Modeling Flathead Lake:
Using 35 years of data to investigate climate change, nutrient loading, and trophic interactions

Dr. Shawn Devlin
Flathead Lake Biological Station University of Montana

ELCOM

Estuary, Lake and Coastal Ocean Model:

Hydrothermal-physical dynamics

CAEDYM

Computational Aquatic Ecosystem Dynamics Model:

Nutrient, Food Web & Trophic Dynamics

In short…

Physical Parameters

- Depth
- Bathymetry
- Landscape Hydrology

Meteorology

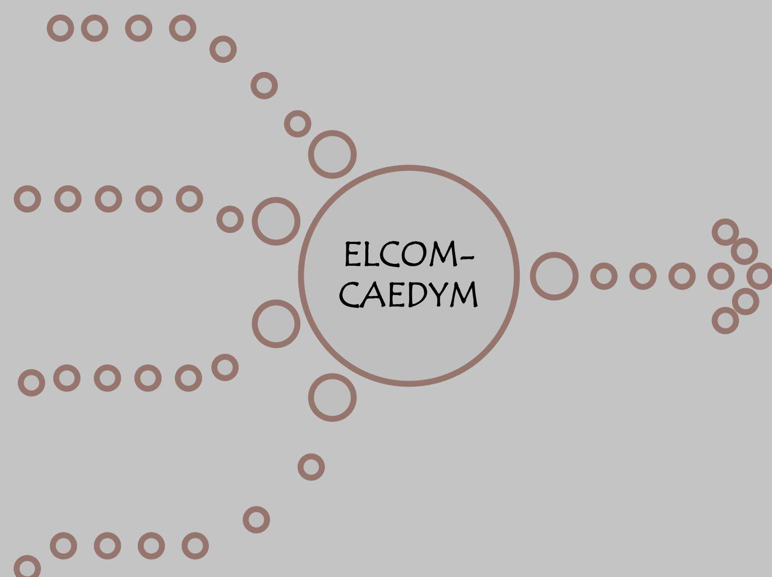
- Temperature
- Solar Radiation
- Wind Speed and Direction

Biology & Chemistry

- Nutrients
- Phytoplankton
- Zooplankton
- Fish

Ecology

- Trophic Interactions
- Behavior



A picture of Flathead Lake

In long…

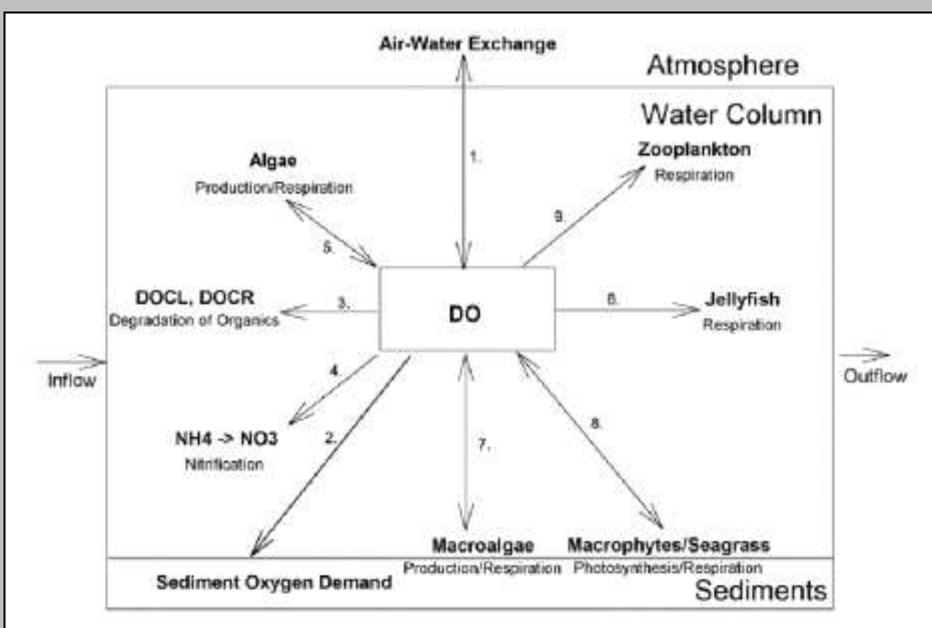
Velocities are mixed my mass such

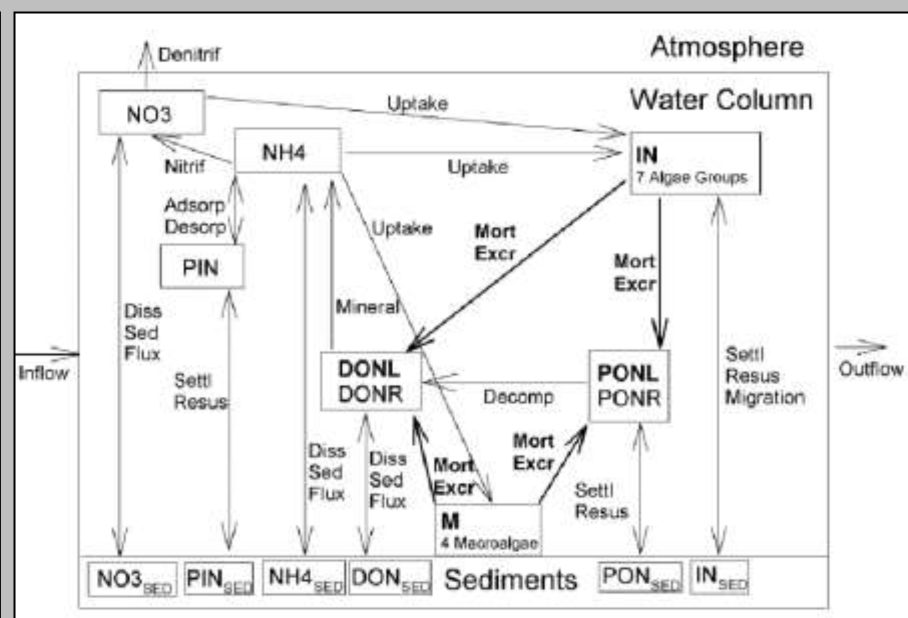
$$U'_{ml} = \frac{\rho_{ml} U_{ml} dz_{ml} + \rho_l U_l dz_l}{\rho_{ml} dz_{ml} + \rho_l dz_l} \tag{6.15}$$

.

For partial mixing only the cell being mixed and the cell at the bottom of the mixed layer are modified.

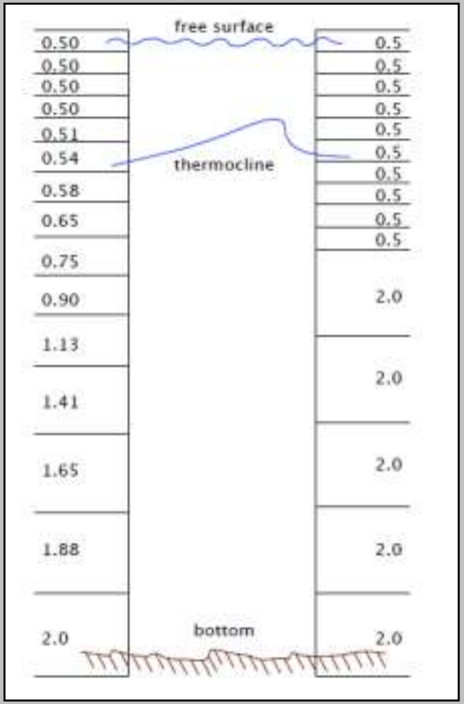
$$C_k = \begin{cases} C_{ml} & k = k_l + 2 : k_{ml-top} \\ (1-\eta_f) C_{ml} + \eta_f \frac{C_{ml} dz_k + C_l dz_l}{dz_k + dz_l} & k = k_l + 1 \\ (1-\eta_f) C_l + \eta_f \frac{C_{ml} dz_{k+1} + C_l dz_l}{dz_{k+1} + dz_l} & k = k_l \end{cases} \tag{6.16}$$

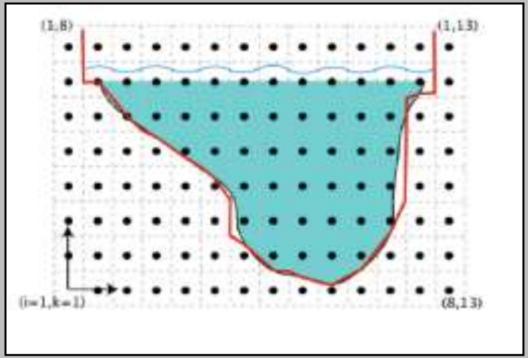


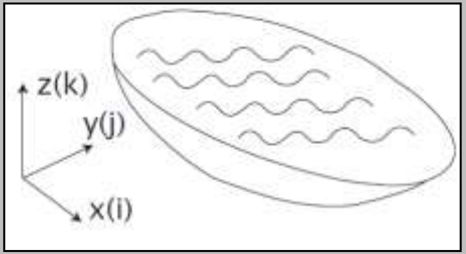


Estuary, Lake, and Coastal Ocean Model ELCOM

- 3 dimensional hydrodynamic model
- Models internal currents, mixing, and movement of energy and matter
- Inputs:
  - Bathymetry and morphology
  - River discharge and loading
  - meteorological data
- In other words: Perfect for studying Climate Change





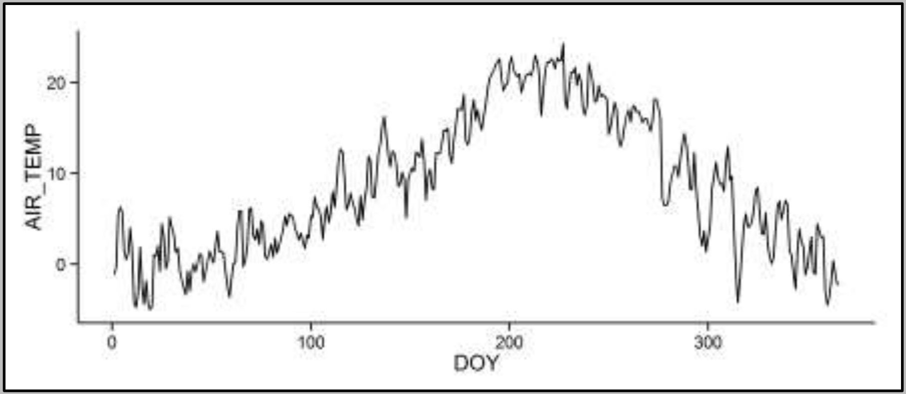


Select a Site

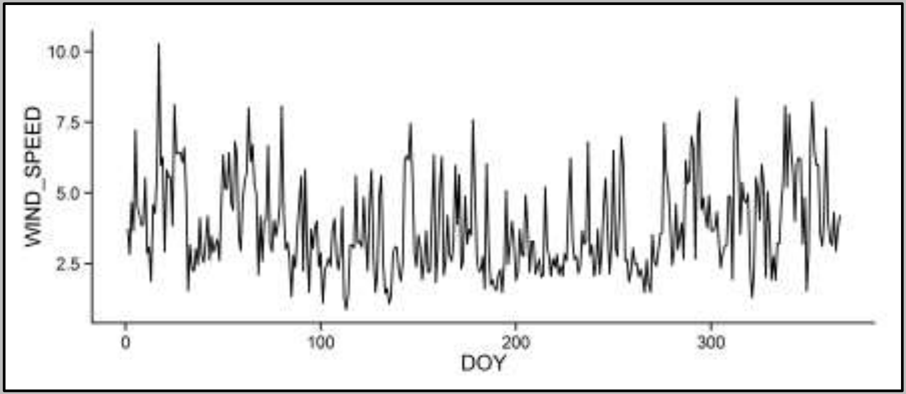
Location	Time	Air Temp	Water Temp	Rel Hum	Bar Pr	Wind Spd/Dir	Precip
FLBS Hill	11:15a	44.4 F		93.9 %	29.9 in Hg	2.8 mph E	0.19 in
West Shore	11:15a	42.9 F		95.2 %	29.9 in Hg	1.2 mph SE	0.09 in
YB Point	11:15a	46.3 F	45.9 F			8.4 mph ENE	
East Shore	11:15a	40.9 F		93.9 %	29.9 in Hg	2.2 mph N	0.35 in
Narrows	11:00a	46.0 F	47.9 F		29.9 in Hg	6.9 mph ENE	
Somers							
North Shore	5:00a	53.7 F	52.7 F		29.8 in Hg	14.2 mph ENE	

