Simulations of Lake Processes within a Regional Climate Model

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Utah State University

- 850 Faculty members
- Founded 1888
- 23,000+ undergraduate and graduate students
- Three branch campuses and Extension offices in all of Utah's 29 counties
- 950 International students from 90 different countries

Funding Agencies

On-going projects in my group

1) Snow Simulations

Snowpack simulation improvement at regional scales

2) Impact of Irrigation and land use change on local and regional climate

Better understanding of the contribution of irrigation and land use change to regional climate change

3) Regional Climate Simulations and Forecasts

Improvements of regional climate simulations and forecasts through statistical and dynamical downscaling approaches.

4) Lake-effect simulations and predictions in regional climate system.

Lakes on the Earth

There are about 304 million lakes (4.2 million km^2 in area) on the Earth (Downing et al. 2006).

In the United States, 7% of the area is covered by lakes.

The area in the Tibetan Plateau is 36,900 km^2, accounting for 52% of the total lake area of China (Bianduo 2009).

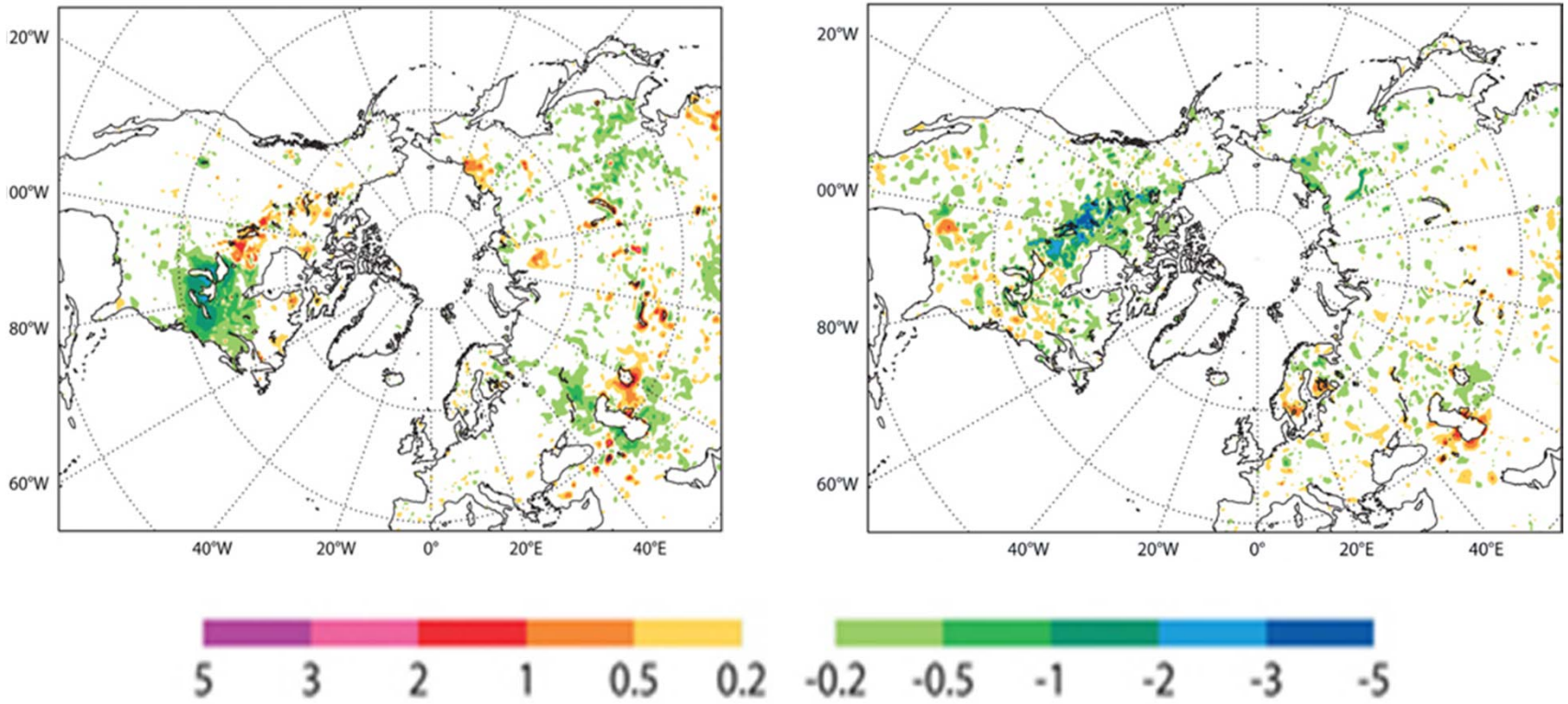
Lake Effect on Precipitation

The Great Lakes enhance precipitation by 200%

Lake-Effect Snow

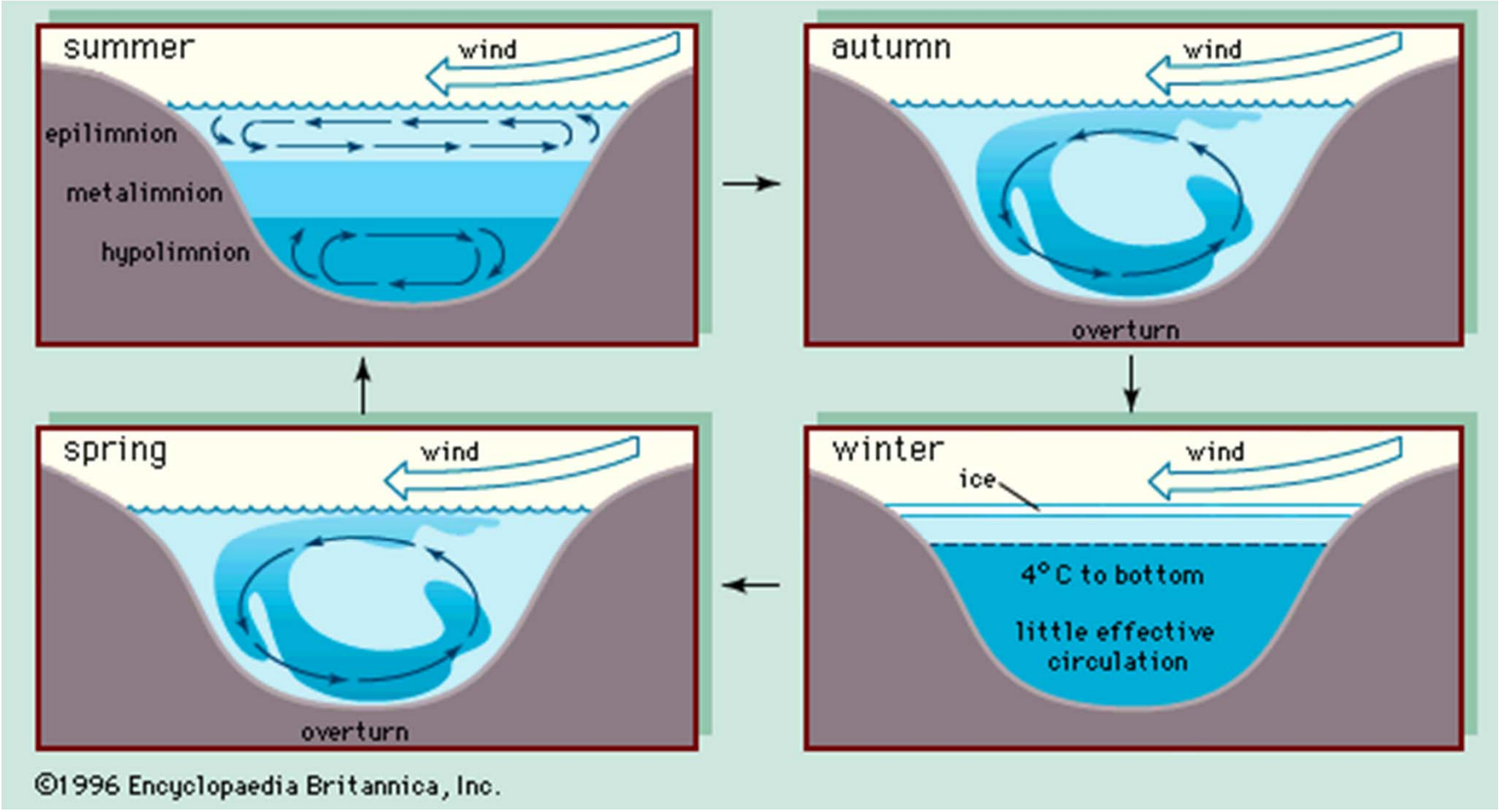
Lake Temperature Predictions

Winter **Summer**

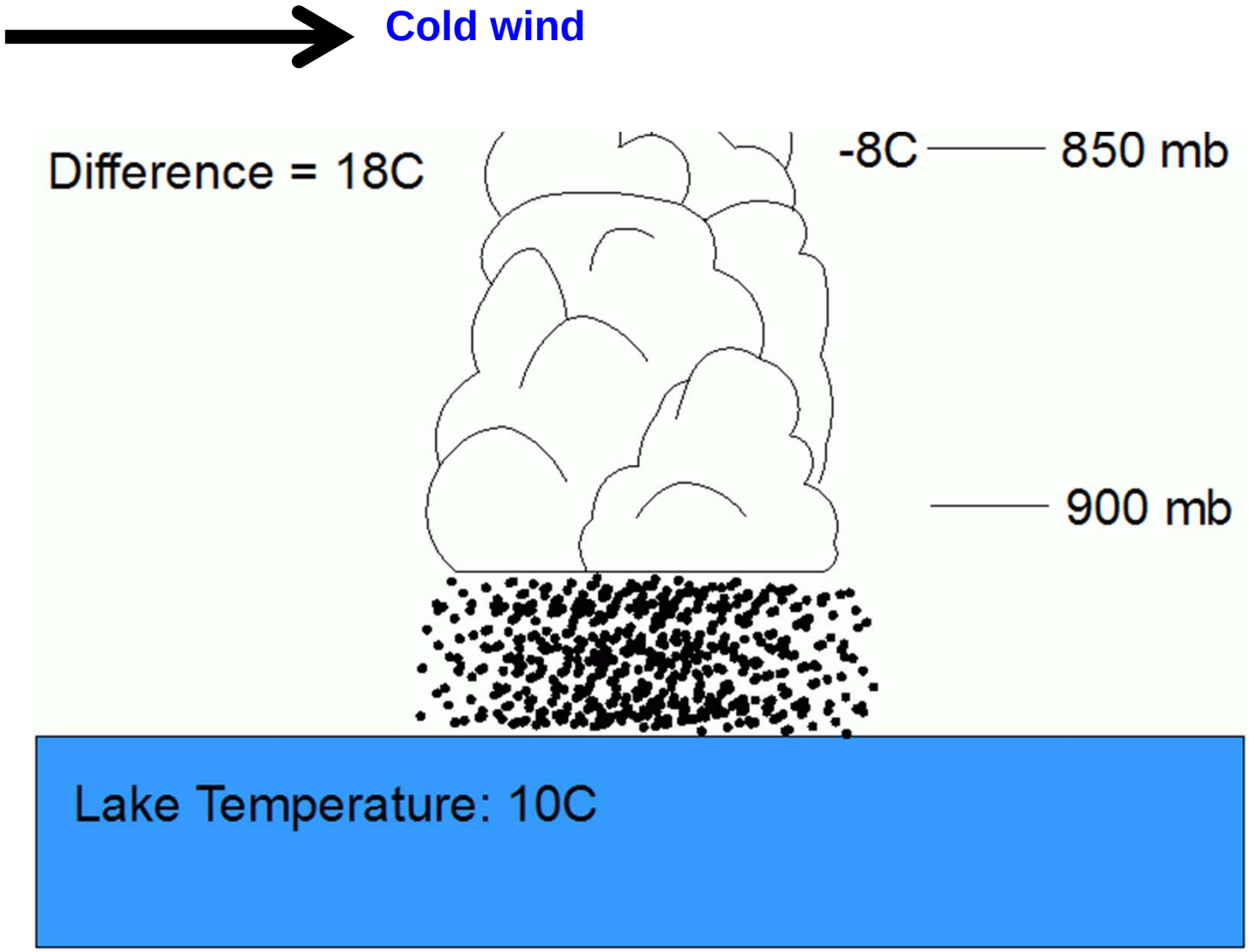


Balsamo et al. (2012)

