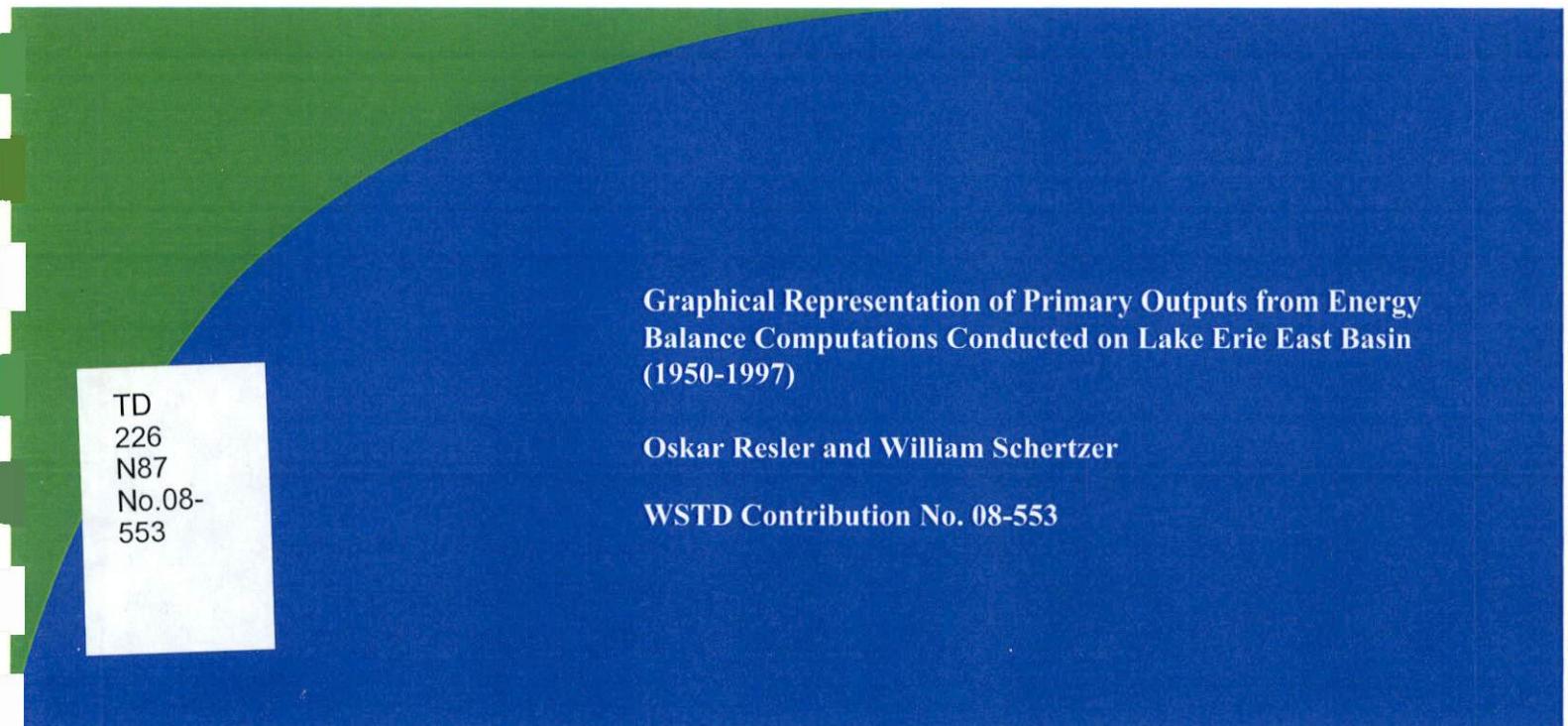


Environment Canada

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**Direction générale des sciences
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**Graphical Representation of Primary Outputs from Energy
Balance Computations Conducted on Lake Erie East Basin
(1950-1997)**

Oskar Resler and William Schertzer

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**Graphical Representation of Primary Outputs
from Energy Balance Computations
Conducted on Lake Erie East Basin
(1950-1997)**

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Prepared - March 2008

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Abstract

As a contribution to the Canada Climate Program, a major research effort was undertaken to examine the long-term heat balance for the lower Great Lakes (Sawchuk and Schertzer, 1988). A new model for evaluating the radiation and surface energy balance components for Lake Ontario and Lake Erie was developed. Improvements included the evaluation of solar radiation from a true radiative transfer model that treats multiple scattering effects explicitly and the evaluation of incoming longwave radiation that incorporated effects of aerosols and clouds. The model derived lake evaporation from a mass transfer formulation that includes dependency on wind speed and atmospheric stability. Accurate evaluation of the lake evaporation component is particularly important since it is a major term in the lake hydrology and longer-term variability in lake levels. A major difficulty in all energy budget studies of lakes over historical periods is the lack of water surface temperatures which is an important variable in evaluation of many of the radiative fluxes and turbulent exchanges at the air-water interface. In this model, a method for estimating surface temperature based on a hysteresis with lake heat content was applied. The relationship represents a strong negative feedback mechanism and provides a constraint that prevents numerical instabilities from amplifying (see Sawchuk and Schertzer, 1988). The model was applied to estimate daily surface radiation and energy balance components for Lake Erie and Lake Ontario over the period 1950 – 1997. This report provides graphical representations of the primary radiative and turbulent exchanges and selected meteorological/limnological components at the daily time scale (1950-1997) for Lake Erie (east basin). The graphical output is particularly relevant for current and future comparisons of the magnitude, variability and interannual variability of key computed variables derived in a consistent method over the 48 year period. In particular, the graphical output documents the limitations in deriving the energy balance of large deep lakes without directly observed water temperatures.

Résumé

Dans le cadre du programme climatologique canadien, d'importants travaux de recherche ont été entrepris pour étudier le bilan thermique à long terme du bassin inférieur des Grands Lacs (Sawchuk et Schertzer, 1988). Les chercheurs ont élaboré un nouveau modèle pour évaluer le rayonnement et le bilan énergétique à la surface des lacs Ontario et Érié. Les améliorations apportées au modèle comprenaient l'évaluation du rayonnement solaire à partir d'un modèle de transfert radiatif réel qui traite de façon explicite les effets de la diffusion multiple, et l'évaluation du rayonnement de grande longueur d'onde incident qui tient compte des effets des aérosols et des nuages. Ce modèle permettait de calculer l'évaporation des lacs à partir d'une formule de transfert de masse qui tient compte de la vitesse des vents et de la stabilité atmosphérique. Une évaluation précise de l'évaporation des lacs est particulièrement importante, puisqu'il s'agit d'un élément essentiel de l'hydrologie des lacs et de la variabilité à long terme du niveau des lacs. À travers le temps, une des principales difficultés de toute étude portant sur le bilan énergétique des lacs est l'absence de données sur la température à la surface de l'eau, laquelle constitue une variable essentielle à l'évaluation des nombreux flux radiatifs et échanges turbulents à l'interface air-eau. Dans le présent modèle, pour estimer la température de la surface de l'eau, les chercheurs ont utilisé une méthode basée sur l'hystérésis de la quantité de chaleur contenue dans le lac. La relation représente un important mécanisme de rétroaction négative et constitue une contrainte qui empêche les instabilités numériques de s'amplifier (voir Sawchuk et Schertzer, 1988). Le modèle a été employé pour évaluer le rayonnement et le bilan énergétique quotidien à la surface des lacs Érié et Ontario entre 1950 et 1997. La présente étude fournit une représentation graphique des échanges radiatifs et turbulents primaires de même que de certaines composantes météorologiques et limnologiques à l'échelle journalière (de 1950 à 1997) pour le lac Érié (bassin est). Le graphique est particulièrement pertinent pour les comparaisons présentes et futures de l'ordre de grandeur, de la variabilité et de la variabilité interannuelle des principales variables informatisées obtenues grâce à une méthode uniforme s'étalant sur une période de 48 ans. On y présente également les limites pour calculer le bilan énergétique de vastes lacs profonds sans observation directe de la température de l'eau.

Table of Contents

Abstract	i
Table of Contents	iii
Introduction.....	1
Elements of the Energy Budget Model Approach.....	1
Data File Processing	3
Table 1: Lake Erie (east basin) Flux and Meteorological Output Parameters.....	4
Figure 1: Sample Ordinal Summary.....	5
Figure 2: Sample Yearly Summary.....	5
Computations Involving Surface Water Temperature	5
Figure 3: Relationship between surface water temperature and total lake heat content for Lake Erie (east basin). Solid line represents warming period and dashed line represents cooling period (based on Sawchuk and Schertzer, 1988).....	6
Table 2: Root mean square errors of differences between predicted and observed water surface temperatures for Lake Erie (east basin) (Sawchuk and Schertzer, 1988).....	6
Implications Regarding Surface Temperature.....	7
References.....	9
Appendix 1 Summary Plots	11
Appendix 2 Heat Fluxes	31
Appendix 3 Other Fluxes	79
Appendix 4 Radiative	127
Appendix 5 Meteorological.....	175
Appendix 6 Evaporation	223
Appendix 7 MATLAB Scripts.....	272

Introduction

Accurate quantification of the energy exchange across the air-water interface of a lake is crucial for understanding processes such as thermal stratification and the potential impacts of climate / climate change on the lake and aquatic ecosystem components (Schertzer and Sawchuk, 1990). The surface heat exchange can be defined as the following:

$$Q^* - Q_H - Q_{LE} - Q_t - Q_i - Q_M = 0$$

where, Q^* is net radiation, Q_H is sensible heat flux, Q_{LE} is latent heat flux, Q_t is the surface heat flux, Q_i is ice heat flux, and Q_M represents minor heat flux terms such as exchanges resulting from hydrological exchanges. The surface heat flux may then be evaluated as a residual. Details of the component formulations and computational techniques can be found in Sawchuk and Schertzer (1988), Schertzer and Sawchuk (1990).

Evaluation of the energy balance components for a large lake requires measurement of individual components at representative locations over the lake. However, other than for specialized research studies, such data is not usually available and recourse is to model mean meteorological conditions at the lake surface using meteorological stations at the lake periphery. Computational techniques can then be applied to estimate radiation and energy balance components. Such approaches have been applied to long-term studies conducted on the lower Great Lakes.

Derecki (1975) estimated monthly totals of energy budget components for Lake Erie (1950-1968) using shoreline meteorology and water intake temperatures to estimate lake surface temperature. Schertzer (1987) computed daily heat flux components, and heat storage of Lake Erie (lakewide and for the west, central and east basins) which formed boundary conditions for Lake Erie water quality model development (Lam et al., 1983, Lam and Schertzer, 1987). Few comparable long-term studies exist for Lake Ontario, although intensive measurements and calculations of energy balance components were performed during the international Field Year for the Great Lakes (IFYGL) from April 1972 to March 1973 (Pinsak and Rodgers, 1981). Quinn and den Hartog (1983) compared latent and sensible heat fluxes evaluated from solving the energy balance components with other methods such as estimates from the water balance equation and mass transfer models with values recommended by the IFYGL Energy Balance Panel.

This report is focused on the model results of Sawchuk and Schertzer (1998), who developed and applied a new energy budget model approach to Lake Erie and Lake Ontario. The objective here is to provide detailed graphical output of the primary input and output variables from the Sawchuk and Schertzer (1988) investigation.

Elements of the Energy Budget Model Approach

Sawchuk and Schertzer (1988) conducted an investigation to develop a model for evaluating daily values of surface radiation and energy balance components for large deep lakes. The focus of the study was to replace empirical and site specific formulations of the energy budget technique with physical models (where possible) in an effort to develop a numerical algorithm with general application. Considerable effort was expended in ensuring the algorithm was numerically stable, provided accurate flux estimates, required little computer time and performed in all environmental conditions. The model was applied to Lake Erie and its three sub-basins and Lake Ontario for the climatological period 1953 to 1983 to evaluate the magnitude and variability of surface energy

balance components and to compare these estimates, where possible, with estimates from other long-term studies.

Model development focused on three aspects: radiation receipt, evaporation rates and ice cover. Net radiation was estimated from the sum of net shortwave and net longwave radiation fluxes. The shortwave model is a true radiative transfer model and marked the first time that such a model was applied to evaluate shortwave radiation receipts in a boundary layer study. Comparison of model estimates with measured values showed that the model could estimate daily totals of incoming shortwave radiation within, or close to, the range of values measured during IFYGL. Largest differences between model estimates and measured values were observed on days with predominately thin, high-altitude clouds, e.g. cirro-stratus combinations with maximum differences up to 30 percent of measured values. The impact of high altitude clouds on surface radiation receipt was much less when low clouds were also present.