Meteorological Variables 2012

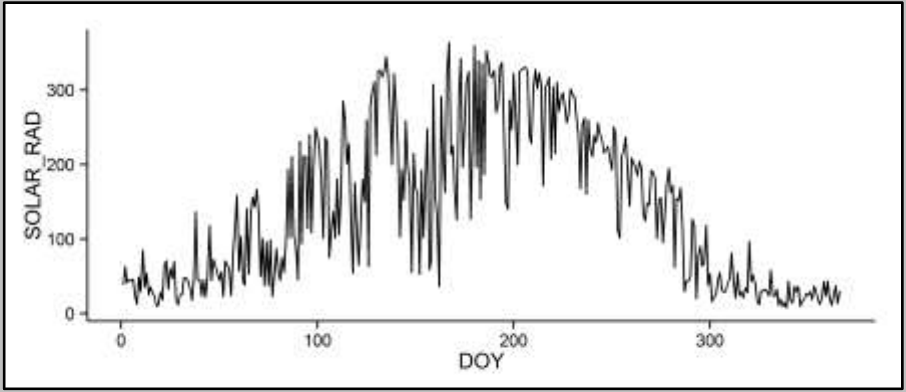
Air Temperature



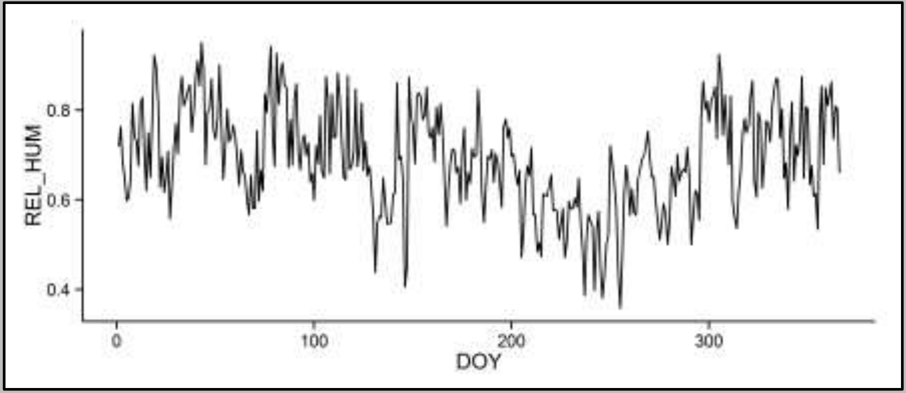
Wind Speed



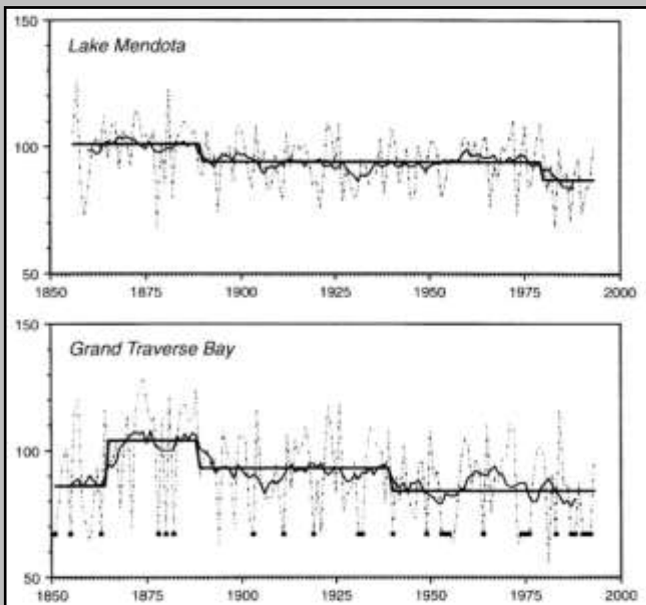
Solar Radiation

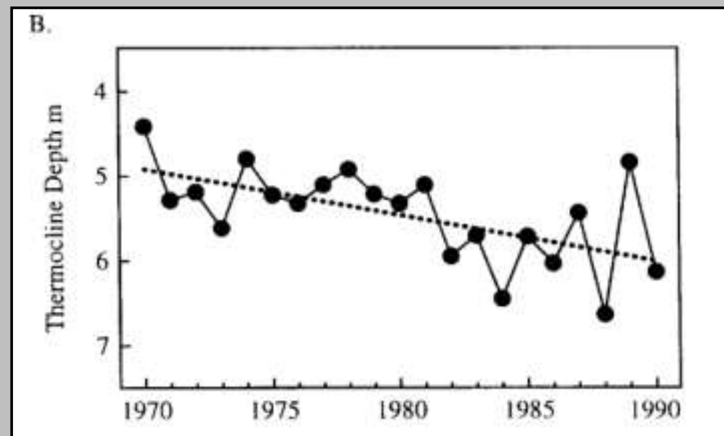


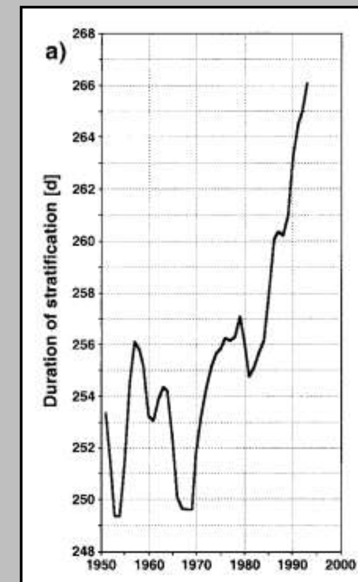
Relative Humidity

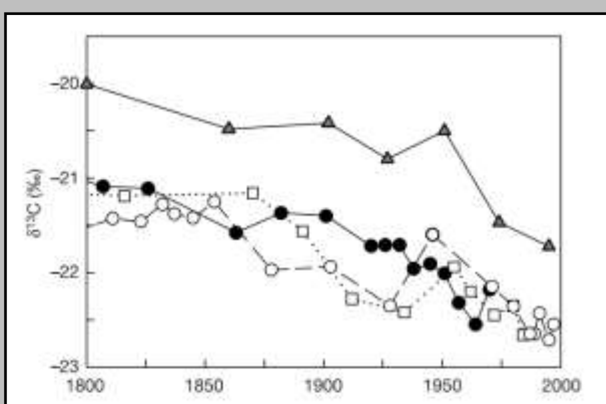


Climate change and large lakes



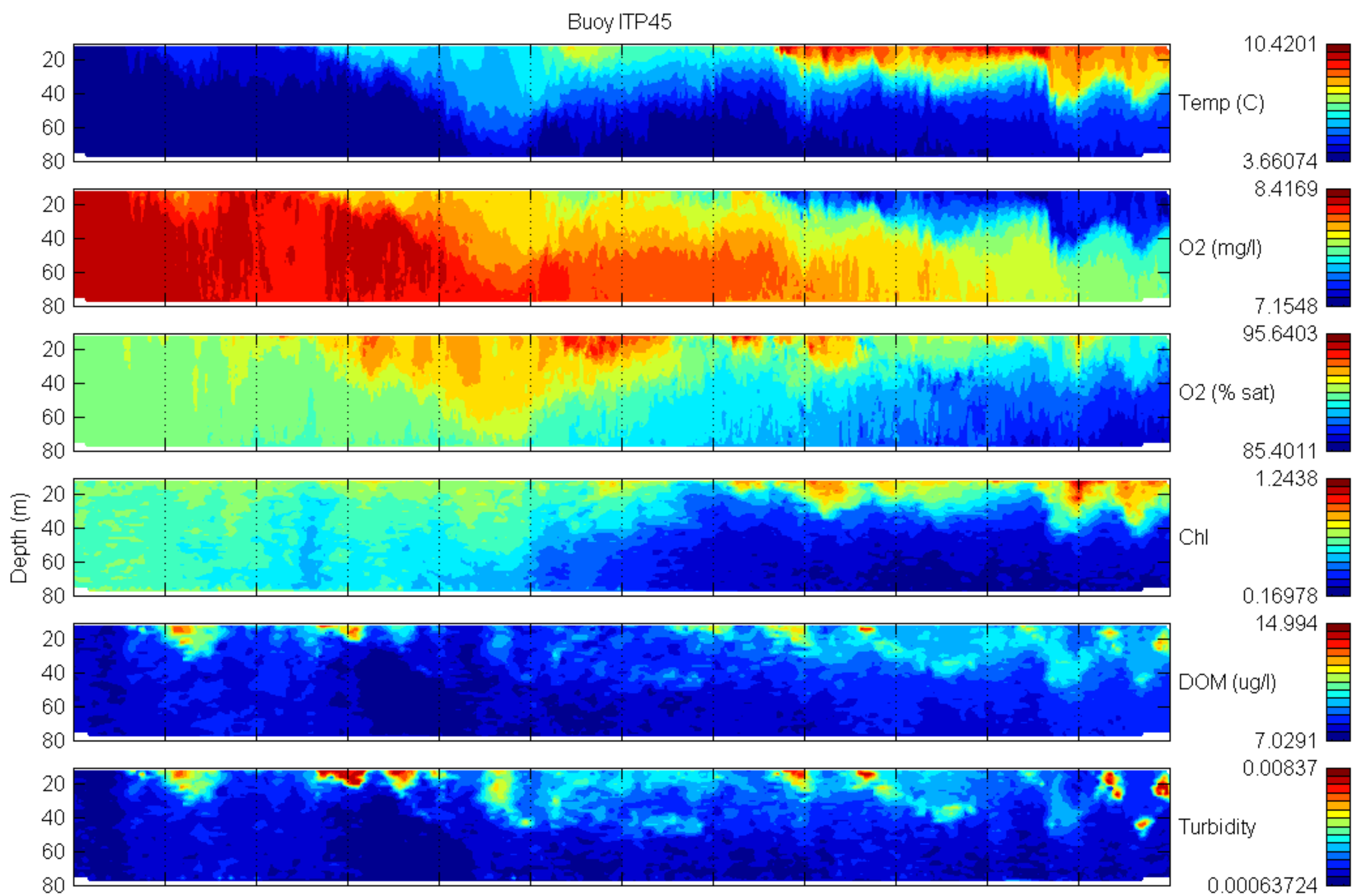