Lake stratification and mixing

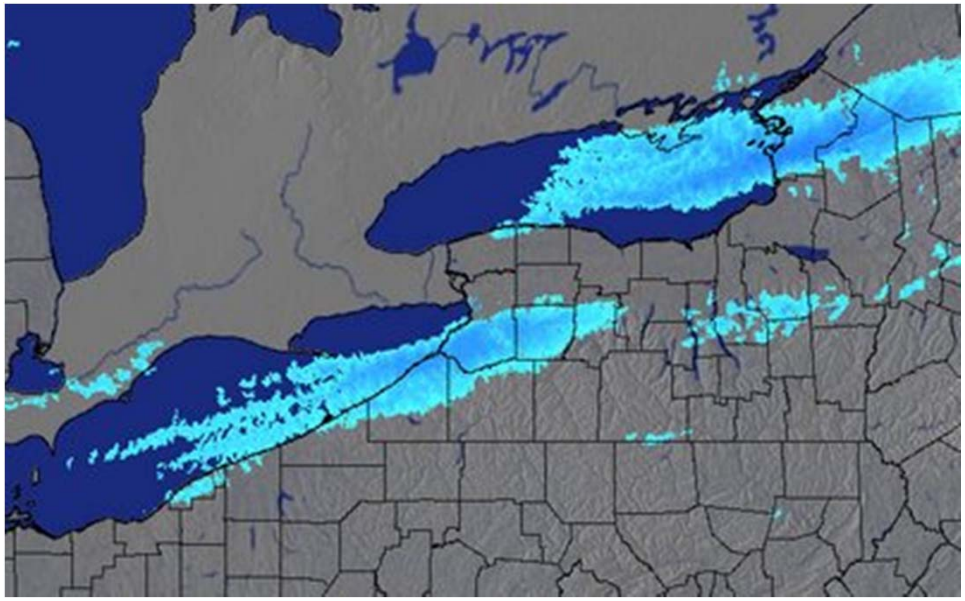


Lake-Effect Precipitation

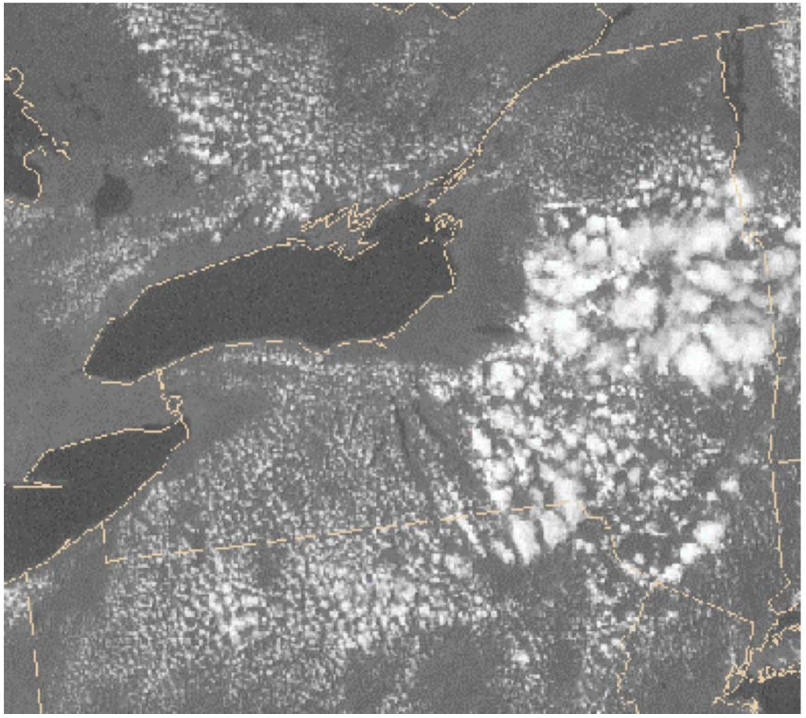


Lake Effects

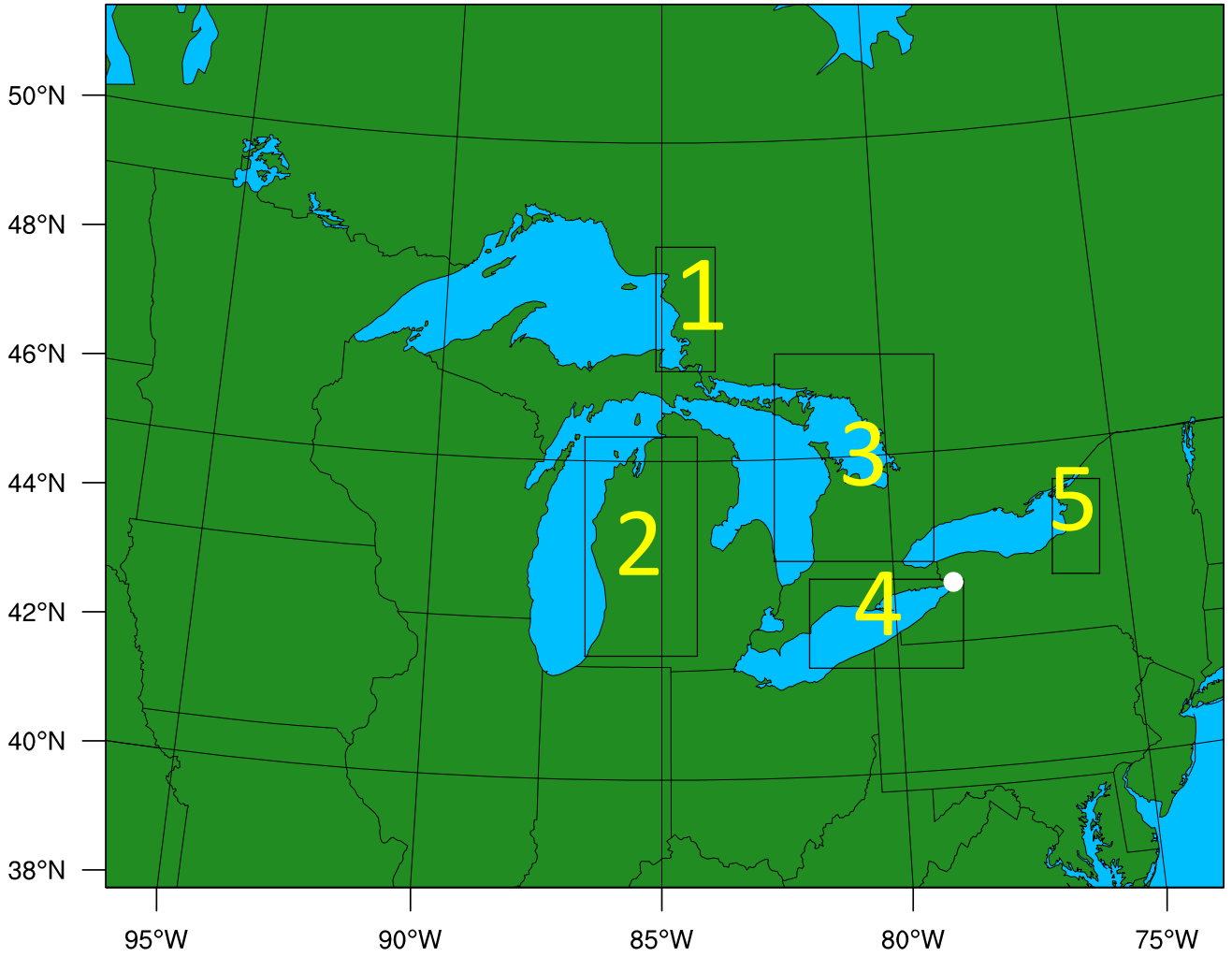
Winter



Summer



Lake affected Regions

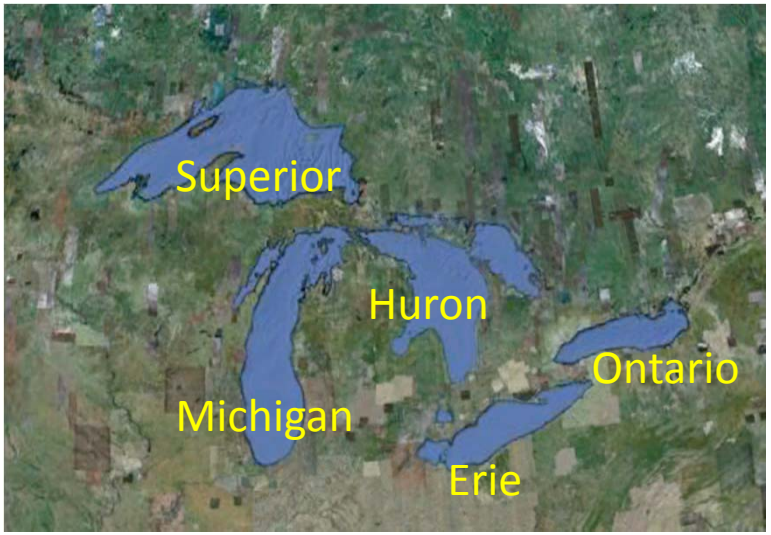


Regional Climate Model

All the release versions of the Weather Research Forecasting (WRF) model do not include a lake scheme.

The lake surface temperature is provided by the forcing data for the WRF model.

Difference of the NARR LST and MODIS LST

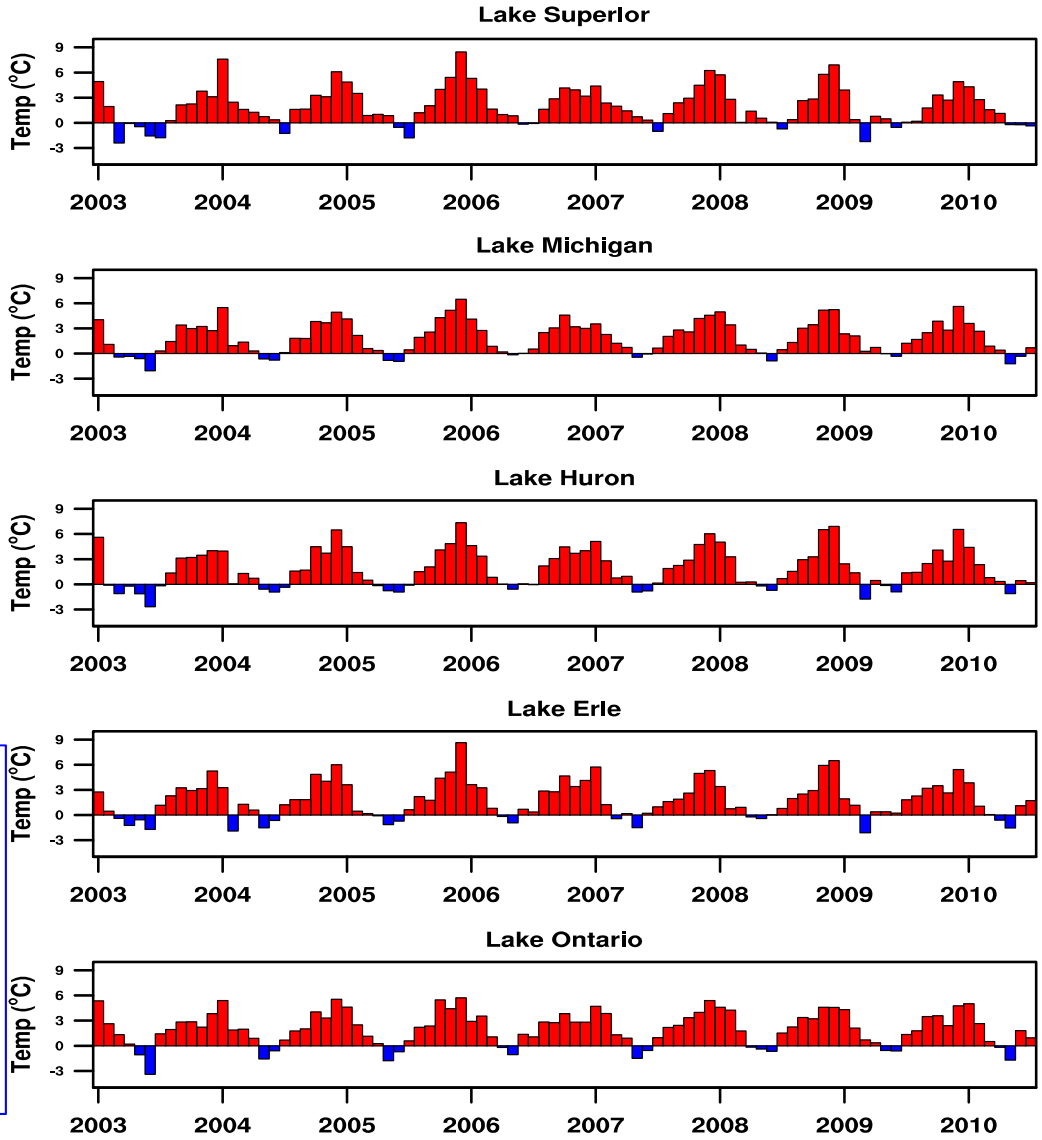


LST: Lake surface temperature

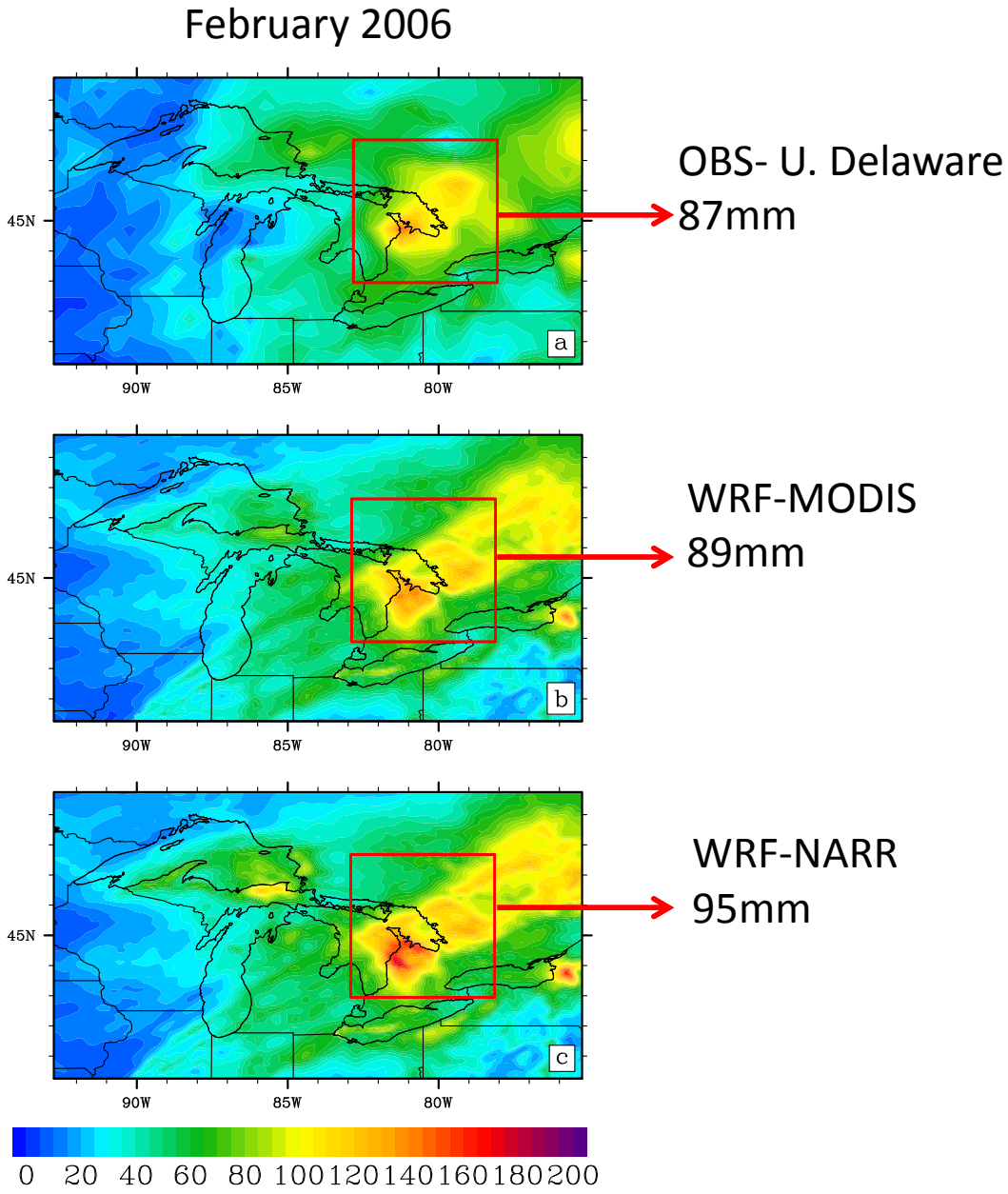
NARR: North American Regional Analysis

MODIS: Moderate Resolution Imaging Spectroradiometer Satellite data

Lake region mean



Precipitation Simulations at 10 km Resolution with WRF over the Great Lakes Region



OBS- U. Delaware
87mm

WRF-MODIS
89mm

WRF-NARR
95mm

A Physically-based Lake Model

- **The lake model used is a one-dimensional water and energy balance model (Hostetler et al,1993;1994).**

- **The lake in the model is divided into 10 vertical layers.**

Lake Taihu

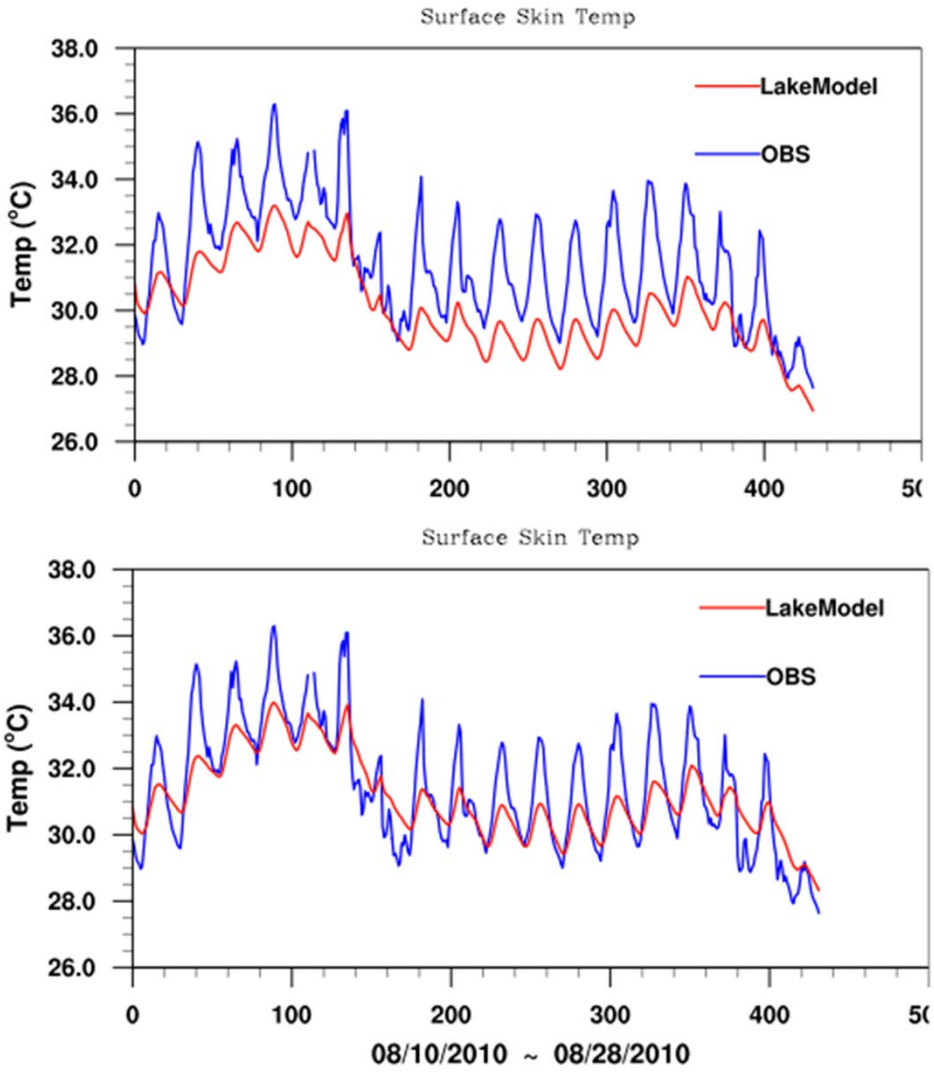
Offline lake model tests over Lake Taihu

