Environment Canada Environnement Canada

Canada

A NEMO-based hydrodynamic/hydraulic system for the Great Lakes

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Government of Canada Gouvernement du Canada
National Search and Rescue Secretariat Secrétariat national Recherche et sauvetage

Fisheries and Oceans Canada Pêches et Océans Canada

Canada

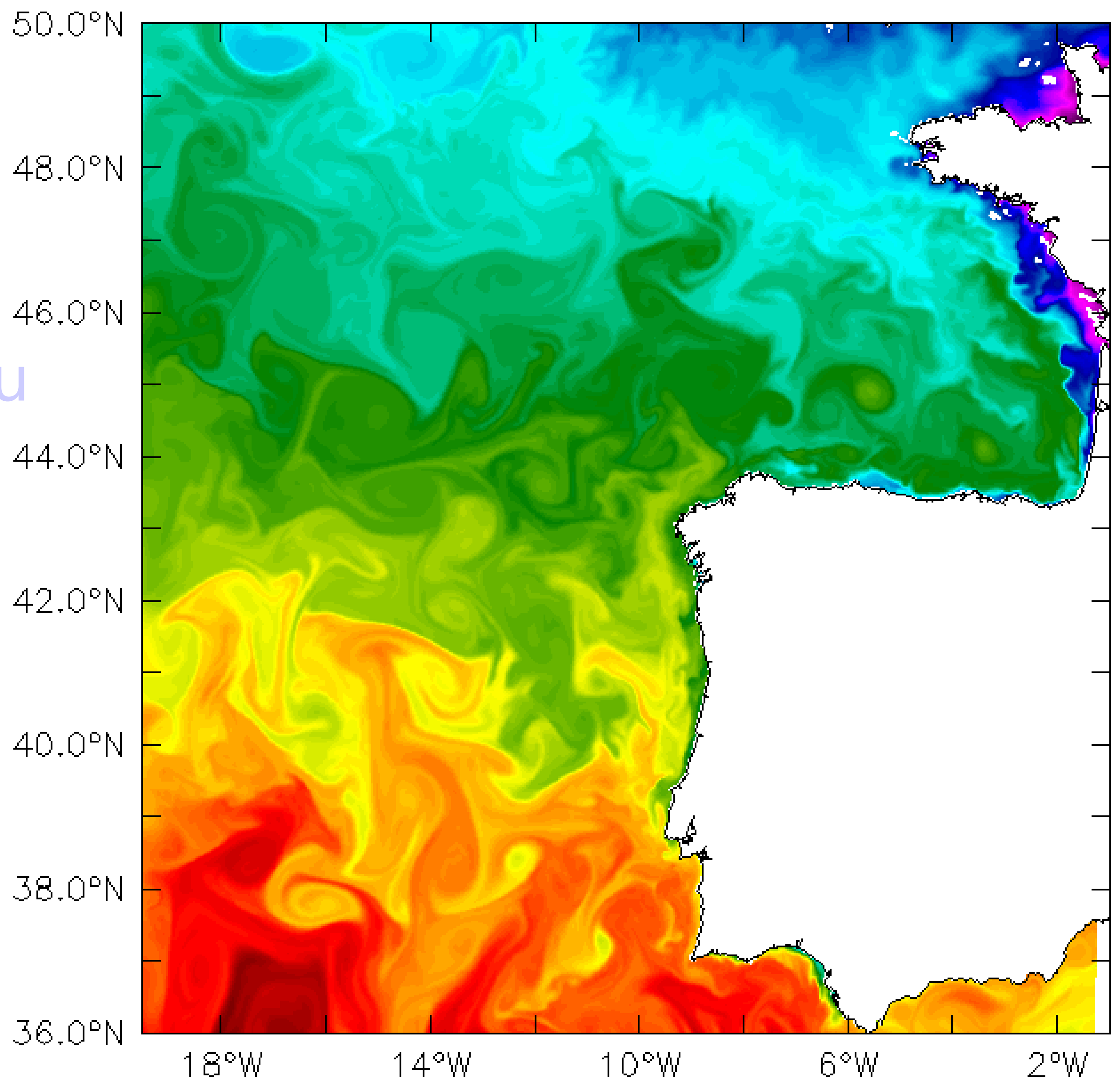
Objectives:

Development of a coupled hydrological forecasting system for the Great Lakes: Improved weather forecast, lake conditions (ice, temperature, currents, lake level, storm surge, waves), hydraulic conditions through the connecting channels, water quality (to come).

Figure, courtesy of G. Reffray, NEATL36 domain, Mercator-Ocean

NEMO: OPA ocean component+LIM2 ocean component

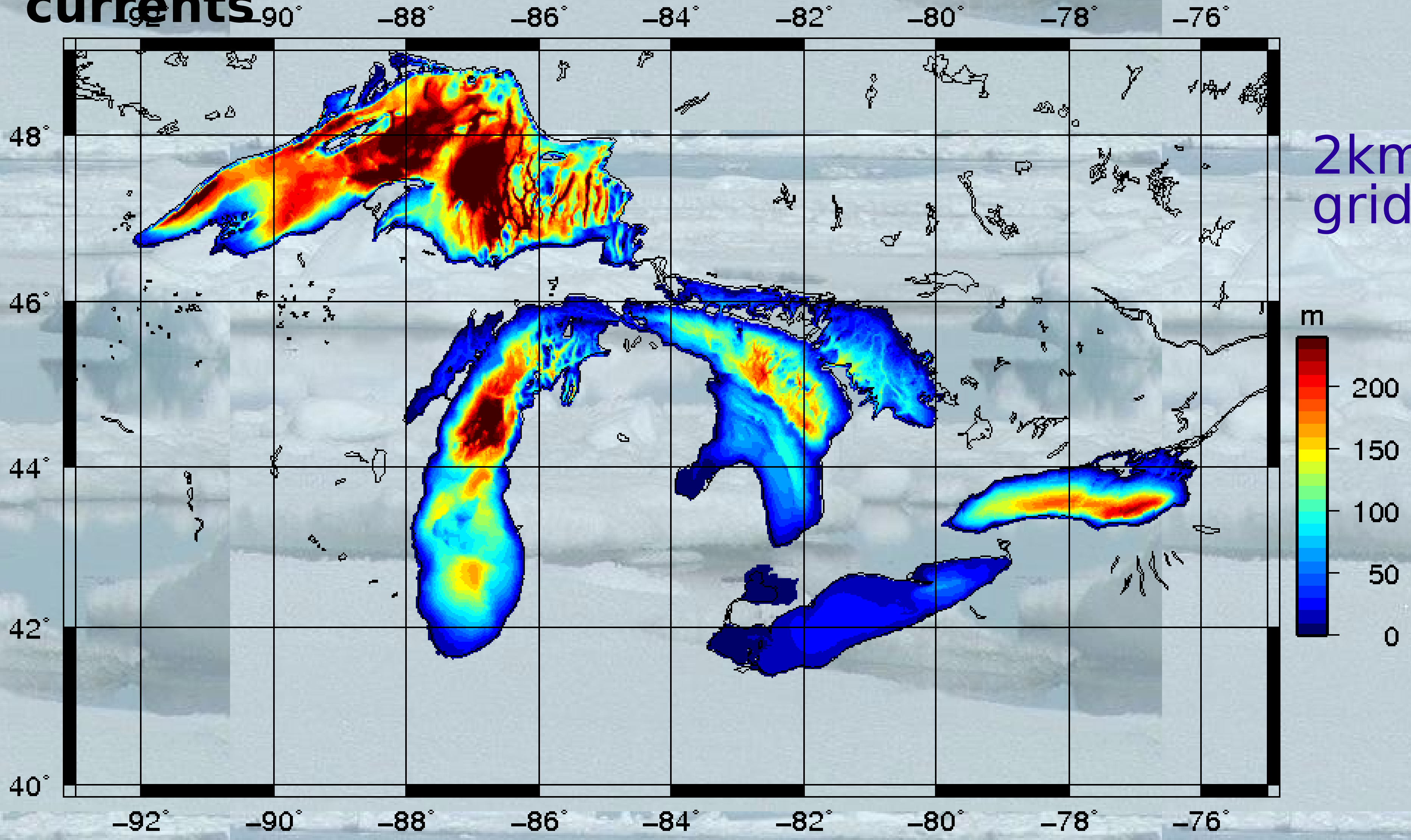
www.nemo-ocean.eu



Features:

- originally designed for climate studies
- now used for operational oceanography (www.mercator-ocean.fr, www.mercator.eu.org)
- C-grid FD
- z level model with partial steps (soon z*)
- Energy-enstrophy conservative scheme
- TVD tracer advection
- tides included +VVL option
- 2-way nesting (AGRIF)
- LIM2: 3 layer ice-snow model + VP dynamics (upcoming LIM3 is multi-category and EVP based)
- Is now the workhorse at EC-DFO, collaboration with Mercator-Ocean, implementation of their data-assimilation system.

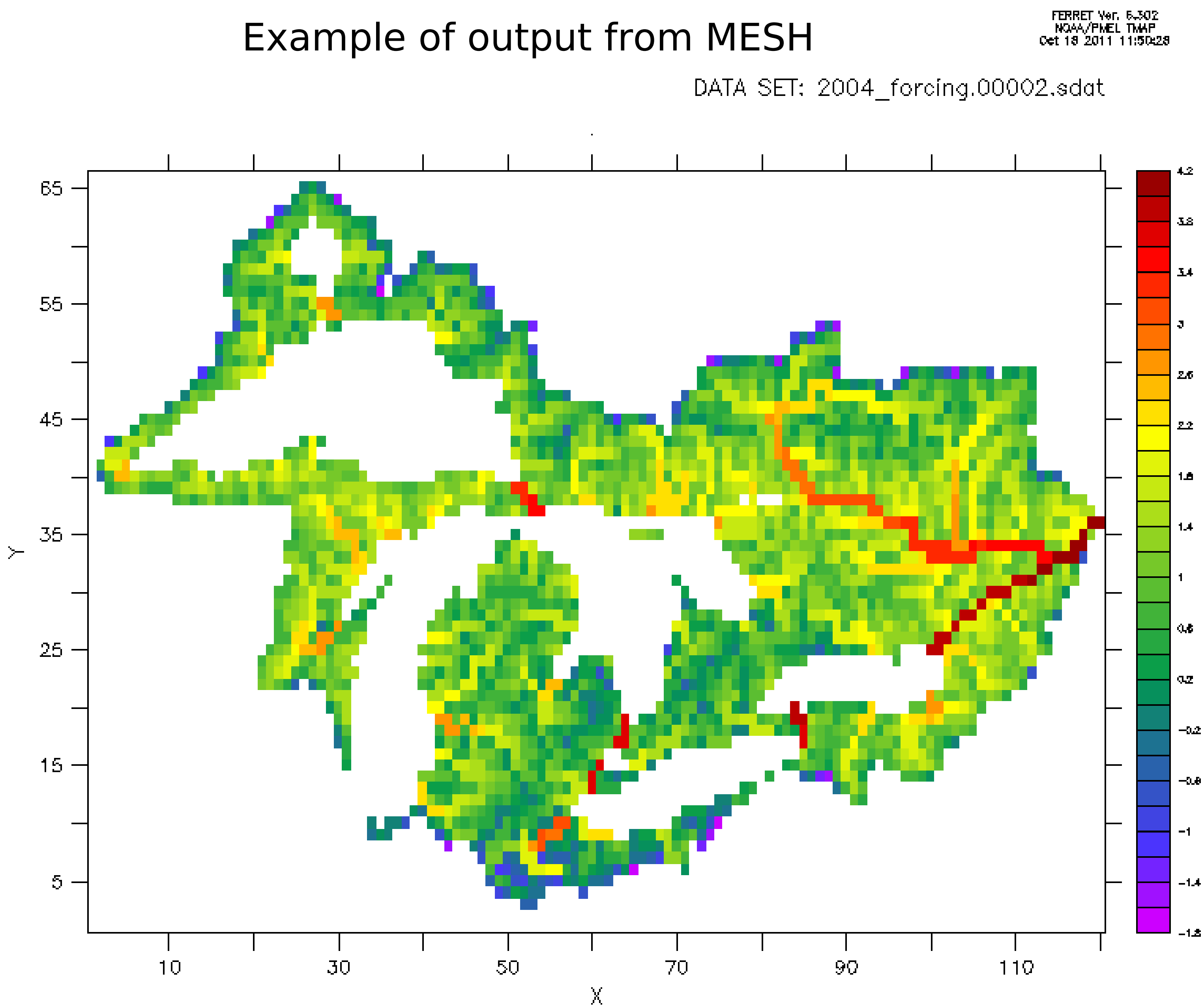
Presentation of the proposed forecasting system for lake level, river flows, temperature and currents



2km grid

NEMO is forced by GEM and CAPA (full coupling in progress), MESH (GEMsurf and river router) and follows the regulation rules for the connecting channels. Compact grid of 355x435x35. Expecting coupling to a 2D barotropic FE river model for Saint-Lawrence river/upper estuary

Example of output from MESH

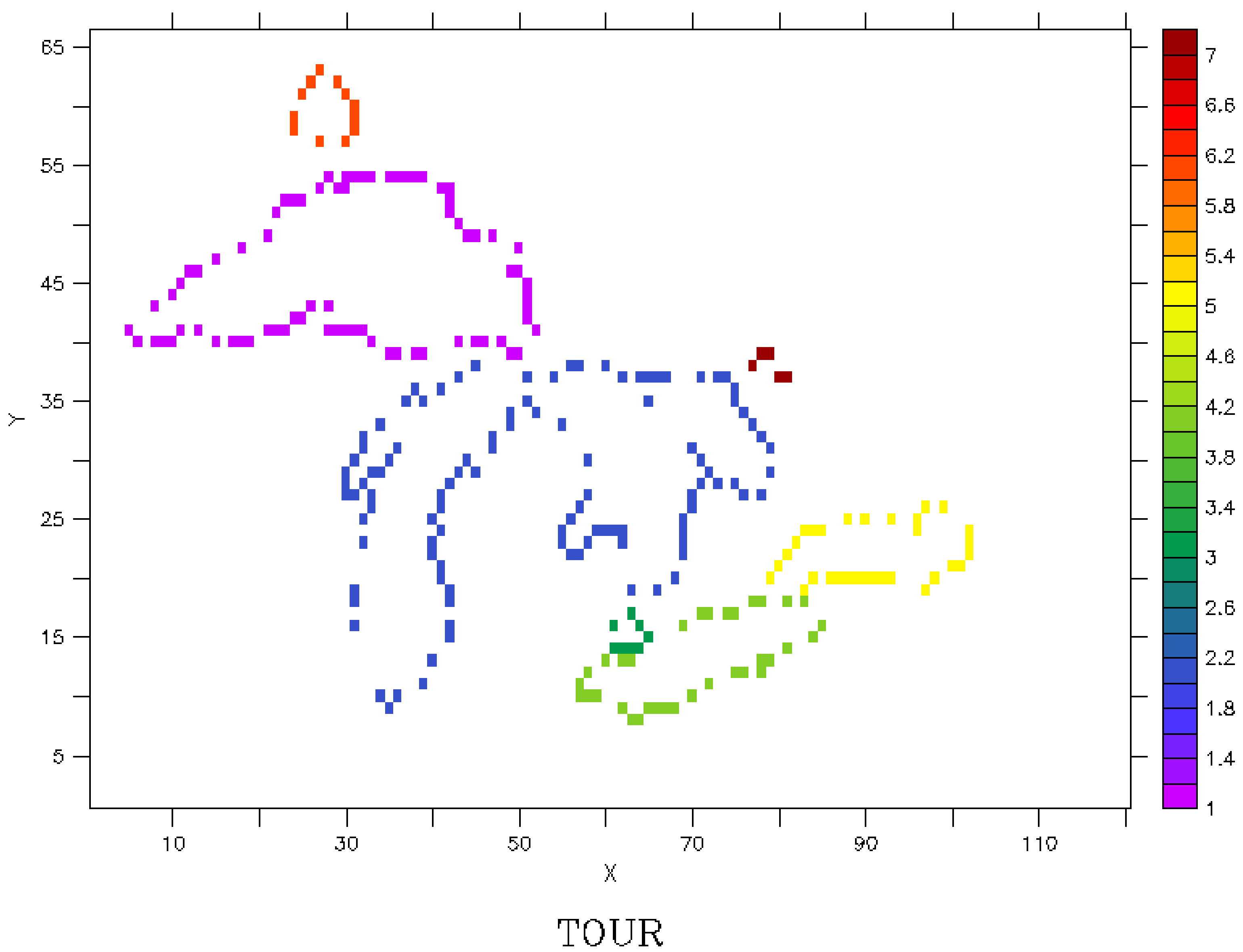


log_10 river flow (log m3/s)

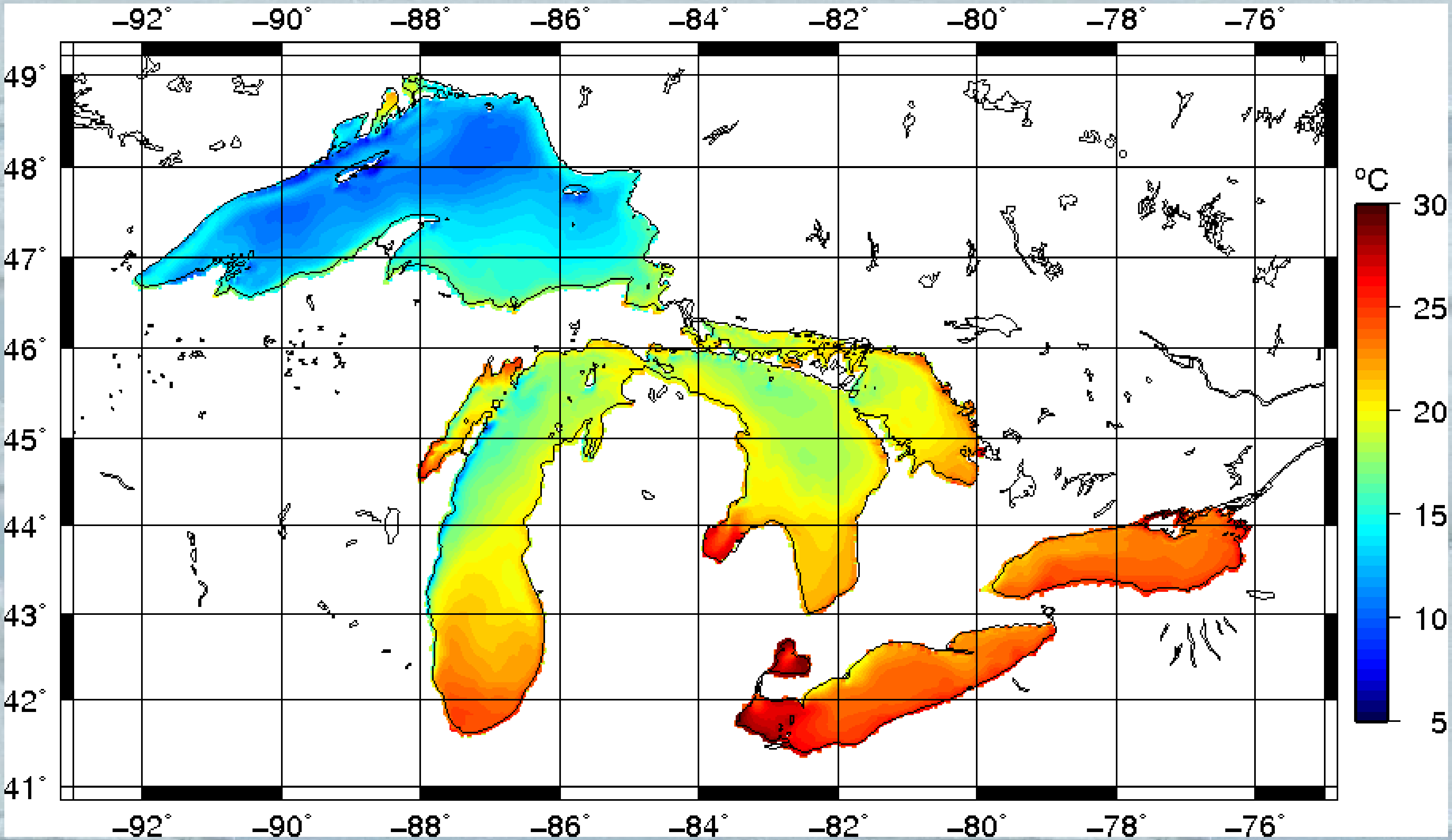
Based on the river head position, a river forcing is derived from MESH for NEMO

FERRET Ver. 6.302
NOAA/PMEL TMAP
Oct 18 2011 11:32:42

DATA SET: glake_shd_29juin.tour.bin

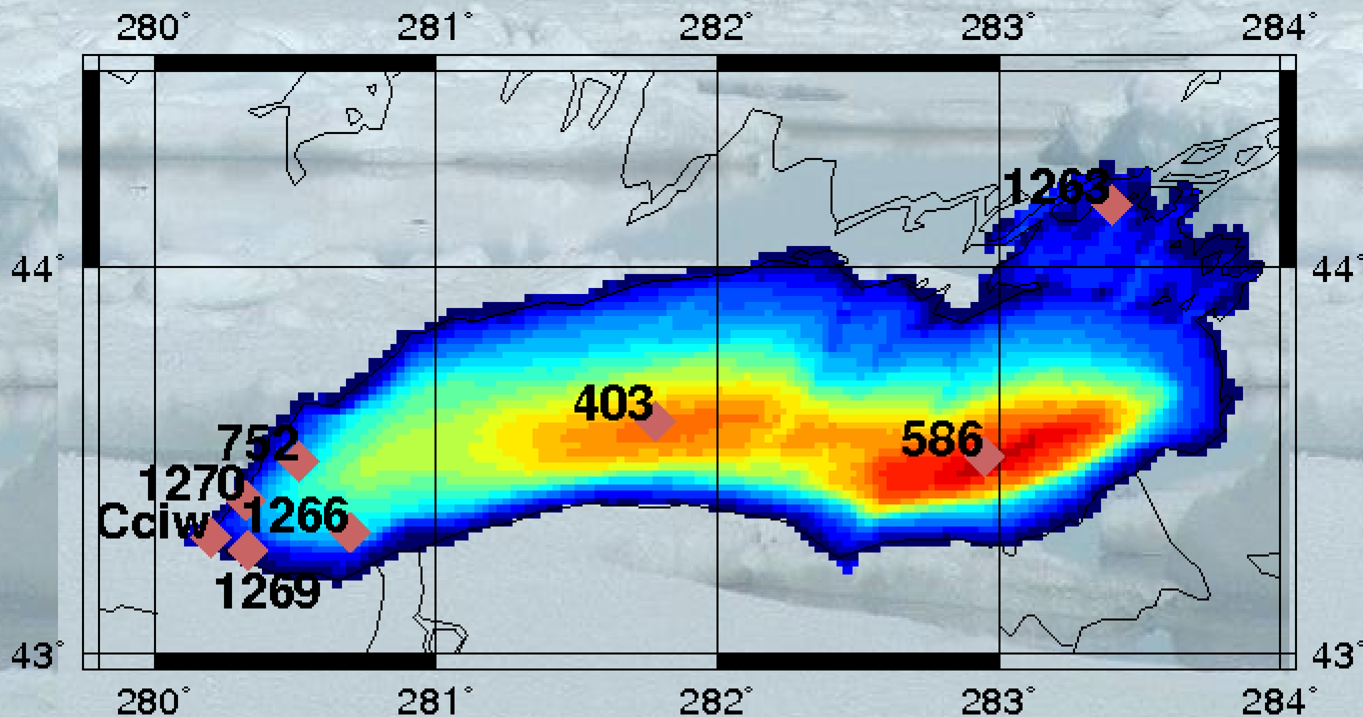


Example, SST on July 1, 2005 from model (with fluxsurf)



Intercomparison of 4 hydrodynamic models for Lake Ontario and some ice season results

Experimental program in 2006 to provide forcings for Hydrodynamic & Water Quality Modeling in Lake Ontario



