Parameterization of Lakes in NWP and Climate Modelling
18-20 September 2008, St. Petersburg (Zelenogorsk), Russia

Lake and climate models; interactions in small and large lakes.

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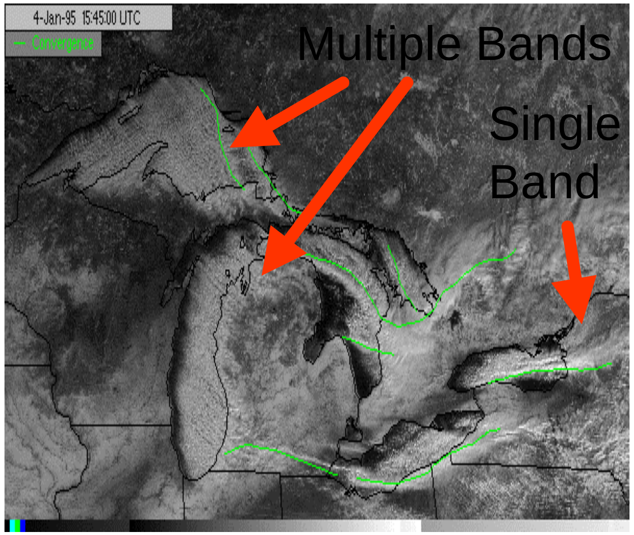
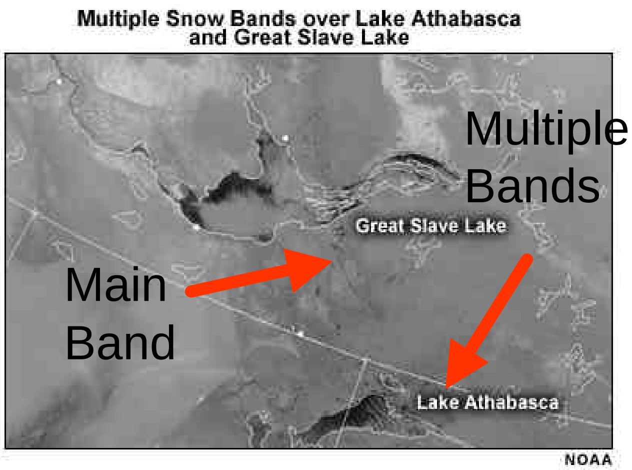
“Lakes significantly affect the structure of the atmospheric boundary layer and therefore the surface fluxes of heat, water vapour and momentum.”



e.g. Lake effect snow events, Intensification of Lee-Cyclogenisis by Lakes
Lake effect precipitation, Destabilization of the boundary layer (BL) by Lakes

Laurentian Great Lakes

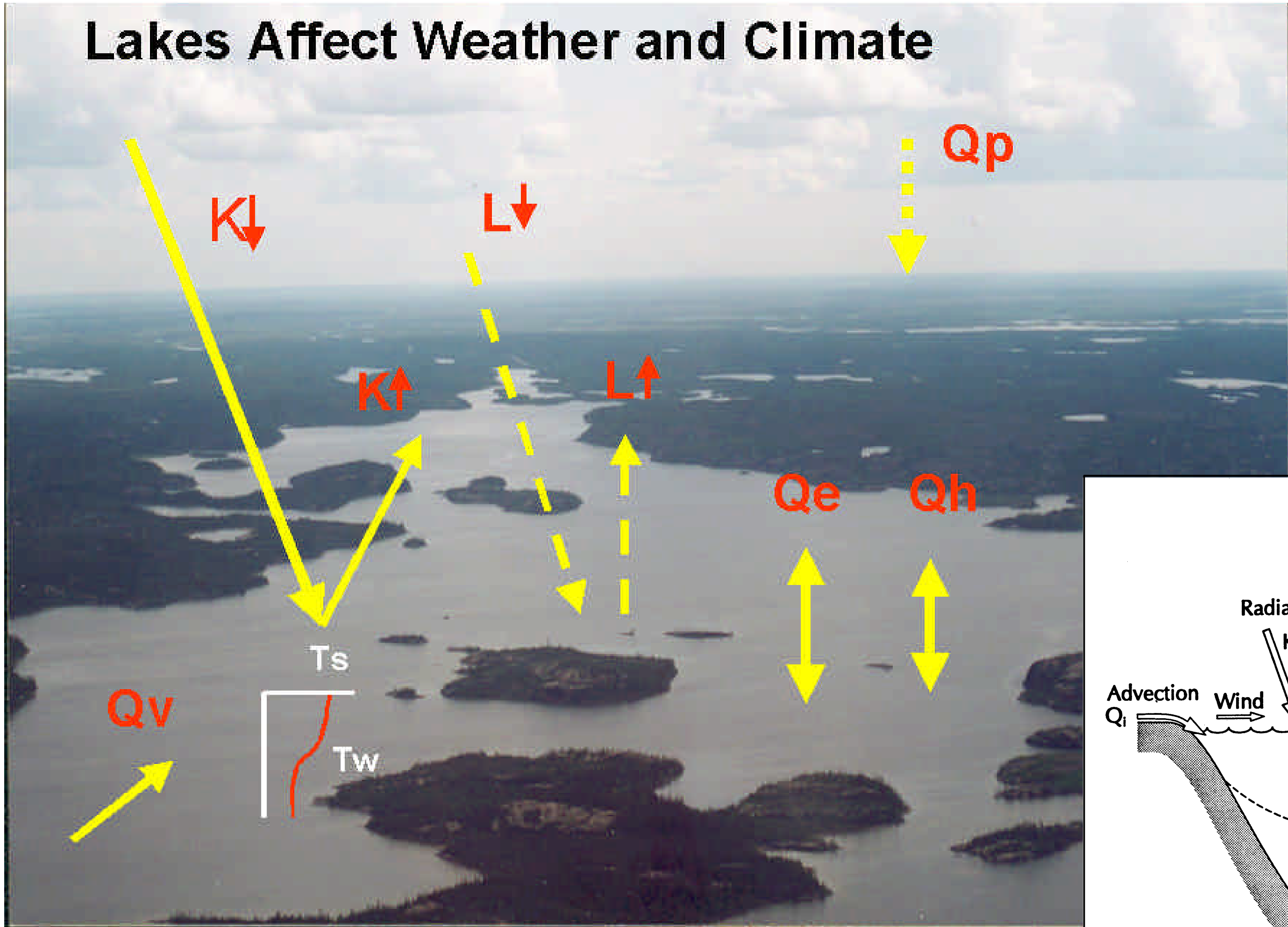
- Lake Superior
- Lake Michigan
- Lake Ontario

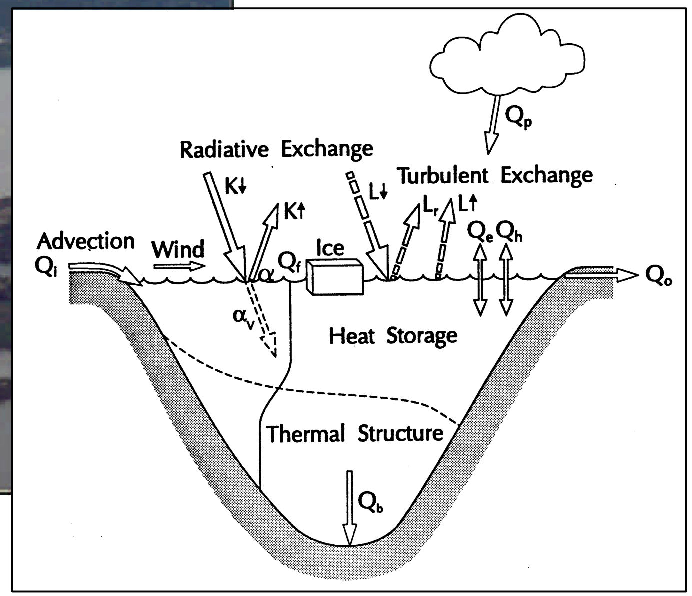


Mackenzie River Basin

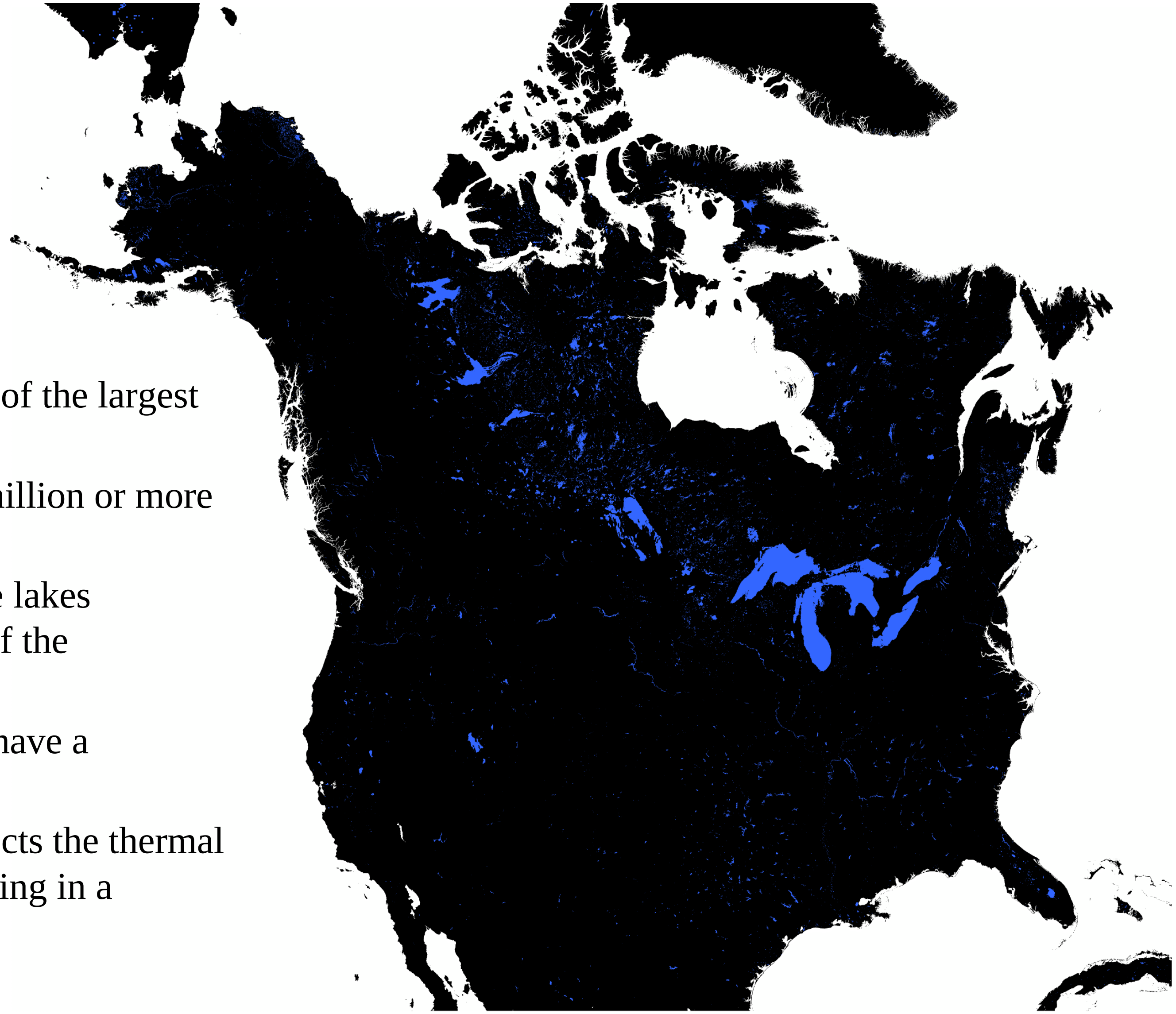
- Great Slave Lake
- Lake Athabasca

“In numerical weather prediction and climate models, the effect of lakes should be adequately parameterised.”





Lakes…With so many, how to neglect?

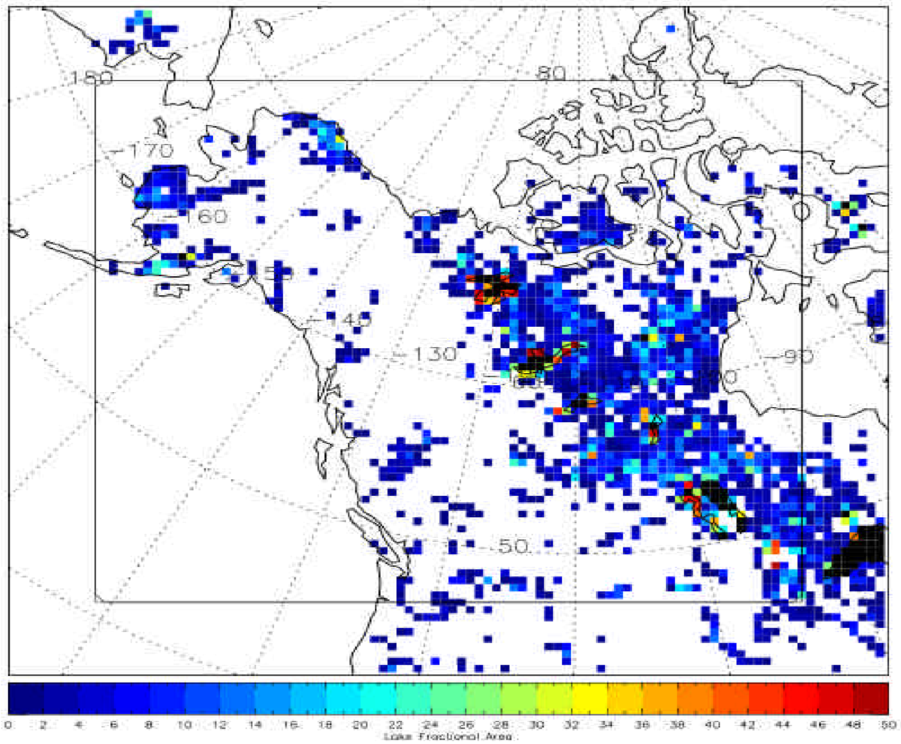


- Canada is home of some of the largest lakes in the world.
- Also contains around a million or more of small ones.
- It is recognized that large lakes influences the circulation of the atmosphere.
- A lot of small ones may have a noticeable effect as well.
- Atmospheric forcing affects the thermal structure of the lakes resulting in a complex interaction.

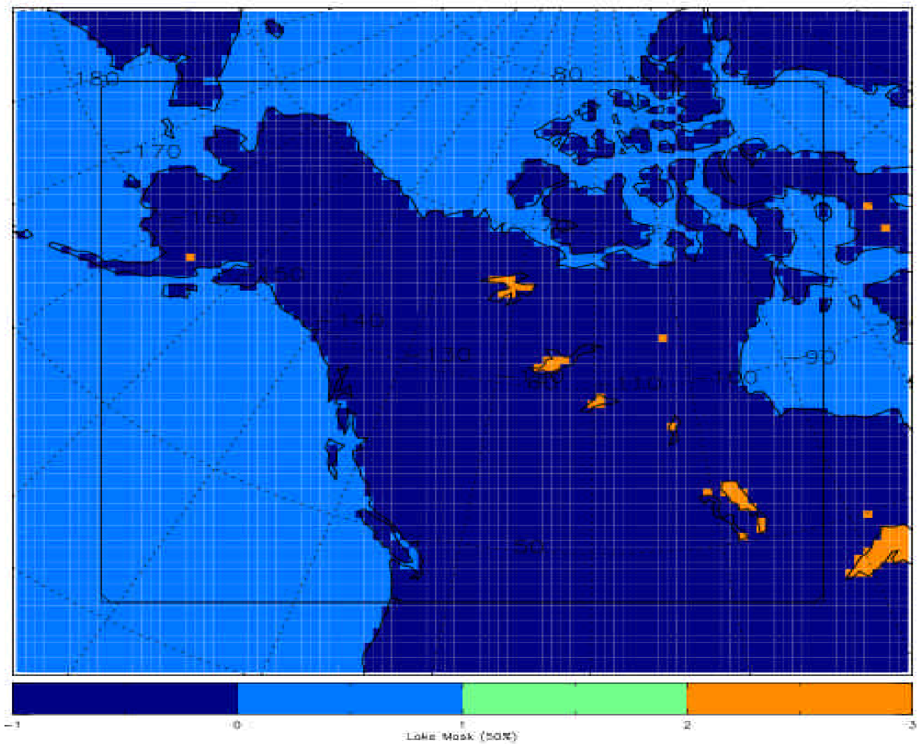
Image courtesy of Dr. Murray MacKay (Environment Canada)

“The problem becomes particularly pressing as the horizontal resolution of numerical models is refined.”

Small to medium lakes: assume uniform surface lake temperature = 1-2D reactor type of models.



Large lakes: spatial distribution of temperature within the lake = 3D models.