1. Roughness length(Z_0)

2. Beta (β) (Fractional solar radiation at the surface)

3. Lake depth (D)

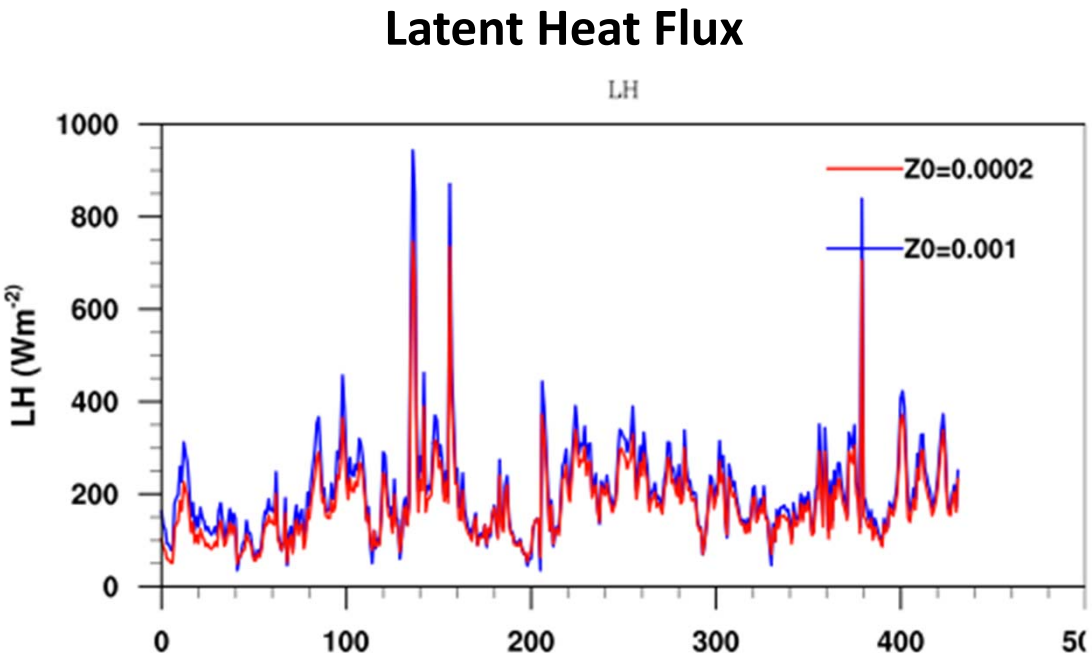
Lake Surface Temperature Simulations



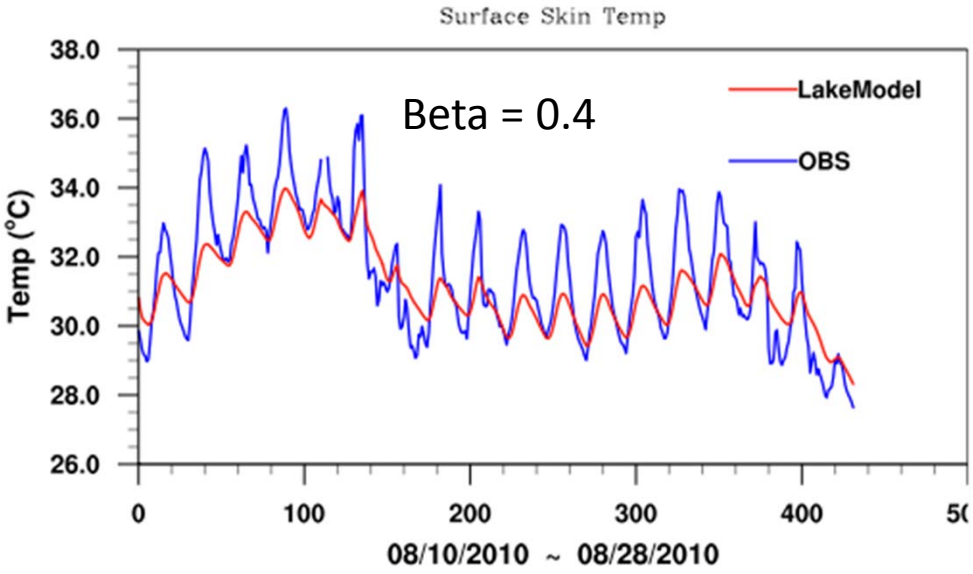
Z_0 = 0.001 m

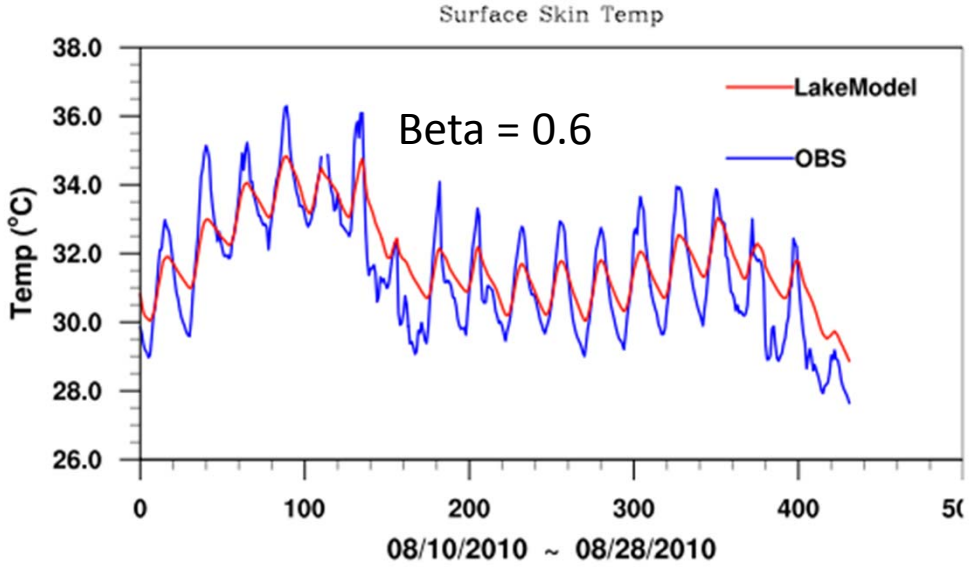
Z_0 = 0.0002 m

Flux differences with different Z_0



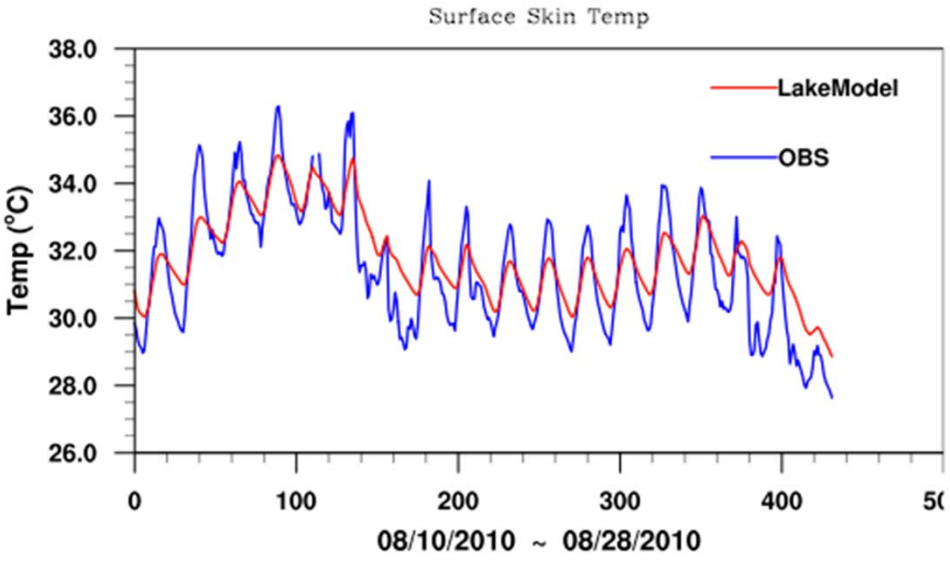
Lake Surface Temperature Simulations





$Z_0 = 0.0002$ m

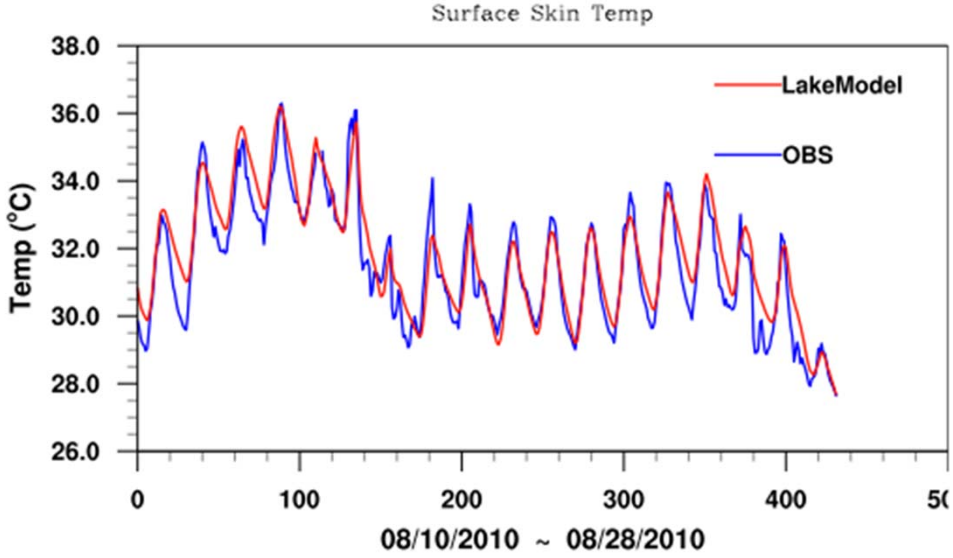
Lake Surface Temperature Simulations



Lake Depth = 2m

Beta = 0.6

Z_0 = 0.0002 m



Lake Depth = 1m

Coupling of the WRF-Lake Model

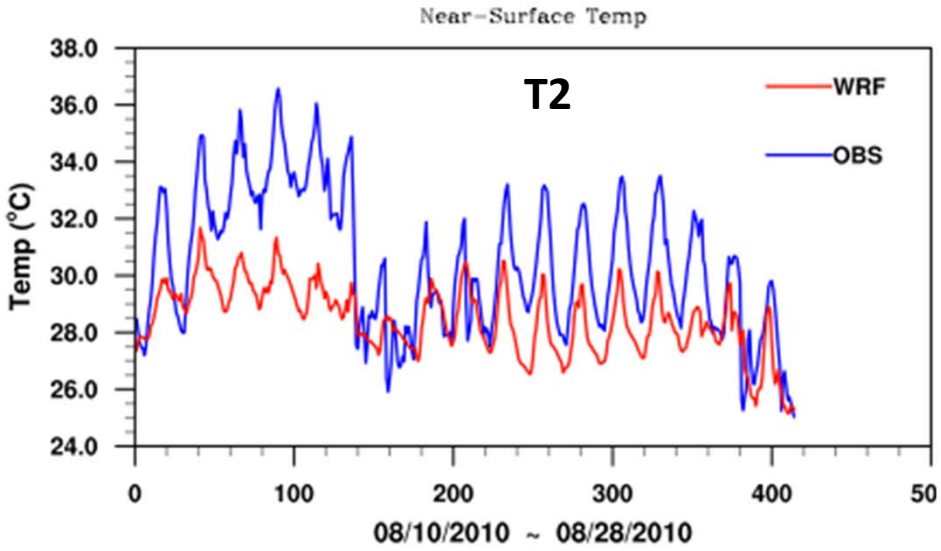
We have recently coupled the lake model into the WRF model.

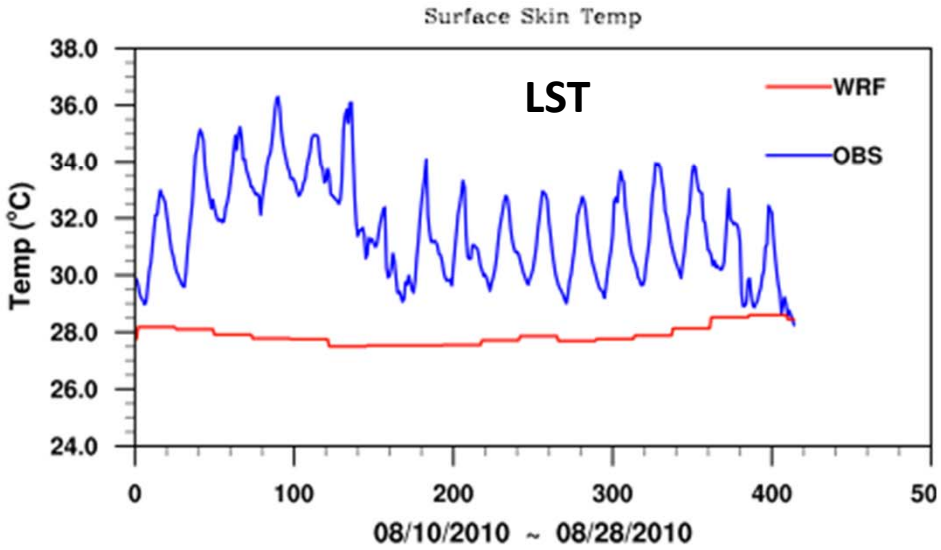
Simulations with the coupled WRF-lake model were performed over Lake Taihu with three nested domains (45-15-5km)

Lake Parameters: Z_0=0.0002m, Beta=0.6, D=1m

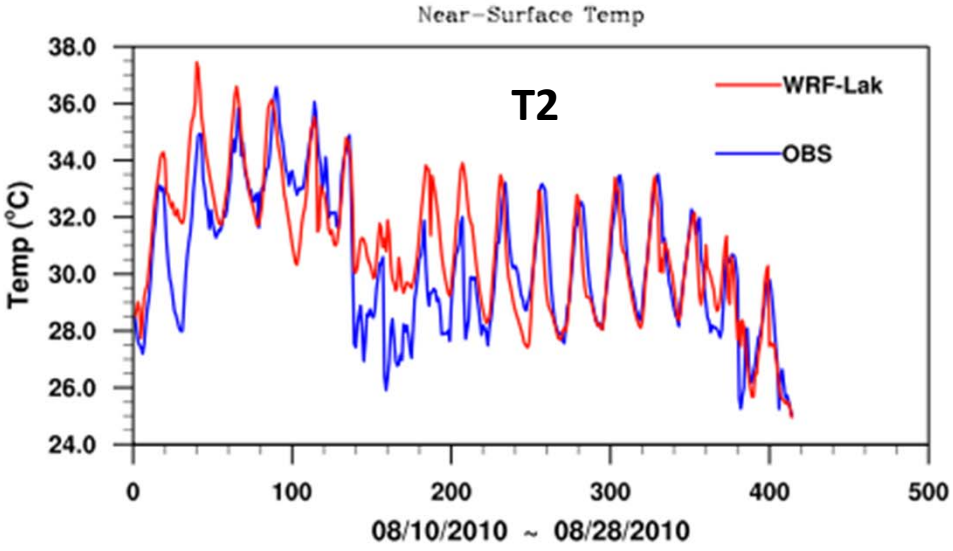
Lake Surface Temperature Simulations (5km resolution)

