Lake Parameterization and Simulation in a Regional Climate Model of the North American Great Lakes (and other places)

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Workshop on Lake Simulation

ЗеЛеноГорск (Zelenogorsk)

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With contributions from…

Nathan Moore, Jia Wang, David Schwab, Dmitry Beletsky, Xianglei Huang, Richard Anyah, and GFDL GAMDT

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Outline

- Geographical introduction
- Formulation of CHARM
- CHARM results--GHG and surface roughness experiments
- Future plans for CHARM
- Coupled dynamical lake & ice model
- Incorporation into GFDL model
- Usage in East Africa
- Issues with temperature as proxy for ET
- Miscellaneous musings


Ontario
Quebec
Superior
Minnesota
Wisconsin
Michigan
Huron
Michigan
Ontario
New York
Erie
Pennsylvania
Illinois
Indiana
Ohio
Image © GLIN

CHARM formulation

- Based on Regional Atmospheric Modeling System (RAMS)
- Non-hydrostatic dynamics
- LEAF3 land scheme (BATS-like)
- 40 km horizontal grid spacing, 24 vertical levels to 16000 m
- Added Hostetler-type vertical diffusion model of lake temperature at each lake gridpoint

Implicit time differencing

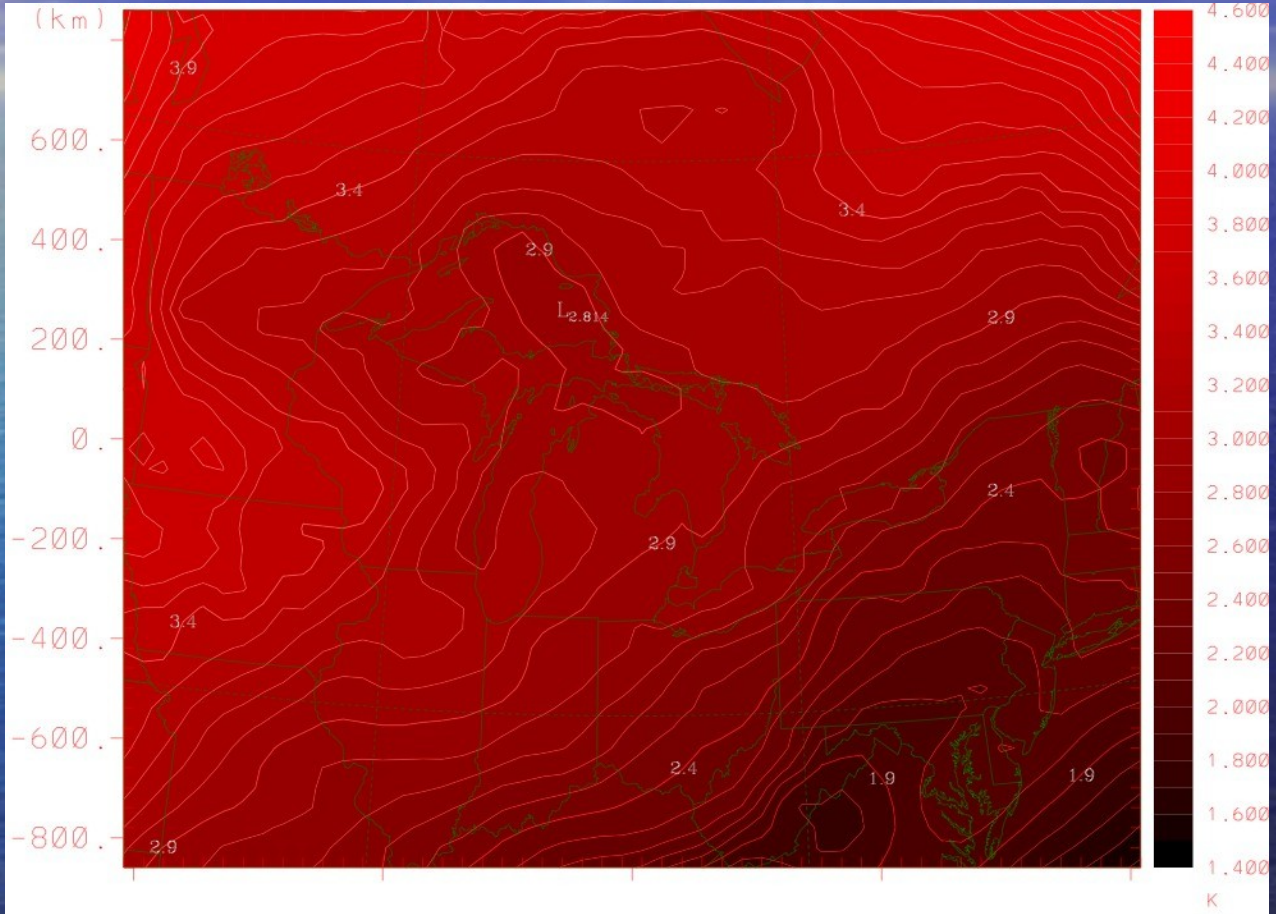
$$T_{j,t} = T_{j,t+1} - k\Delta t(T_{j-1,t+1} - 2\,T_{j,t+1} + T_{j+1,t+1})/(\Delta z)^2 + \ldots$$

$$\begin{vmatrix} b_1 & c_1 & 0 & 0 & \ldots & 0 & 0 & 0 & 0 \\ a_2 & b_2 & c_2 & 0 & \ldots & 0 & 0 & 0 & 0 \\ 0 & a_3 & b_3 & c_3 & \ldots & 0 & 0 & 0 & 0 \\ \ldots & \ldots & \ldots & \ldots & \ldots & \ldots & \ldots & \ldots & \ldots \\ 0 & 0 & 0 & 0 & \ldots & a_{n-2} & b_{n-2} & c_{n-2} & 0 \\ 0 & 0 & 0 & 0 & \ldots & 0 & a_{n-1} & b_{n-1} & c_{n-1} \\ 0 & 0 & 0 & 0 & \ldots & 0 & 0 & a_n & b_n \end{vmatrix} \begin{vmatrix} T_{1,t+1} \\ T_{2,t+1} \\ T_{3,t+1} \\ \ldots \\ T_{n-2,t+1} \\ T_{n-1,t+1} \\ T_{n,t+1} \end{vmatrix} = \begin{vmatrix} T_{1,t} \\ T_{2,t} \\ T_{3,t} \\ \ldots \\ T_{n-2,t} \\ T_{n-1,t} \\ T_{n,t} \end{vmatrix}$$

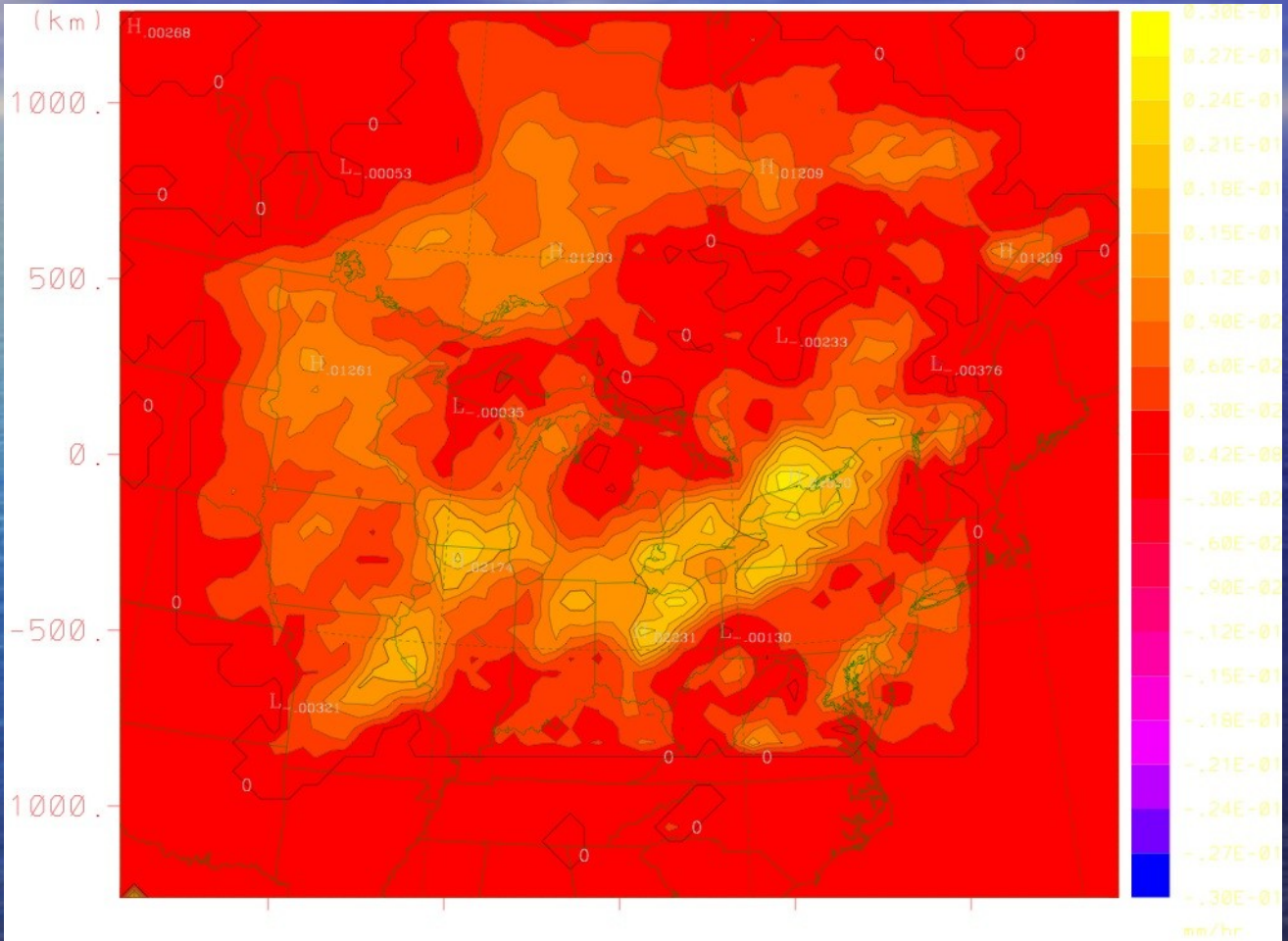
Enhanced GHG experiment

- Used input from NCAR CCSM model (SRES scenario A1) as boundary conditions to simulate 1997-1999 and 2067-2069, analyzed data from Sept. of 1st year to August of 3rd year
- Also increased CO_2 concentration within CHARM