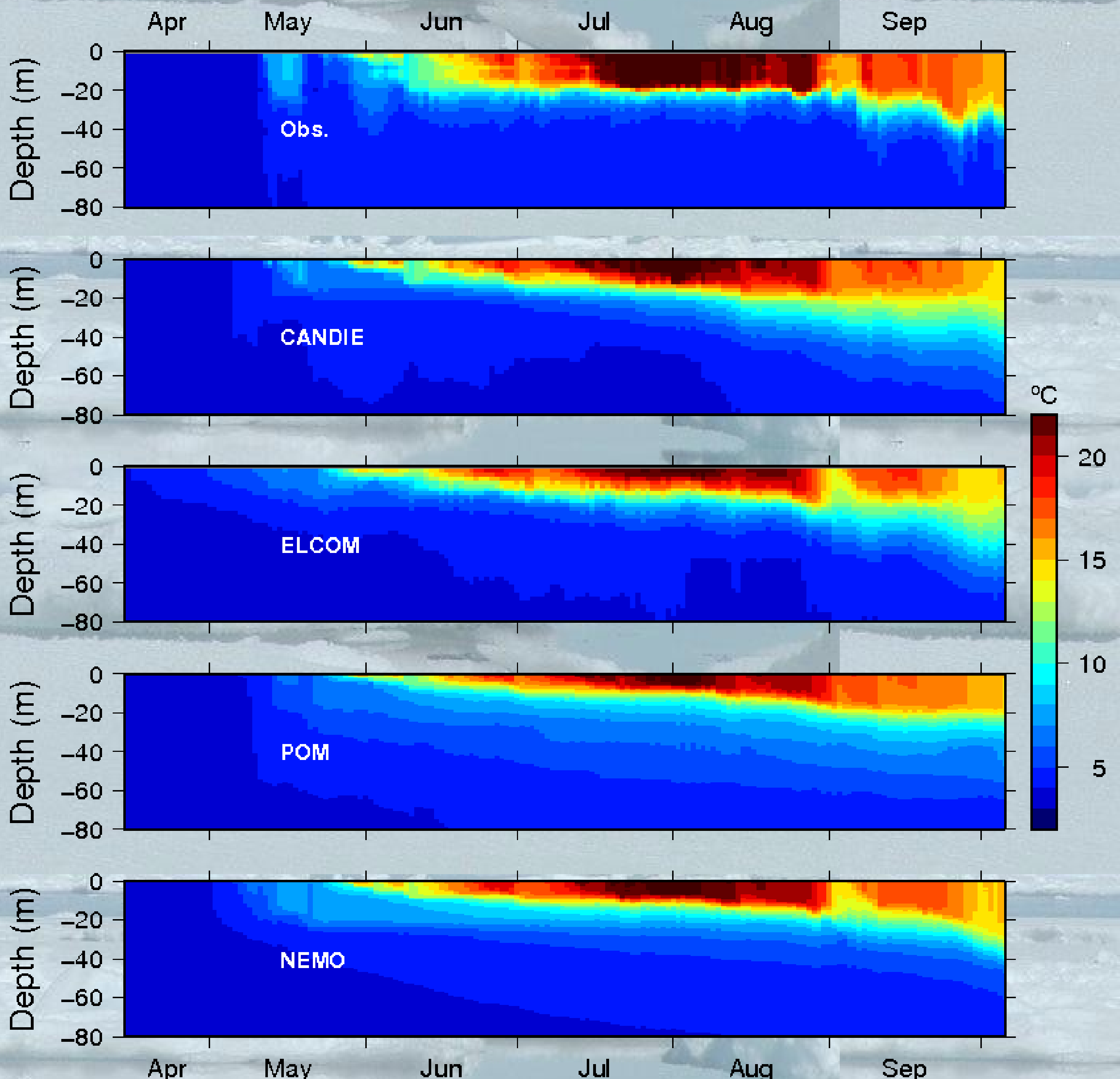
- 3 met buoys & land station with solar radiation measurements, used for forcing models
- ADCPs: 1266, 1269, 1270
- Water levels at 4 stations
- All: thermistor chains
- Water Survey of Canada inflows & water levels

Model short description

Models	CANDIE	ELCOM	POM	NEMO
Z-coordinate	Z	Z	sigma	Z, partial steps
Turbulence scheme	KPP	Mixed layer Imberger	MY2.5	GASPAR1.5
Vertical levels	61	61	31	31
Thickness 1st level	1m	1m	2-20 cm	1m
Rad. heat flux	net	net	net	descending
Turbulent heat flux	Bulk	Bulk	Bulk Schertzer	CORE Bulk

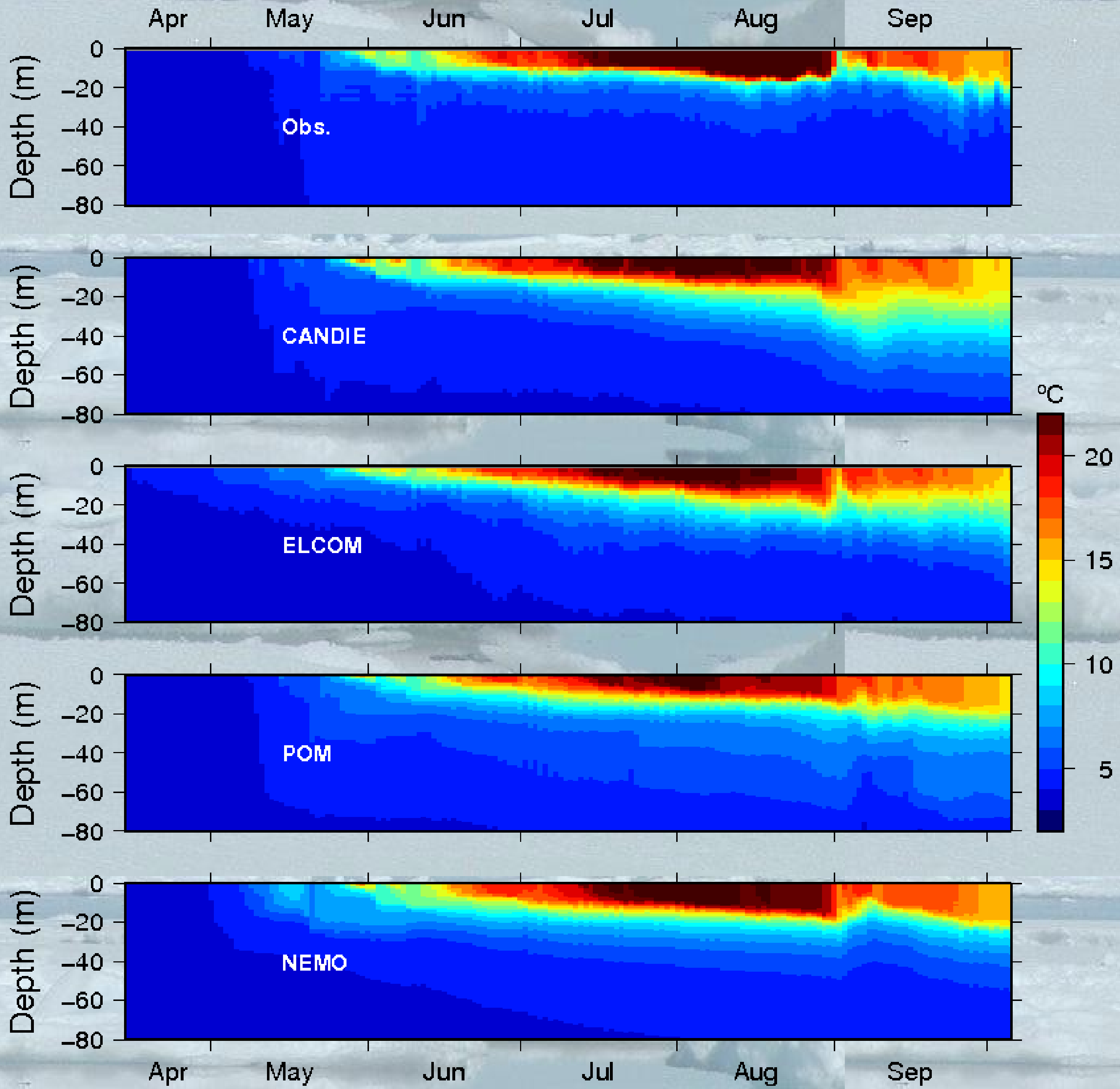
Temperature at station 403

No model captured very well the deeper mixed layer and the very sharp thermocline

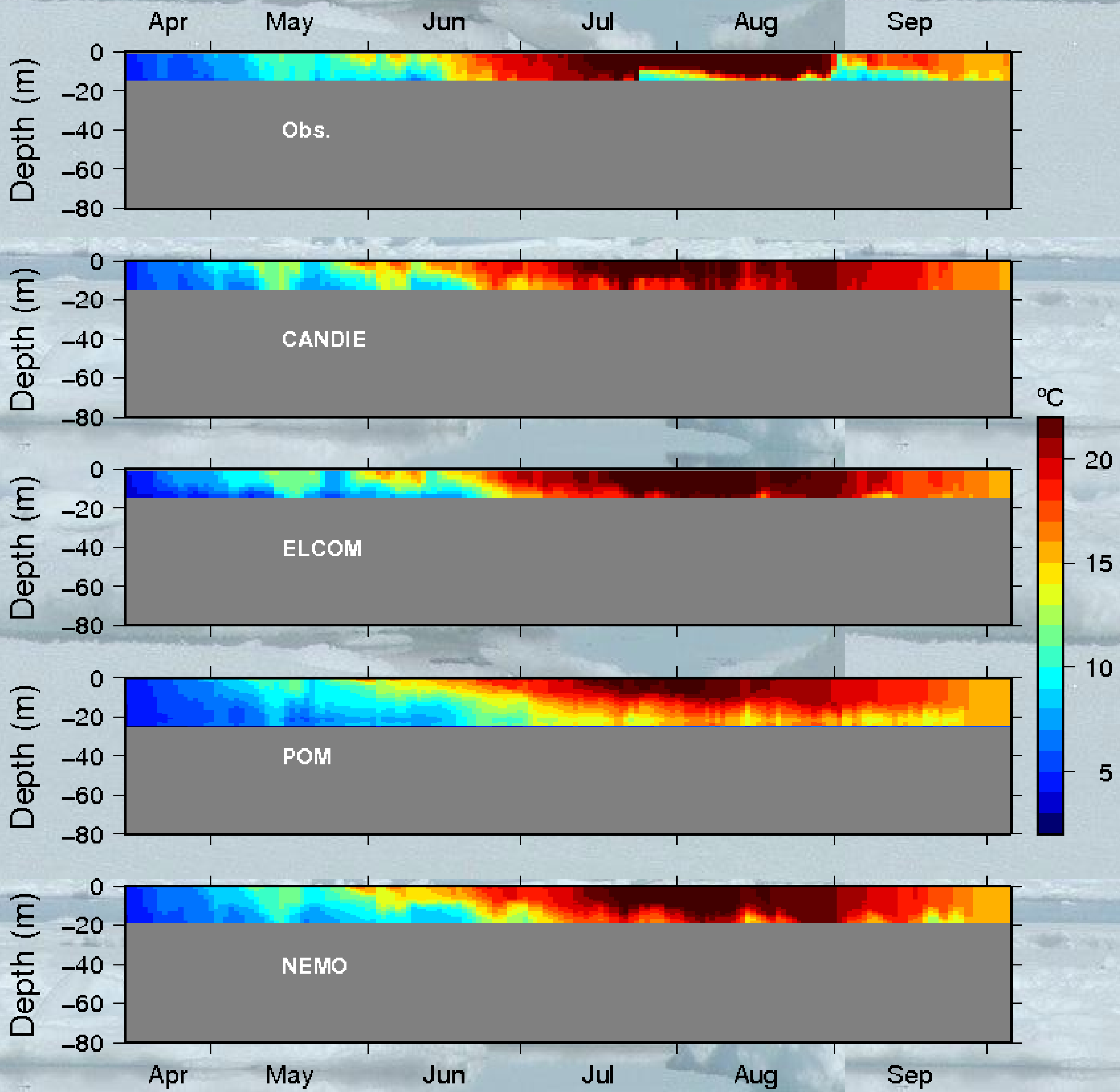


Temperature at station 586

ELCOM and CANDIE show the least amount of diffusion below the thermocline in June-July



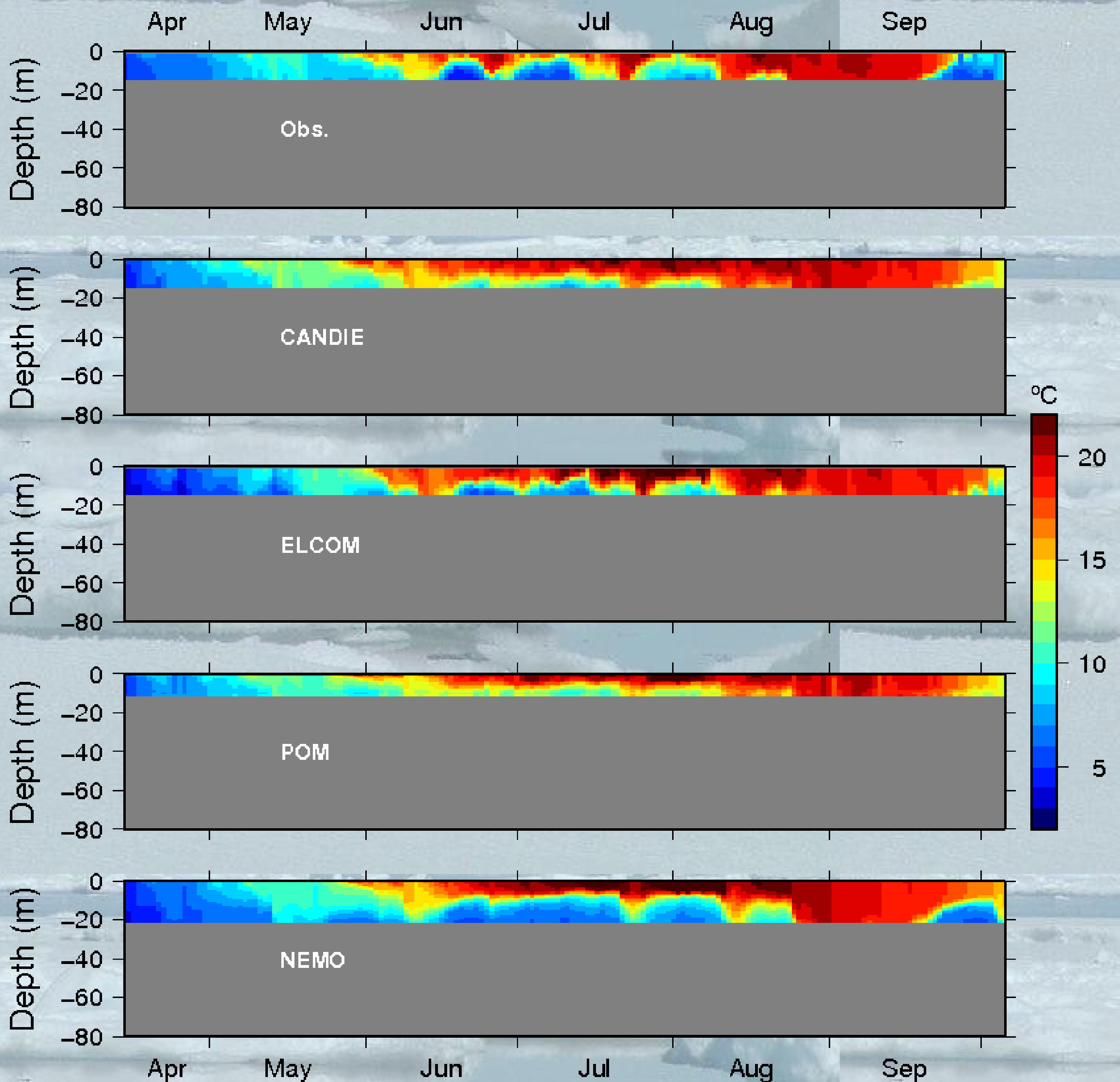
Temperature at station 1263



No model captured the 2 cold water penetrations (upwelling?)

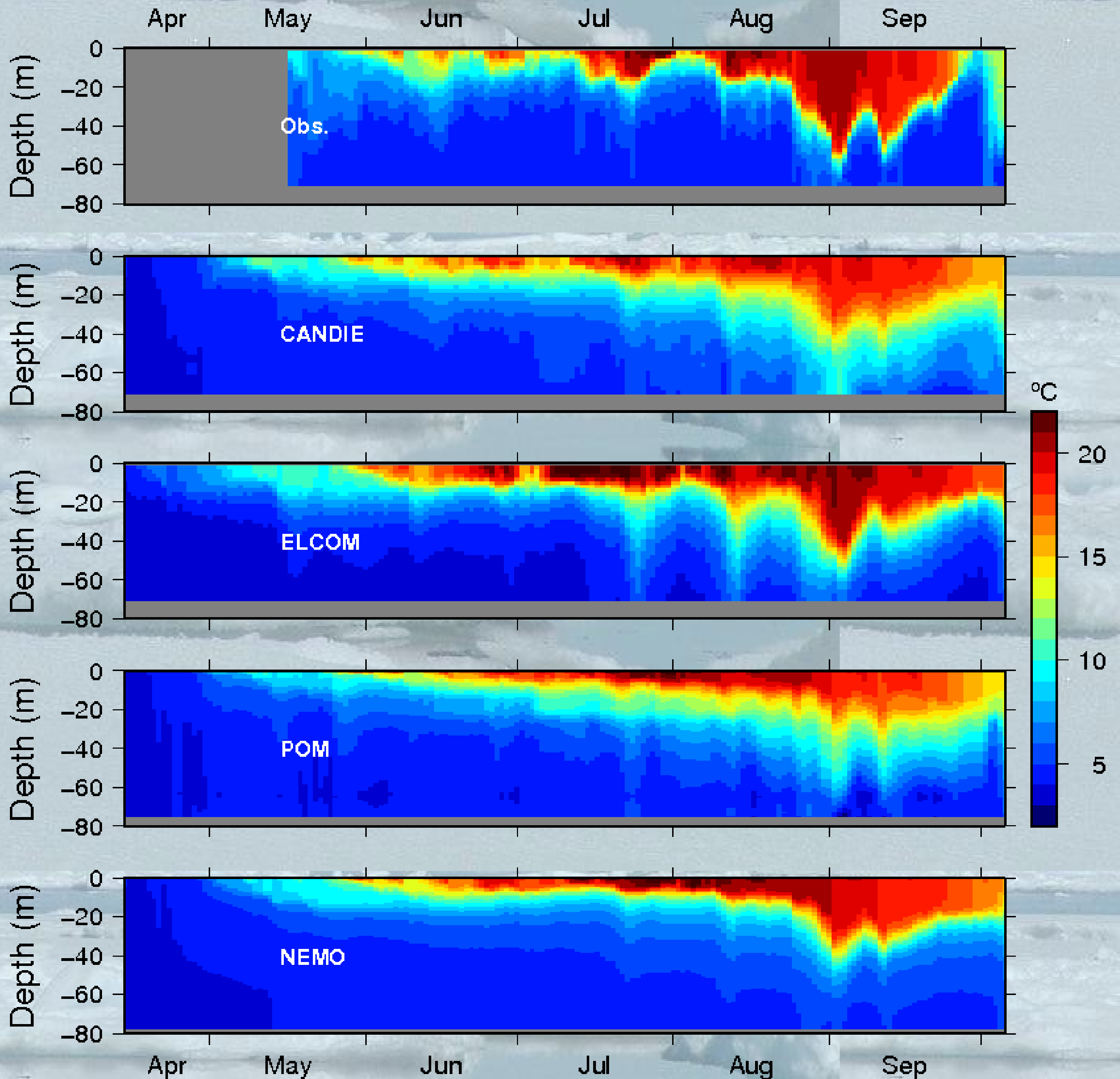
Temperature at station 1269

NEMO shows the best restratification in early fall, captures also well the 3 episodic upwellings during summer. It is also the deepest there.

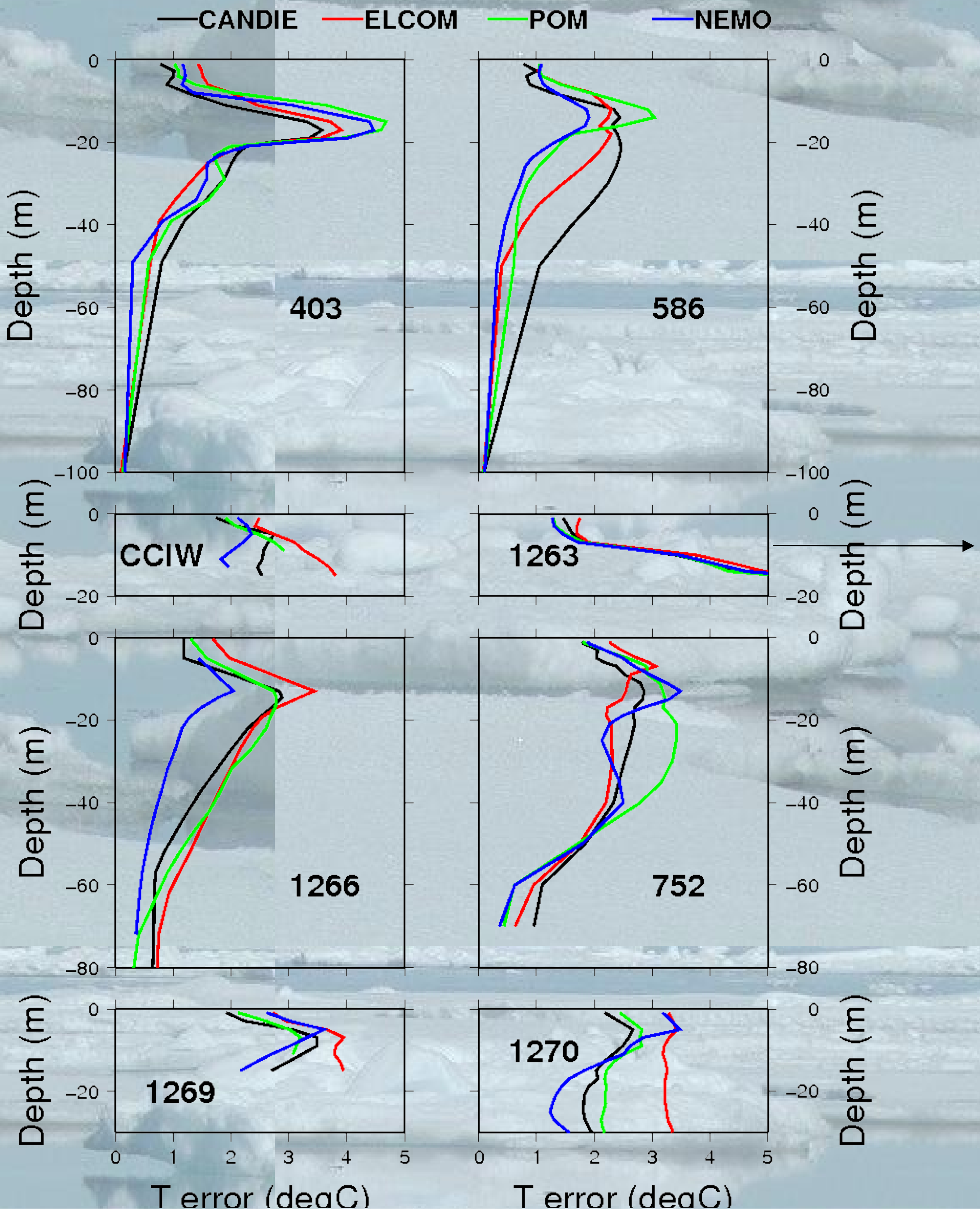


Temperature at station 752

Strong downwelling event in late August-early September. ELCOM got it best.



