001 NWRI GLNPO
2002 GLNPO NWRI
2003 NWRI GLNPO
2004 GLNPO NWRI
2005 NWRI GLNPO GLERL
2006 GLNPO
2007 GLERL GLNPO

S3. Estimated DO concentrations in August and September from the cruise with the observed maximum hypoxic extent from 1987-2007

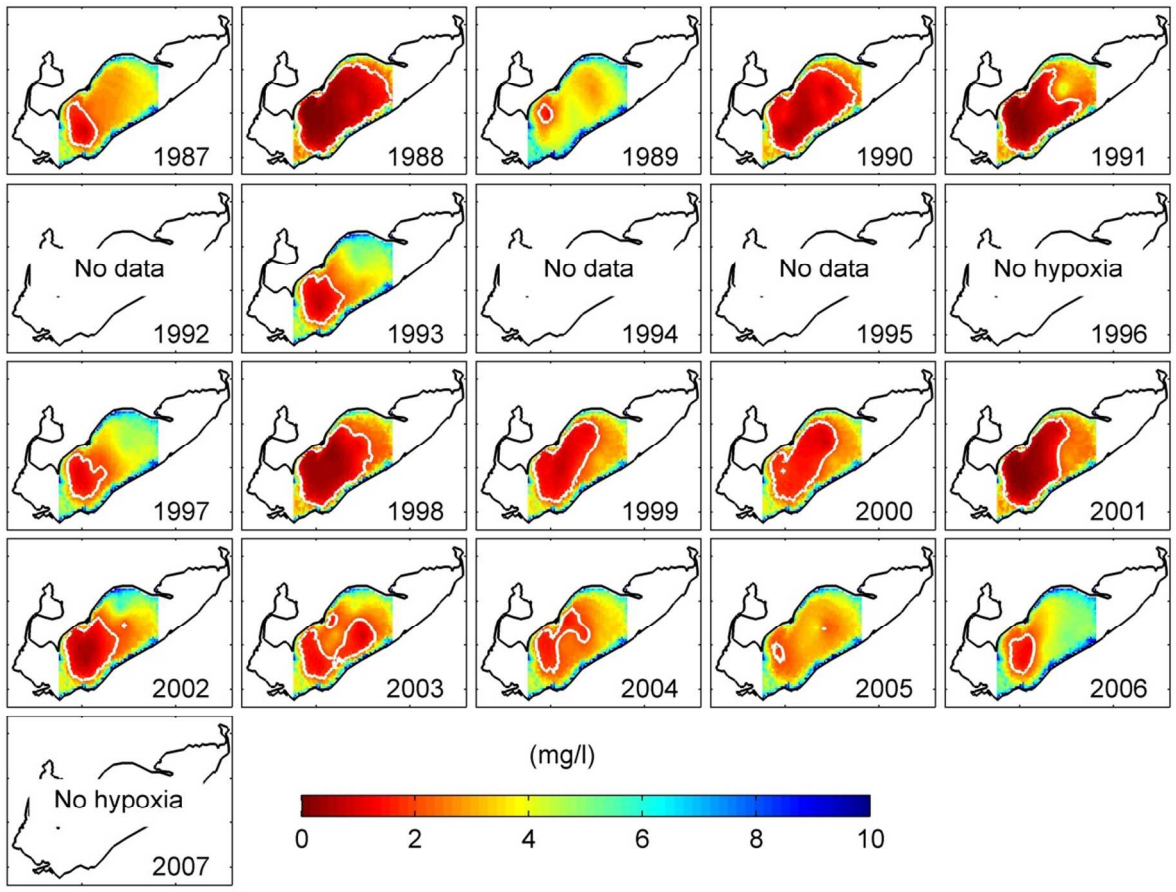

Figure S3 Estimated August DO concentrations using UK from the cruise with the observed maximum extent in each year. The hypoxic zone (DO < 2mg/l) is outlined in white.