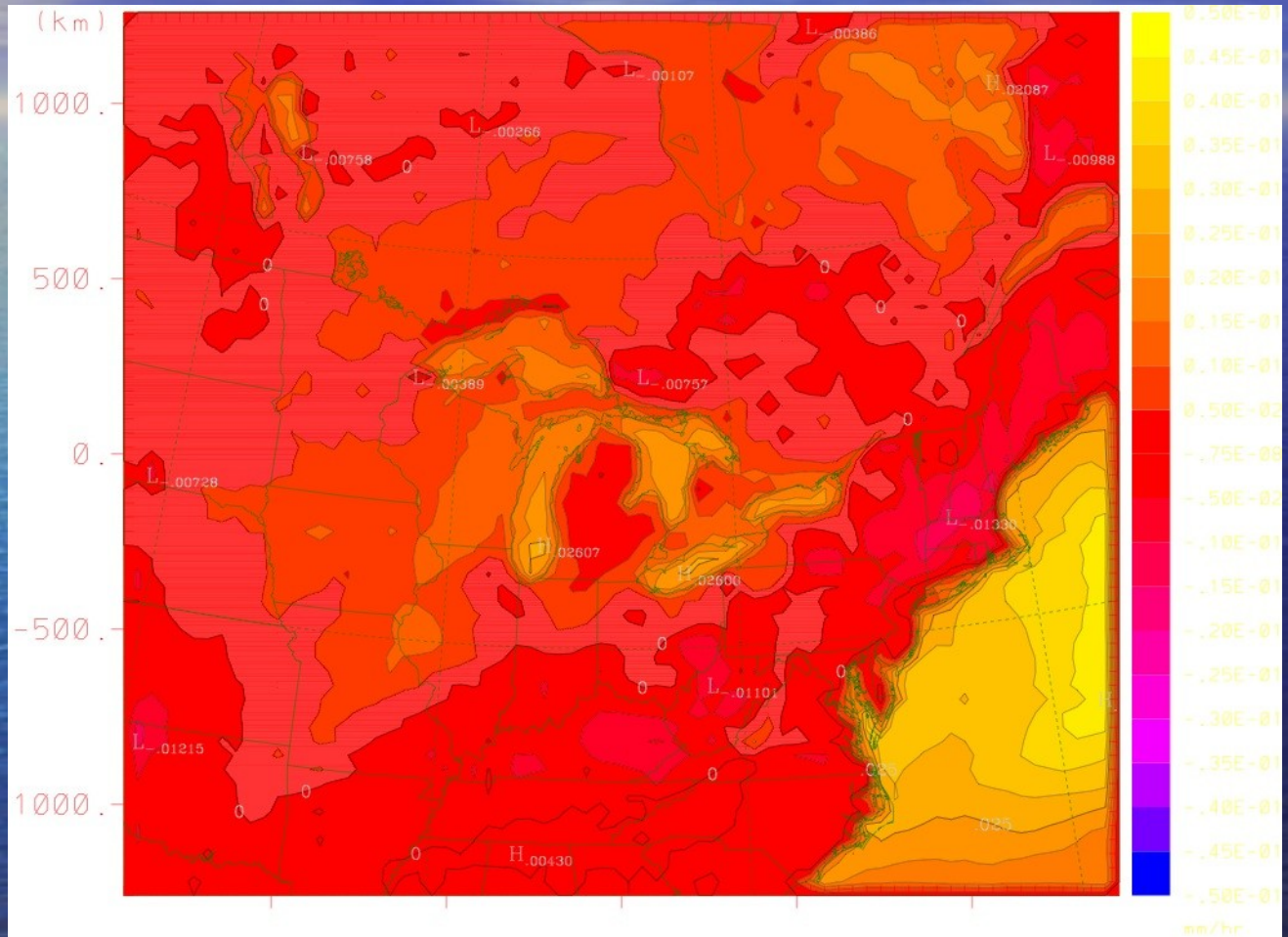
Annual Temperature 2068-1998



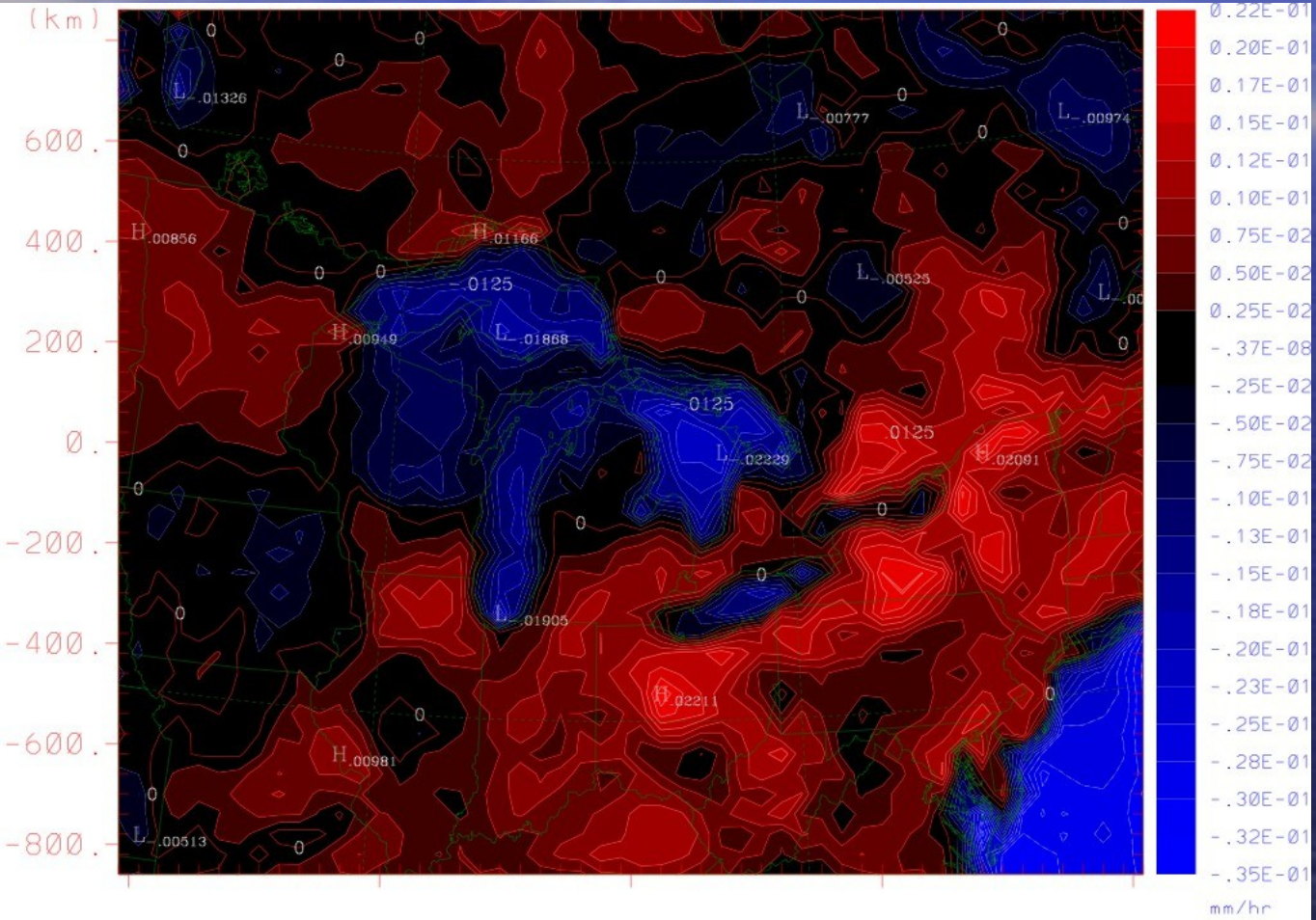
Annual Precipitation 2068-1998



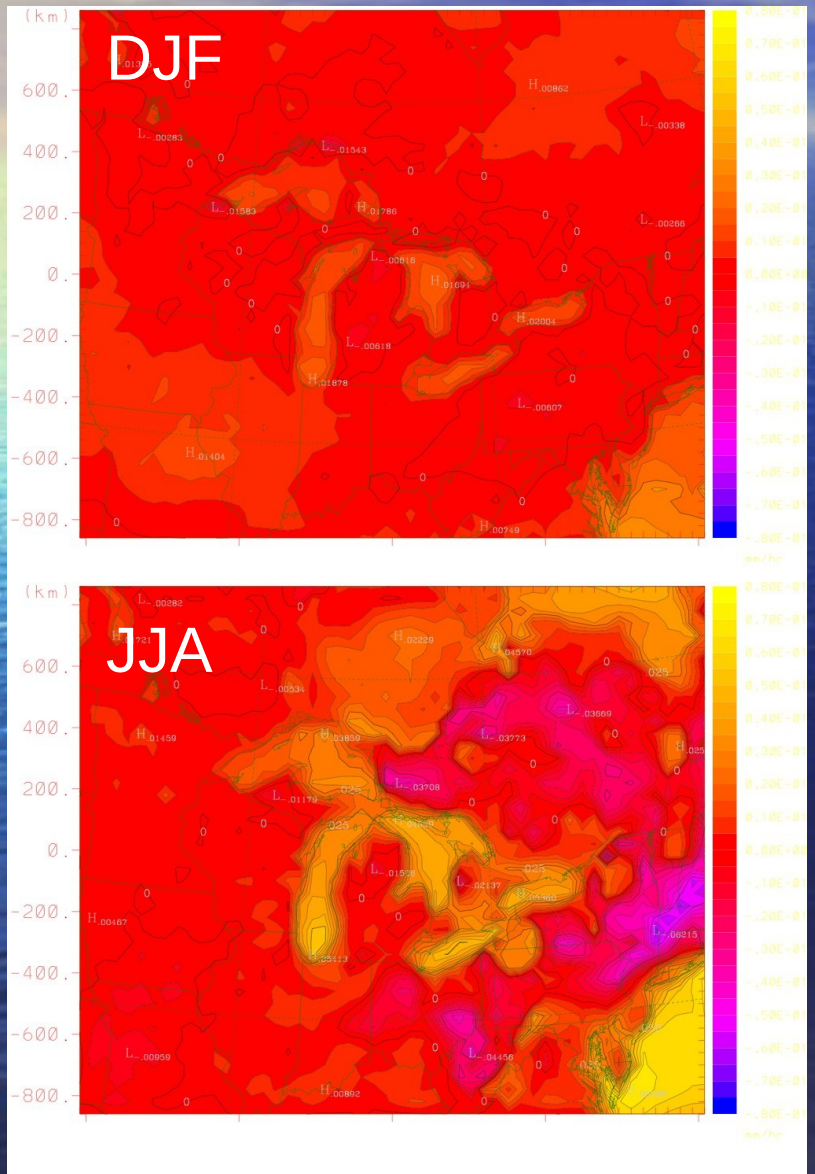
Annual Evapotranspiration 2068-1998

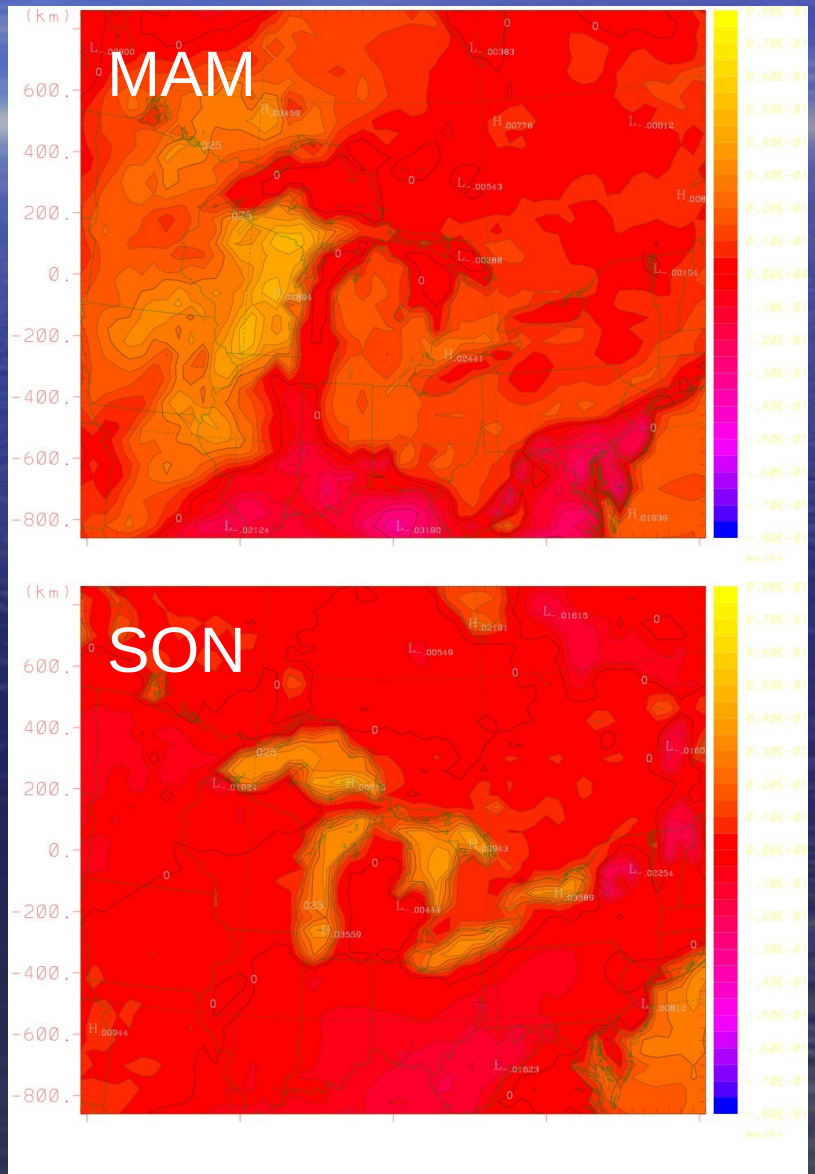


Annual P - E 2068-1998



Seasonal Evapotranspiration 2068-1998





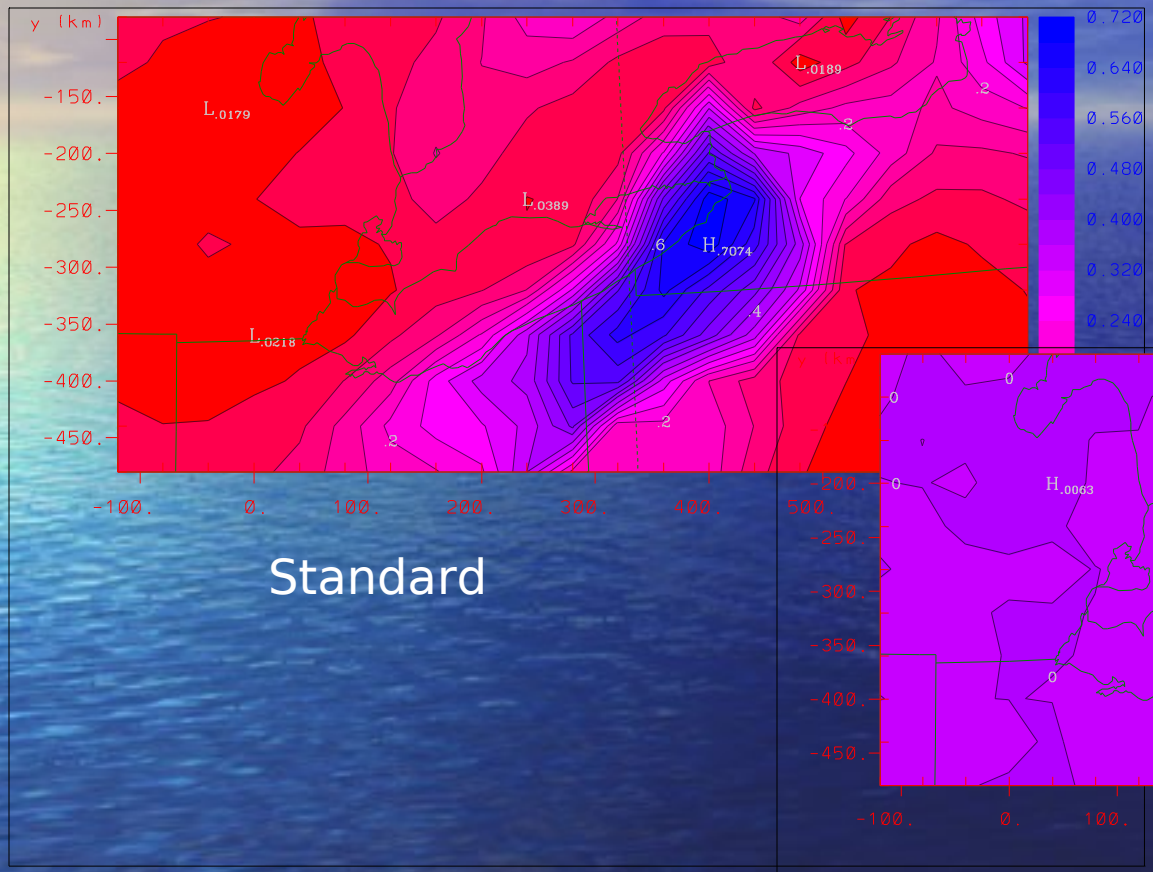
Summary of results--GHG expt.

