Transparency, geomorphology, and mixing regime explain variability in trends in lake temperature and stratification across northeastern North America (1975 - 2012)

David C. Richardson[1*], Stephanie J. Melle[2], Rachel M. Pilla[3a], Amy L. Hetherington[4], Lesley B. Knoll[5], Craig E. Williamson[3b], Benjamin M. Kraemer[6,7], James R. Jackson[8a], Elizabeth C. Long[9], Karen Moore[10], Lars G. Rudstam[8b], James A. Rusak[11], Jasmine E. Saros[12], Sapna Sharma[13], Kristin E. Strock[14], Kathleen C. Weathers[15], Courtney R. Wigdahl-Perry[16]

[1] SUNY New Paltz; 1 Hawk Drive; New Paltz, New York 12561, US; richardsond@newpaltz.edu
[2] Ryerson University; 350 Victoria Street; Toronto, Ontario M5B 2K3, CA; stephanie.melles@ryerson.ca
[3] Miami University, Department of Biology; 700 E High Street; Oxford, Ohio 45056, US; [a]pillarm@miamioh.edu, [b]willia85@miamioh.edu
[4] Virginia Polytechnic Institute and State University; 2011 Derring Hall; 926 West Campus Drive; Blacksburg, Virginia 24061, US; amyheth@vt.edu
[5] University of Minnesota Twin Cities; Itasca Biological Station and Laboratories; 28131 University Circle; Lake Itasca, Minnesota 56470, US; lbknoll@umn.edu
[6] University of Wisconsin-Madison, 680 North Park Street, Madison, Wisconsin 53706, US
[7] Leibniz Institute of Freshwater Ecology and Inland Fisheries, Müggelseedamm 310, Berlin, Germany 12587, DE; ben.m.kraemer@gmail.com
[8] Cornell University Biological Field Station, Department of Natural Resources, 900 Shackelton Point Road, Bridgeport, New York 13030, US; [a]jrj26@cornell.edu, [b]lgr1@cornell.edu
[9] Mohonk Preserve, Daniel Smiley Research Center, P.O. Box 715, New Paltz, New York 12561, US; elong@mohonkpreserve.org
[10] New York City Department of Environmental Protection, 71 Smith Avenue
Kingston, New York 12401, US; karenmoore@dep.nyc.gov
[11] Dorset Environmental Science Centre, Ontario Ministry of the Environment and Climate Change, P.O. Box 39, Dorset, Ontario, P0A1E0, CA; Jim.Rusak@ontario.ca
[12] University of Maine, 137 Sawyer Research Center, Orono, ME 04401, US; jasmine.saros@maine.edu
[13] Department of Biology, York University, Toronto, Ontario M3P1J3, CA; sharma11@yorku.ca
[14] Dickinson College, 28 North College Street, Carlisle, Pennsylvania 17013, US; strockk@dickinson.edu
[15] Cary Institute of Ecosystem Studies, Box AB, Millbrook, NY 12545, US; weathersk@caryinstitute.org
[16] State University of New York at Fredonia, 280 Central Avenue, Fredonia, NY 14063, US; courtney.wigdahl@fredonia.edu
* Correspondence: richardsond@newpaltz.edu; Tel.: +01-845-257-3805

Supporting Information

Figure S1. Histograms of lake surface area, maximum depth, and deepwater depths relative to maximum depth. Figure S2: Principal component analysis of all explanatory variables, Figure S3: Linear regression between near-surface temperature trends and deepwater temperature trends, Figure S4: Boosted regression tree model estimates compared against Sens Slopes for each response slope, Figure S5: Maps of deepwater temperature trends in the NENA region, Figure S6: Maps of mean lake temperature trends in the NENA region