RMS Error plot at each station in function of depth



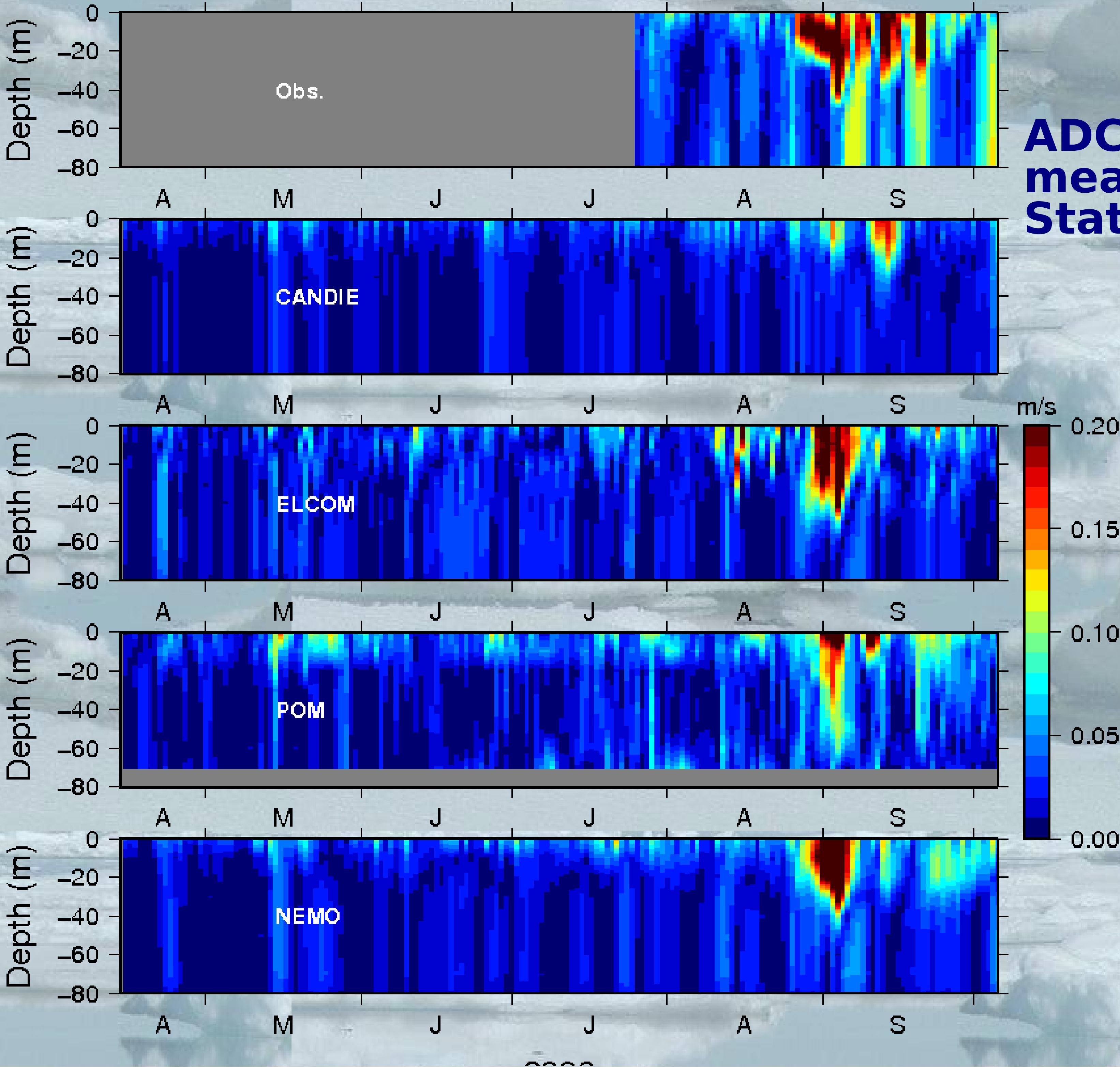
All models missed a cold water penetration event in mid-summer (bottom)

CANDIE is usually the best model for surface error and NEMO is usually better at depth

RMS Error tabulated for all temperature stations, averaged for at most the 50m upper meter

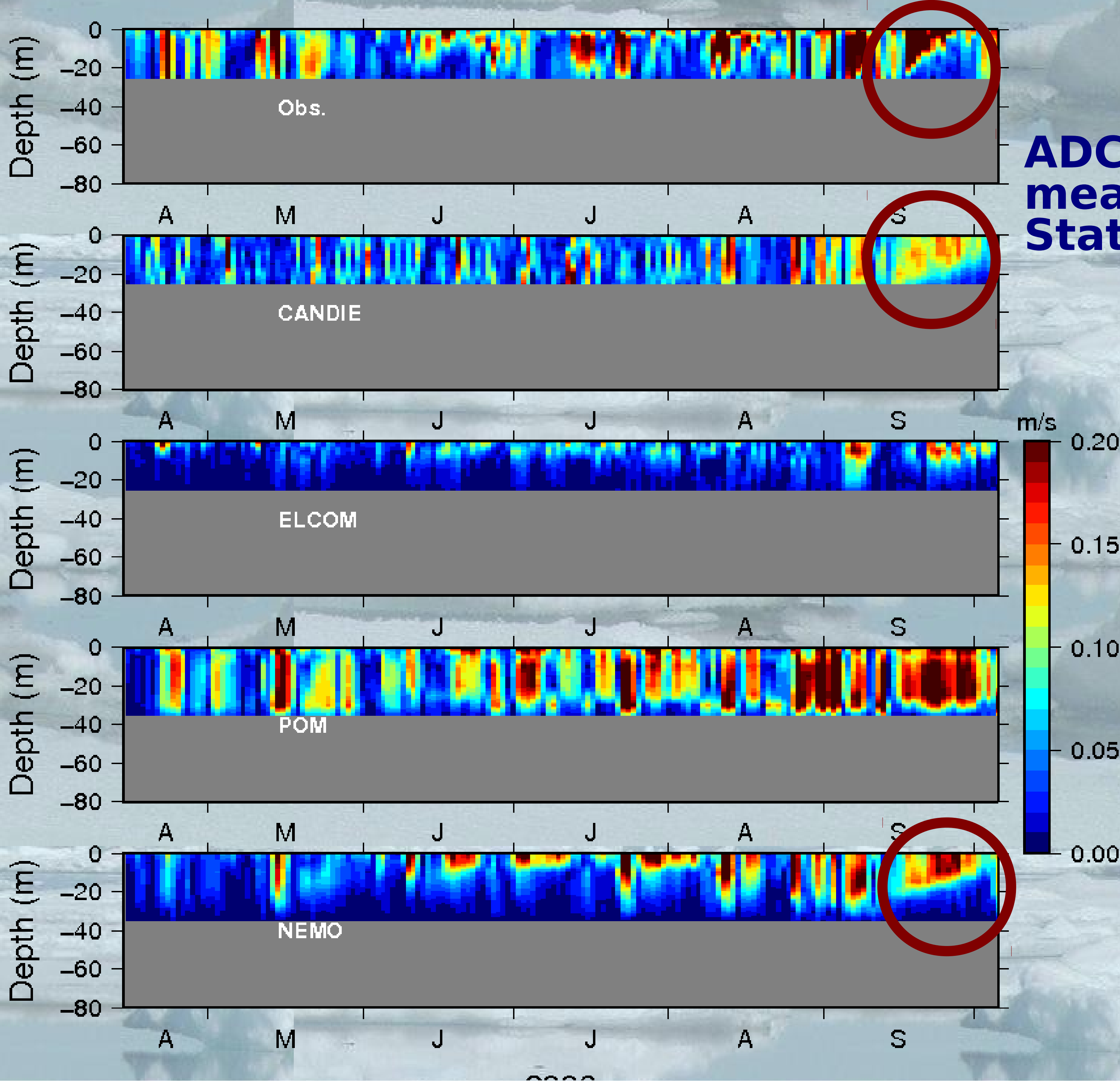
Stations	CANDIE	ELCOM	POM	NEMO
CCIW	2.41	3.13	2.42	**2.11**
403	1.69	**1.67**	1.93	1.74
586	1.80	1.43	1.26	**0.95**
1263	2.74	3.01	**2.64**	2.69
1266	1.79	2.15	2.03	**1.14**
1269	2.88	3.59	**2.85**	2.86
1270	2.13	3.27	2.38	**2.10**
752	2.42	**2.31**	2.91	2.46
Mean	**2.23**	**2.57**	**2.30**	**2.01**

ADCP measurement Station 1266



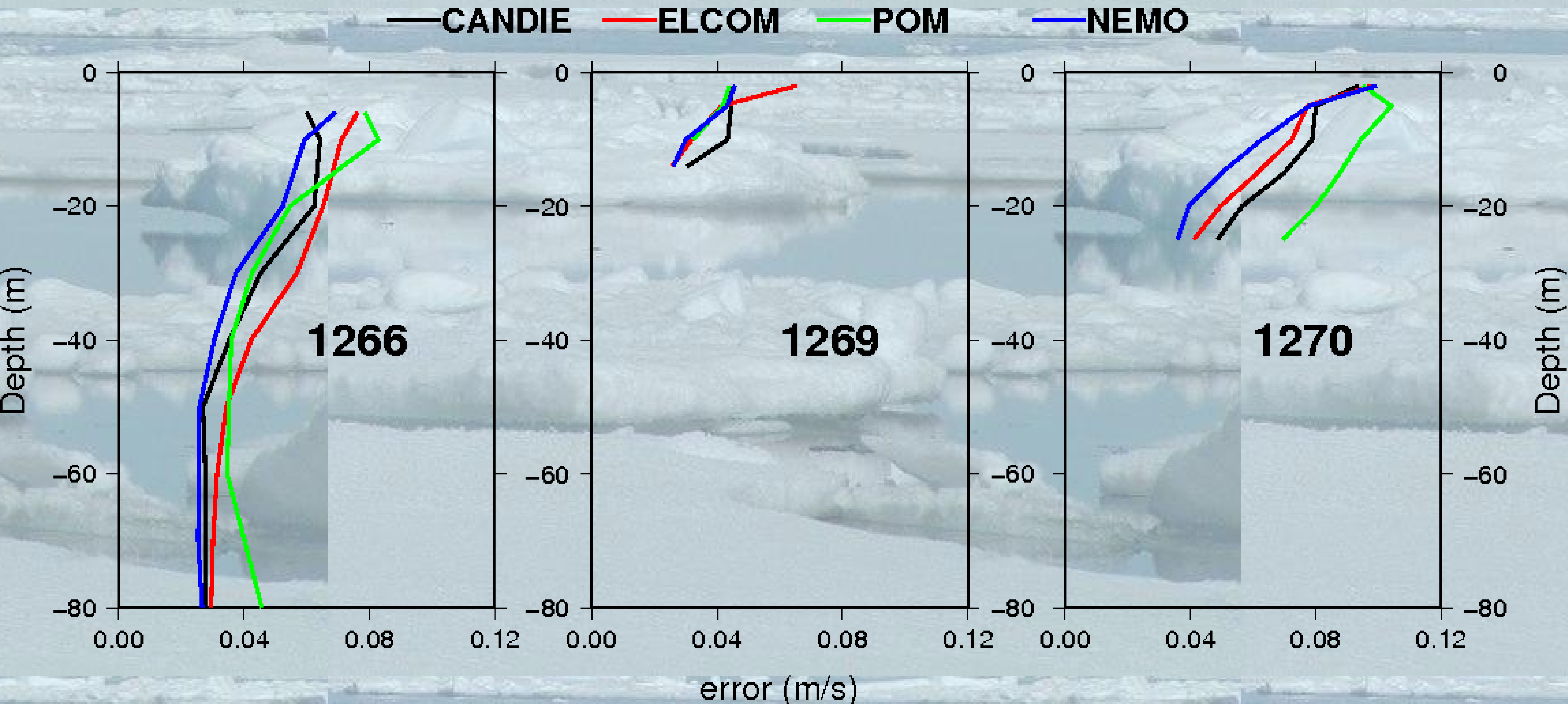
CANDIE did not well capture the intense event of early September, although all models show an equivalent signal in temperature

ADCP measurement Station 1270



A lot of small events. NEMO and CANDIE captured the reduced penetration of an intense slap at the end of September. All models captured the associated restratification.

RMS Error at each velocity station in function of depth



RMS Error vertically averaged at each velocity station over at most 50m

Stations	CANDIE	ELCOM	POM	NEMO
1266	0.049	0.057	0.052	**0.044**
1269	0.069	0.064	0.087	**0.057**
1270	0.041	0.039	0.039	**0.036**
Mean	**0.053**	**0.053**	**0.059**	**0.046**

Last year intercomparison with more common features

Models	CANDIE	POM	NEMO
Z-coordinate	Z	sigma	Z, partial steps
Turbulence scheme	KPP	MY2.5	GASPAR1.5
Vertical levels	61	31	31
Thickness 1st level	1m	2-20 cm	1m
Forcing	GEM 40m	GEM 40m	GEM 40m
Turbulent heat flux	Bulk Schertzer	Bulk Schertzer	Bulk Schertzer

Effect of different vertical grid in CANDIE and NEMO (60 versus 35 z-levels) was tested in NEMO but did not draw any clear winner

The forcing and bulk parametrization pair is not ideal presently working on fixing this.
Candie was not started similarly to the 2 other models

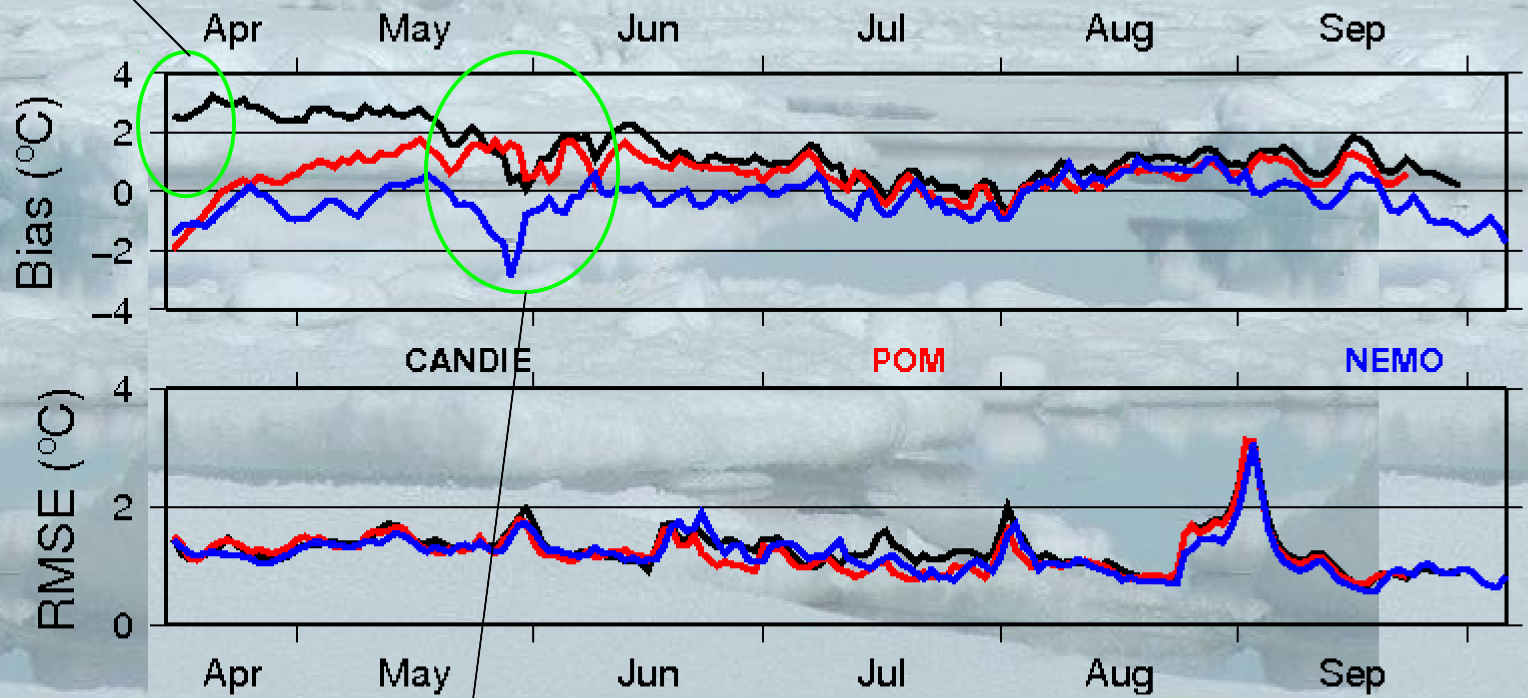
RMS Error tabulated for all temperature stations, averaged for at most the 50m upper meter

Stations	CANDIE	POM	NEMO
CCIW	2.49	2.21	**1.72**
403	2.16	2.05	**1.96**
586	2.61	2.84	**2.52**
1263	**2.43**	2.46	2.58
1266	2.49	2.21	**1.72**
1269	2.80	2.49	2.48
1270	2.40	2.70	**2.20**
752	2.69	2.42	**1.85**
Mean	**2.51**	**2.42**	**2.13**

In red the best scores

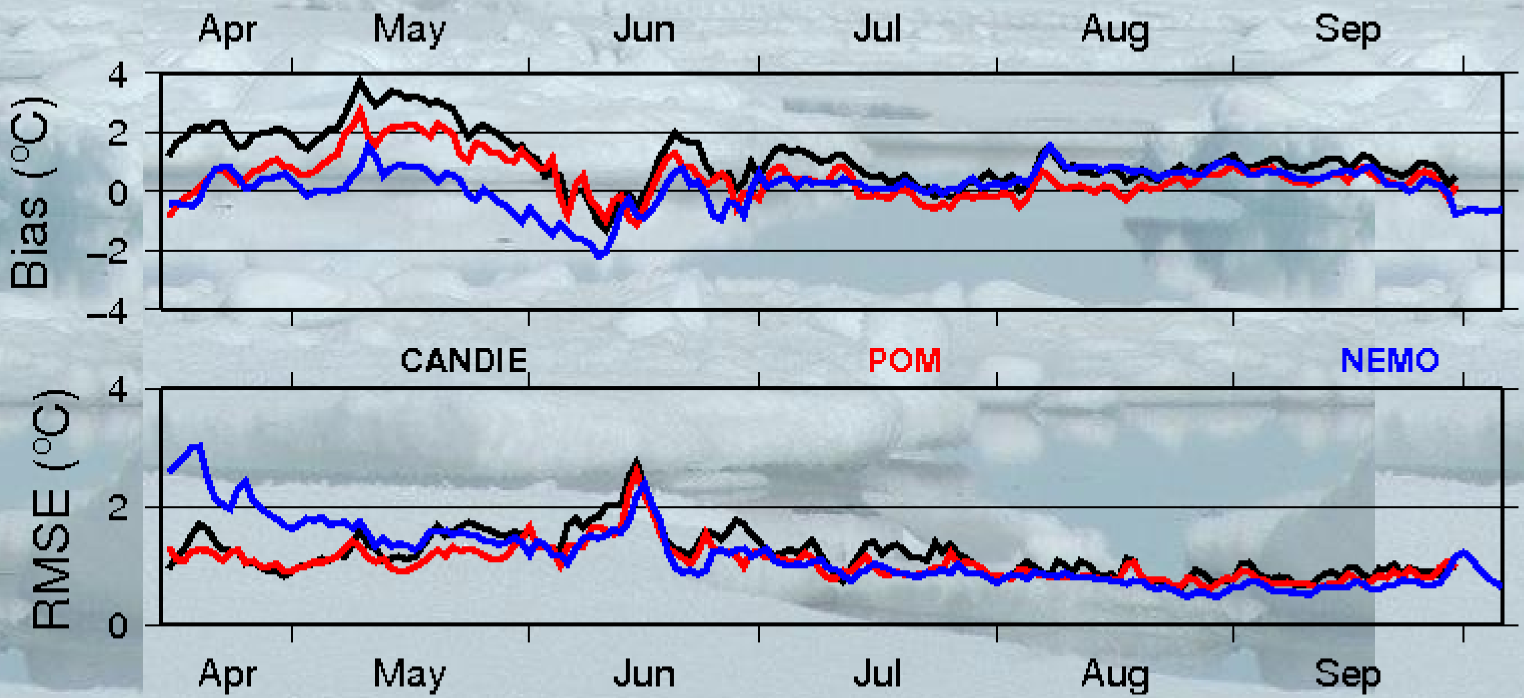
AVHRR satellite comparison with model SST
Ontario + Erie
2006

Init problem in CANDIE?



Spring warming not coinciding with obs.

AVHRR satellite comparison with model SST
Ontario + Erie
2005

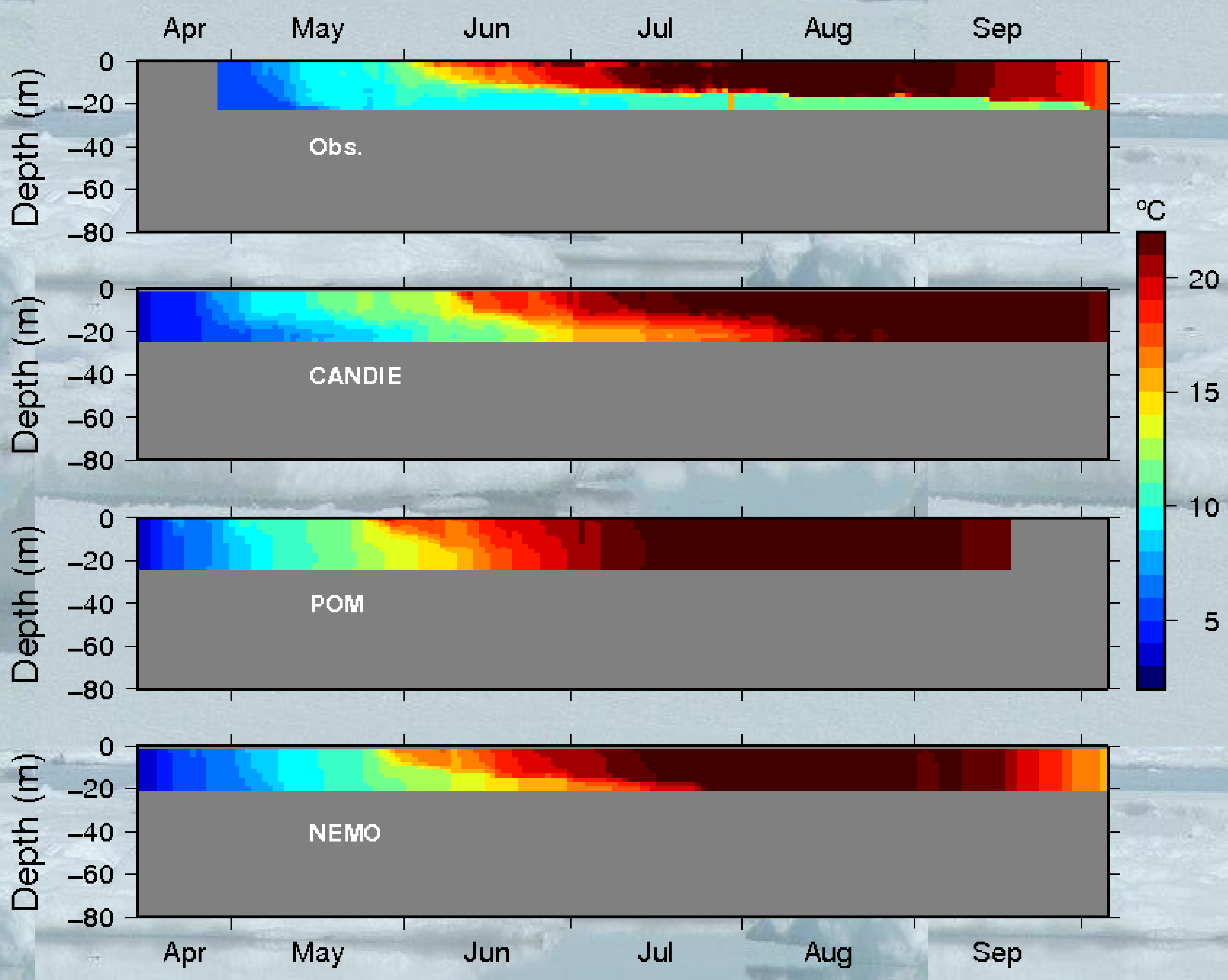


Example of problem in Central Lake Erie with thermocline representation

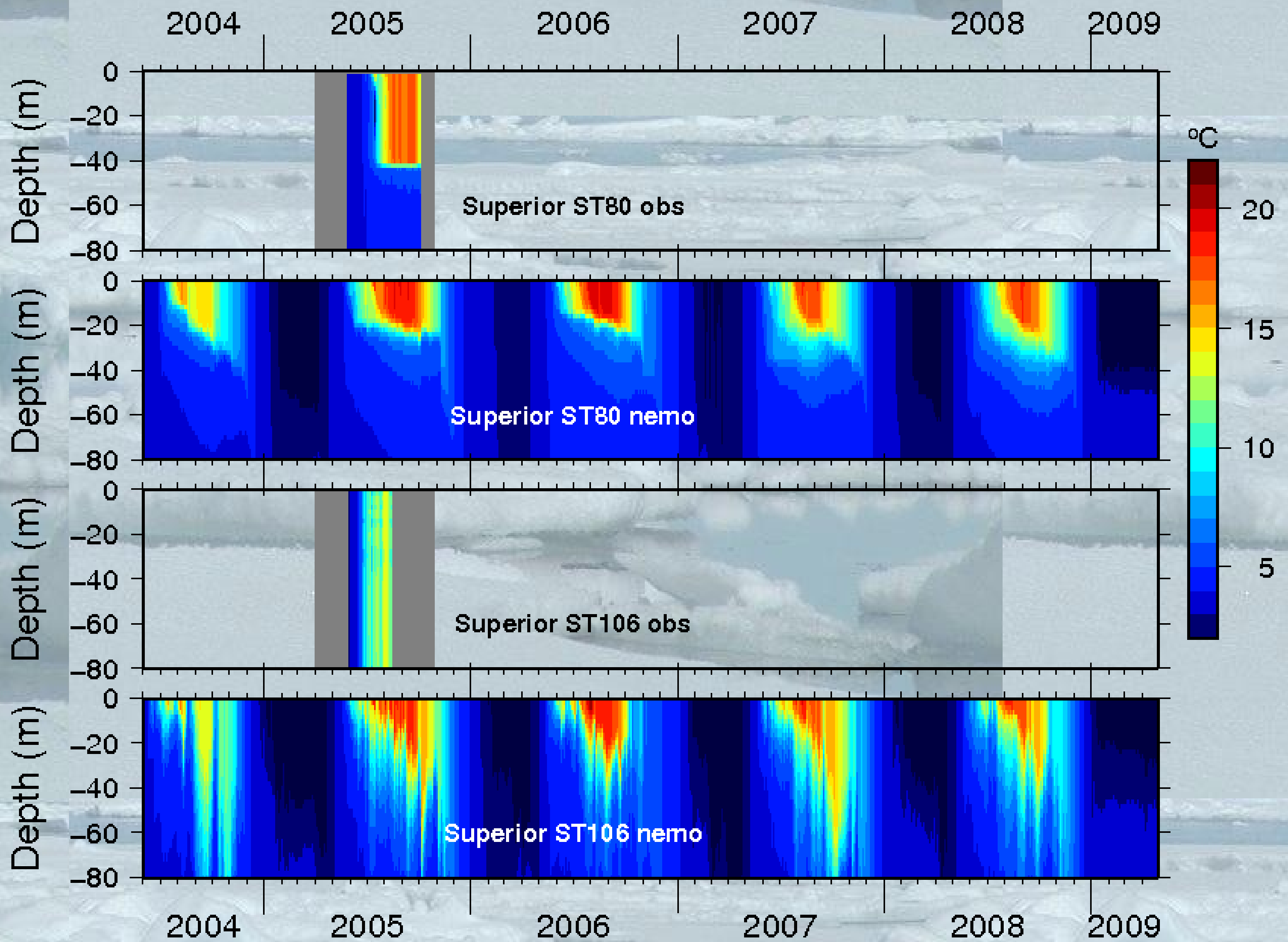
The thermocline is very sharp and survives until the end of September.