- Increased ET
- Increased precip
- Slight increase in net basin supply
- Contradicts widely accepted results
- Caveat: preliminary results

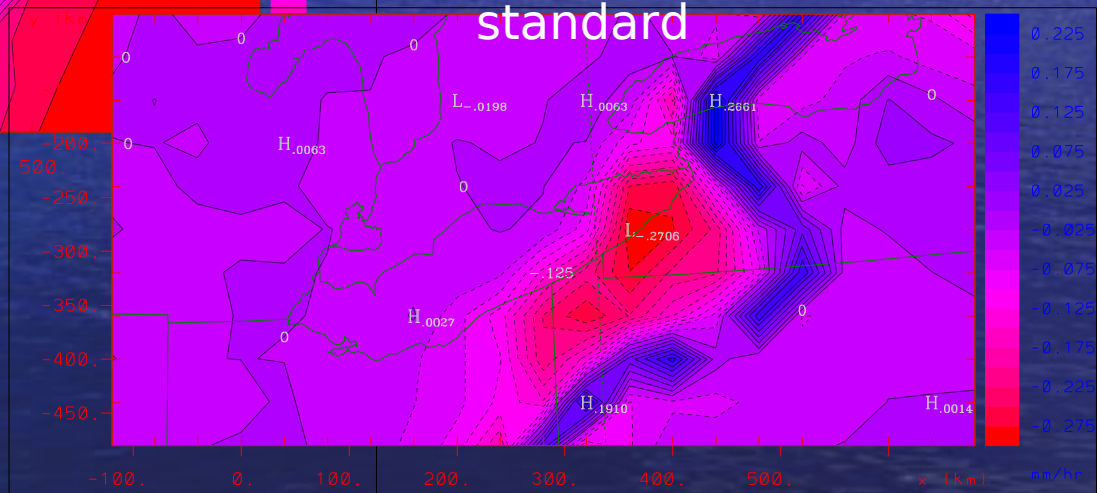
Surface roughness experiment

- Compared case with standard land use parameters to one with surface roughness reduced to values consistent with grass--radical deforestation
- Concentrated analysis on a lake effect snow event in eastern/southeastern Lake Erie

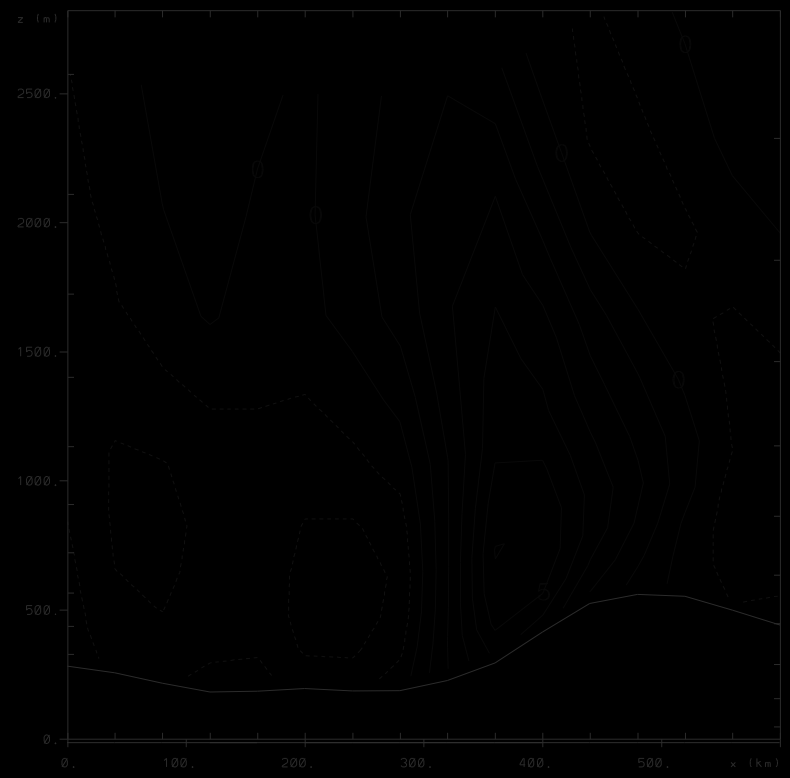
6-hourly precip Dec 11



Standard



Grass-standard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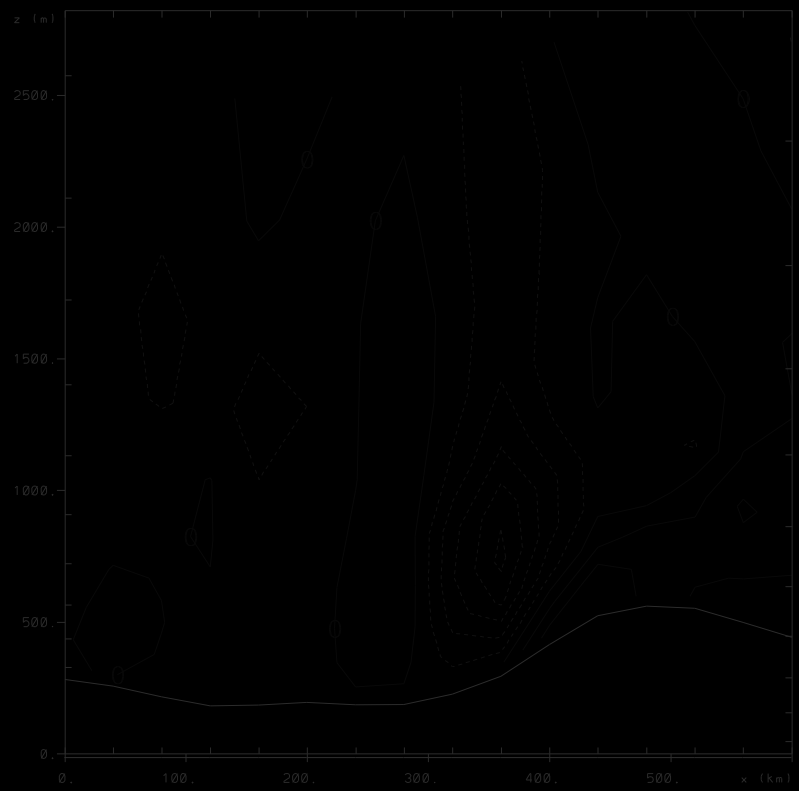
2000.
1500.
1000.
500.
0.
0.
100.
200.
300.
400.
500.
x (km)


z (m)
2500.
2000.
1500.
1000.
500.
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100.
200.
300.
400.
500.
x (km)

Summary of results--roughness expt

- A drastic reduction in land surface roughness leads to a decrease in lake effect precipitation
- It also redistributes precipitation--can move precipitation outside of the drainage basin
- These results apply more generally than the special case presented

Plans for CHARM

- Currently porting to new system with new version of RAMS
- Carefully incorporate flux adjustment
- Longer-period GHG simulations
- Assessment of ice feedback

Great Lakes Ice Model (GLIM):

Developing Great Lakes Ice Model (GLIM) in Lake Erie using the CIOM (Coupled Ice-Ocean Model)

Jia Wang (NOAA GLERL)

Haoguo Hu, Dima Beletsky (CILER, UoMich), David Schwab, George Leshkevich, Anne Clites (NOAA GLERL)

Sponsors: NOAA, GLERL, USCG

Motivation

Needs for prediction of lake ice using numerical models

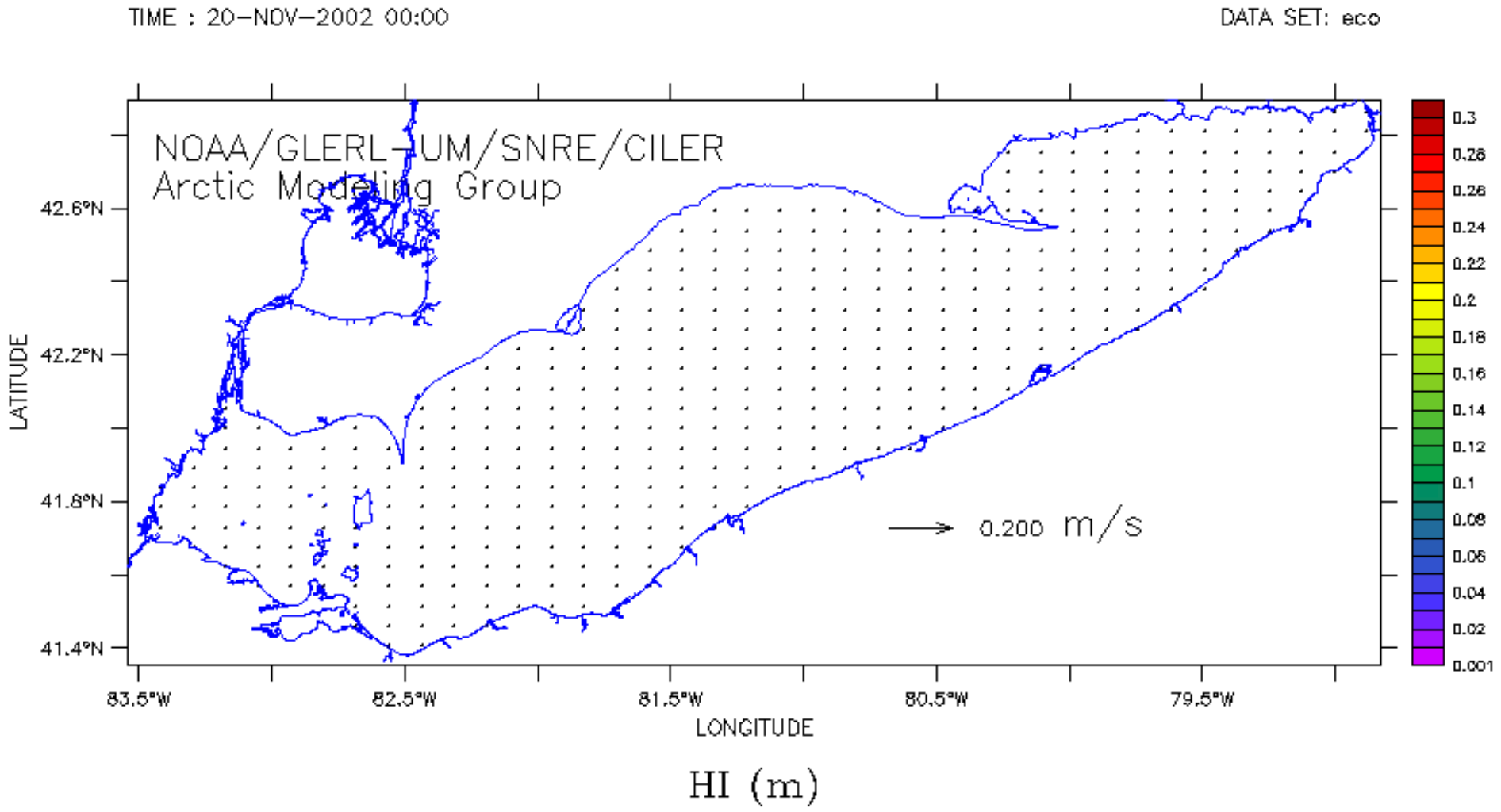
- No single climate pattern (PNA, NAO/AO) influencing the GL is dominant, so the predictability of sea ice based on climate pattern indices is poor (Assel and Rodionov 2001, 2002)
- Sediment resuspension and transport during winter storm and lake ice season (Schwab et al. 2006, Hawley et al. 2006); Lake Circulation Studies and the Great Lakes Coastal Forecast System (GLCFS) (Schwab)
  —Need lake ice coupled to a hydrodynamic-sediment model
- Biogeochemical/ecosystems modeling such as hypoxia—Multiple stressors (Chen et al. 2004)
  —Need hydrodynamic-ice circulation model
- Regional climate model in the Great Lakes (Lofgren 2005)
  —Need lake ice model to predict radiation/nergy balance/feedback to the atmosphere, and lake water level (Assel, Quinn&Sellinger 2004)
- Great Lakes as a platform for INTERDISCIPLINARY research in a “mini climate system”:
  Atmosphere, hydrosphere (hydrodynamics, lake ice, biosphere, and lithosphere (land processes, hydrology, coastal erosion)
  —Need lake ice component

GLIM in Lake Erie

based on CIOM (Wang et al. 2002, 05, 08)

1. POM (Mellor 2000)
2. Multicategory sea ice model (Yao et al., 2000; Wang et al. 2002, 2005, 2008) based on: two-layer ice thermodynamics with 1-layer snow, ice dynamics with viscous-plastic rheology
3. 2-km in Lake Erie similar to Schwab's GLOFS
4. 22 vertical sigma layers.
5. Daily atmospheric forcing from NCEP/NCAR daily forcing fields (air temperature and humidity at 2m, wind at 10m), solar radiation and air longwave radiation
6. Initial (T/S) fields from measurements