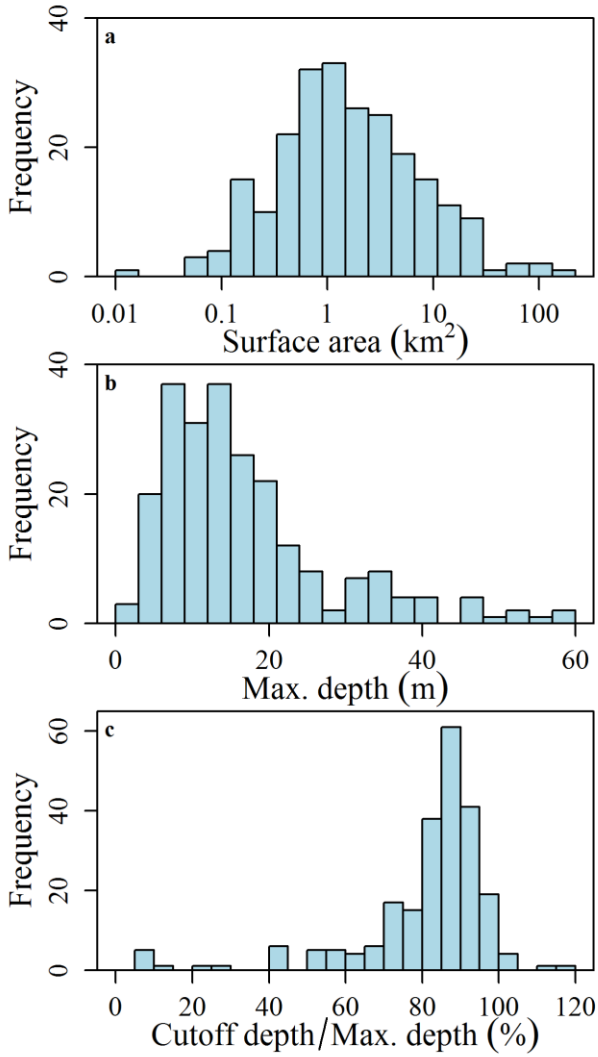

Figure S1. The distributions of (a) surface area (note the log scale), (b) maximum depth, and (c) the percent of cutoff for deepwater temperature relative to maximum depth for all 231 lakes in the study across both 1975 and 1985 cohorts. See Table S1 for individual lake metadata.

Principal component analysis - To account for the collinearity between explanatory variables, we performed a Principal Component Analysis (PCA) on all ten lake descriptors (Table 1). We used selected principal components with eigenvectors greater than one for interpretation. The top three PCs for each cohort explained 73% of total variance in explanatory variables (Fig. S2). Each of the three significant components provides an index of lake characteristics along three dimensions. The first component is an index of increasing water clarity (Secchi) and lake depth, which in the early cohort was also related to total phosphorous and chlorophyll *a*, and in the later cohort was more related to surface area and fetch (Supplemental Fig. 1). The second component is an index of lake size for the early cohort, whereas in the 1985 cohort PC2 captures the trophic status (TP and Chl a) of lakes. The third component represents geographic position, with distance from the coast loading most highly on this axis (Fig S2).