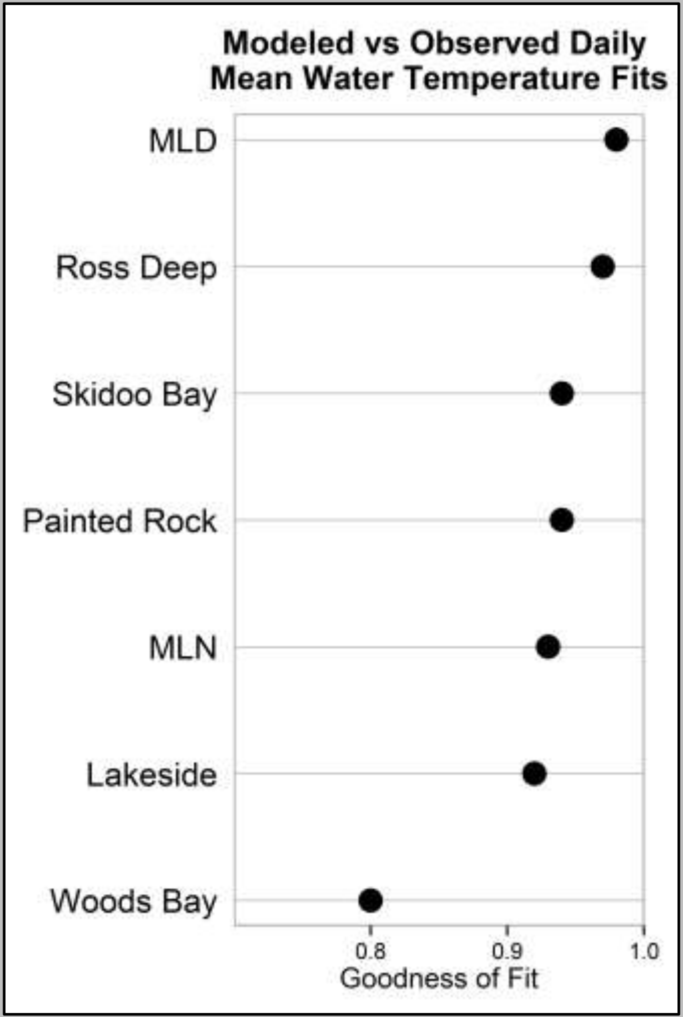


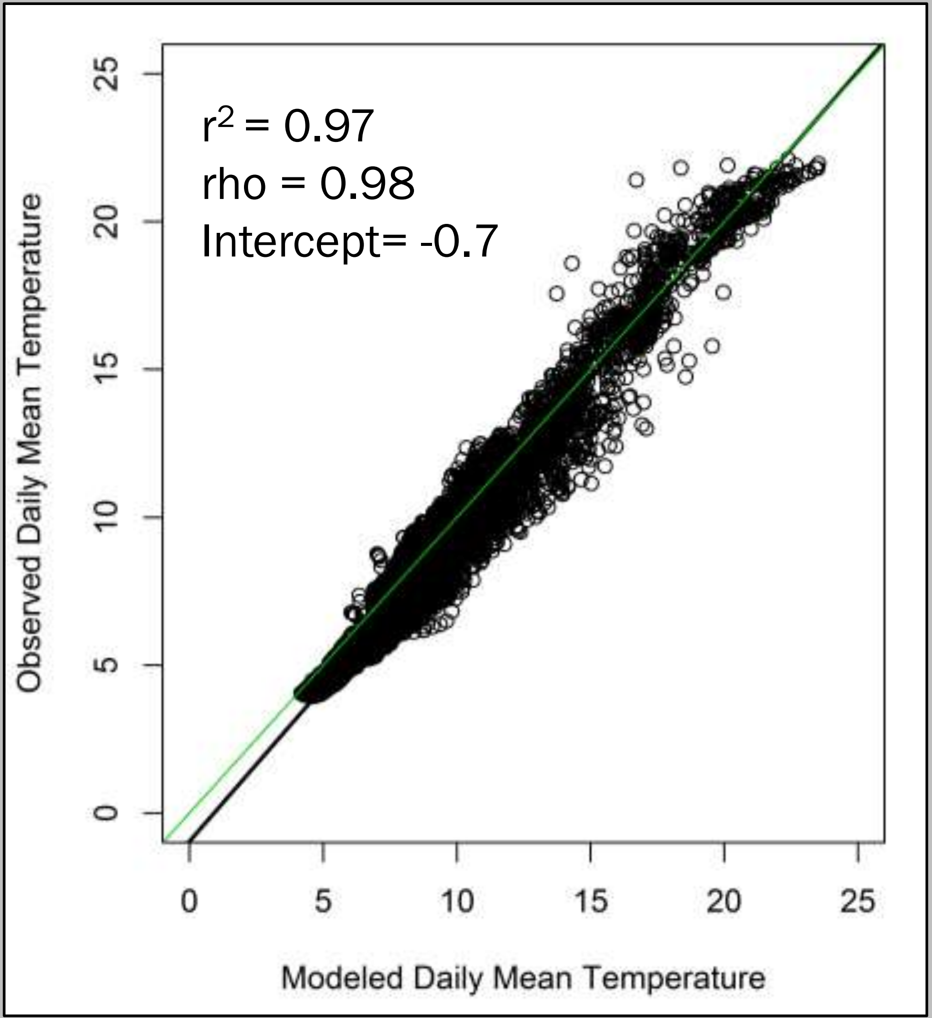
Magnuson et al, 1997; O'Reilly et al, 2003; Livingstone 2003

Buoy data proved invaluable!

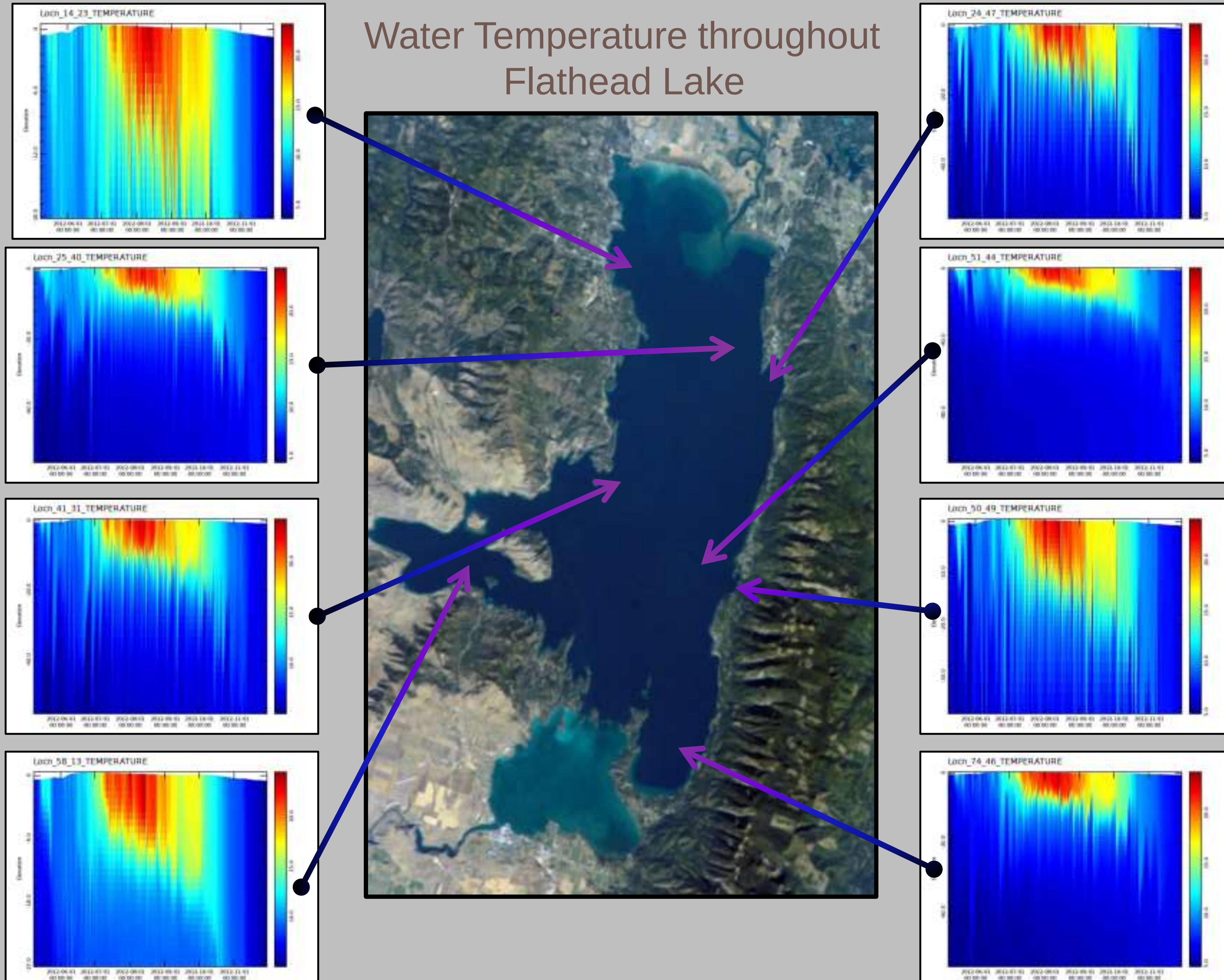


How does ELCOM do?





Water Temperature throughout Flathead Lake



Climate Projections

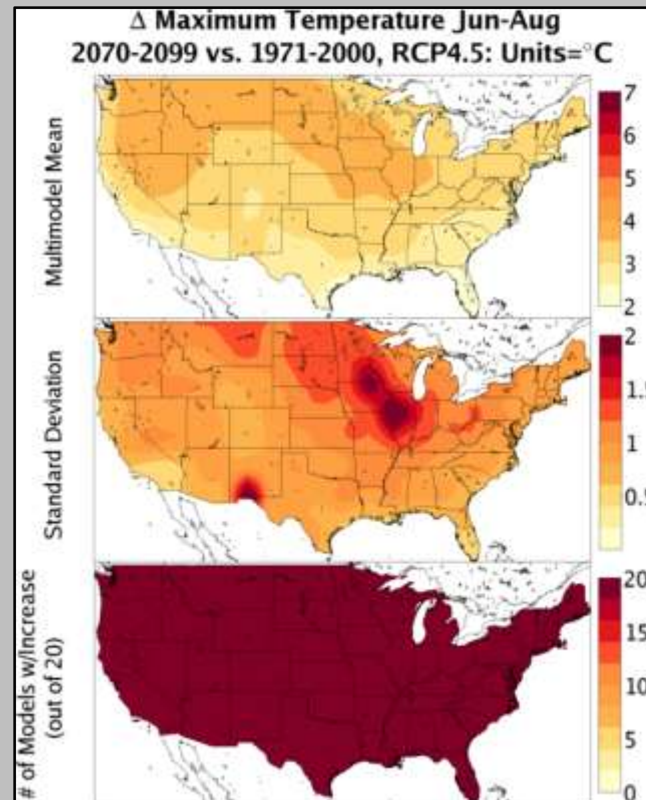
Multivariate Adaptive Constructed Analogs (MACA) Statistical Downscaling Method