The Great Lakes Ice Model (GLIM): Ice velocity and thickness



Seasonal cycle of ice thickness

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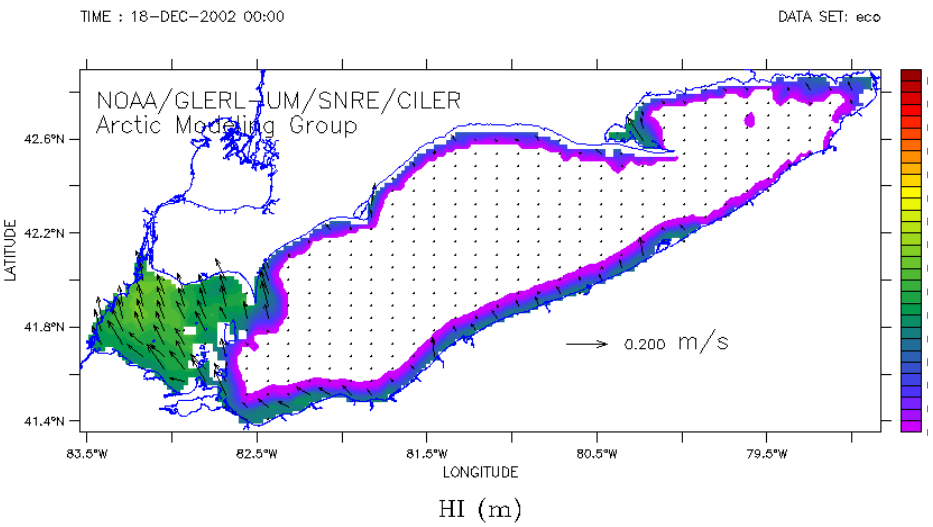
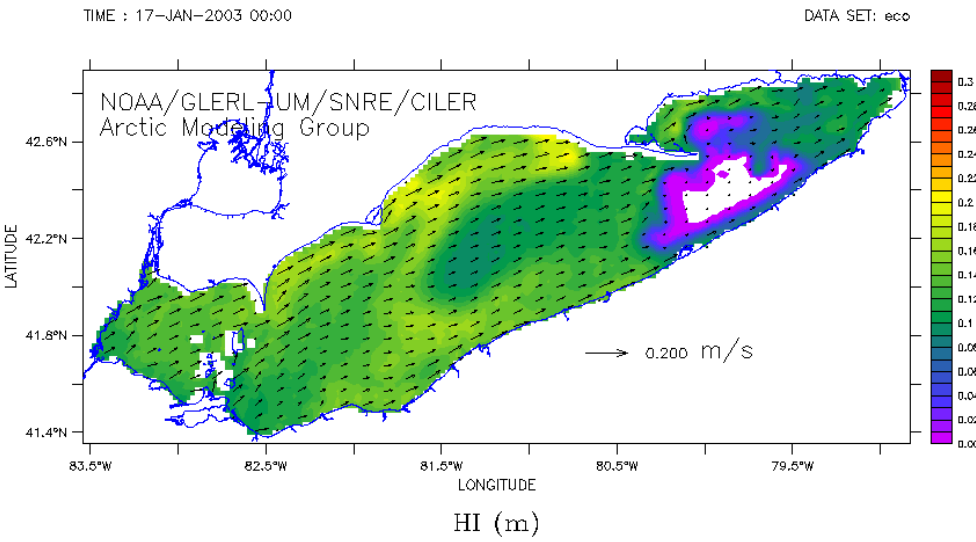
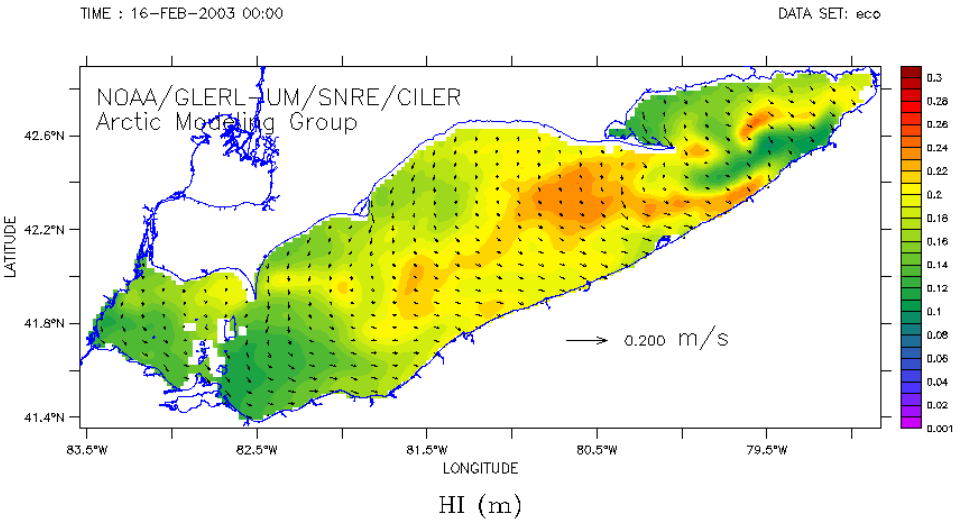
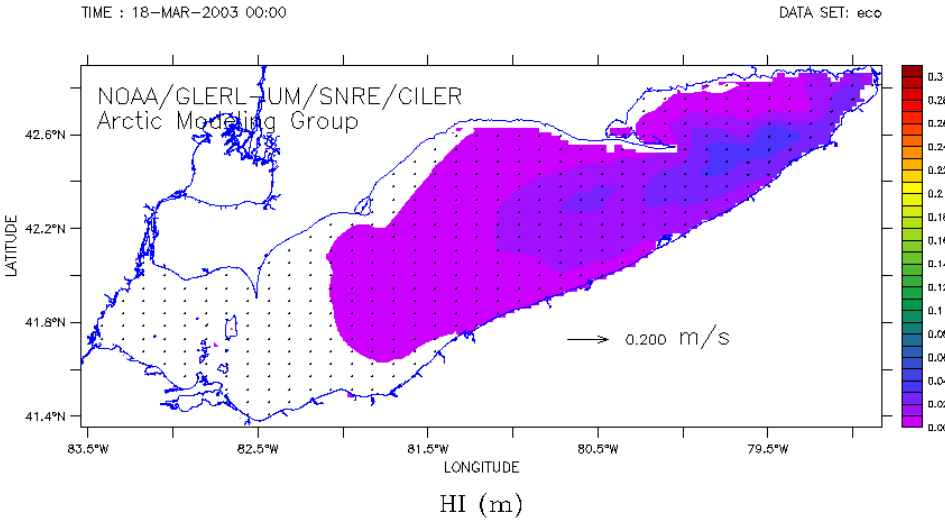
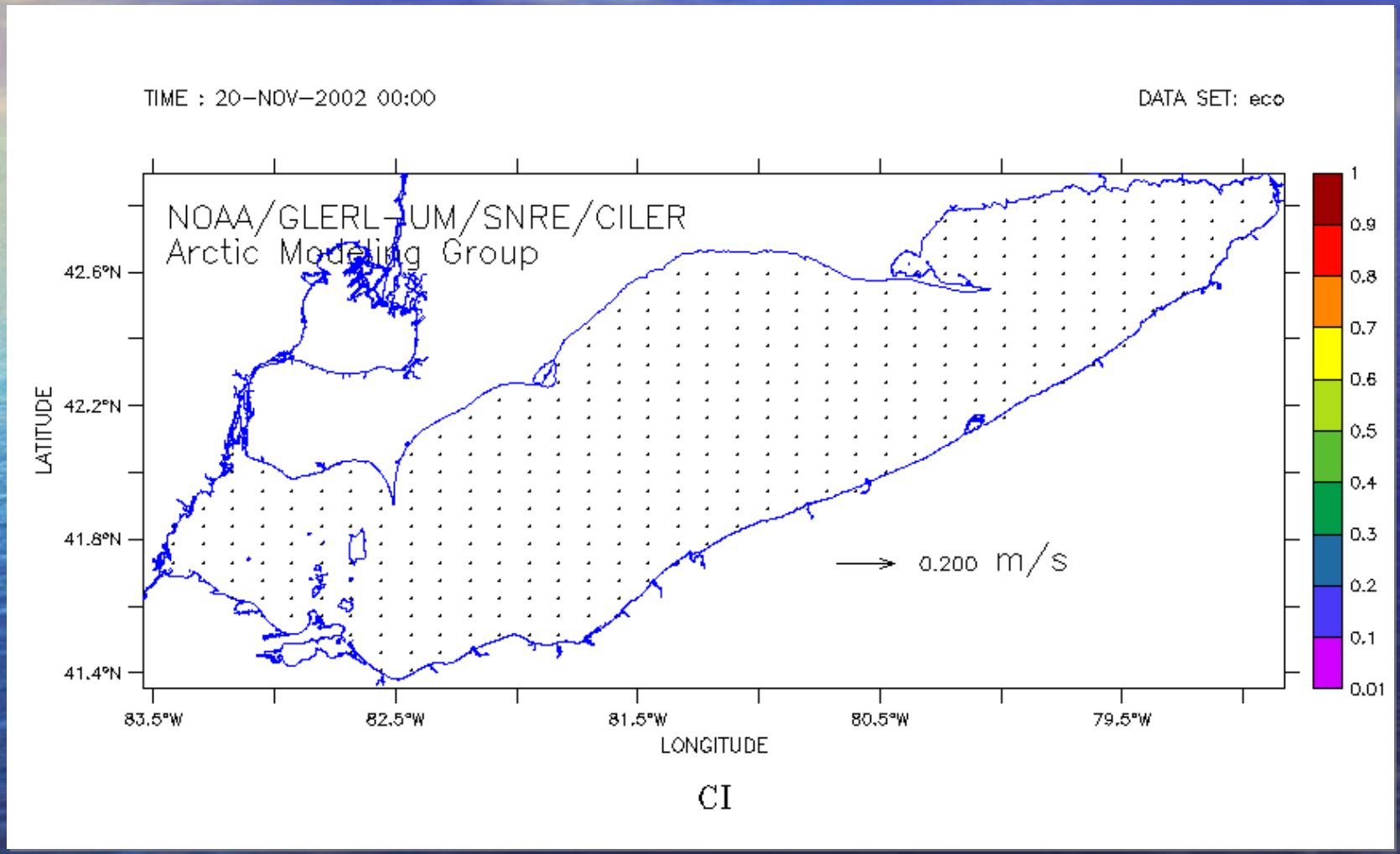


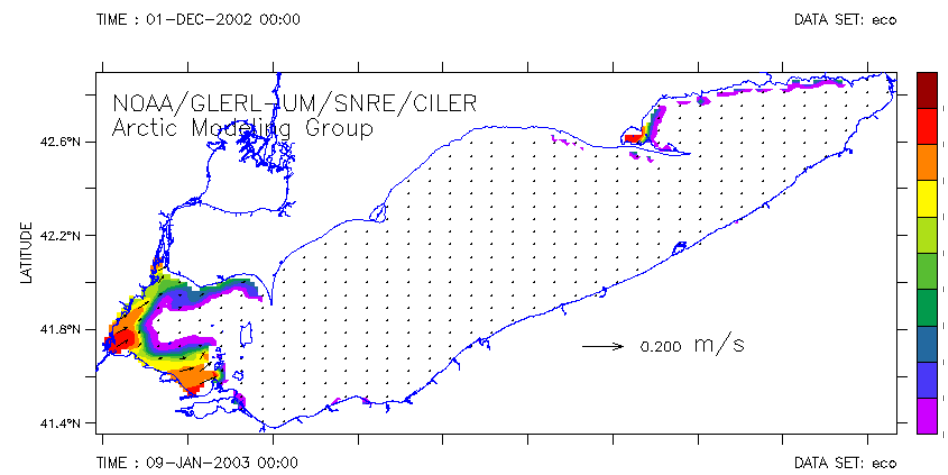






Ice velocity and concentration (compactness)

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NOAA/GLERL-UM/SNRE/CILER
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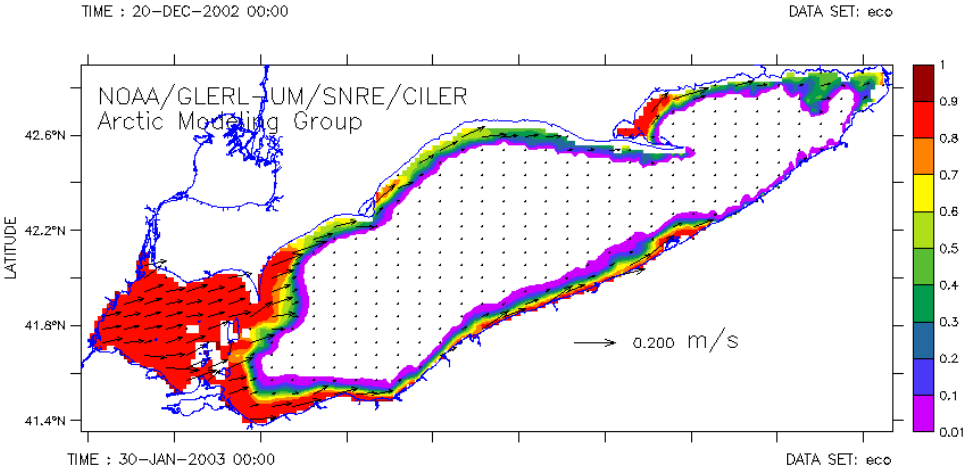
42.2°N
41.8°N
41.4°N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41.8°N
41.4°
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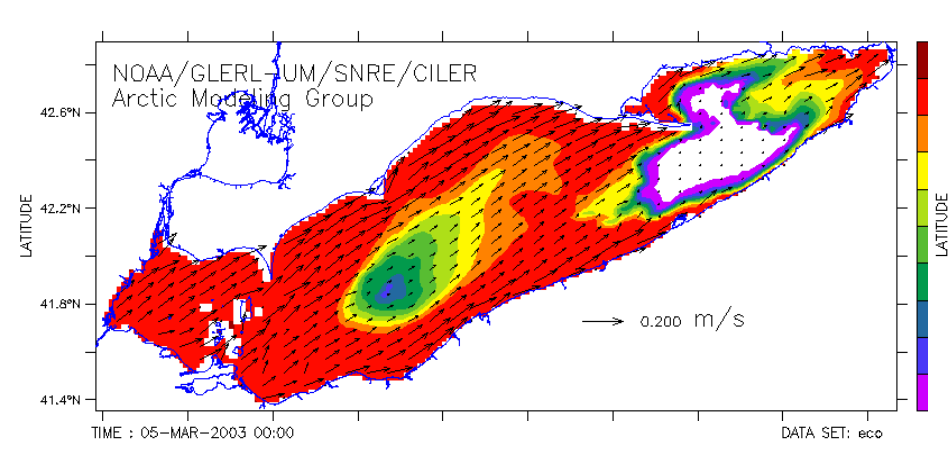
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.01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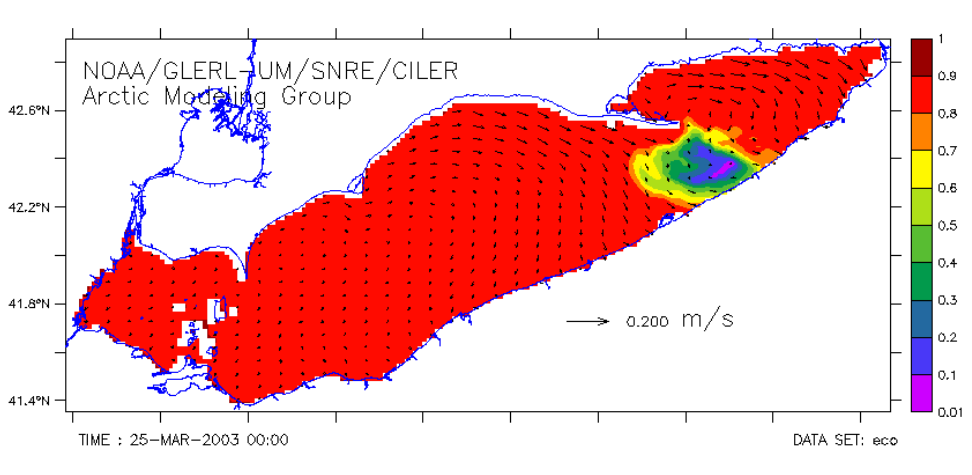
41.8°N
41.4°N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41.8°N
41.4°N
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0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.01

TIME : 05-MAR-2003 00:00
DATA SET: eco
NOAA/GLERL-UM/SNRE/CILER
Arctic Modeling Group
0.200 m/s
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42.2°N
41.8°N
41.4°N

