Parameterizing Open Water Evaporation Rates

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IP3 Study of Lake Evaporation :

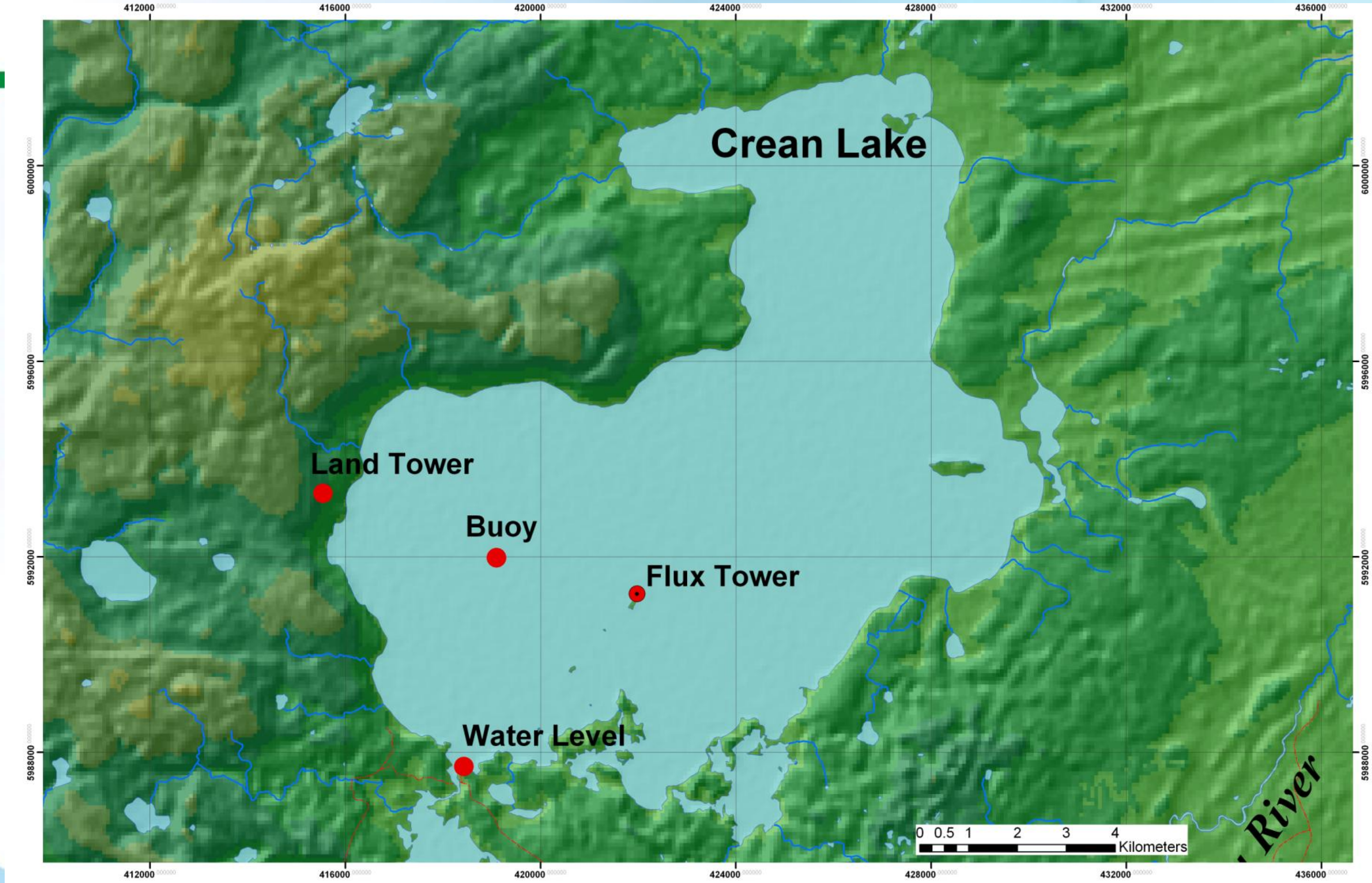
Evaporation is the process that links the energy and water balances at the earth's surface;

Meteorology, Climate and Hydrology Models operate with short time steps; ~ 1 hr;

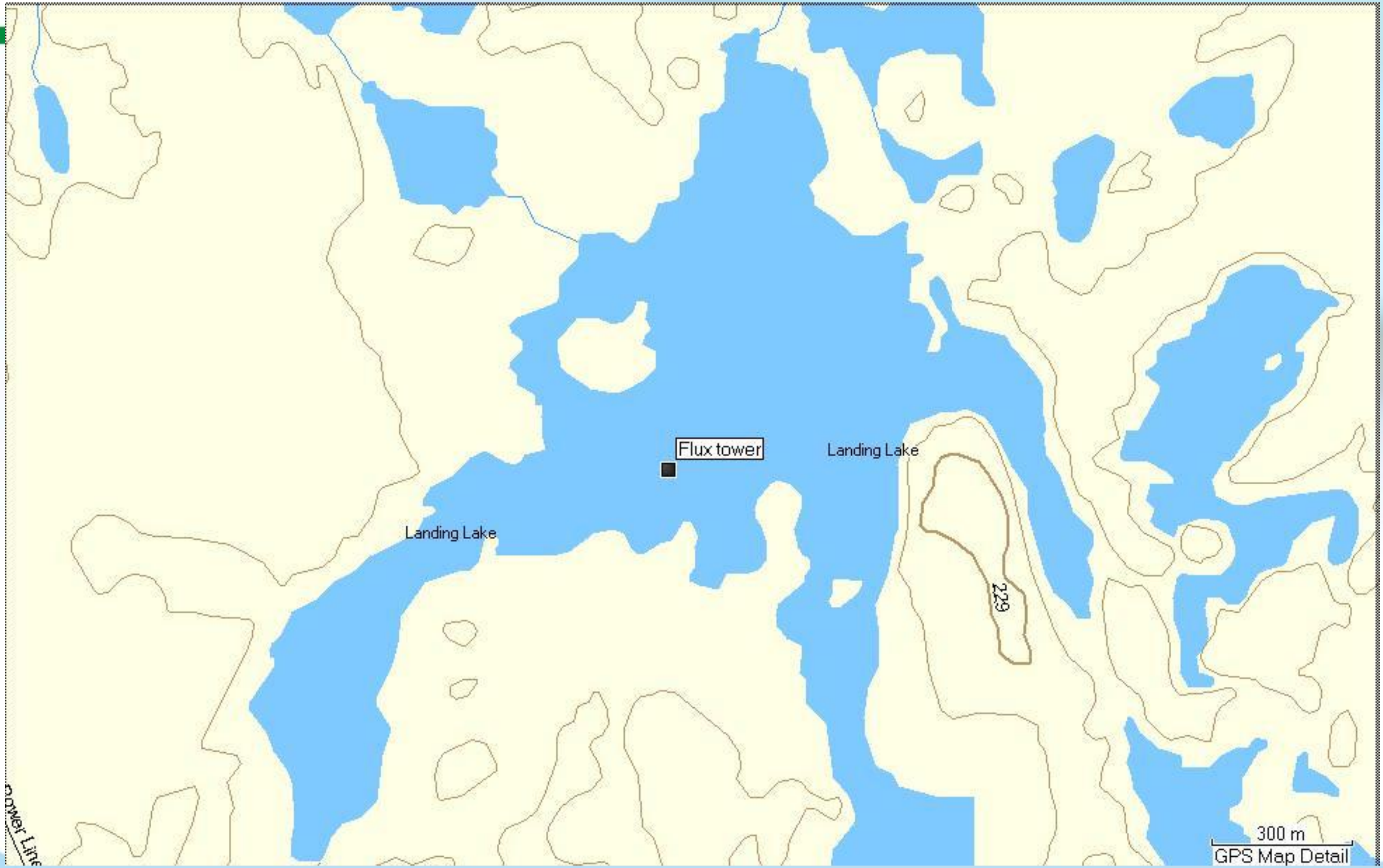
Modifying, Adjusting or Transporting Land-based models for Open water evaporation does not work;

OBJECTIVE: An Open Water Evaporation Model for Hourly time steps.

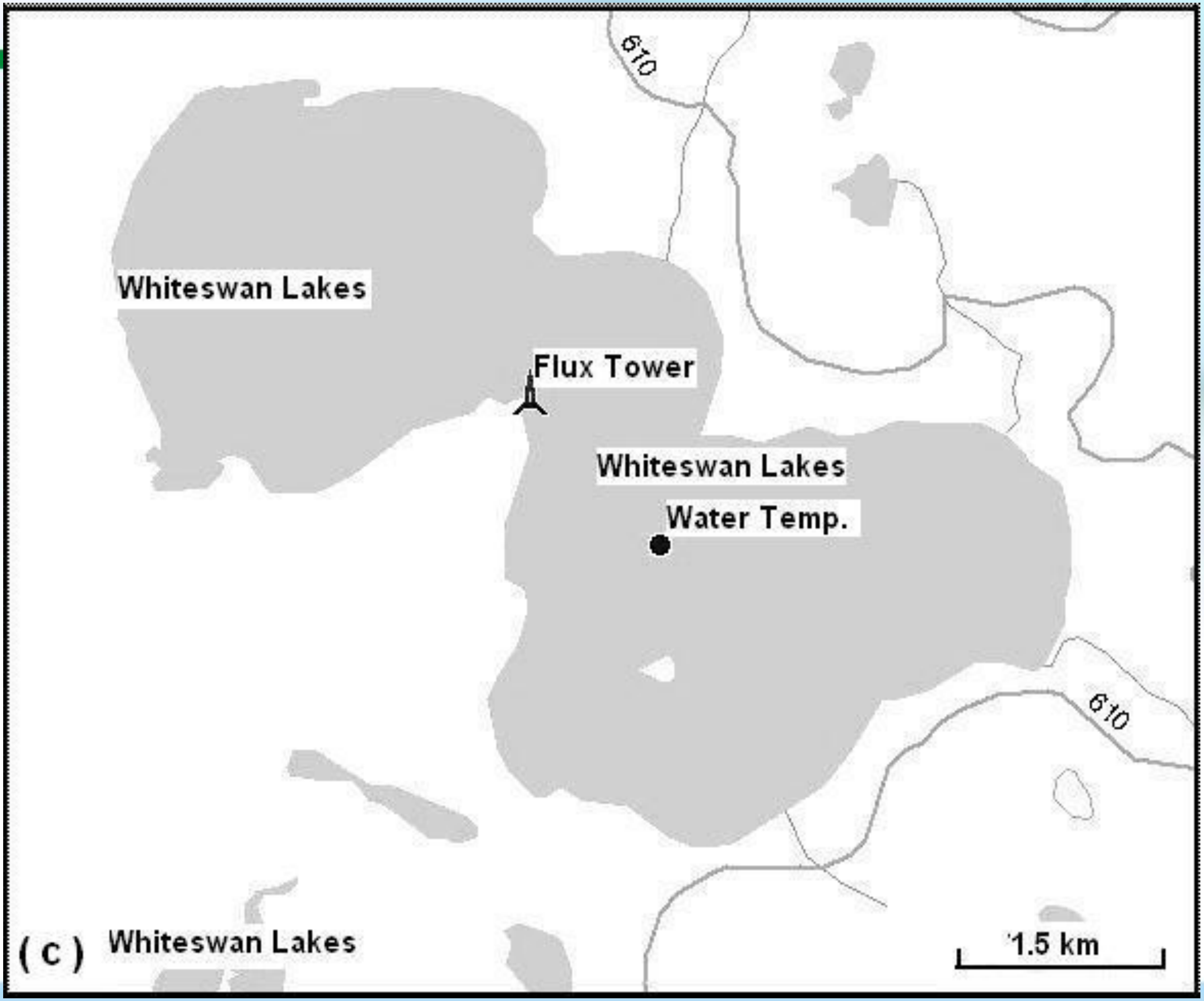
Crean Lake, PANP, 2006-2010



Landing Lake, NWT, 2007-2009



Whiteswan Lake (#4), SK, 2009-2010



Landing Lake, NWT, 2007-2009

Controls on Evaporation

Evaporation Models are parameterizations of one or more of the conditions required for evaporation to occur:

For evaporation to occur there must be:

- a **supply of water** at the surface,
- a **supply of energy** to satisfy the requirement for the phase change, and
- a **transport mechanism** to carry the vapour away from the surface (wind, vapour gradient).