2 Future Projection scenarios

RCP 4.5 (optimistic)
&
RCP 8.5 (dire)

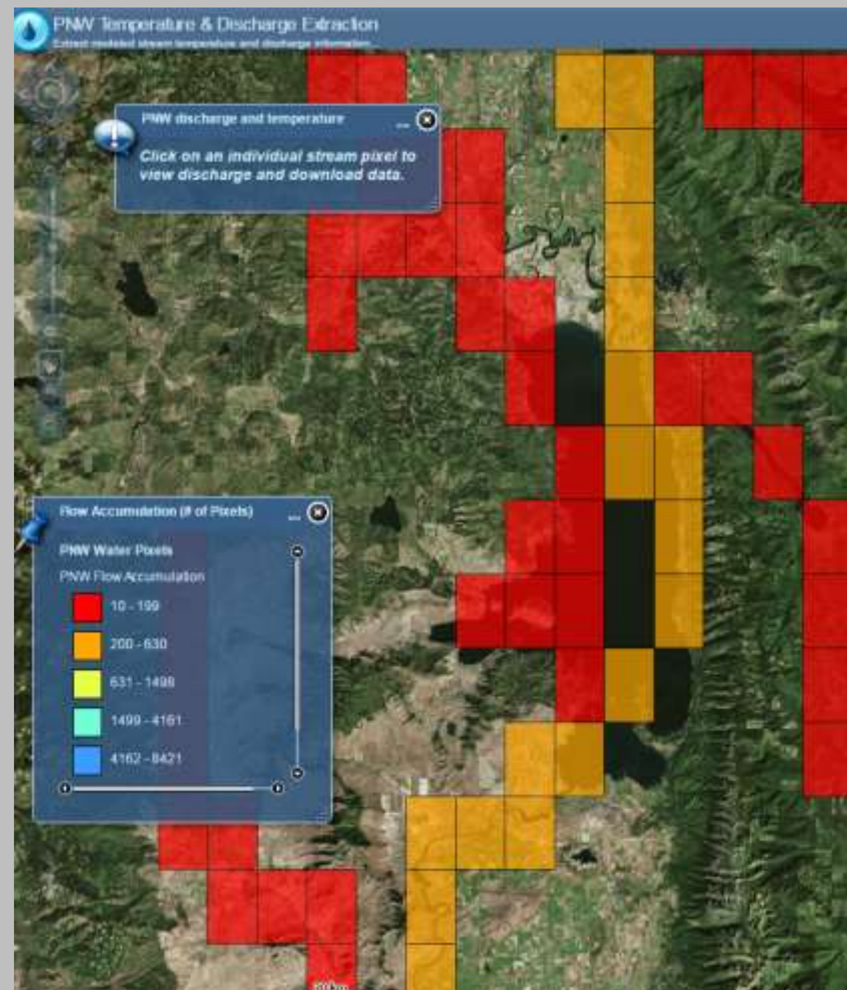
All meteorological variables necessary for ELCOM

Used mean value of 20 climate projection models from Coupled Model Inter-Comparison Project (CMIP5) to project 2012 forward through 2100

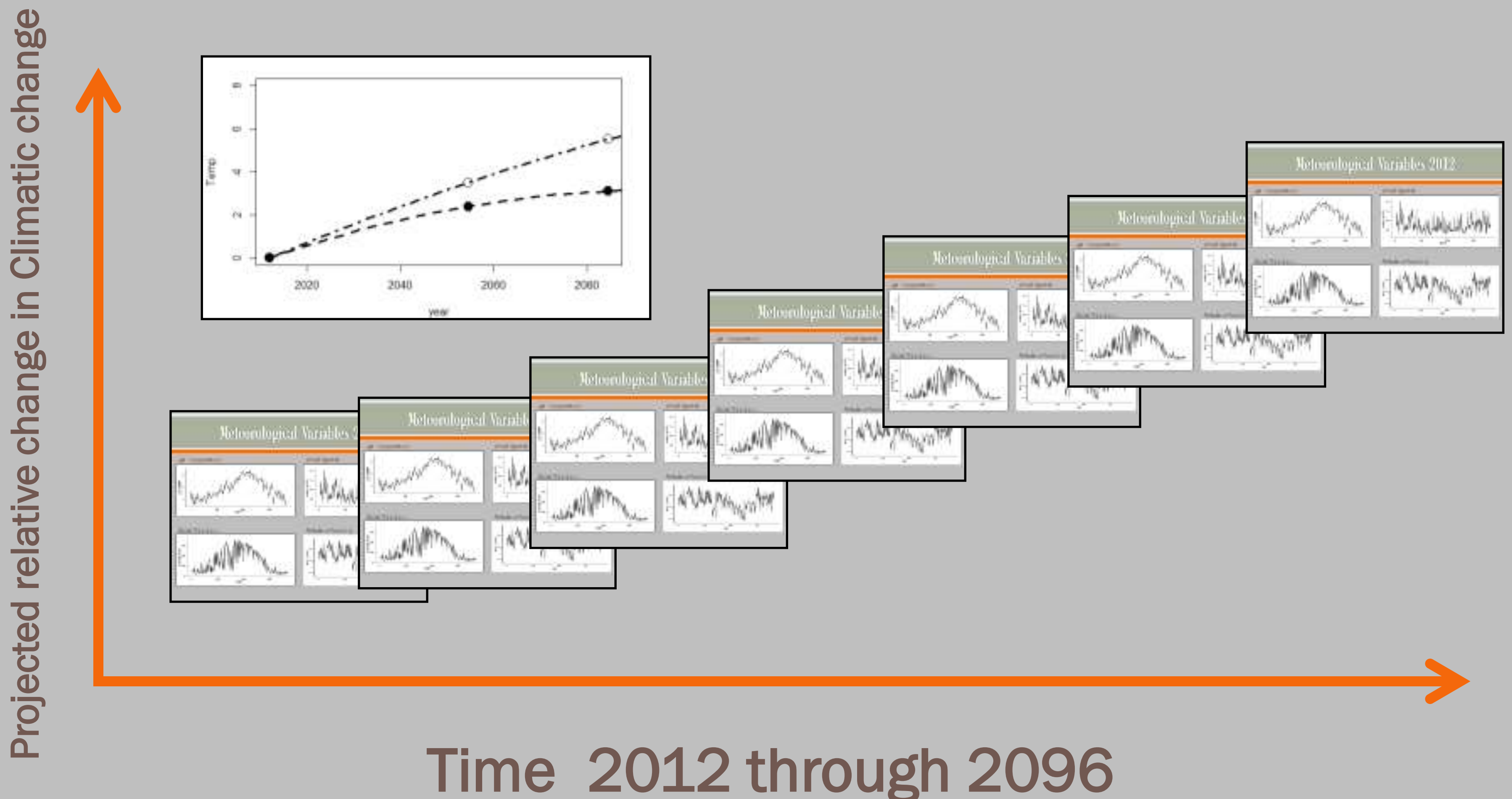


Climate Projections

Riverscape Analysis Project's (RAP) Extraction toolkit projected phenology of the Flathead and Swan Rivers for 2020, 2040 & 2080