Impact of oxygen depletion

Candie has the longest surviving deep layer



Thermocline in Lake Superior



Validation of the hydraulic and hydrology in NEMO

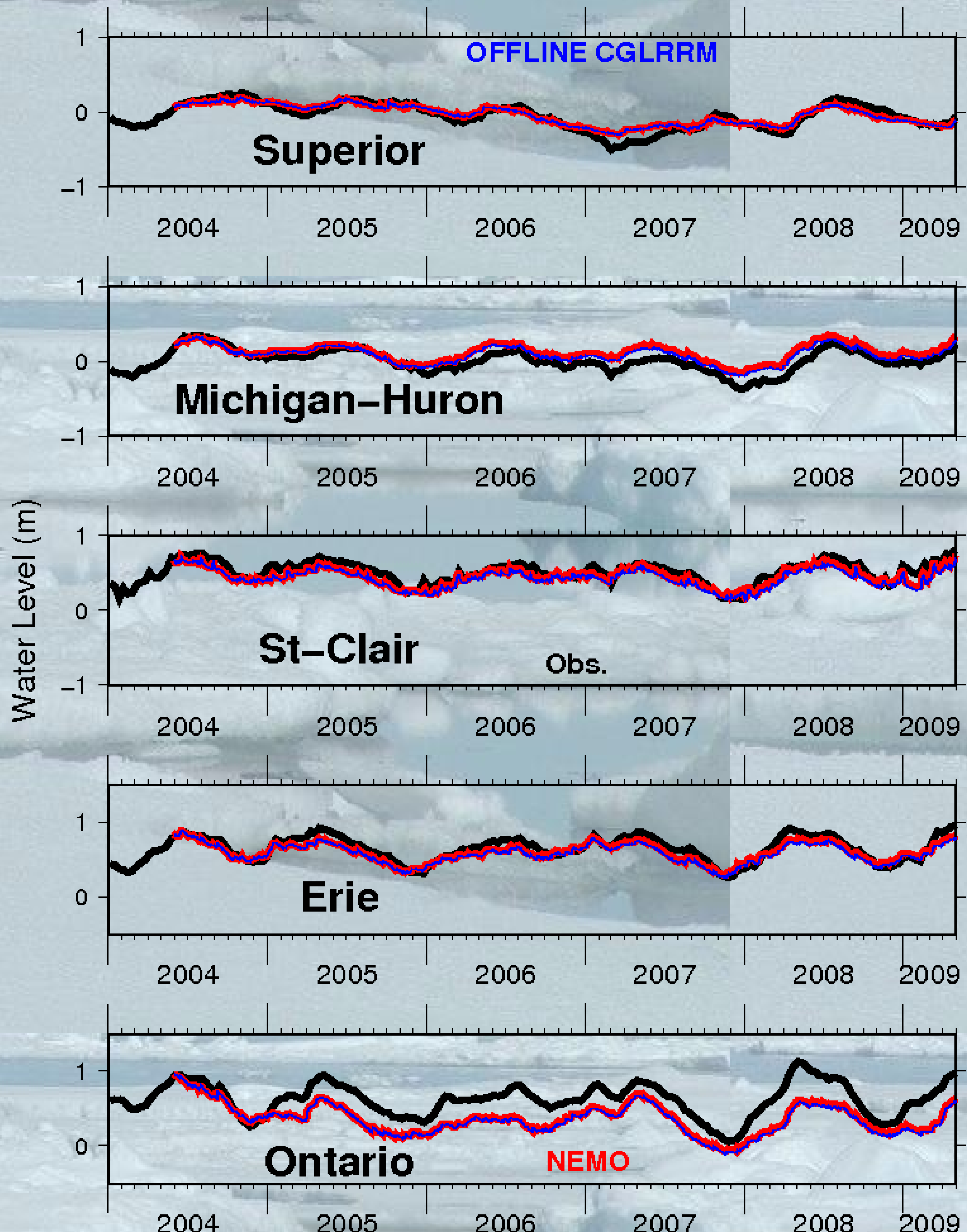
2 experiments:

NEMO with CORE bulk formulae

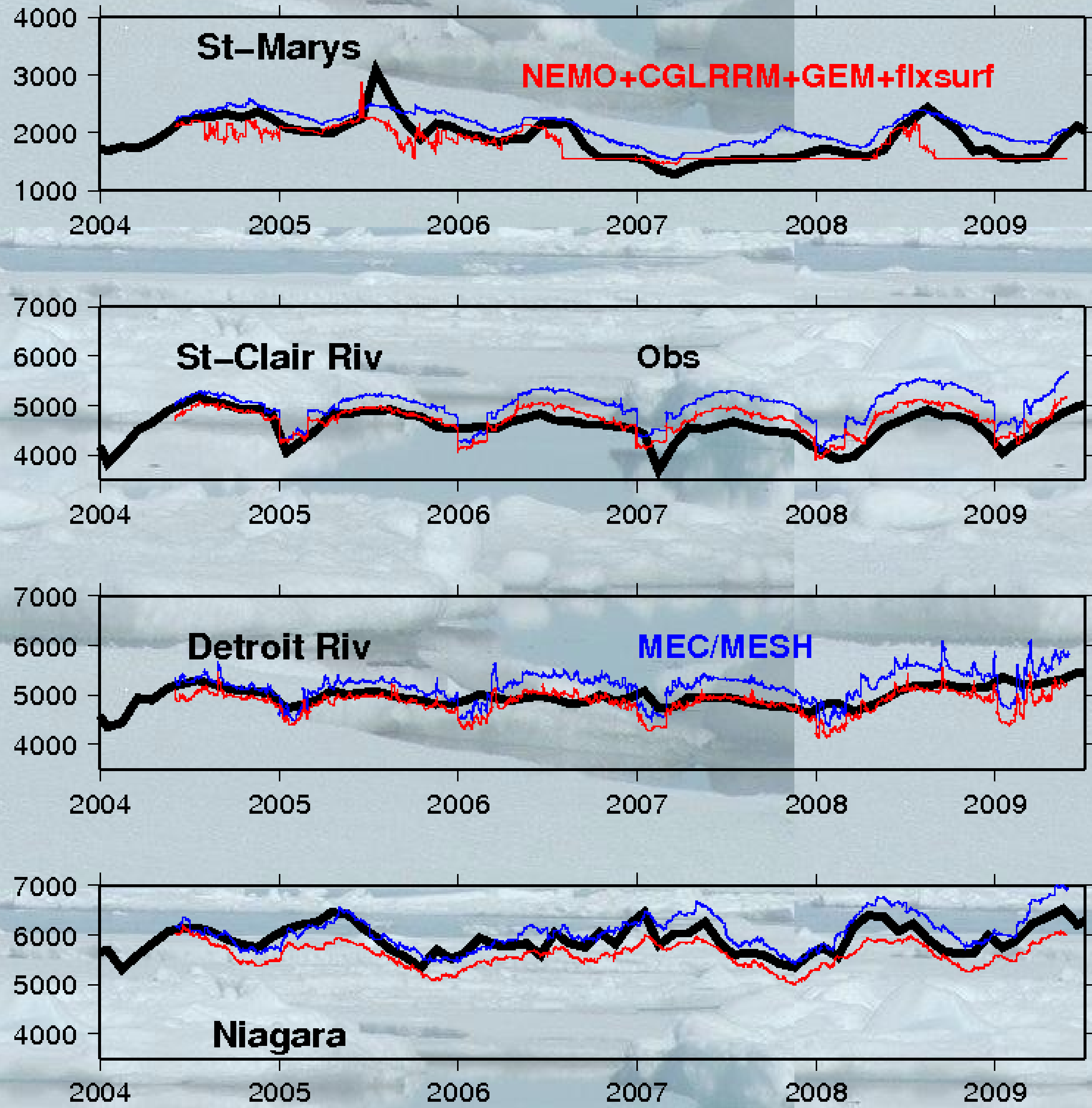
NEMO with RPN bulk formulae + Deacu et al.'s (2011, submitted) corrections

Validation of NEMO-regulation model against offline calculation and observations. Black: obs., blue:expected levels based on NEMO evaporation and river routing, red modelled by NEMO. There are no defined regulation rules for Lake Ontario, so an adhoc equation for the outflow is used there instead.

One remaining problem: NEMO evaporation is too strong in the upper lakes and leads to weaker than observed connecting flows. Corrections implemented in GEM bulk formulae to fix the same problem have been ported to NEMO but do not completely solve the problem

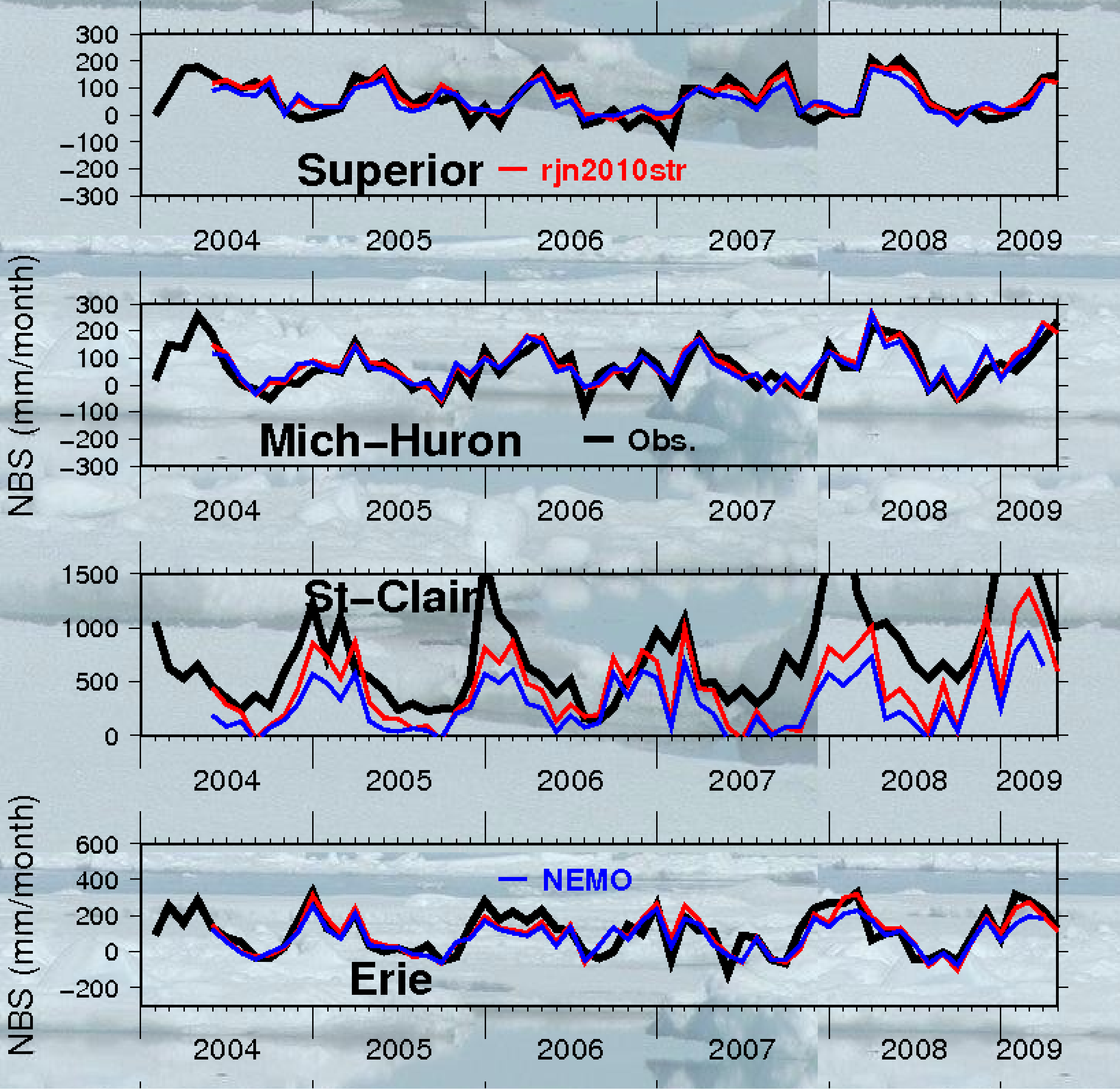


Validation of NEMO-regulation model against offline calculation and observations for the flow through the connecting channels. Evaporation again leads to the flow at St-Marys reaching the minimum limit.



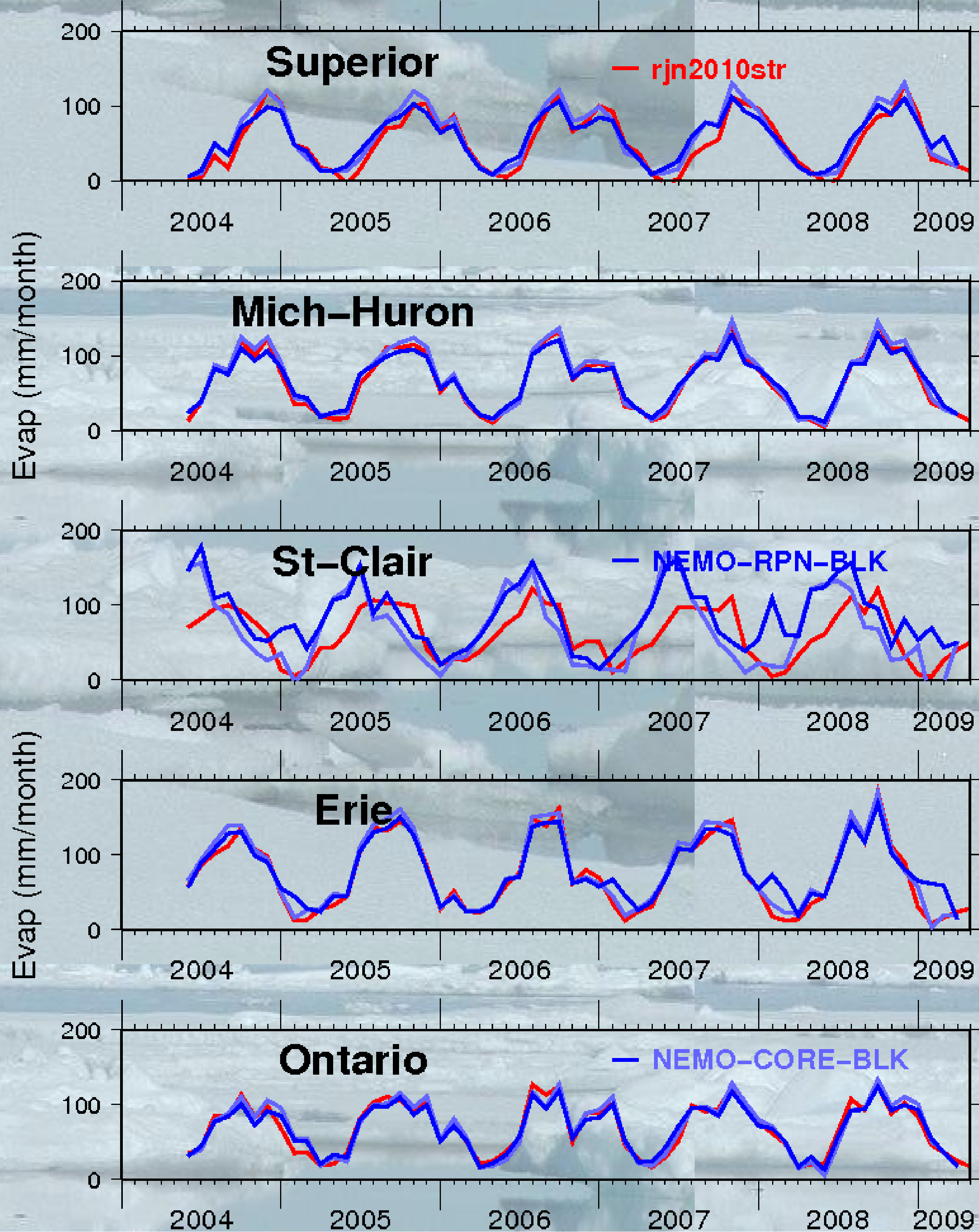
Monthly Net Basin Supply (i.e. Runoff+P-E; mm/month) for each lake, NEMO in blue, red from MESH, residual obs.NBS in black.

MESH NBS was compared advantageously to weather tower measurements and GLERL estimates

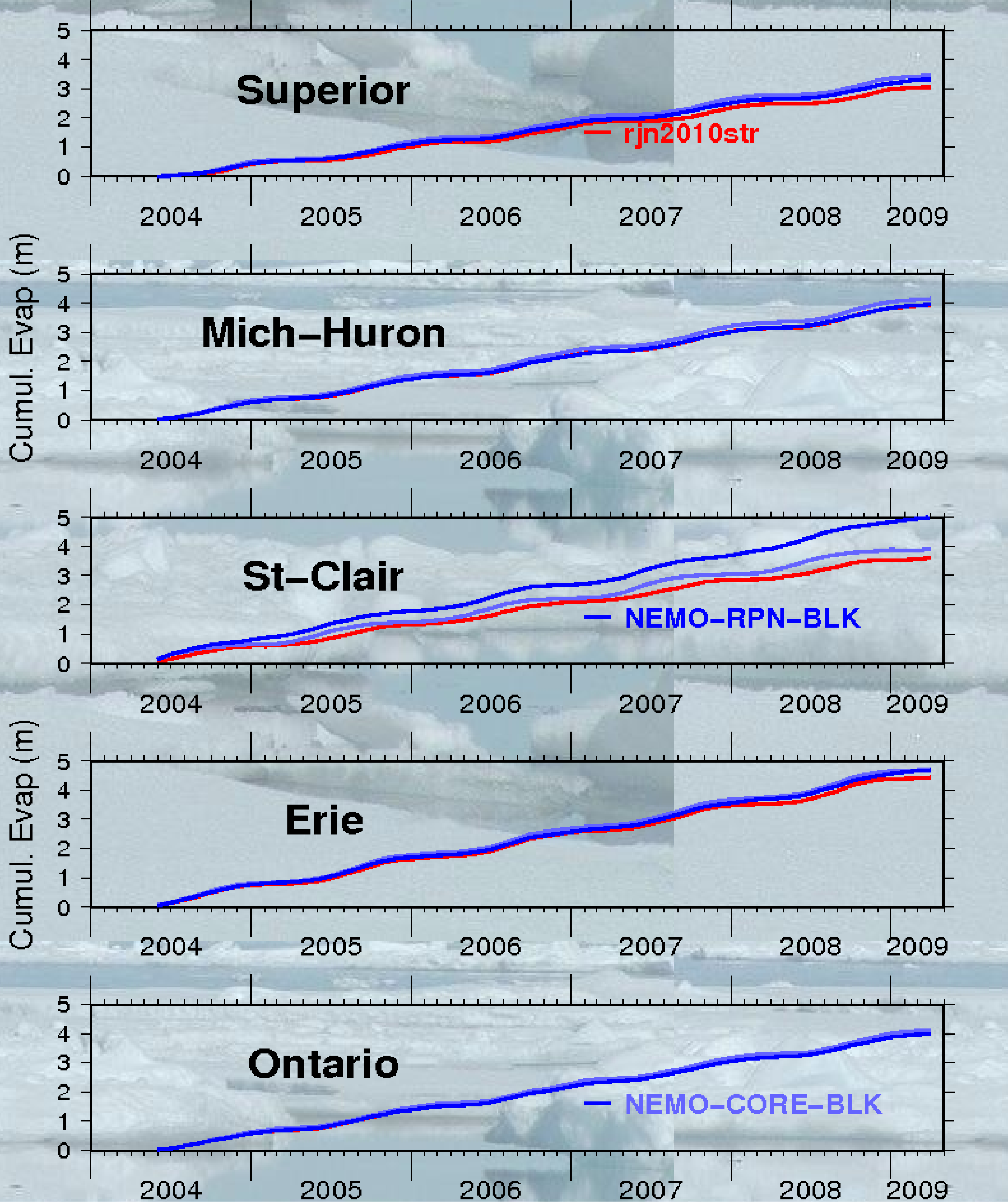


Monthly evaporation (mm/month) for each lake, NEMO in blue, red from MESH.

NEMO seems to overestimate evaporation in most lakes, but not by a large factor!