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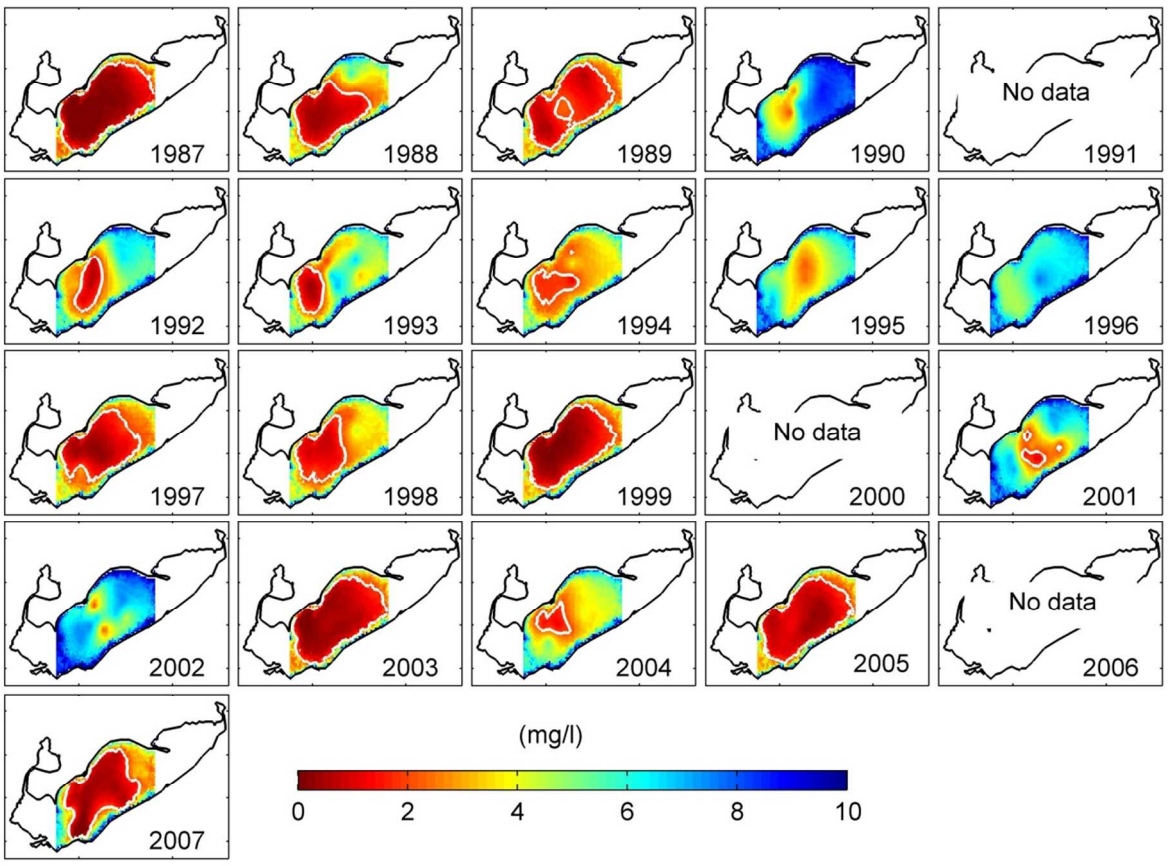

Figure S4 Estimated September DO concentrations using UK from the cruise with the observed maximum extent in each year. The hypoxic zone (DO < 2mg/l) is outlined in white.

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S4. Comparison of Universal Kriging (UK) results to Ordinary Kriging (OK)

Unlike UK, OK does not use auxiliary variables, and the spatial structure representing the DO distribution is obtained only from the *in situ* measurements. In this case, the matrix $\mathbf{X_z}$ includes only categorical variables:

$$\mathbf{X_z} = \begin{bmatrix} \mathbf{1}_1 & \cdots & \emptyset \\ \vdots & \ddots & \vdots \\ \emptyset & \cdots & \mathbf{1}_y \end{bmatrix} \quad \text{(S1)}$$

such that the (spatial) mean DO concentration is constant for each cruise but can differ from cruise to cruise. $\mathbf{X}_s$ is modified similarly, and eqs 5-10 remain otherwise unchanged.