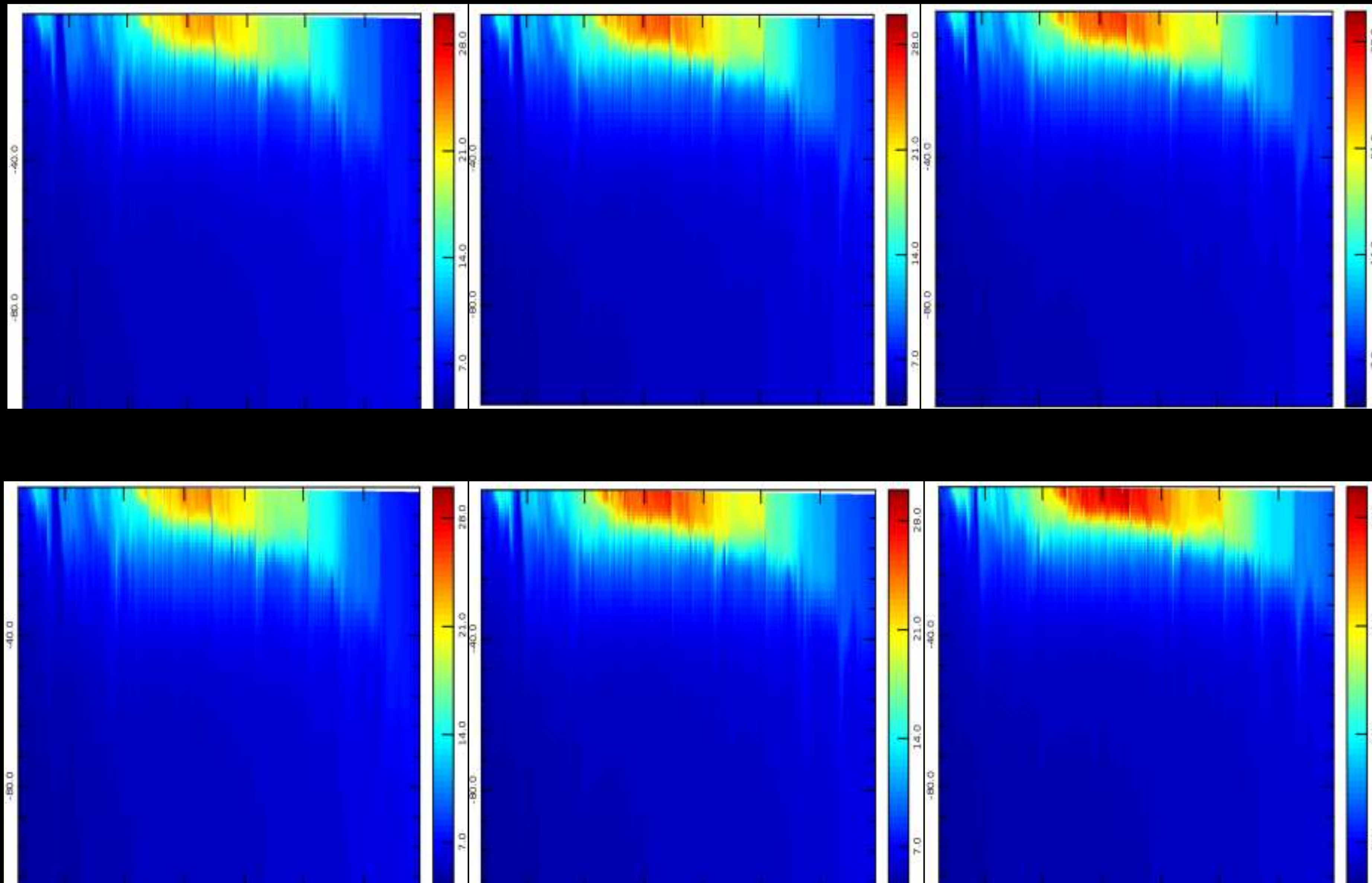


Projecting future climate using 2012 intra-annual variation



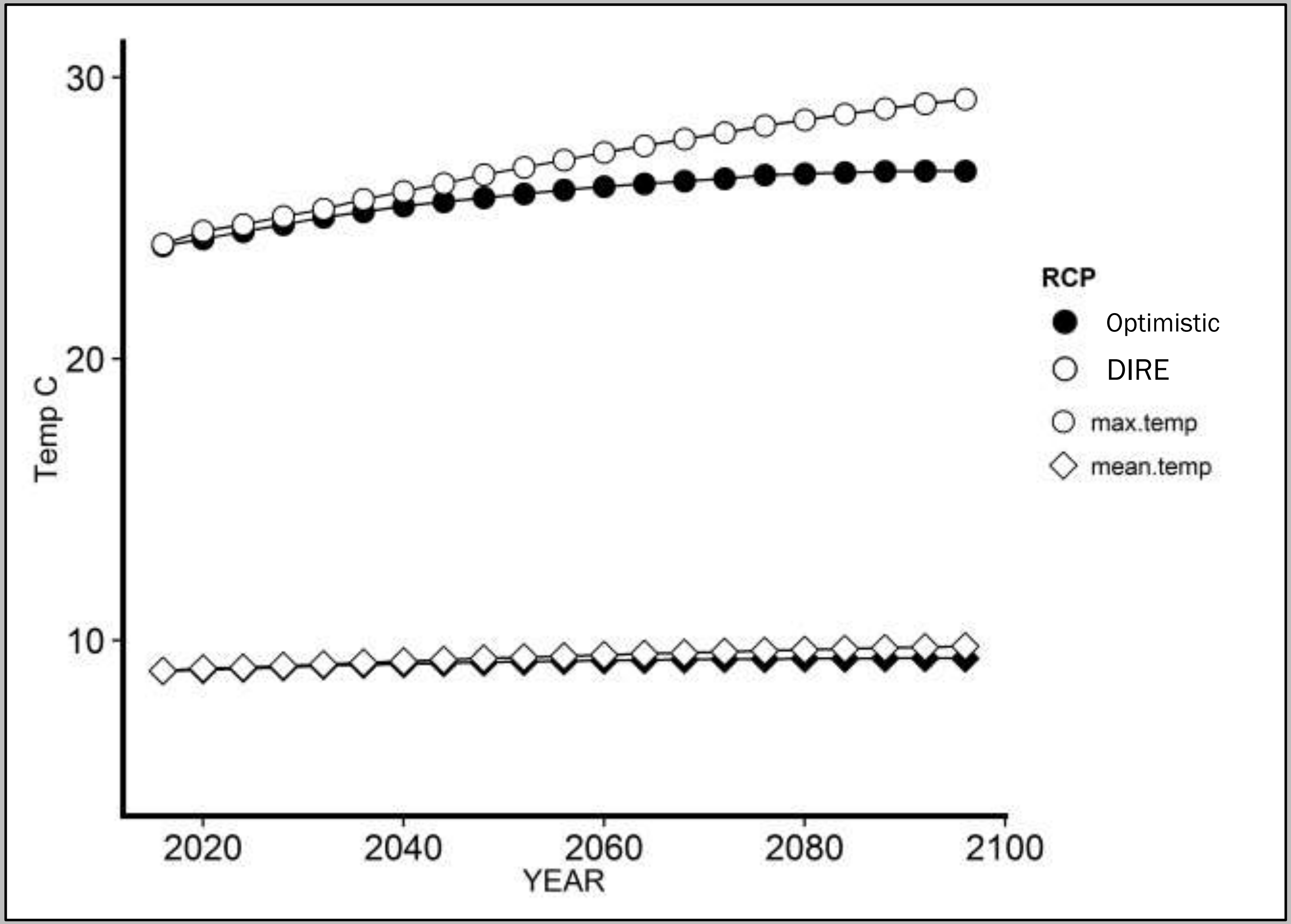
RCP 4.5

RCP 8.5

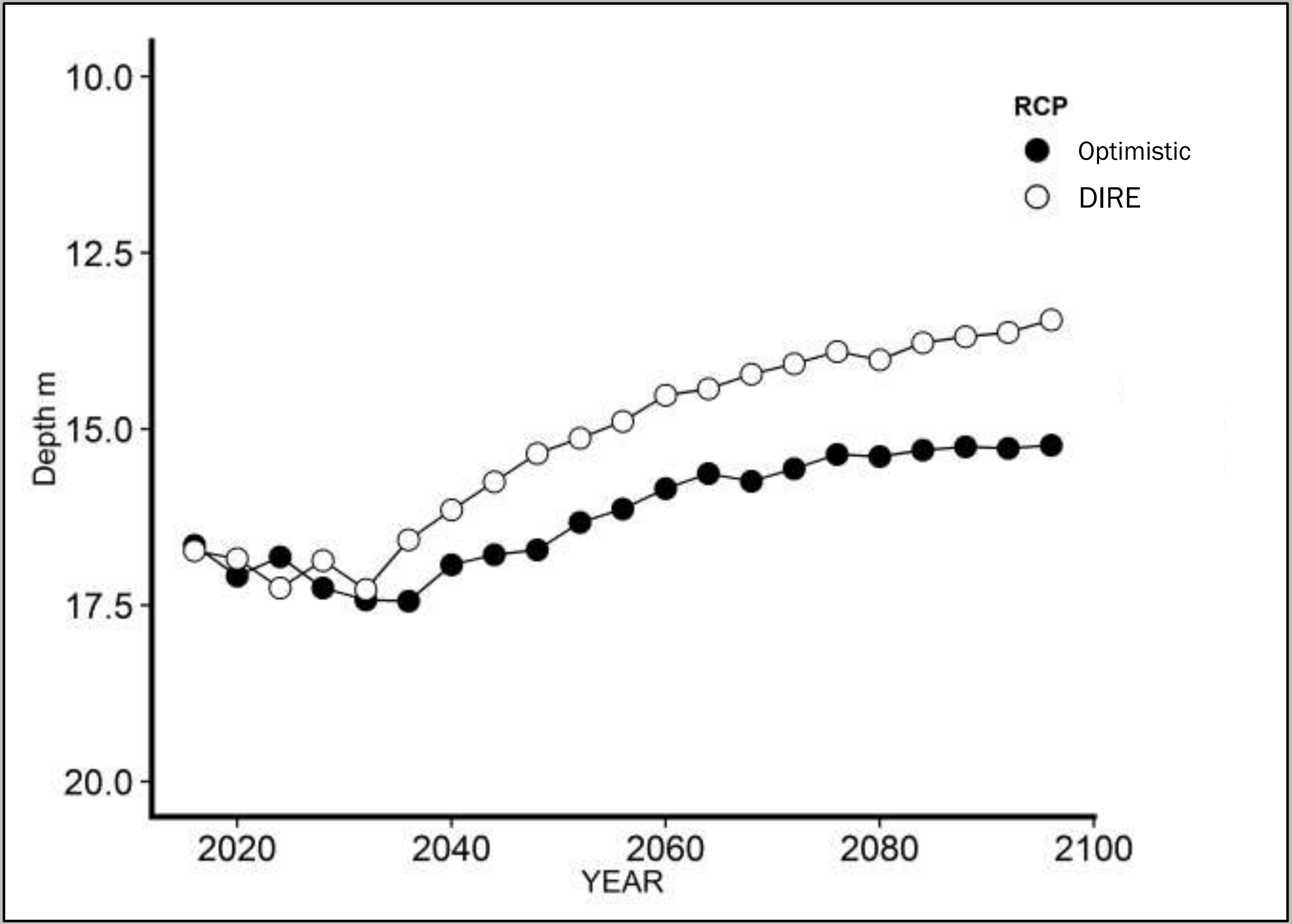


2020 2056 2092

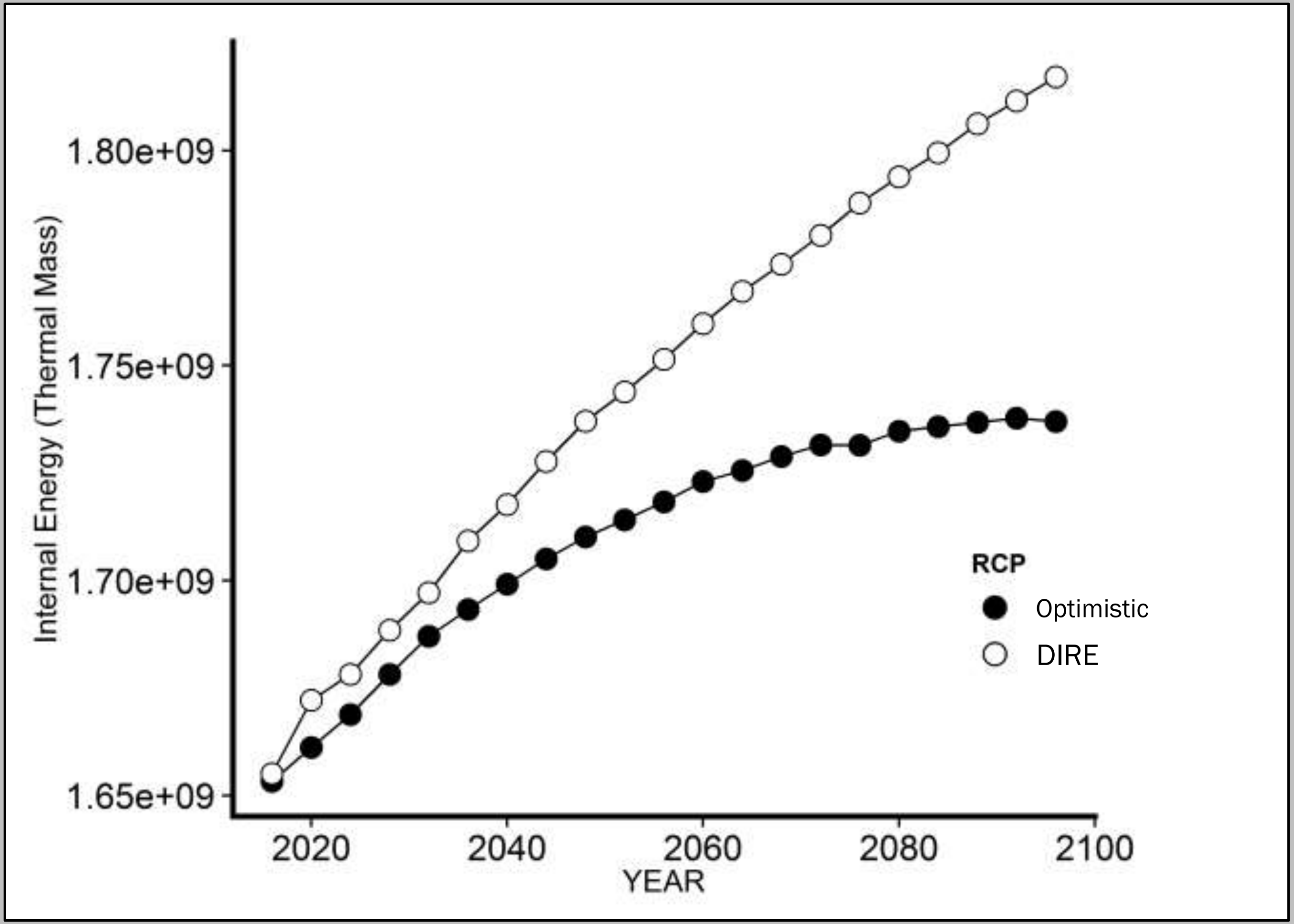
Water Temperature



Thermocline

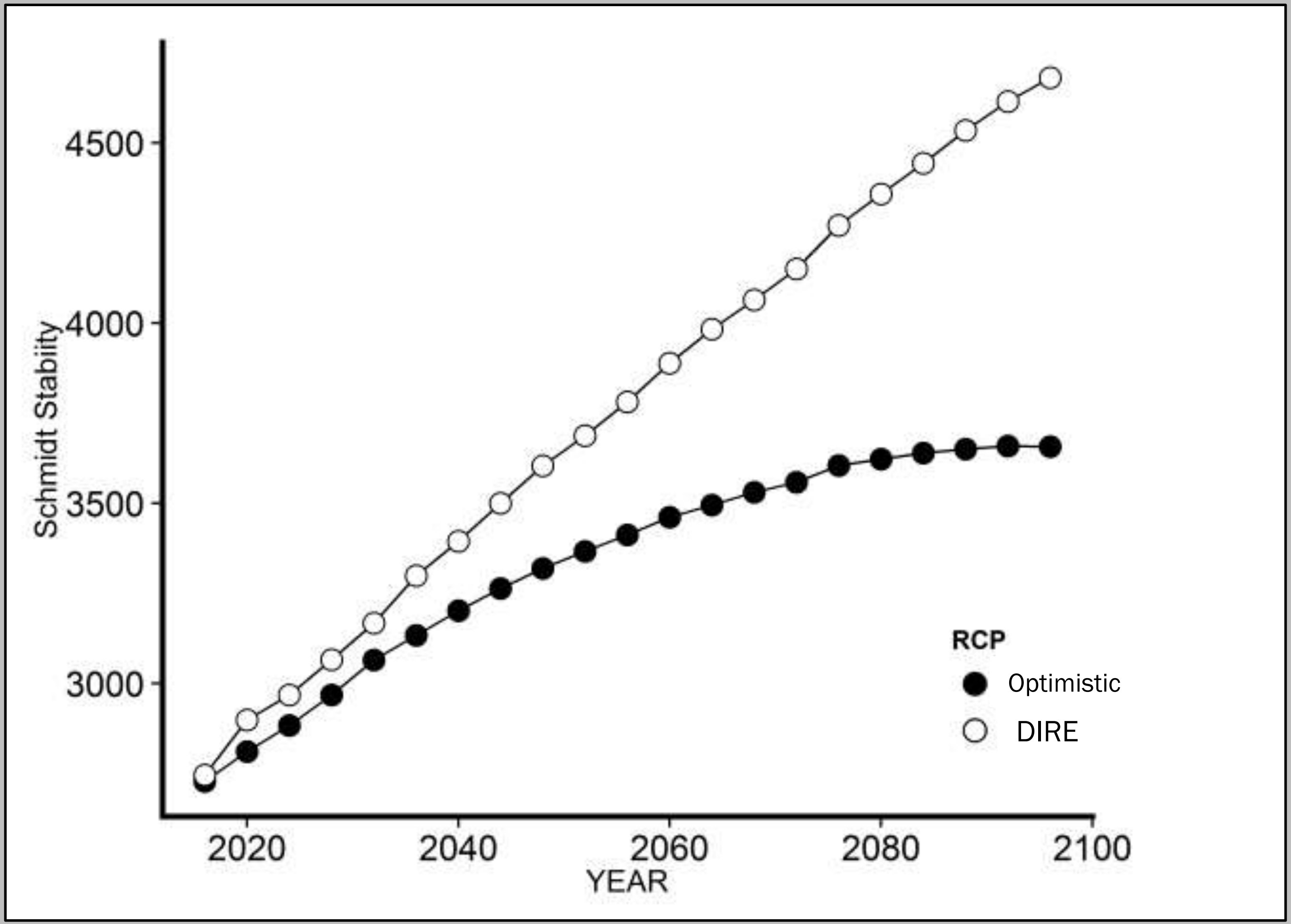


Internal Energy – Heat Budget

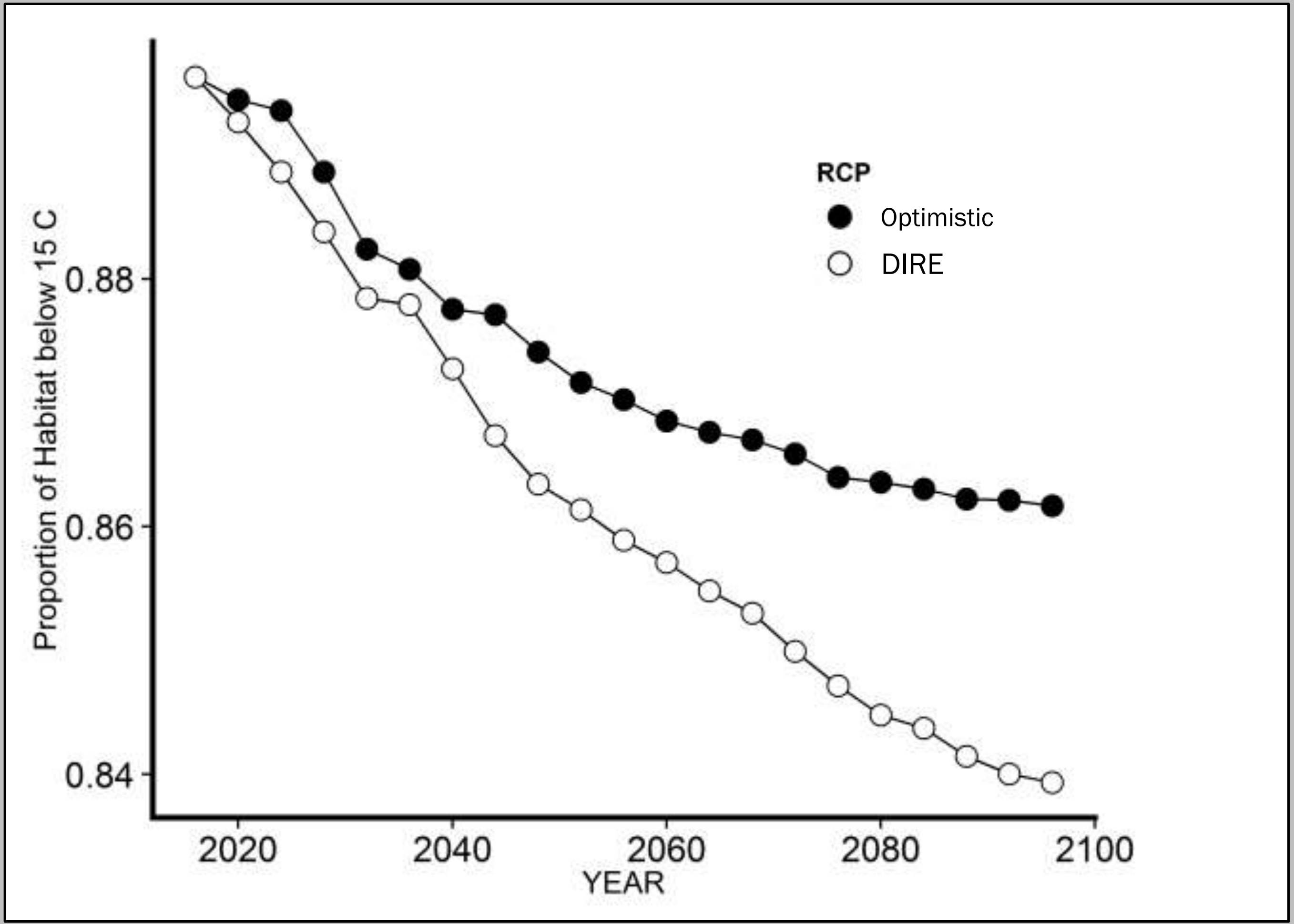


Schmidt Stability

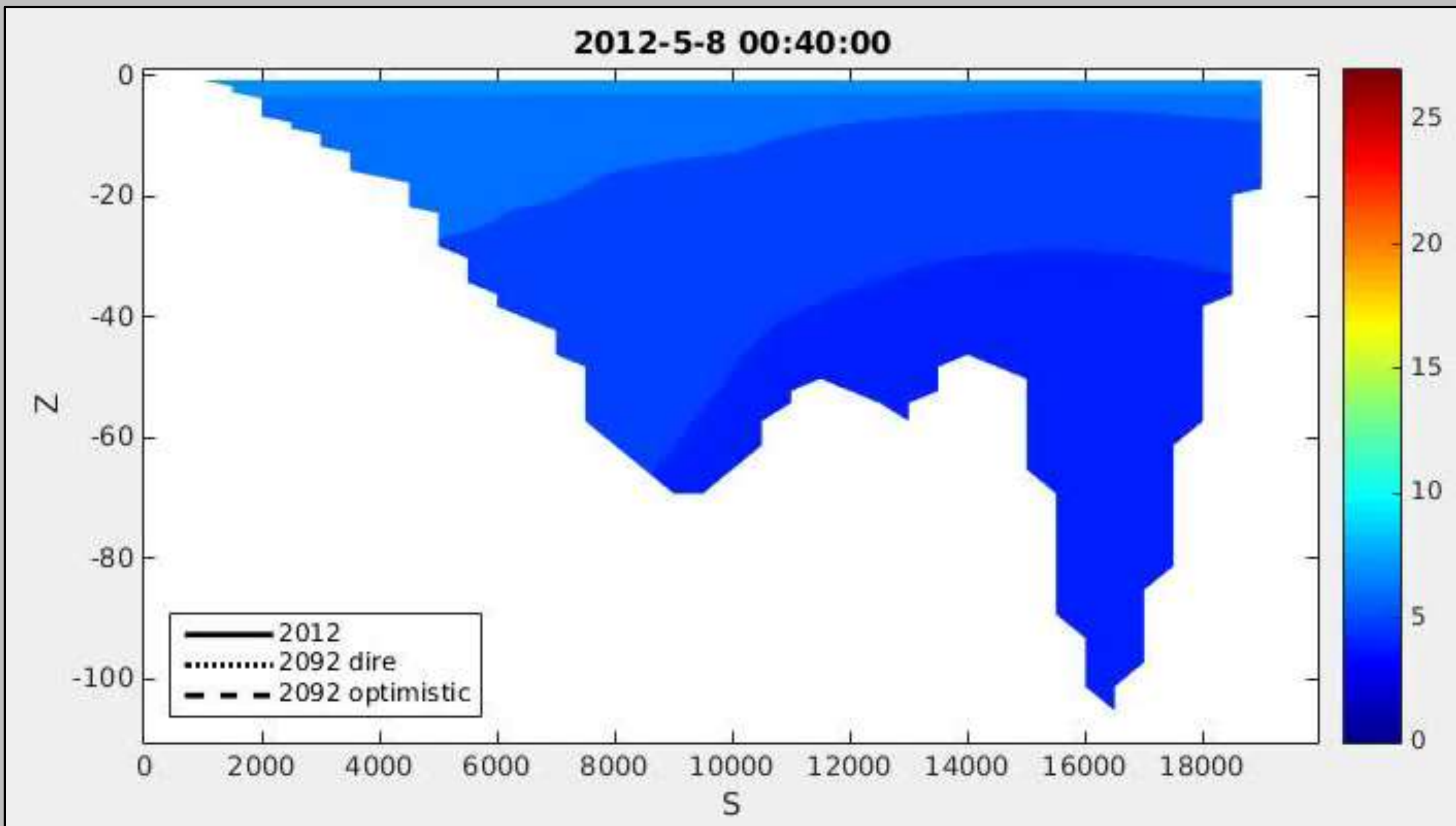