Estimates of longwave radiation were obtained from a variant of Beer's law that incorporated effects of clouds, aerosols, and atmospheric gases on incoming longwave radiation. Estimates of daily totals of incoming longwave radiation were usually within 2 to 3 MJ m⁻² day⁻¹ of measured values which is within the uncertainty of incoming longwave radiation measurements on most days. In general, largest errors in estimates of incoming longwave radiation were observed for mostly clear days resulting in model underestimates. These underestimates may have resulted from several causes, (a) underestimated over-lake air temperatures, (b) inaccurate specification of reference heights for mean atmospheric temperature for emission of radiation and/or inaccurate specification of vertical temperature profile for a mostly clear atmosphere, and (c) neglect of multiple scattering effects. Specification of reference height and vertical temperature profile are likely the most important considerations. Sawchuk and Schertzer (1988) assumed a reference height ranging from 200 m (winter) to 300 m (summer) as recommended by Paltridge and Platt (1976). If the reference height was changed to 50 m as recommended by Ulden and Holtslag (1985), mean atmospheric temperature for emission would increase by approximately 2.5 °C. This temperature increase would be sufficient to bring clear sky longwave radiation estimates to within instrumental uncertainty of measured values on most days.

The evaporation model used in Sawchuk and Schertzer (1988) is a variant of the mass transfer approach. The primary improvement is the replacement of the Lake Hefner value for the mass transfer coefficient with a formulation that includes a dependency on wind speed (Quinn, 1978; Quinn and den Hartog, 1981). Although this formulation was strictly applicable to neutral conditions, atmospheric stability is incorporated through scaling of over-lake wind speeds. This approach resulted in evaporation estimates for Lake Ontario during IFYGL that compared favourably with values recommended by the IFYGL Energy Balance Panel. Estimated Bowen ratios were found to compare favourably with values tabulated by Pinsak and Rodgers (1981).

A simple model of ice extent, based on the cumulative freezing day concept provided acceptable estimates of ice heat flux due to ice formation and decay. Although the heat transfer associated with ice formation and decay is small, ice extent is important because of the high albedo for shortwave radiation and the effect of ice in reducing evaporation rates. Comparison of mean ice extent derived from a 31 year simulation for Lake Ontario and Lake Erie with tabulated values of Assel et al. (1983) showed good agreement.

The model was applied to produce 31 year simulations of daily radiation and energy balance components for Lake Erie and Lake Ontario. Daily lake heat contents were obtained from the product of estimated surface heat flux and lake surface area. Heat content estimates were compared

with measured heat contents for both lakes for the period 1967-1982 (Schertzer and Sawchuk, 1985; Schertzer, 1987). Estimated and measured heat contents showed excellent agreement on most days, usually within the accuracy of heat content measurements.

Examination of annual surface heat flux values, obtained from summing daily estimates, reveals that annual surface heat fluxes are not balanced on an annual basis. For Lake Erie, surface heat flux appears to be balanced over periods ranging from three to six years. Lake Ontario appeared to be gaining heat, although gains were small and within the uncertainty of measured heat contents.

One of the important recommendations resulting from the Sawchuk and Schertzer (1988) study was that future research was required for improvement of estimates of surface water temperature. Surface water temperature is the crucial variable in energy balance studies over lakes. It arises in estimation of over-lake meteorology variables, Bowen ratio, and incoming and emitted longwave radiation, etc. Consequently, almost all components of the model require knowledge of surface water temperature. In this investigation, a first approximation was estimated as the hysteresis between surface temperature and lake / basin heat content.

The computations conducted by Sawchuk and Schertzer (1988) for Lake Erie, Lake Erie West, Central and East Basin and Lake Ontario resulted in an enormous input and output database. The final report summarized the results for the 1953 – 1983 period as monthly and annual means. This report provides a detailed graphical summary of primary variables of the lake / basin heat flux, meteorological components and computed evaporation. While the graphs and tables of Sawchuk and Schertzer (1988) served to provide the essential overview of the energy budget conducted over these lakes and basins, the detailed summary plots in this report document the magnitude and variability in the key components at a finer temporal scale. The figures in this report documents the results of the current stage of computations and provides a solid basis for future advanced research on the development of improved techniques and applications of energy budget research for climate change impacts research on large deep lakes.

Data File Processing

The detailed meteorological data supplied for Lake Erie (East Basin) consisted of plain ASCII text files. Initial processing of the file was required to allow efficient processing by MATLAB and Excel. Two conditions need to be corrected before they could be processed.

Originally, these file were formatted for efficient processing by FORTRAN programs. At first glance, the files looked like they could be processed as space delimited files but, where missing data values occurred in adjacent columns the value "-999.99M" did not leave a separating space. These values were replace with the simpler "-999.99" along with a blank space.

It was also found that some entries consisted of the character string "*****". These would cause MATLAB to fail, expecting only numeric entries. Since no documentation existed as to the meaning of this string, they were also replaced with the generic "missing value" value.

The parameters present in these meteorological files (see table 1 for a detailed description) were grouped into five categories with detailed daily time series plots produced:

1. Heat Fluxes (Appendix 2),
2. Other Fluxes (Appendix 3),
3. Radiative (Appendix 4),

4. Meteorological (Appendix 5),

5. Evaporation (Appendix 6).

Plotting routines were written using MATLAB to generate yearly plots and to produce some basic statistics. All routines used to process the data file are listed in Appendix 7.

Table 1: Lake Erie (east basin) Flux and Meteorological Output Parameters

Kd	MJ m ⁻² day ⁻¹	incoming solar radiation
Ku	MJ m ⁻² day ⁻¹	reflected solar radiation
Ld	MJ m ⁻² day ⁻¹	incoming long wave radiation
Lu	MJ m ⁻² day ⁻¹	emitted long wave radiation
Q*	MJ m ⁻² day ⁻¹	net radiation
Uk	m/s	over-lake wind speed
Ta	°C	over-lake air temperature
Td	°C	over-lake dew point temperature
Rh	percent	over-lake relative humidity
Tw	°C	surface water temperature
As	fractional value	surface albedo
Qh	MJ m ⁻² day ⁻¹	sensible heat flux
Qe	MJ m ⁻² day ⁻¹	latent heat flux
Ev	Mm	daily evaporation
Qi	MJ m ⁻² day ⁻¹	ice heat flux
Ic	fraction surface area	lake ice extent
Qm	MJ m ⁻² day ⁻¹	minor heat flux terms
Qt	MJ m ⁻² day ⁻¹	total surface heat flux
Qc	Exa Joules	lake heat content (computed)

In addition to the detailed plots, two types of summary plots were also produced (see Appendix 1 for the complete set of summary plots). The first averages the above listed parameters for each ordinal (also sometimes referred to as Julian) day over the study period, in this case 1950 through 1997. The Maximum, Mean and Minimum values are plotted.

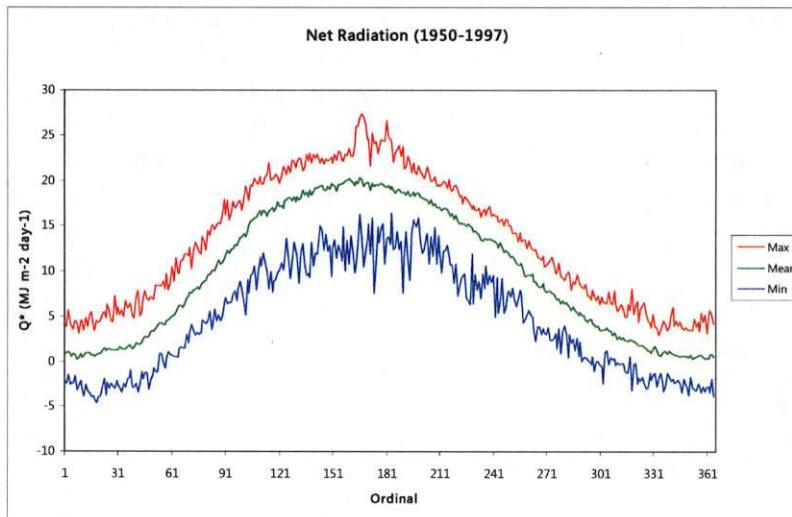


Figure 1: Sample Ordinal Summary

The second summary plot consists of simple yearly averages. Each year is represented by a vertical line, Maximum to Minimum (Absolute), along with a horizontal bar representing the Mean.

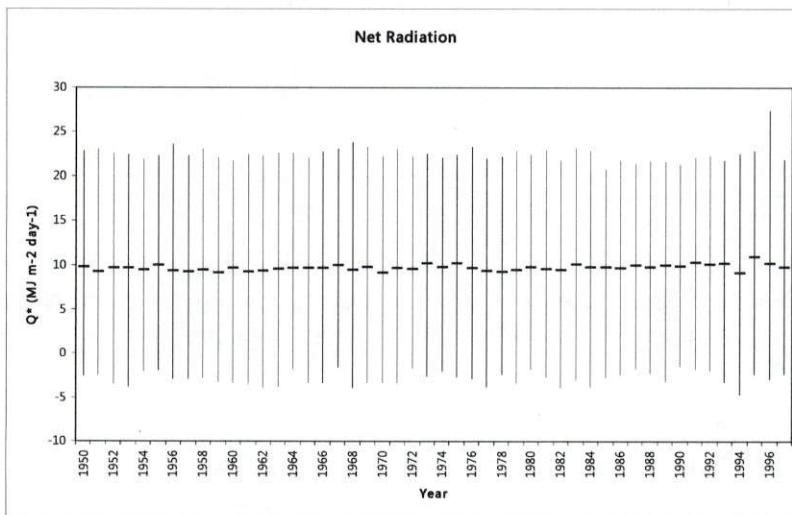


Figure 2: Sample Yearly Summary

Computations Involving Surface Water Temperature

Sawchuk and Schertzer (1988) modeled surface water temperature as surface temperatures were generally not available till 1966 and from then on there were different databases involving water intake temperatures, airborne radiometer measurements, lake surveillance observations and finally remote sensing from satellite observations. Schertzer and Sawchuk (1985) summarized all available water temperature measurements for the lower Great Lakes. Schertzer computed one dimensional temperature profiles for the lakes and estimated the lake and basin heat contents.

The algorithm used to estimate surface water temperature is based on the relationship between surface water temperature and the total heat content of the lake or basin. The relationships were derived by using paired surface water temperatures and heat content values. Figure 3 illustrates this "hysteresis" relationship for two periods of the year: a warming phase (15 March to 10 September) and a cooling phase (11 September to 14 March) (Sawchuk and Schertzer, 1988). The relationship between surface temperature and heat content was approximated by a linear combination of Legendre Polynomials of order 0 to 5 shown as dashed and solid curves on Figure 3. Higher order approximations did not appreciably reduce the root mean square error of the estimates or improve statistics of the fit (Table 2).

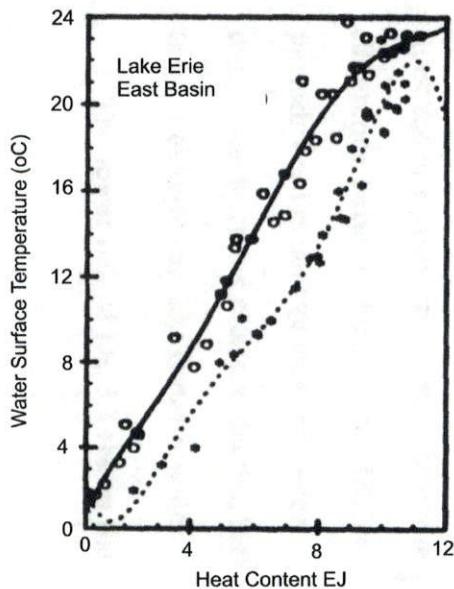


Figure 3: Relationship between surface water temperature and total lake heat content for Lake Erie (east basin). Solid line represents warming period and dashed line represents cooling period (based on Sawchuk and Schertzer, 1988)

Table 2: Root mean square errors of differences between predicted and observed water surface temperatures for Lake Erie (east basin) (Sawchuk and Schertzer, 1988).

	Warming Phase	Cooling Phase
RMSE	1.09 °C	1.11 °C

As indicated in Table 2, the approximations to water surface temperature in the present approach perform better during the cooling phase of the lake. Figure 3 also illustrates that there is larger variability during the warming period of the year, especially during late summer especially when heat content is at or near the maximum. Procedures used to initialize the heat content for a particular year and the computation of the daily mean surface temperature is described in detail in Sawchuk and Schertzer (1988) and also applied in Schertzer and Sawchuk (1990).