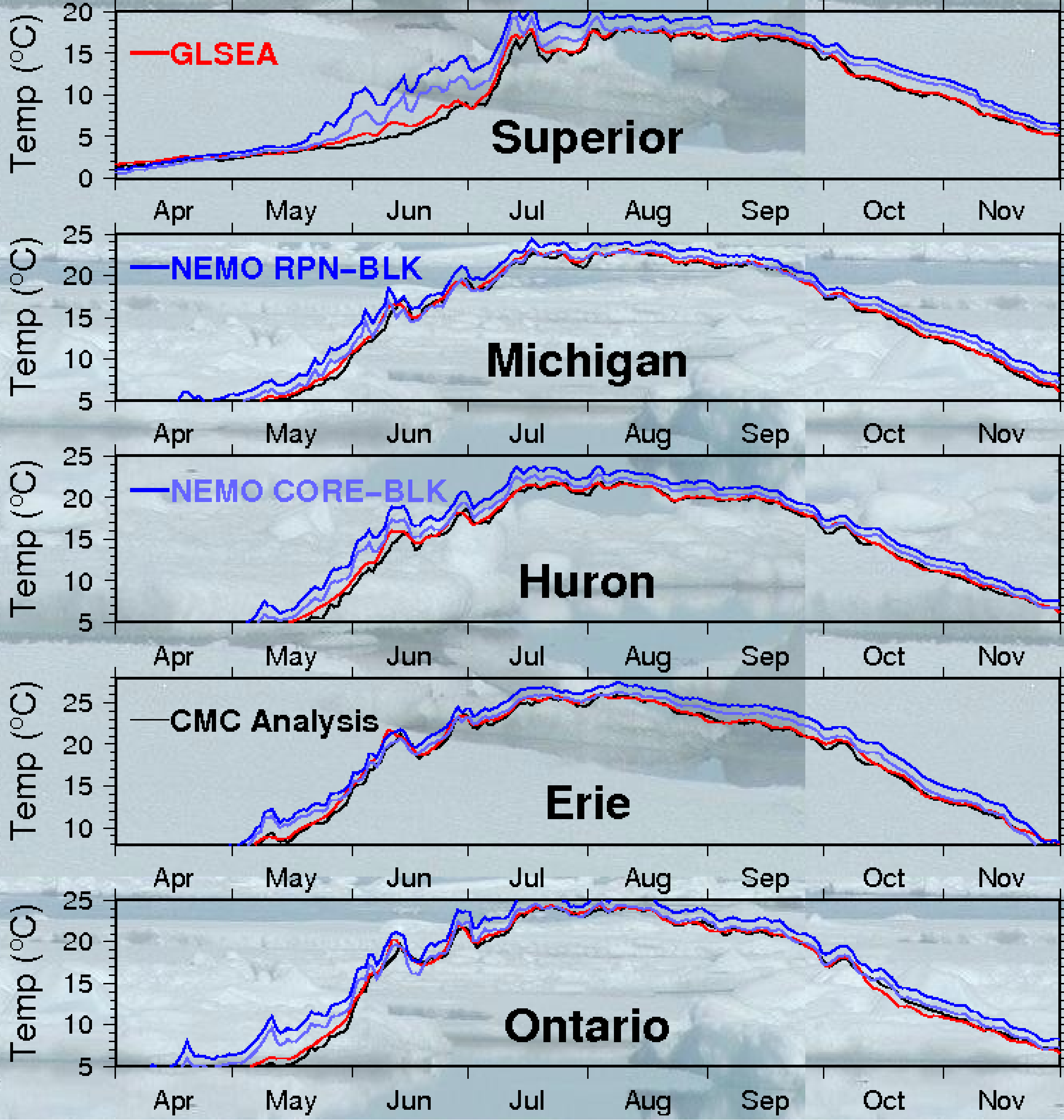
The cumulated evaporation from MESH and NEMO indicates that NEMO evaporation agrees well in Ontario, Michigan and Huron but less elsewhere



Comparison of lake-averaged temperature timeseries for GLSEA, CMC analysis, NEMO with CORE or fluxsuf bulk formula:

NEMO with CORE bulk has a bit of a positive bias, but with fluxsurf, the bias can increased to 2 degC.

Question: why GLSEA and CMC analysis disagree in spring in Lake Superior?



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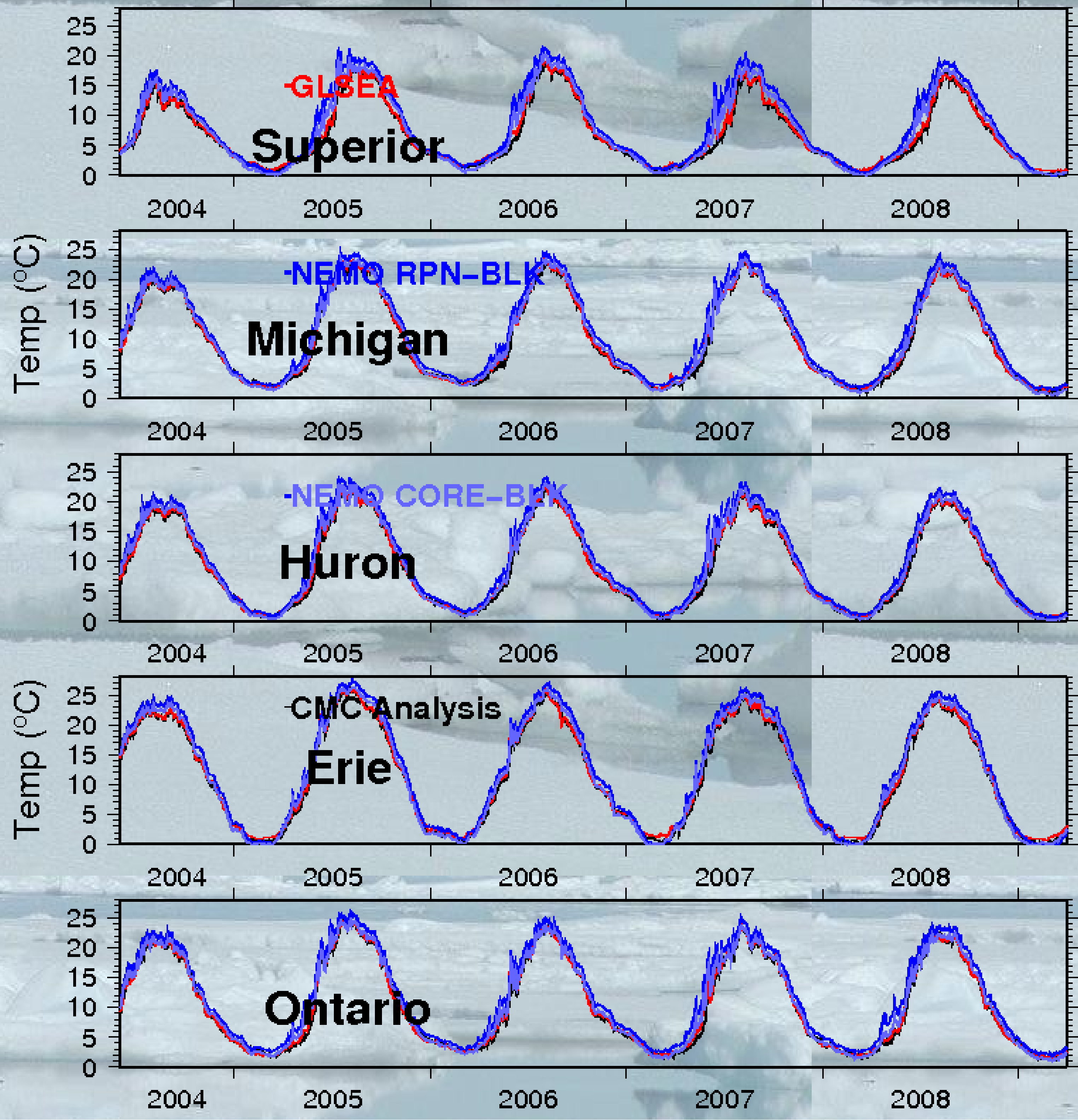
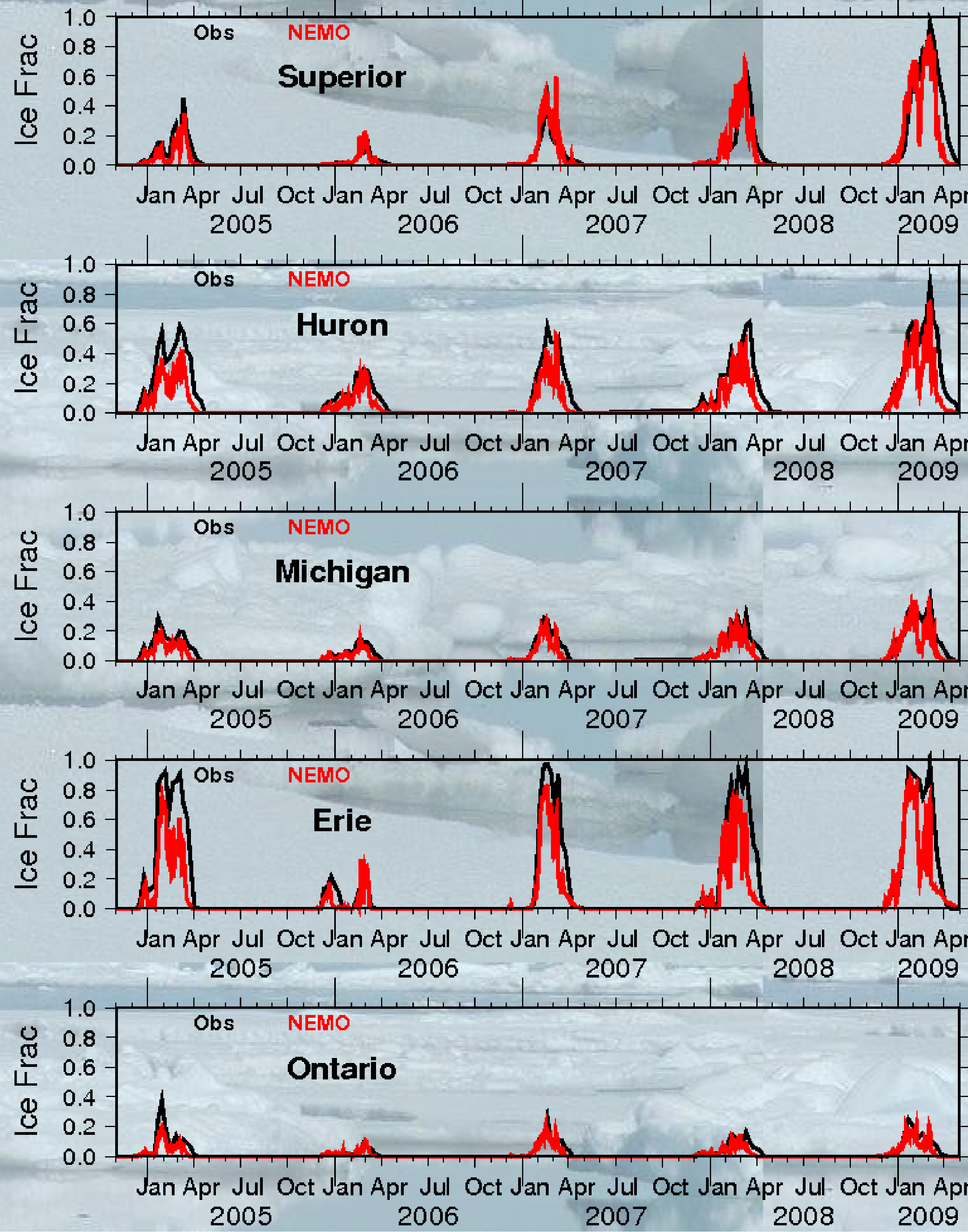


NEMO-CORE-BLK

Ice Season 2004-2009

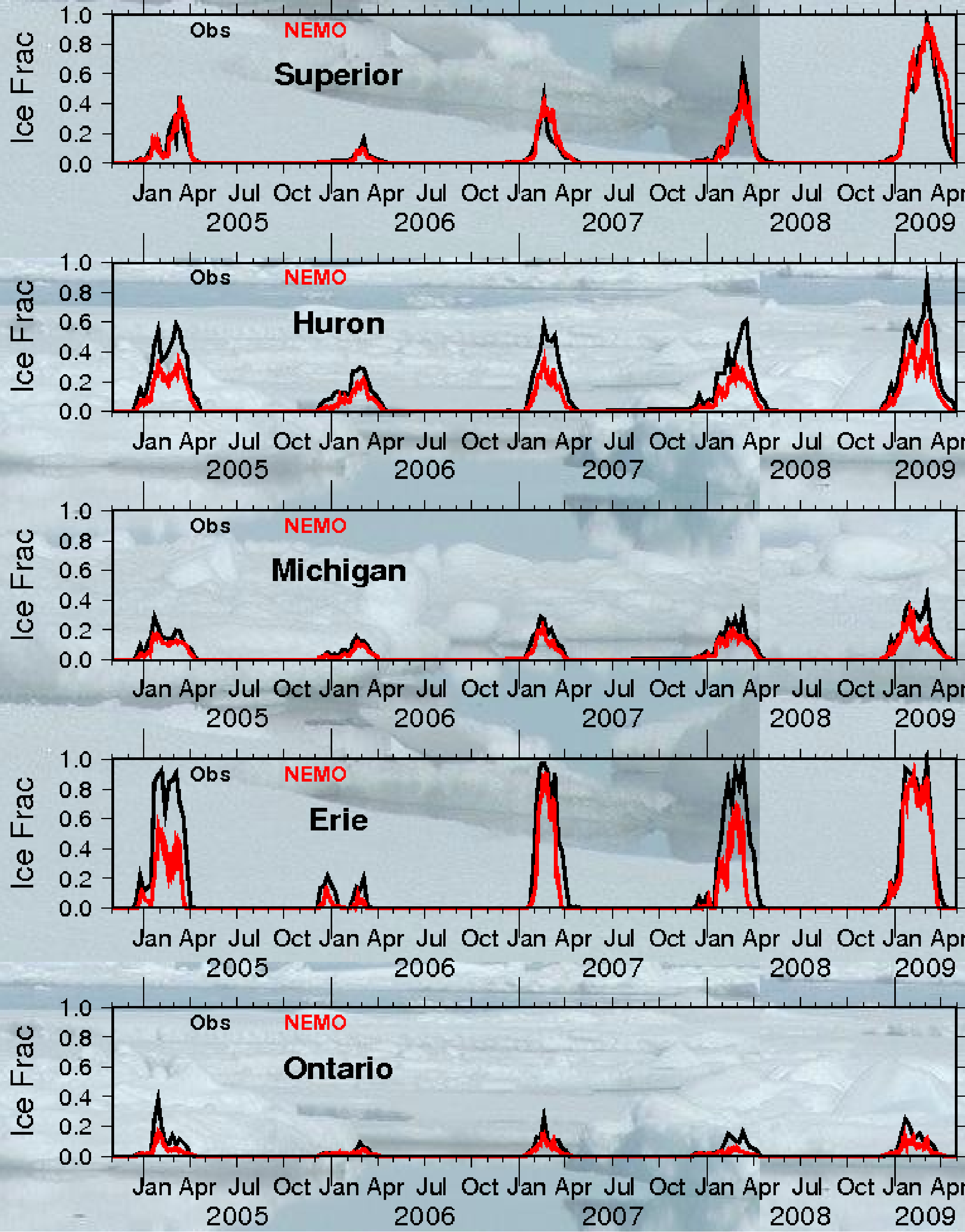
Results not as nice, but still reasonable



NEMO-RPN-BLK

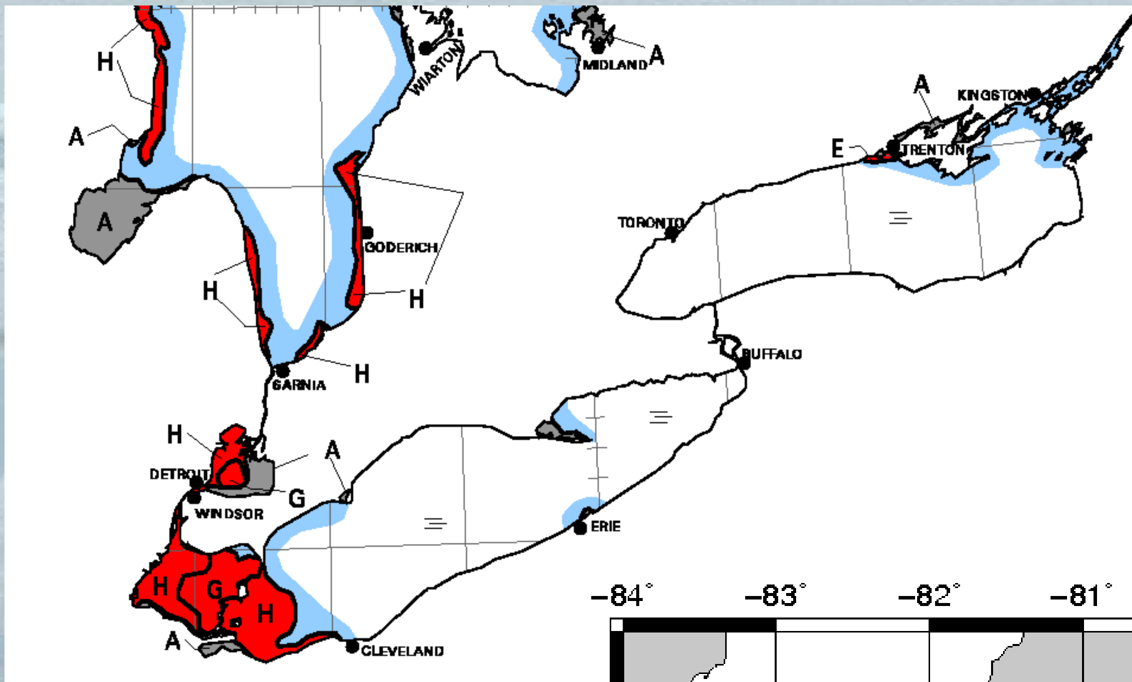
Ice Season 2004-2009

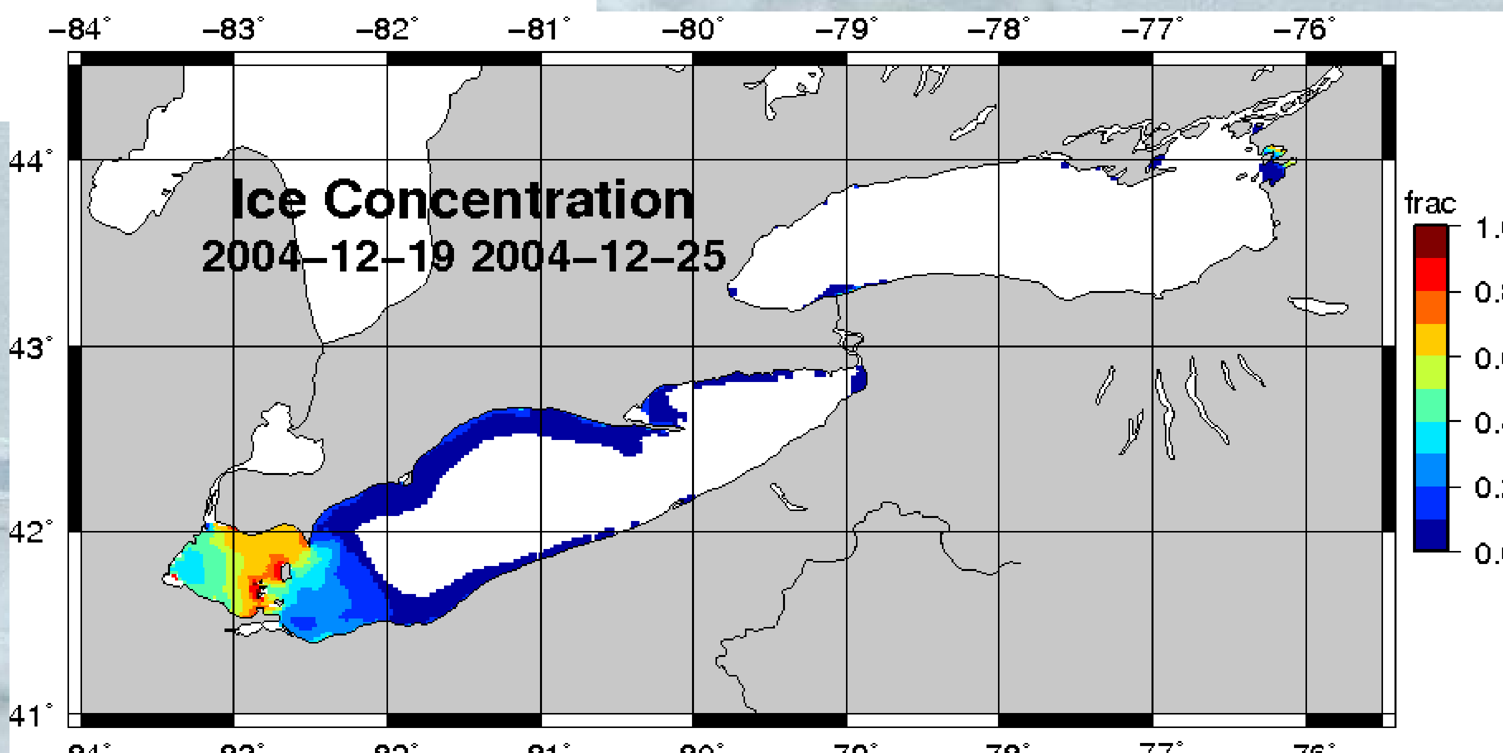
NEMO does a fair job at reproducing the mean ice concentration of each lake, even though Huron and Erie are slightly underestimated