Images courtesy of Dr. Murray MacKay (Environment Canada)

Research Challenges

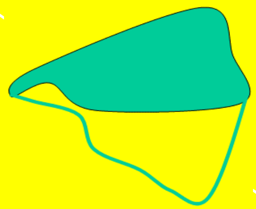
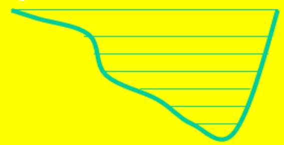
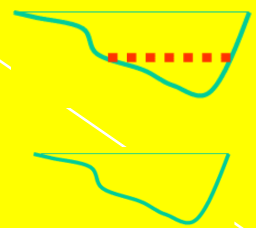
Technical Challenges

- Optimal lake model selection
- Classification of lakes
- Function and sensitivity of lake models
- Modelling of air-water interactions
- Efficient computational algorithms
- Effective coupling schemes
- Consistency between RCM and lake model fluxes

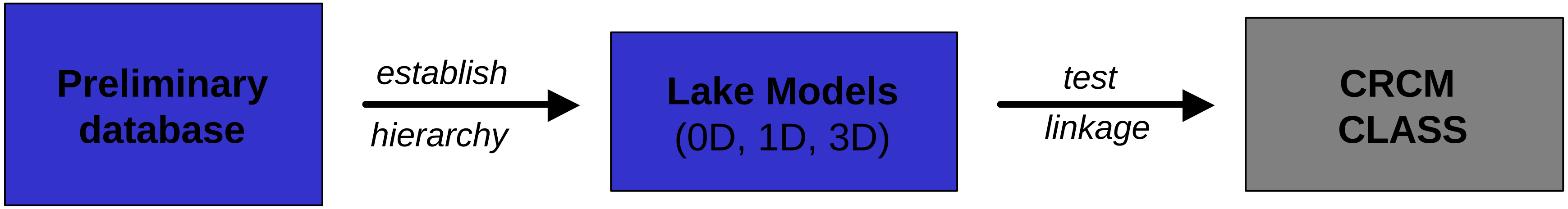
Research Outcomes

- Improved regional climate predictions and scenarios
- Increased reliability in climate impact analyses
  – e.g. aquatic ecosystems
- Better understanding of lake models in climate applications

Optimal Lake Model Selection

	Large Lakes	Medium Lakes	Small Lakes
3-D models		inefficient	over-kill (storm in a teacup)
1-D models	inaccurate		inefficient
0-D models	over-simplified	inaccurate	

Modelling Approach



da : > 1 Million Lakes

e.g. Large Lakes (km^2)

1.	Superior	82,100
2.	Huron	59,600
3.	Great Bear	31,328
4.	Great Slave	28,568
5.	Erie	25,700
6.	Winnipeg	24,387
7.	Ontario	18,960

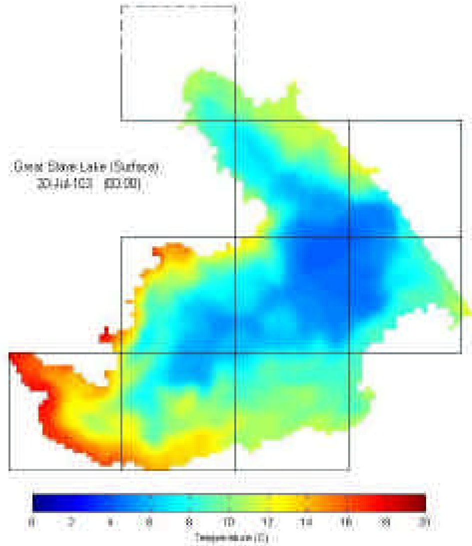
Lakes are not represented in the Canadian Regional Climate Model (CRCM @ 51 km grid resolution = 2,601 km^2)

Modeling: Classification of Lakes

3-D Hydrodynamic Model

e.g. ELCOM

- Verification
  Lake Erie, Great Slave Lake



3-D Model
Direct Linkage
to a 3-D
Atmospheric
Model

1-D Lake Thermal Model

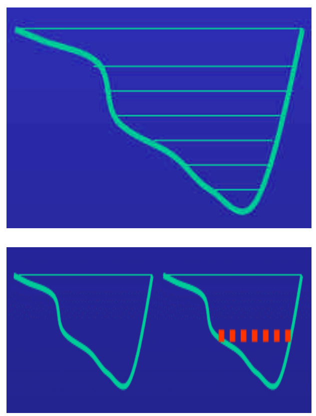
e.g. DYRESM / NWRI

- Verification
  Mid Lakes, Small lakes

0-D Lake Model

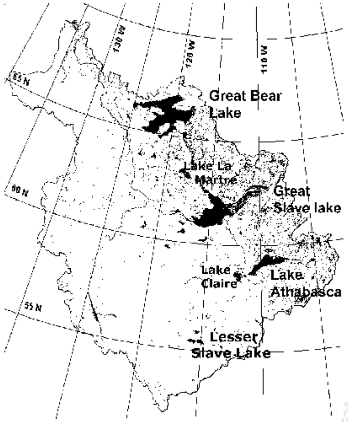
e.g. SLTM

- Verification
  Gar Lake, Sleepy Dragon,
  Skeeter Lake



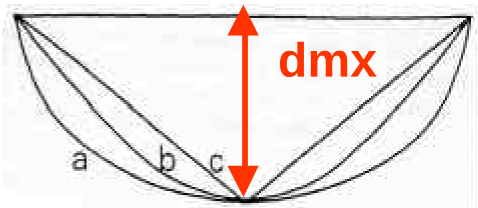
1-D, 0-D Models
Lake size at
sub-RCM grid
(< 51 km grid)
Linkage to
CRCM through
CLASS

Lake Regionalization a Possible Approach



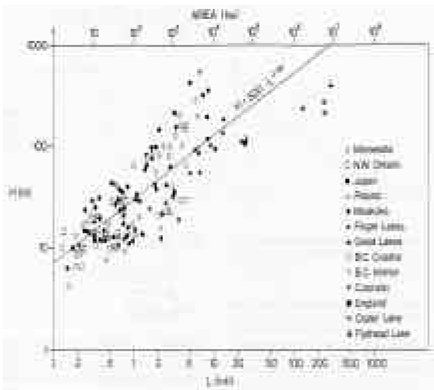
Generate Lake Shape Hypsometry

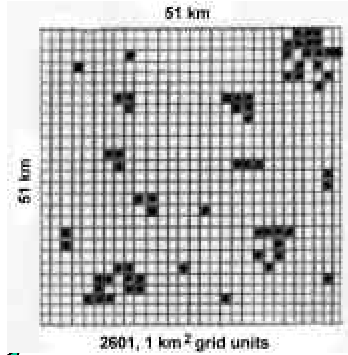
As



dmx

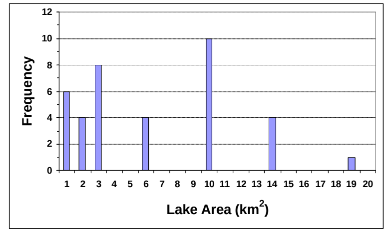
b = elliptical sinusoid





Lake Distribution

- AVHRR

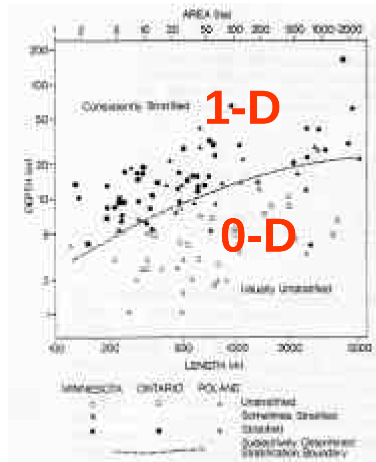


Generate Frequency Distribution

Generate Sub-grid Lake Shapes and Compute Fluxes

•select lake model

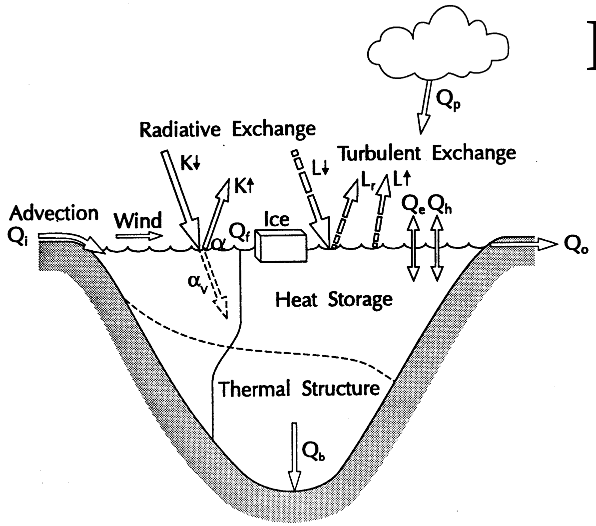
•scale fluxes



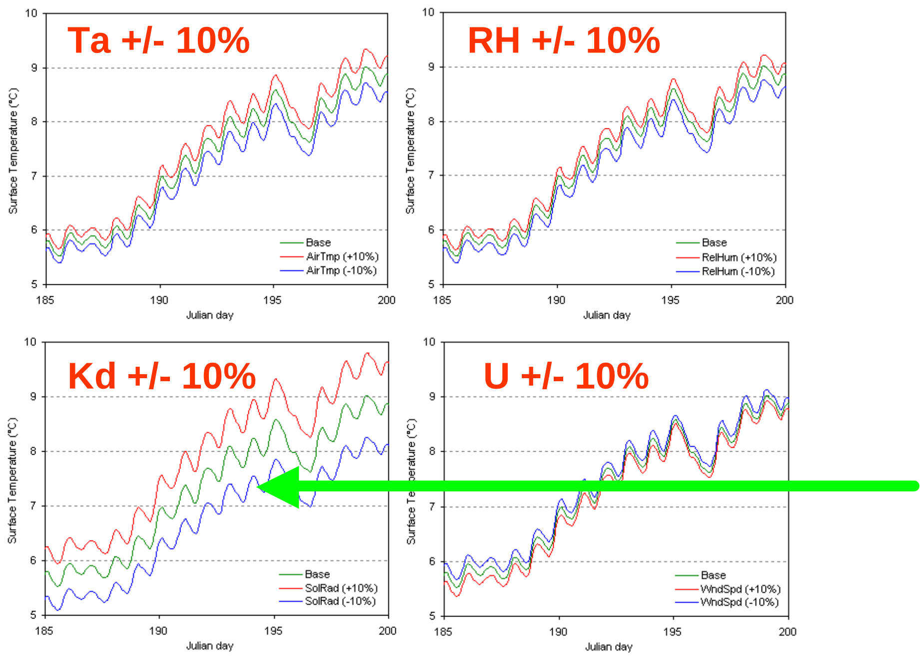
Assemble Multi-Model Results

- advanced computational schemes

Lake Model Validation, Sensitivity Analysis and Error Propagation



- Verify simulations of temperature, heat fluxes, currents for 0-D, 1-D and 3-D models
- Evaluate lake models using inputs from field data over lakes of different sizes



Sensitivity Analysis and Error Propagation

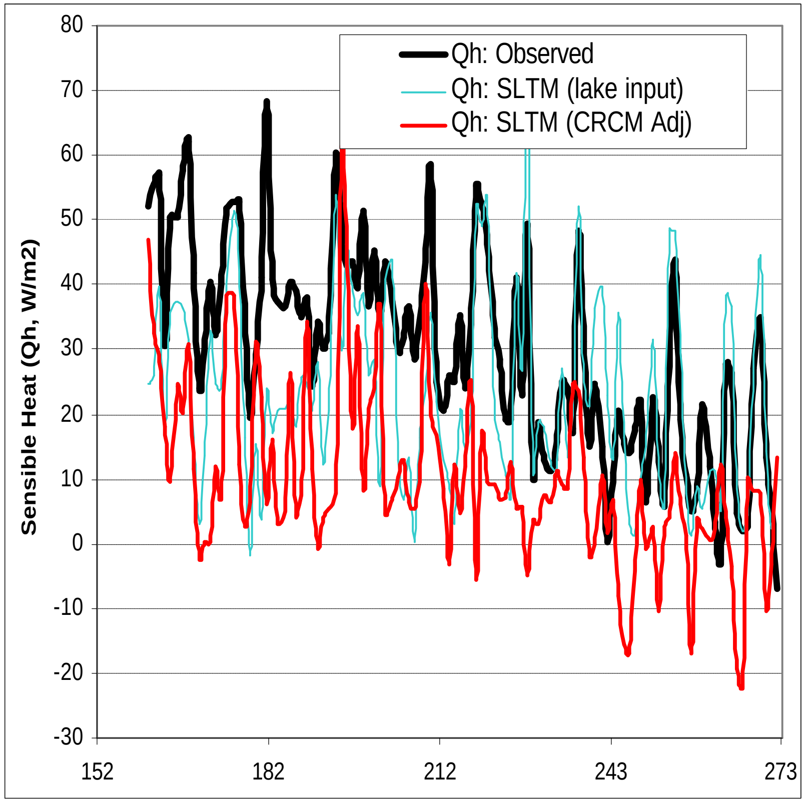
e.g. sensitivity of model surface water temperature for +/- 10% changes in key input variables

Surface water temperature is significantly affected by solar radiation

Surface Boundary Layer Processes

Air-Water Heat Flux Exchange

Need to evaluate and improve lake model simulation capability when forced with CRCM grid-averages.

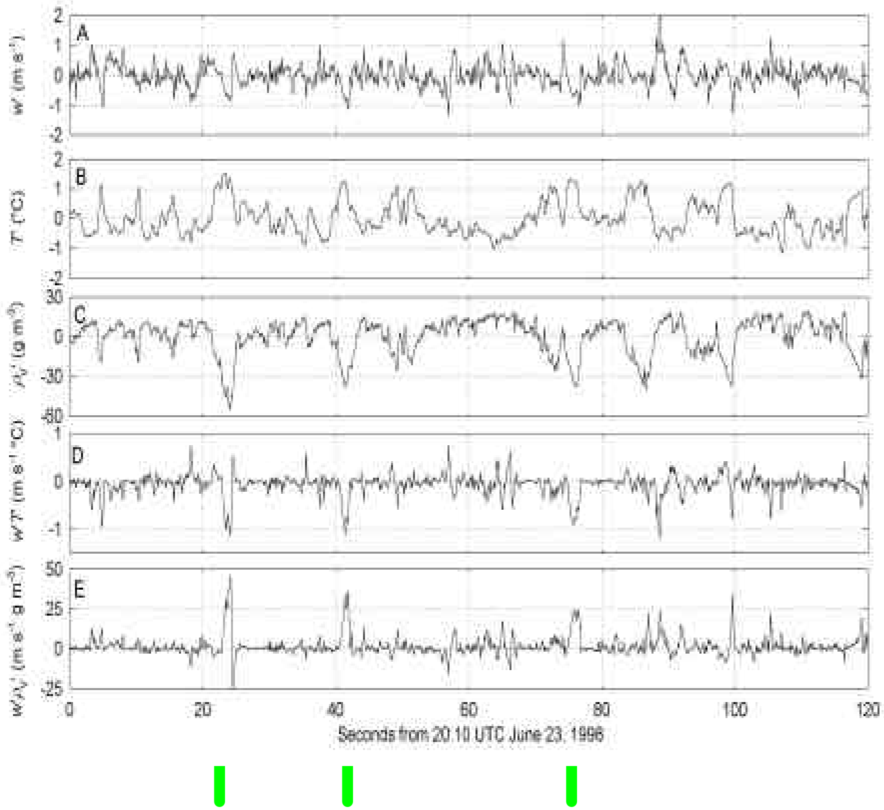


J J A S

e.g. Qh from SLTM (CRCM Adj) large error compared to **Observed**

Enhanced Evaporation Events

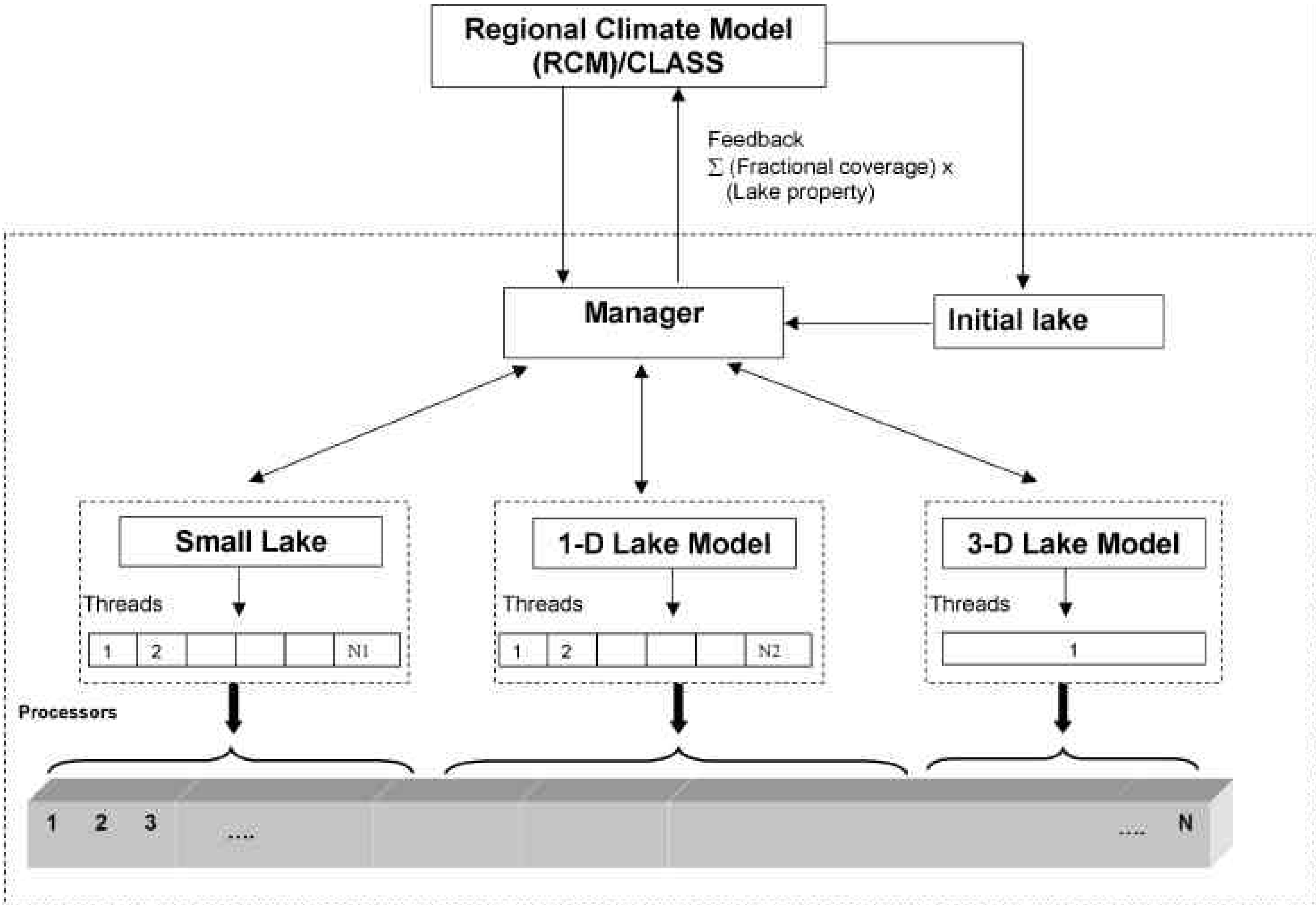
Convective fluxes on northern lakes can be periodic responding to meso- and micro-scale atmospheric processes. Boundary layer processes need to be understood.