Resistance to mixing



Thermal Habitat Changes



Loss of thermal habitat for Mysis and Lake Trout



Climate Change Conclusions

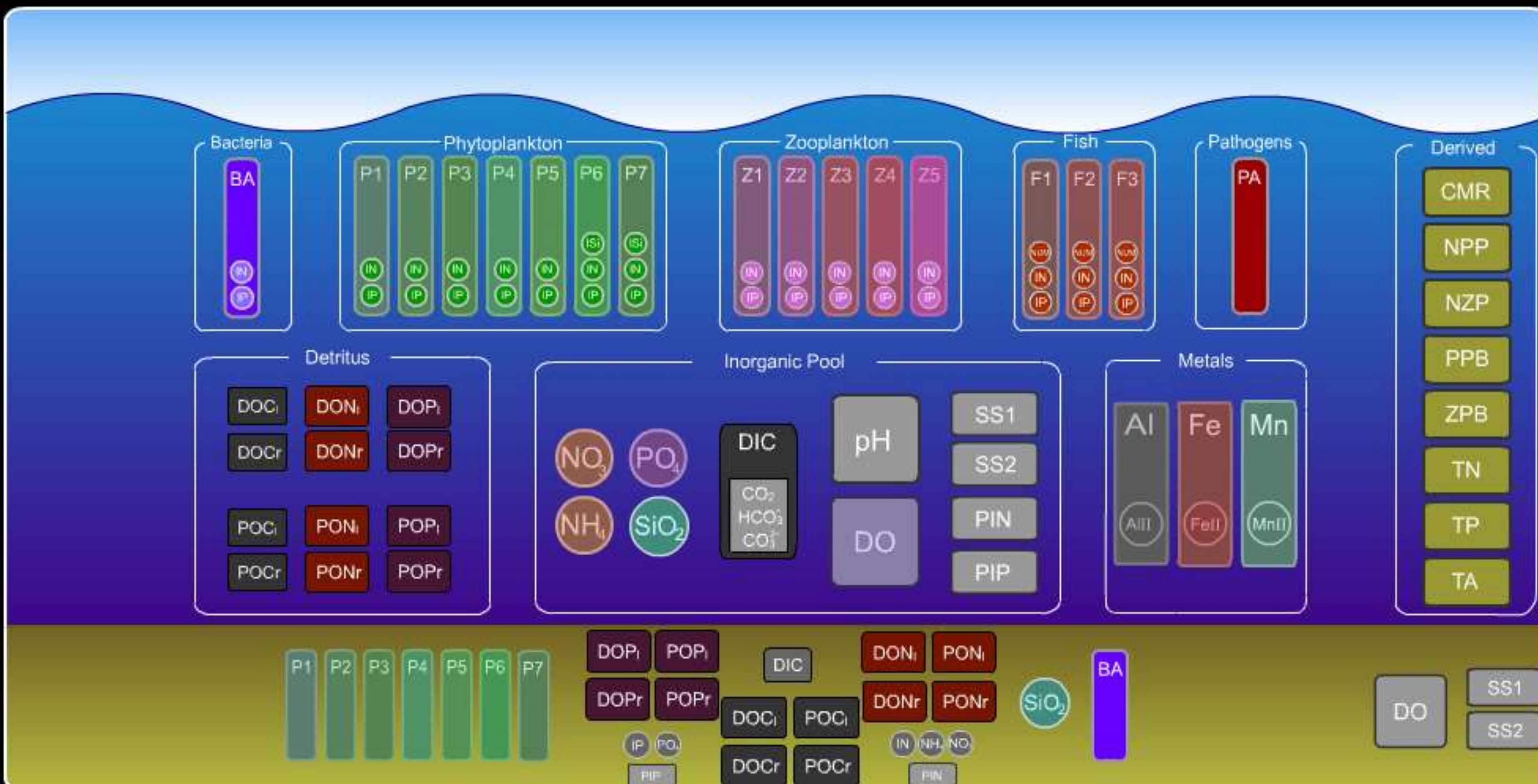
- Significant increase in epilimnion temperatures but no overall increase in mean temperature of the lake (weighted or unweighted)
- Significant decrease of thermocline depth
- Increase in Schmidt Stability and Thermal Mass
  - Longer period of stratification (Nutrients)