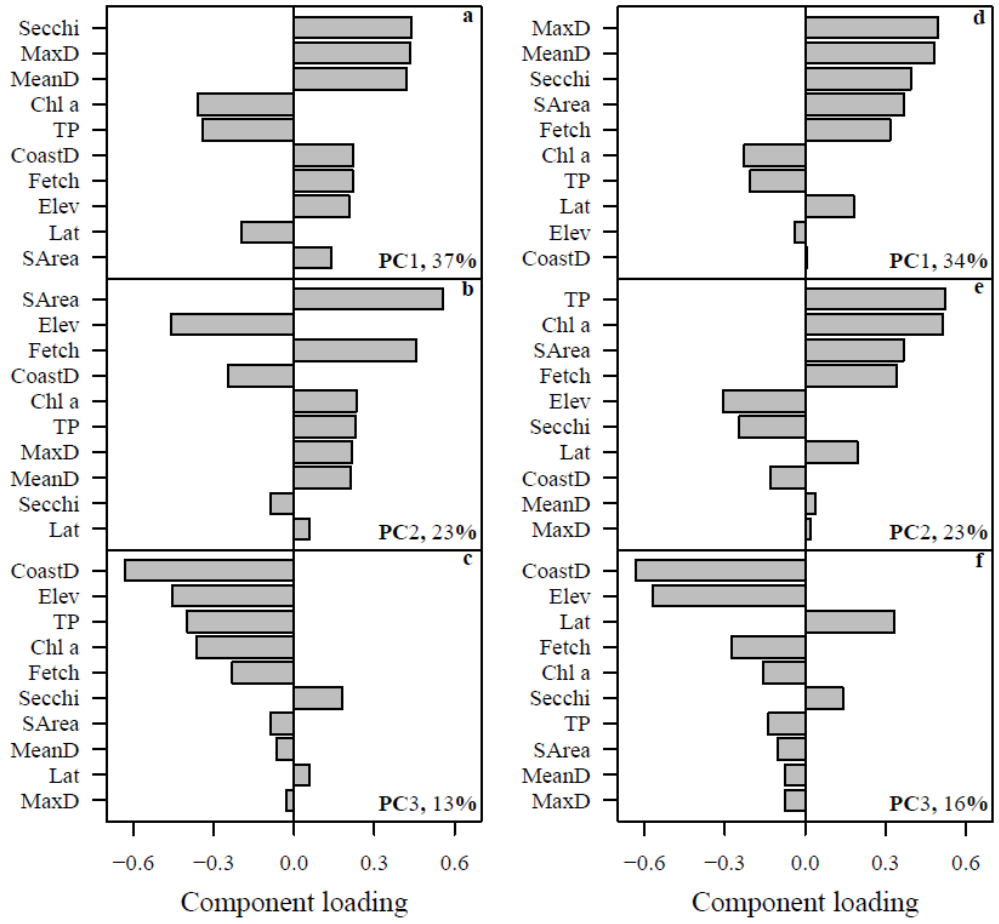

Figure S2. The principal component loadings for the top three principal components in the 1975 cohort (a-c, left column) and 1985 cohort (d-f, right column). The order of the principal component (e.g., PC1 is the first) and the proportion of overall variance that principal explains are given on each panel. The variables (y-axis) are sorted by the absolute value of the component loadings from greatest (top) to least (bottom).

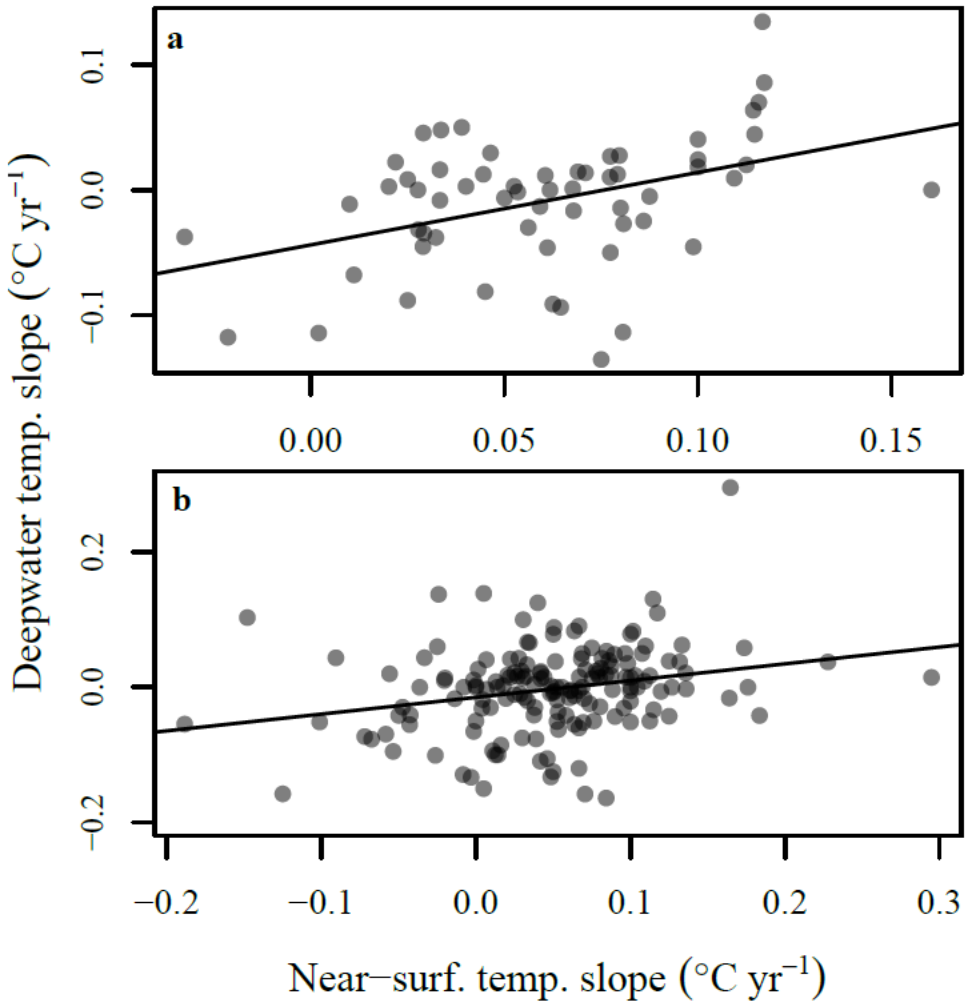

Figure S3. The linear best-fit regressions between the near-surface temperature trends and deepwater temperature trends in the (a) 1975 cohort [Deepwater trends = 0.58*near-surface trends – 0.04, t = 3.5, df = 58, R^2 = 0.16, p = 0.001] and (b) 1985 cohort [Deepwater trends = 0.25*near-surface trends – 0.01, t = 3.3, df = 162, R^2 = 0.06, p = 0.001].