Implications Regarding Surface Temperature

Appendix 1 shows a summary of the magnitude and variability of the long-term (45 year) daily computations of the radiative and turbulent fluxes and selected meteorological and limnological variables and succeeding Appendices show the detailed computations for each year. Many of the variables are dependent on the accuracy of water surface temperature; however, water temperature is not often available in historical databases. The application of hysteresis functions, in this case, the relation between surface temperature and lake heat content has advantages and limitations. The advantage is that root mean square errors in the overall temperature approximations are not dissimilar to comparisons between surface temperature observations from different measurement types (e.g. ART vs. satellite vs. buoy observations). However, there are times of the year when variability is larger as noted during the warming phase and, in particular, at the period of maximum heat content. The effect of this variability can be seen in examination of the summary graphs for the surface water temperature in Appendix 1 and also in the Detailed Appendices. In particular, surface water temperature in many cases is constrained at the time of peak heat content. The inaccuracy in the surface water temperature at this time of year will affect computation of the temperature dependent radiative flux and turbulent exchange components.

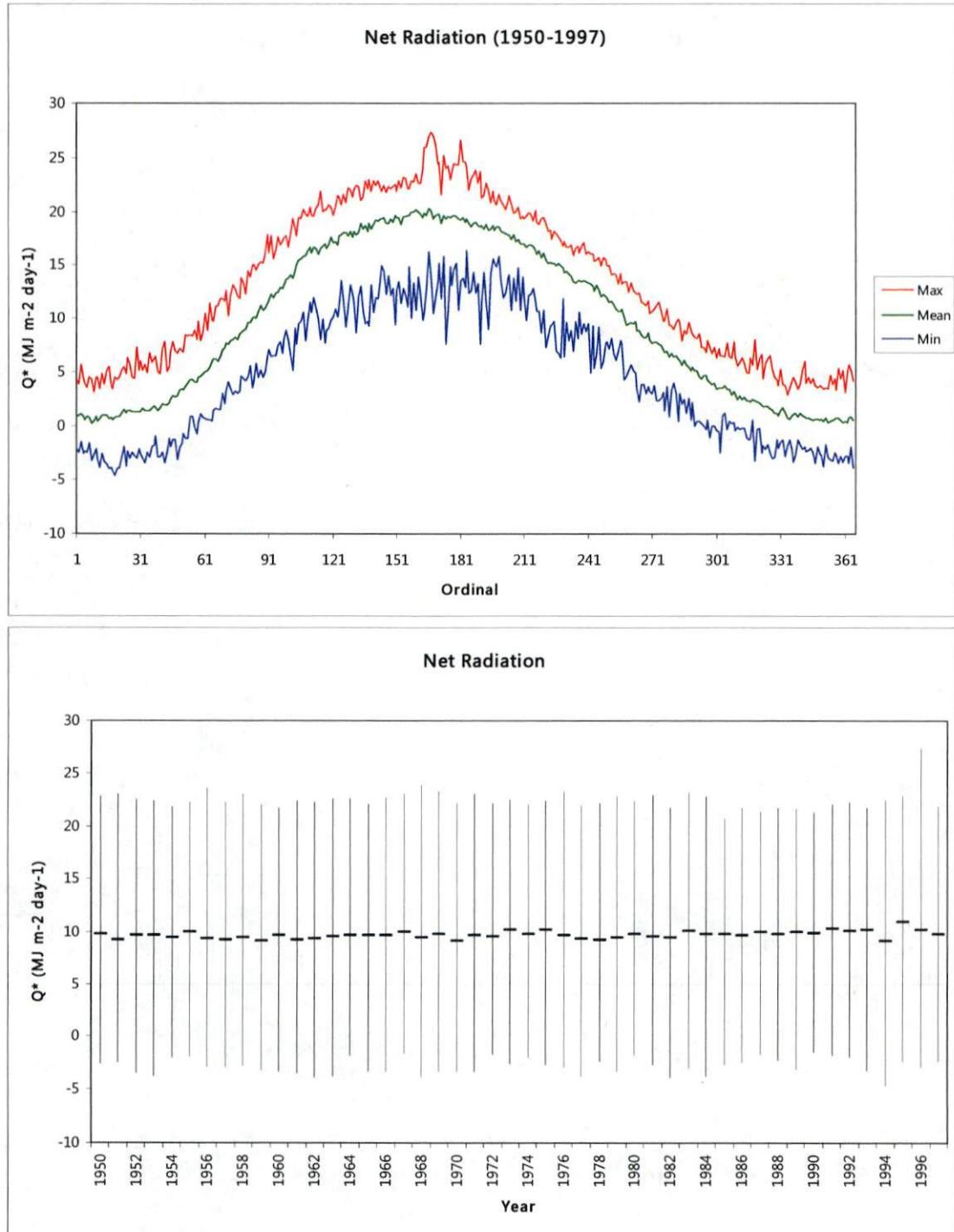
Future research is required in order to develop new algorithms / approaches that can be applied to approximate water surface temperature in this lake as well as many lakes in Canada that do not have detailed water temperature observations, especially over climatologically significant periods. Such research is required especially in developing baseline conditions for future climate impacts analyses on lakes.