- Decreased habitat for Lake Trout and Mysis, however relative to total habitat available only about 5%
- Thermal Refugia for riverine species immigrating from high elevation stream systems??

NO_3

Science Man.

$$\frac{dNO_3}{dt} = -f_{NO_3}^{DEN}(T, DO, NO_3) + f_{NH_4}^{NIT}(T, DO, NH_4) + f_{NO_3}^{DSF}(T, DO, pH) + f_{NO_3}^{BUP}(A, M, NH_4)$$

Click here to view nitrogen schematic



Long Term Data

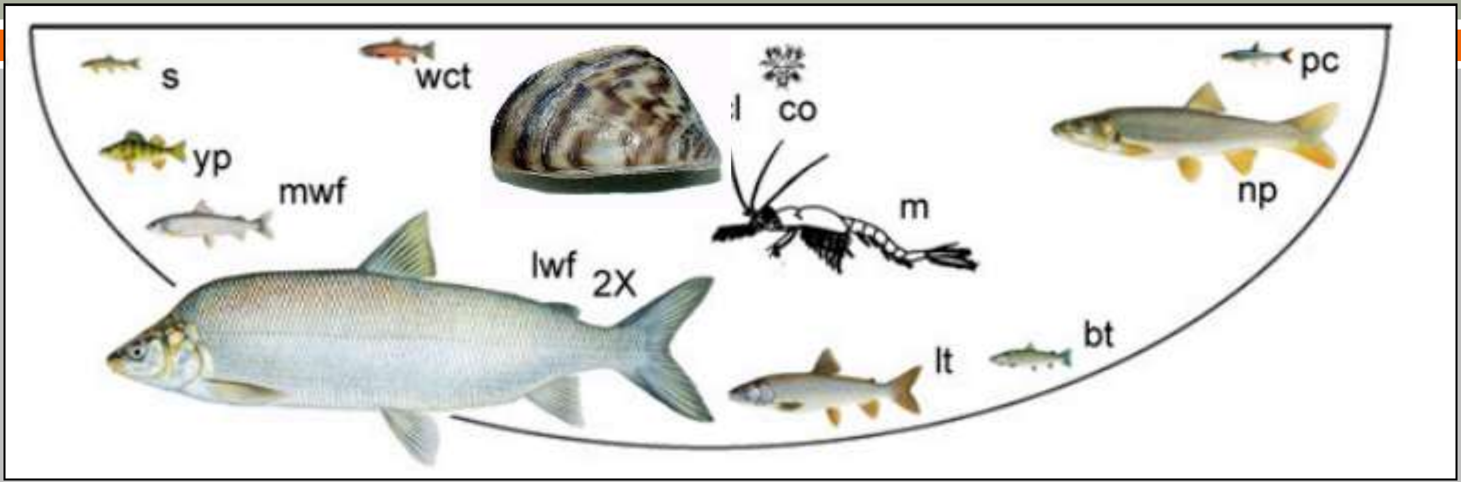
1998 *NORTHEASTERN NATURALIST* 5(2): 127-136