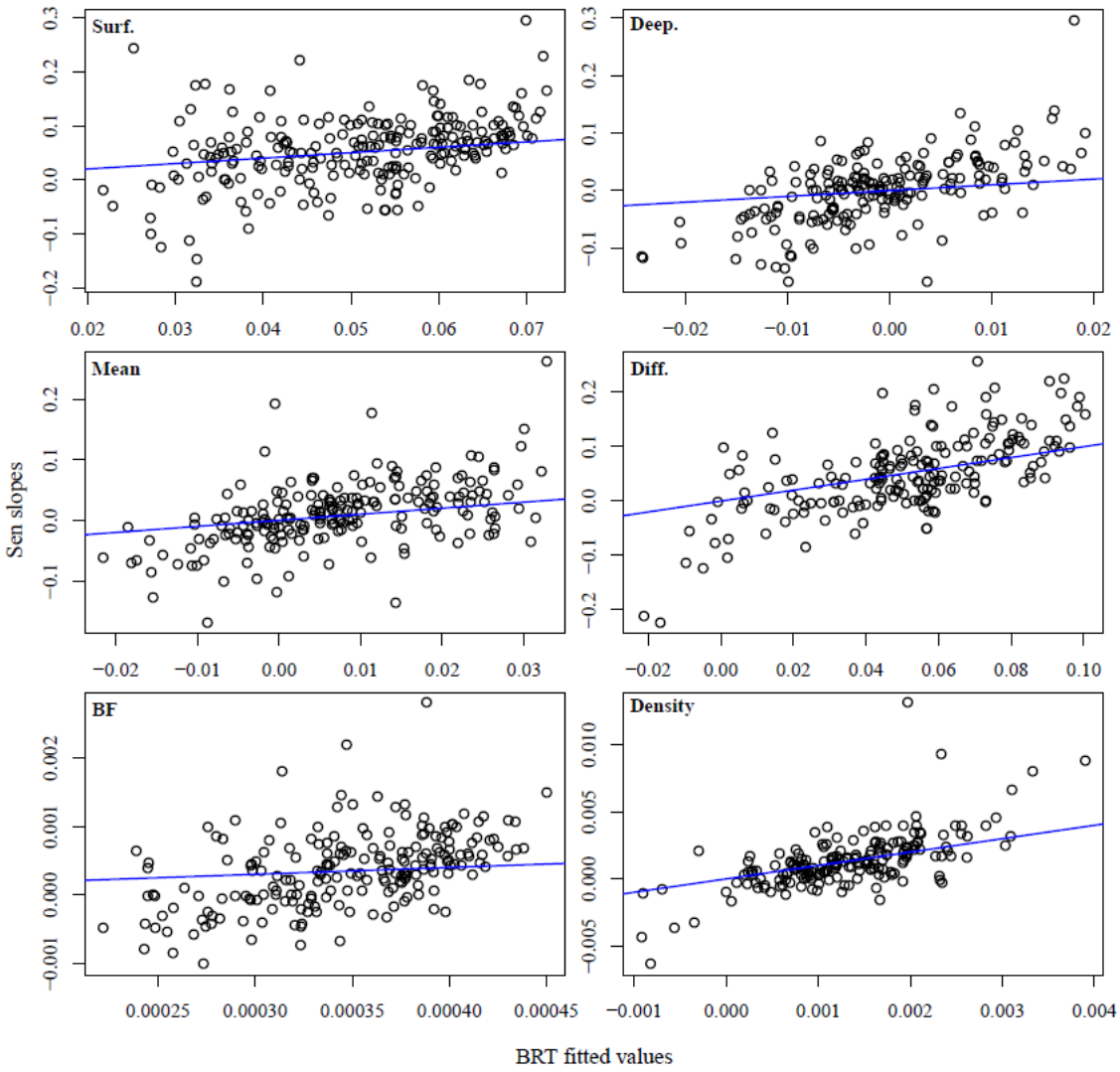

Figure S4. Boosted regression tree model estimates compared against Sens Slopes for each response slope where Surf. is the near-surface temperature (r = 0.40), Deep. is deepwater temperature (r = 0.61), Mean is the depth-weighted mean temperature (r = 0.51), Diff. is the temperature difference between near-surface and deepwater (r = 0.66), BF is the buoyancy frequency (r = 0.49), and Density is the density gradient (r = 0.67). The blue line is the 1:1 line. The correlation coefficients are also provided in Fig. 3.