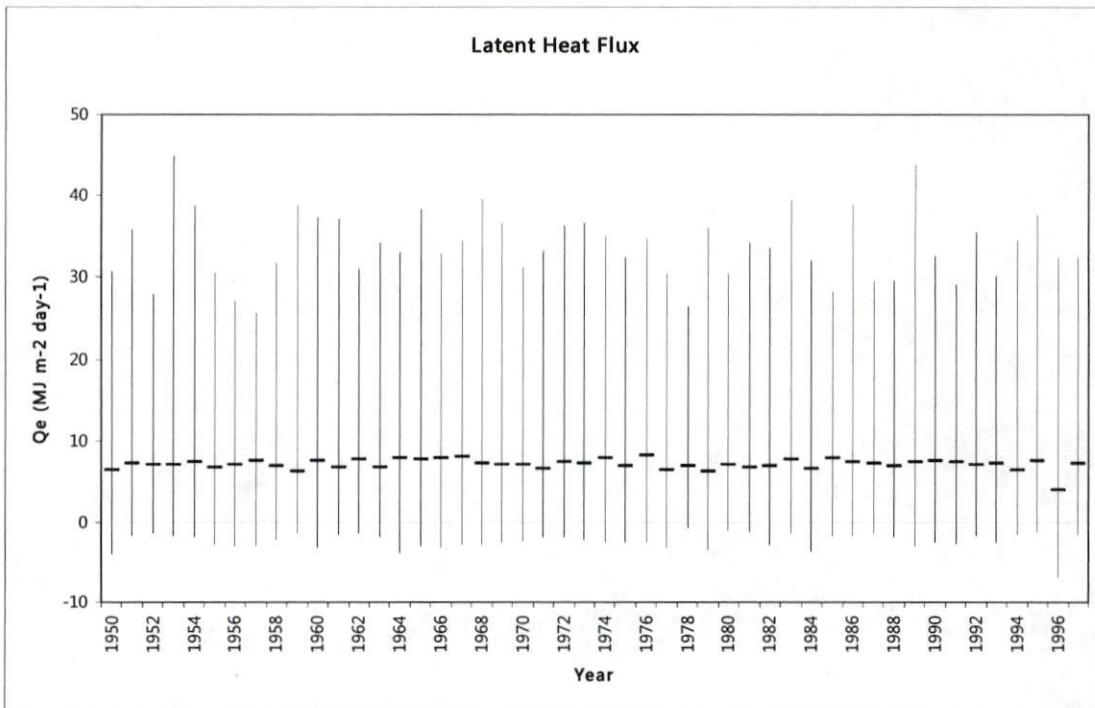
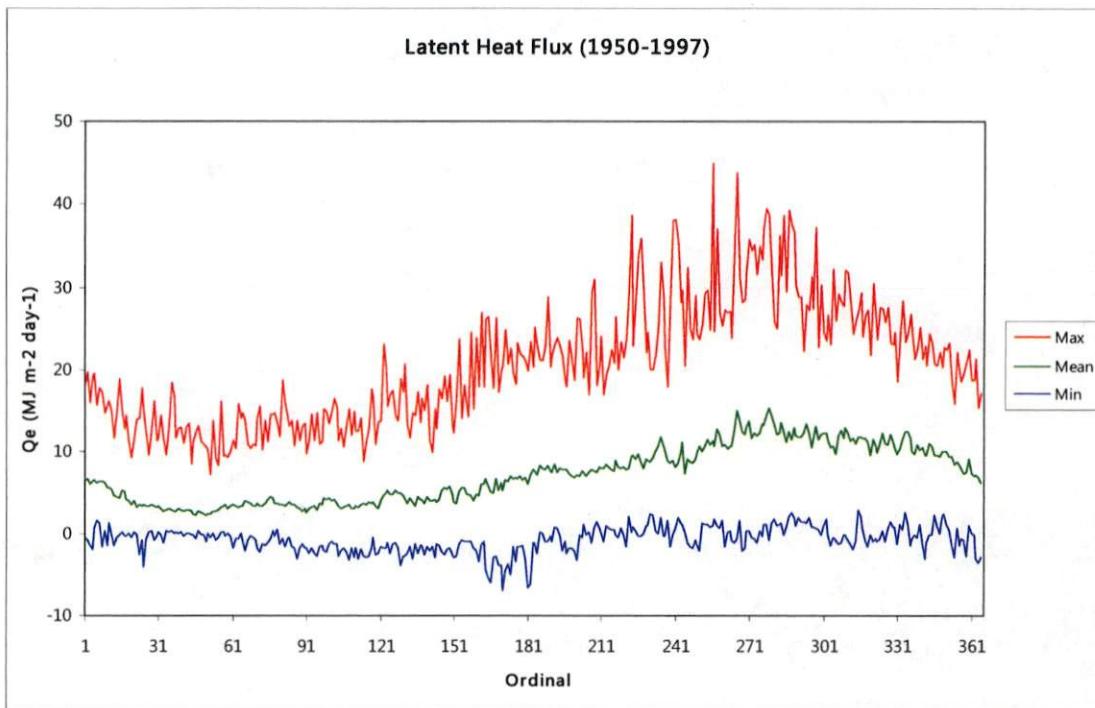
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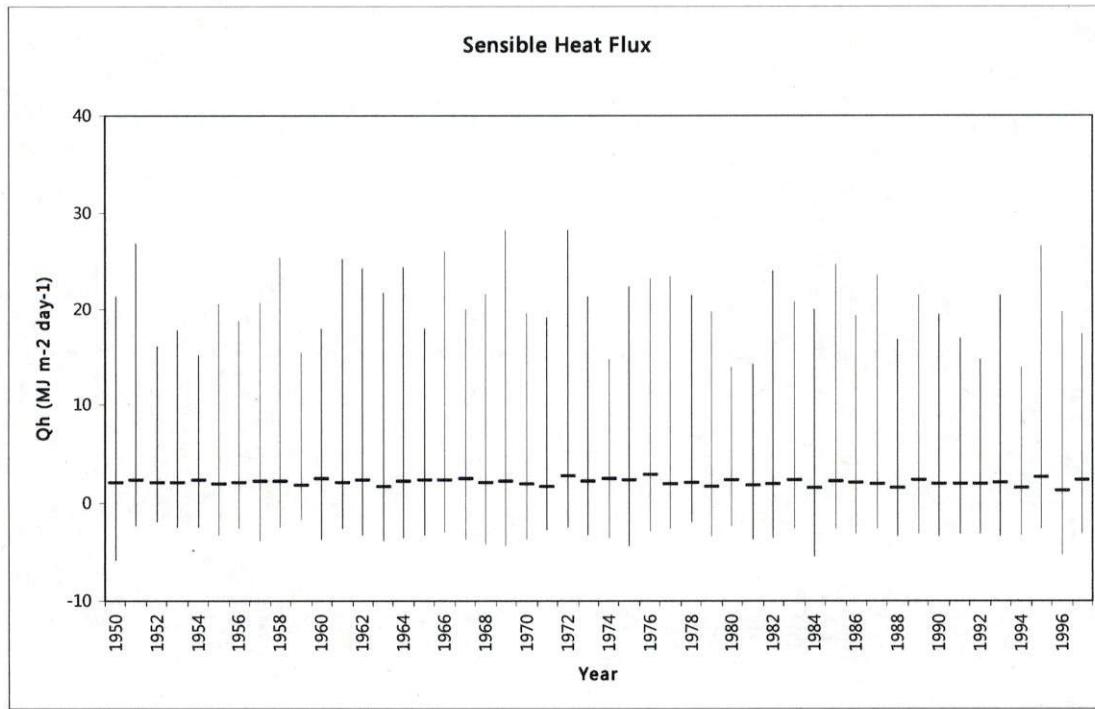
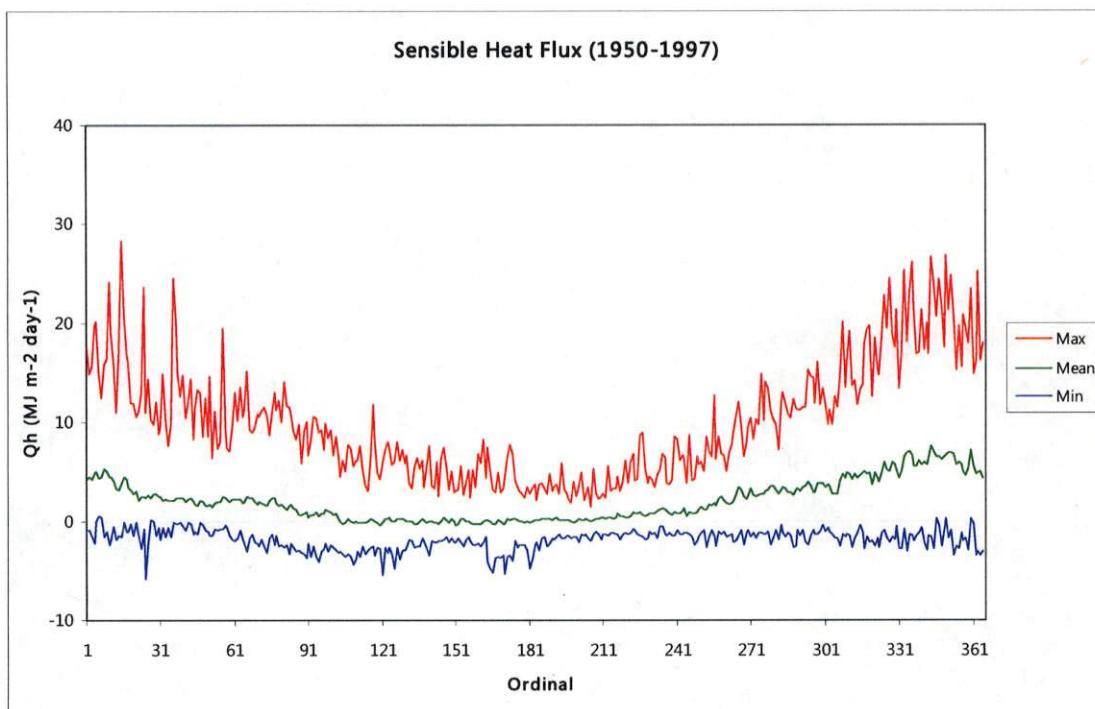
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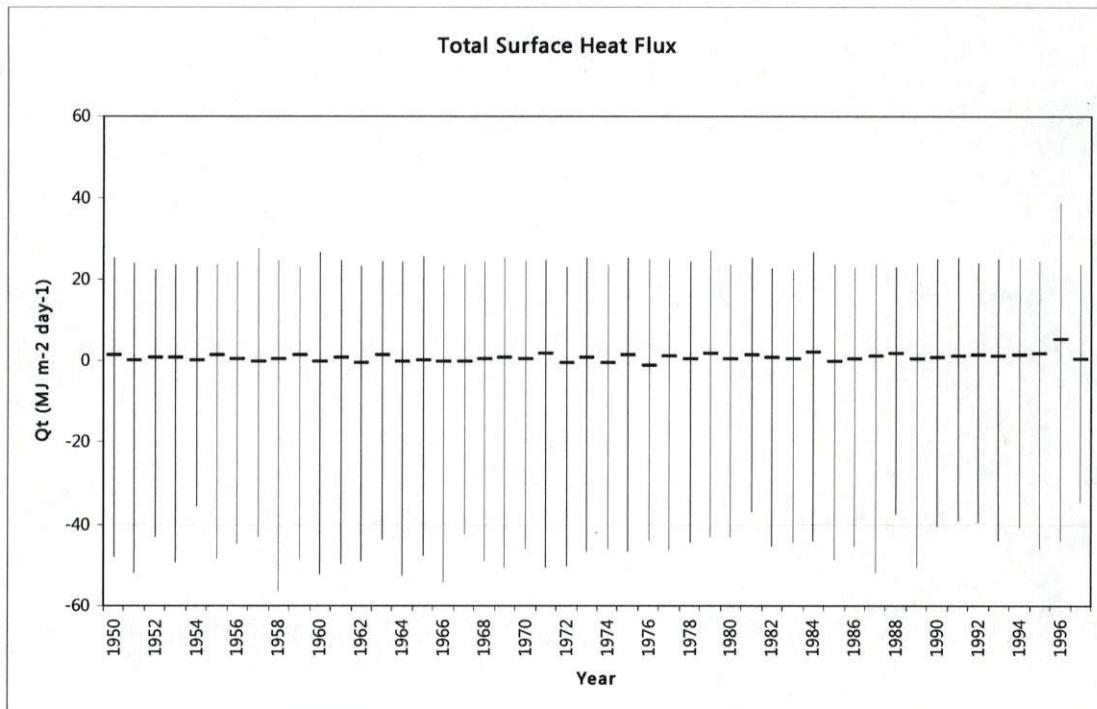
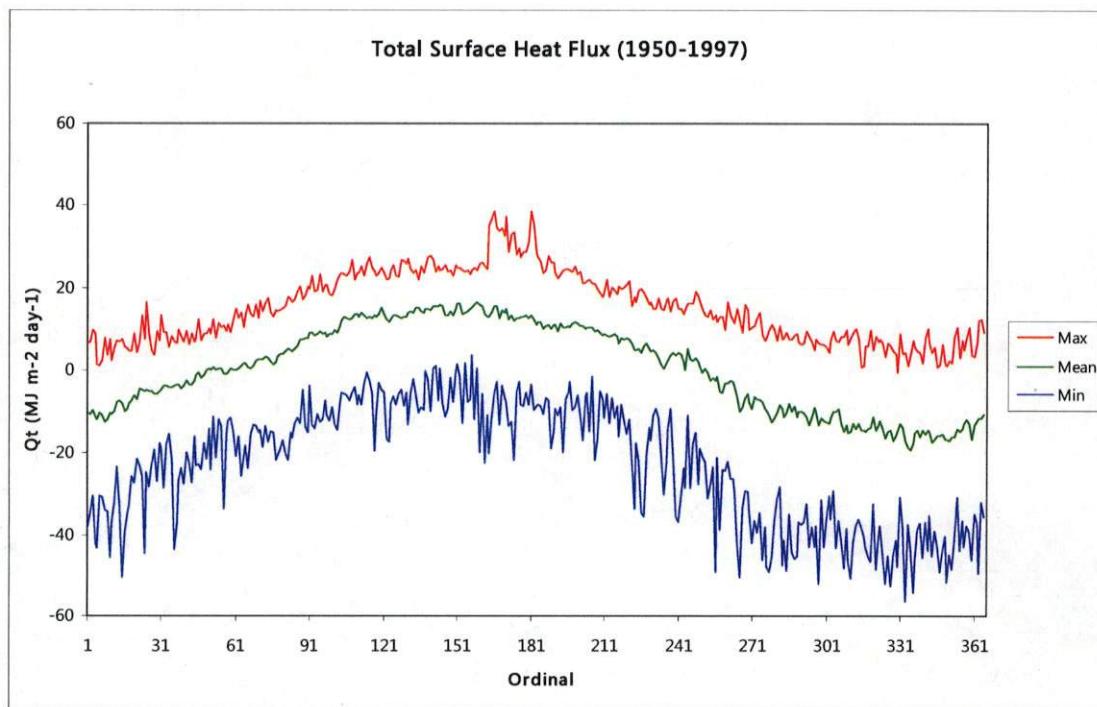
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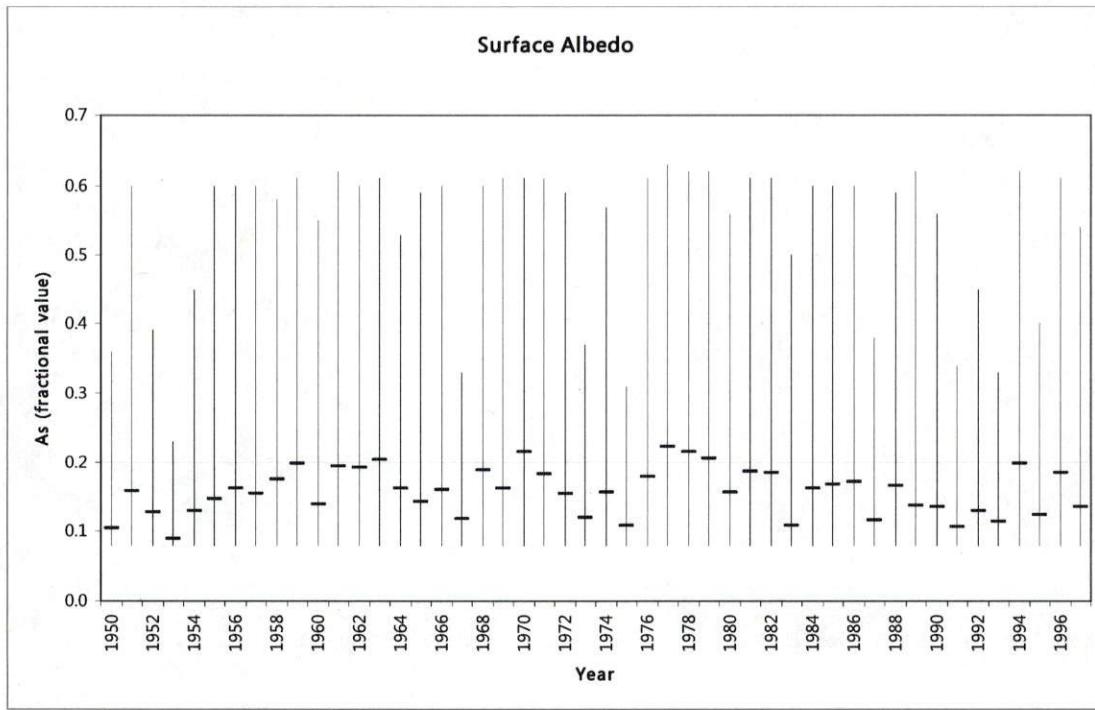
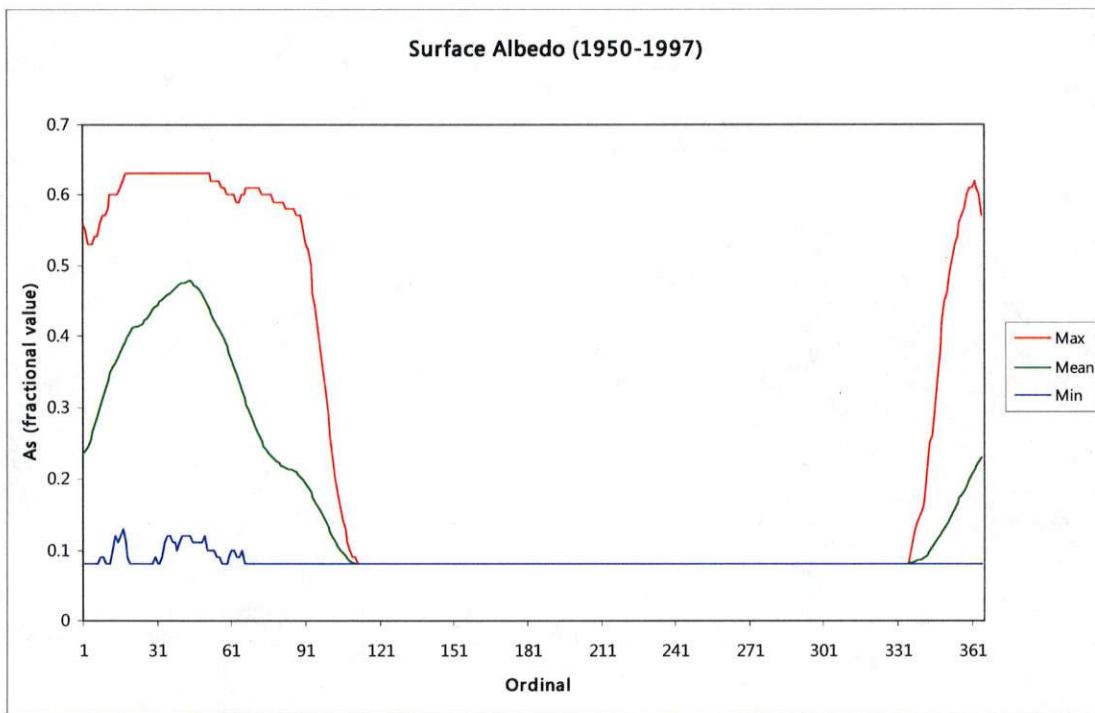
Summary Plots