Week 2004-12-27

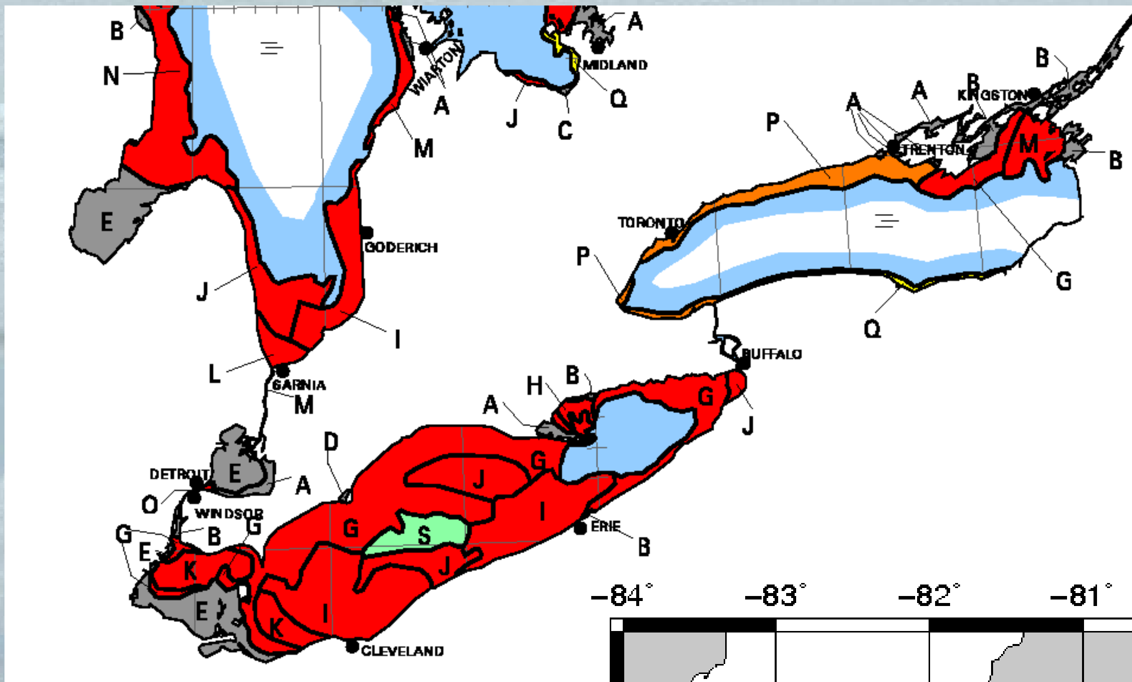
Ice Season 2004-2005

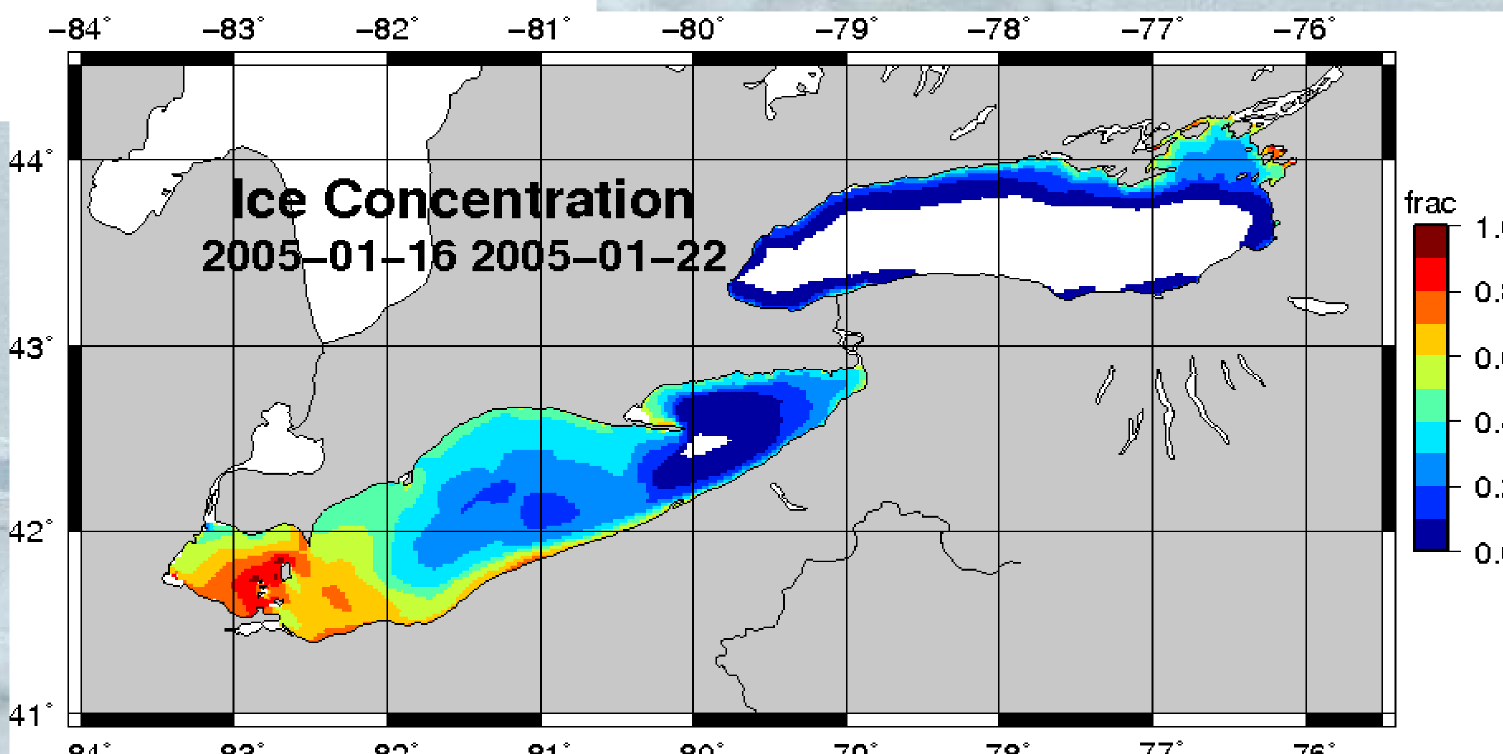




Ice Season 2004-2005

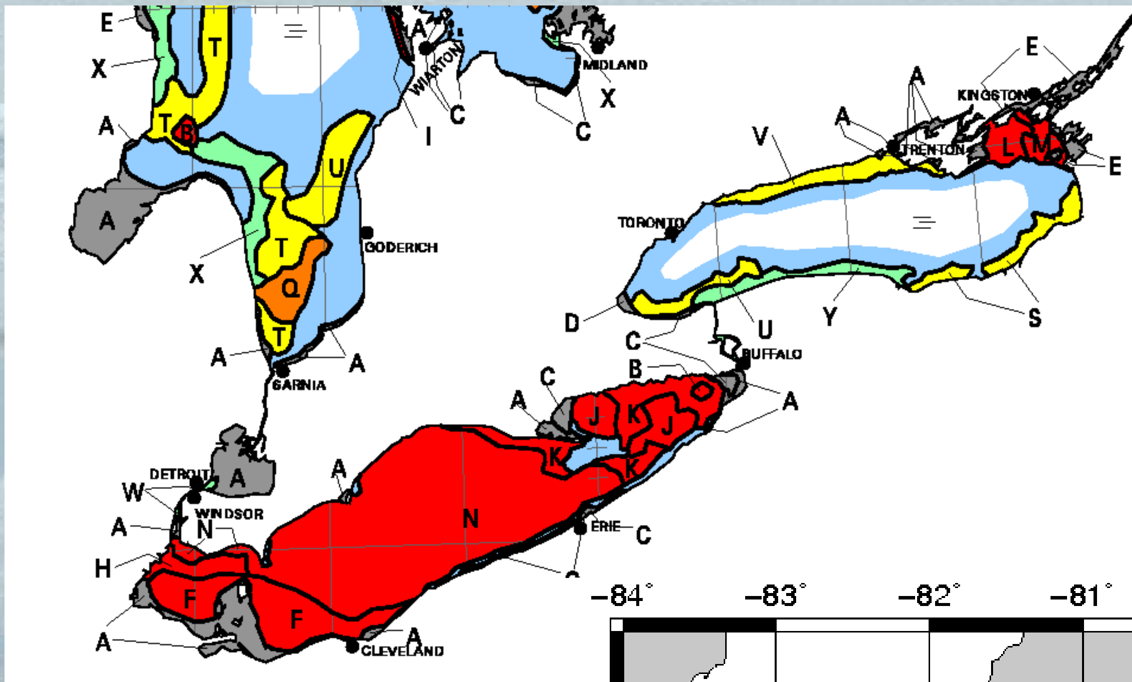
Week 2005-01-24

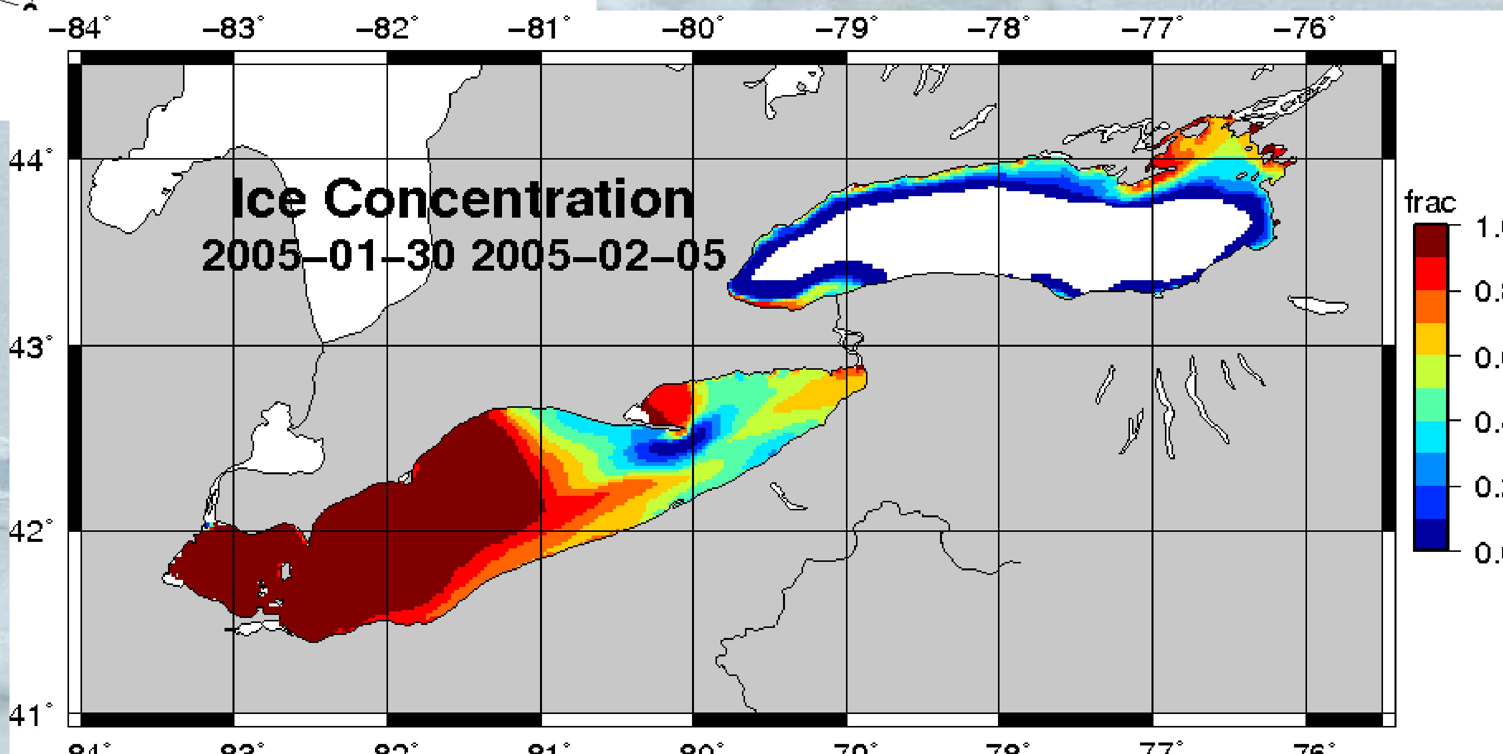




Ice Season 2004-2005

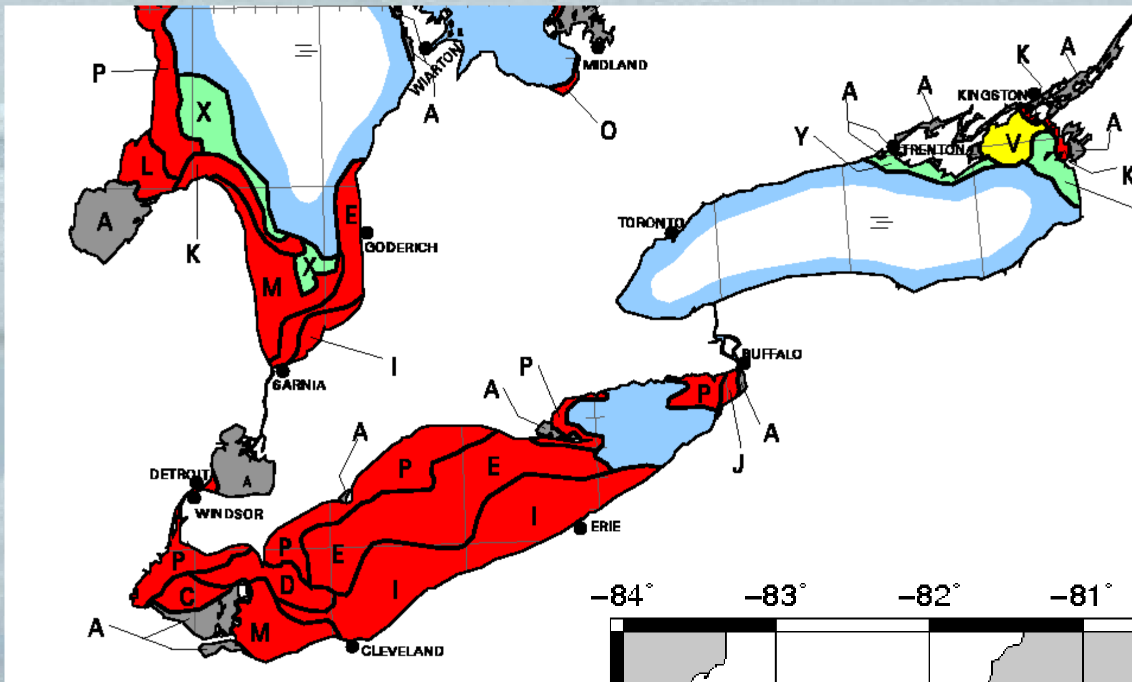
Week 2005-02-07

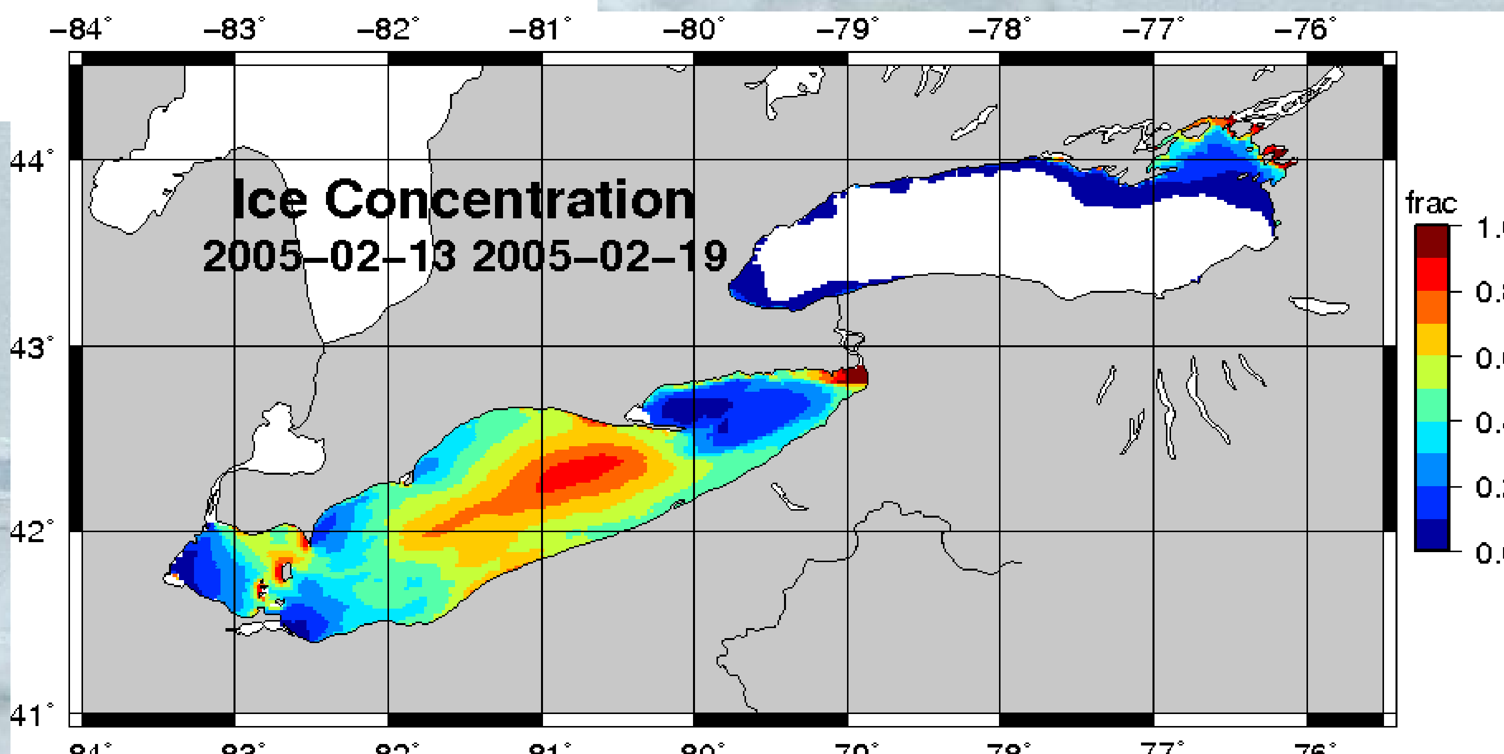




Week 2005-02-21

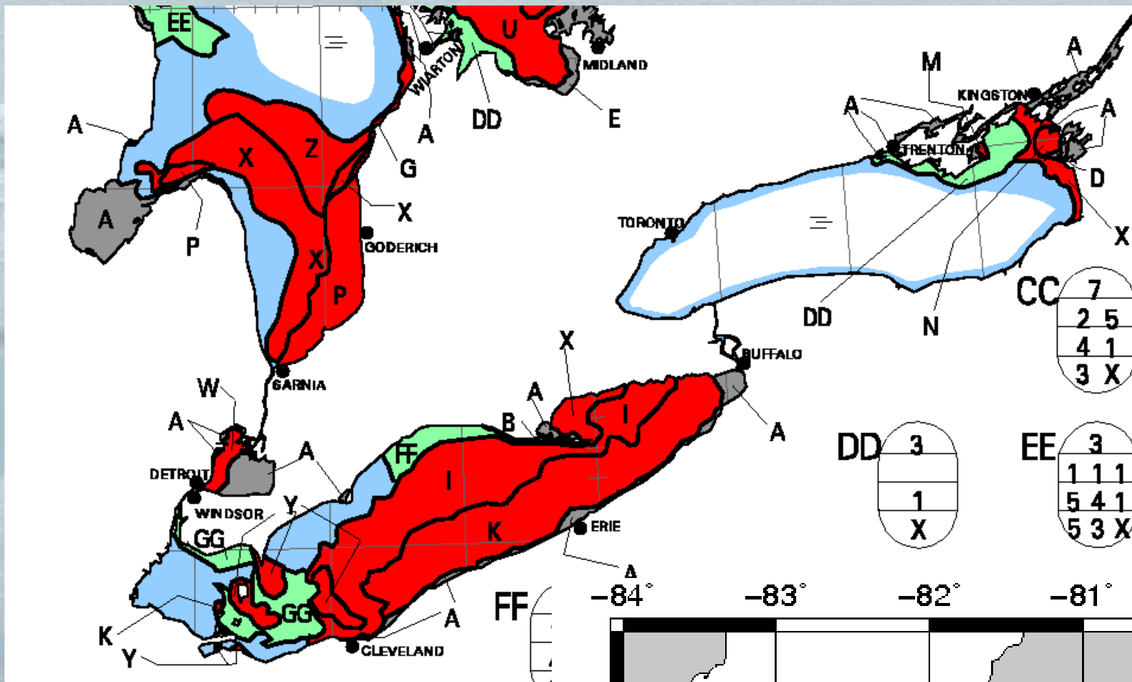
Ice Season 2004-2005

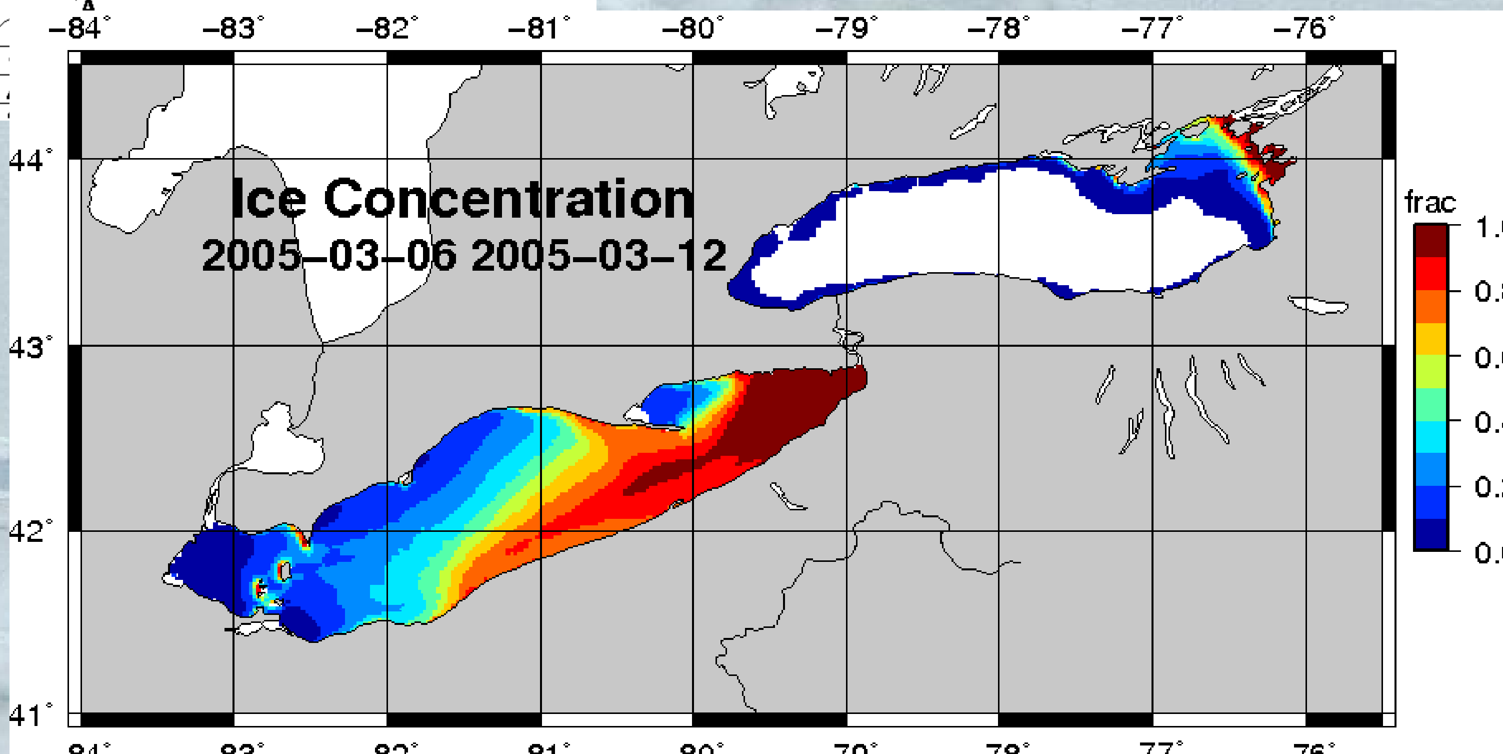




Ice Season 2004-2005

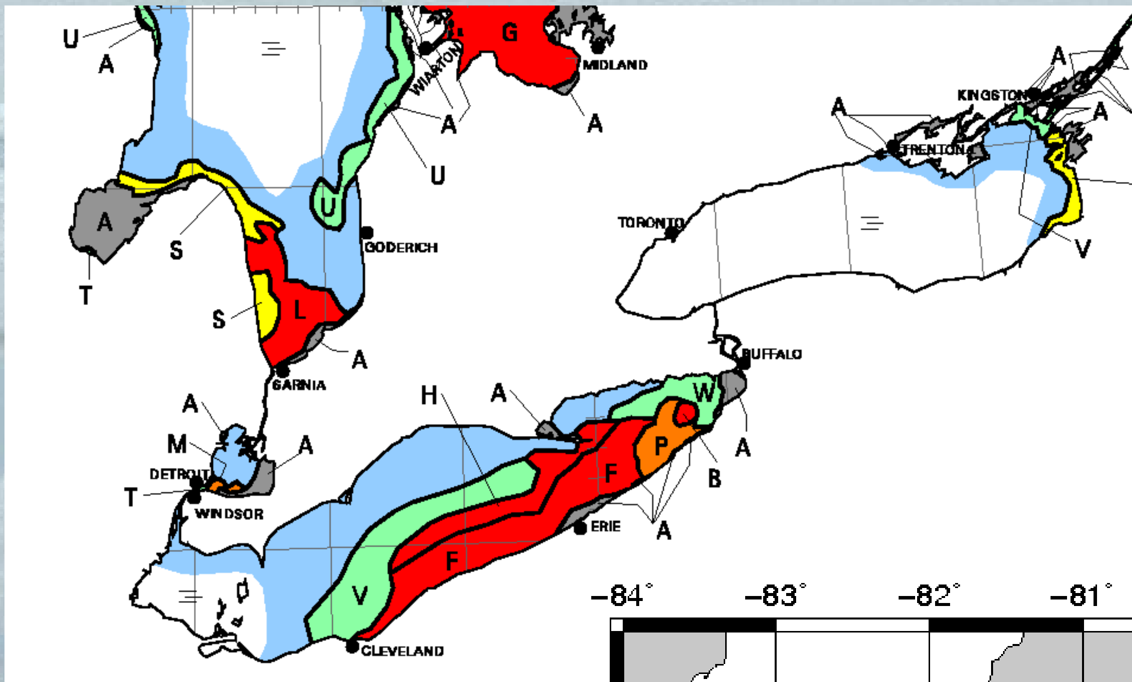
Week 2005-03-14

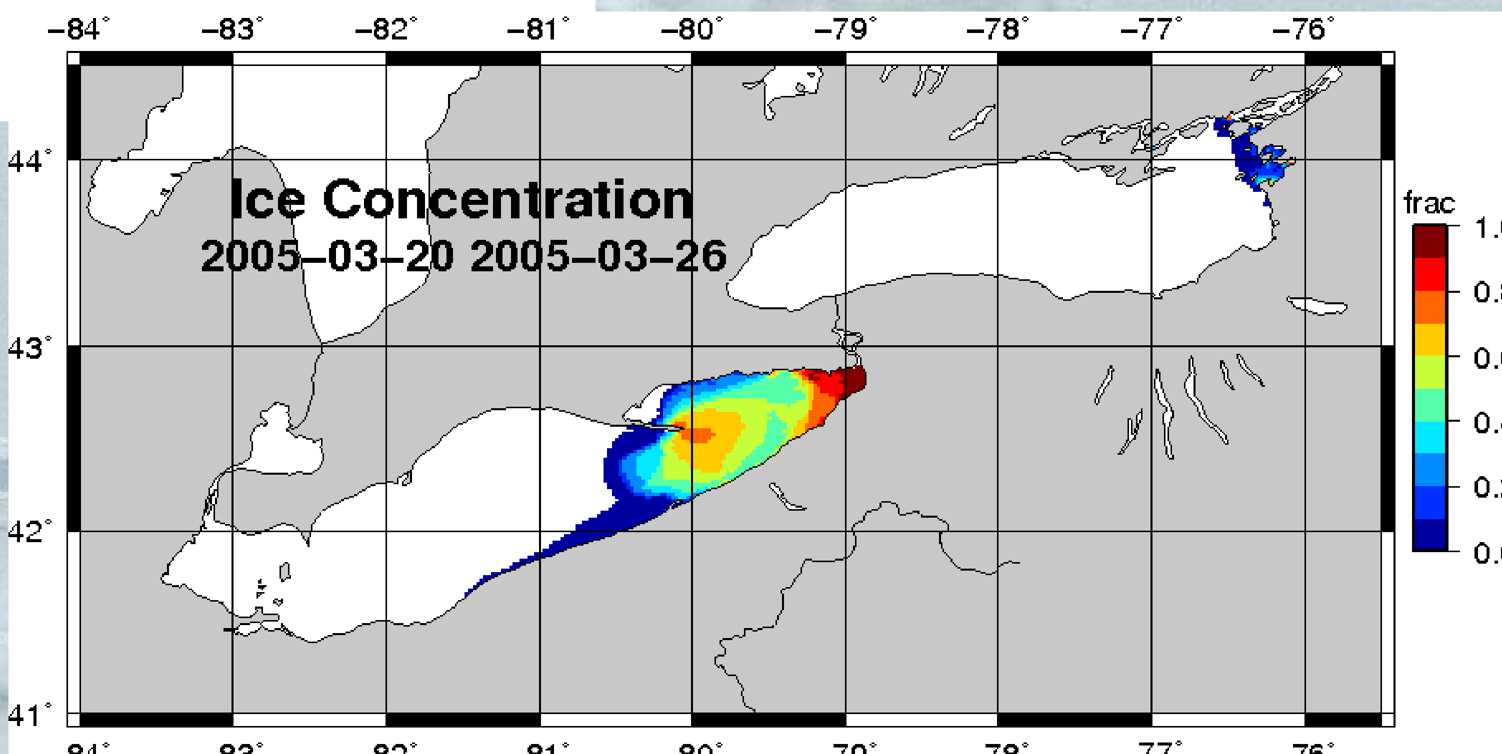




Week 2005-03-28

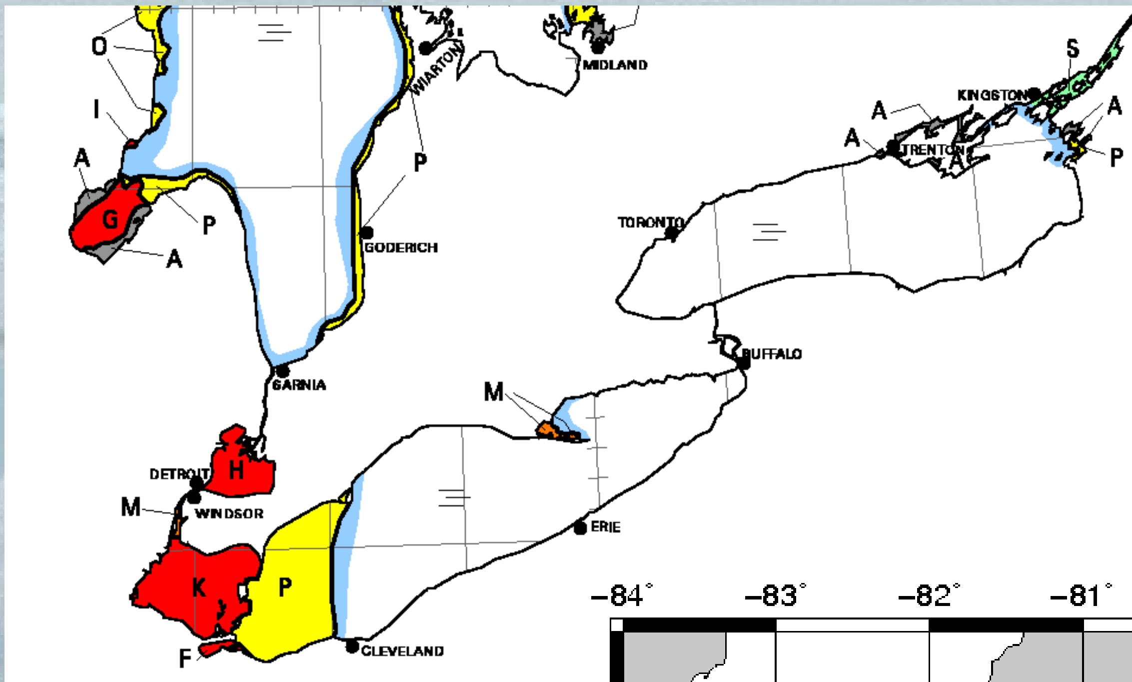
Ice Season 2004-2005

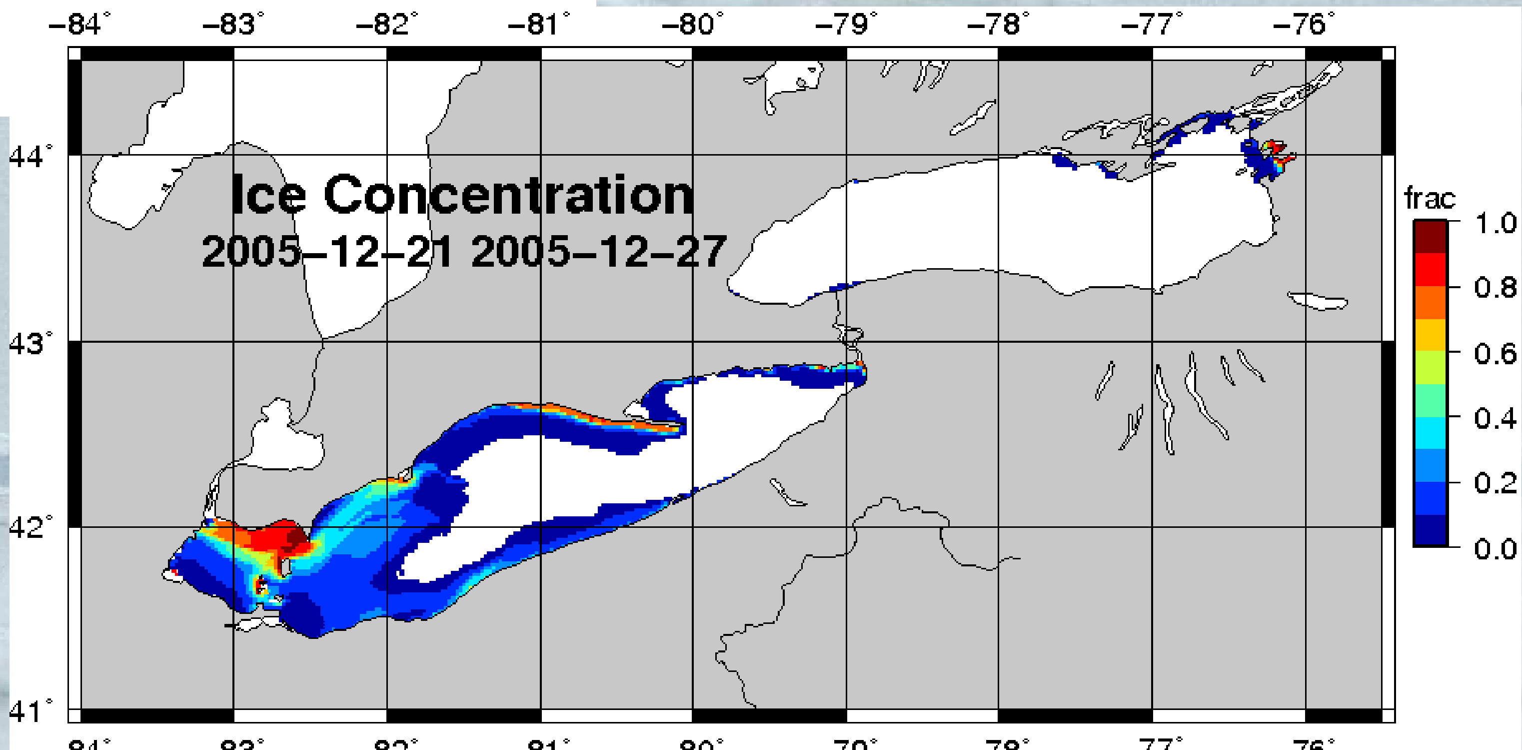




Ice Season 2005-2006

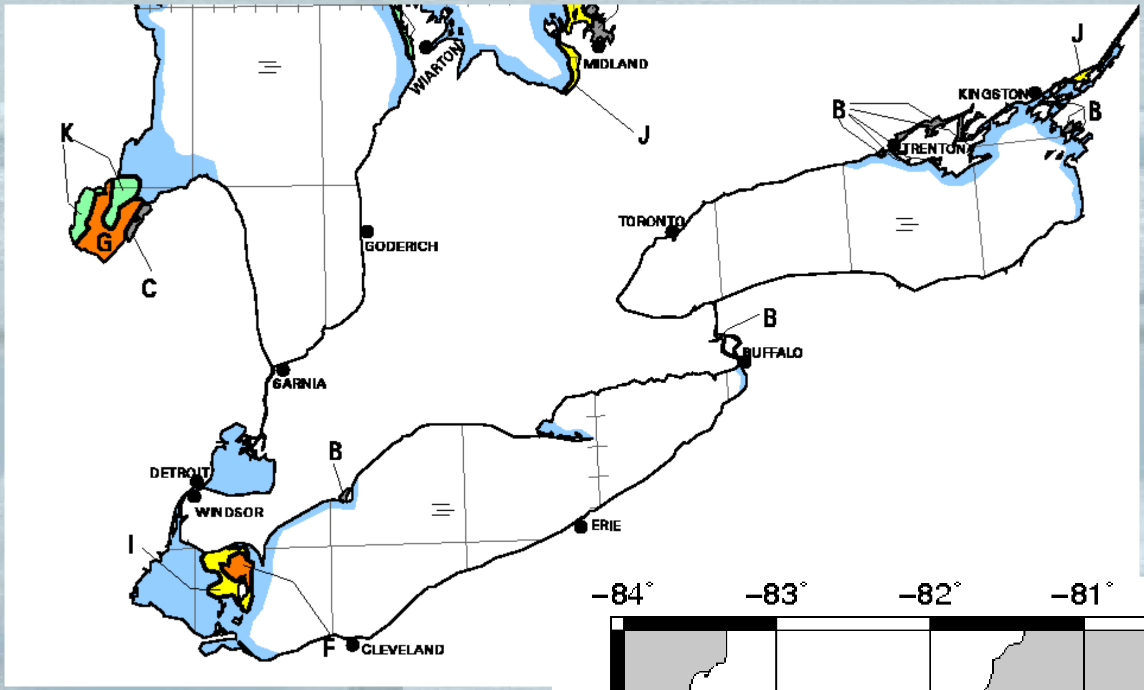
Week 2005-12-26

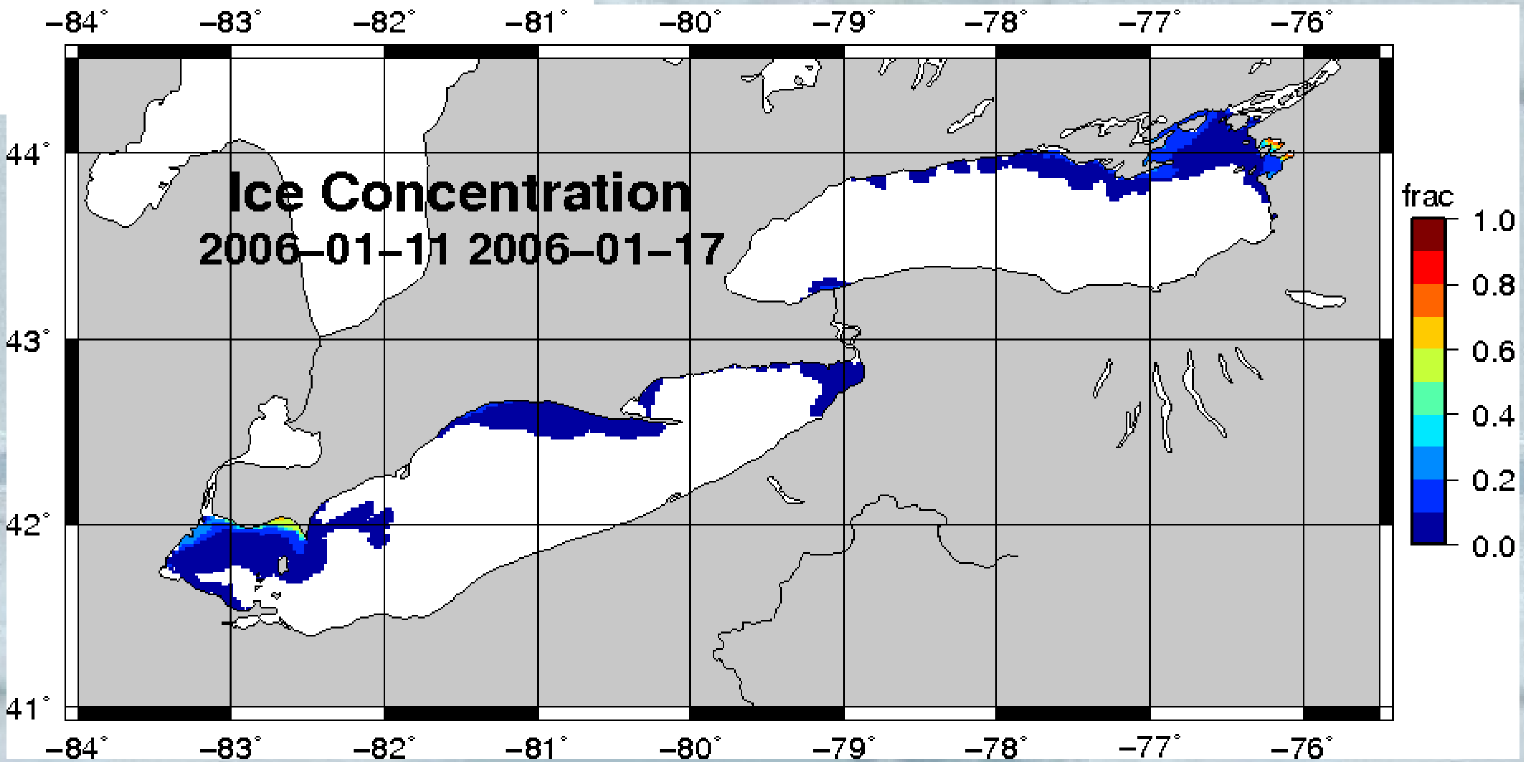




Ice Season 2005-2006

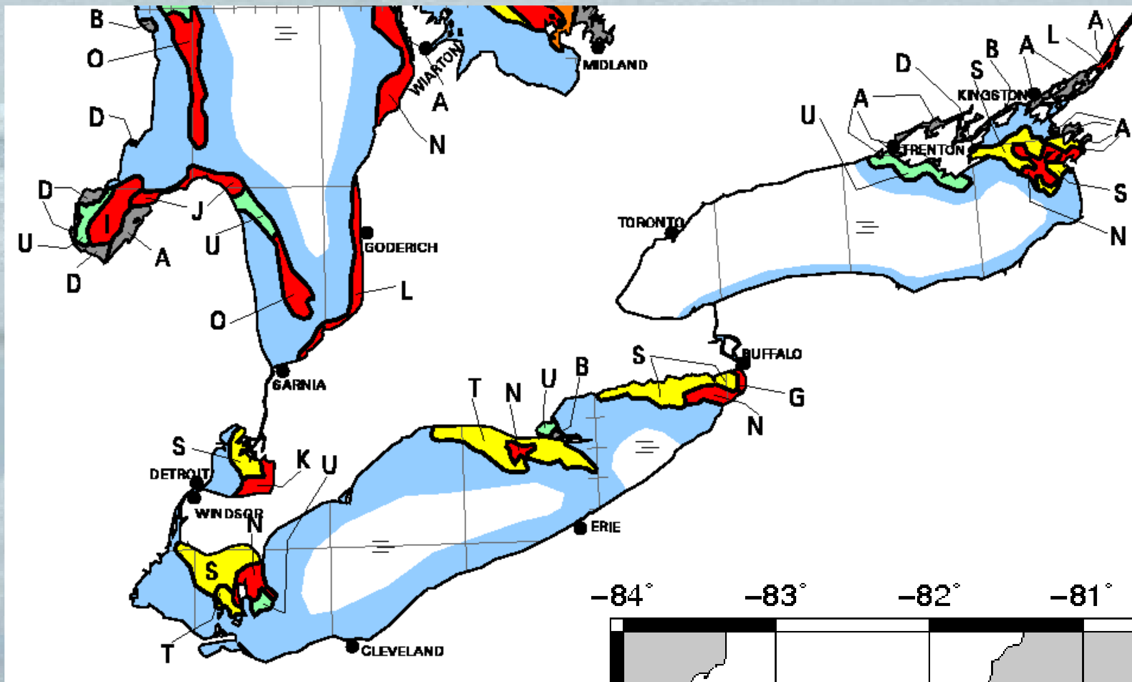
Week 2006-01-16

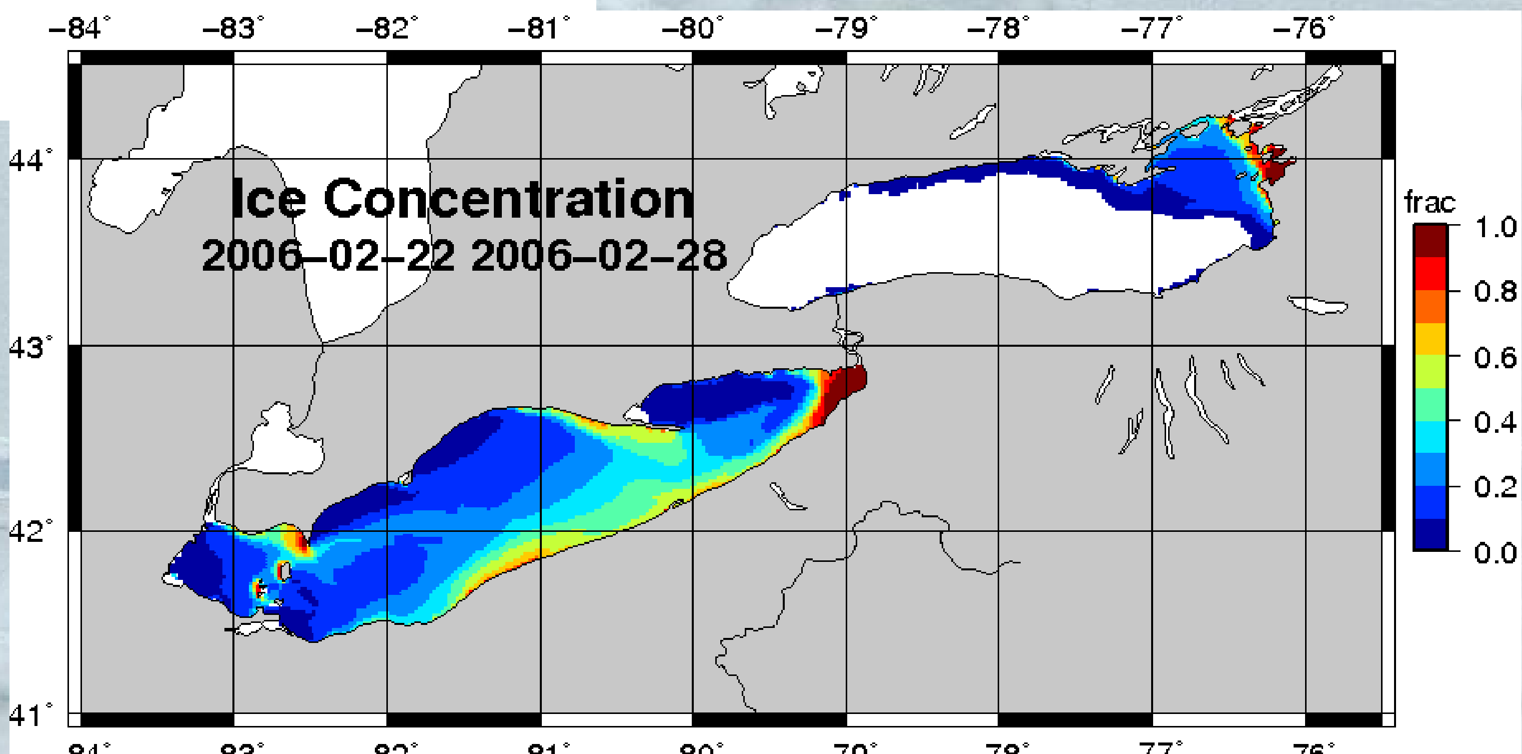