TIME : 25-MAR-2003 00:00
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41.8°N
41.4°N
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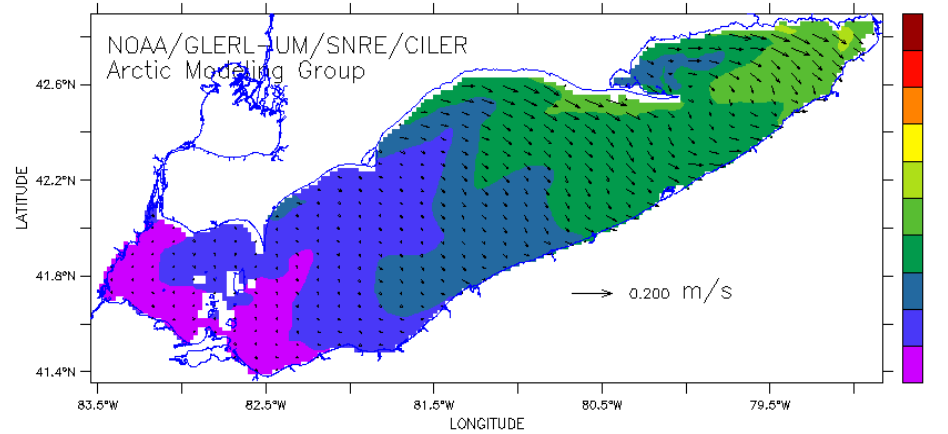
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.01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LATITUDE
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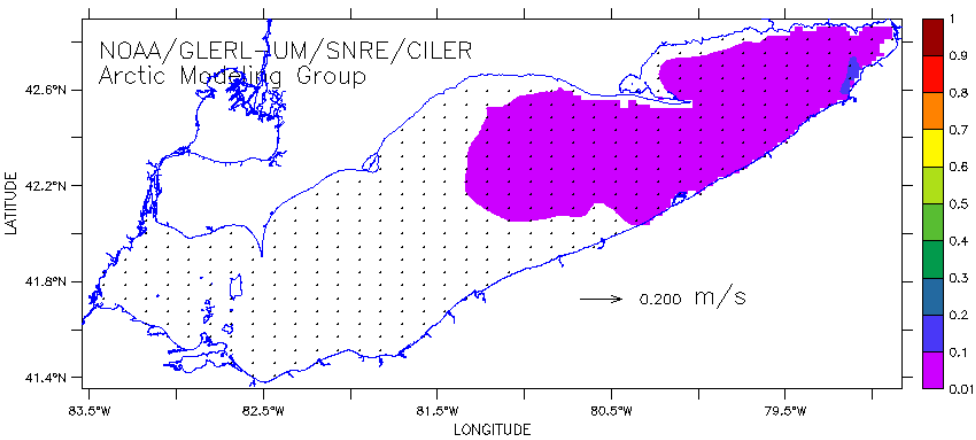
80.5°W
79.5°W
LONGITUDE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82.5°W
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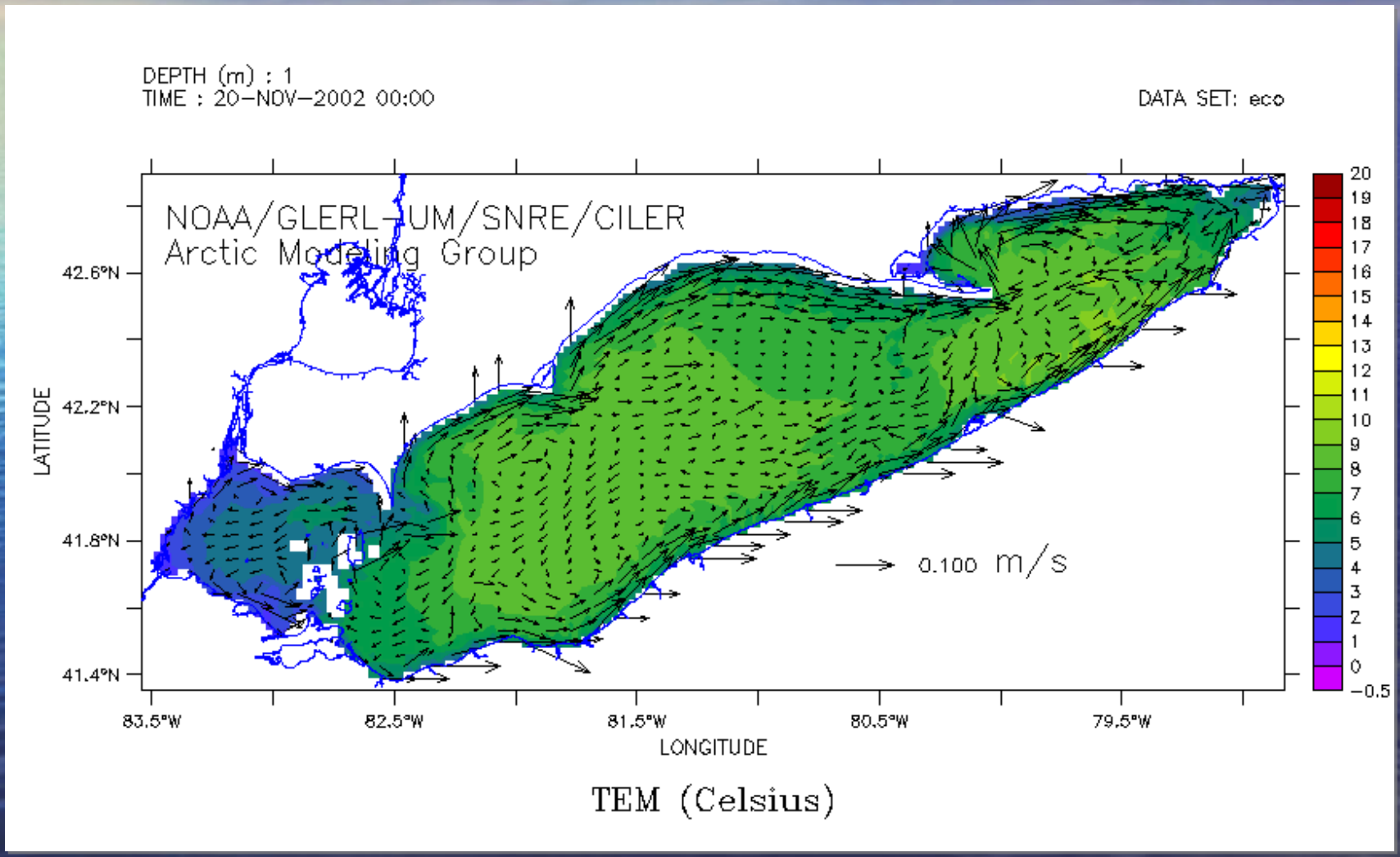
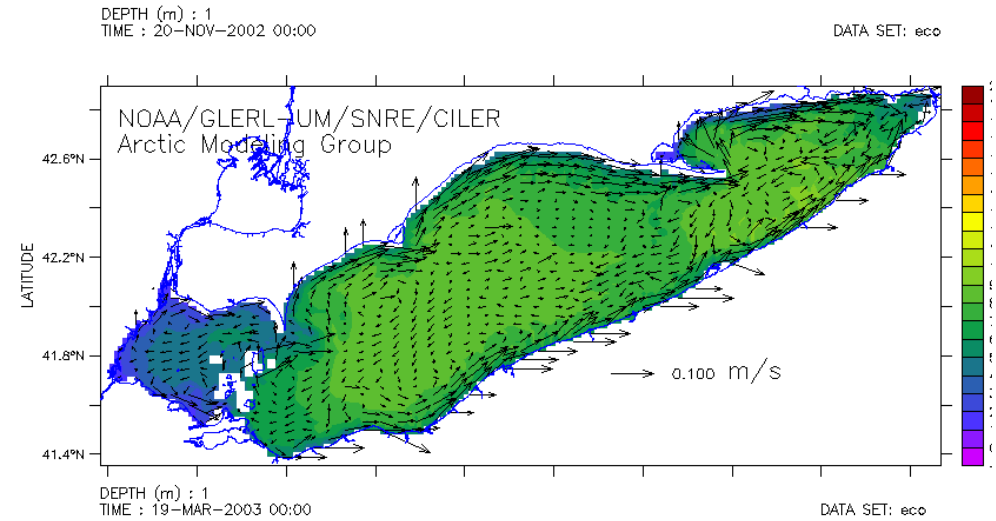
80.5°W
79.5°W
LONGITUDE
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.01

Lake surface velocity and lake surface temperature

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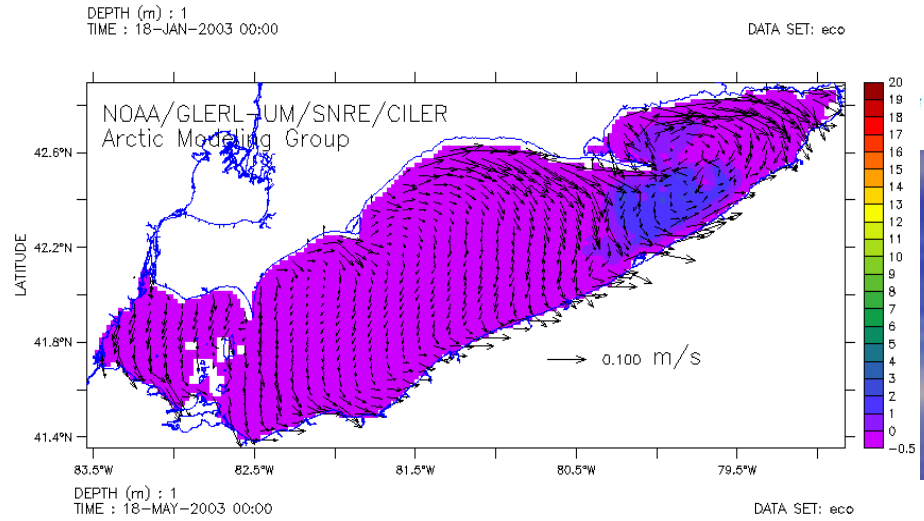
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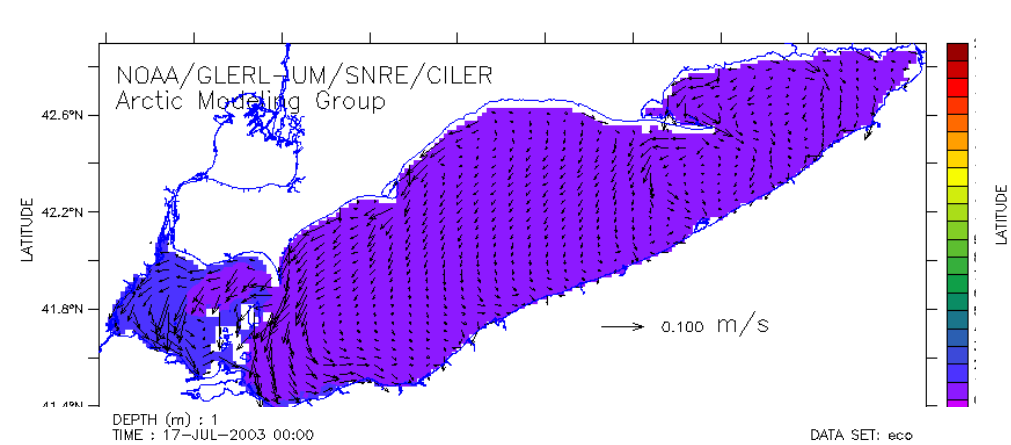
82.5°W
81.5°W
80.5°W
79.5°W
0.100 m/s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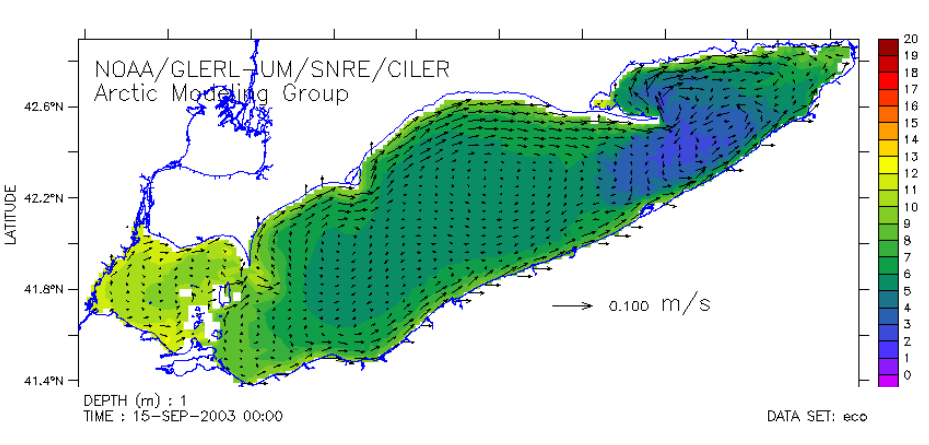
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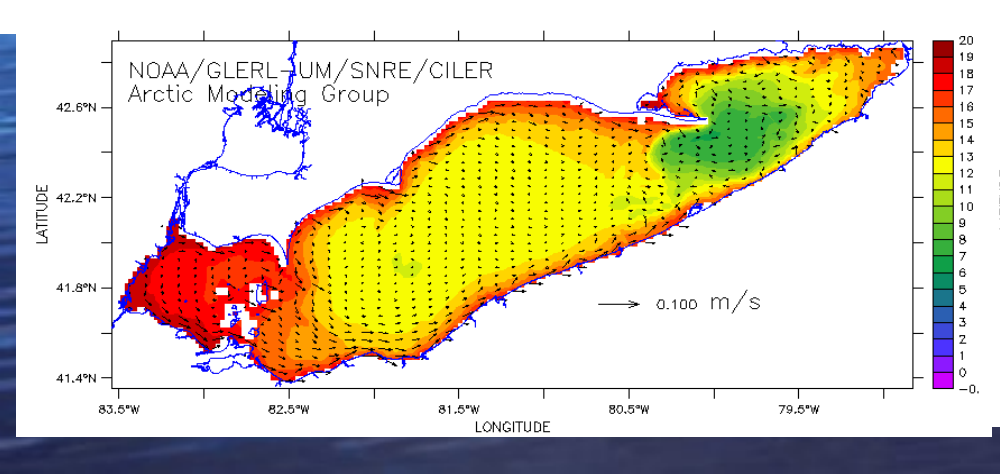
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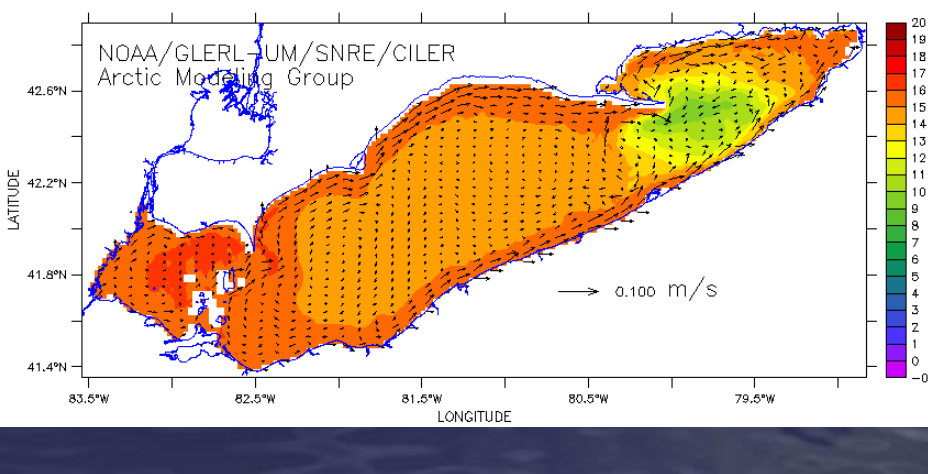
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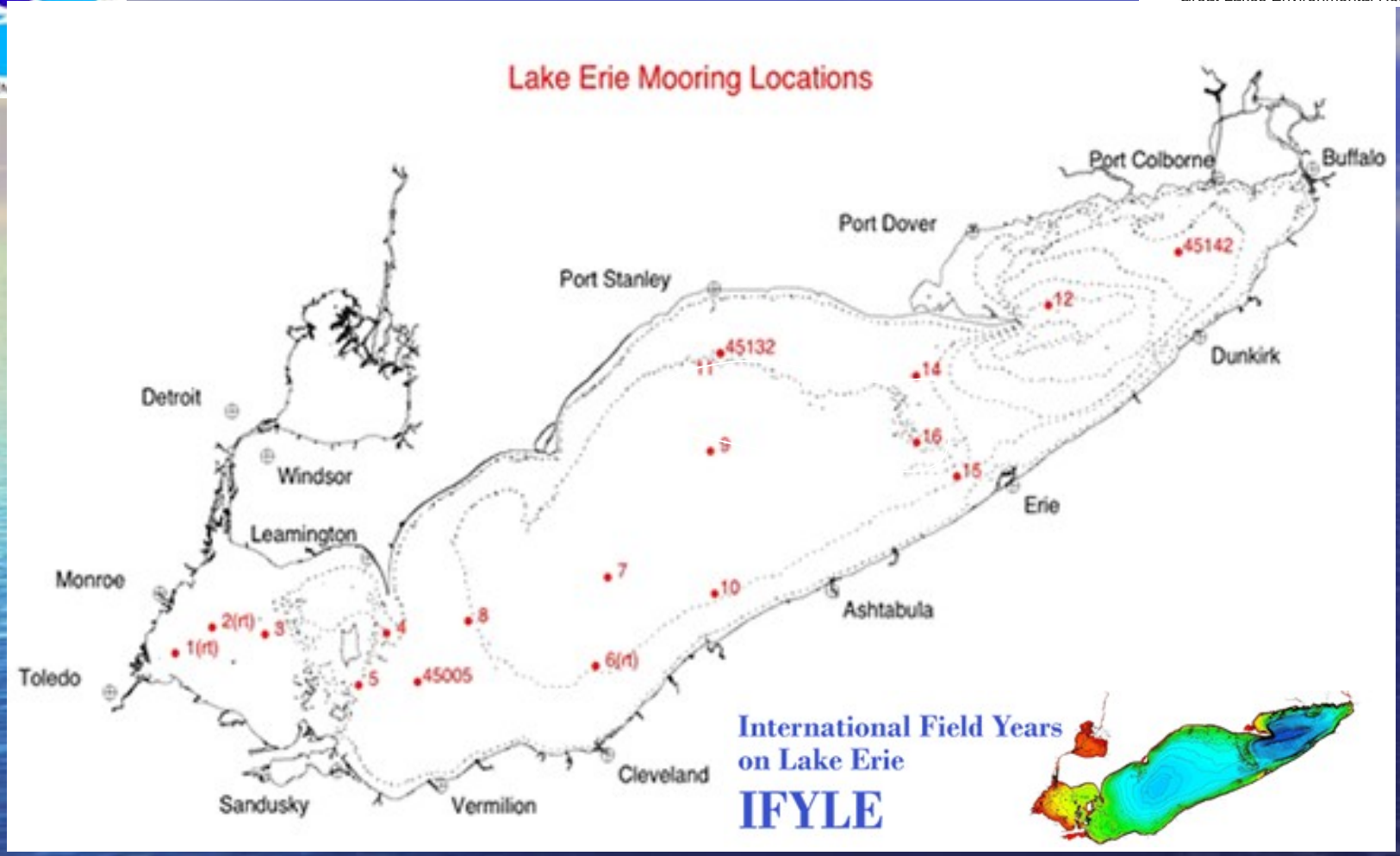
42.2°N
41.8°N
41.4°N
0.100 m/s