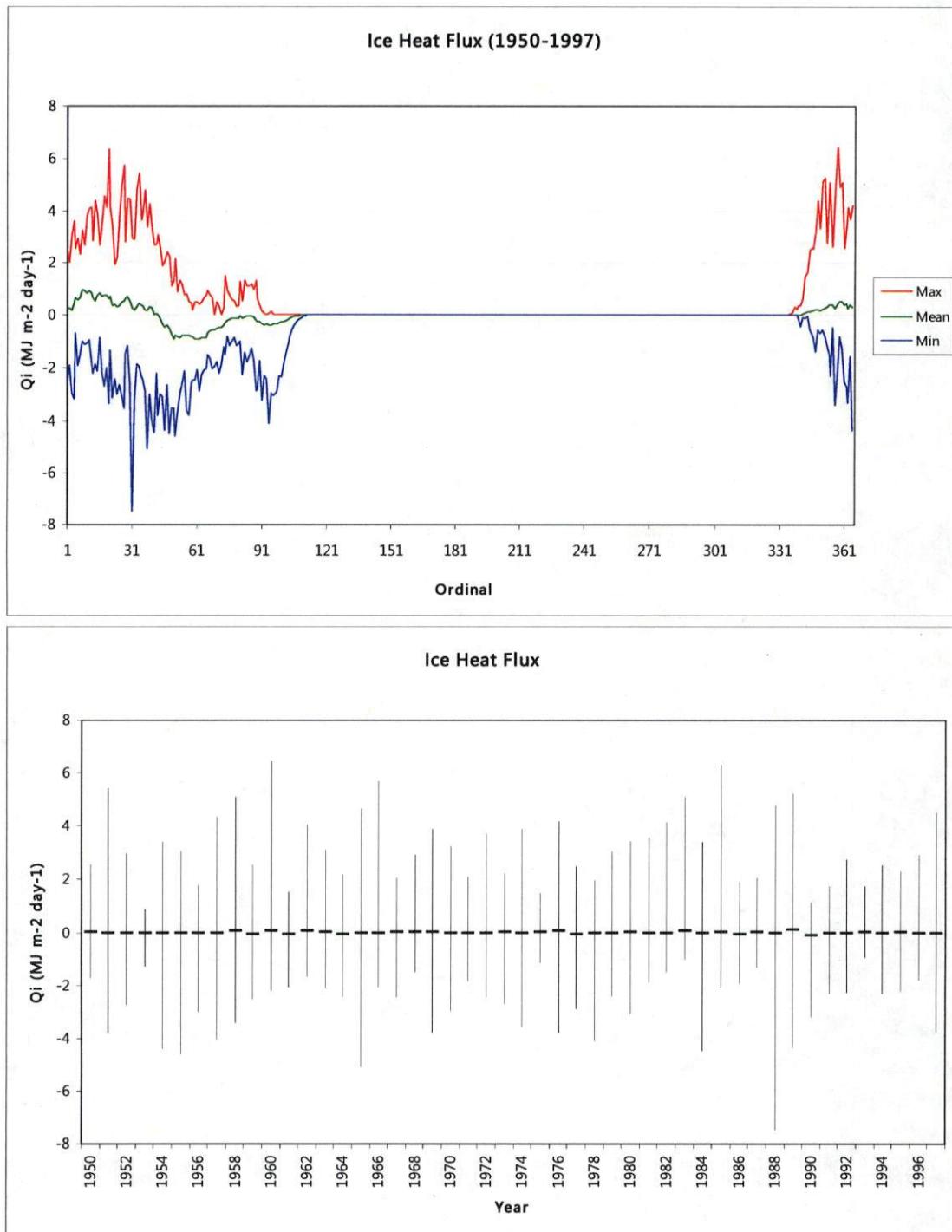


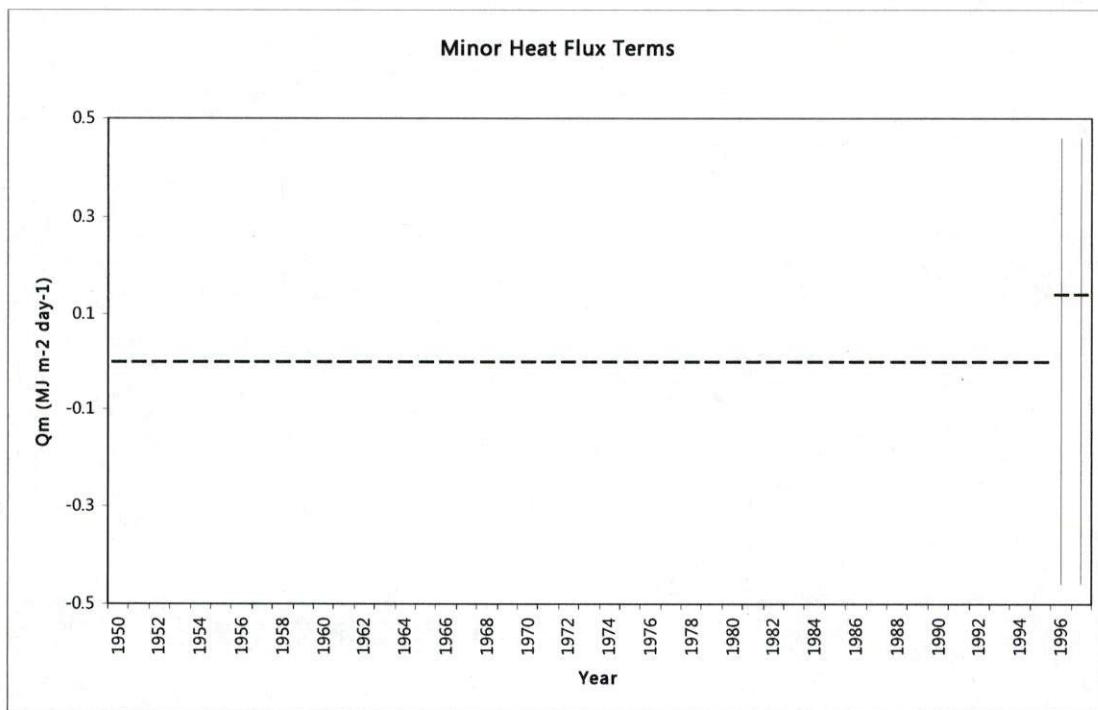
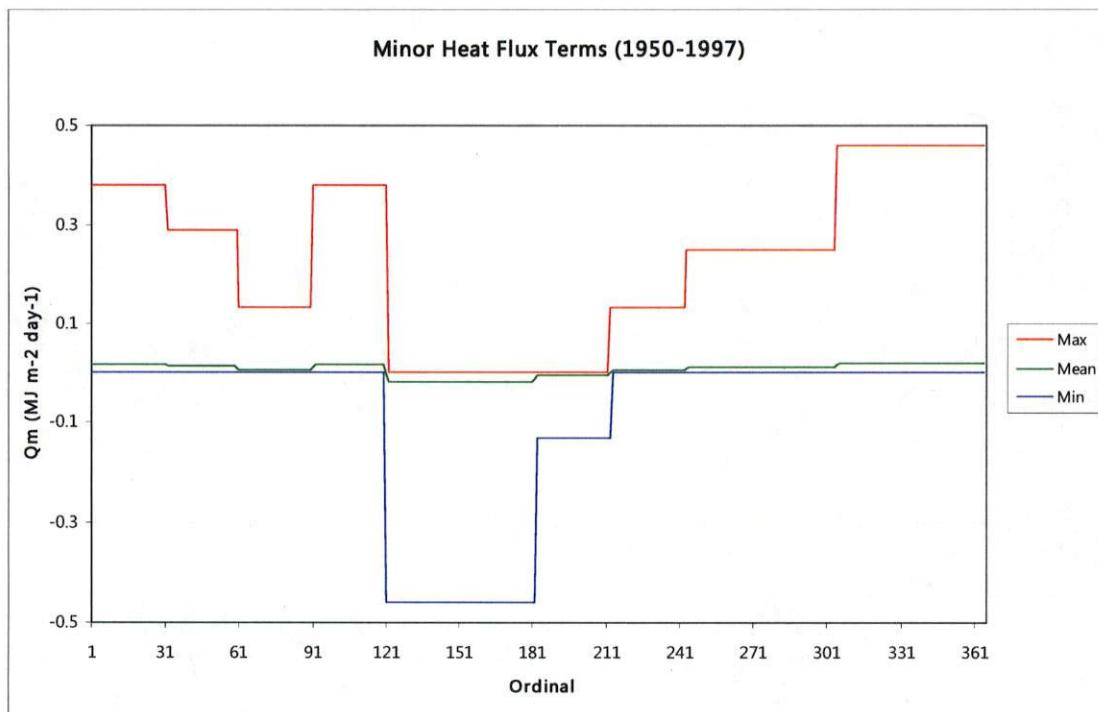