Ice Season 2005-2006

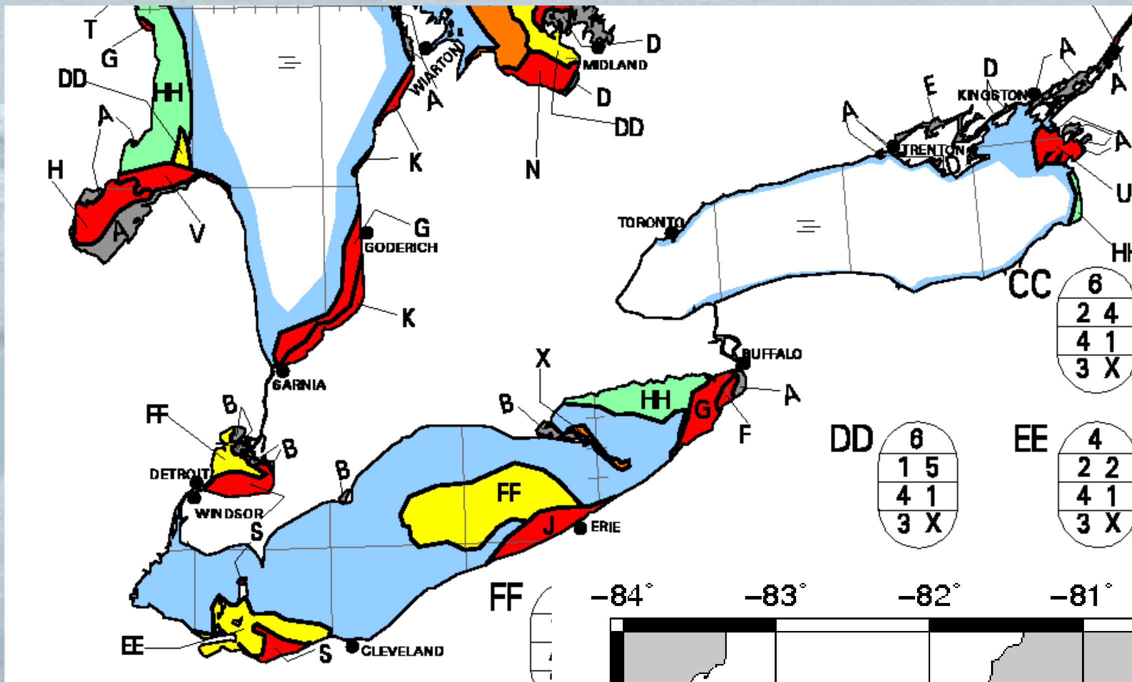
Week 2006-02-27

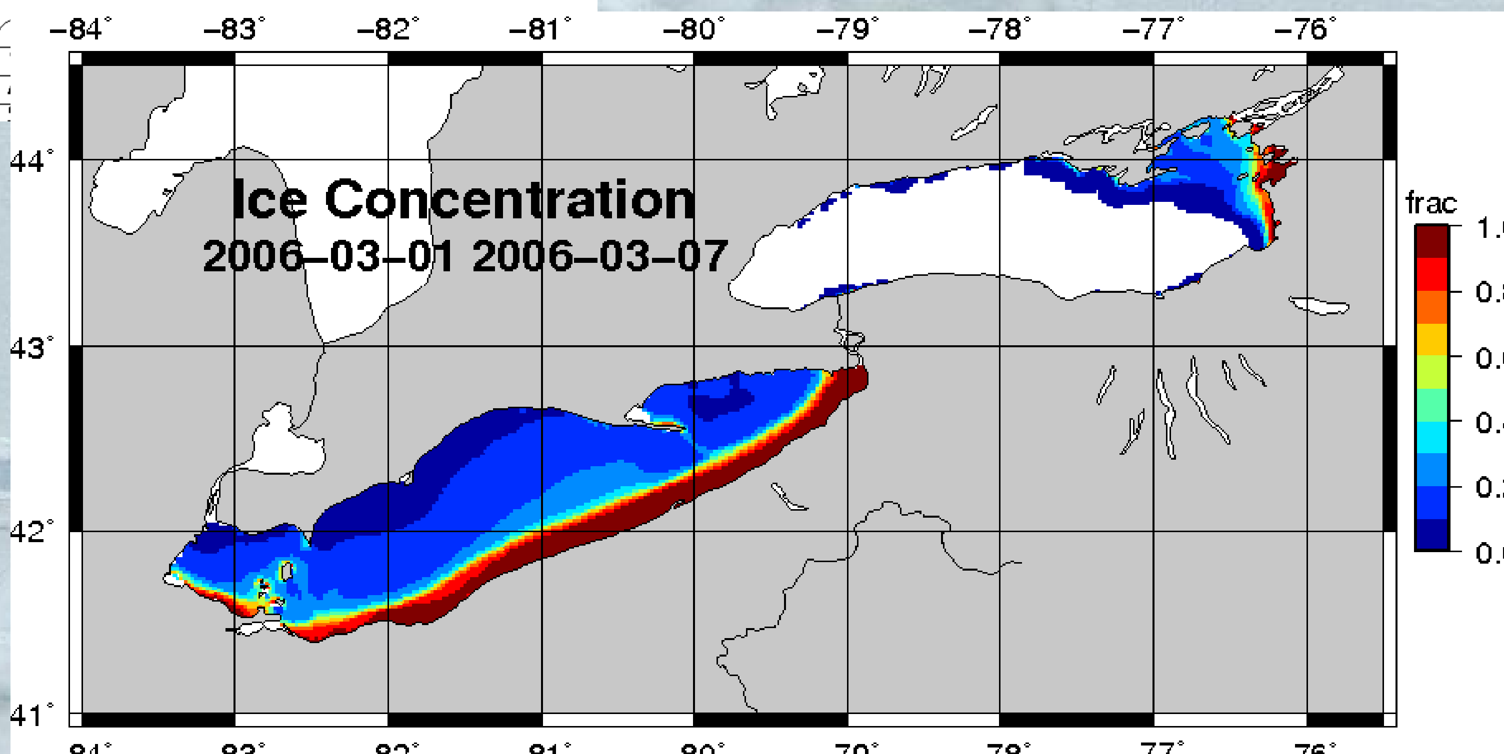




Ice Season 2005-2006

Week 2006-03-06

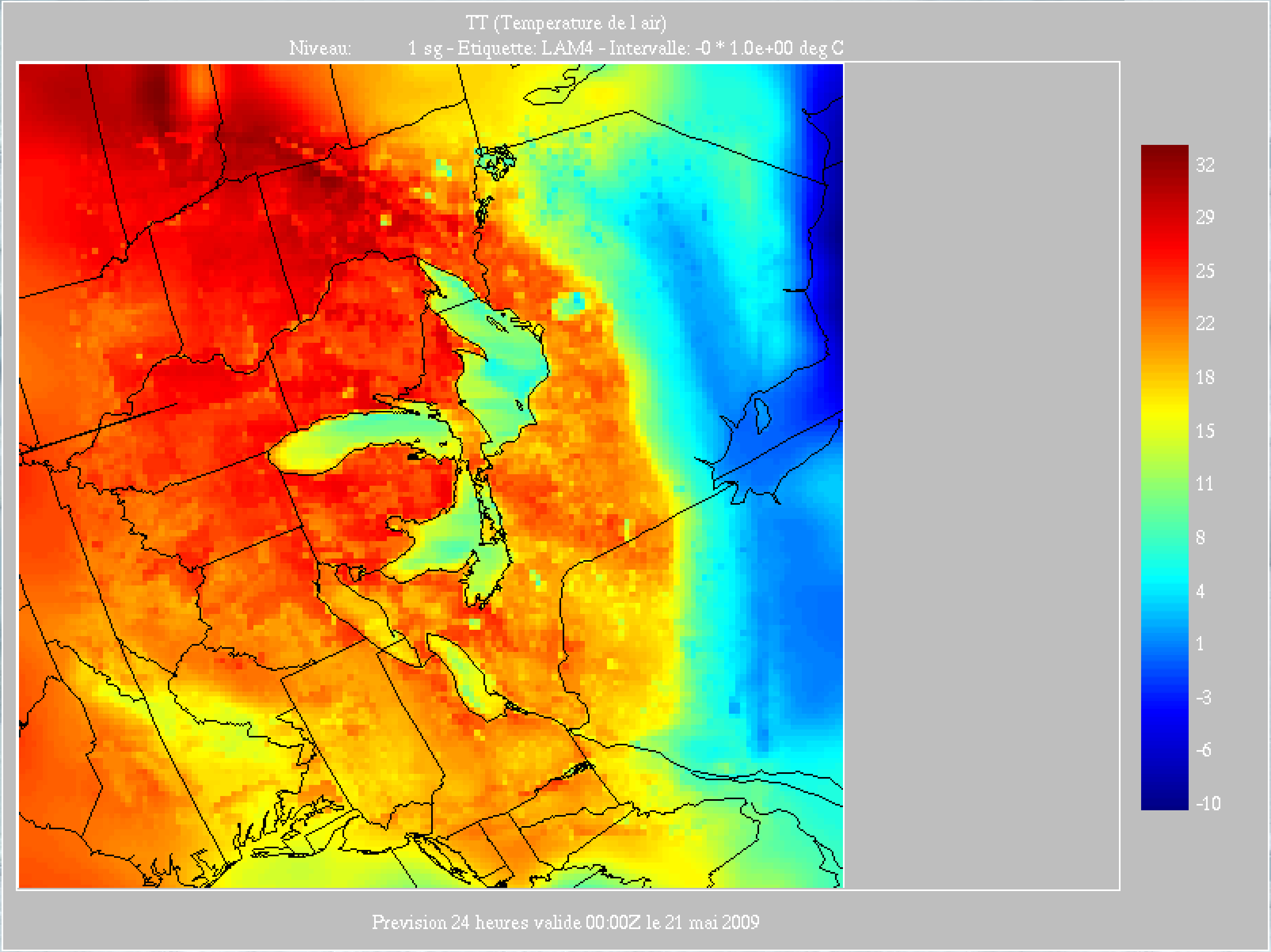




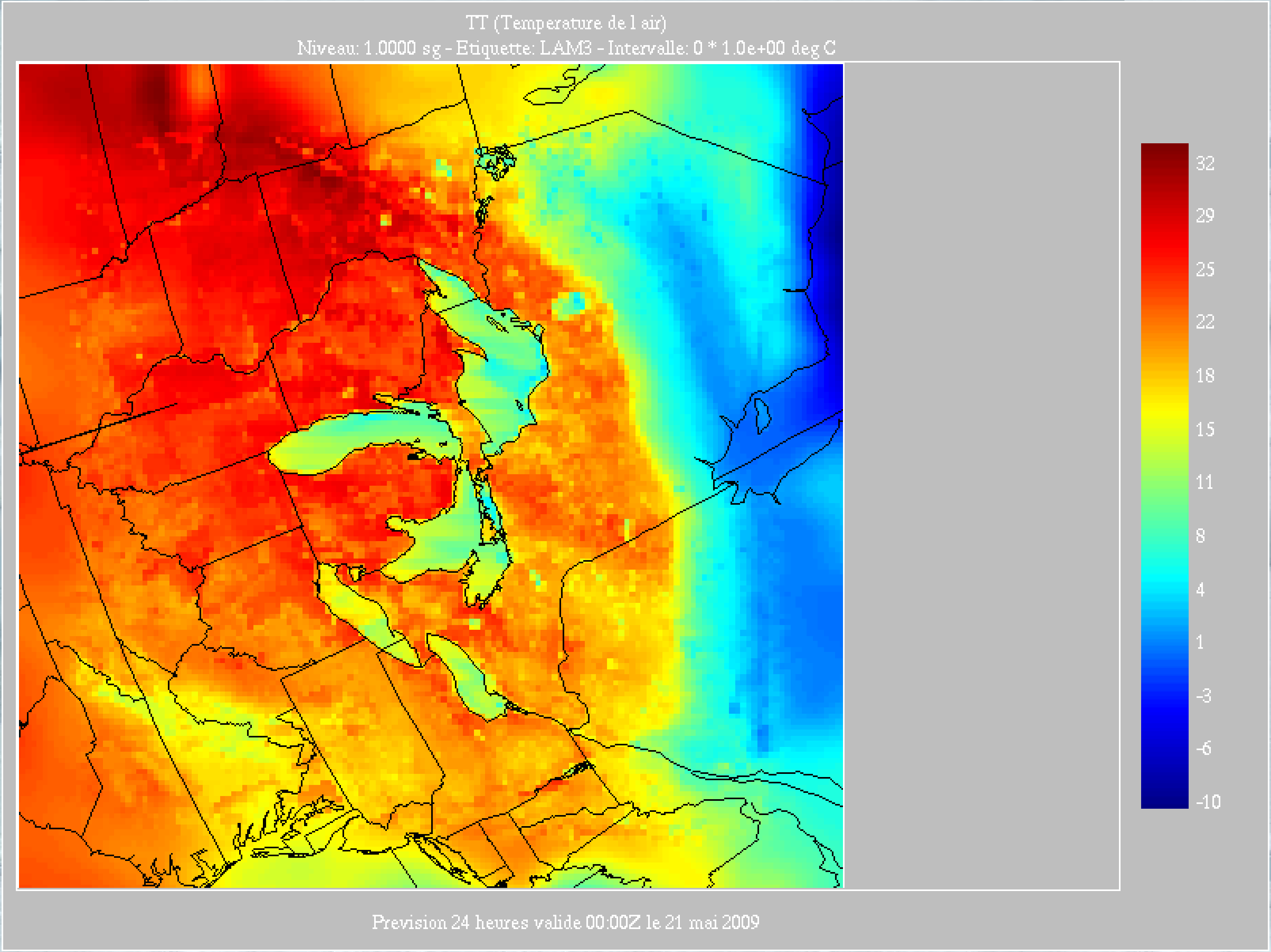
Coupling:

- GEM LAM 15km collocated with regional GEM.
- Grid of 150x150
- Same timestep for both models.

NEMO-GEM coupling after 24 hours



GEM driven by fixed analysis after 24 hours

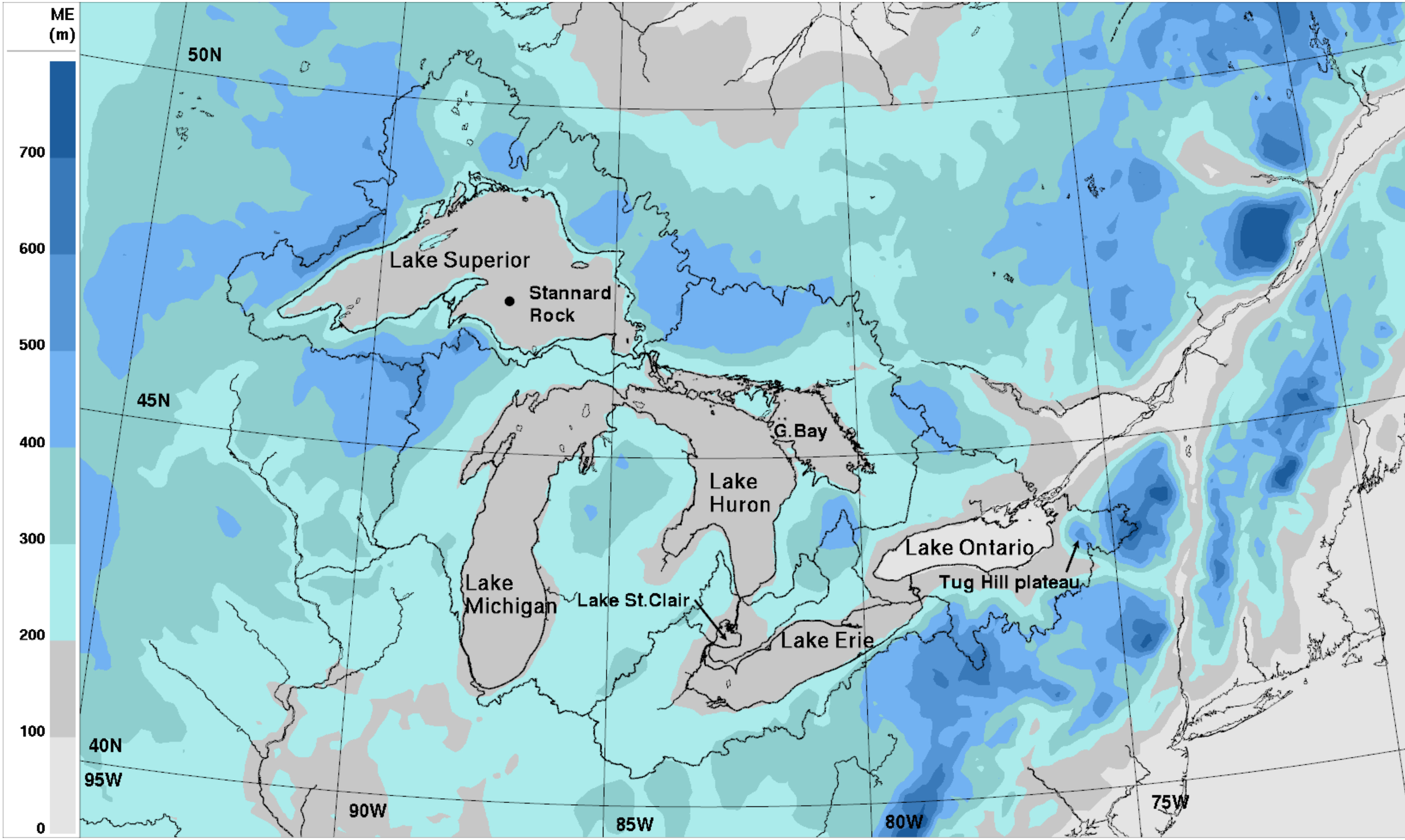


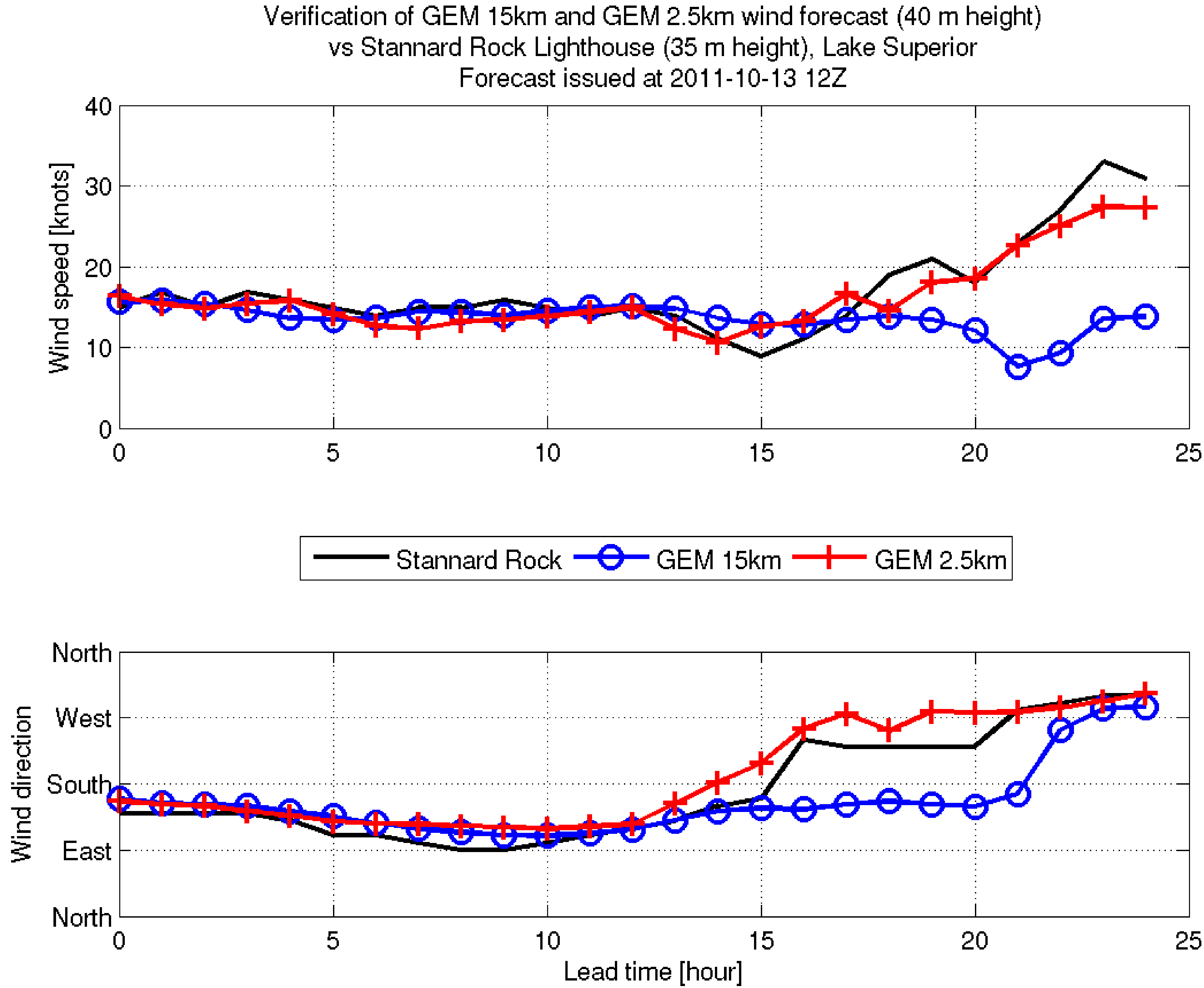
Data assimilation:

- Global CMC SST analysis too coarse but could be used to adjust the lake-averaged temperature in the mixed layer
- sea ice concentration can be inserted
- lake level can be inserted

A bright future: GEM with even more resolution:

Example of GEM2.5 in Lake Superior for one case

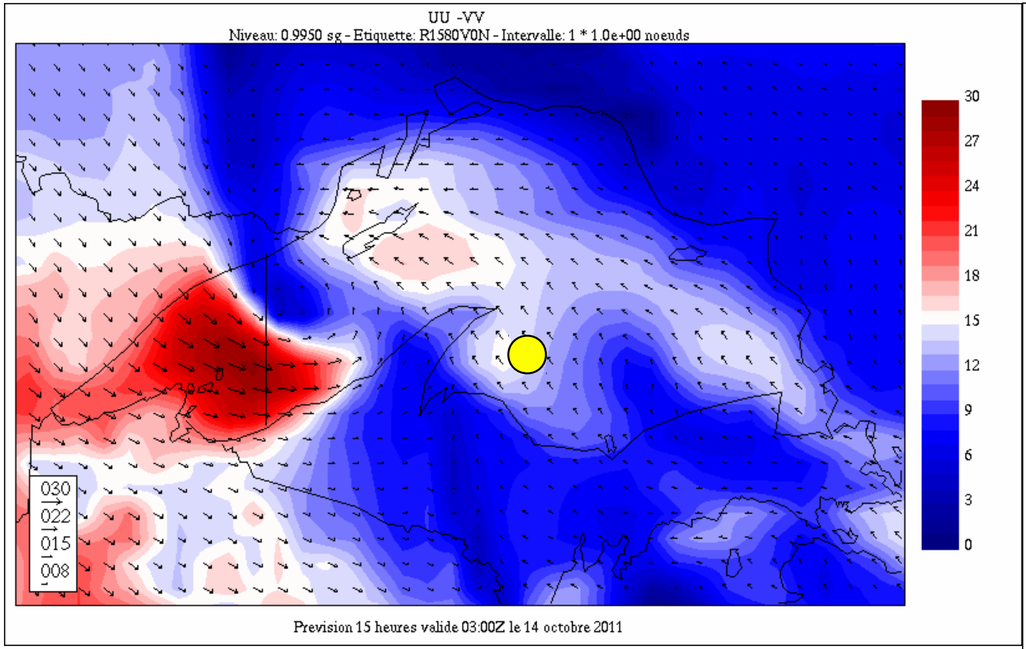

ME
(m)
700
600
500
400
300
200
100
0
50N
45N
40N
95W
90W
85W
80W
75W
Lake Superior
Stannard
Rock
G. Bay
Lake