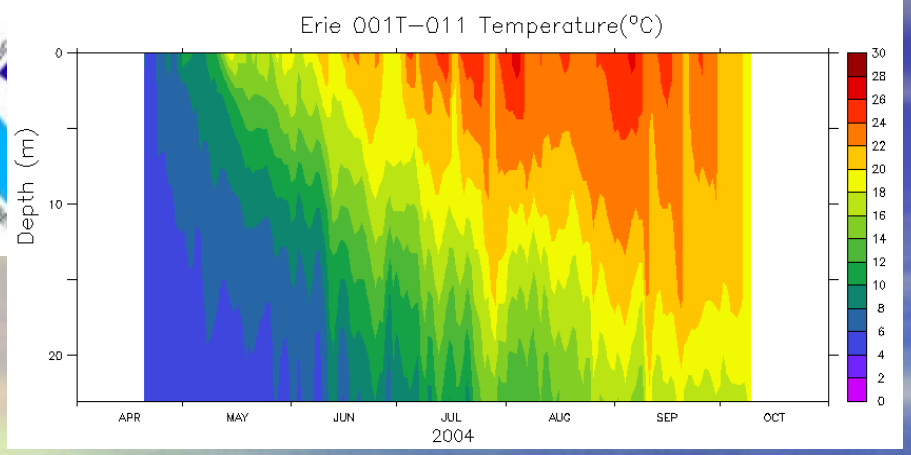
NOAA/GLERL-UM/SNRE/CILER
Arctic Modeling Group
LATITUDE
42.6°N
42.2°N
41.8°N
41.4°N
83.5°W
82.5°W
81.5°W
80.5°W
79.5°W
LONGITUDE
0.100 m/s

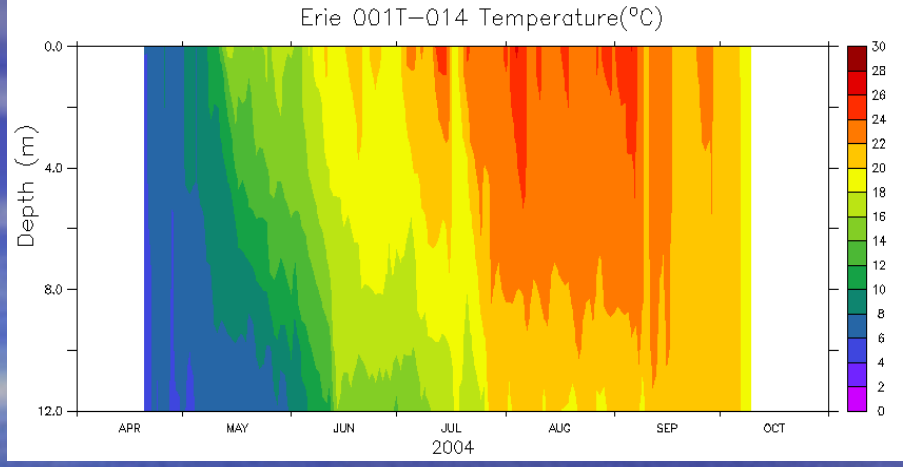
NOAA/GLERL-UM/SNRE/CILER
Arctic Modeling Group
LATITUDE
42.6°N
42.2°N
41.8°N
41.4°N
83.5°W
82.5°W
81.5°W
80.5°W
79.5°W
LONGITUDE
0.100 m/s

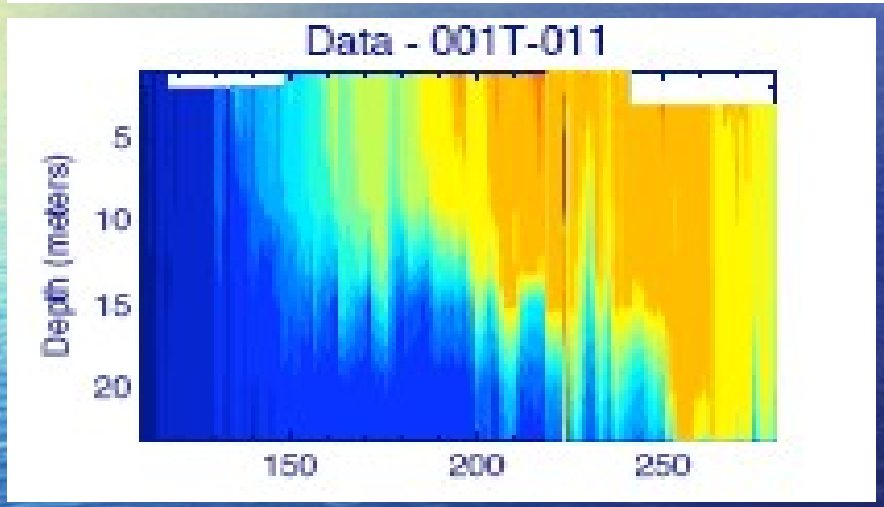
Model-data comparison

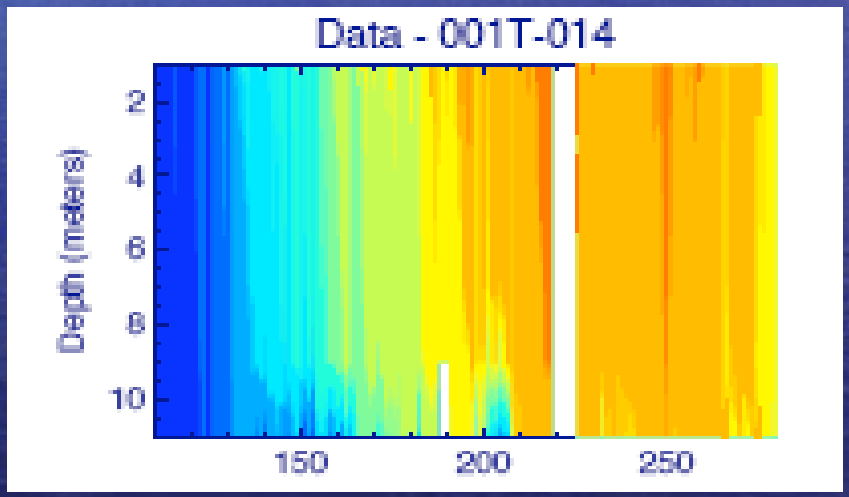


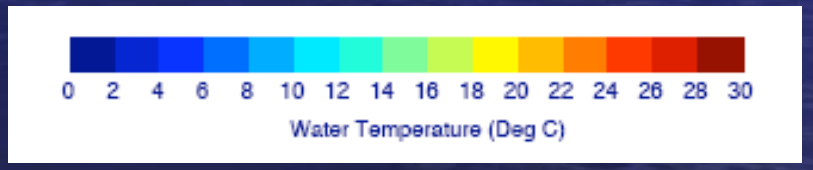
Stations 45005, 45132, and 45142 are shown on the map, but not in the table. These are meteorological stations maintained by either the National Bata Buoy Center (45005) or by Environment Canada (45132 and 45142). (
+ NDBC Eastern Great Lakes Marine Data web page)











GLIM model simulation

From Dima Beletsky

Summary

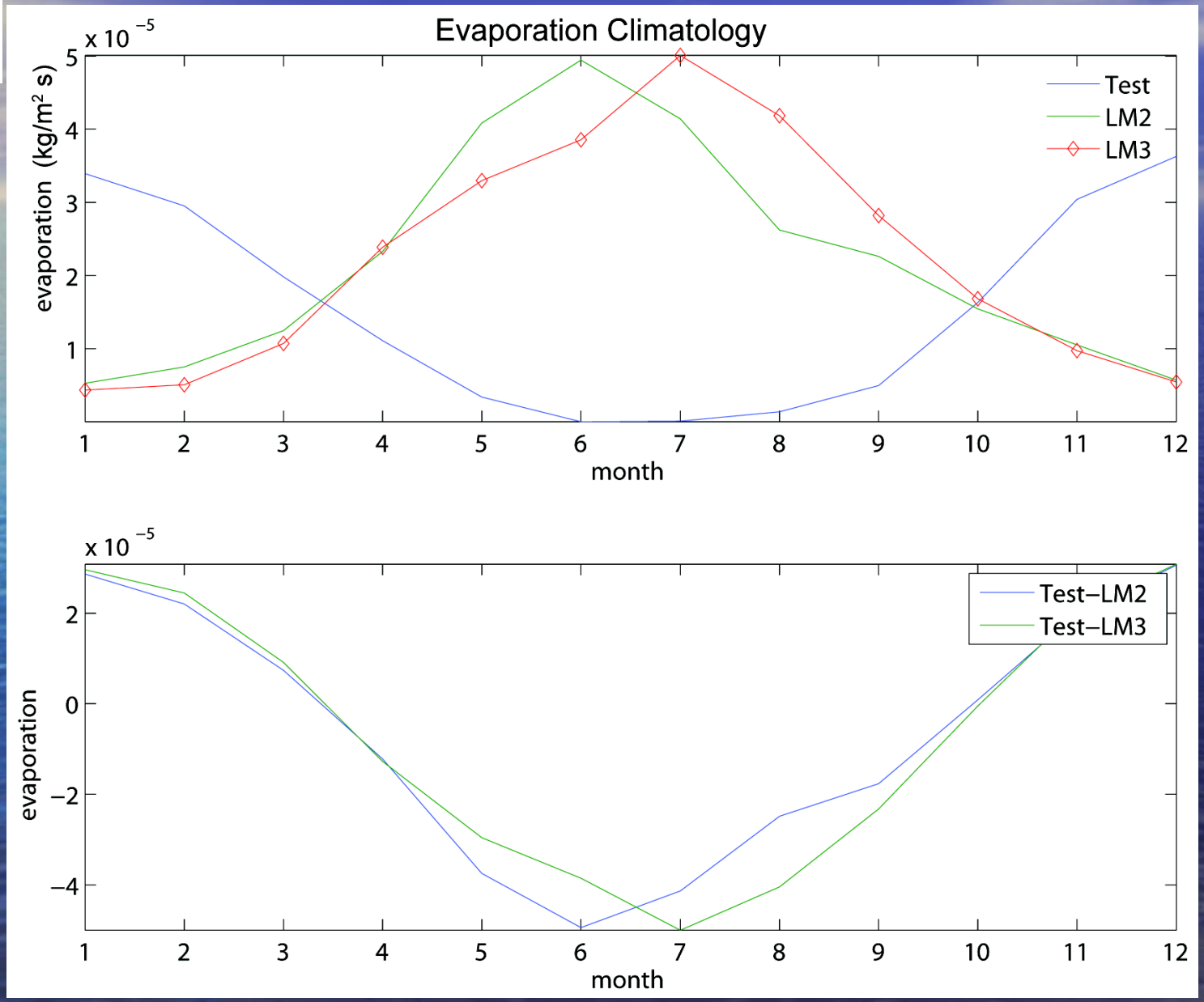
- Lake ice seasonal cycles are successfully reproduced, but needs for solid validation of GLIM, plan for 2004-05 ice season (IFYLE obs.), and 2007-08 season (ice thickness obs.) using hourly atmospheric forcing
- Model-model intercomparison shows GLIM lake-hydrodynamic model can reproduce similar results to the GLOFS