For Open Water:

- The supply of water at the surface is non-varying.

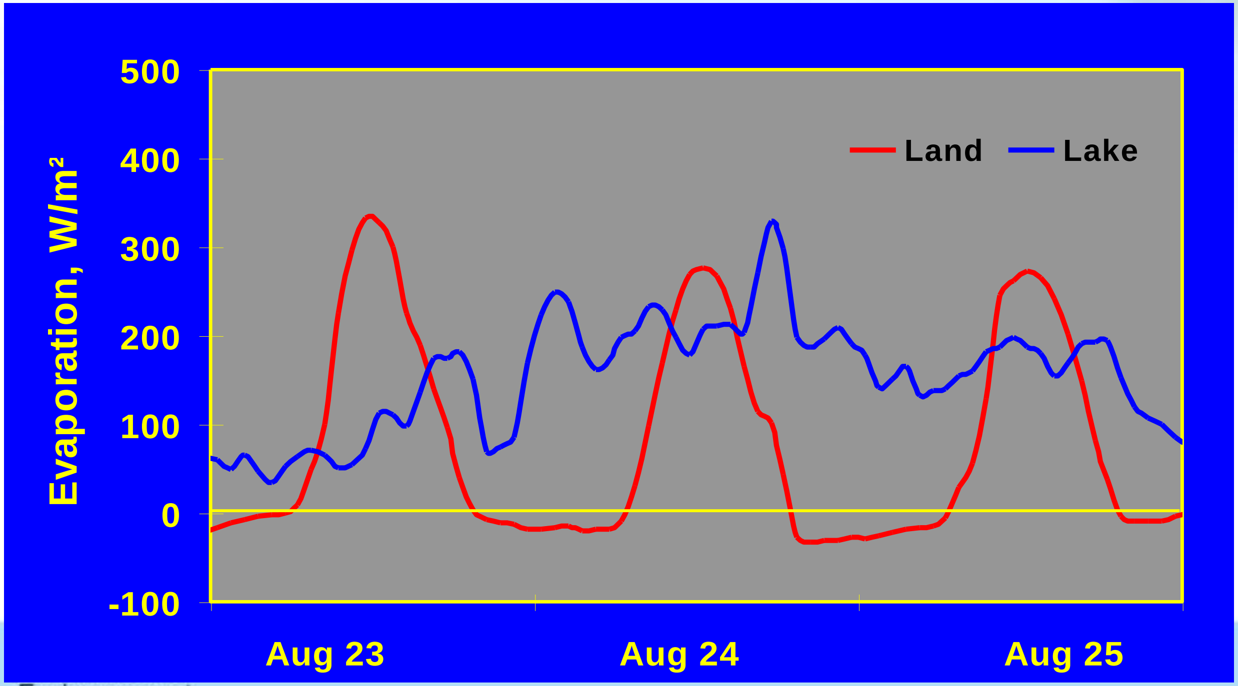
The surface is continuously saturated;
Unlike for land surfaces, parameterizing the water supply does not help.

For Open Water:

- The radiant energy penetrates deeply and so is not immediately partitioned at the surface.

One should not expect a relationship between net radiant and evaporation for short time periods.

Quill Lake 1993



For Open Water:

- The transport mechanism : the single, most important approach which can be used to describe evaporation at sub-daily rates.

The governing parameters are:

- vapour gradient
- wind speed
- stability

The available observations are:

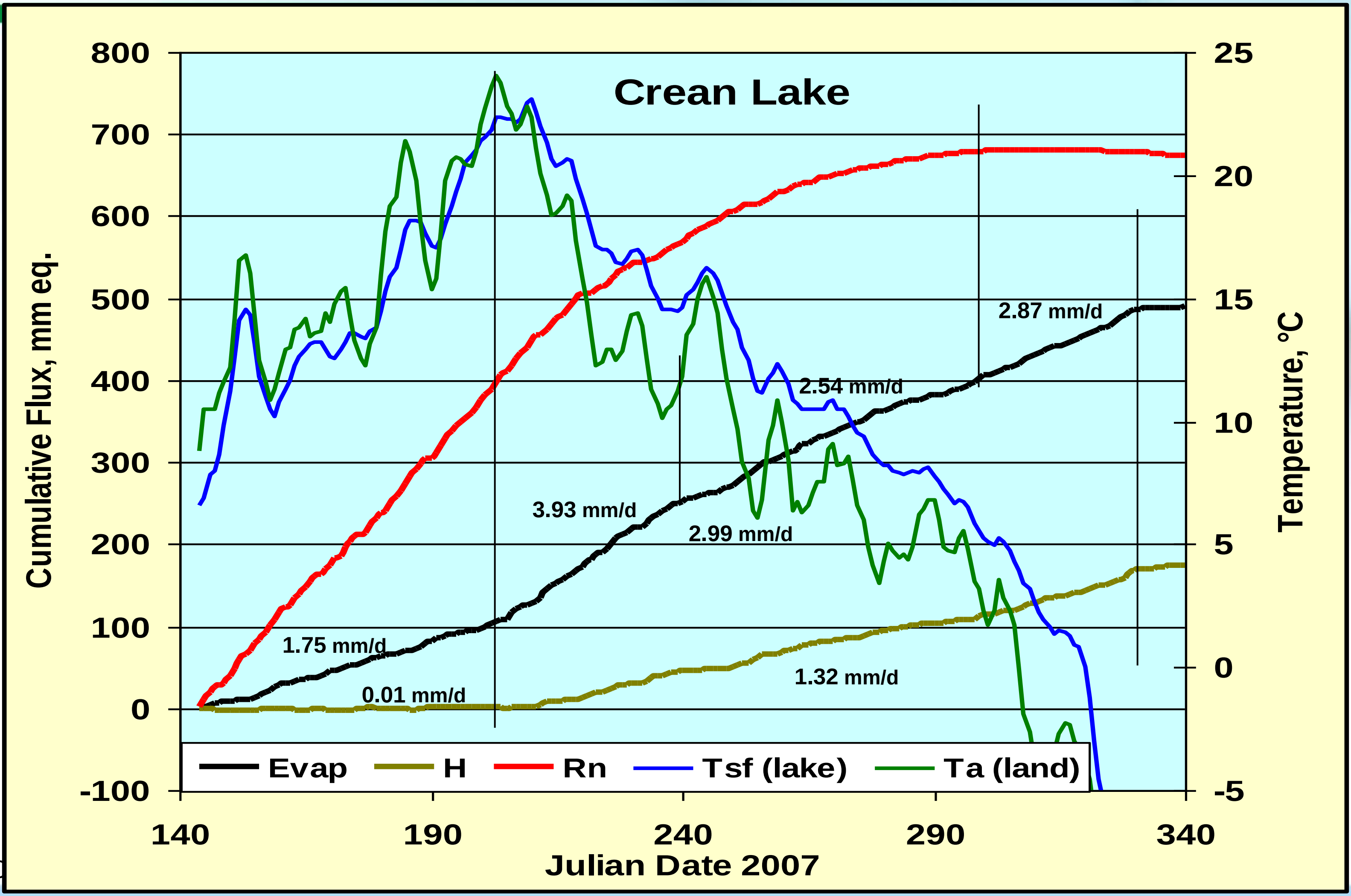
- water surface temp.(?)
- wind speed over water(?)

Evaporation from open water (lakes and ponds) involves *advection*:

Conditions over the water are affected by:

- **Conditions over the adjacent land surface (Vapour and Temperature Gradients are affected by the *land-water contrast*);**
- **Distance from the upwind shore.**