Entrainment of warm, dry air increases Qh to water surface enhancing Evaporation (E)

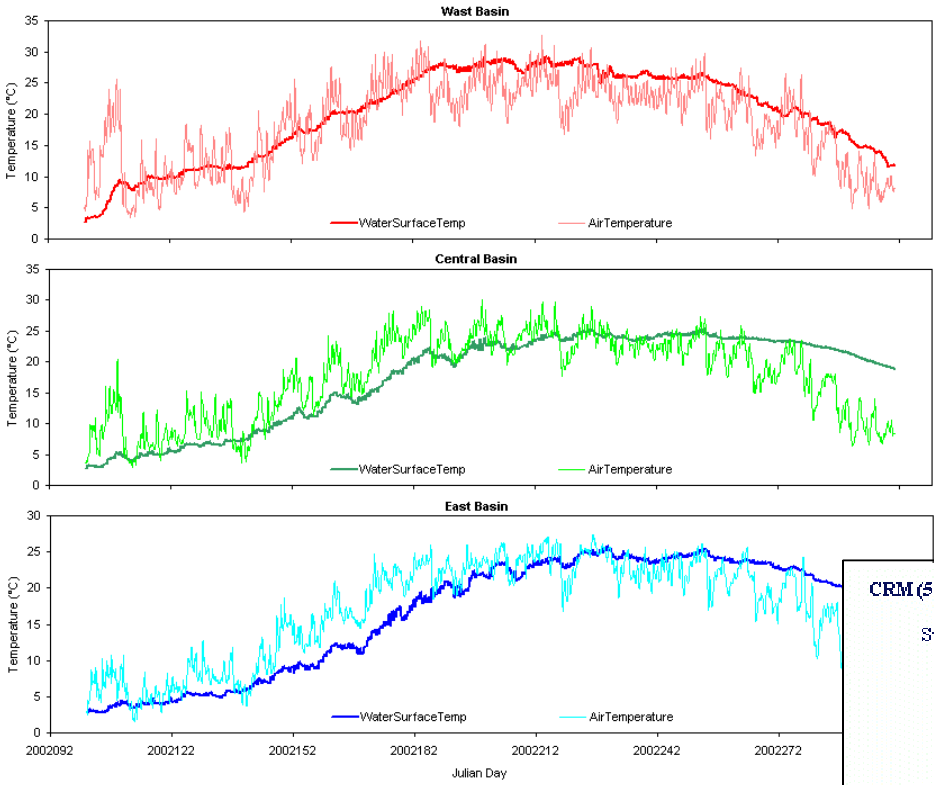
Computational Efficiency

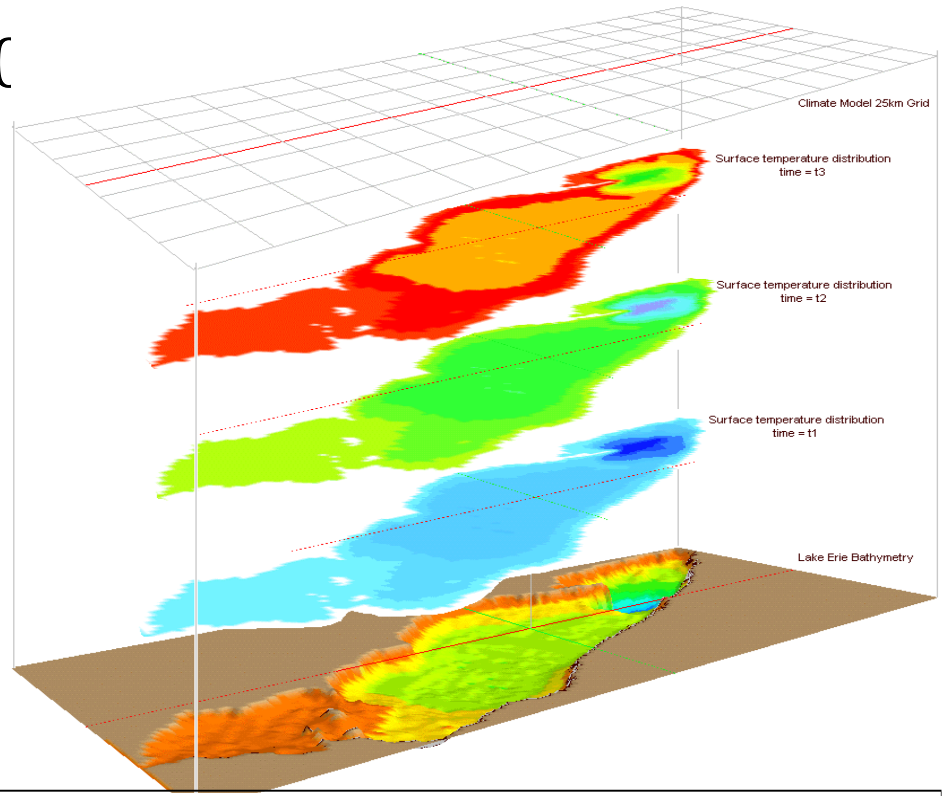
Multi-threading and multi-processing will gain efficiencies and adapt to any configuration (single processor, multiprocessor)

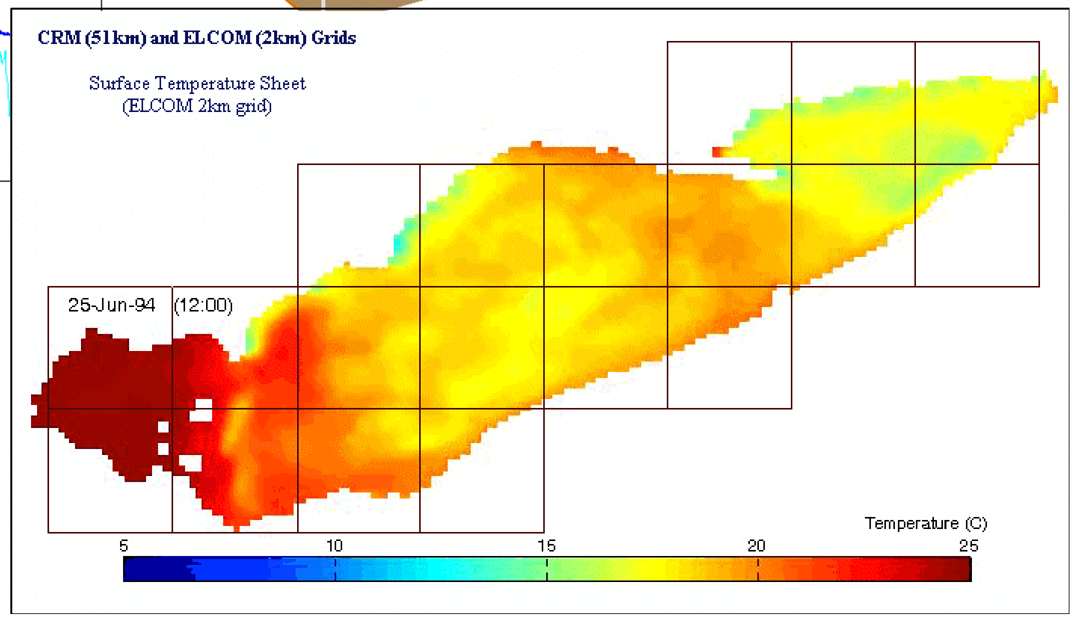


Project Examples

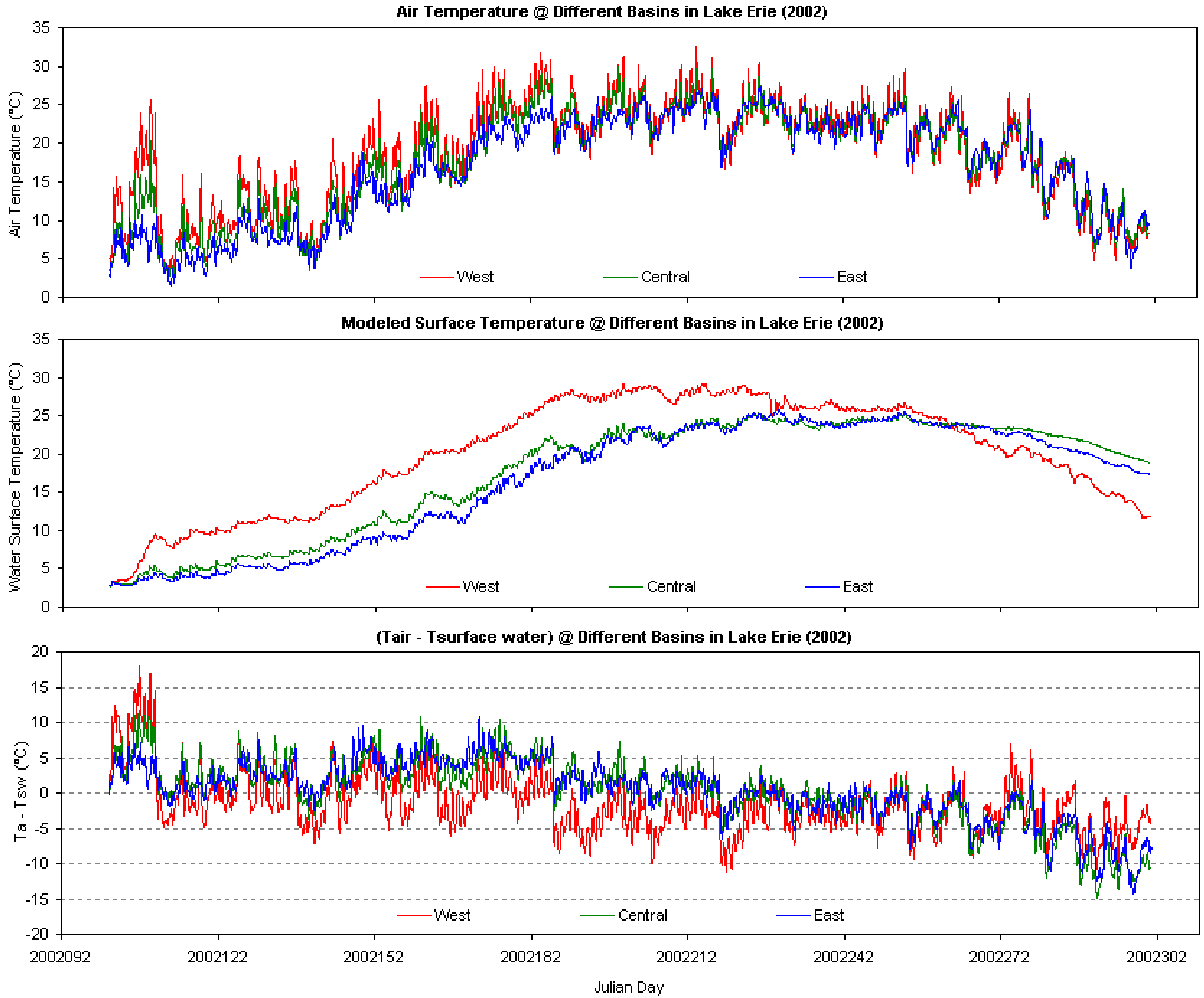
3D Model in Lake Erie (20(



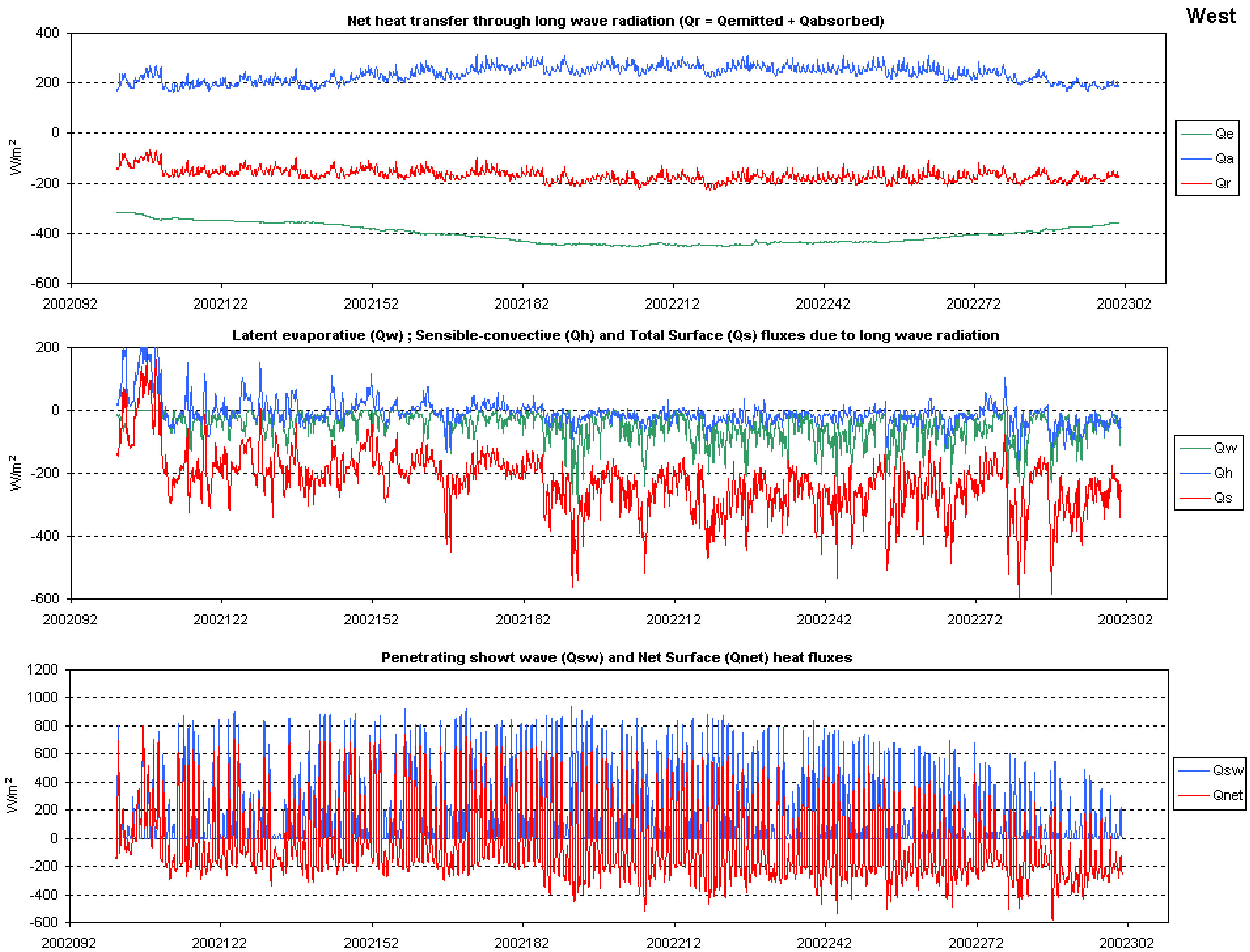




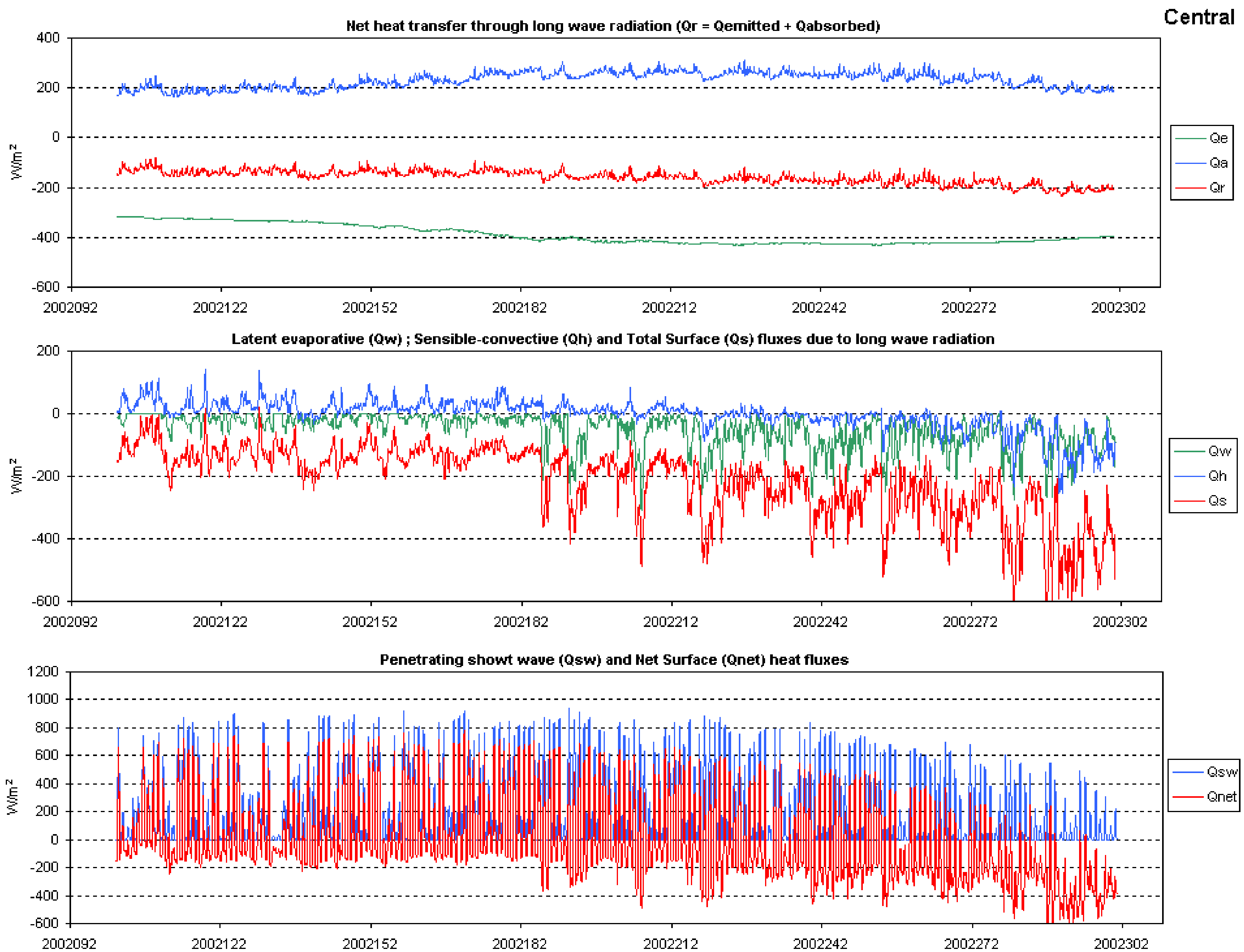
Lake Erie: Lake-wide Temperature differences (2002)



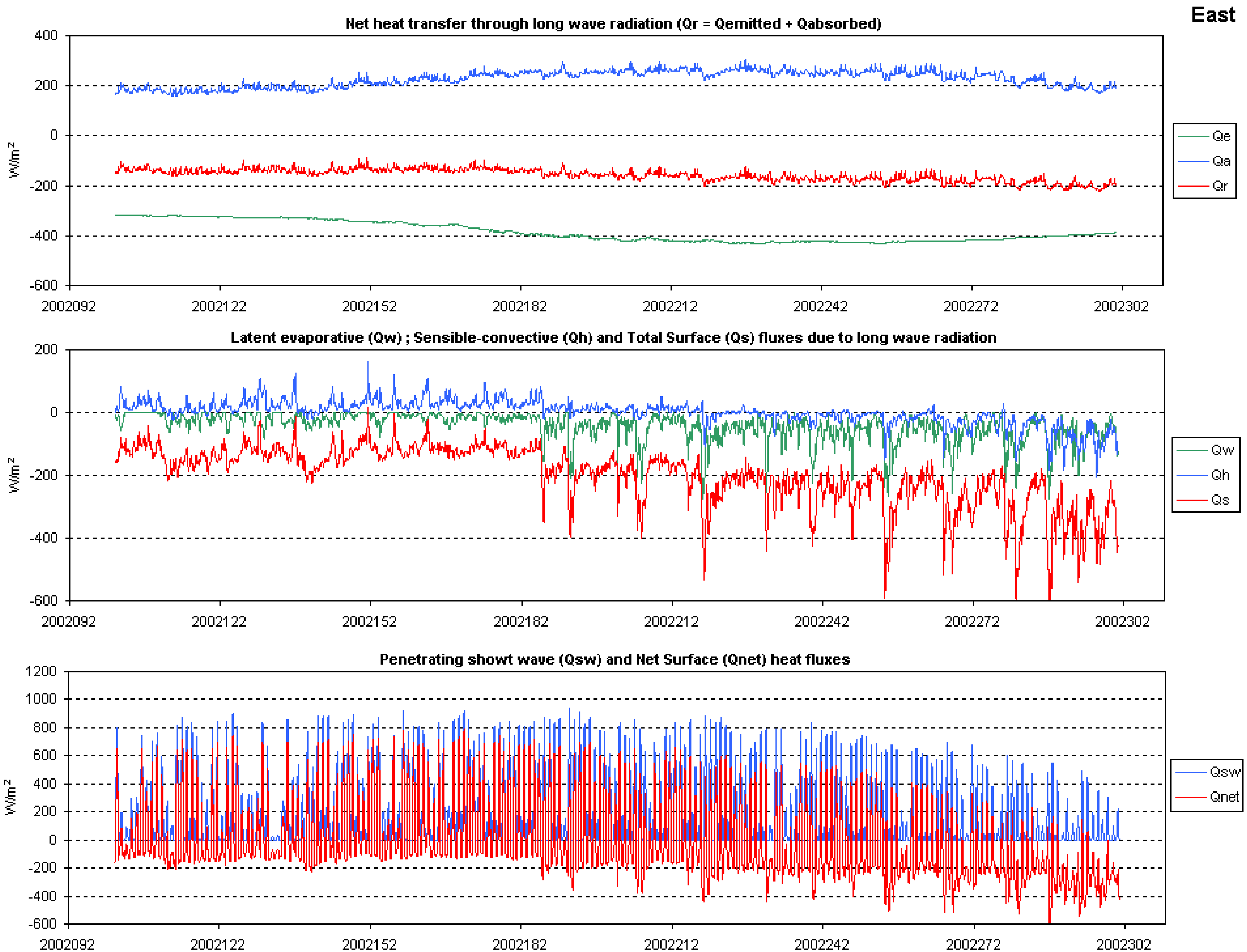
Heat Fluxes @ West Basin (2002)