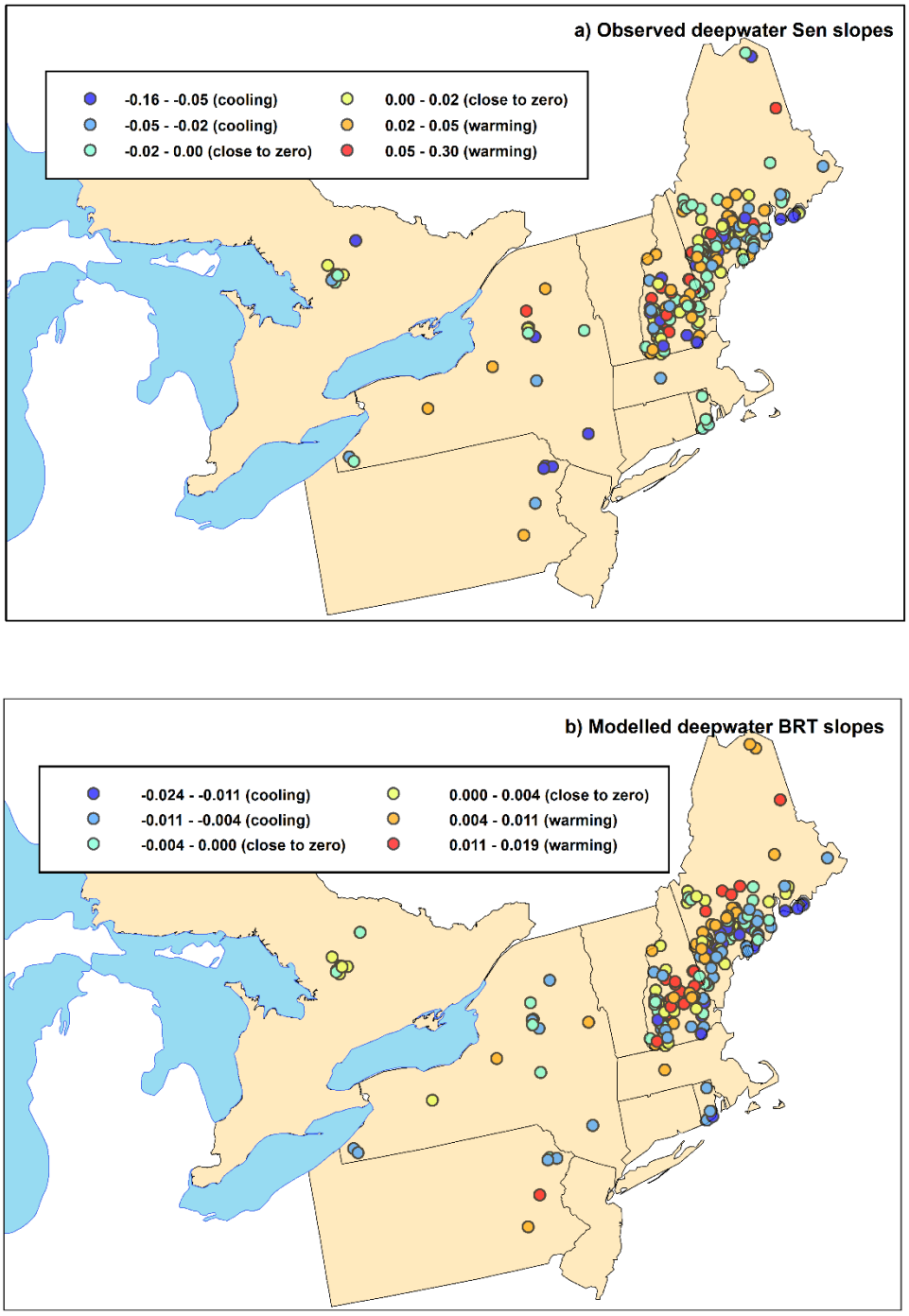

Figure S5. Maps of **deepwater temperature trends** in the NENA region over the last few decades (1985 cohort). (a) depicts observed Sen slope trends, whereas (b) depicts modelled BRT trends.