Seasonal Cycle of Stability

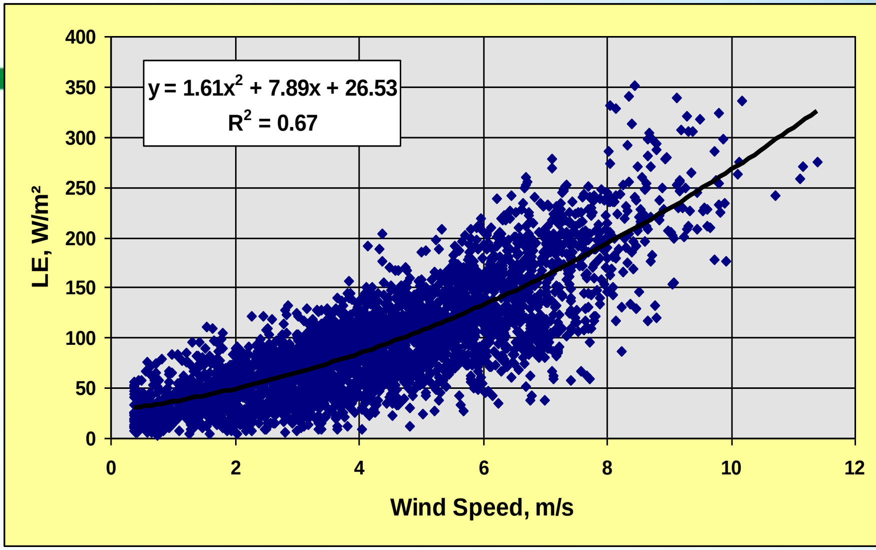


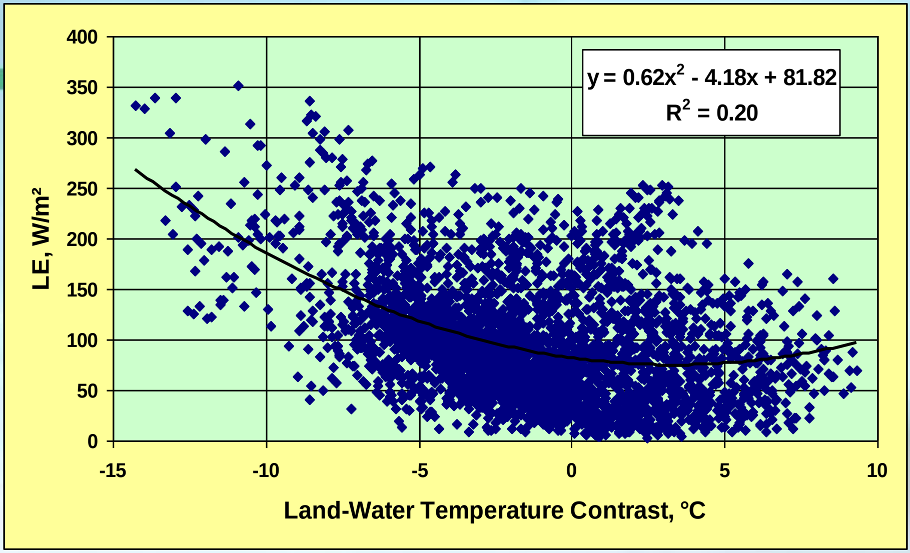
Modeling Hourly Lake Evaporation

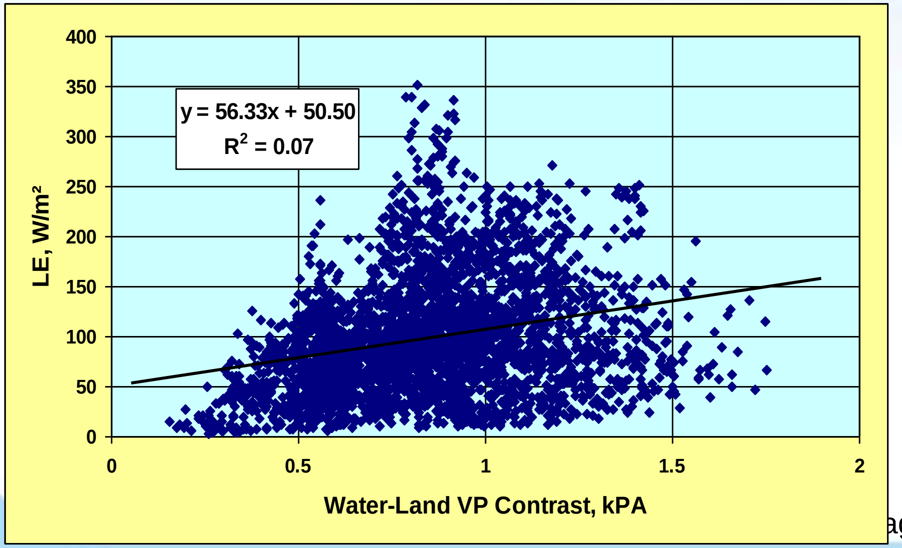
Approach using the development of relationships based on:

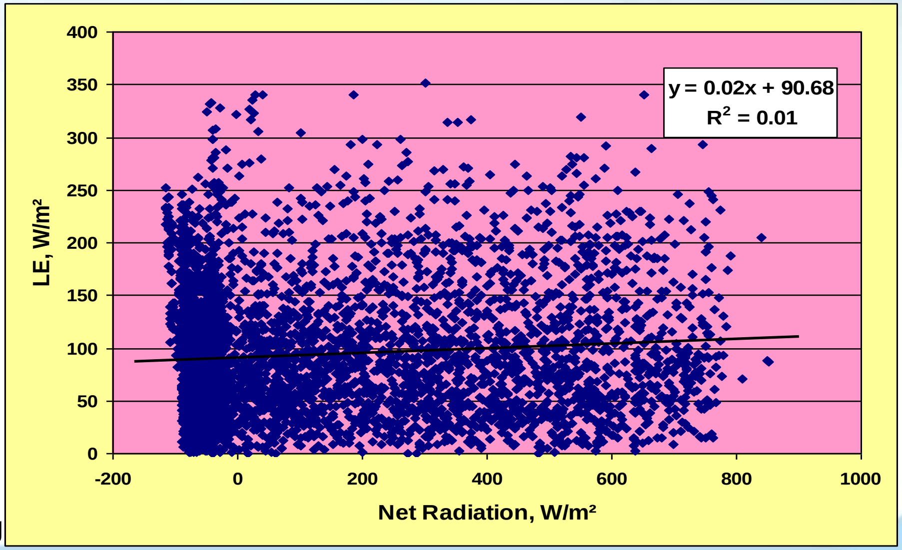
- **Wind speed,**
- **Stability**
  (land-water temperature contrast)
- **Distance from shore**
- **Vapour gradient**
  (water-land VP contrast)

Effect of Wind, T, VP and Rn on Lake Evaporation









Modeling Hourly Lake Evaporation

Half-hourly data from

Crean Lake (2006-2010)

Landing Lake (2007-2009)

Whiteswan Lake (2009-2010)

Oscar Lake (2010)

Sorted into:

- stable and unstable categories

- distance from shore (fetch: 90m – 10,000m)

- land-water temperature contrast

Succssive regression

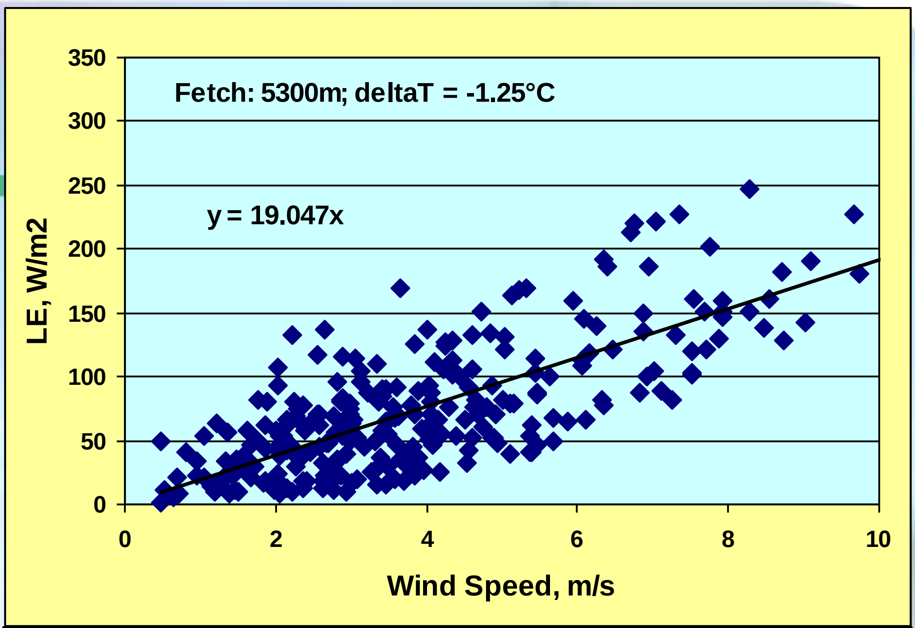
- LE related to wind speed, dT, dVP, Fetch

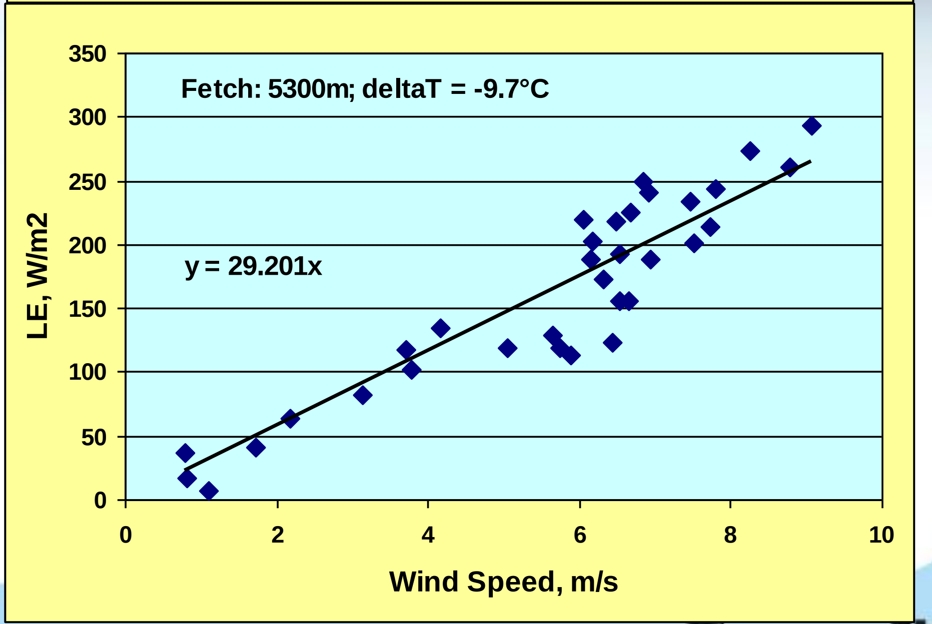
Modeling Hourly Lake Evaporation

LE = a*U

Using coefficients from all categories

a = f(X, ΔT, ΔVP)





Hourly Lake Evaporation Model

$$LE = a*U \; ; \quad a = f(\Delta T, \Delta VP, X)$$

For Unstable cases:

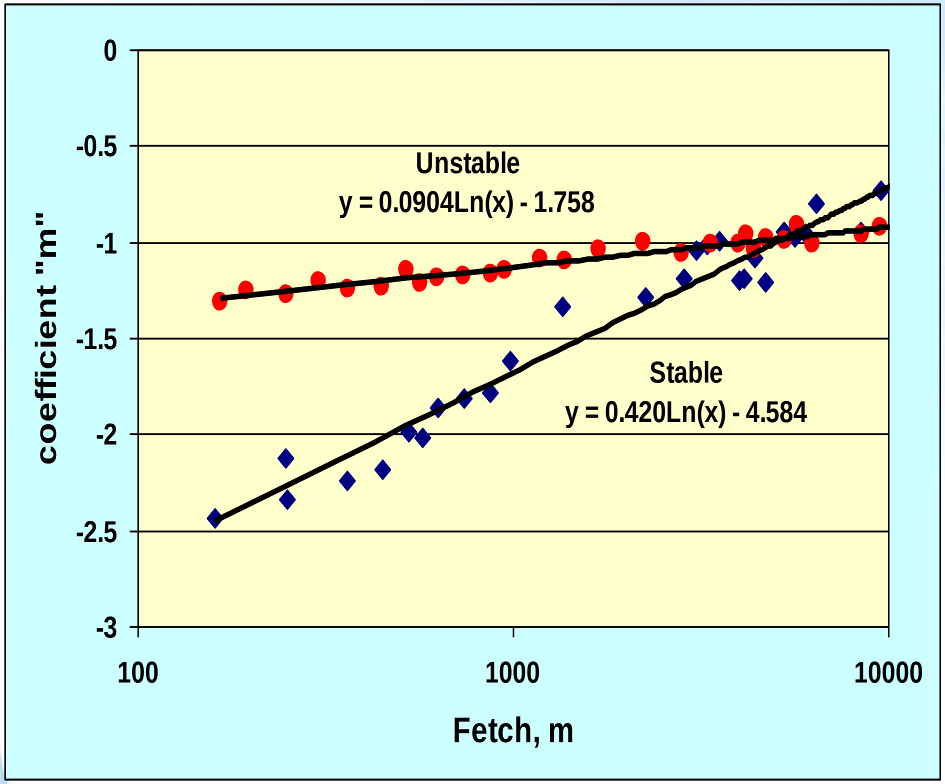
$$a = b + m* \Delta T + n* \Delta VP$$

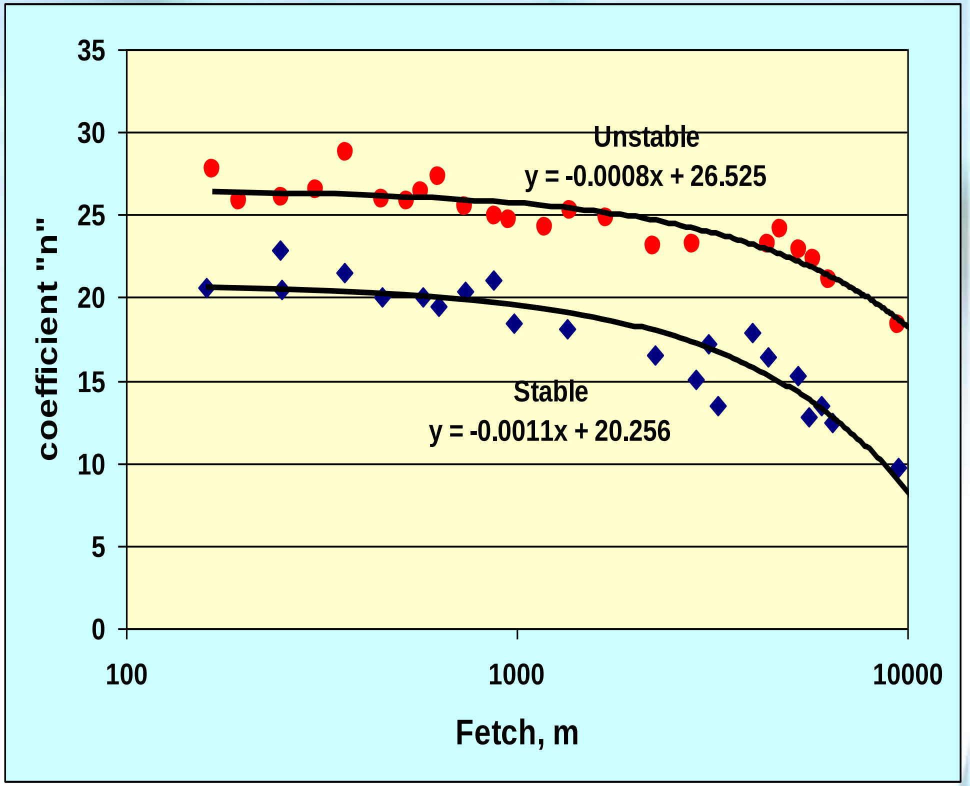
For Stable cases:

$$a = b + c*\exp(m* \Delta T) + n* \Delta VP$$

$$b, c, m, n = f(X)$$

Modeling Hourly Lake Evaporation





Hourly Lake Evaporation Model

$$LE = a*U\ ; \quad a = f(\Delta T, \Delta VP, X)$$

$$a = b + m*\ \Delta T + n*\ \Delta VP$$

Stable cases: $a = b + c*\exp(m*\ \Delta T) + n*\ \Delta VP$

$b = -23.78 + 2.1212 \bullet \ln(X)$

$c = 22.387 - 0.0007*X$

$m = -0.442 + 0.035 \bullet \ln(X)$

$n = 15.607 - 0.0007 \bullet X$

Unstable cases: $a = b + m*\ \Delta T + n*\ \Delta VP$

$b = 2.489 + 0.0002 \bullet X$

$m = -1.805 + 0.095 \bullet \ln(X)$

$n = 27.053 - 0.0008 \bullet X$

Hourly Lake Evaporation Model

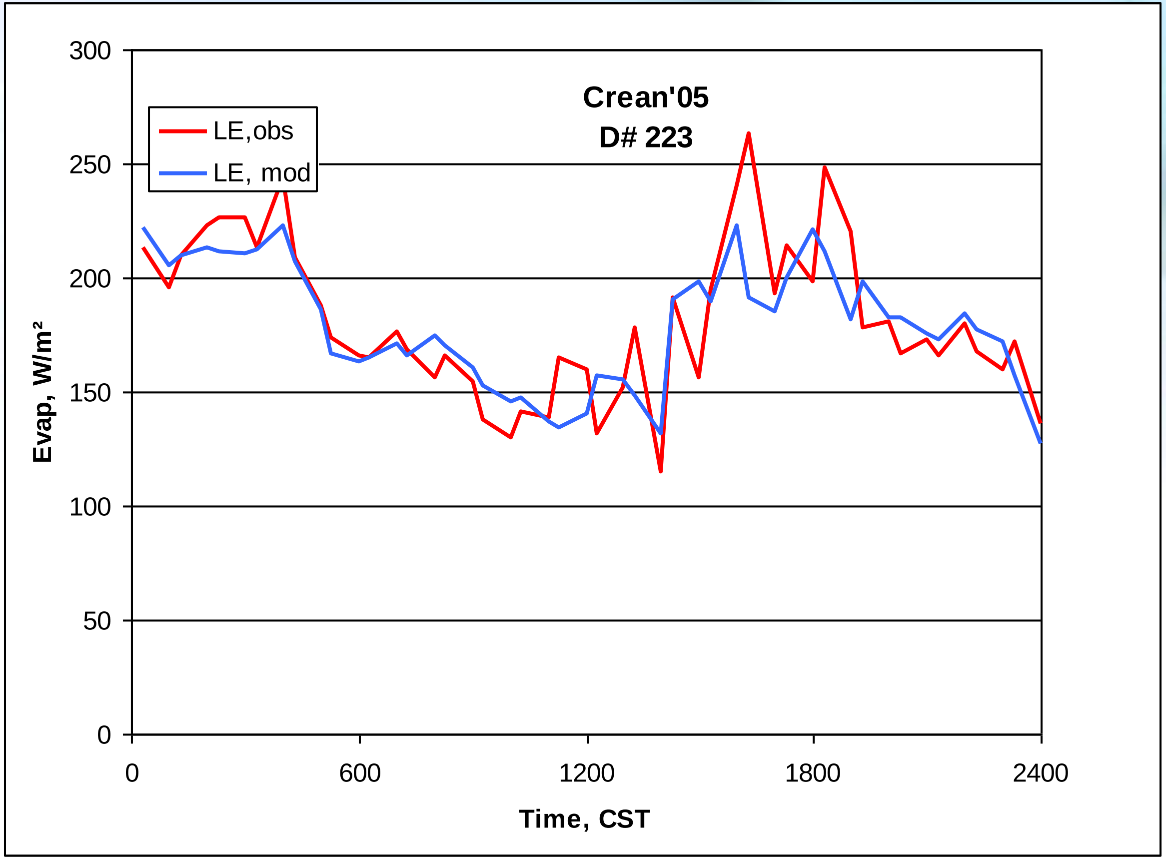
Verification data sets :

Crean 2005 (land data from mixedwood site)

Quill 1993 (Heatmex data)