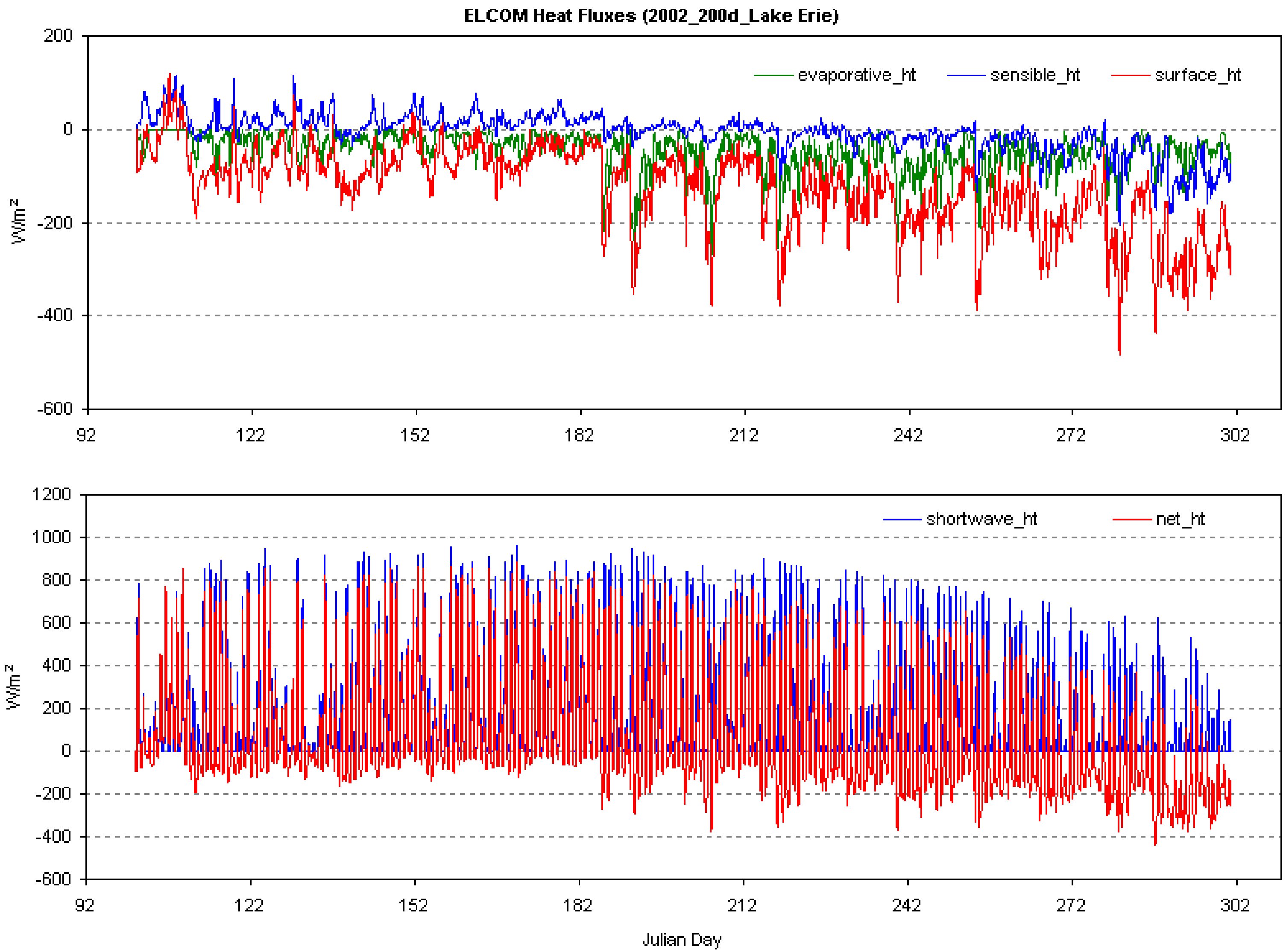
Heat Fluxes @ Central Basin (2002)



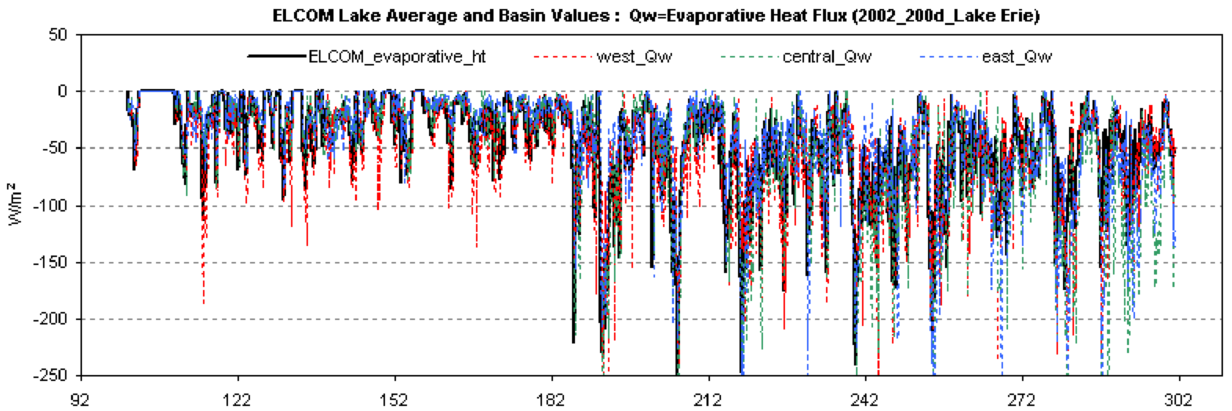
Heat Fluxes @ East Basin (2002)