The benefit of including the auxiliary variables in UK relative to relying solely on the DO observations as in OK is illustrated in Figure S5 for September 1998. Because areas close to eastern basin are generally not hypoxic, the hypoxic extent represented in UK (Figure S5b) is likely more representative of the actual DO distribution compared to that from OK (Figure S5a). Both methods have the lowest uncertainties near the measurement locations, but the uncertainties for OK are generally higher than those for UK away from the measurement locations (Figures S5c and S5d).

The superior performance of UK was further confirmed through cross validation using data from 2005, when substantially more DO observations are available (Figure S6). To compare the methods, we used DO measurements at the ten locations (Figure S6a) that are sampled in most years to predict DO throughout the central basin, and then compared the estimated DO distributions (Figure S6c for UK; Figure S6b for OK) with estimates obtained using the expanded dataset of 63 observations (Figures S6d and S6e). The shape of the hypoxic area derived from the limited set of ten observations using UK is relatively consistent with the more

extensive observations (Figure S6d) and associated estimates (Figure S6e), whereas the hypoxic area predicted by OK using only the limited dataset (Figure S6b) deviates from the GLERL observations and associated estimates. Overall, UK provides more reliable estimates, and with lower uncertainties, relative to OK.

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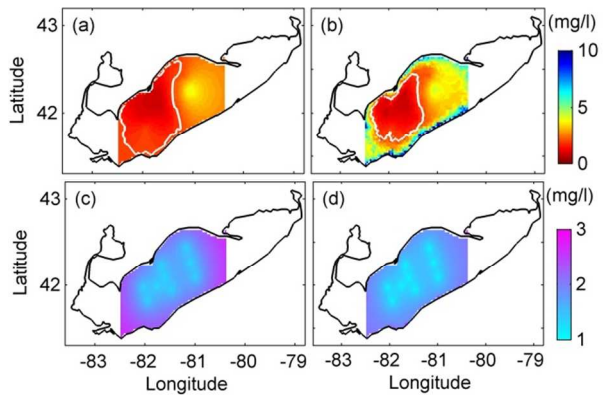

Figure S5 Estimated DO concentration for September 1998 using (a) OK and (b) UK; Kriging uncertainty (expressed as one standard deviation) using (c) OK and (d) UK. The white line defines the boundary of the hypoxic zone (DO<2mg/l).

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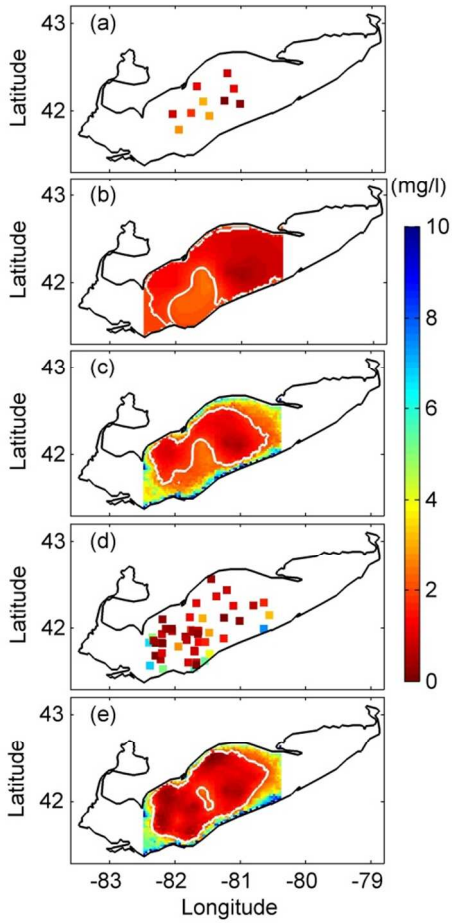

Figure S6 Validation results for September 2005. Best estimate of DO concentration obtained from OK (panel b) and UK (panel c), using only the 10 measurement locations available in most years (panel a). All available observations for September 2005 are presented in panel (d). The estimated hypoxic extent using all the available observations is presented in panel (e).

101