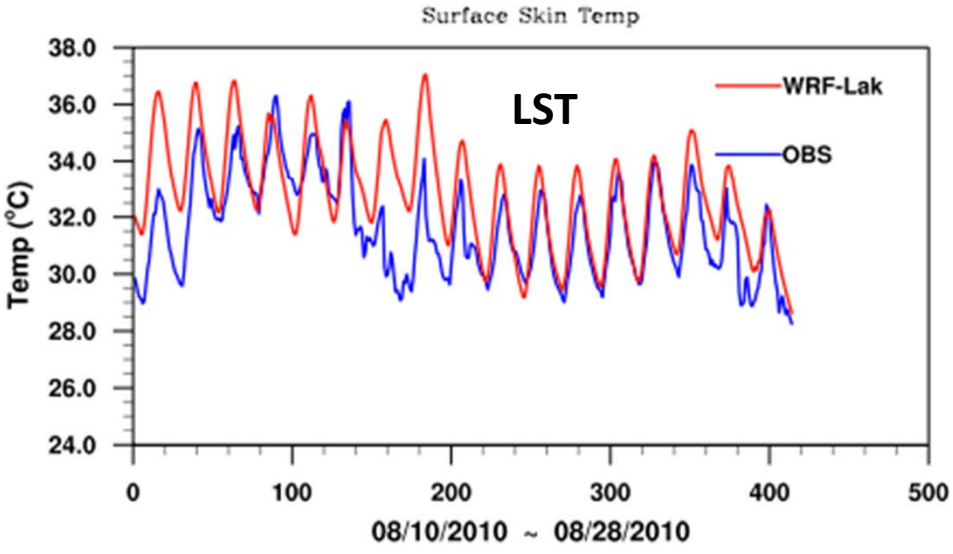
WRF without the lake model



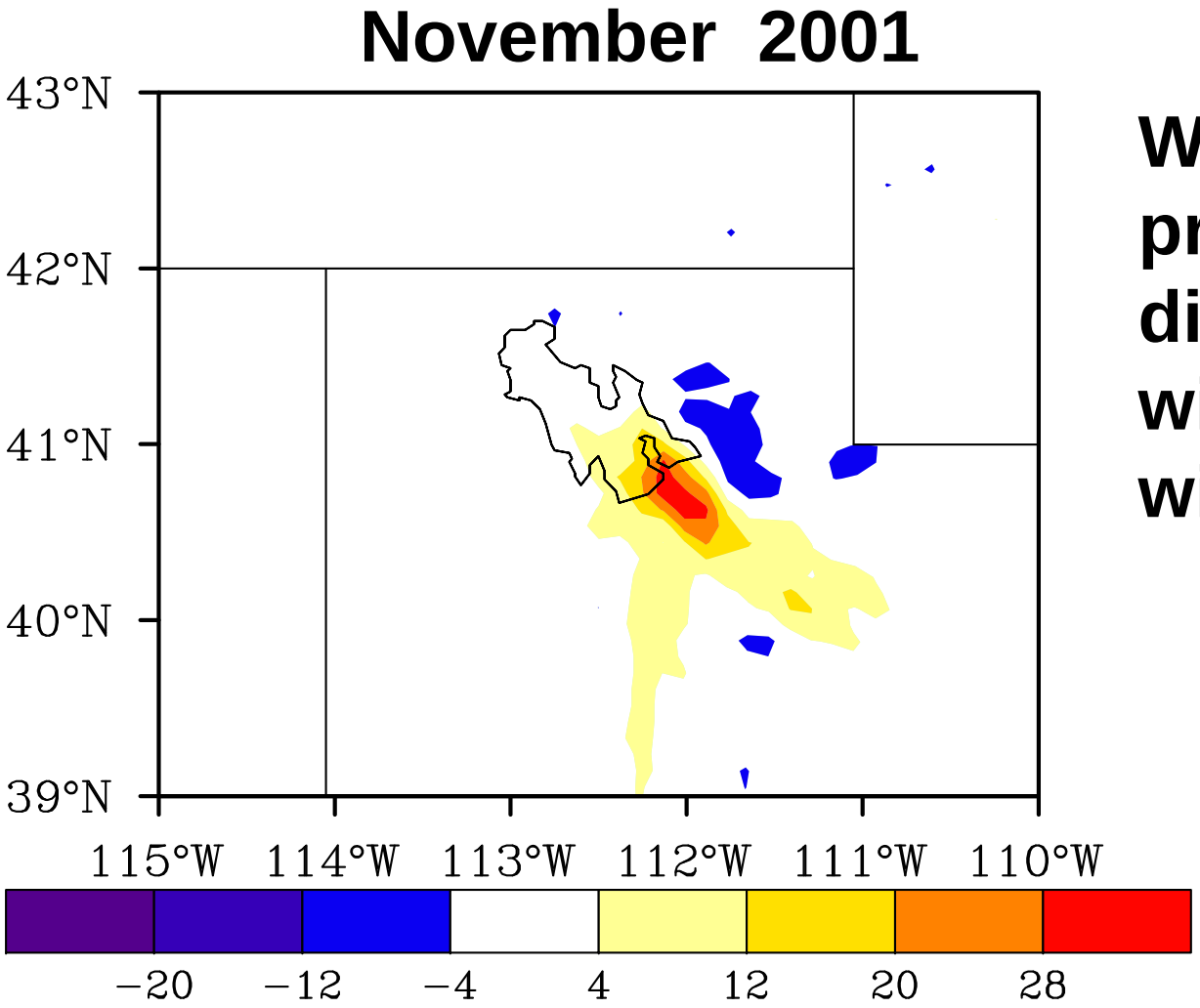


WRF with the lake model





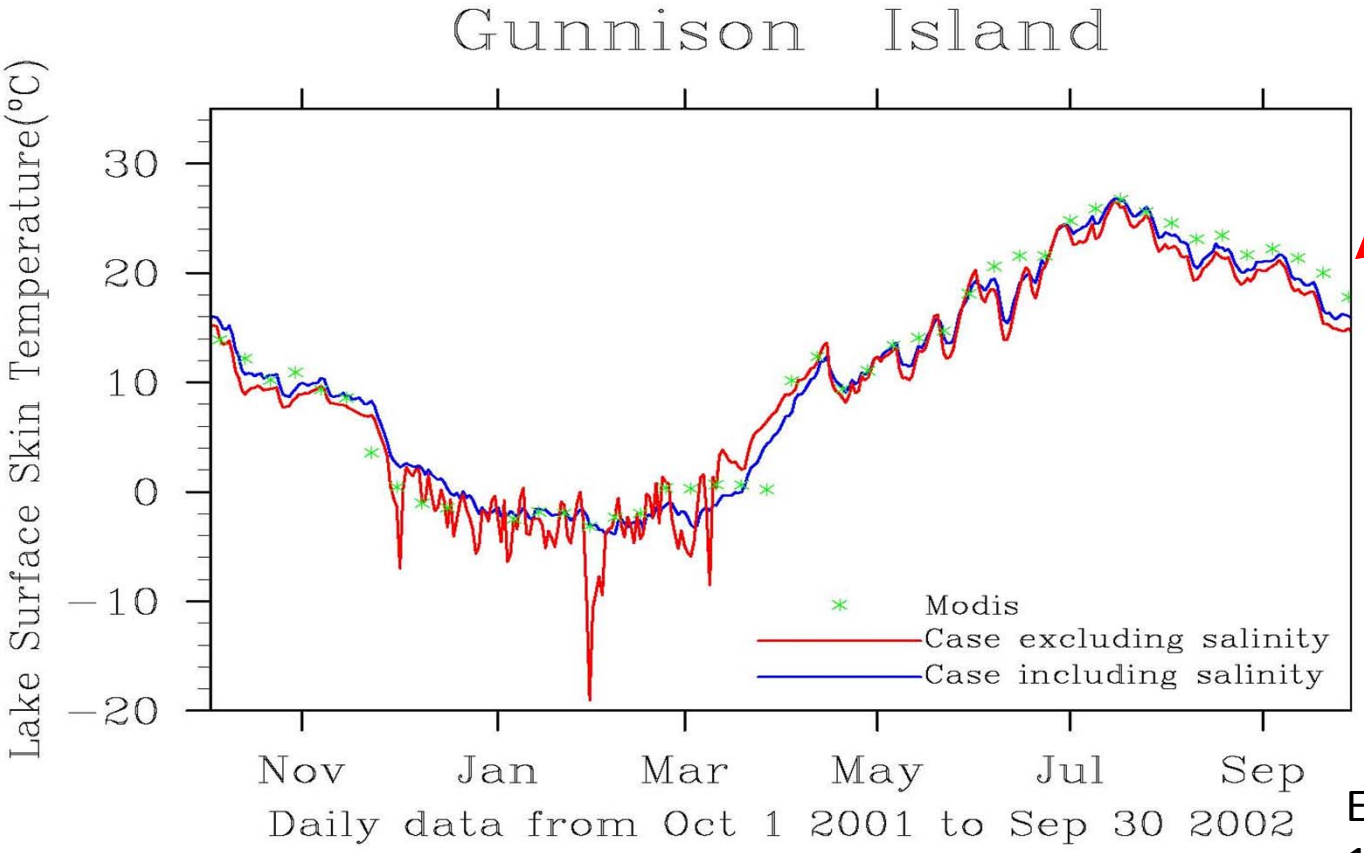
Simulated Lake-Effect Precipitation with the WRF-lake model over the Great Salt Lake



WRF simulated precipitation difference between with lake and without lake

Average Lake depth : 5 m

Lake Surface Temperature Simulations over Great Salt Lake



Great Salt Lake

Salinity:
GSL: ~ 20%
Ocean: ~ 3.5%

WRF-Lake Simulations at 10 km resolution

Average Lake depth : 5 m

Effects of salinity:

1) Freezing point
2) Water Density
3) Thermal Conductivity
4) Heat capacity
5) Evaporation

Great Lakes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CANADA
Ontario
Quebec
Superior
MN
Duluth
Superior
Sault Ste. Marie
Manitoulin Island
MI
Escanaba
Marinette
WI
Green Bay
Mackinac Island
Huron
Michigan
MI
Muskegon
Port Huron
Lake St. Clair
Toronto
Ontario
Rochester
Milwaukee
Detroit
Erie
Buffalo
Welland Canal
IA
Chicago
Gary
Toledo
Cleveland
Erie
USA
IL
IN
OH
PA
NY
NJ
New York City
St. Lawrence River
Ottawa
Quebec
Montreal
Gulf of St. Lawrence
New Brunswick
PEI
ME
Augusta
Nova Scotia
VT
NH
Concord
MA
Boston
CT
RI
Atlantic Ocean
N
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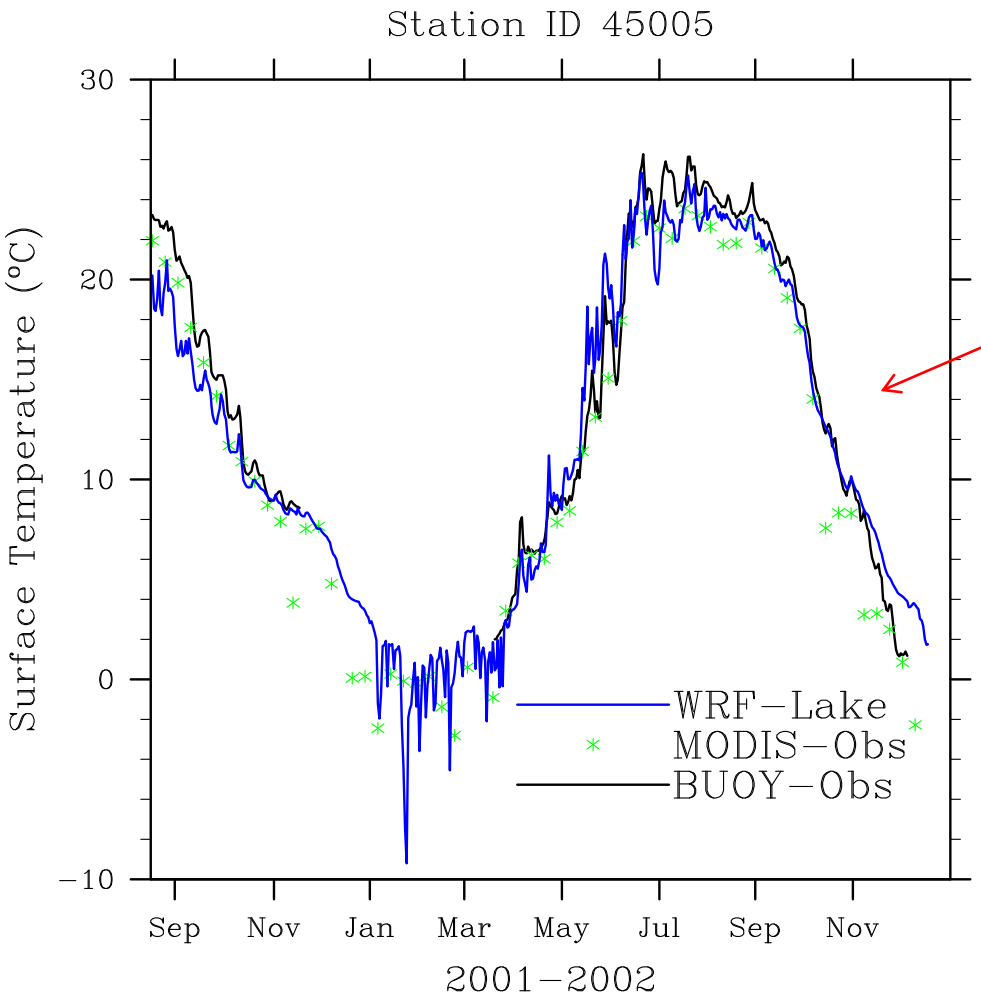
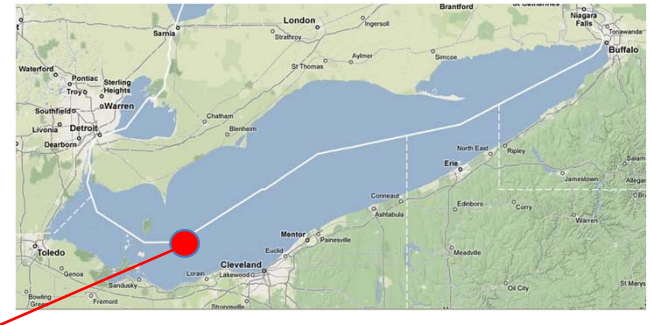
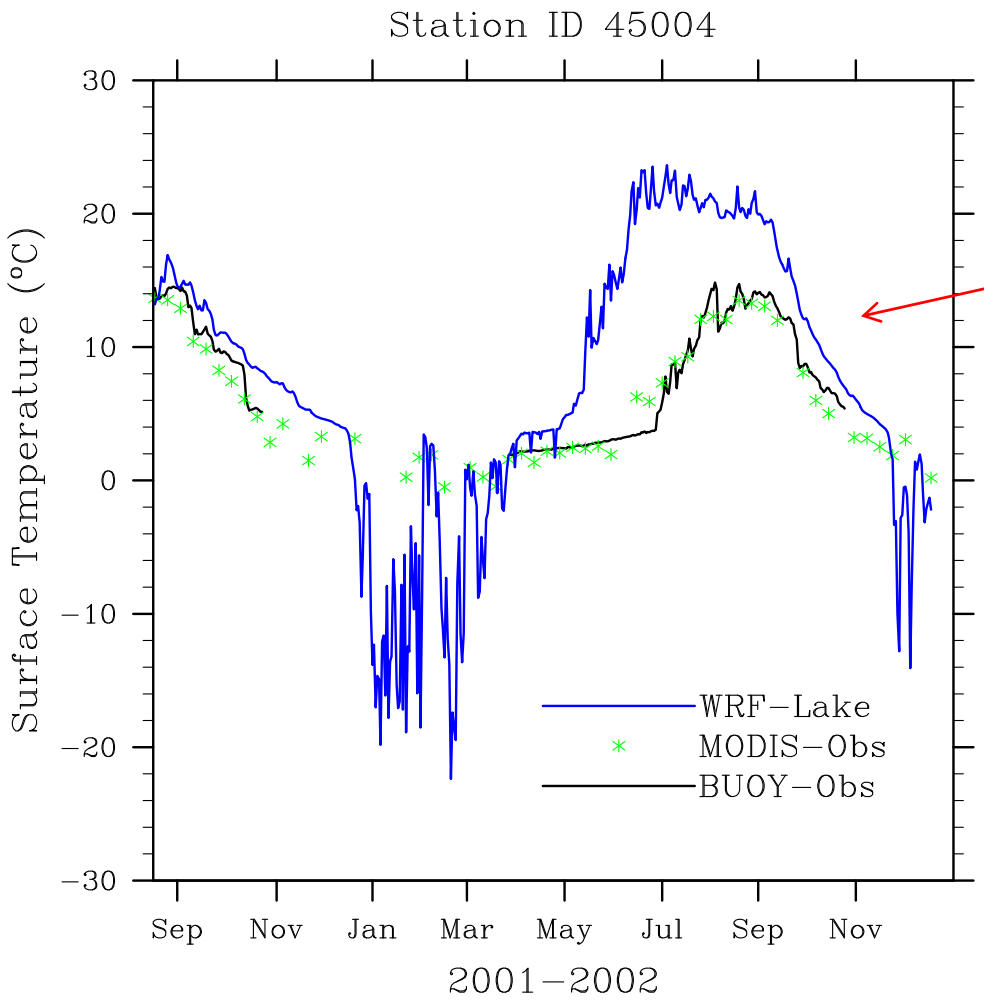
Surface Temperature Simulations at 10 km resolution for Lake Erie