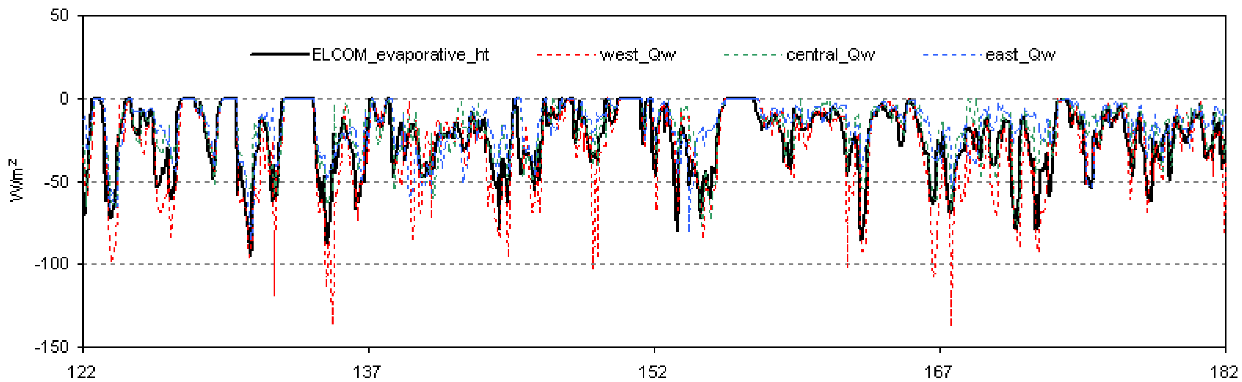


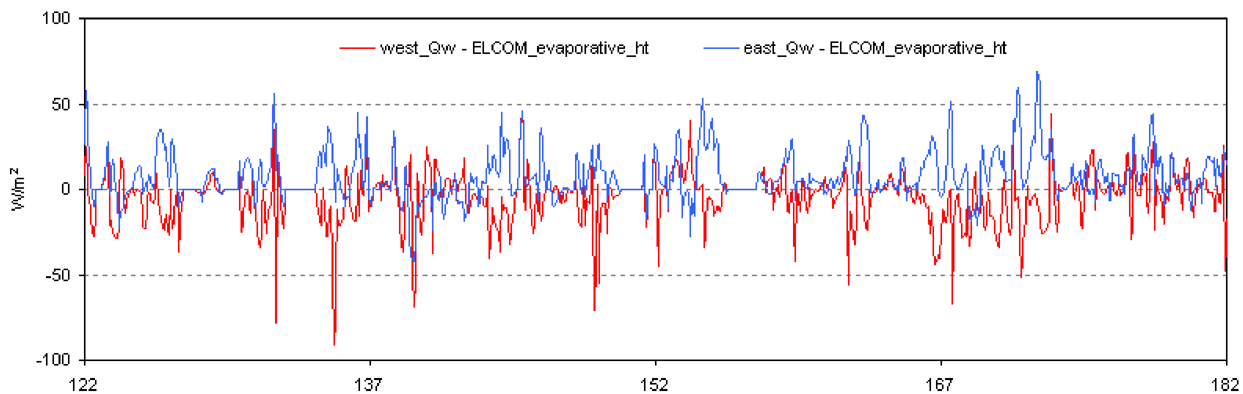
Average Heat Fluxes



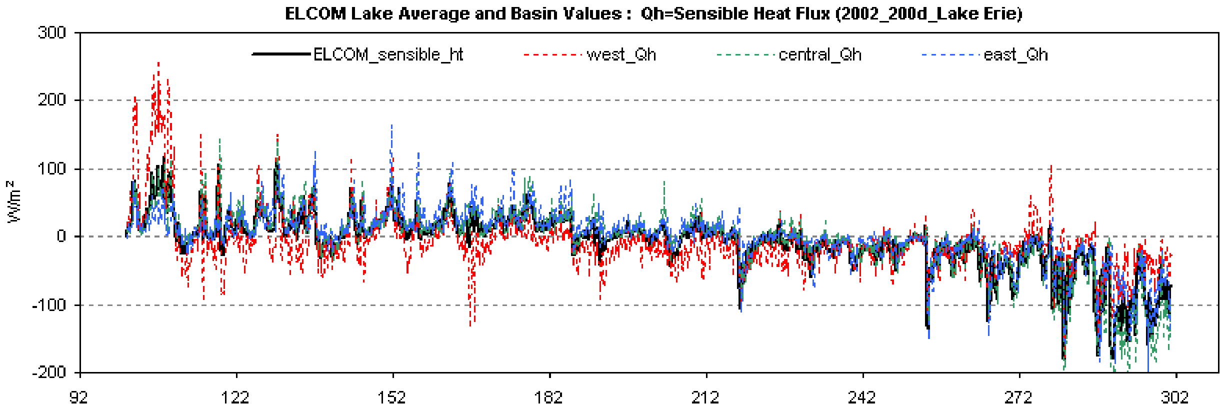
Evaporative Heat

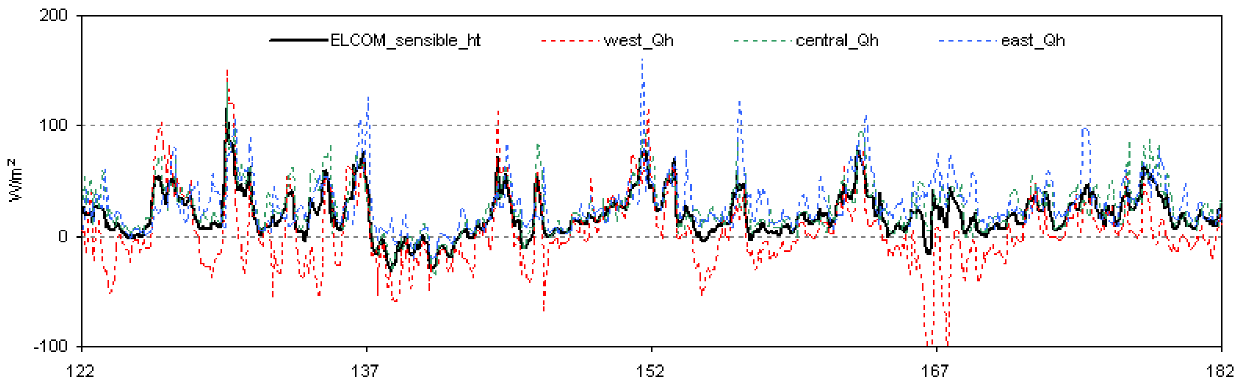


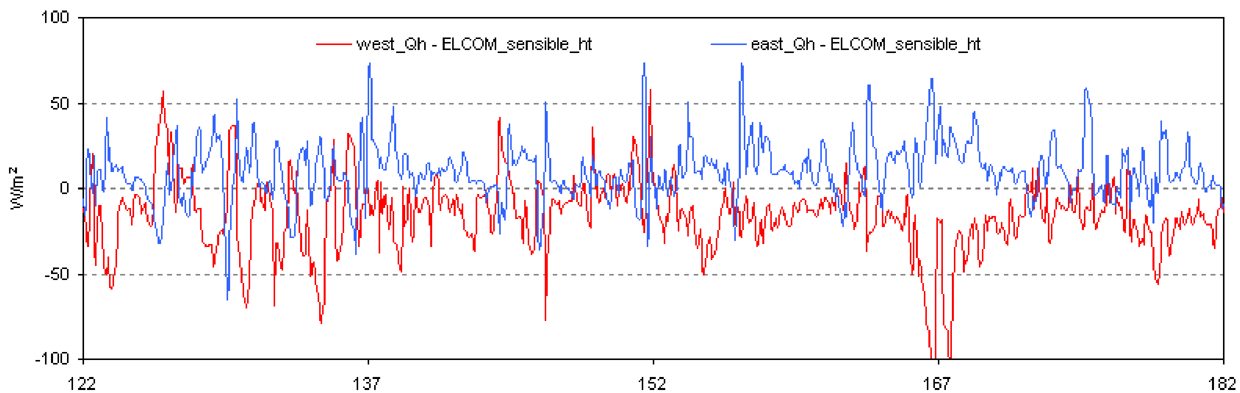




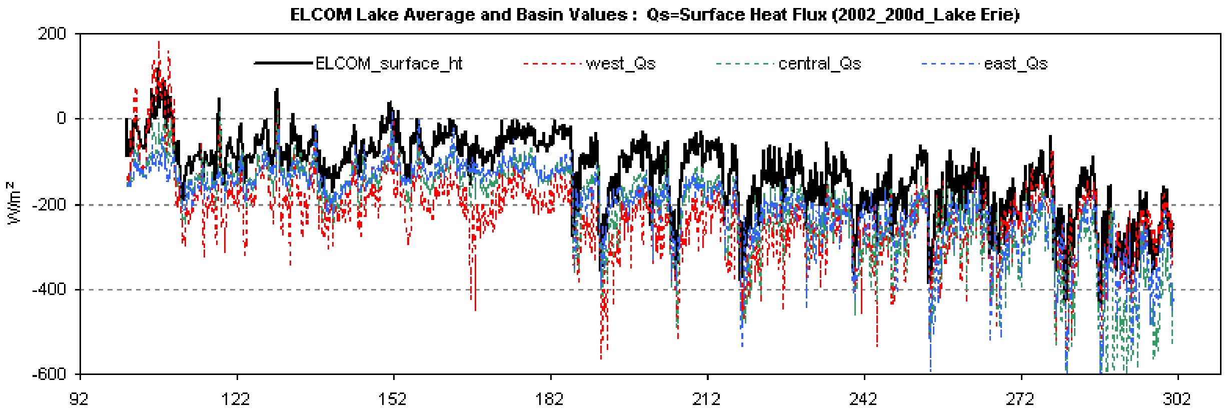
Sensible Heat

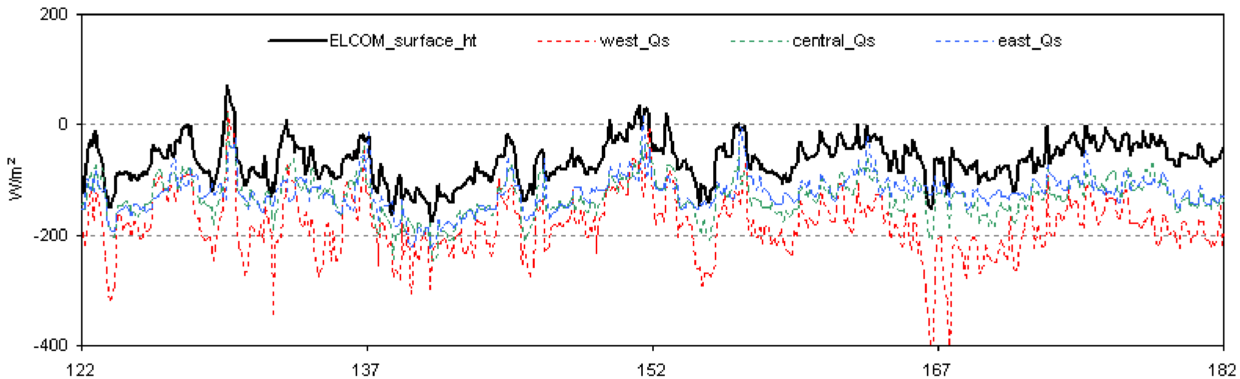


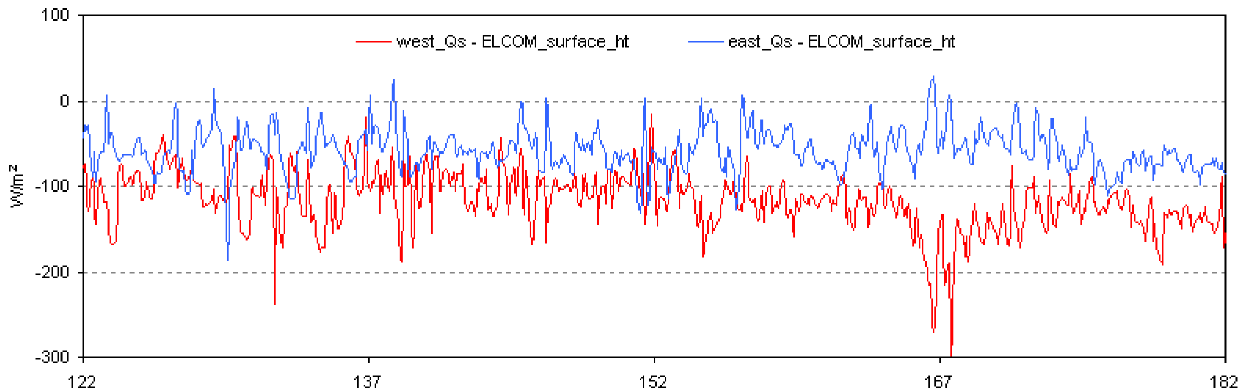




Surface Heat

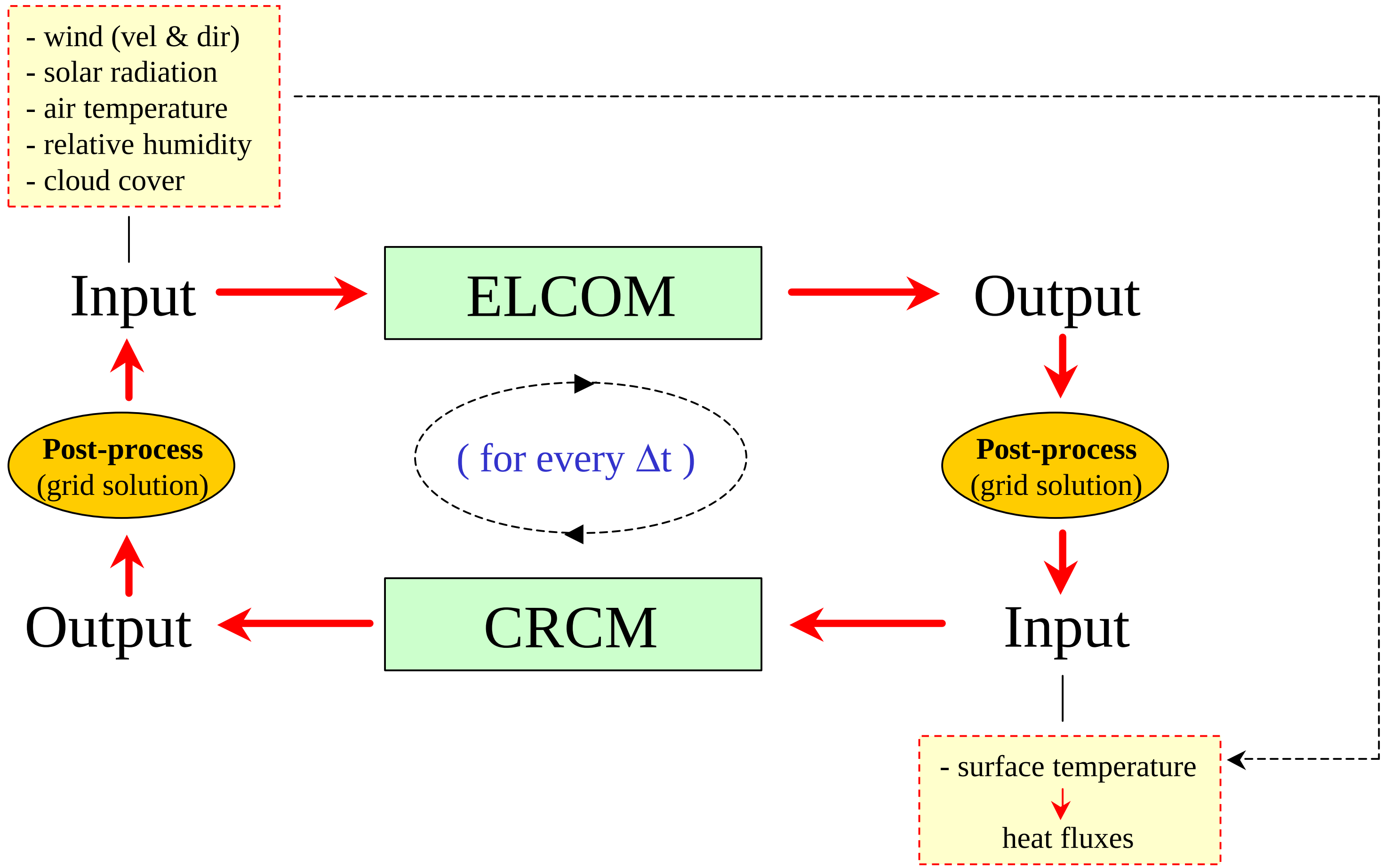






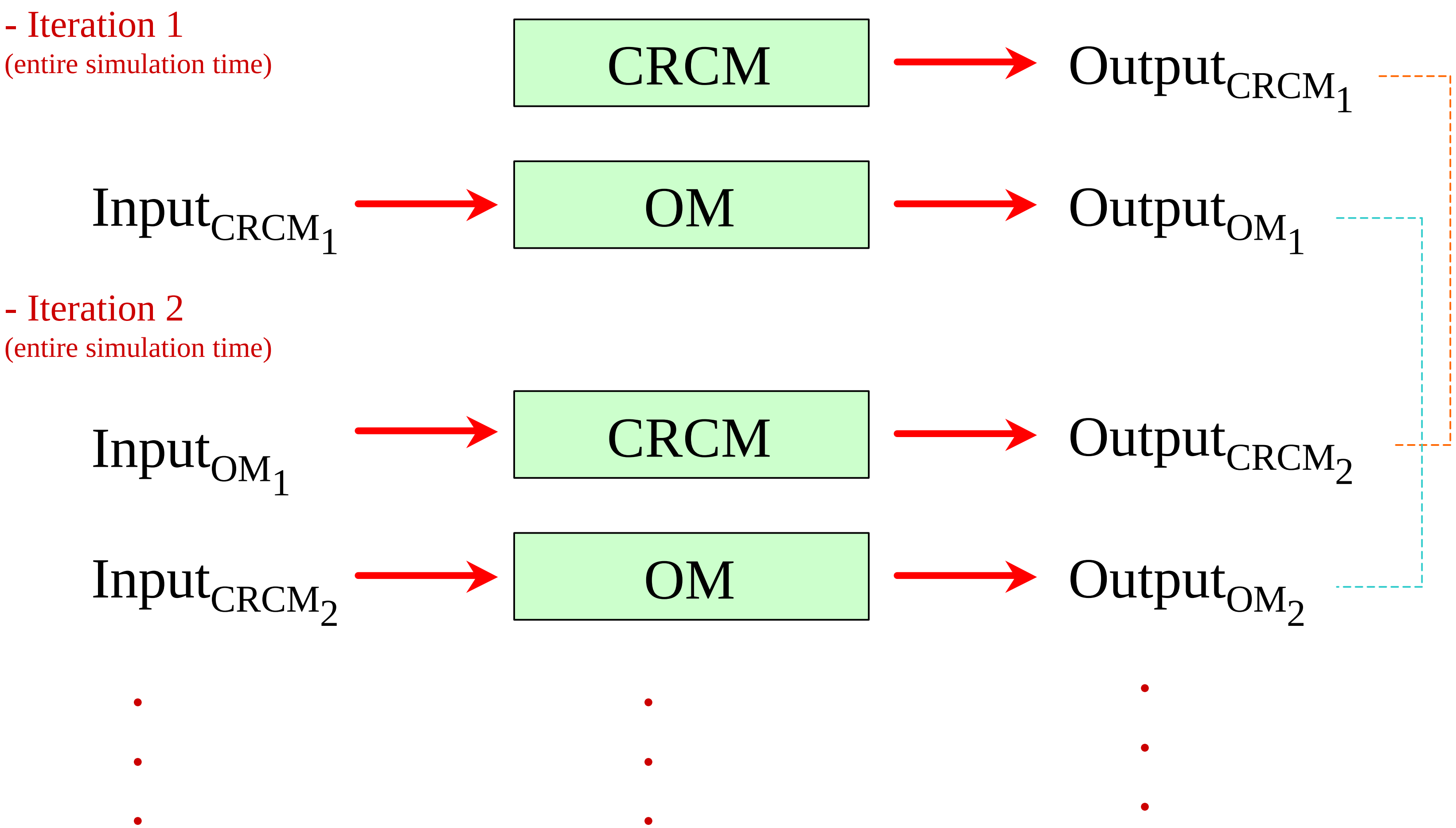
ELCOM & CRCM Data Coupling

- Coupled Simulations



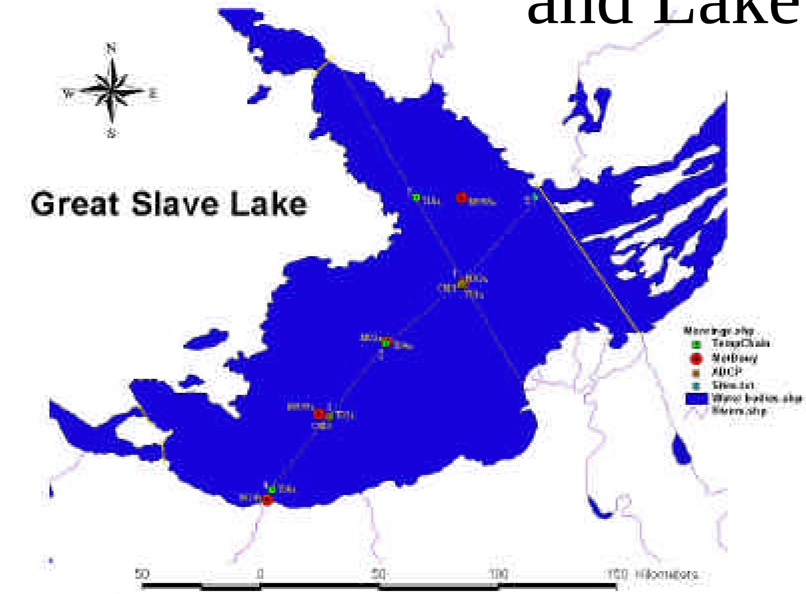
Sensitivity and Convergence

• Uncoupled Iterations (Faucher *et al*., 2004)*



* after the 3rd iteration the output from both models converge to same previous output (diff. $\rightarrow$ 0) with similar converging results when performing the coupled simulation (for every time step).

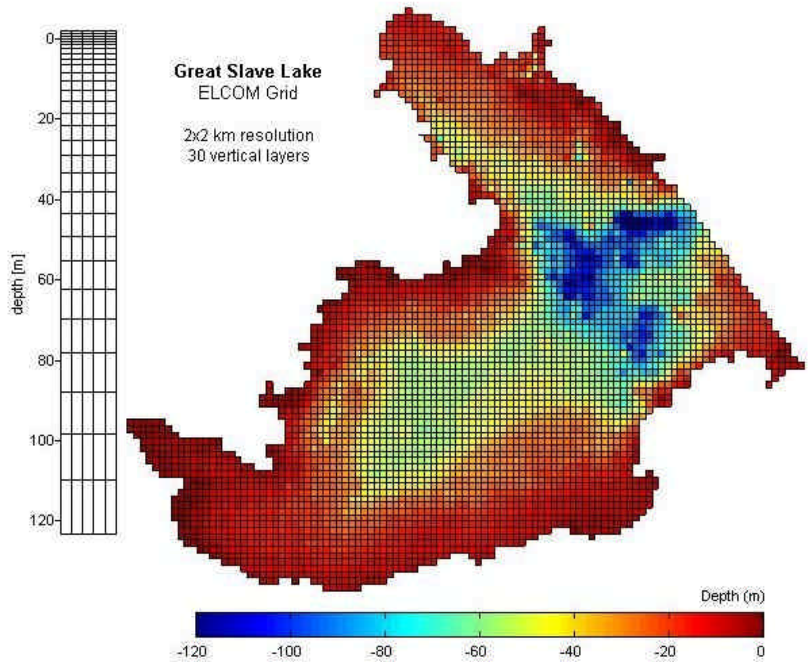
Great Slave Lake: Modelling the Thermal Structure and Lake Hydrodynamics



GSL Moorings : 2003

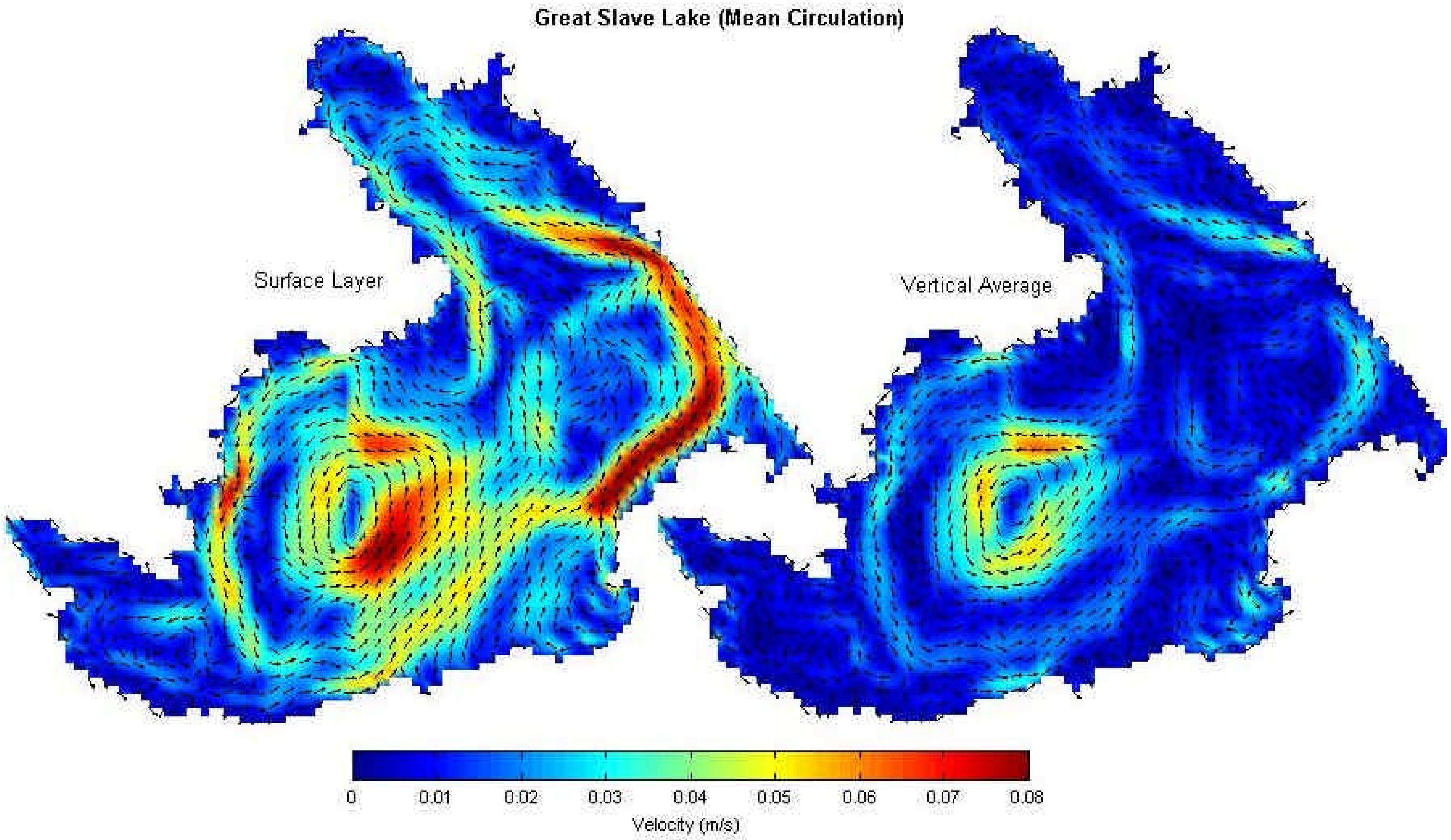
- Meteorology : Ta, RH, U, Udir
- Radiation : Kd, Ld
- Phys. Lim. : Ts, Tprof, ADCP

3-D Hydrodynamic Model
ELCOM : 2 x 2 km grid



Initial Assumptions:
No exchange between
GSL and Christie Arm
Inflow and Outflow are set to zero

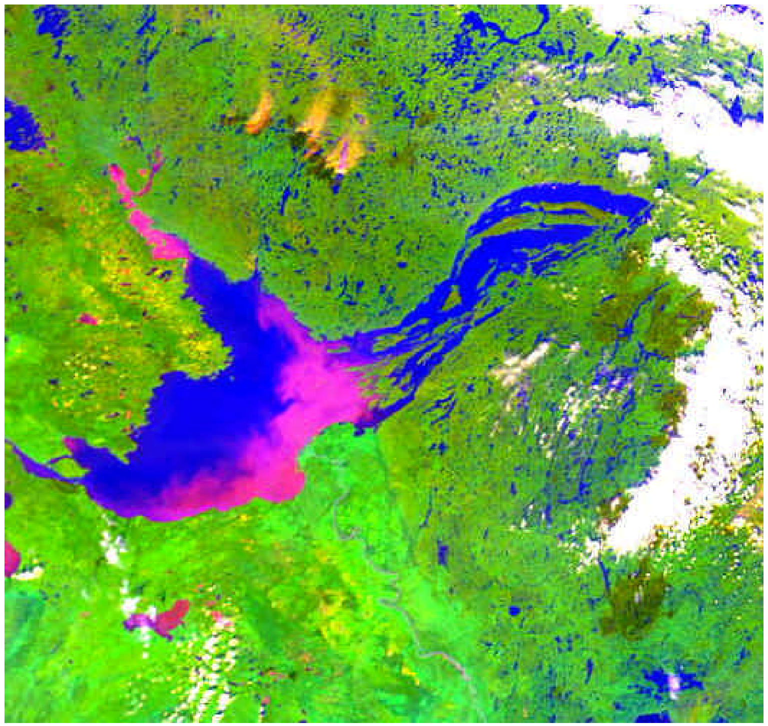
Mean Circulation Patterns



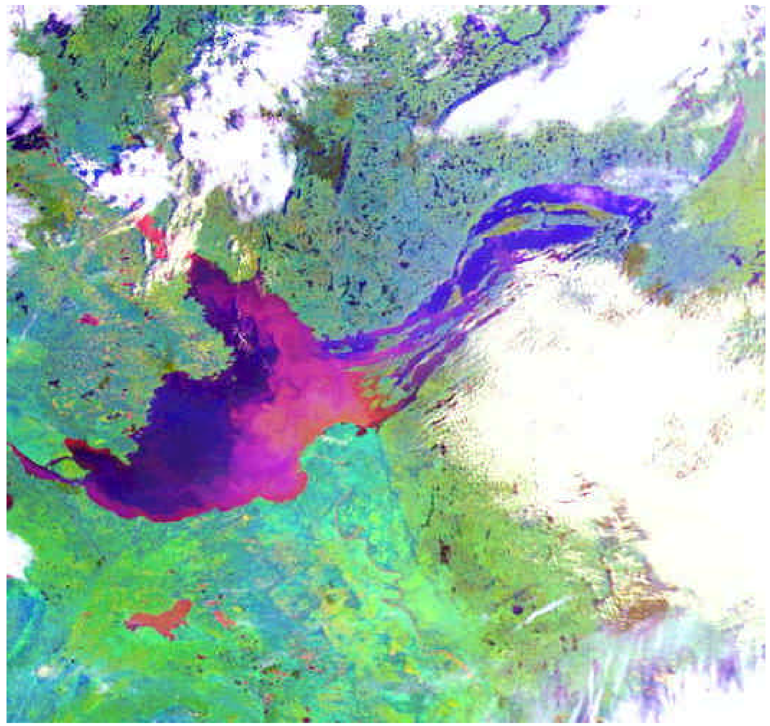
Images of Sediment Transport in Great Slave Lake