Huron
Lake
Michigan
Lake St.Clair
Lake Erie
Lake Ontario
Tug Hill plateau



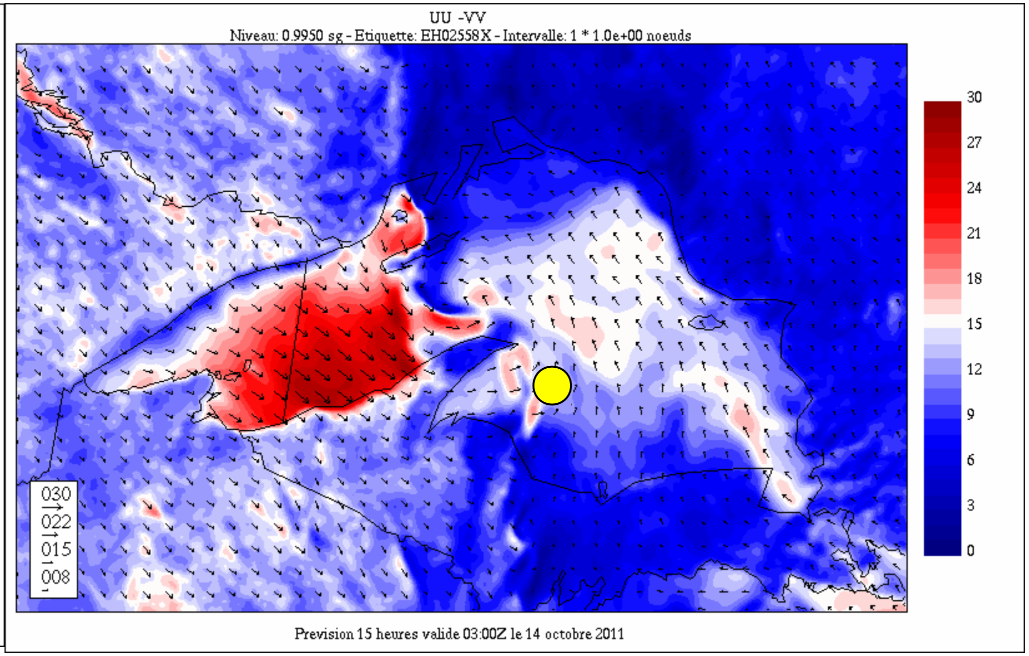
Verification of GEM 15km and GEM 2.5km wind forecast (40 m height)
vs Stannard Rock Lighthouse (35 m height), Lake Superior
Forecast issued at 2011-10-13 12Z
Wind speed [knots]
0
10
20
30
40
0
5
10
15
20
25
Stannard Rock
GEM 15km
GEM 2.5km
Wind direction
North
West
South
East
North
Lead time [hour]

Wind field as seen by 15km and 2.5km GEM model as the frontal system is passing over Stannard Rock

GEM 15 km



GEM 2.5 km



Conclusions:

- NEMO has been validated in an intercomparison project with positive results
- Main remaining problem: surface mixed layer physics: fetch issue over lake? Lack of salinity? Lack of mixing by internal waves? => impact SST and heat fluxes => lake level
- Coupling under progress, hindcast over 2004-2009 expected
- Coupling to St-Lawrence FE model to come, Lake Champlain, water quality?
- Possible coupling with 2.5 km GEM LAM?