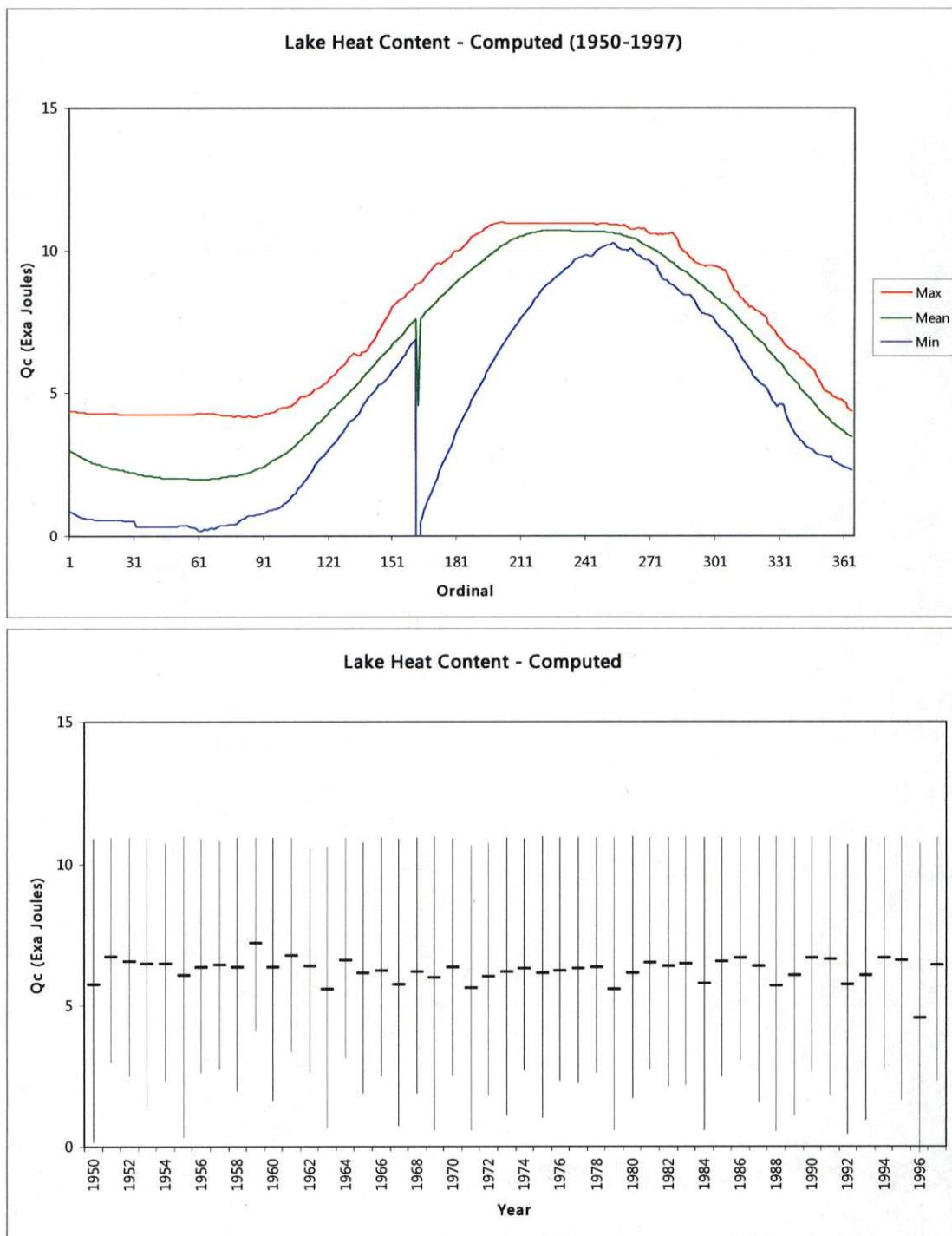


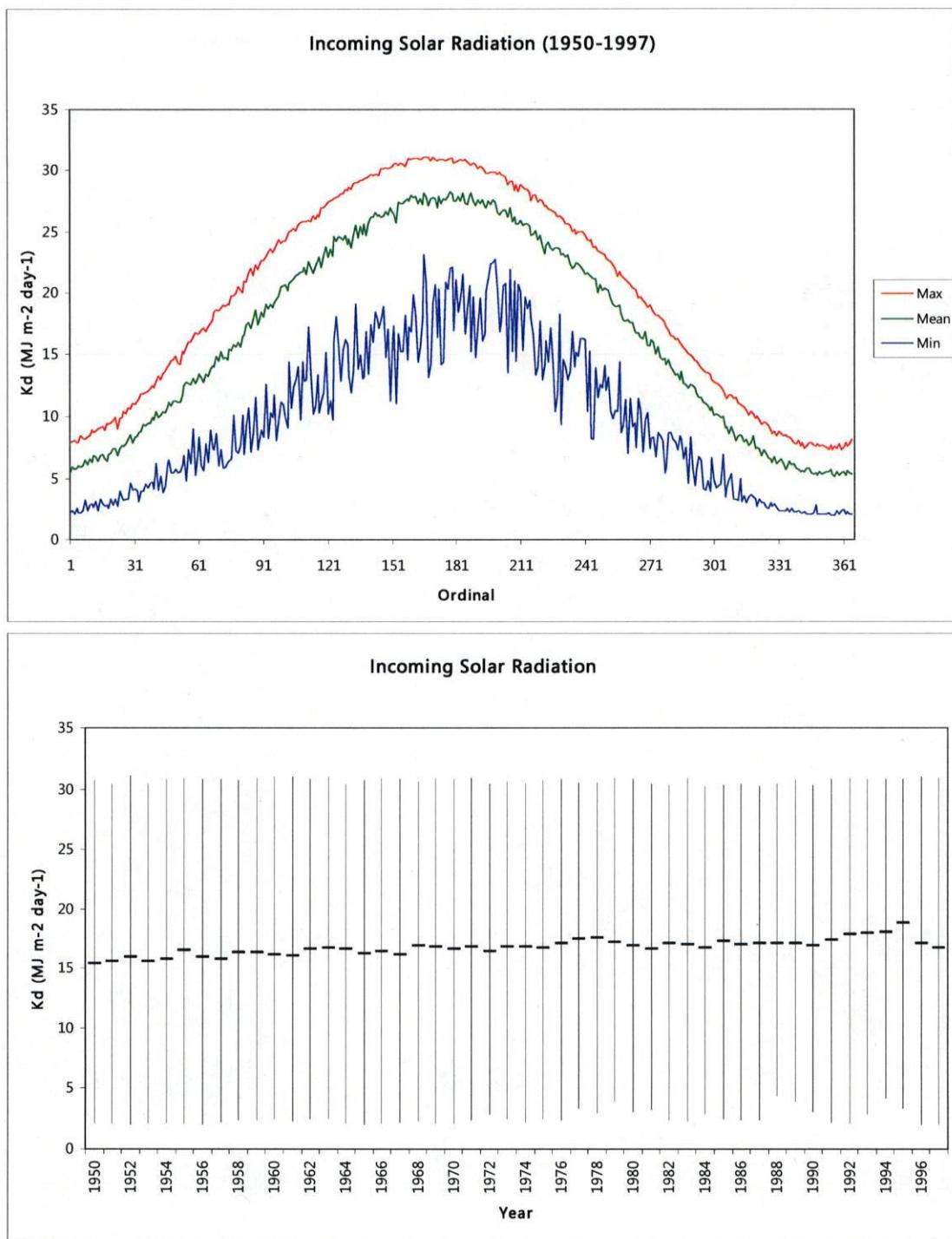




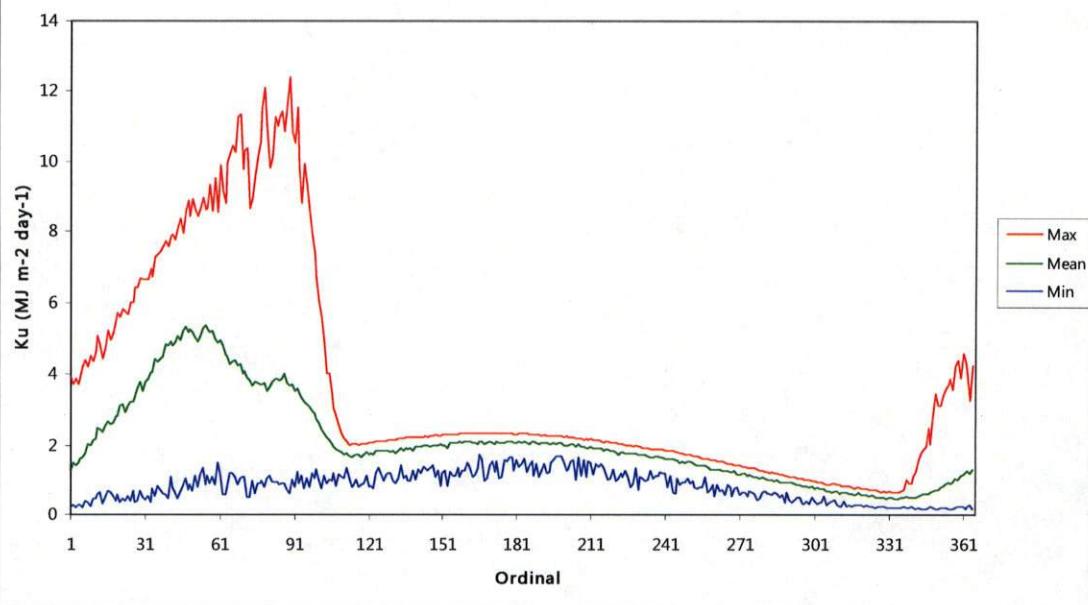




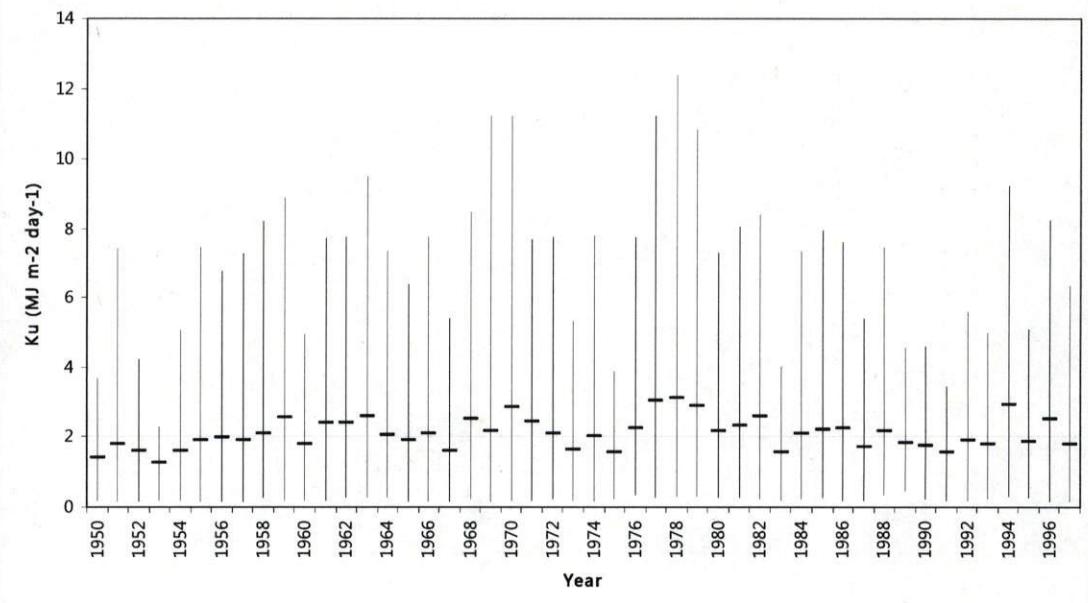


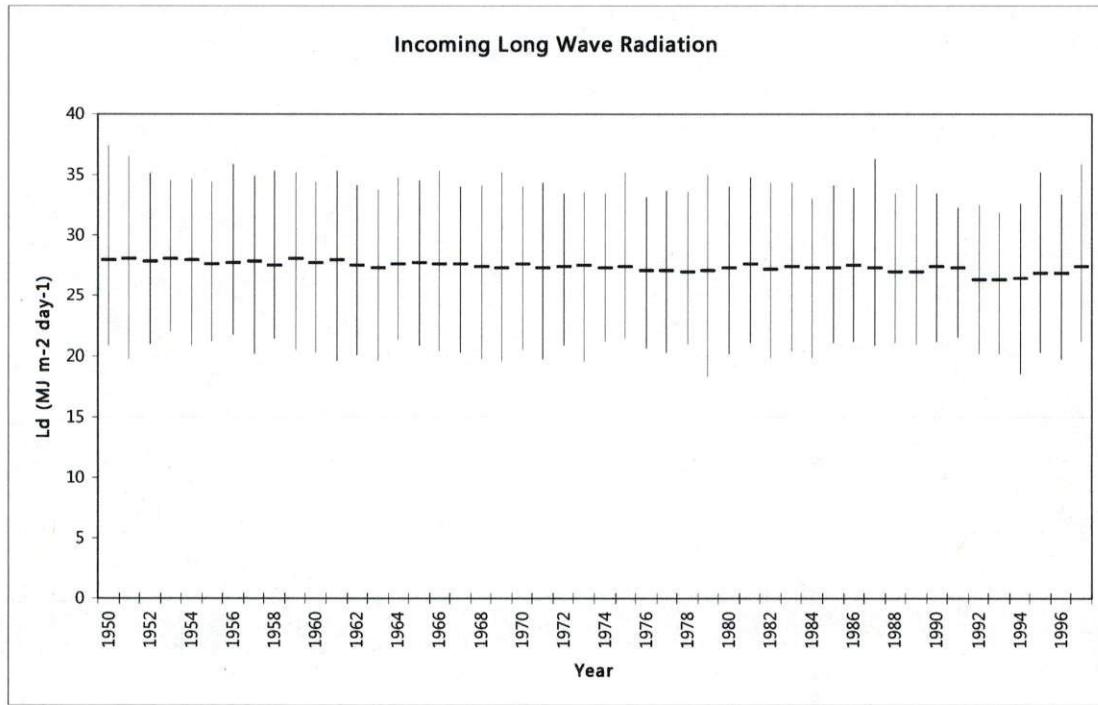
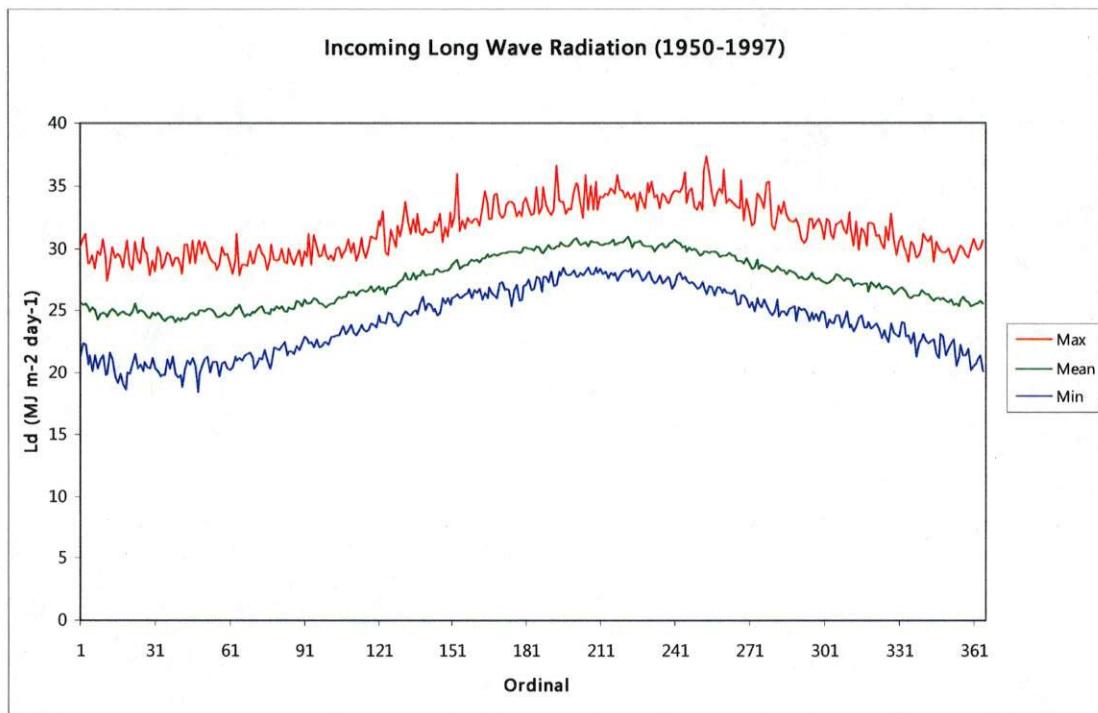