- Sediment released from repair of Bennett Dam and introduced into Great Slave Lake from the Slave River

July 29, 1996



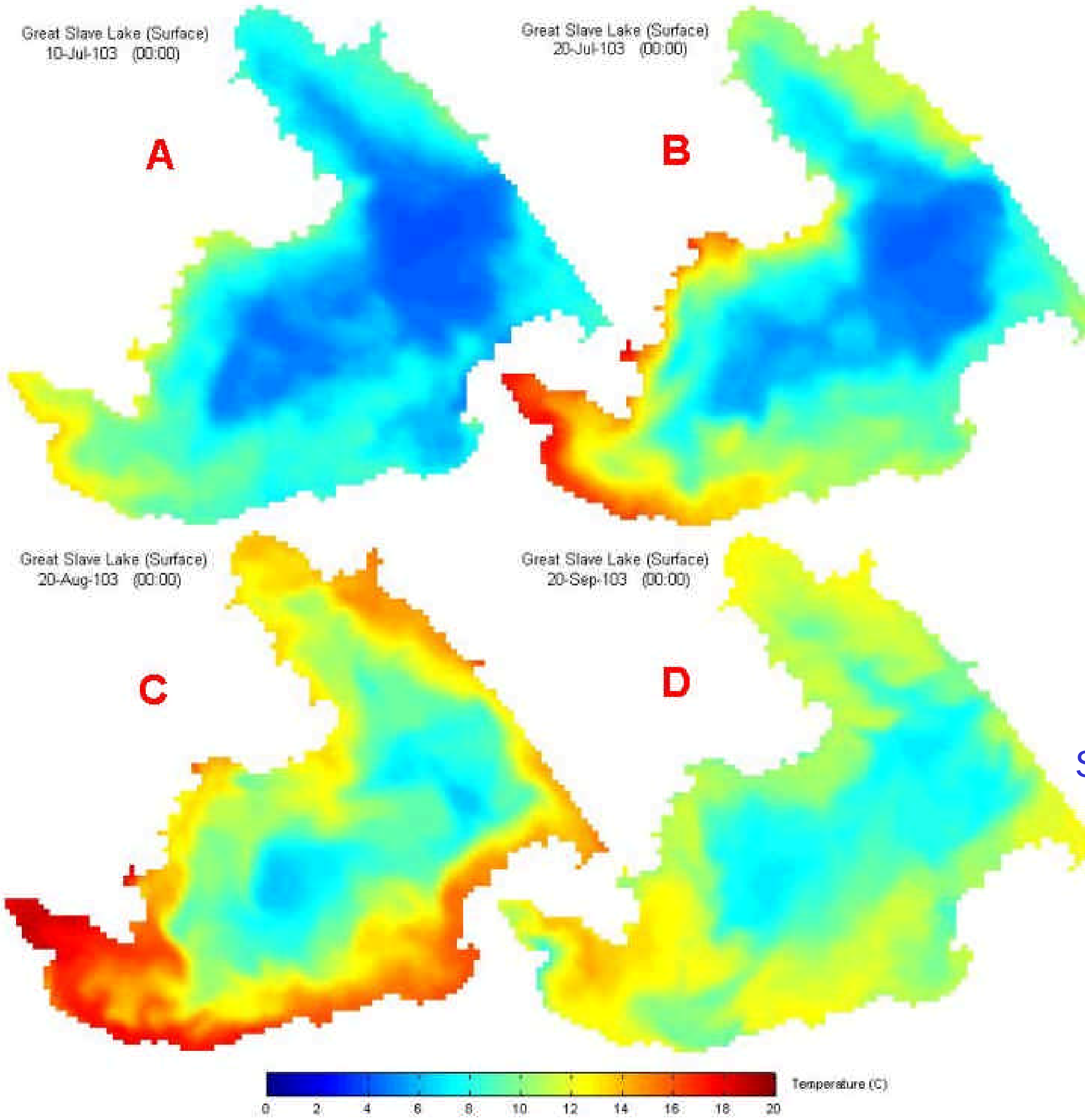
August 15, 1996



Modeled Surface Temperatures

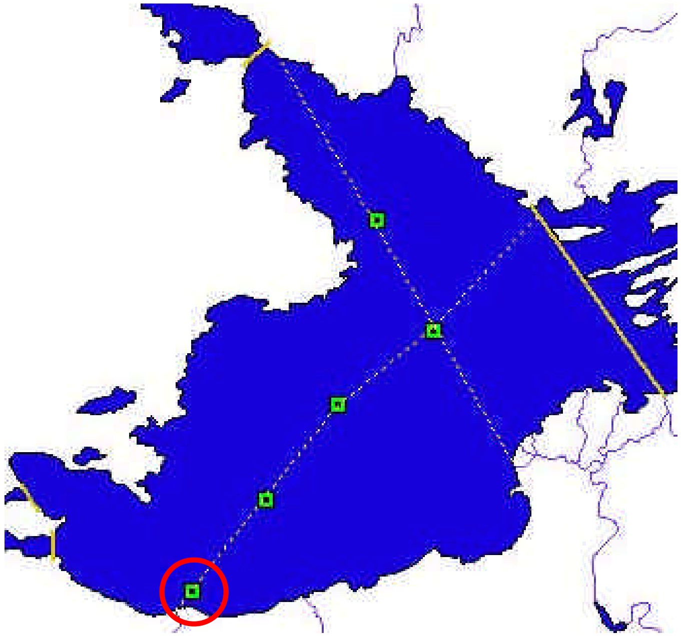
July 10, 2003

July 20, 2003

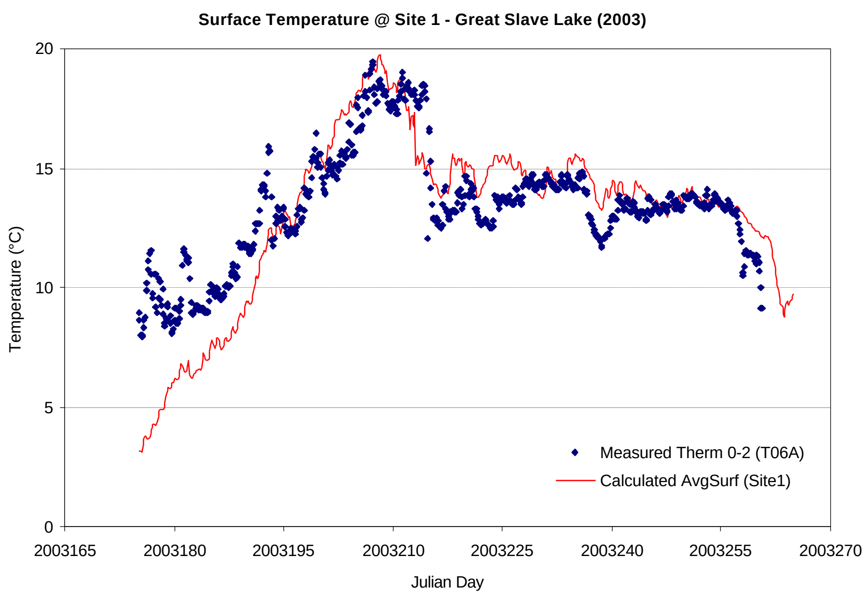


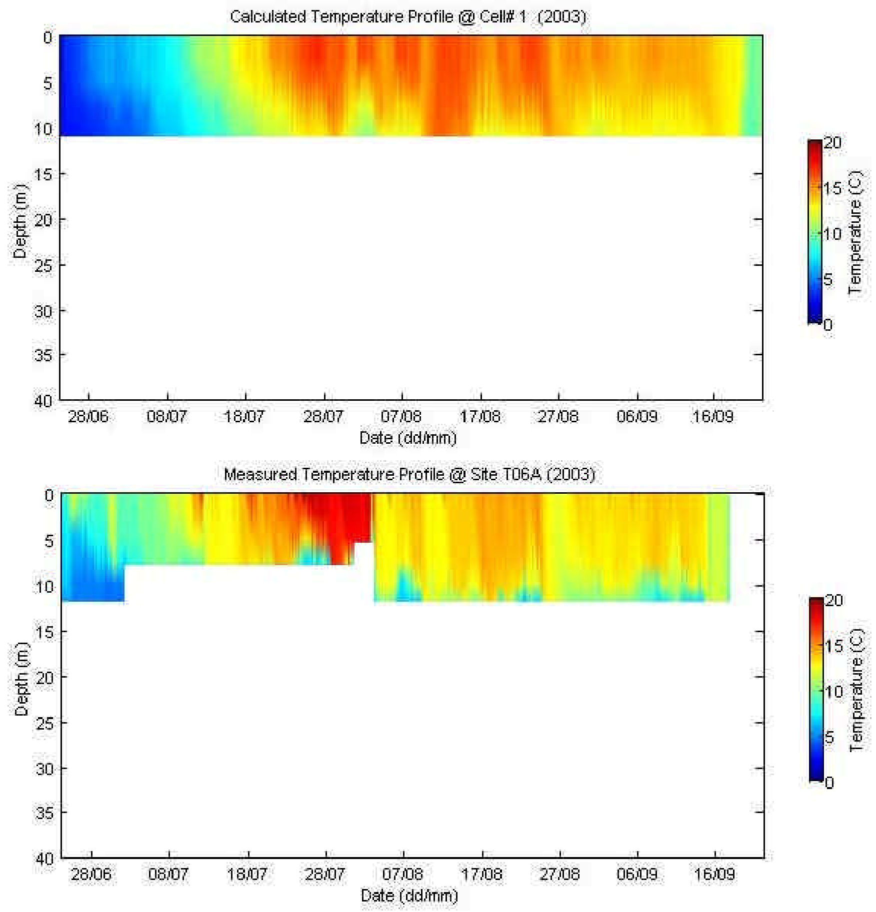
Aug. 20, 2003

Sept. 20, 2003

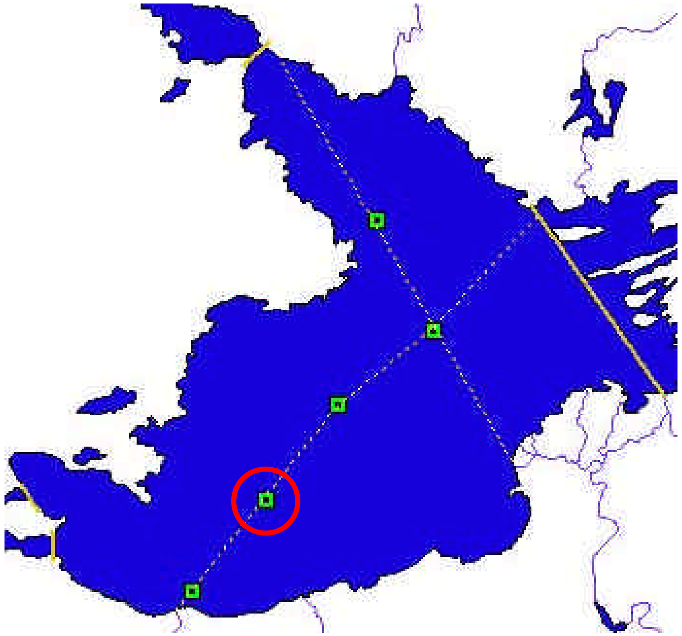


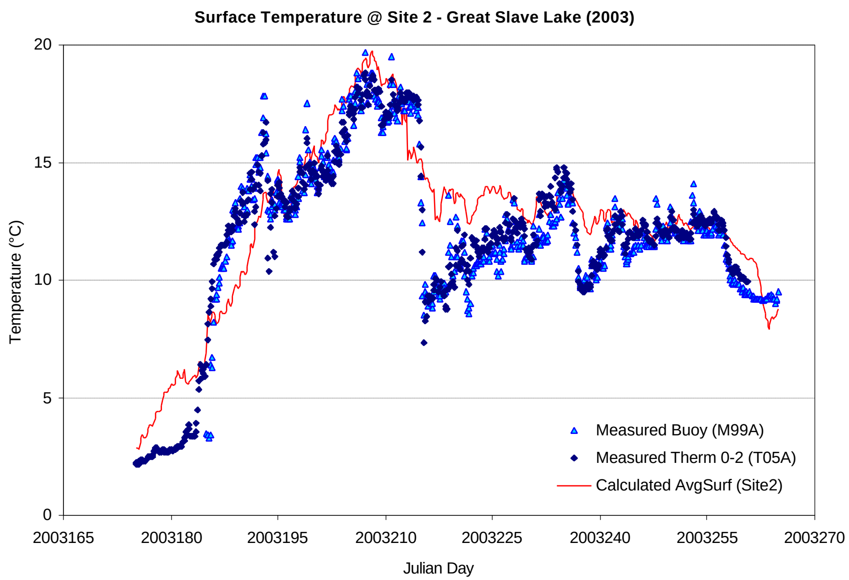
Simulated and Observed Temperature Isotherms at Site (1)

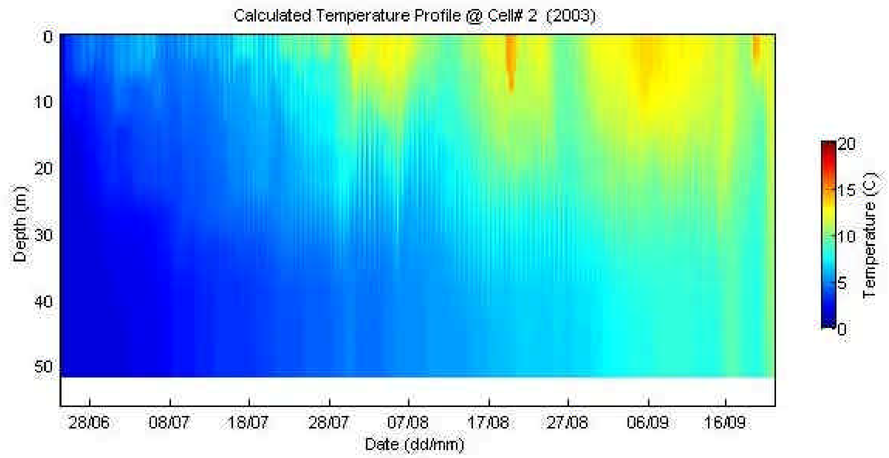


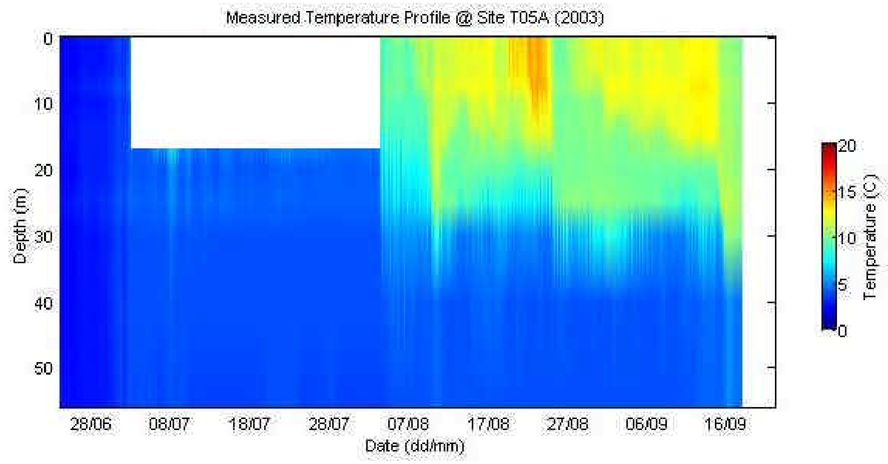


Simulated and Observed Temperature Isotherms at Site (2)