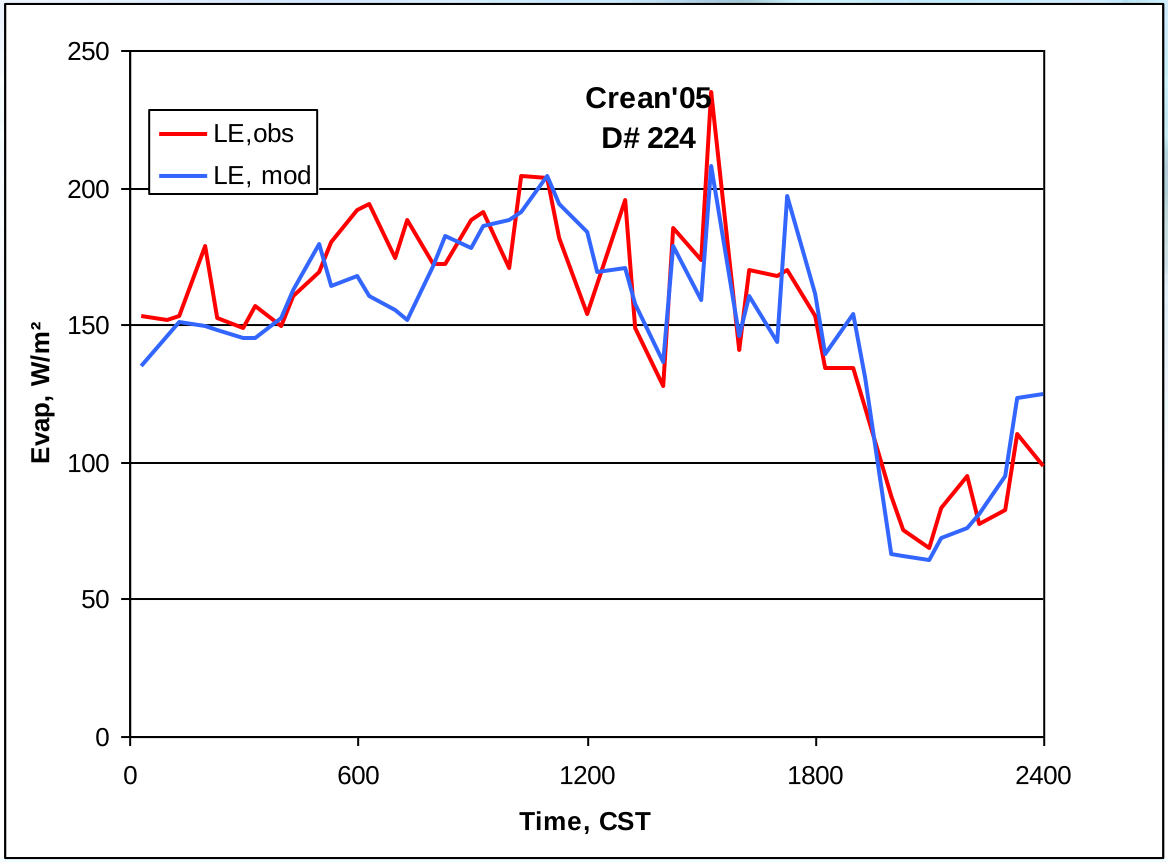
Hourly Lake Evaporation Model

Verification results *Crean 2005*



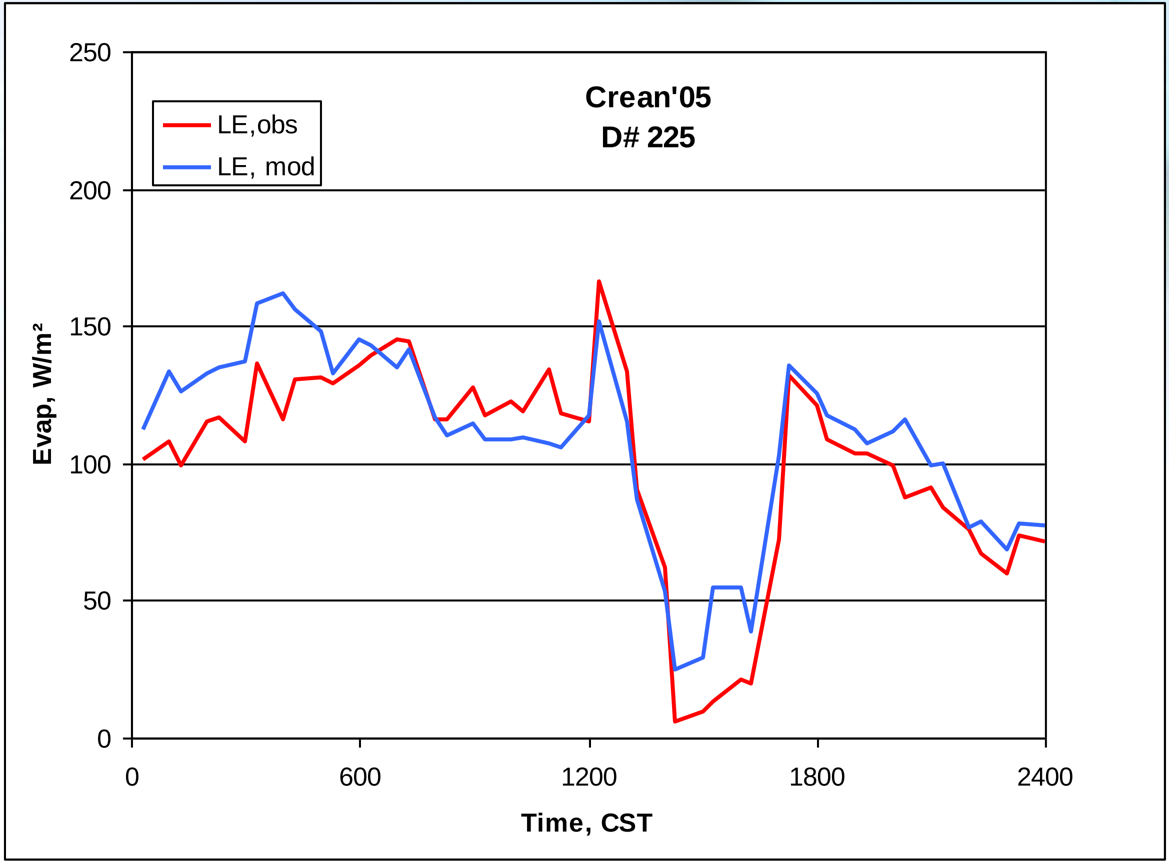
Hourly Lake Evaporation Model

Verification results *Crean 2005*



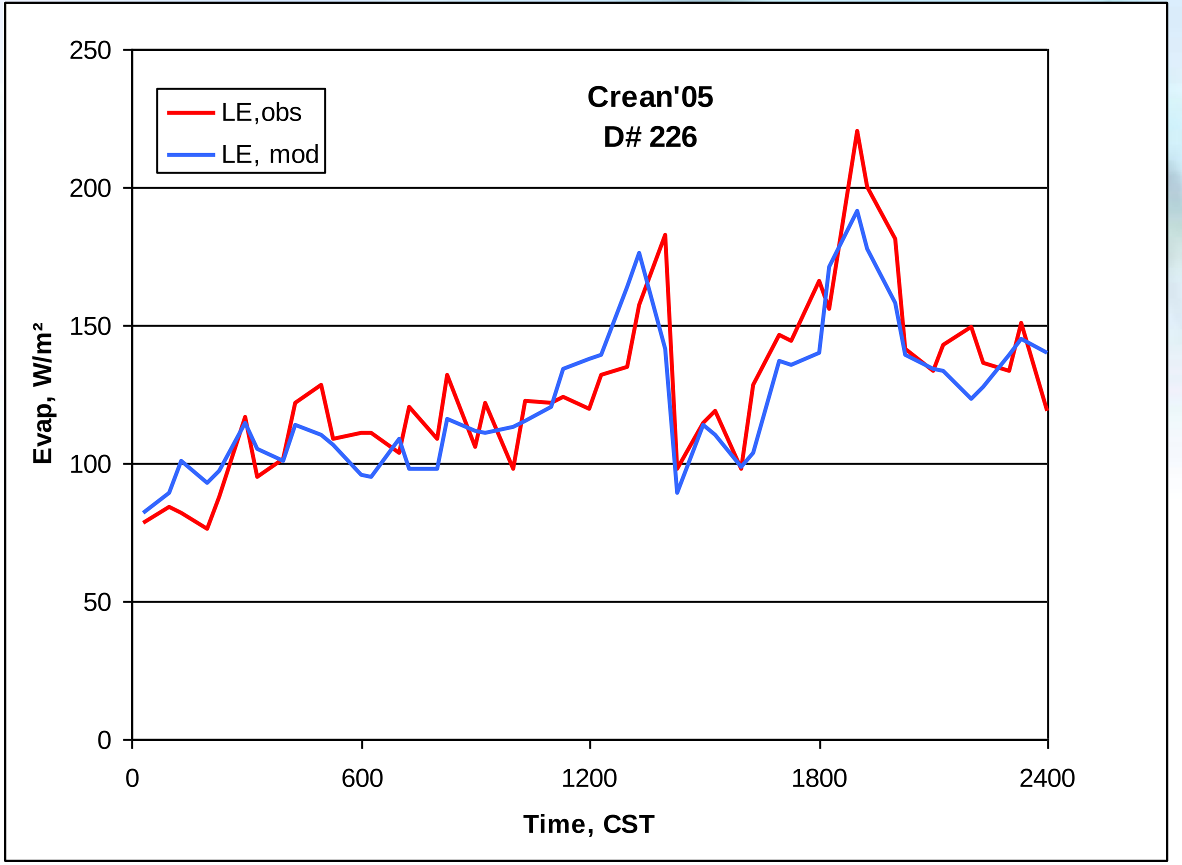
Hourly Lake Evaporation Model

Verification results *Crean 2005*



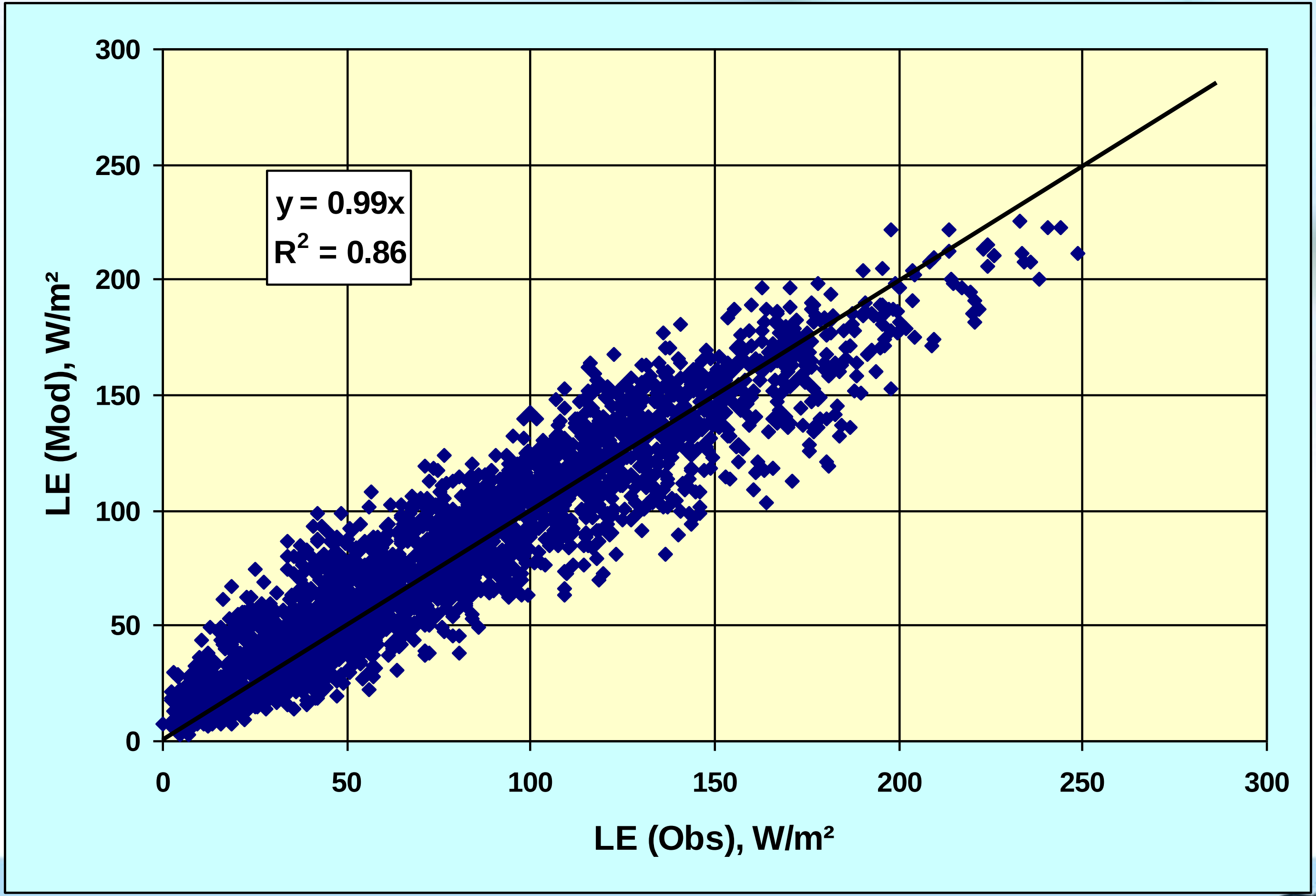
Hourly Lake Evaporation Model

Verification results *Crean 2005*



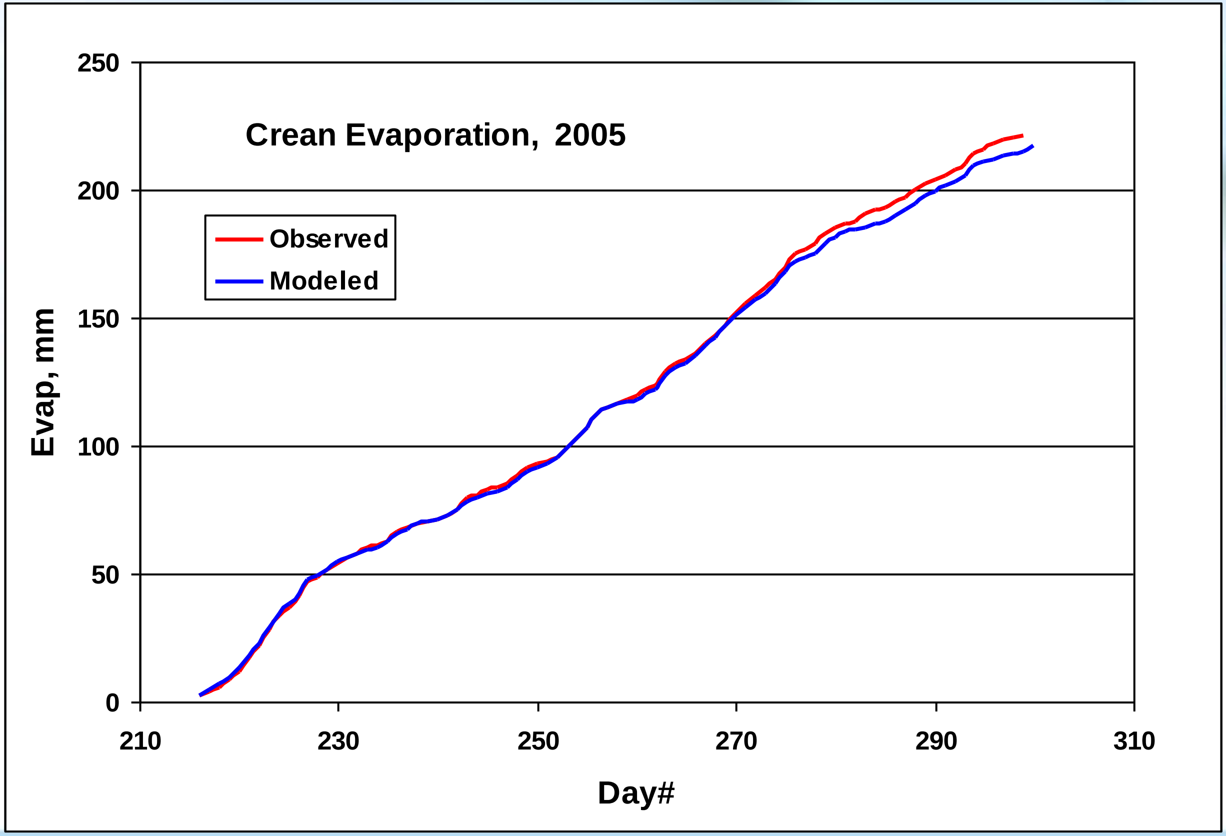
Hourly Lake Evaporation Model

Verification results *Crean 2005*



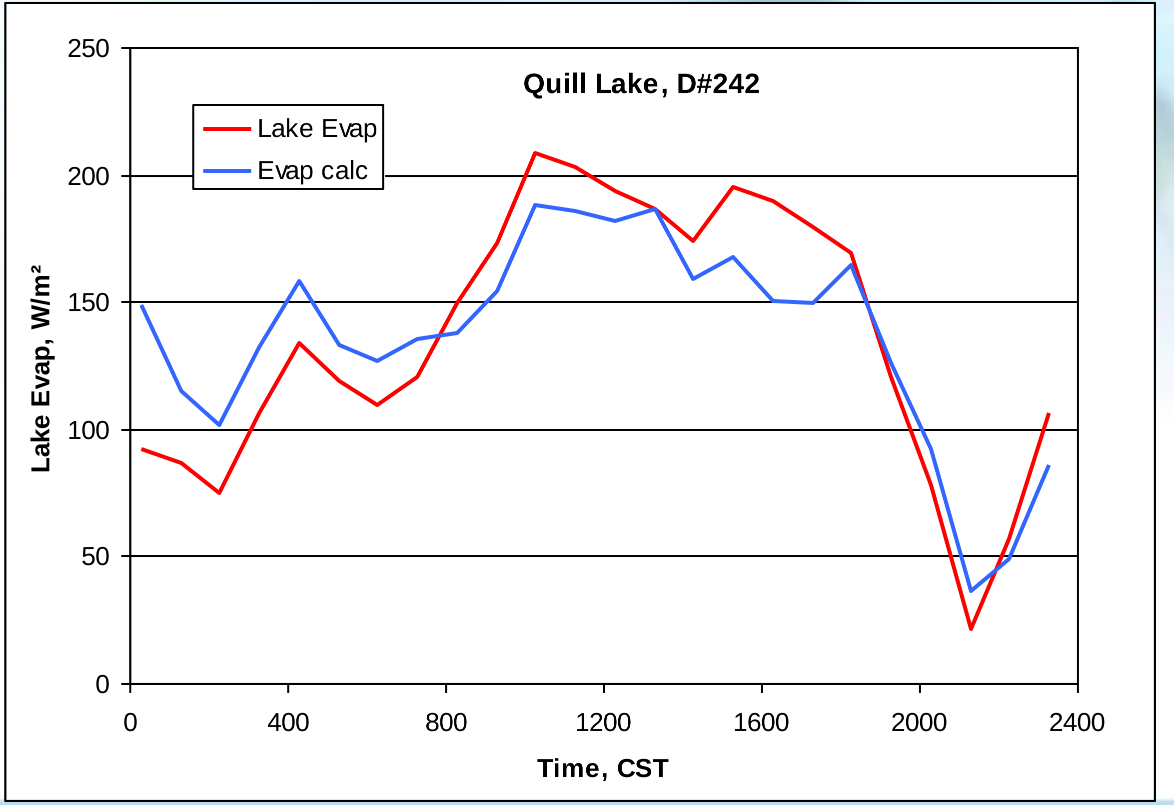