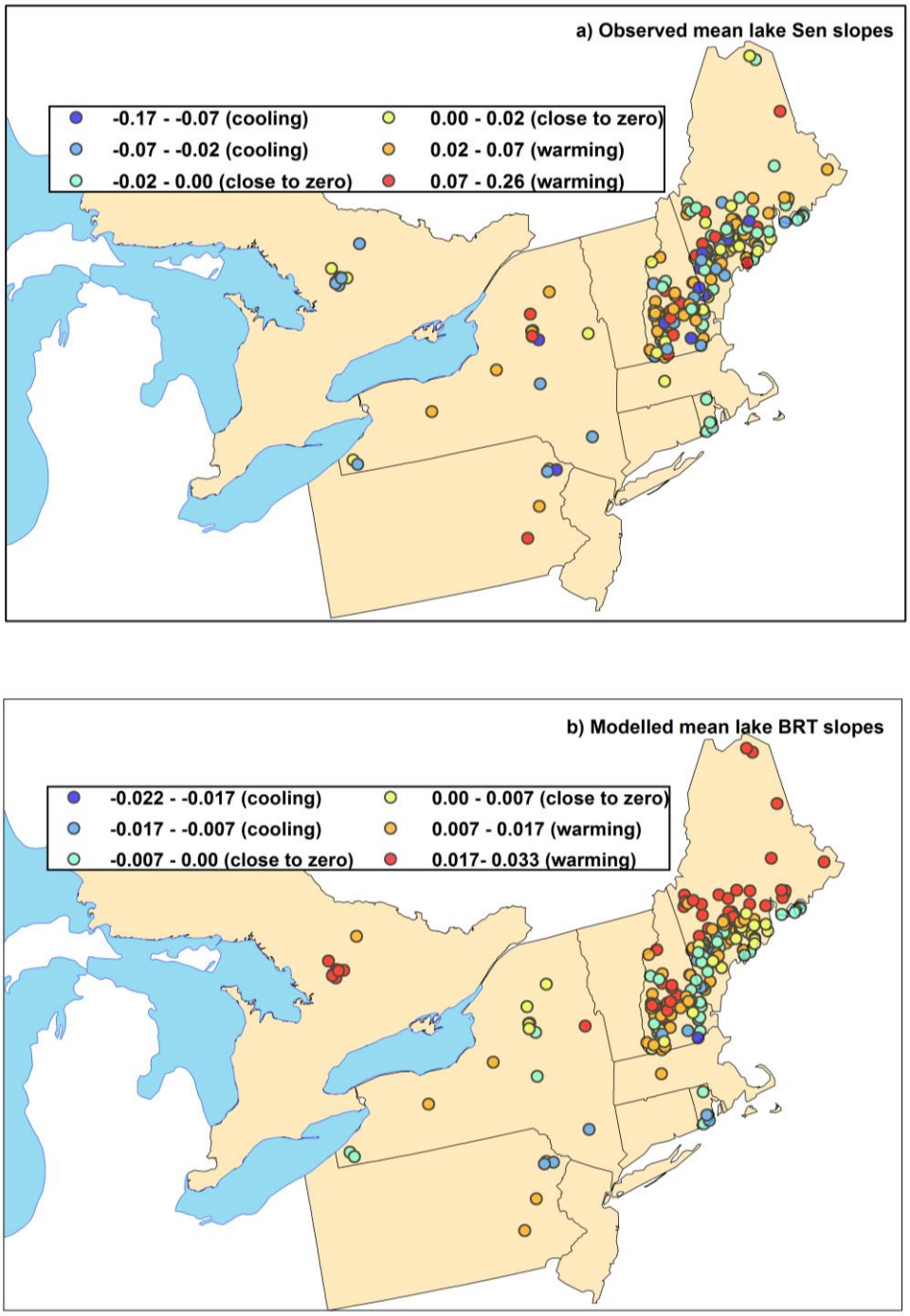

Figure S6. Maps of **mean lake temperature** trends in the NENA region over the last few decades (1985 cohort). (a) depicts observed Sen slope trends, whereas (b) depicts modelled BRT trends.