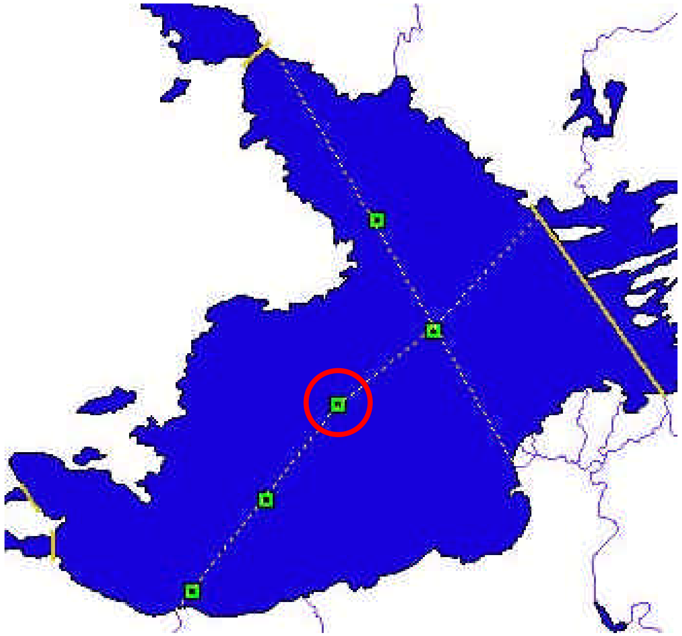


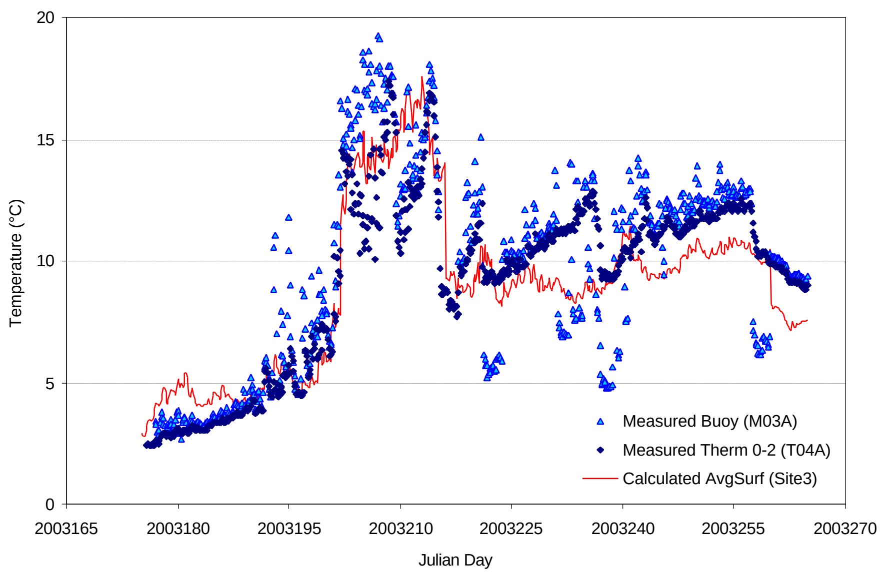


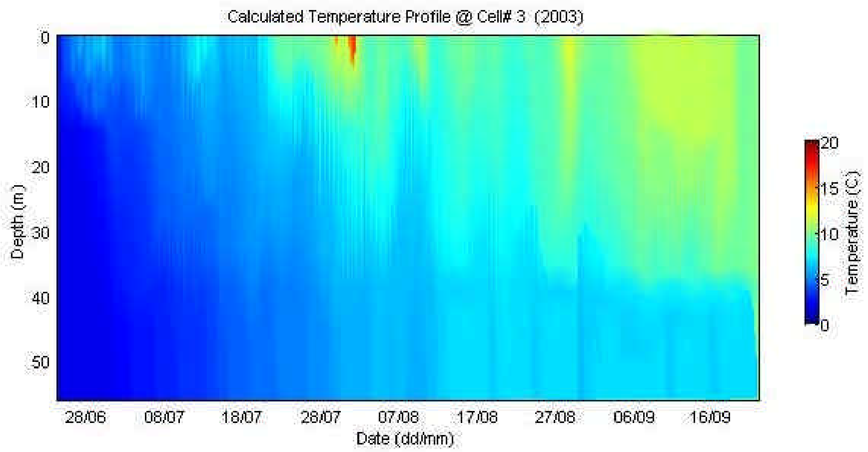


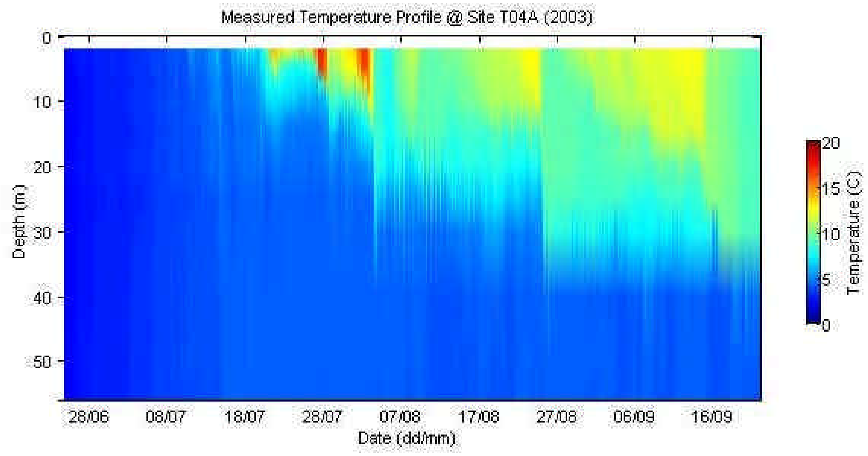


Simulated and Observed Temperature Isotherms at Site (3)

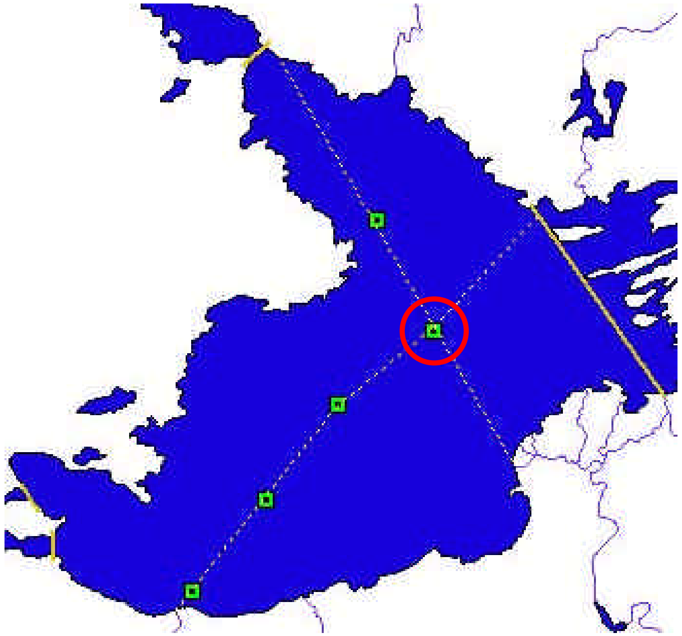


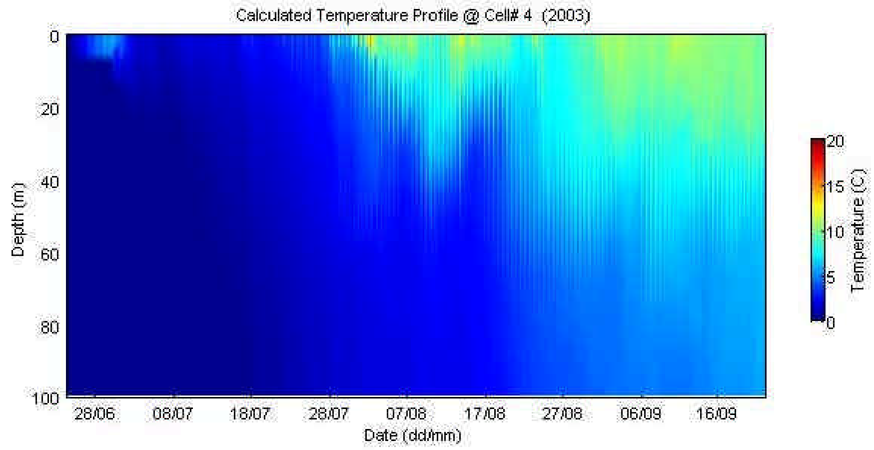


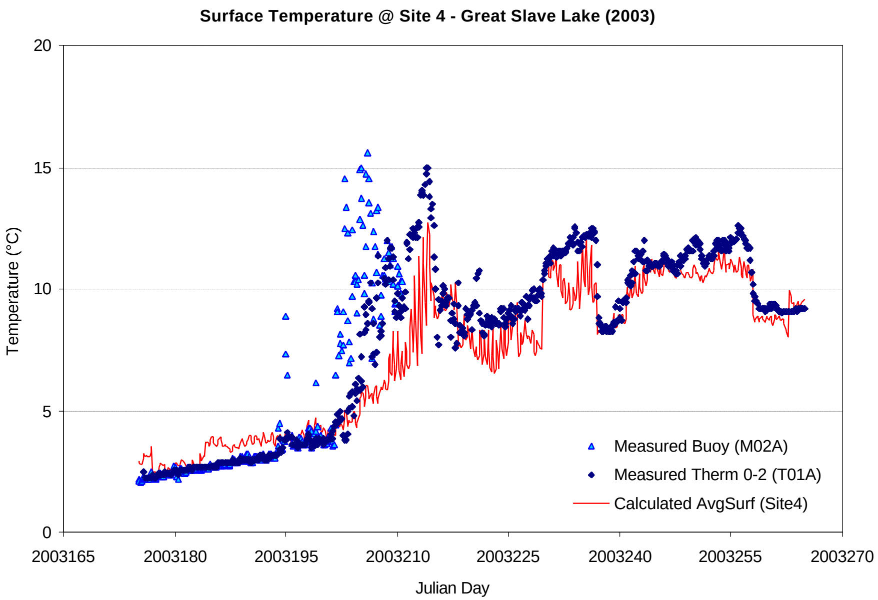


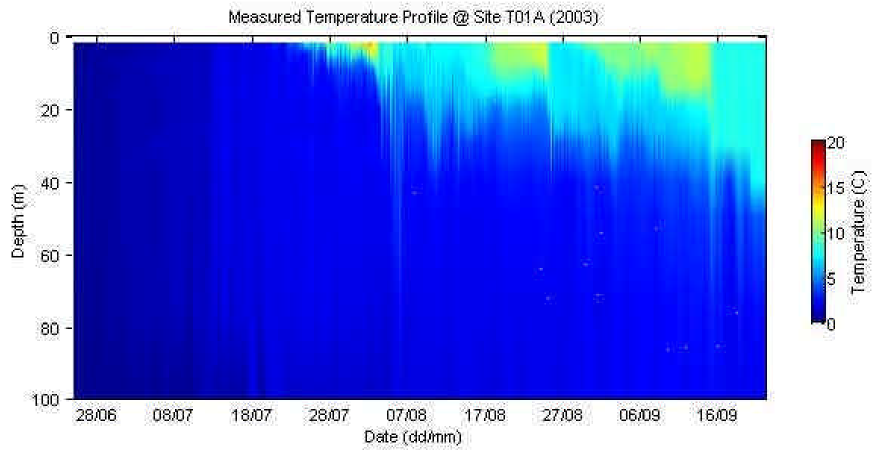


Simulated and Observed Temperature Isotherms at Site (4)

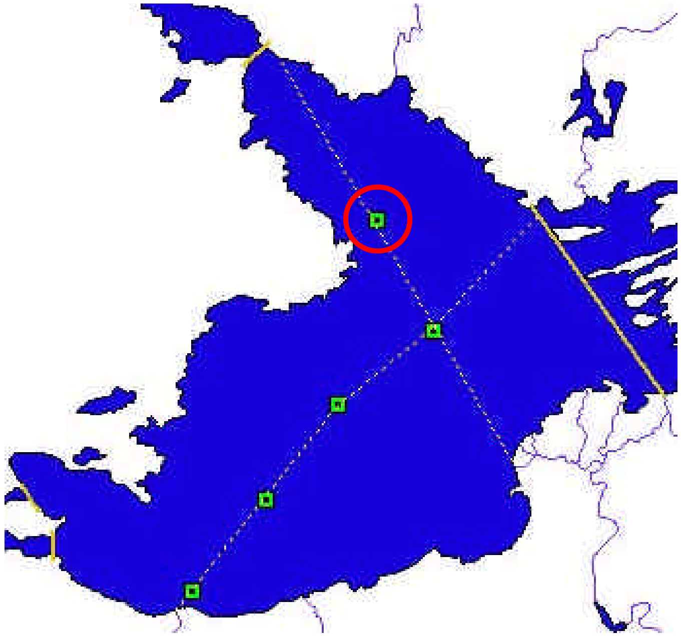


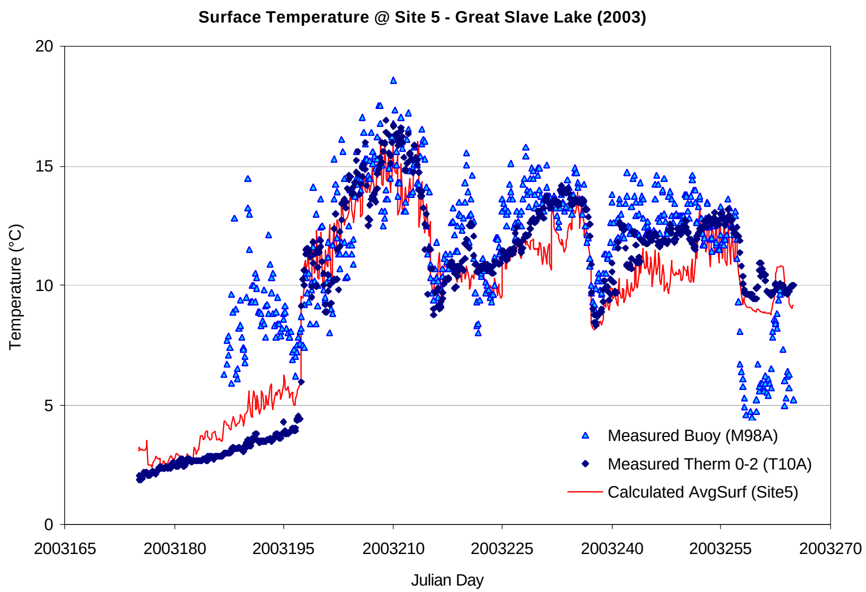


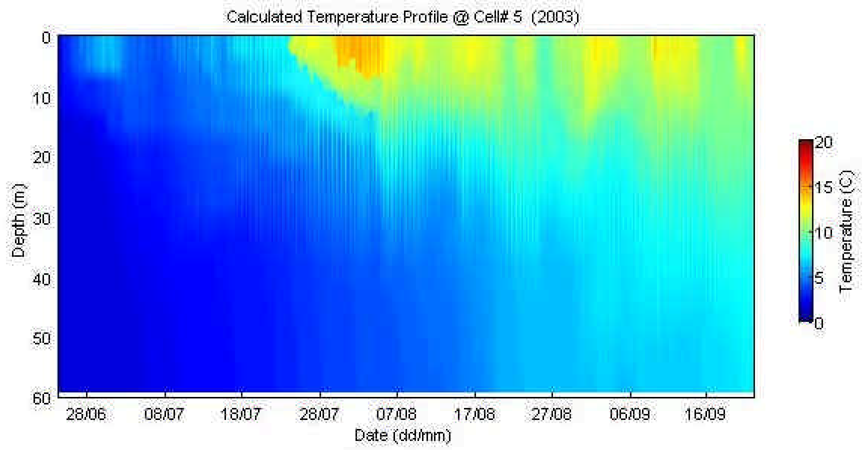


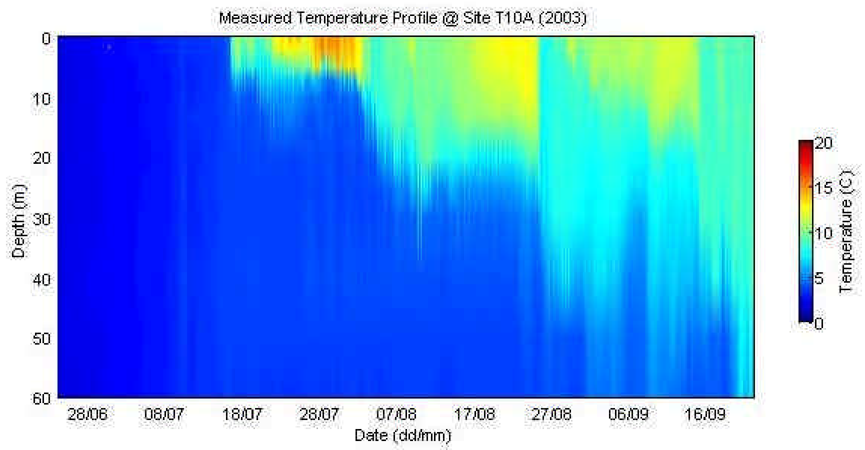


Simulated and Observed Temperature Isotherms at Site (5)





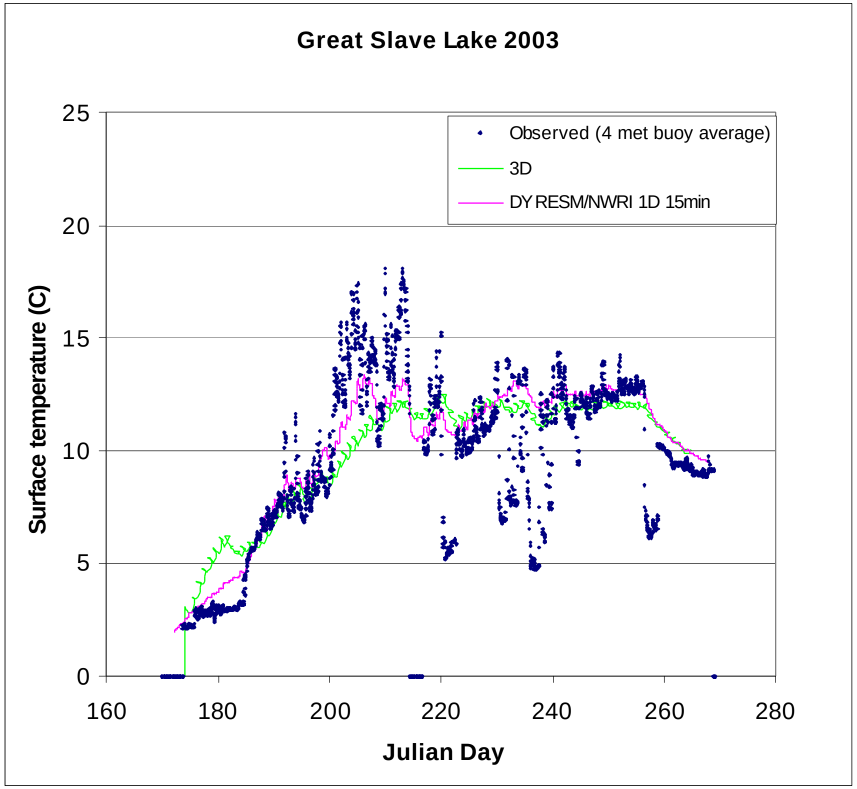




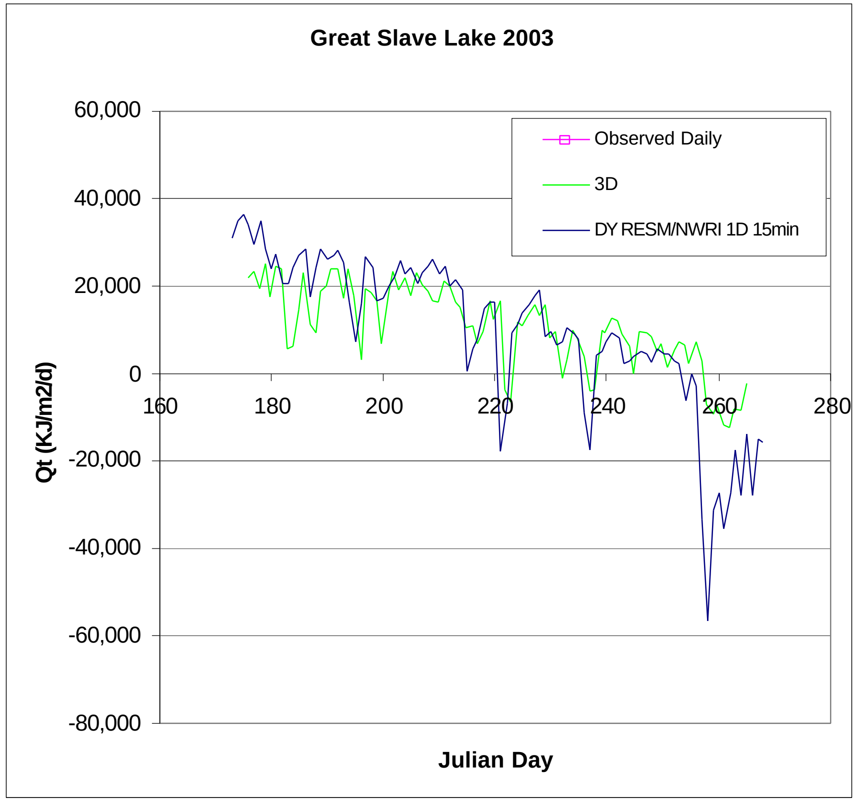
Comparison of 1-D and 3-D Model Simulations of Ts and Qt : GSL for Summer 2003