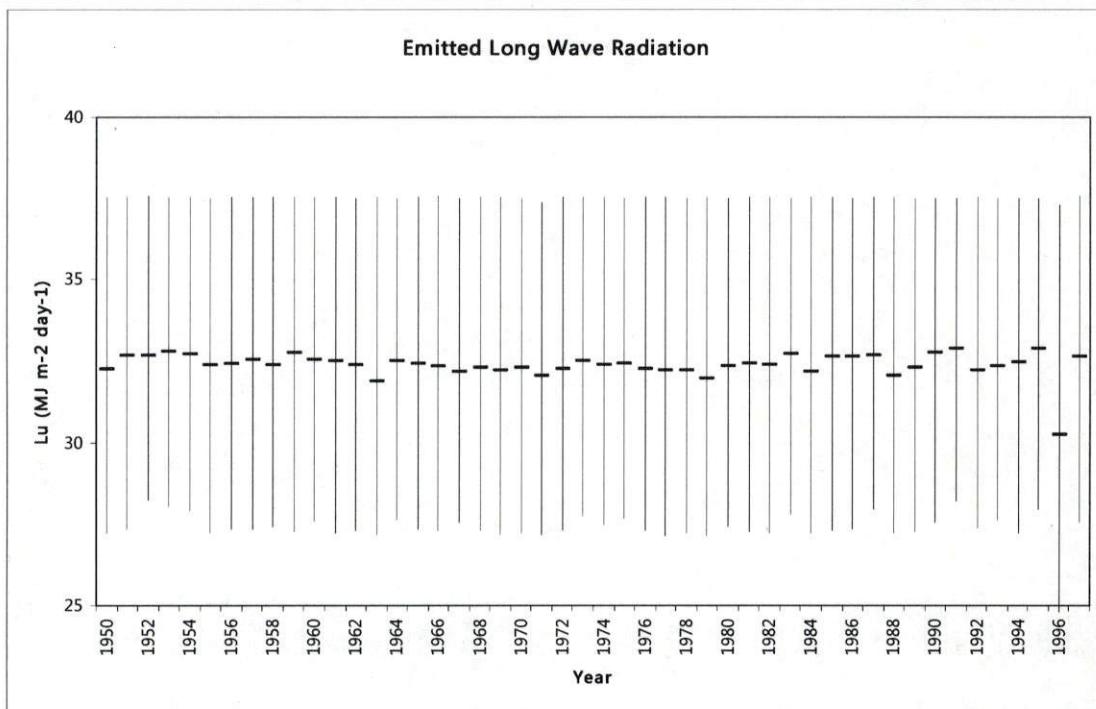
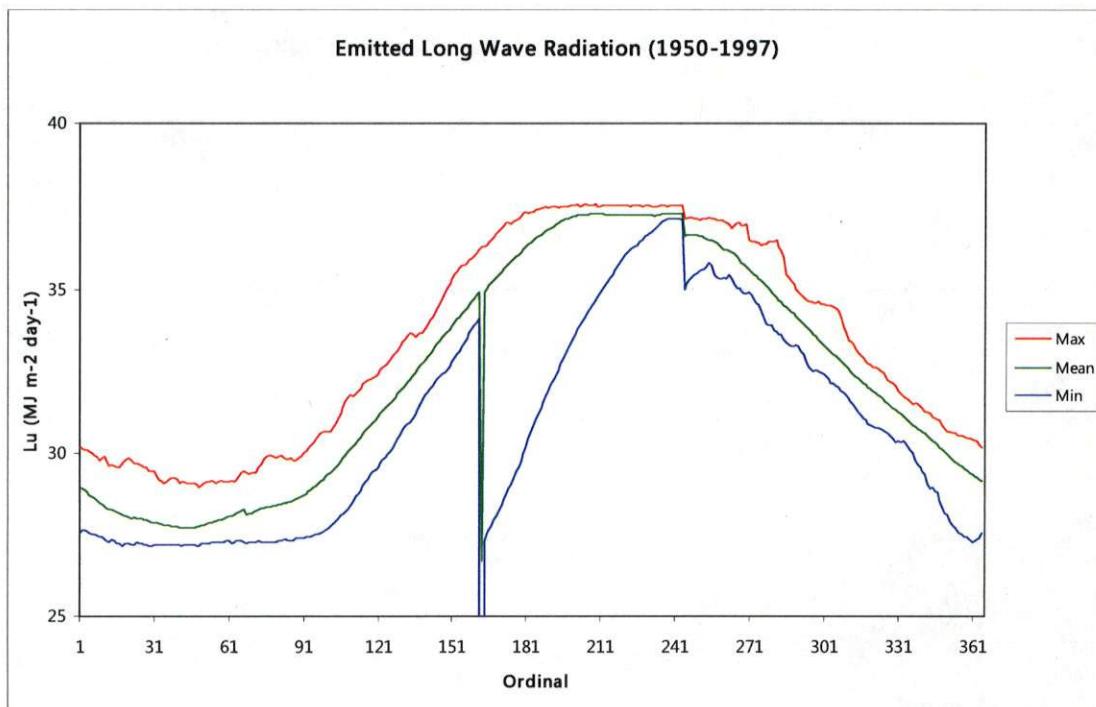
Reflected Solar Radiation (1950-1997)

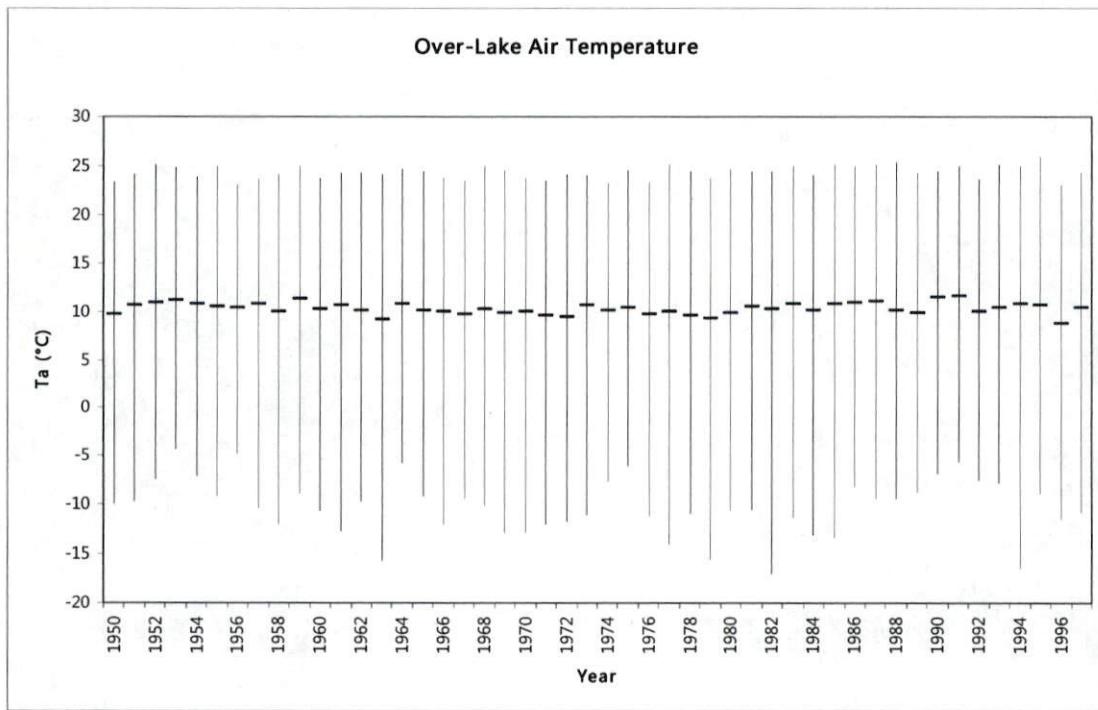
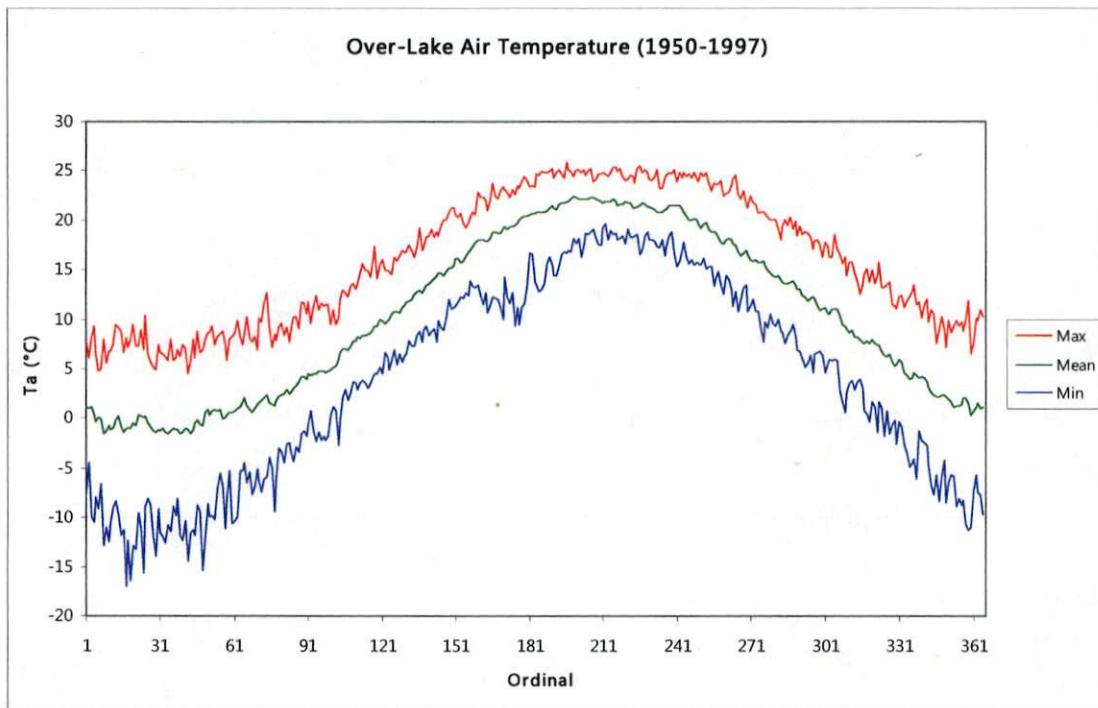