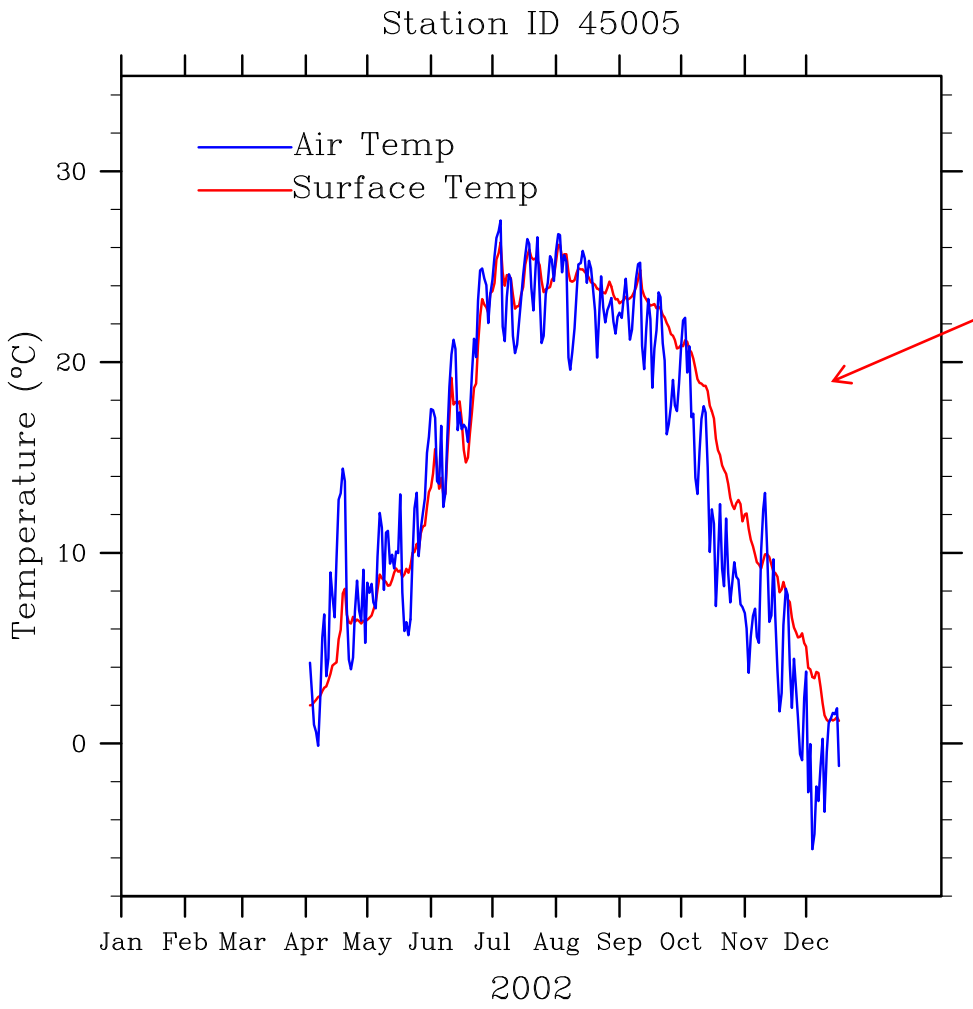
The average depth of Lake Erie is 19 m with a maximum depth of 64 m

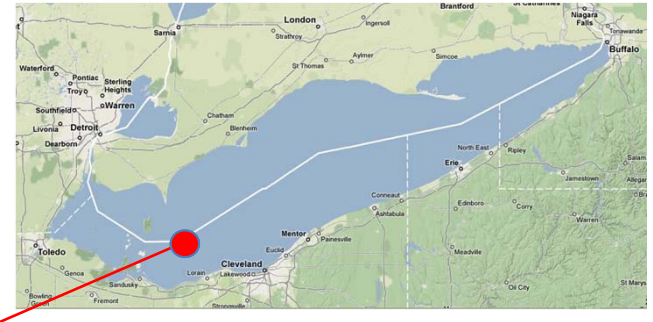
Surface Temperature Simulations at 10 km Resolution for Lake Superior



The average depth of Lake Superior is 147 m with a maximum depth of 406 m.

Observed Surface Temperature and Near-Surface Air Temperature over Lake Erie

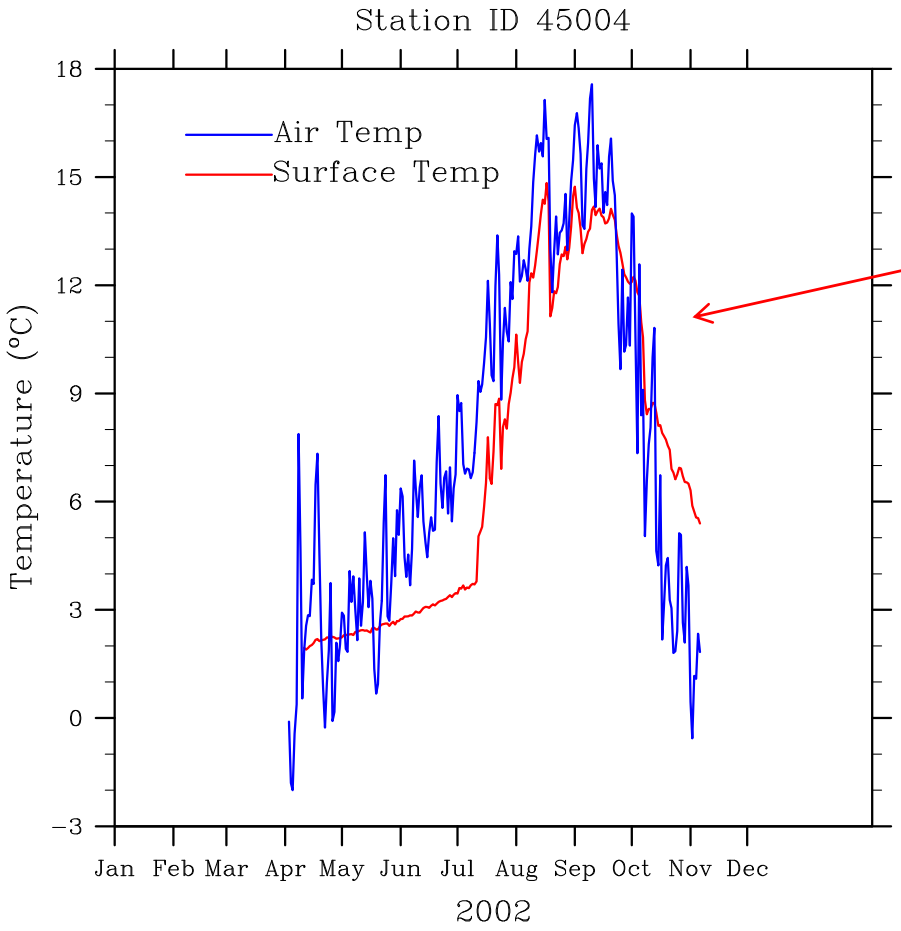




The air temperature was measured at a height of 4 m

The average depth is 19 m

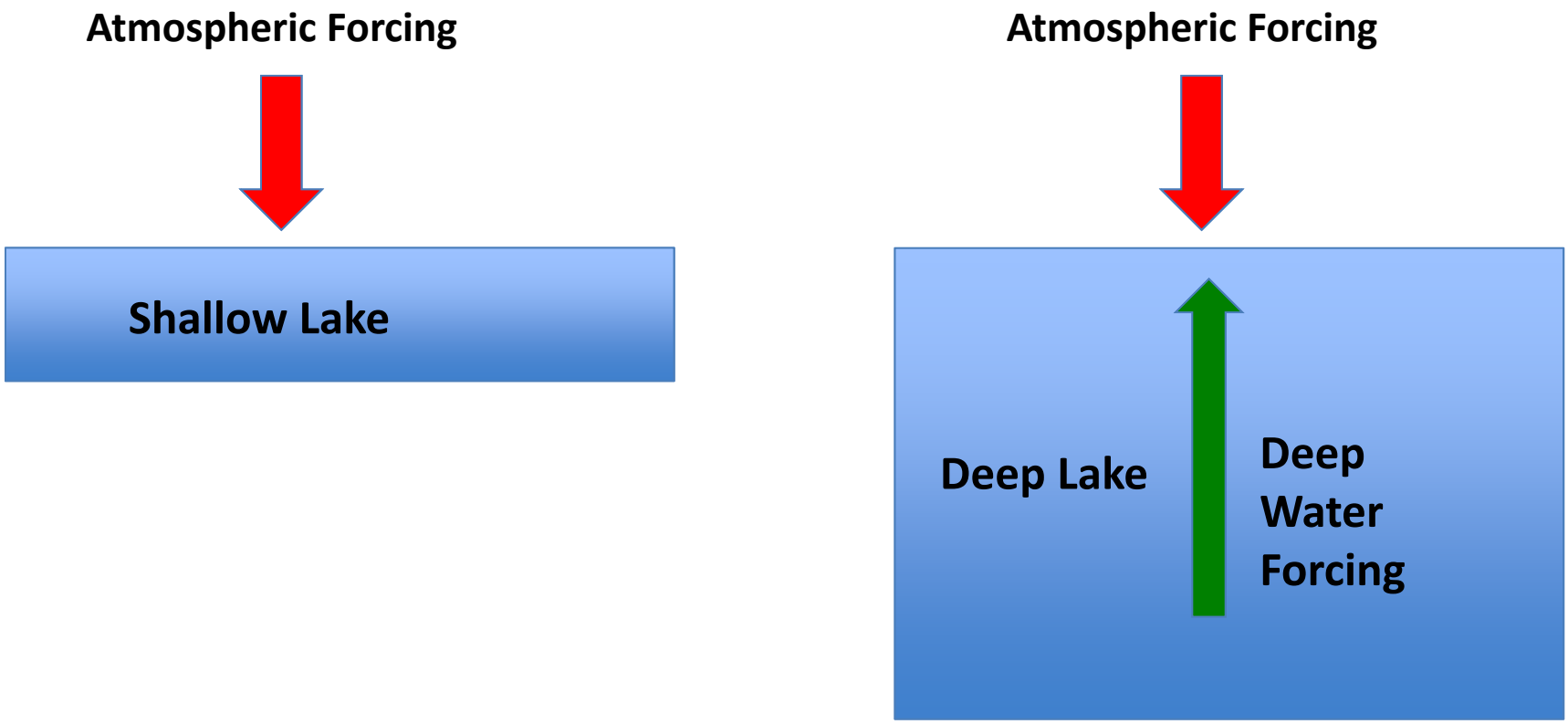
Observed Surface Temperature and Near-Surface Air Temperature over Lake Superior



The air temperature was measured at a height of 4 m

The average depth is 147 m

Processes Affecting Lake Surface Temperature



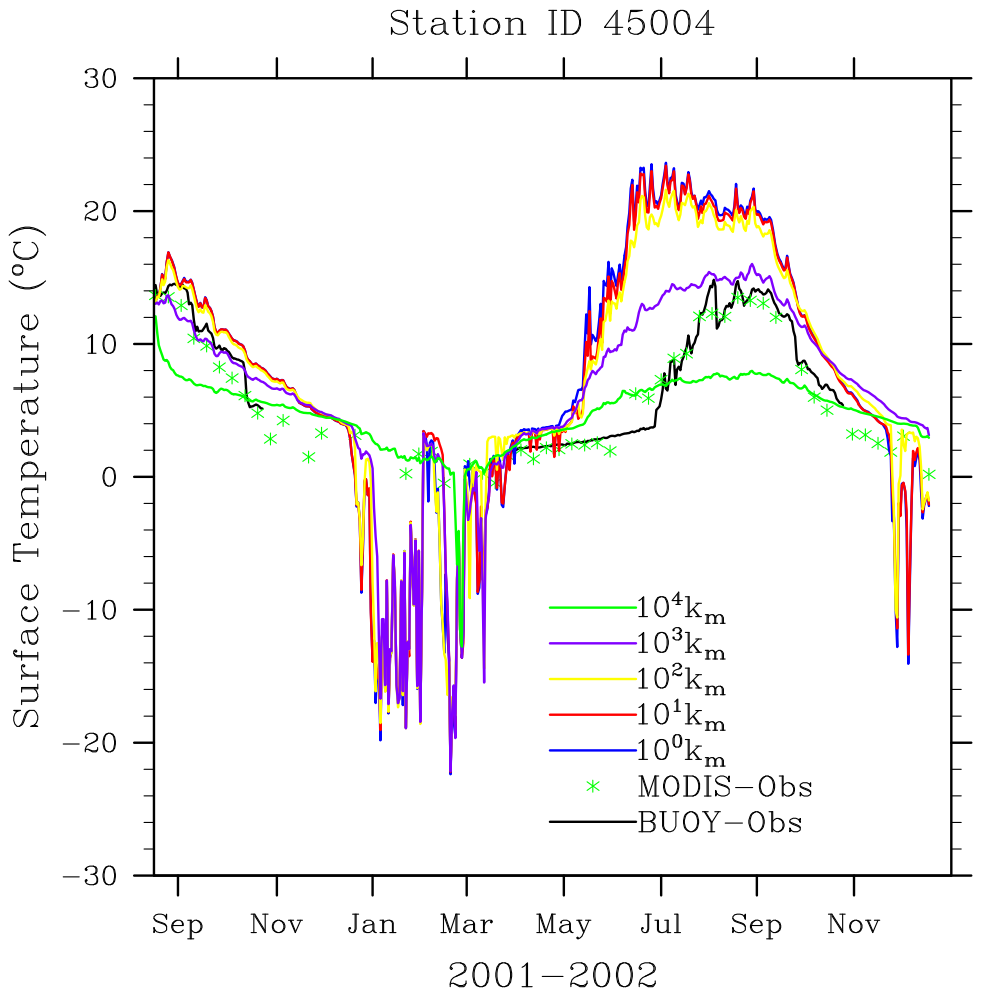
Vertical Energy Transfer within the Lake Water

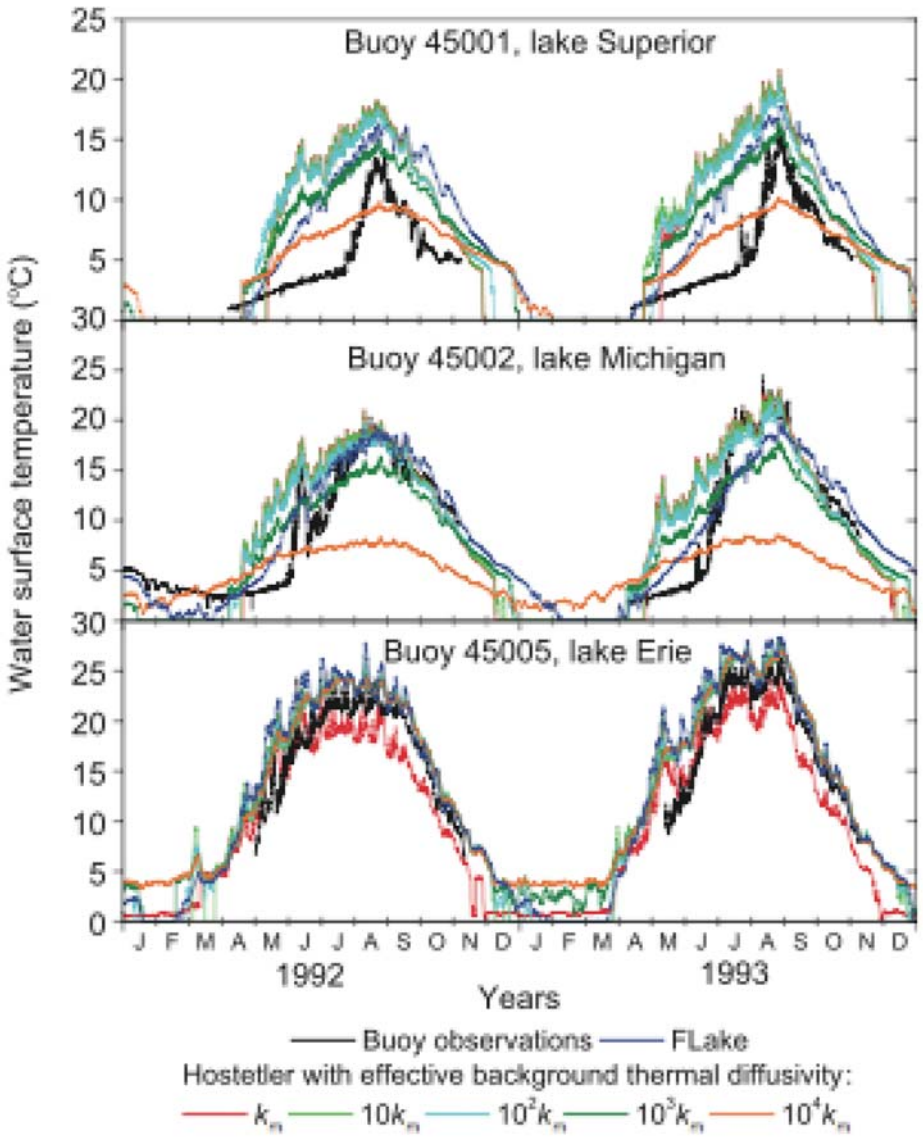
1) Molecular Diffusion Coefficient (K_m) = 1.433x10^{-7} (m^2/s)