3-D Model : ELCOM
1-D Model : DYRESM-NWRI

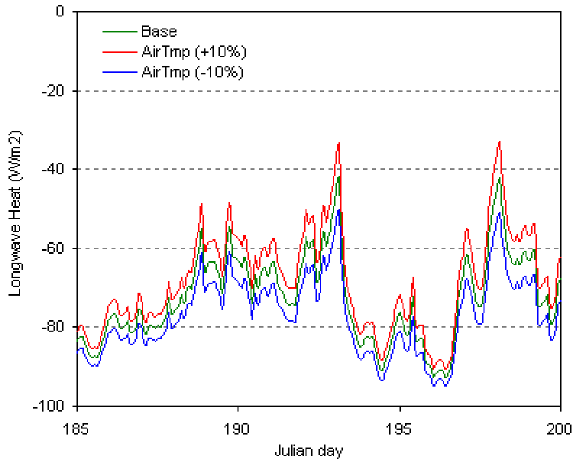
Surface Temperature (Ts)

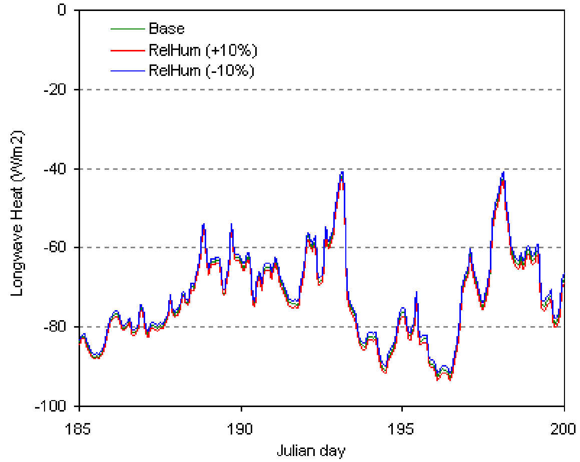


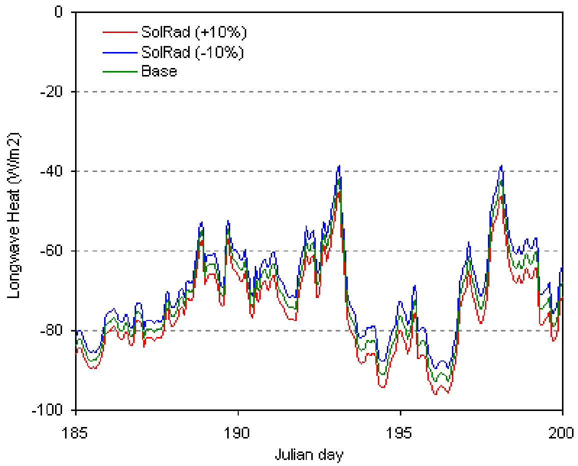
Total Heat Flux (Qt)

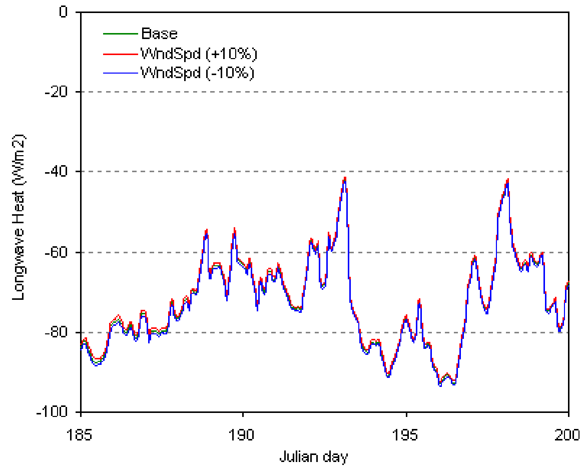


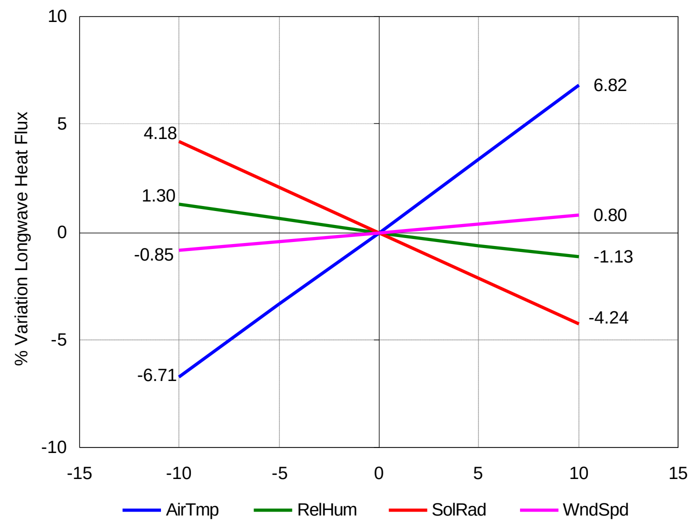
Sensitivity: Longwave Heat Flux



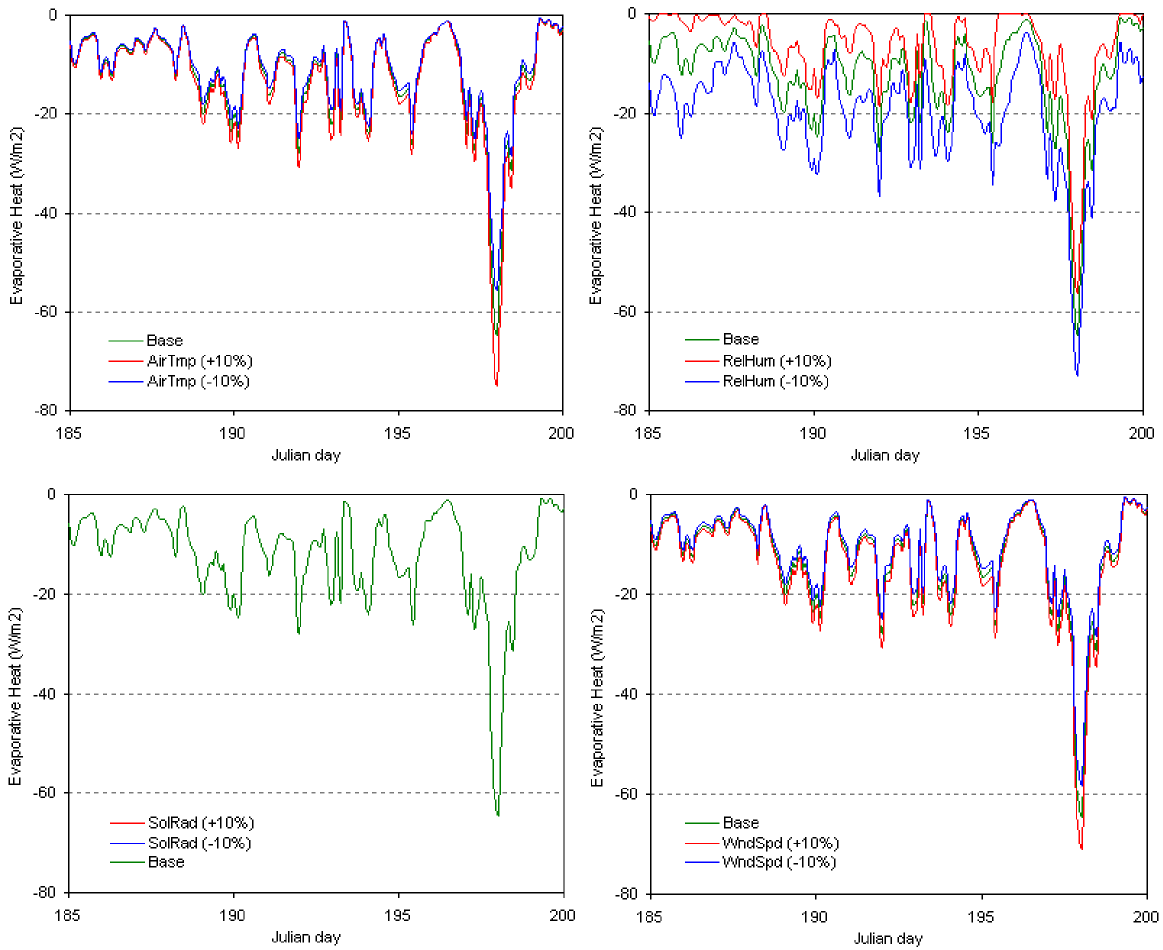


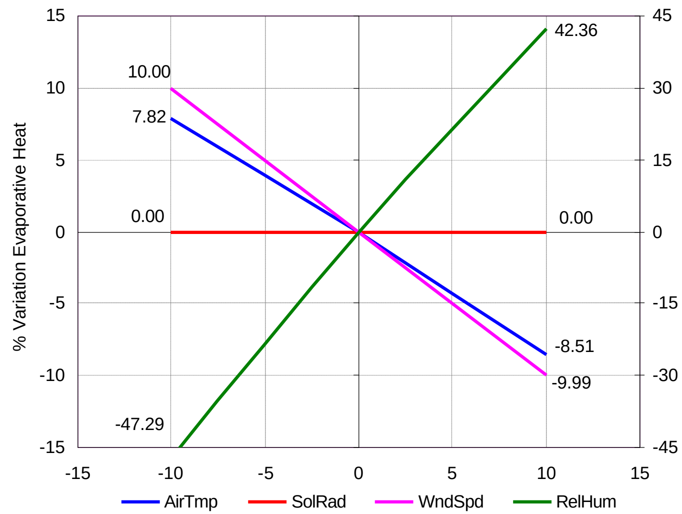




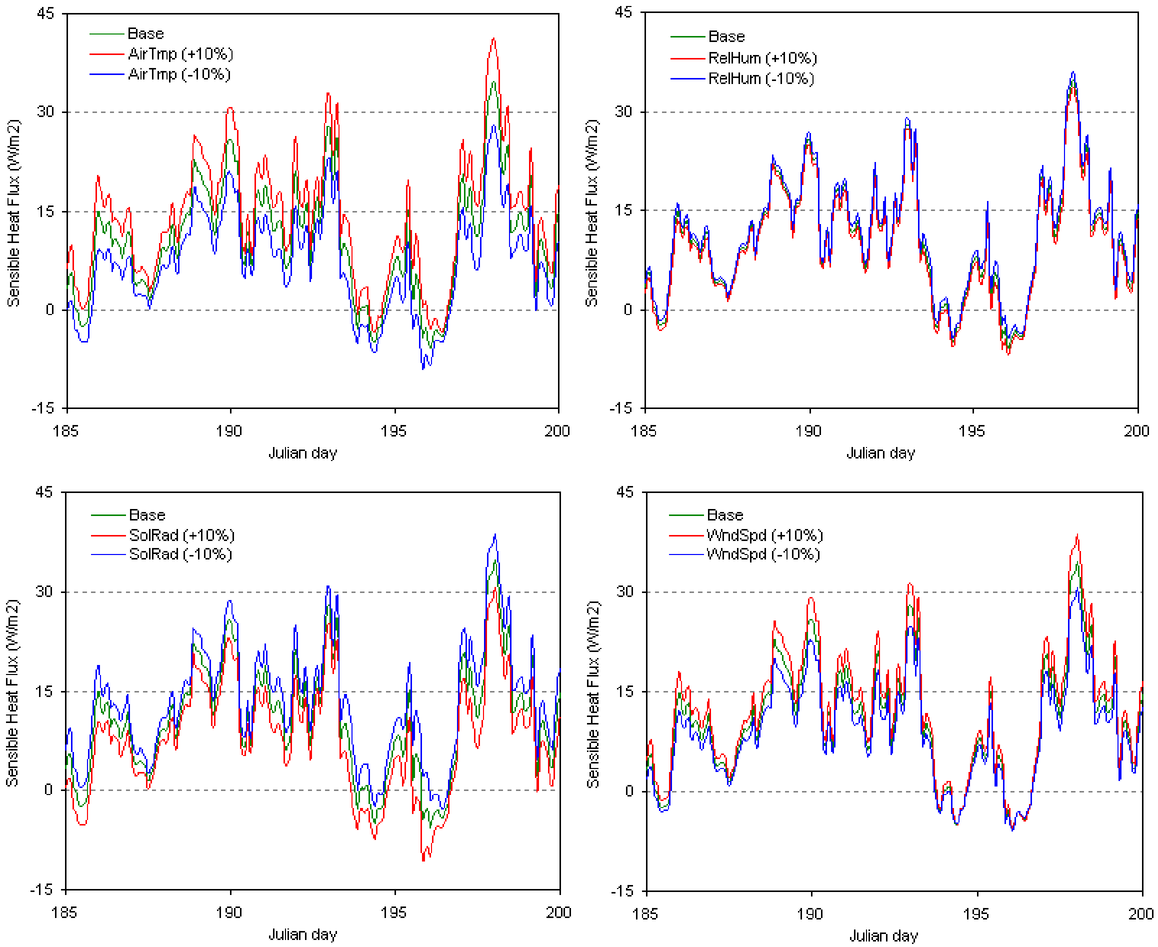


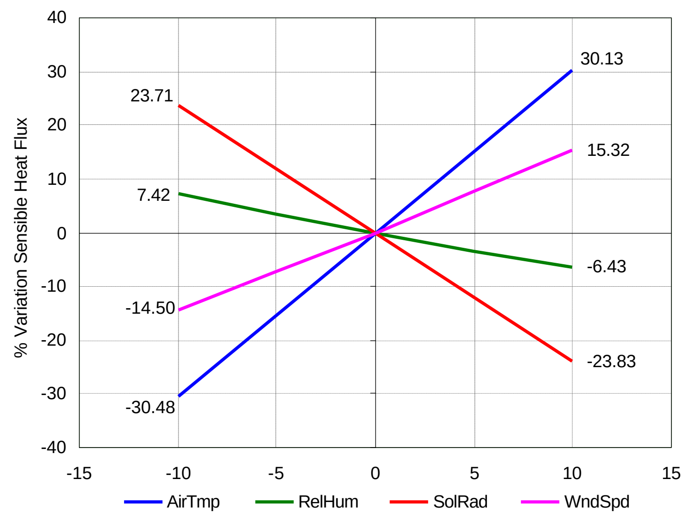
Sensitivity: Evaporative Heat Flux



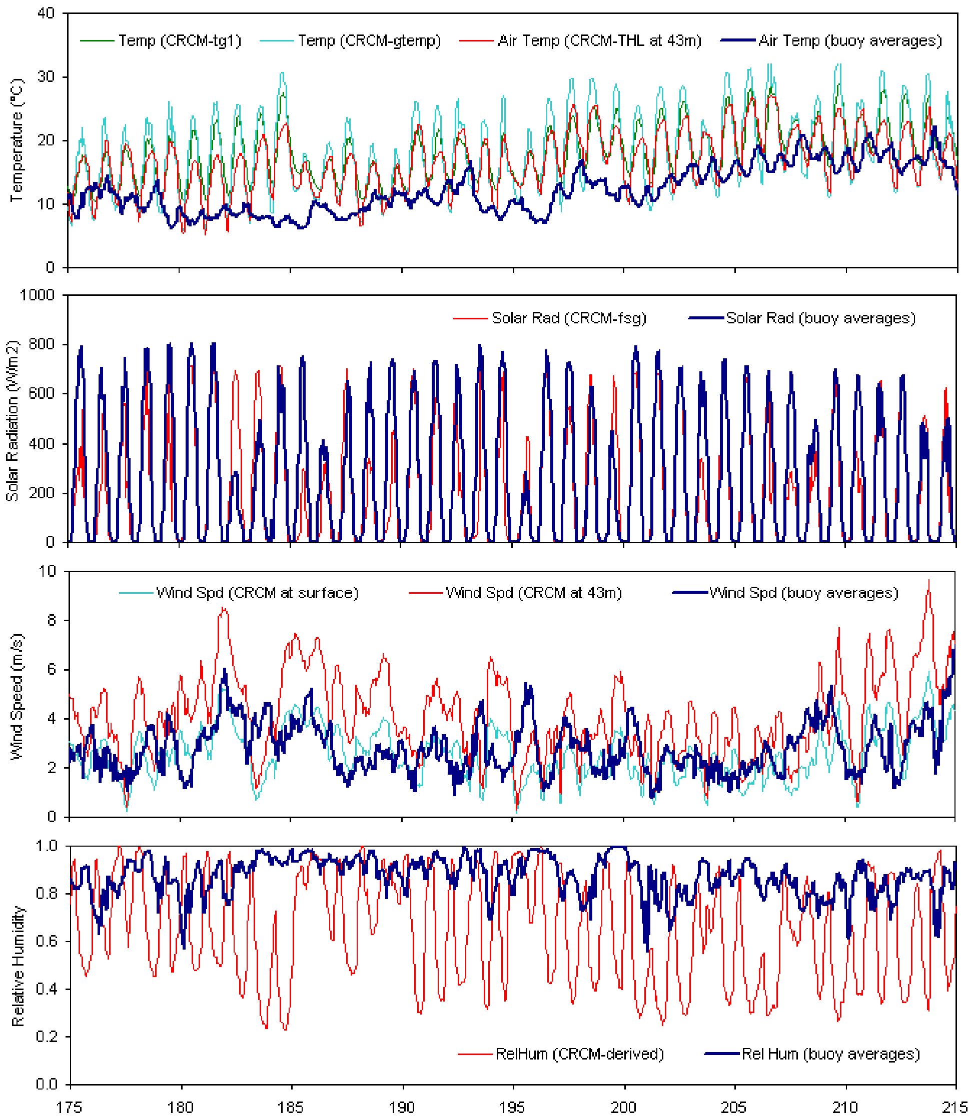


Sensitivity: Sensible Heat Flux





ELCOM-CRCM (sensitivity to input)



Air Temp. → **+16%**

SurfTemp	**+ 4.8 %**
Longwave	**+ 10.8 %**
Evaporative	**- 10.6 %**
Sensible	**+ 48.1 %**

Solar Rad. → **-10%**

SurfTemp	**- 8.2 %**
Longwave	**+ 4.2 %**
Evaporative	**0**
Sensible	**+ 23.7 %**

Wind Speed → **- 8%**

SurfTemp	**+ 1.4 %**
Longwave	**- 0.7 %**
Evaporative	**+ 8.0 %**
Sensible	**- 11.7 %**

Rel. Hum. → **-23%**

SurfTemp	**- 5.8 %**
Longwave	**+ 3.0 %**
Evaporative	**- 95.0 %**
Sensible	**+ 17.1 %**