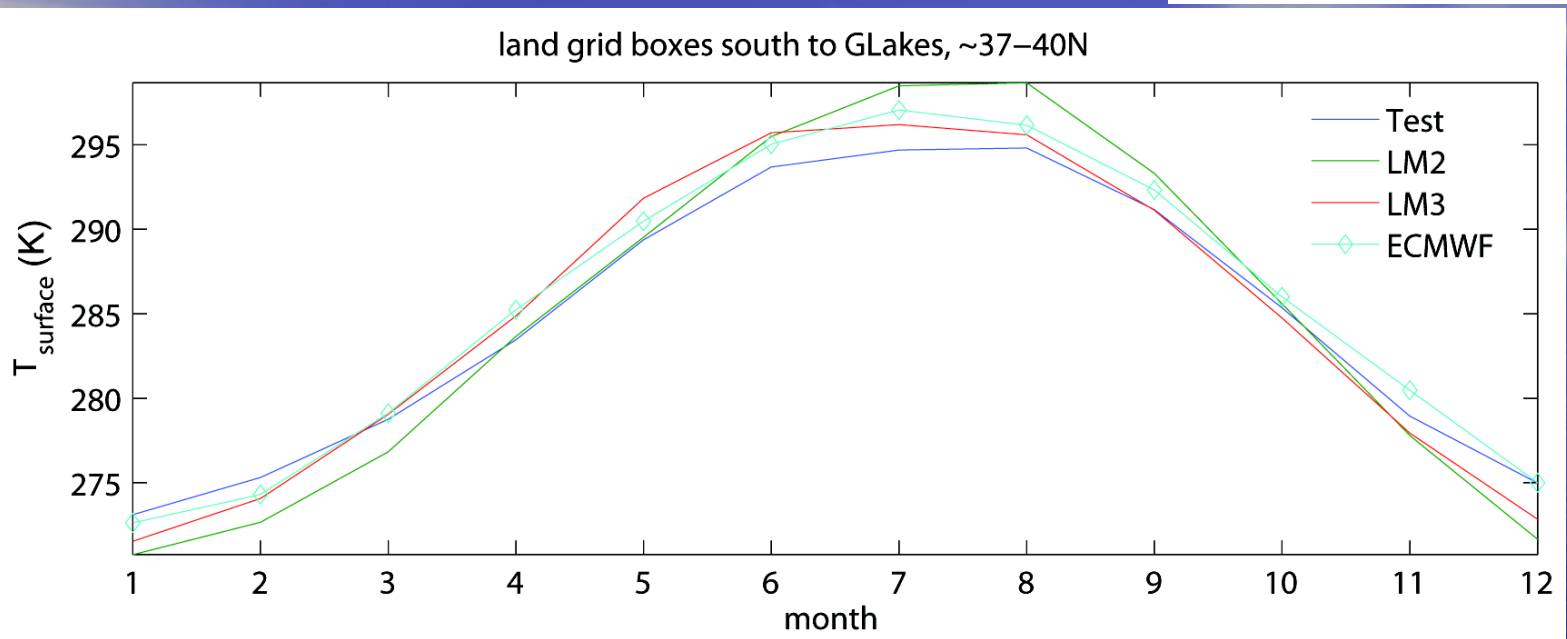
Future efforts:

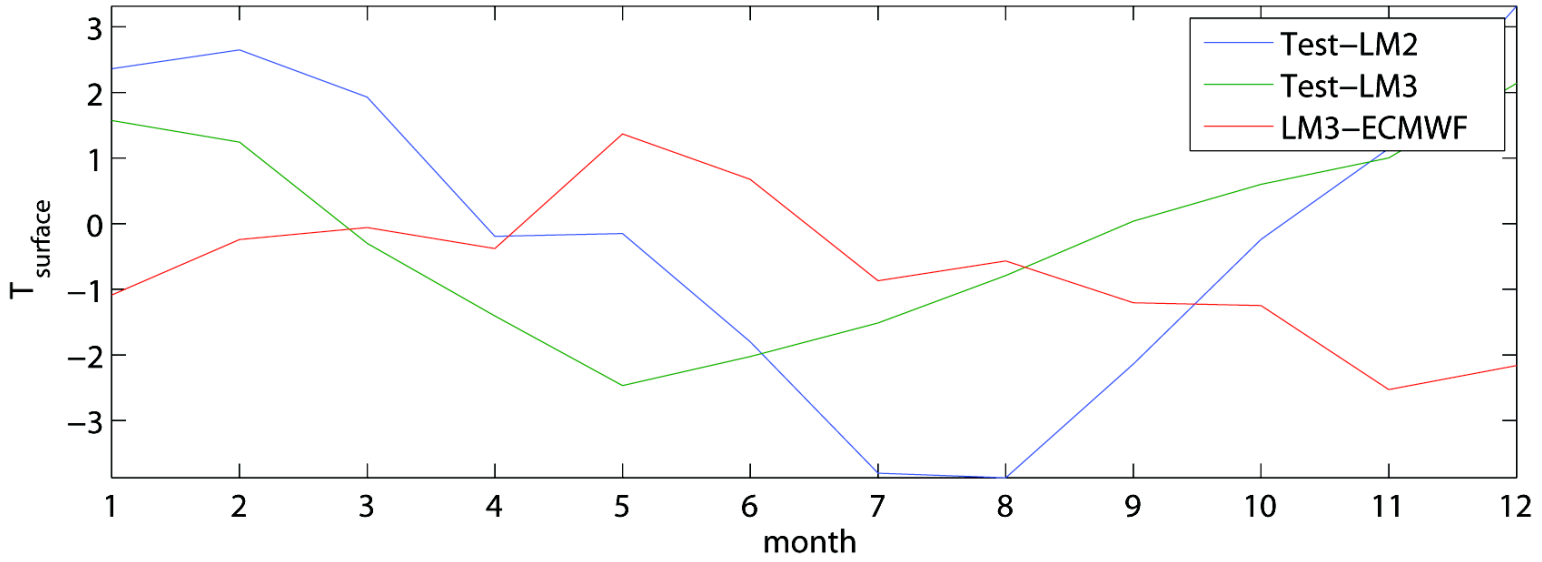
- Transformed GLIM to GLERL (Schwab) GLOFS
- Expanded to other Lakes
- Applied to Interannual variability of lake ice in Lake Erie
- Applied to ecosystem modeling

Inclusion of lakes in GFDL GCM

- Part of LM3, developed by GFDL team
- Participation by Xianglei Huang (U. of Michigan)
- Formulation very similar to 1-d diffusion lake component in CHARM


Evaporation Climatology
x 10 −5
evaporation (kg/m2 s)
5
4
3
2
1
Test
LM2
LM3
1
2
3
4
5
6
7
8
9
10
11
12
month
x 10 −5
evaporation
2
0
−2
−4
Test−LM2
Test−LM3
1
2
3
4
5
6
7
8
9
10
11
12
month


land grid boxes south to GLakes, ~37–40N
T surface (K)
295
290
285
280
275
1
2
3
4
5
6
7
8
9
10
11
12
month
Test
LM2
LM3
ECMWF


T surface
3
2
1
0
−1
−2
−3
1
2
3
4
5
6
7
8
9
10
11
12
month
Test−LM2
Test−LM3
LM3−ECMWF

Regional climate/lake modeling in East Africa

- RAMS coupled to model of Lake Victoria
- 3-dimensional lake model based on Princeton Ocean Model
- Looking at influence of two forcing mechanisms on climate--GHG and land use

Lake Victoria physical setting

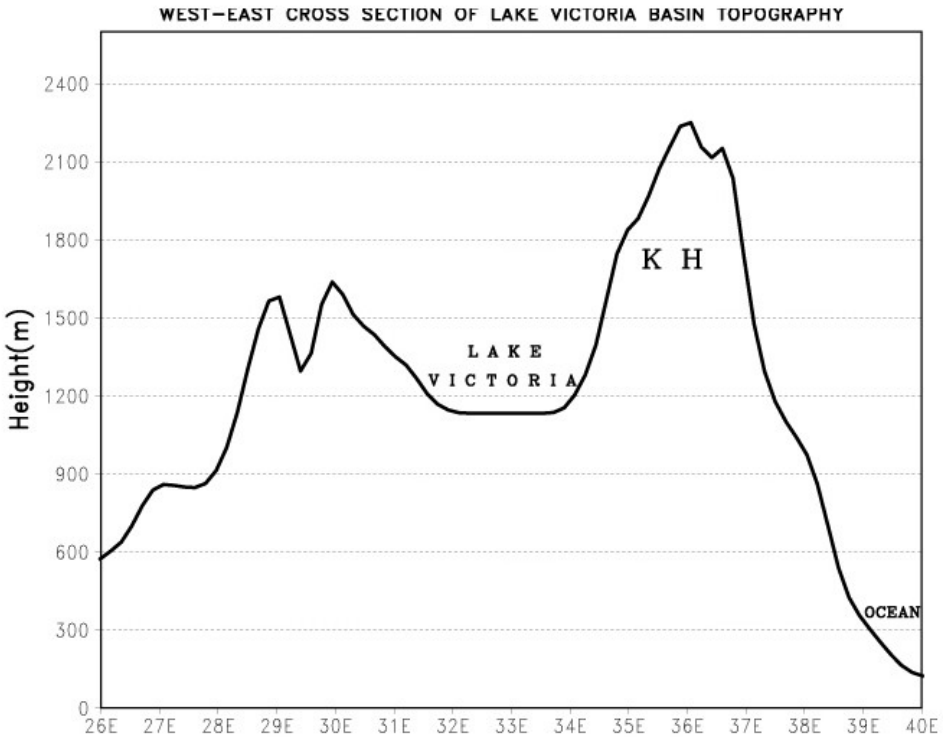


Figure 1b: Horizontal cross section of the elevation around Lake Victoria Basin(KH: Kenya Highlands)

Anyah et al., 2006, *Mon Wea. Rev.*

Vertical velocity associated with Lake Victoria

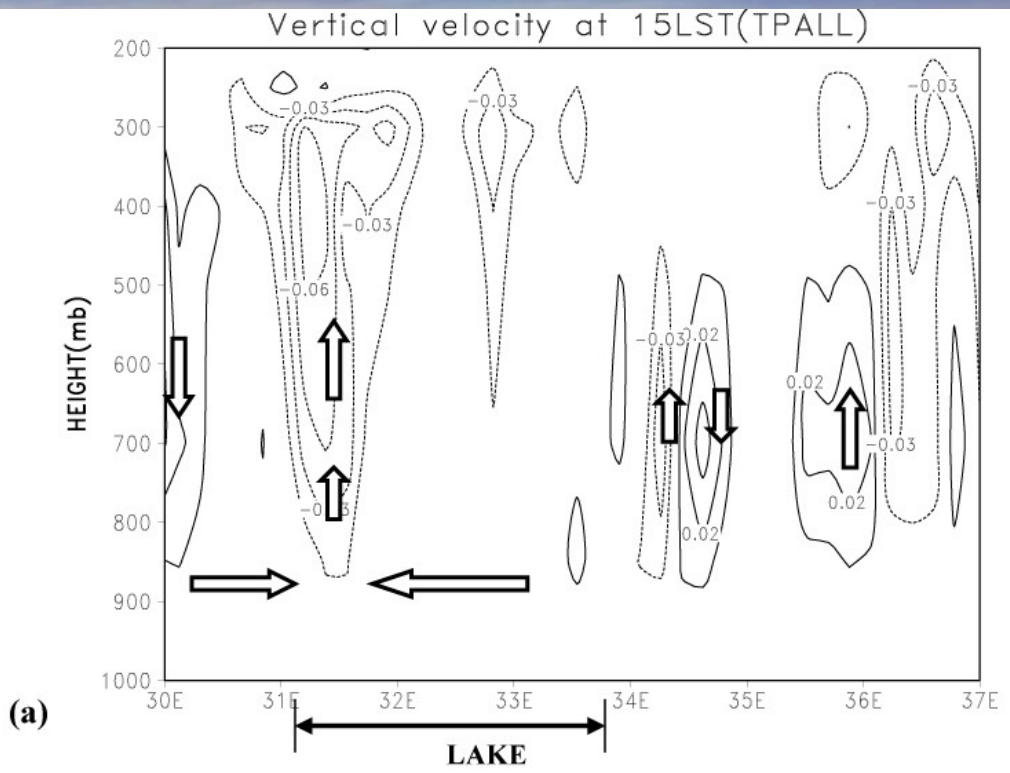
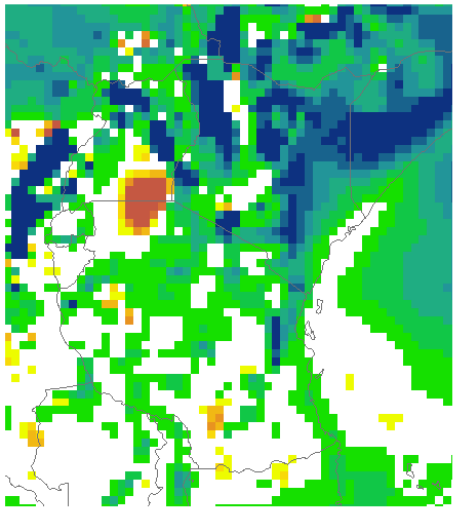
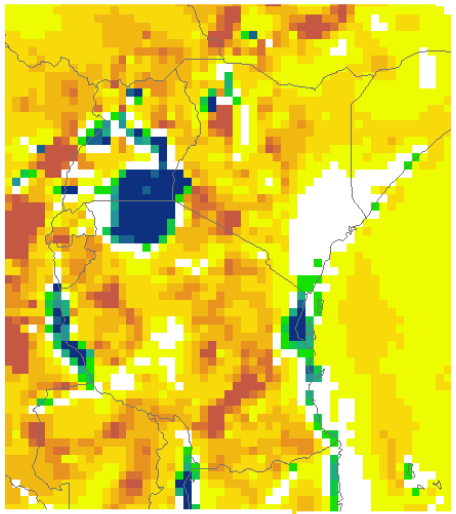