Hourly Lake Evaporation Model

Verification results *Crean 2005*



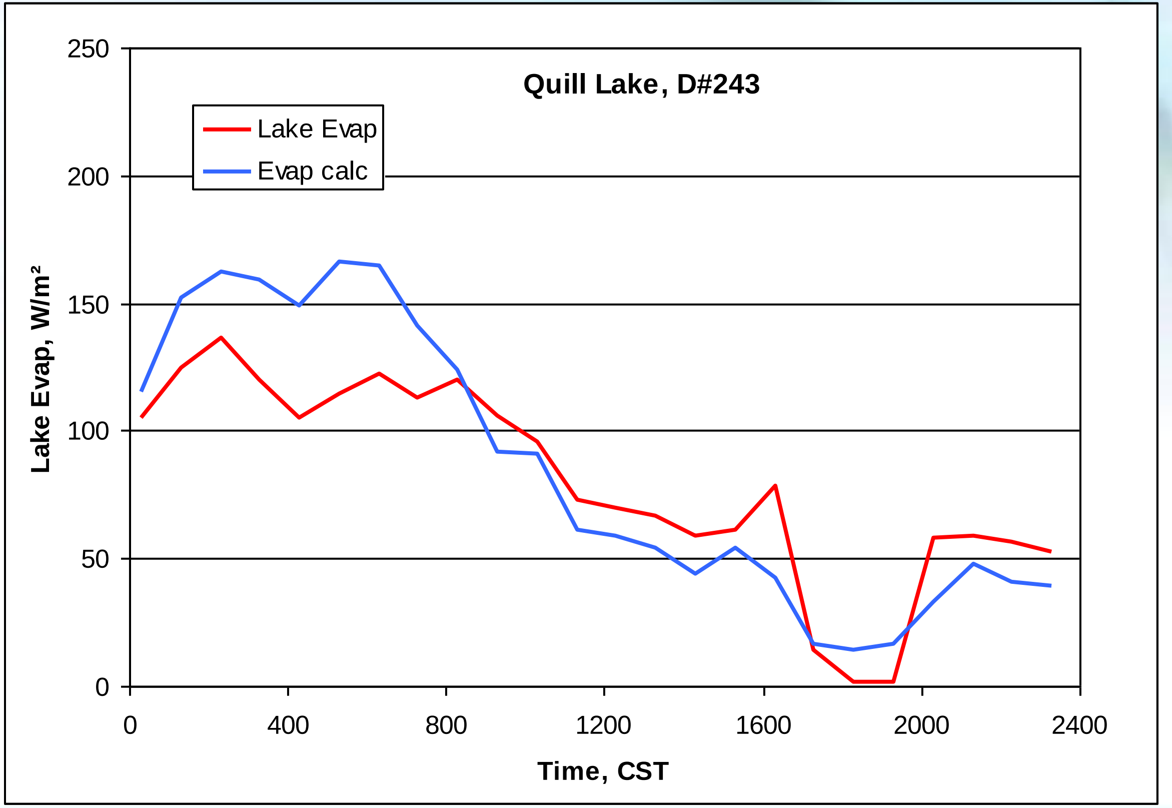
Hourly Lake Evaporation Model

Verification results *Quill 1993*



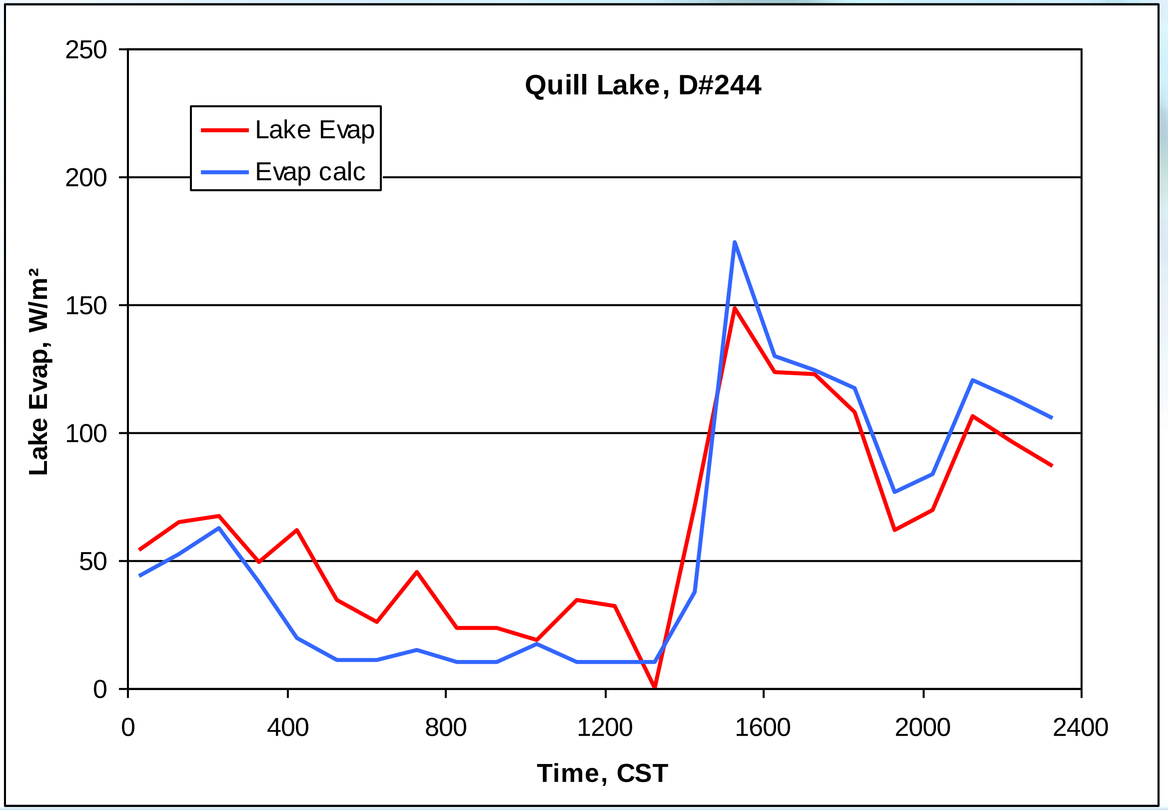
Hourly Lake Evaporation Model

Verification results *Quill 1993*



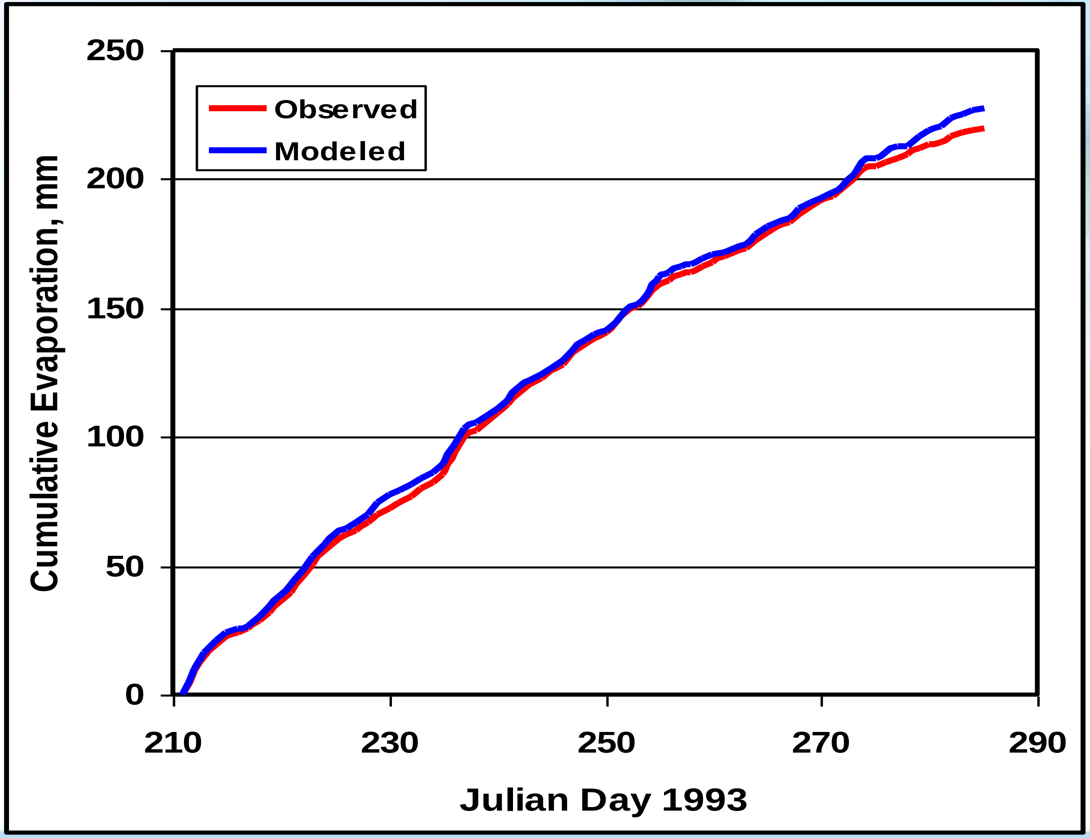
Hourly Lake Evaporation Model

Verification results *Quill 1993*



Hourly Lake Evaporation Model

Verification results *Quill 1993*



Daily Lake Evaporation Model

$$LE = a*U \; ; \quad a = f(\Delta T, \Delta VP, X)$$

For Unstable cases:

$$a = b + m*\,\Delta T + n*\,\Delta VP$$

For Stable cases:

$$a = b + c*\exp(m*\,\Delta T) + n*\,\Delta VP$$

$$b, c, m, n = f(X)$$

Daily Lake Evaporation Model

$$LE = a*U ; \quad a = f(\Delta T, \Delta VP, X)$$

$$a = b + m* \Delta T + n* \Delta VP$$

Stable cases: $a = b + c*\exp(m* \Delta T) + n* \Delta VP$

$b = -22.905 + 2.098 \cdot \ln(X)$

$c = 22.336 - 0.0007*X$

$m = -0.572 + 0.049 \cdot \ln(X)$

$n = 15.668 - 0.0008 \cdot X$

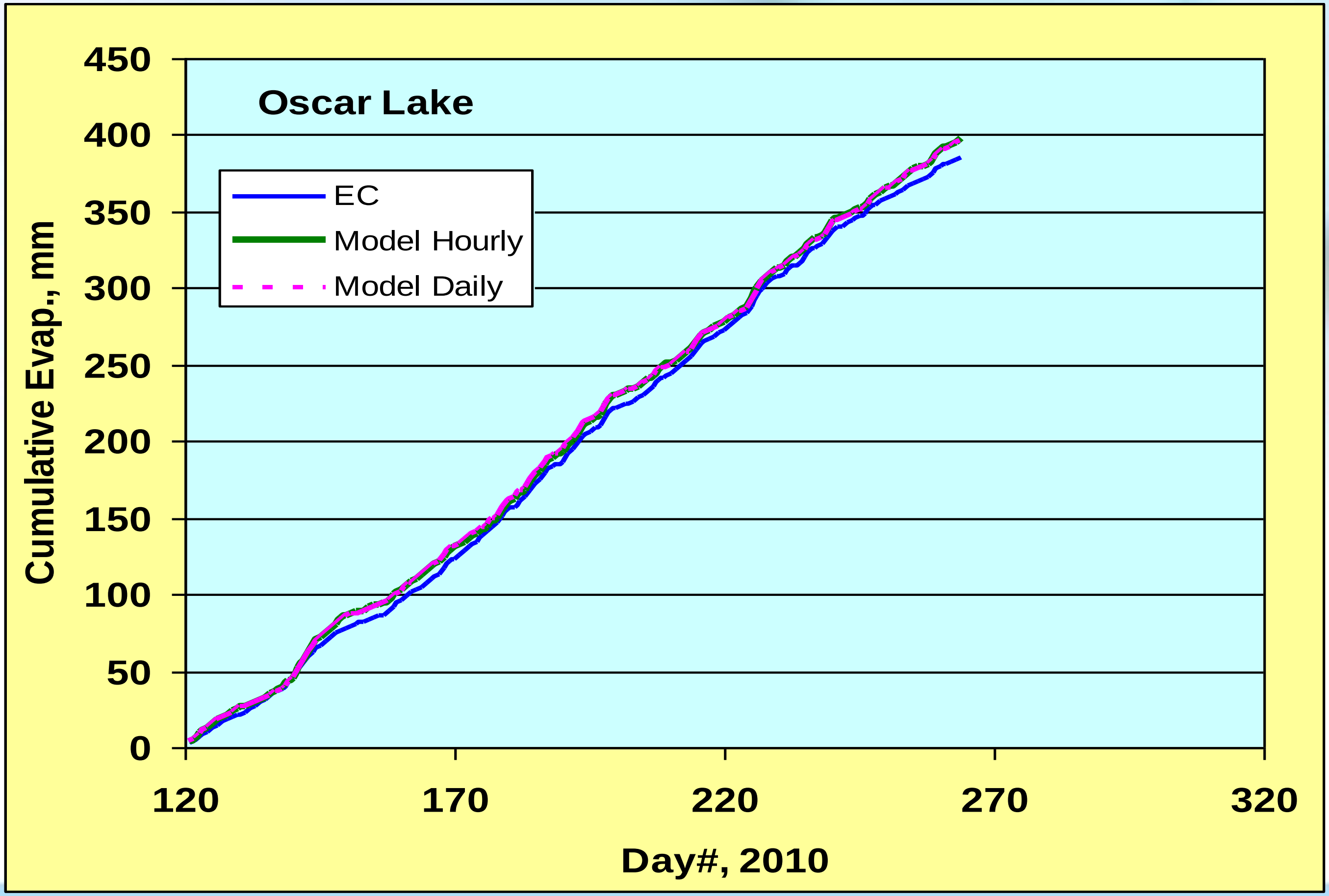
Unstable cases: $a = b + m* \Delta T + n* \Delta VP$

$b = 3.701 + 0.0007 \cdot X$

$m = -1.878 + 0.106 \cdot \ln(X)$

$n = 28.723 - 0.0008 \cdot X$

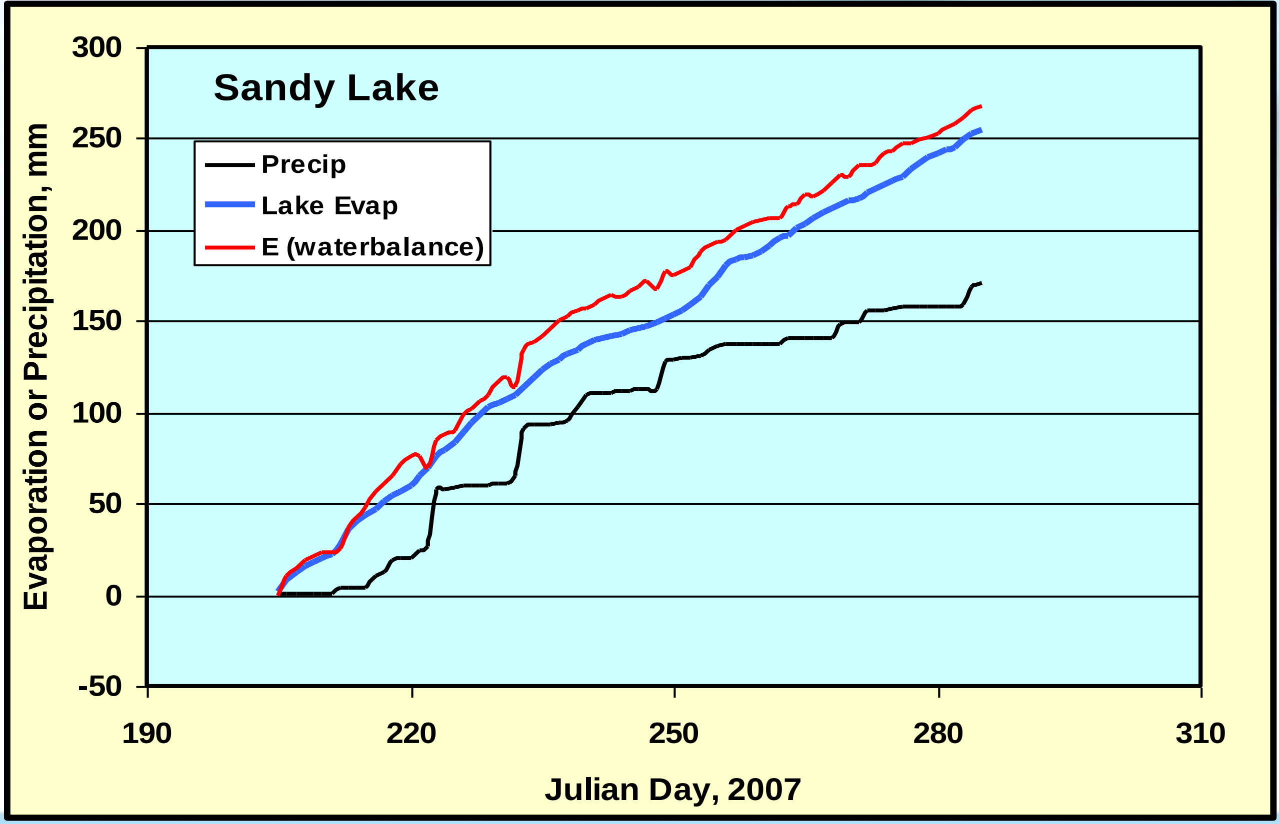
Comparing Hourly and Daily Lake Evaporation Estimates



Testing Lake Evaporation Model

Water Balance Application

Sandy Lake, *PANP*



Summary

- A model for ***Hourly Lake Evaporation*** has been developed**.**

- Relatively simple, reliable
- Requires land data: **Ta, VP, U, Udir**
  NB: In forested areas, these data must be obtained above the forest canopy!
- Requires lake data: **Tsf, U, Fetch**

- Model coefficients were generated for **Daily** values.

Possible Next Steps

- Testing and Application
  - Waskesiu
  - Diefenbaker ?
- Expand range of Fetch sizes
  - Larger lakes: Lake Okanagan;
- Apply to total lake area.
  - (“Effective fetch” vs Wind Direction)
- Test in model framework (RCM?, MESH?)