2) Eddy Diffusion Coefficient (K_e) (Unit: m^2/s)

$$K_{e,i} = \left\{ \begin{array}{ll} \dfrac{kw^* z_i}{P_0(1+37Ri^2)} \exp(-k^* z_i) & T_g > T_f \\ 0 & T_g \le T_f \end{array} \right\} 1 \le i < 10$$

Sensitivity Tests over Lake Superior with Different Molecular Diffusion Coefficients (K_m)





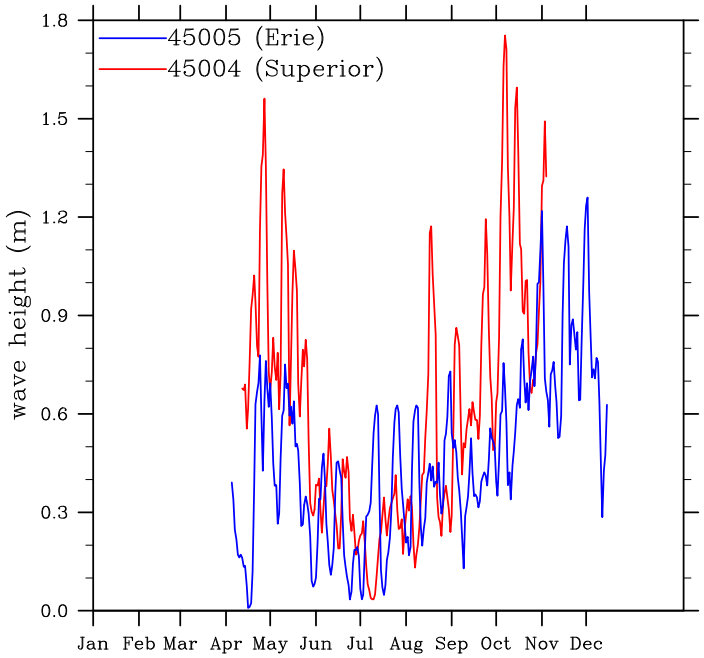
Lake Depth: 147 m

Lake Depth: 85 m

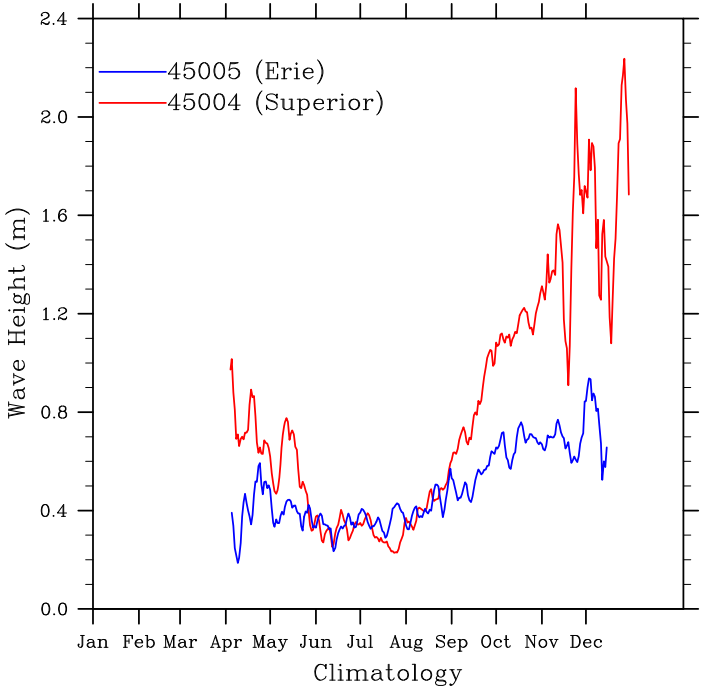
Lake Depth: 19 m

Martynov et al., 2010, *Boreal Environmental Research*

Observed Wave Height

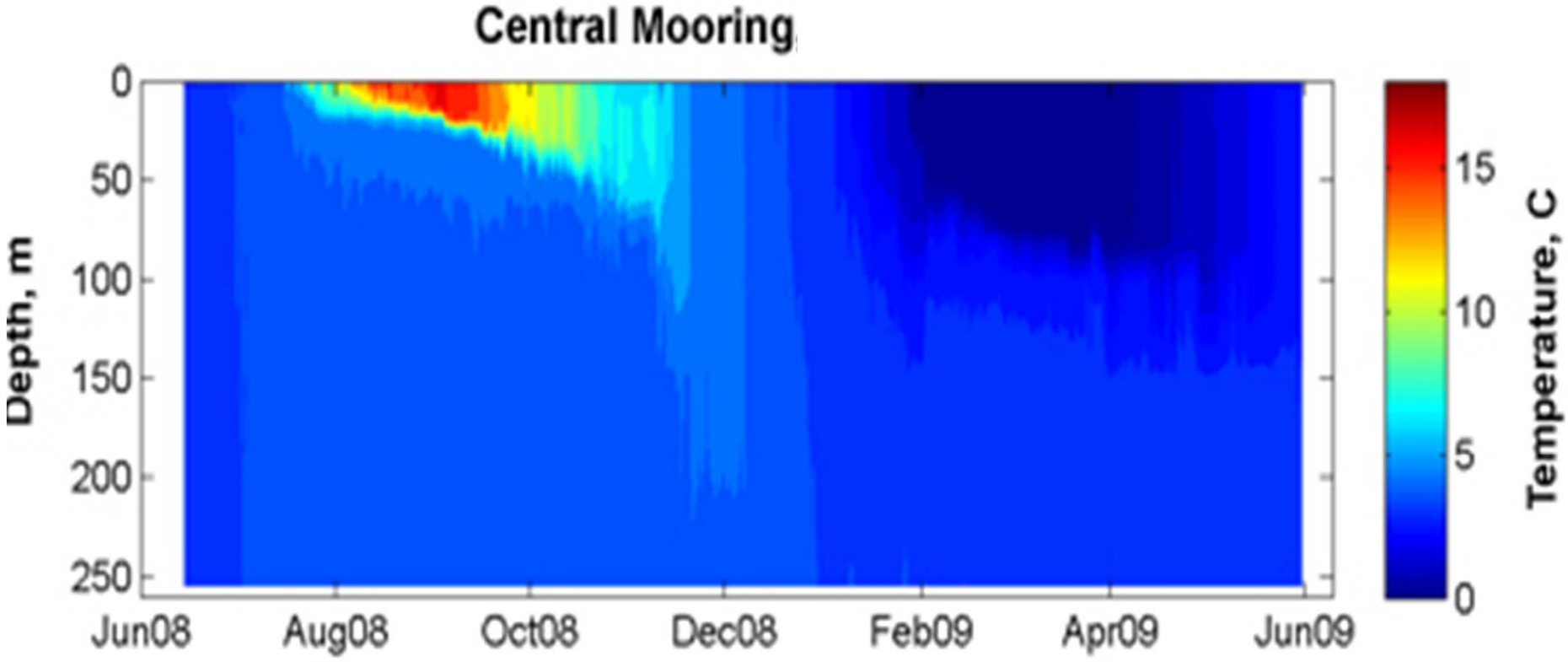


2002



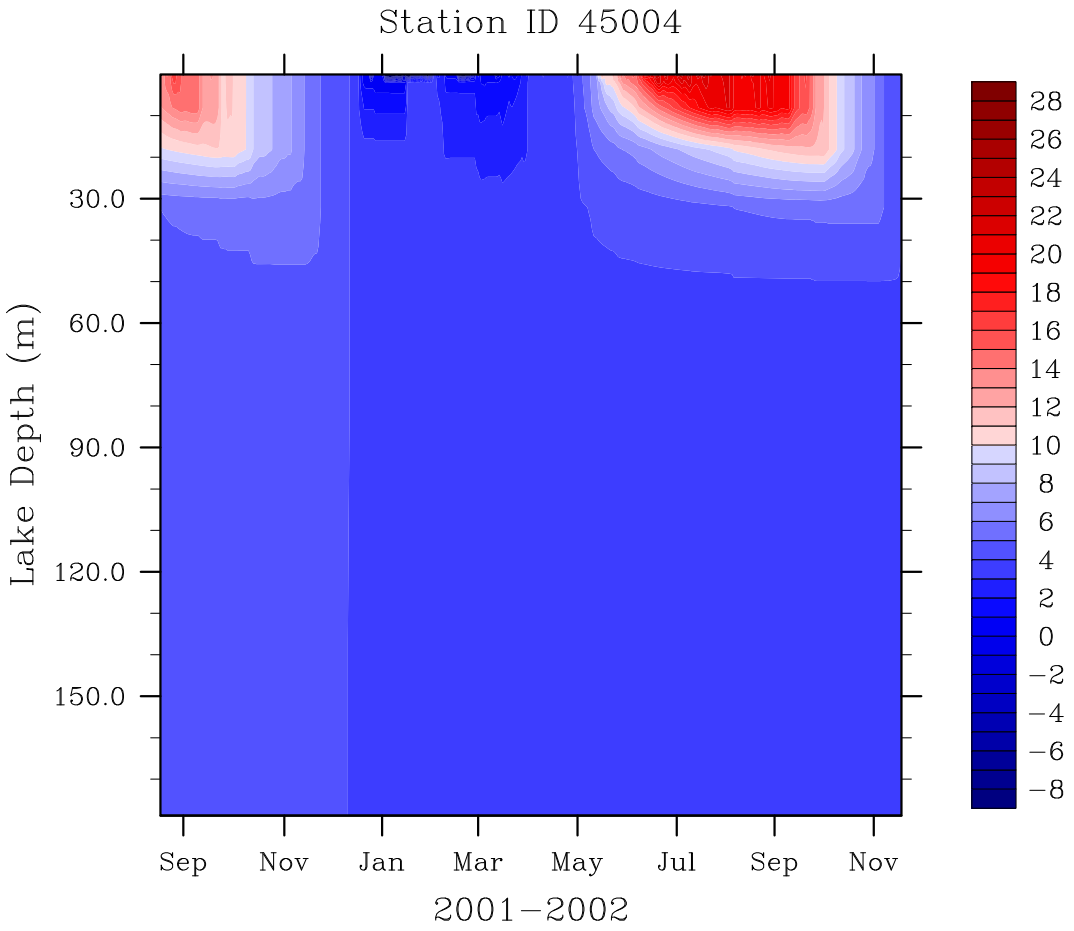
1980-2009

Observed Temperature Profile over Lake Superior

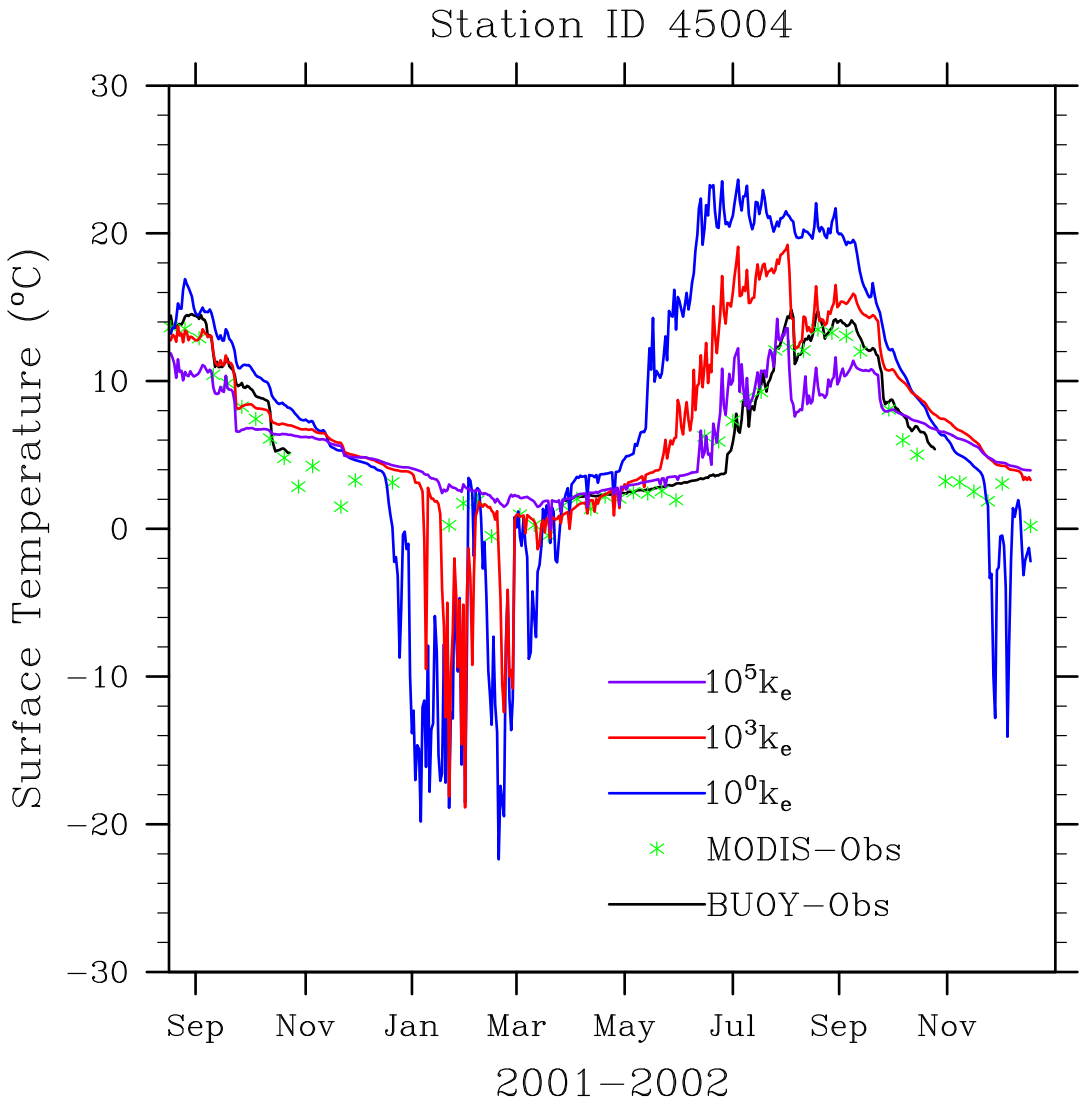


University of Minnesota (http://www.seagrant.umn.edu/superior/processes)