Figure 13: Same as figure 12, but at 15LST

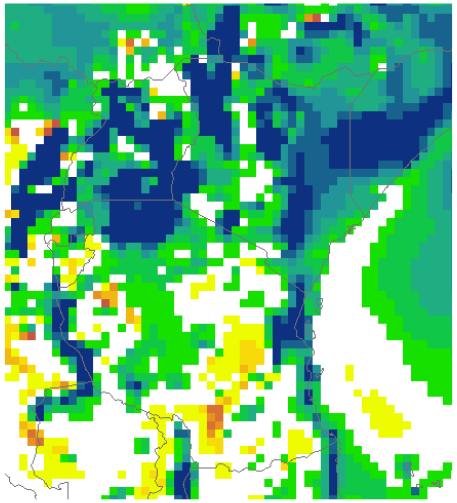
Anyah et al., 2006, *Mon Wea. Rev.*



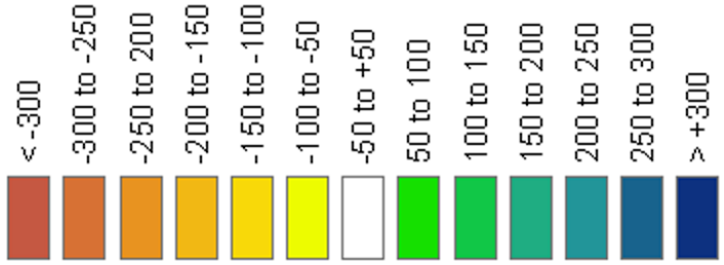
Case 2 - Case 1:
effects due to future Greenhouse Gas Concentrations only



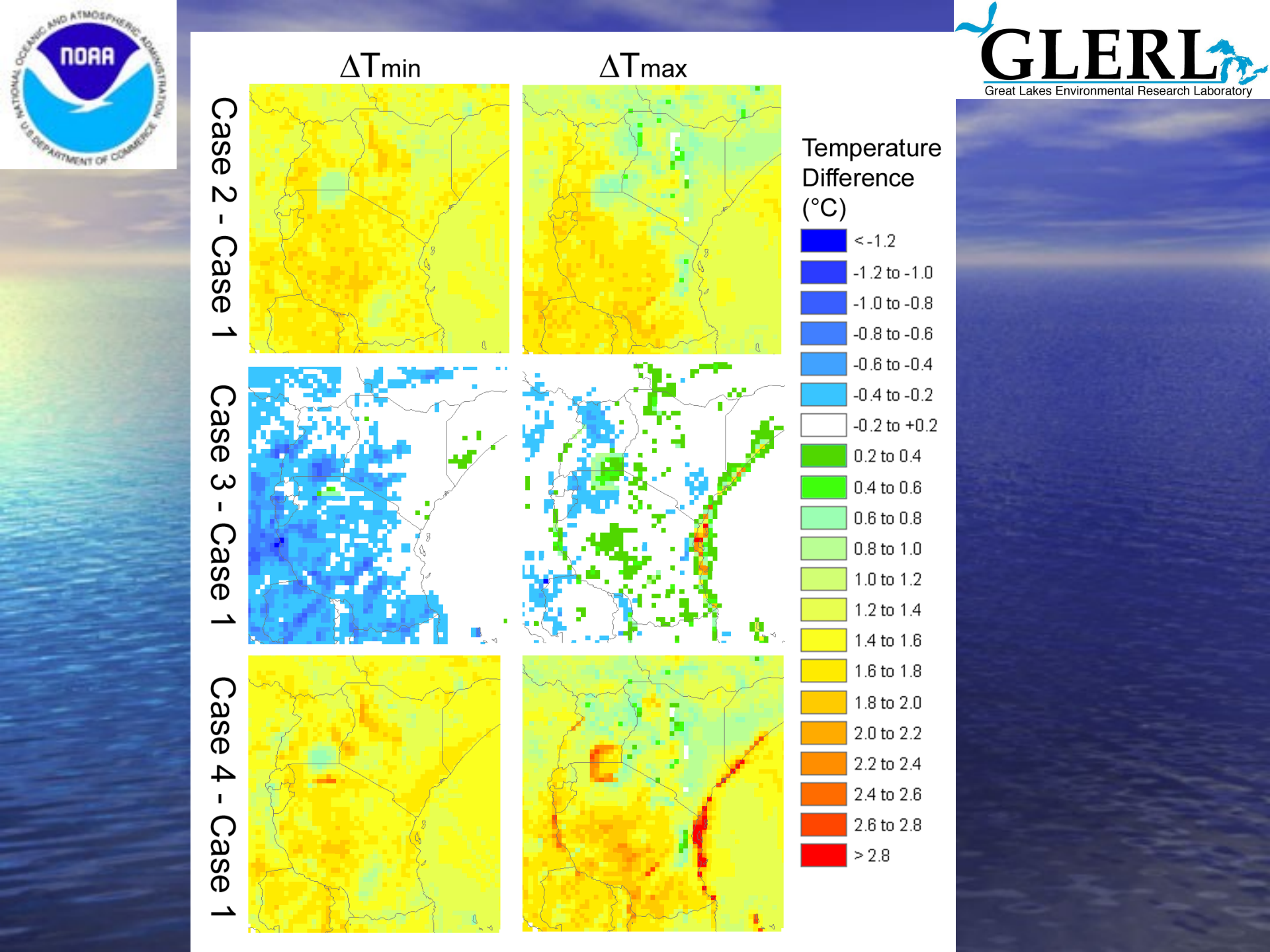
Case 3 - Case 1:
effects due to LCLUC only



Case 4 - Case 1:
combined effects of future Greehouse Gas Concentrations and future LCLUC



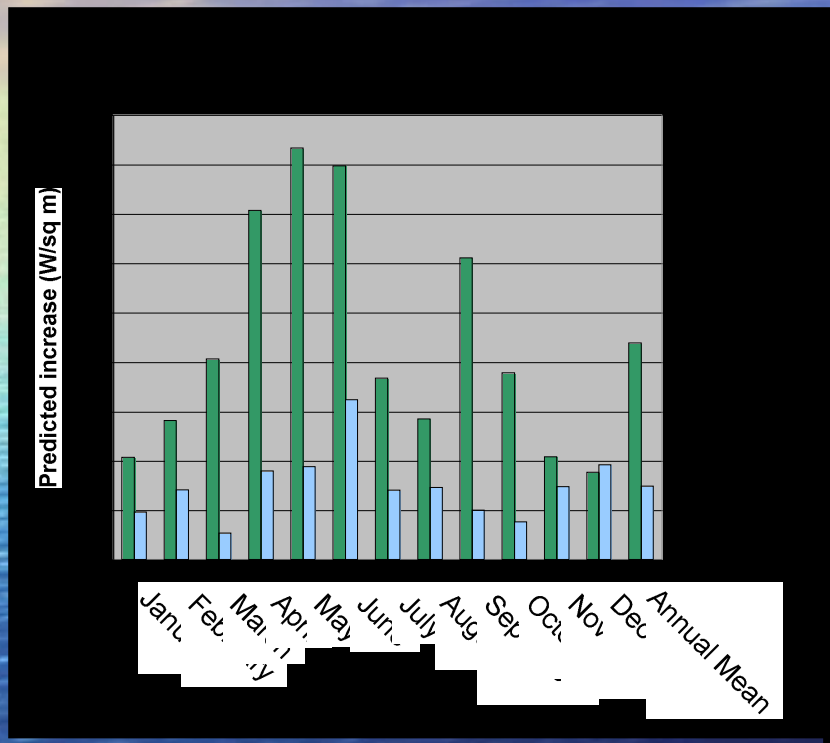
Average Annual Precipitation Difference (mm)

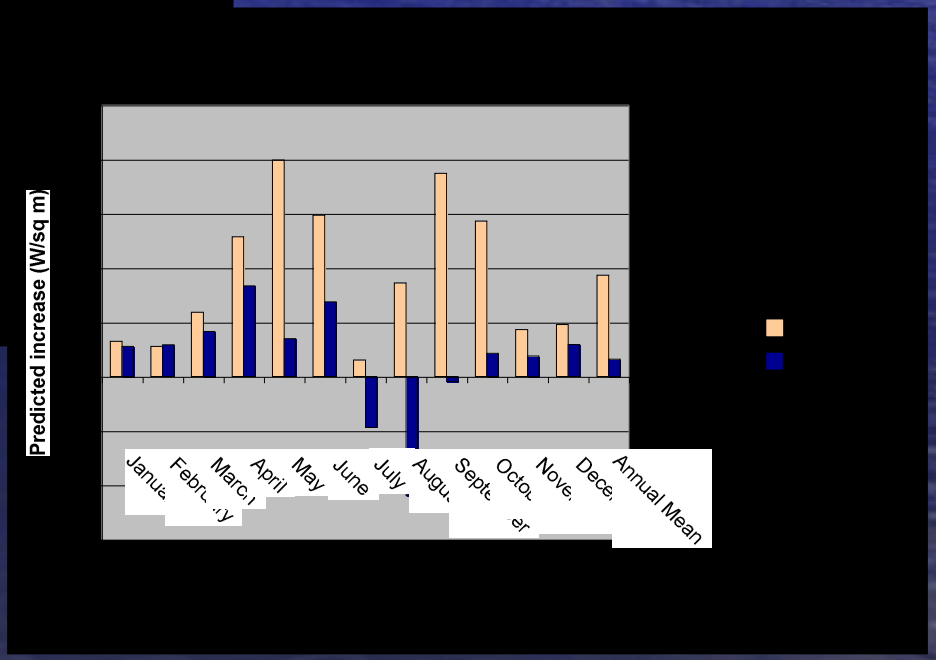


Issues with air temperature as proxy for ET

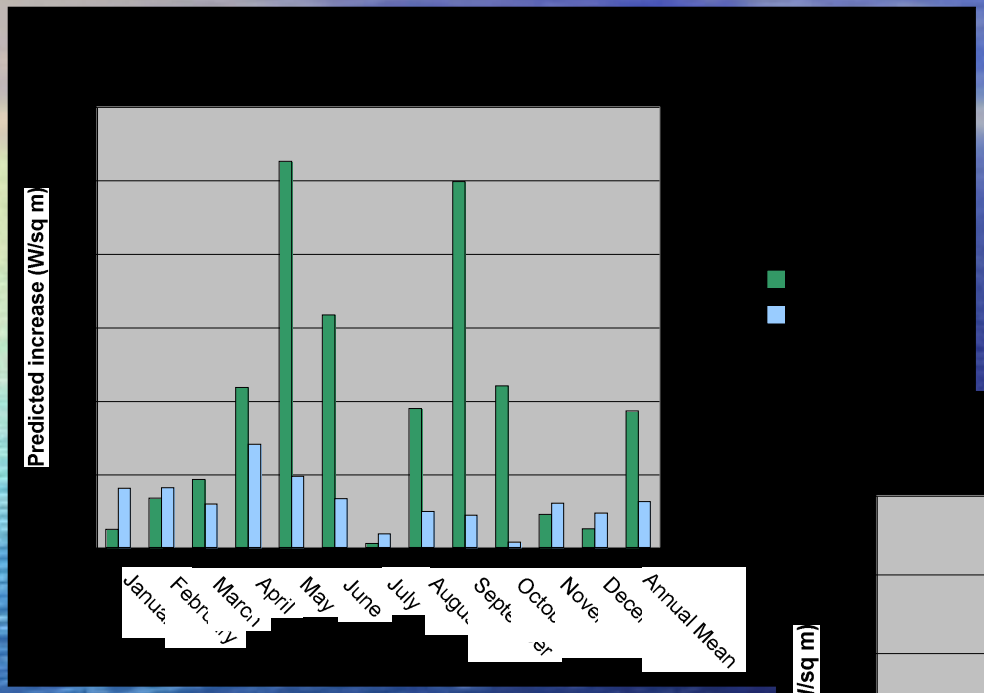
- Comparison of ET (on land) predicted by GCMs vs. predicted by off-line hydrologic model driven by the same GCM
- Off-line model uses air temperature as a proxy for potential ET
- Results are shown in terms of latent heat flux (W/m^2)

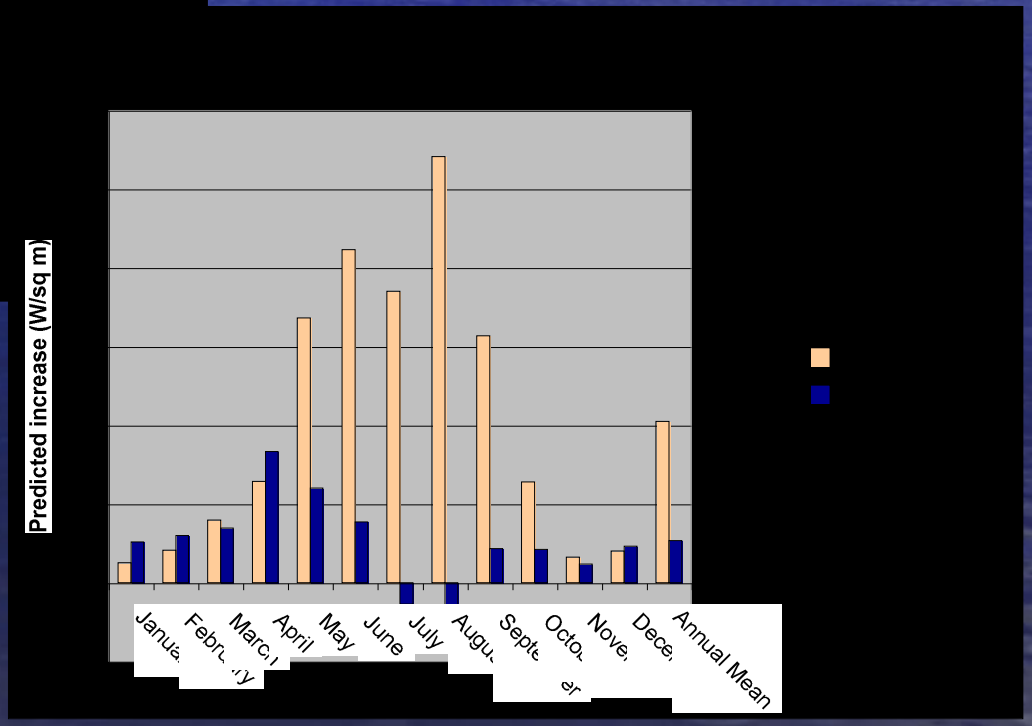
Change in ET-L. Michigan basin





Change in ET--L. Superior basin





Summary of temperature proxy issues

- Change in annual ET using temperature as a proxy greatly exceeds that predicted by GCM
- This should have an effect on surface and air temperature, but doesn't
- Results vary by month

Musings

- Lakes are an important part of the landscape in many regions
- Even in regions where their area is small relative to land, there may be important ecological function of lakes
- On climatological scales, lakes are unlike land in that they have thermal memory across seasons, and unlike ocean in that they do not have memory of many years

More musings

- Warming due to GHGs is good at holding energy in the atmosphere-earth system, but perhaps not as good at enhancing its movement (e.g. latent heat flux)