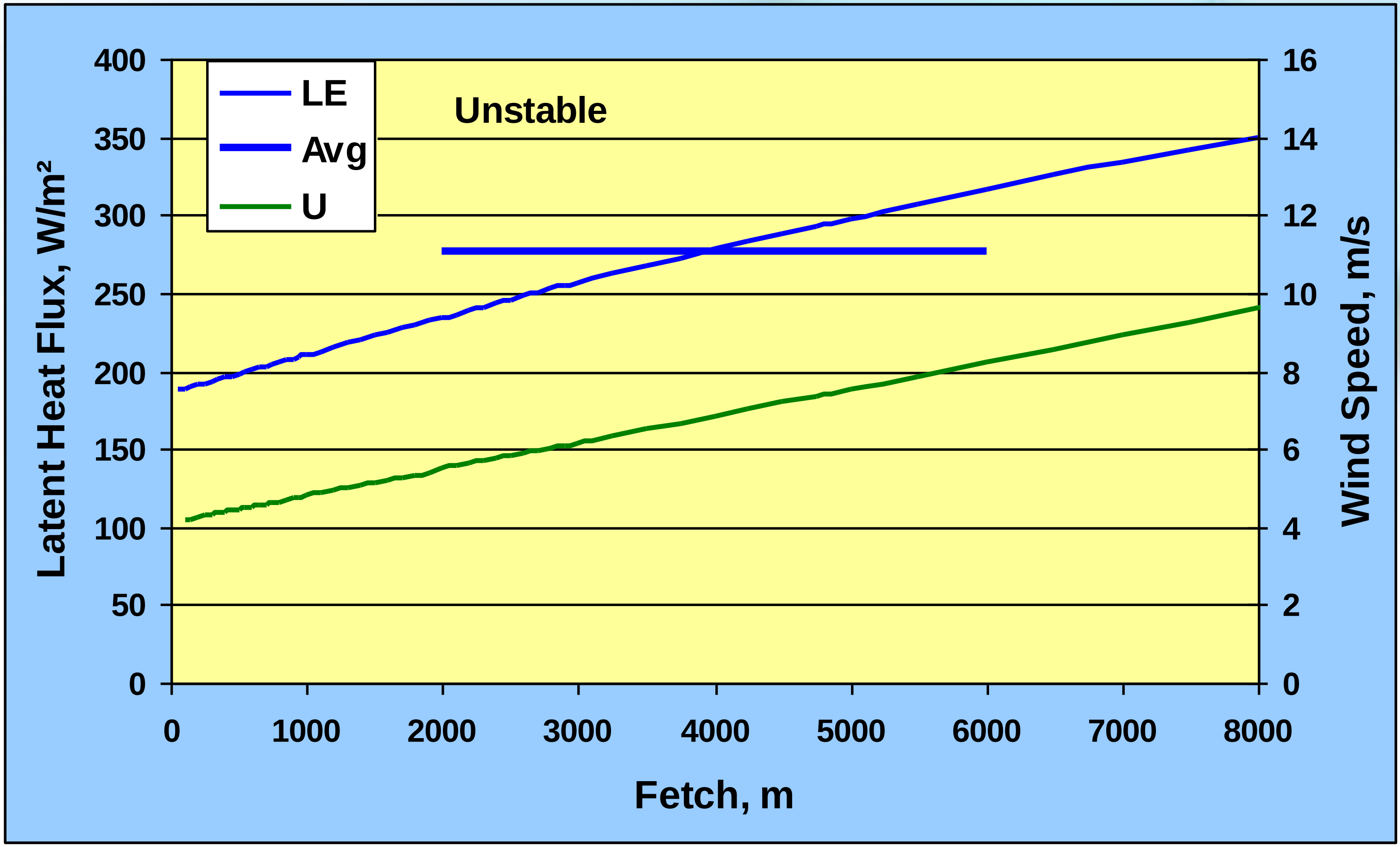
Thank you!

- IP3, IPY ($$)
- Chris Spence (Baker Creek Land data)
- PANP (logistics support)

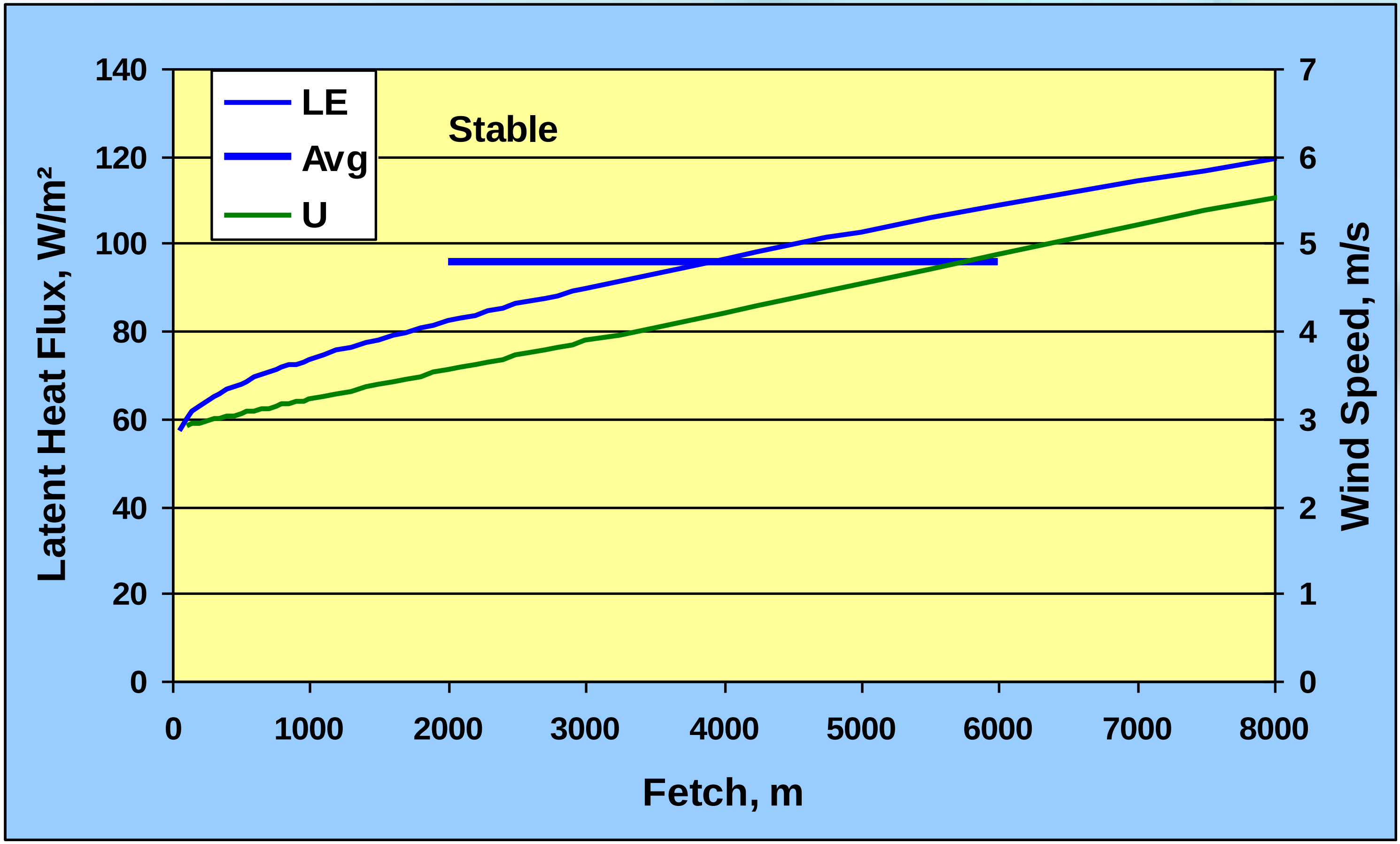
Publication

- Granger, R. J. and Hedstrom, N.: **Controls on open water evaporation**, *Hydrol. Earth Syst. Sci. Discuss*., 7, 2709-2726, doi:10.5194/hessd-7-2709-2010, 2010.
- Granger, R. J. and Hedstrom, N.: **Modelling hourly rates of lake evaporation**, *Hydrol. Earth Syst. Sci. Discuss*., 7, 2727-2746, doi:10.5194/hessd-7-2727-2010, 2010.

Mean Evaporation, Unstable Case

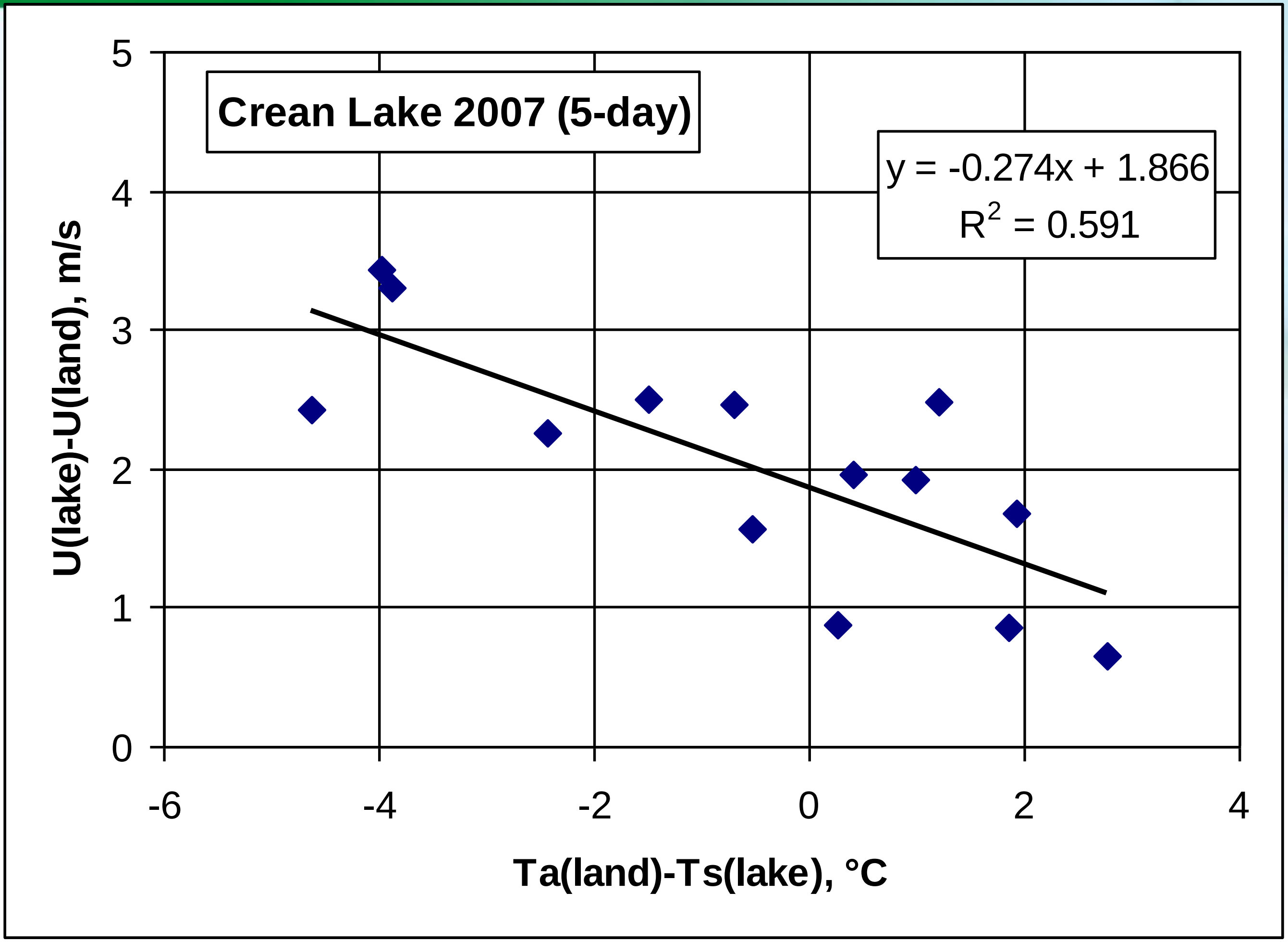


Mean Evaporation, Stable Case



Crean Lake, 2006

Effect of Stability on Lake Wind Speed



Hourly Lake Evaporation Model

Verification results *Crean 2005*