Simulated Temperature Profile over Lake Superior

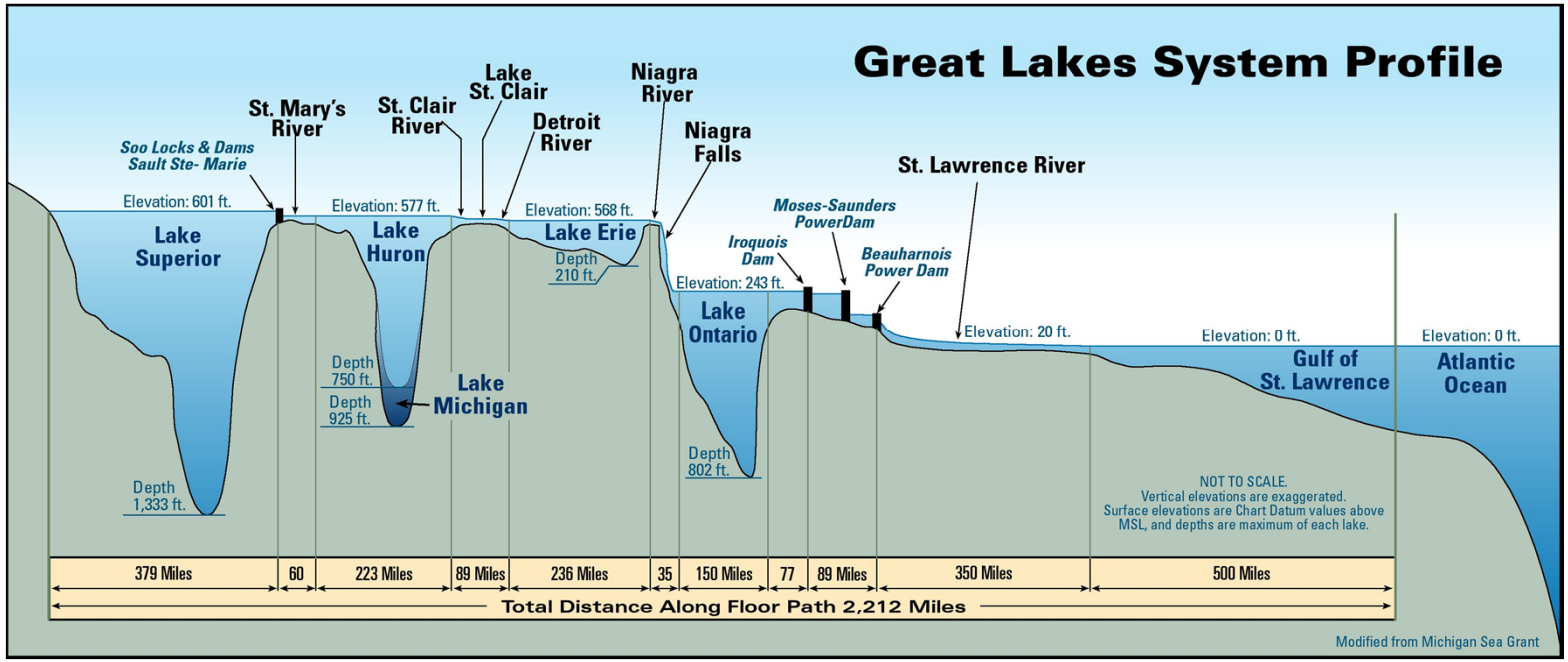


Sensitivity Tests with Different Eddy Diffusion Coefficients (K_e)

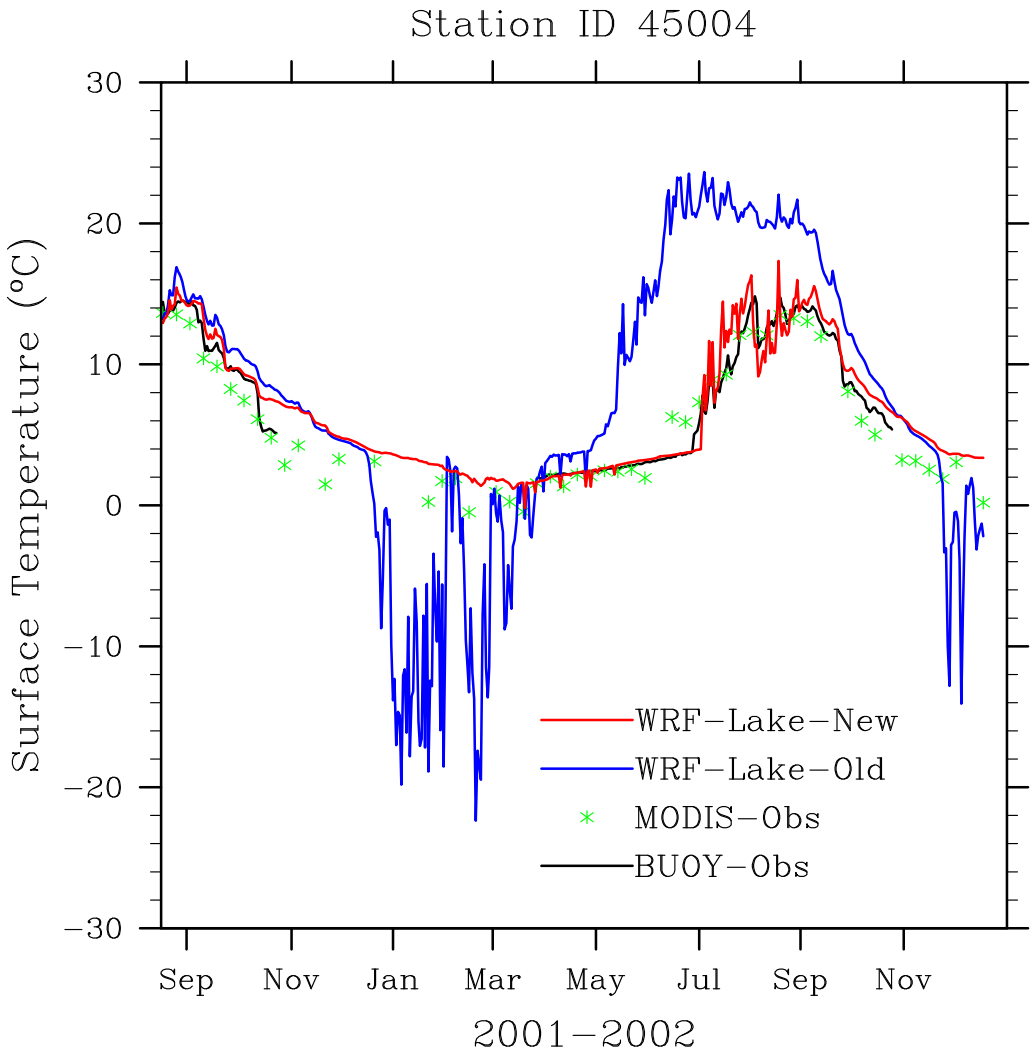


Eddy Diffusion Coefficients (K_e)

Lake Depth	T>4 °C	0°C ≤T≤4°C	T<0°C
>150m	10^2K_e	10^5K_e	0
15~150m	10^2K_e	10^4K_e	0
<15m	K_e	K_e	0

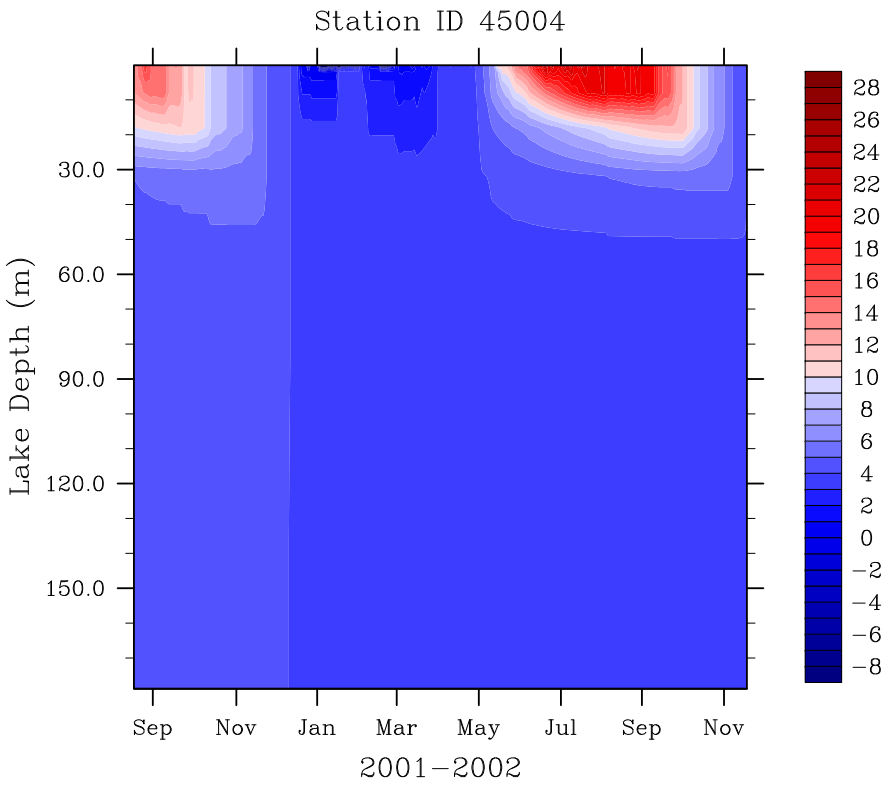


Surface Temperature Simulations for Lake Superior

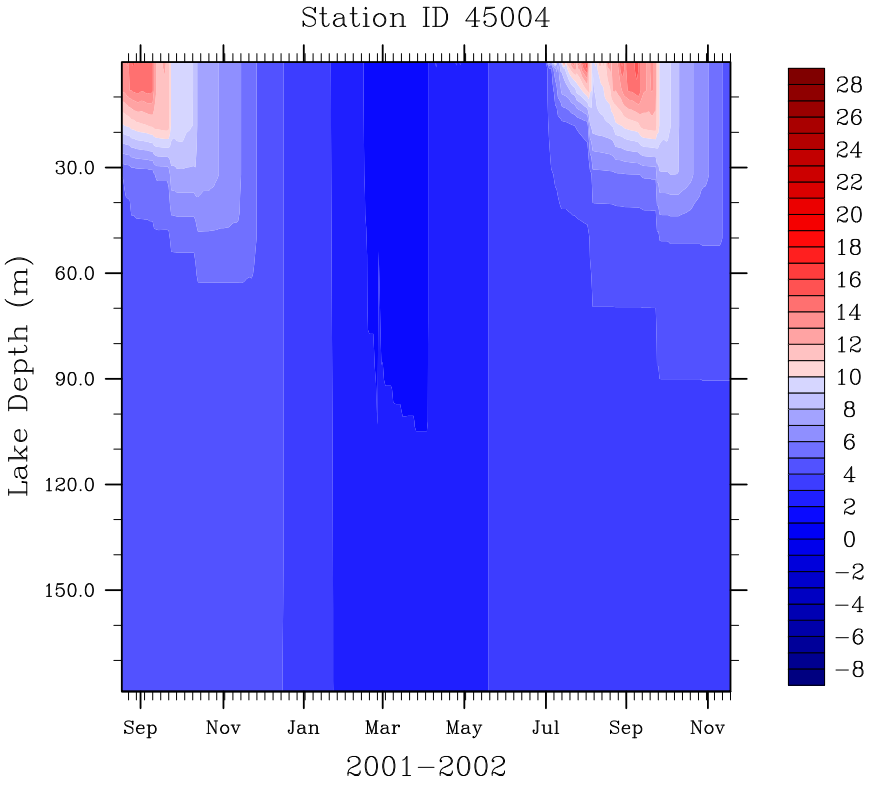


Simulated Temperature Profiles over Lake Superior

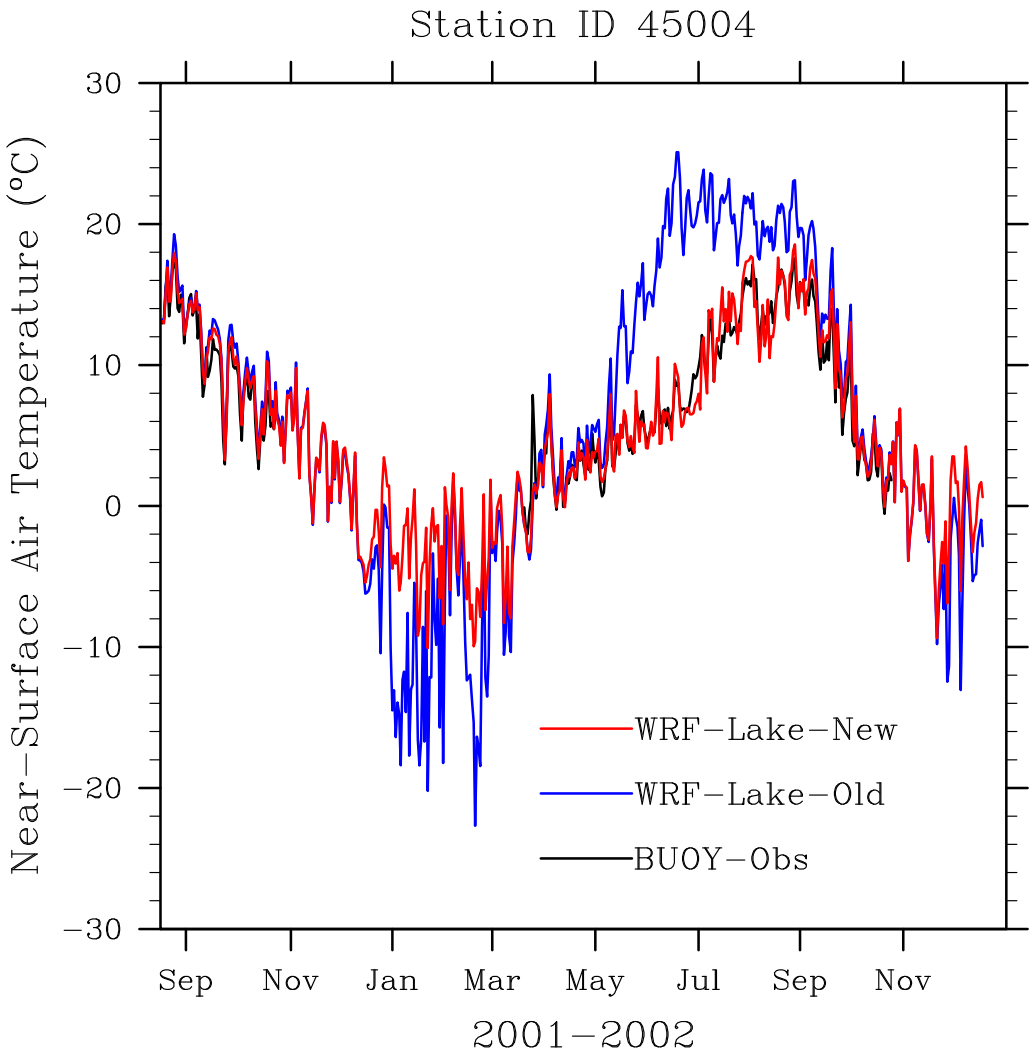
Old K_e



New K_e



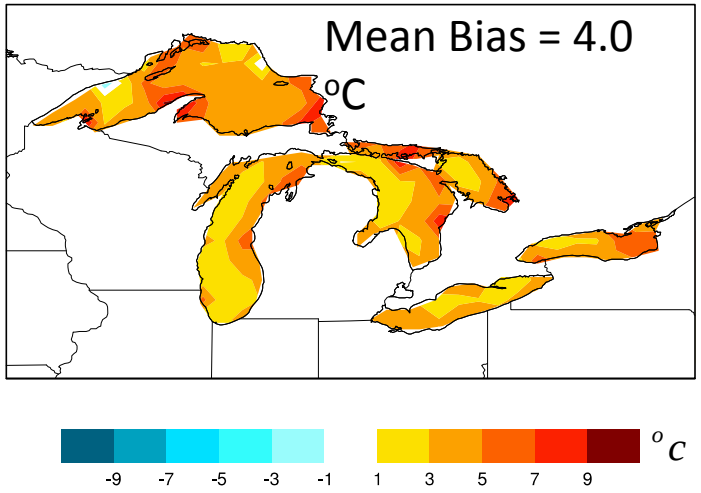
Near-Surface Air Temperature Simulations for Lake Superior