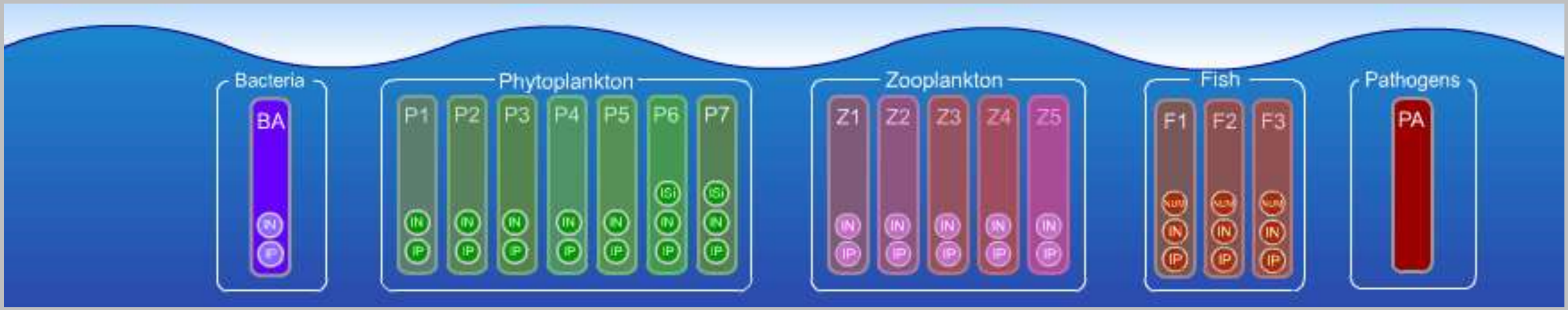
THE IMPORTANCE OF LONG-TERM DATA IN ADDRESSING REGIONAL ENVIRONMENTAL ISSUES

GENE E. LIKENS * AND KATHLEEN FALLON LAMBERT **

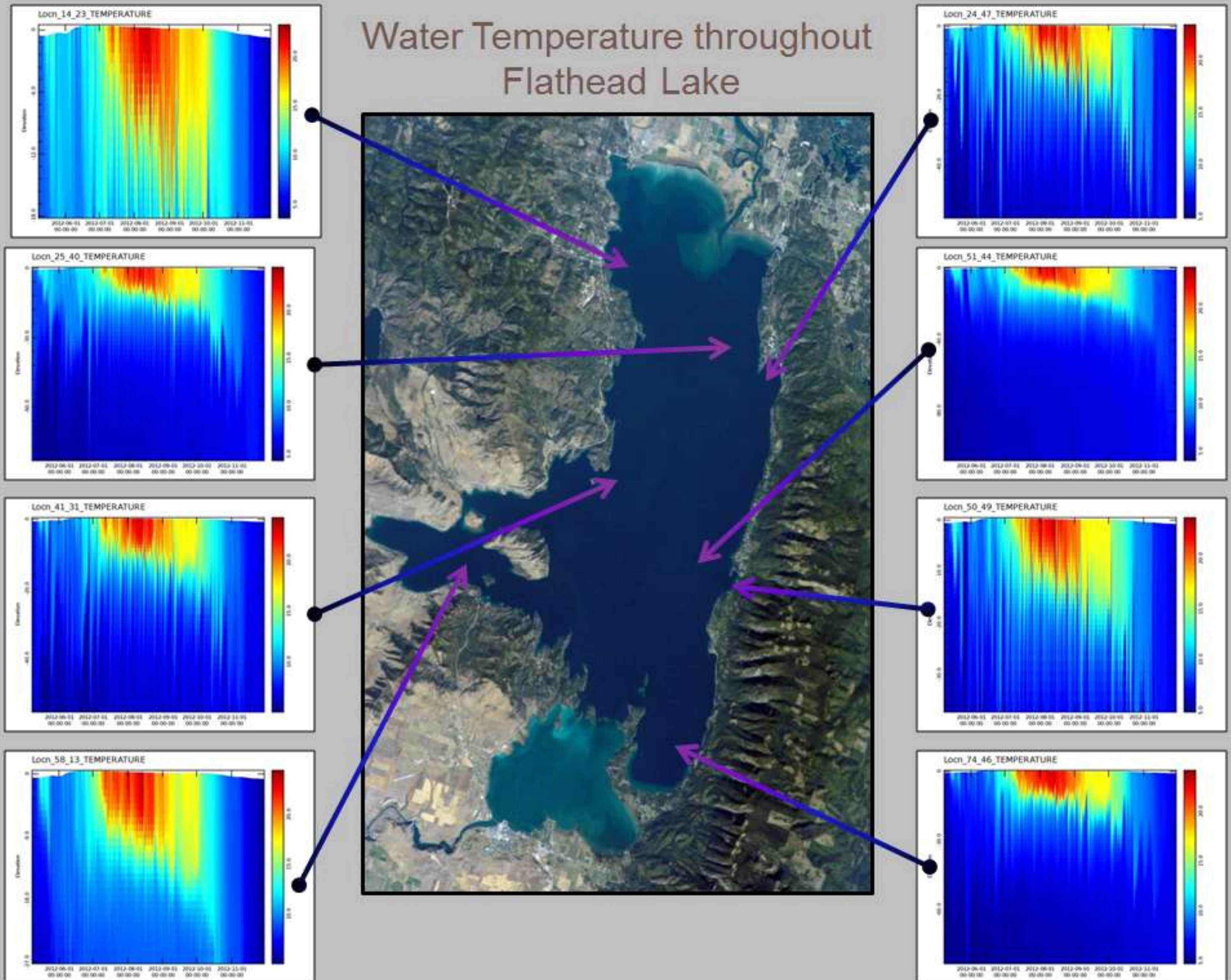
ABSTRACT - Long-term data have been used to evaluate complex, environmental problems, such as the anthropogenic acidification of regional landscapes by acid rain, and to quantify changes in ecosystem function associated with large-scale land use, such as forest harvesting and development. In this paper, we discuss the importance of long-term monitoring in addressing regional environmental issues by examining two examples of anthropogenic stress—acid rain and forest harvesting. We also suggest that a watershed-ecosystem approach is useful for understanding, and for managing, the potential synergistic effects of chemical and vegetational changes in forest ecosystems in the northeastern U.S.

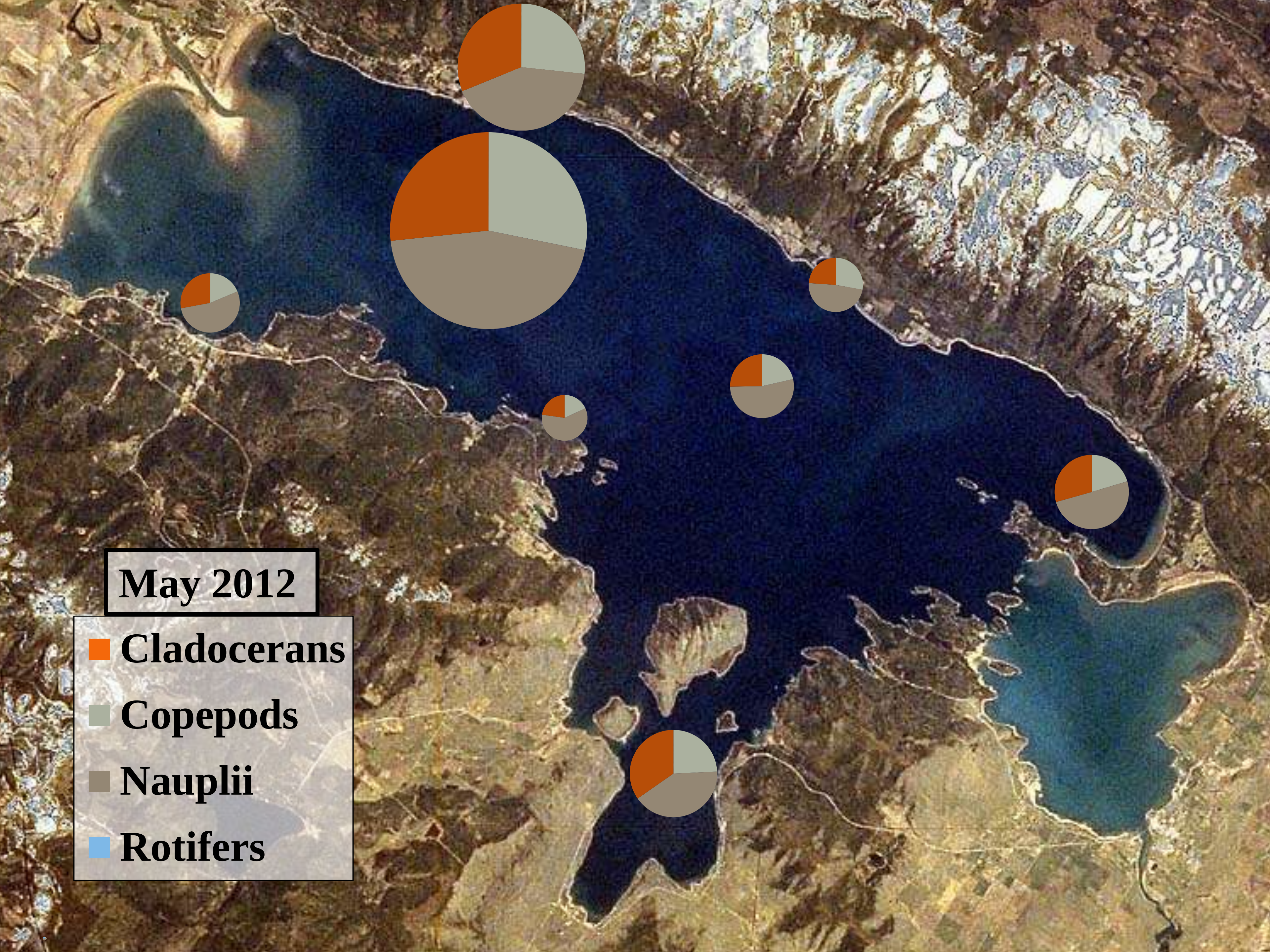
Trophic Interactions



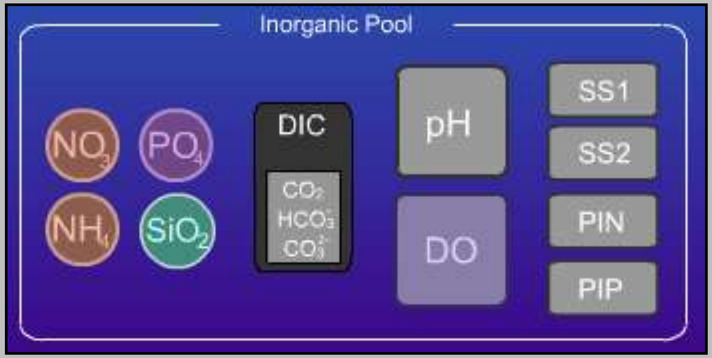


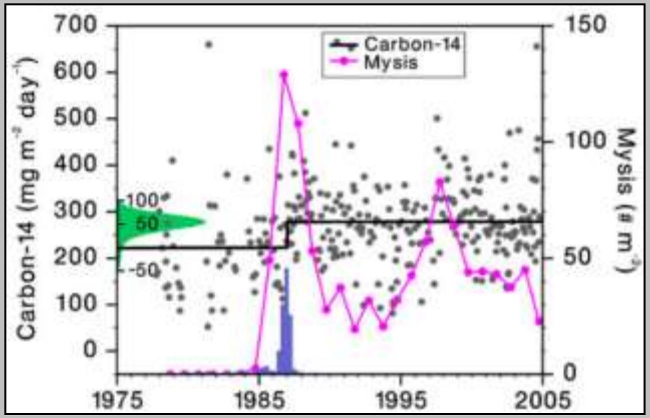
Water Temperature throughout Flathead Lake

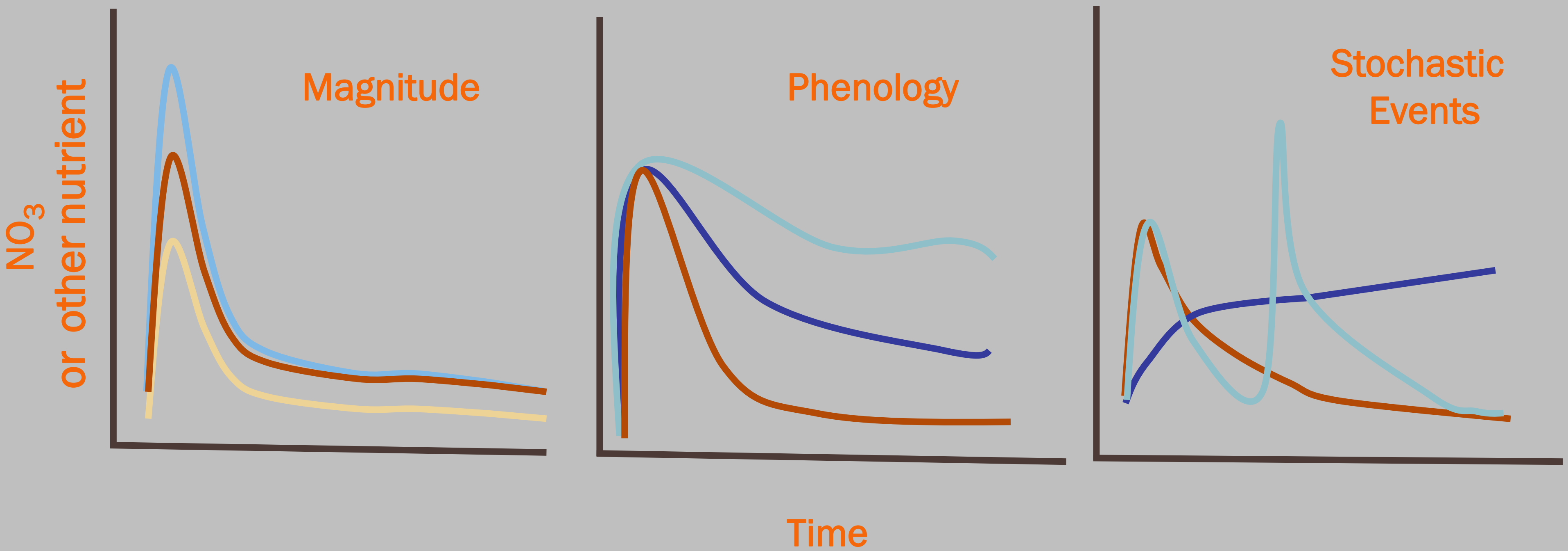



May 2012
Cladocerans
Copepods
Nauplii
Rotifers

Nutrient Loading







Summary

Models allow us to conduct impossible experiments:

- Examine implications of invasions or community manipulations without potential damage to systems
- Determine what effect changes in nutrient loading will have on water quality
  - Magnitude
  - Hydrology
  - Stochastic/ catastrophic events
- Assess how 100 years of warming and drying climate will effect the thermal and physical dynamics of Flathead Lake

Something to keep in mind