The air temperature was measured or simulated at a height of 4 m

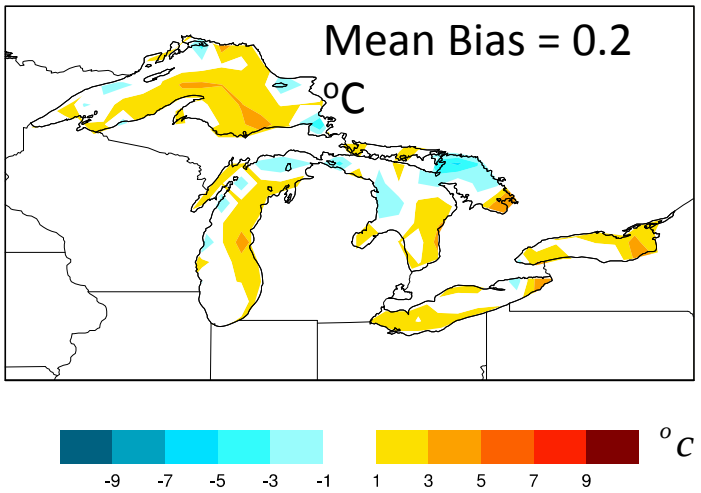
Lake Surface Temperature Bias

NARR minus MODIS



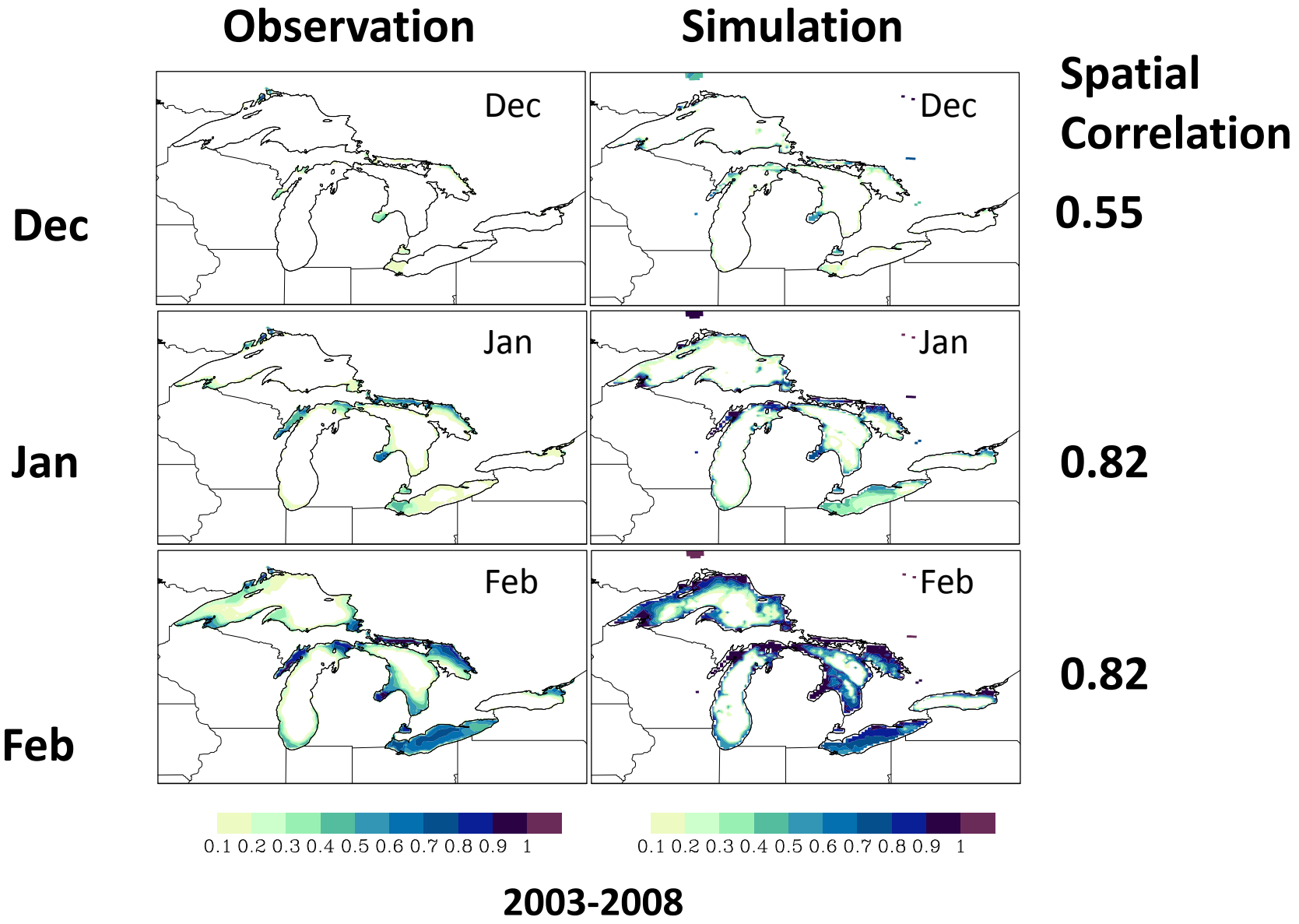
Winter (DJF), 2003-2008

WRF-Lake minus MODIS

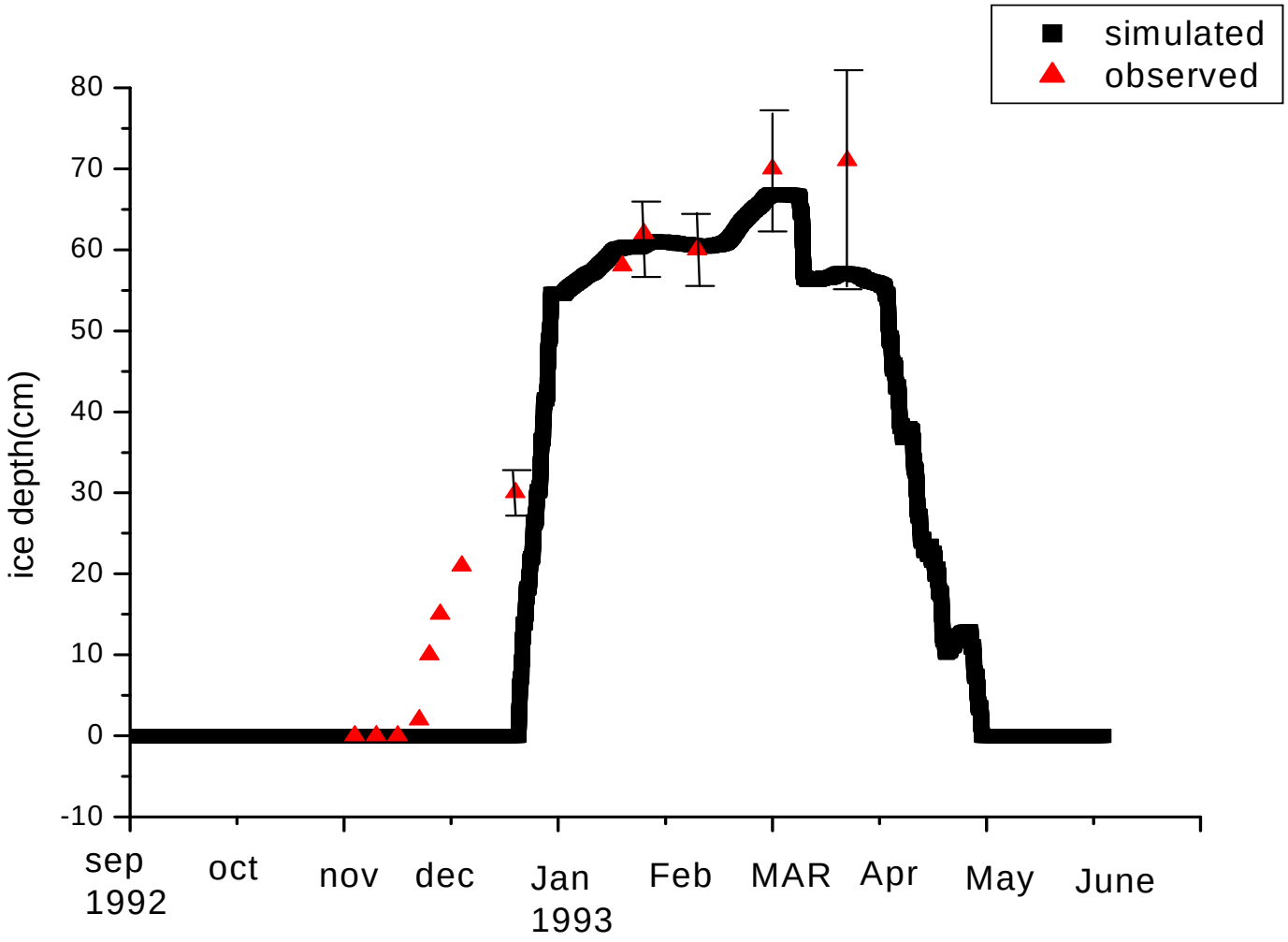


Winter (DJF), 2003-2008

Lake Ice Fraction Simulations

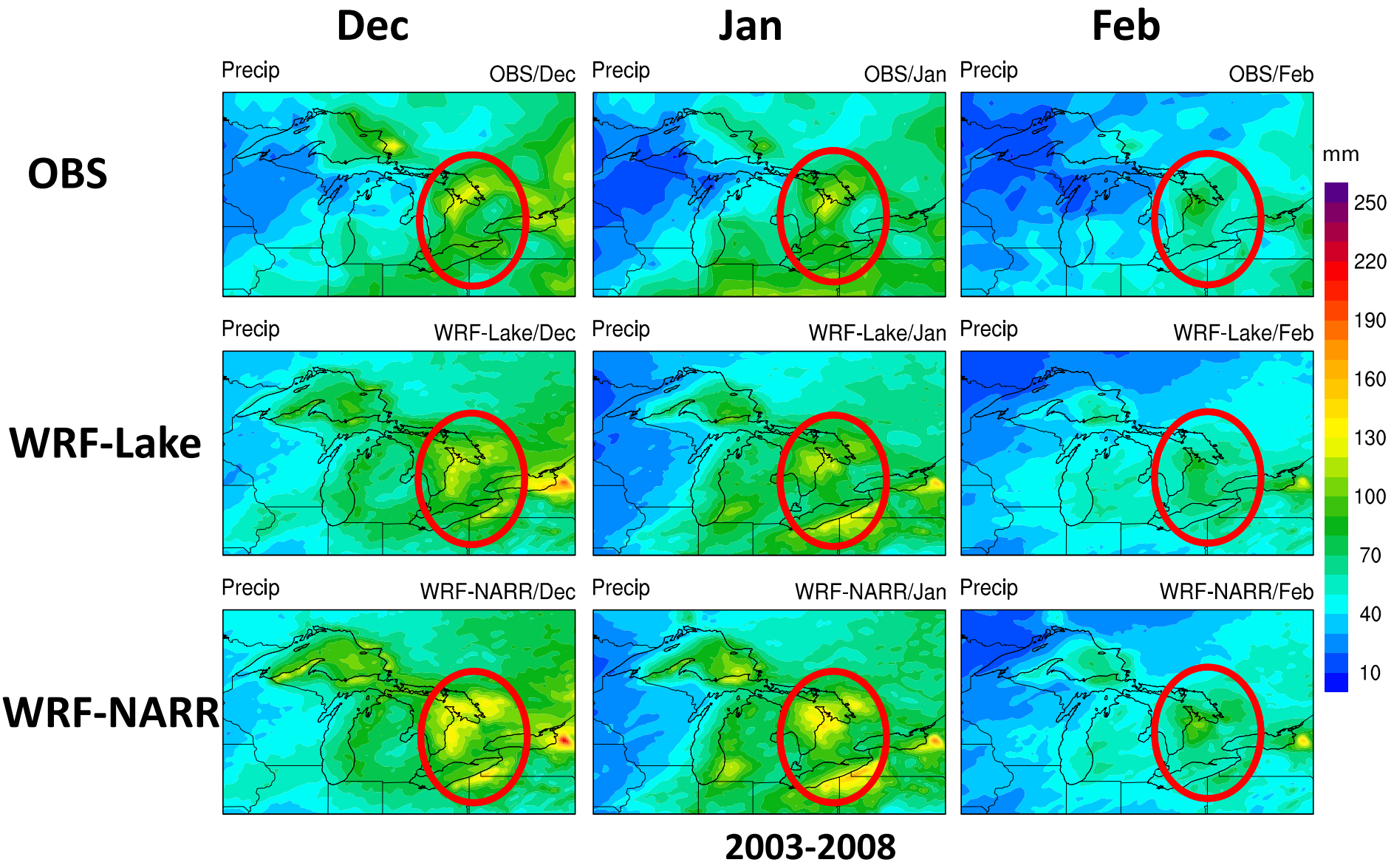


Ice Thickness Simulations for Lake Lower Two Medicine



Sun and Jin 2012

Winter Precipitation Simulations



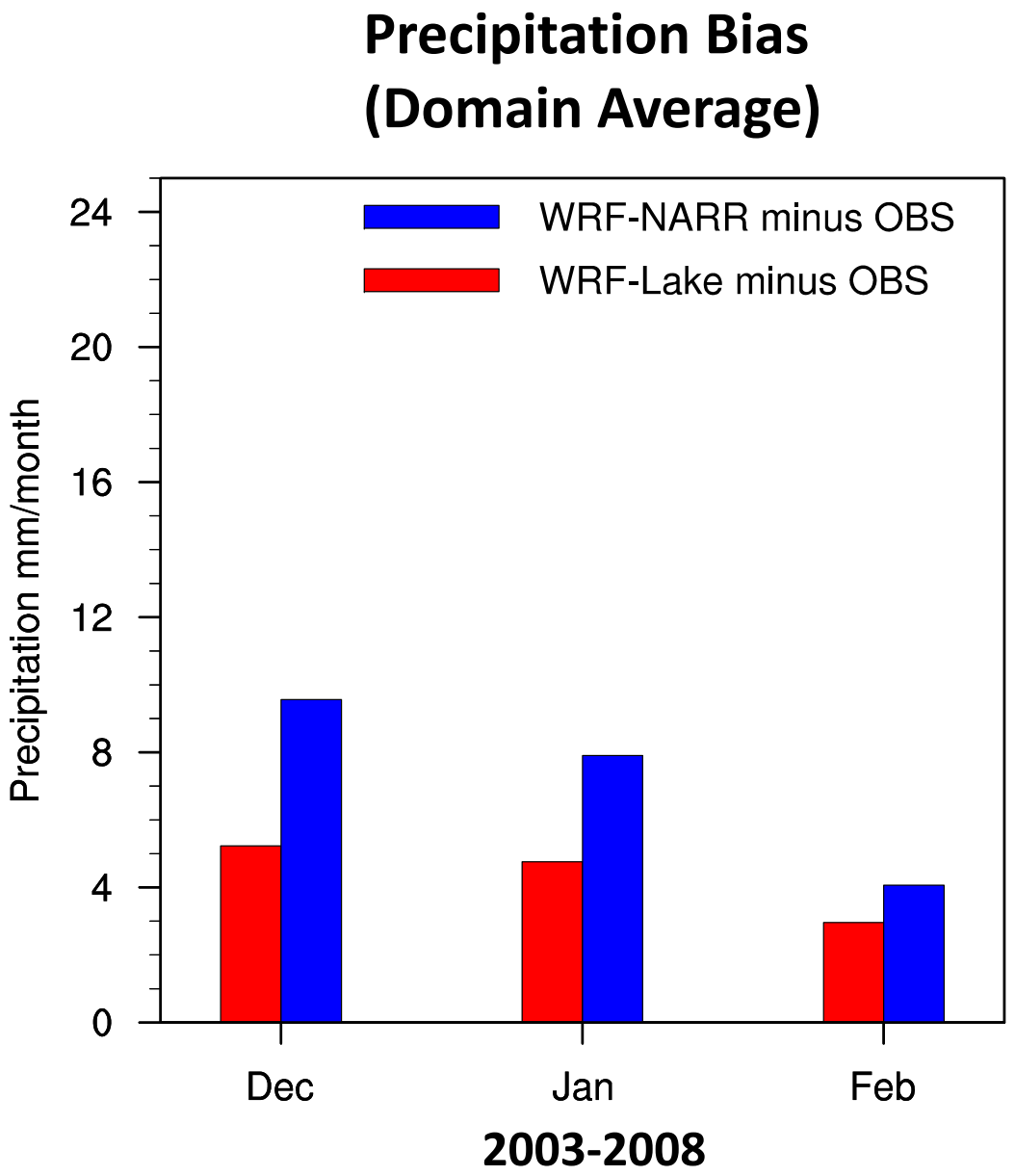
Simulated Precipitation Bias

Bias = 7.2mm/month

WRF-NARR minus OBS

Bias = 4.3mm/month

WRF-Lake minus OBS



Summary

- **The coupled WRF-Lake model realistically simulates the lake surface temperature and lake ice fraction for the Great Lakes.**

- **This coupled model also reduces the biases in the lake-effect precipitation simulations and has a capability of dynamic simulations of lake-atmosphere interactions.**

Acknowledgement

This project was supported by the NOAA Modeling, Analysis, Predictions, and Projections Program. Grant Number: NA090AR4310195.