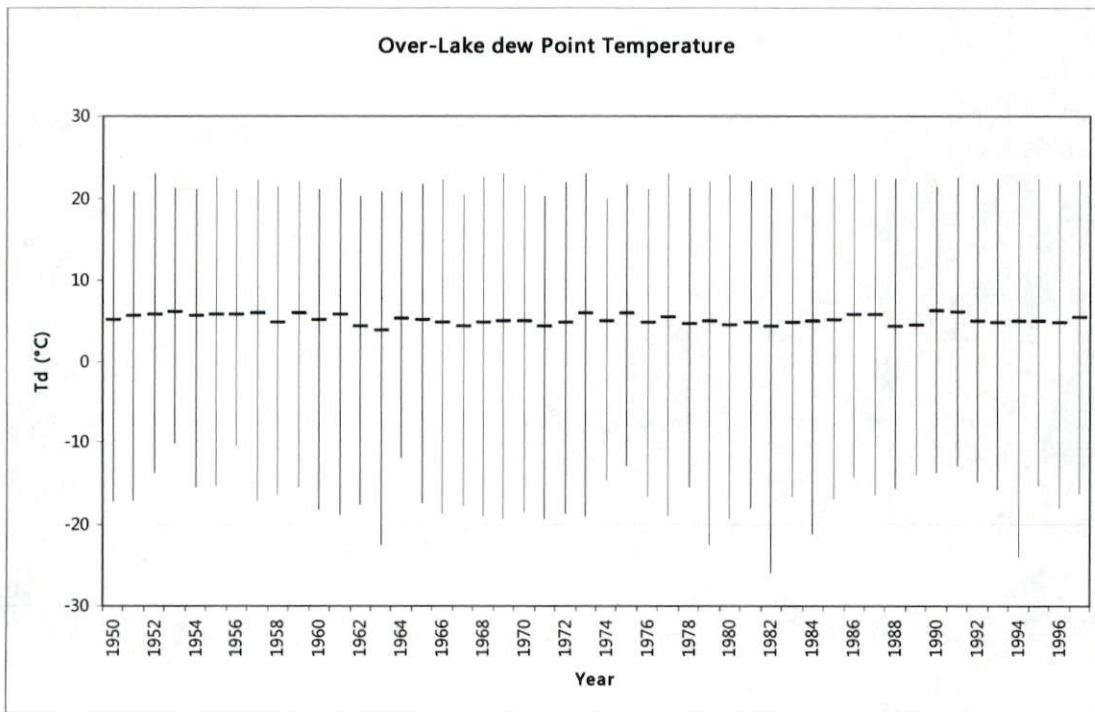
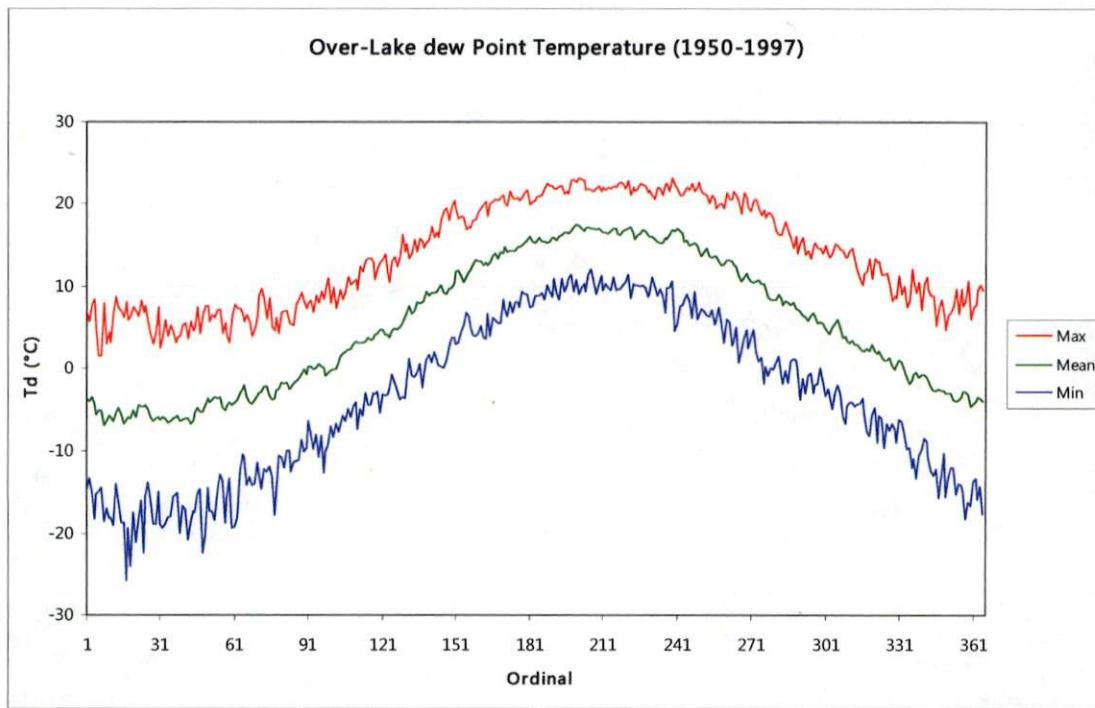
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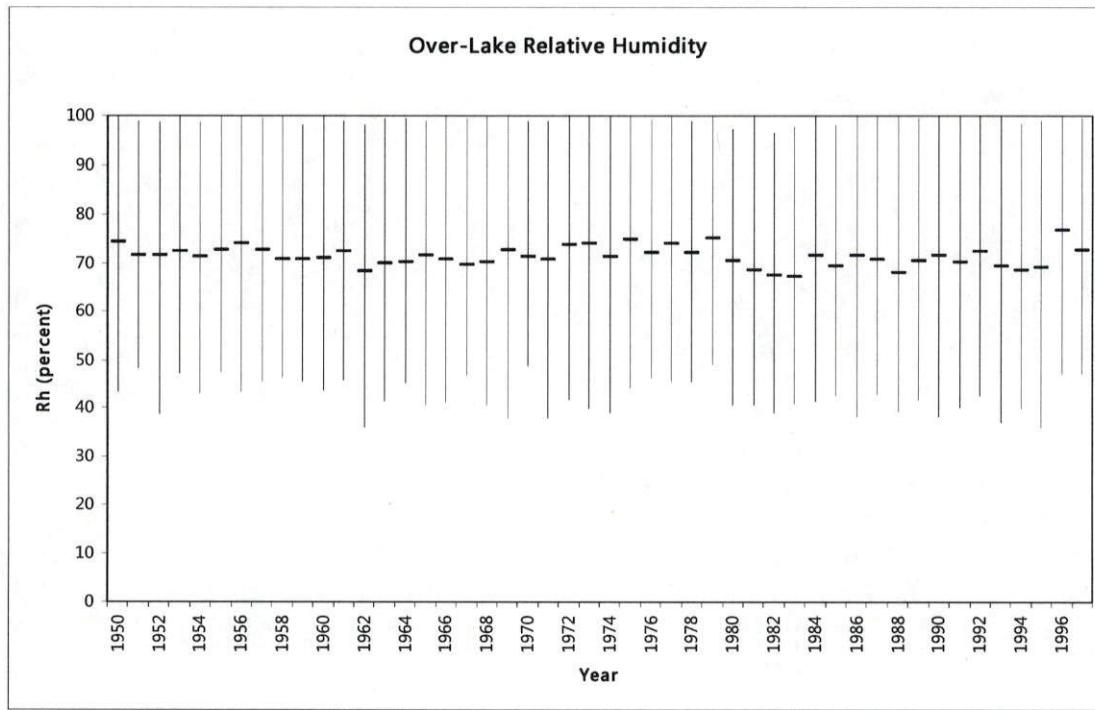
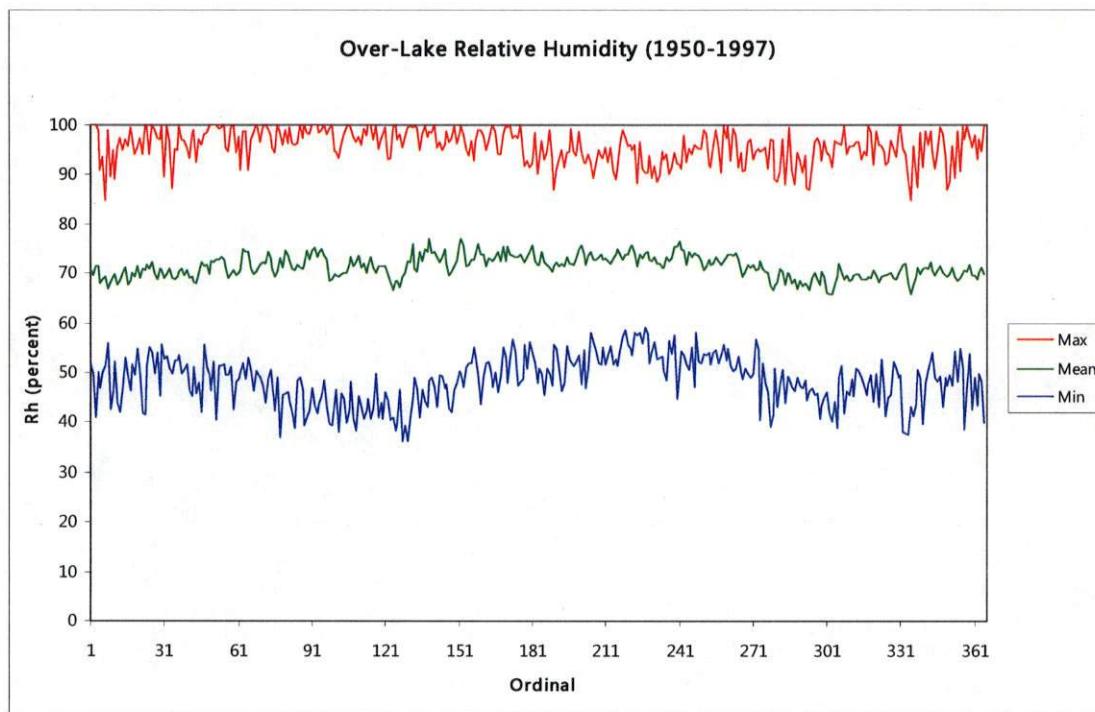


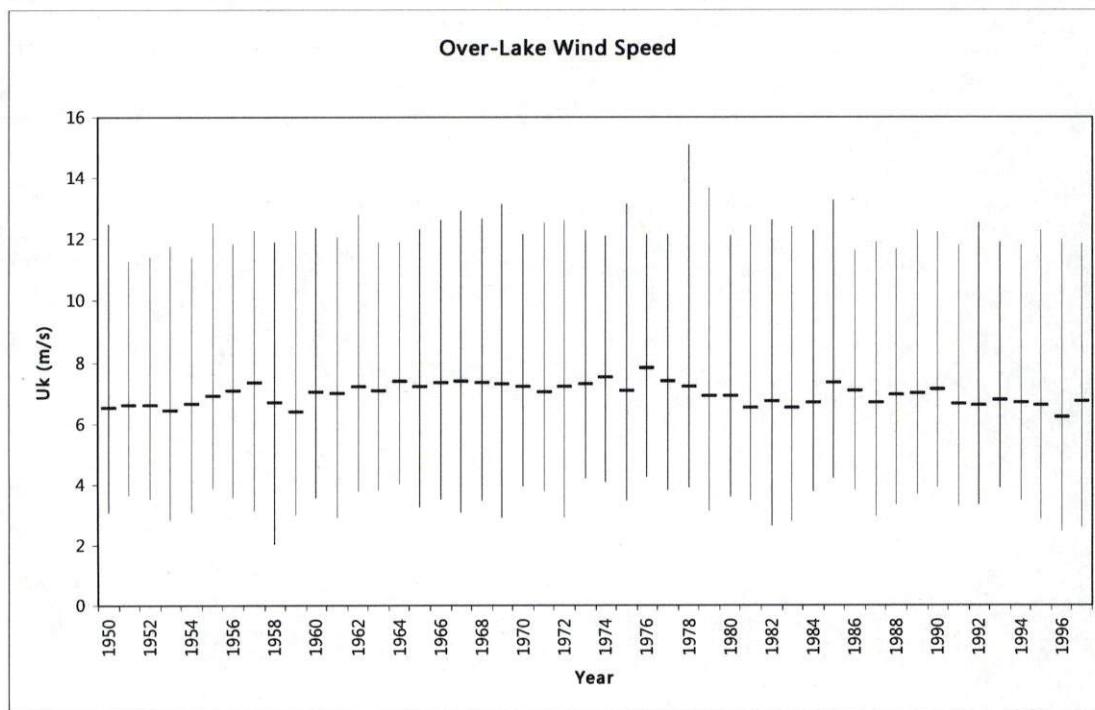
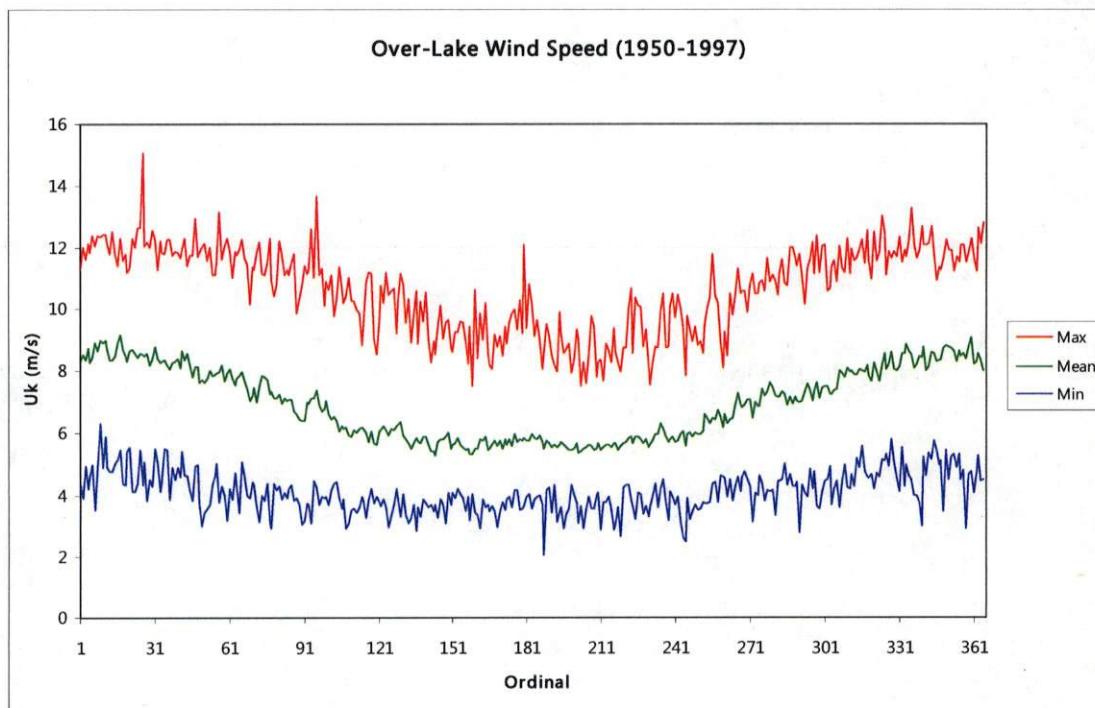


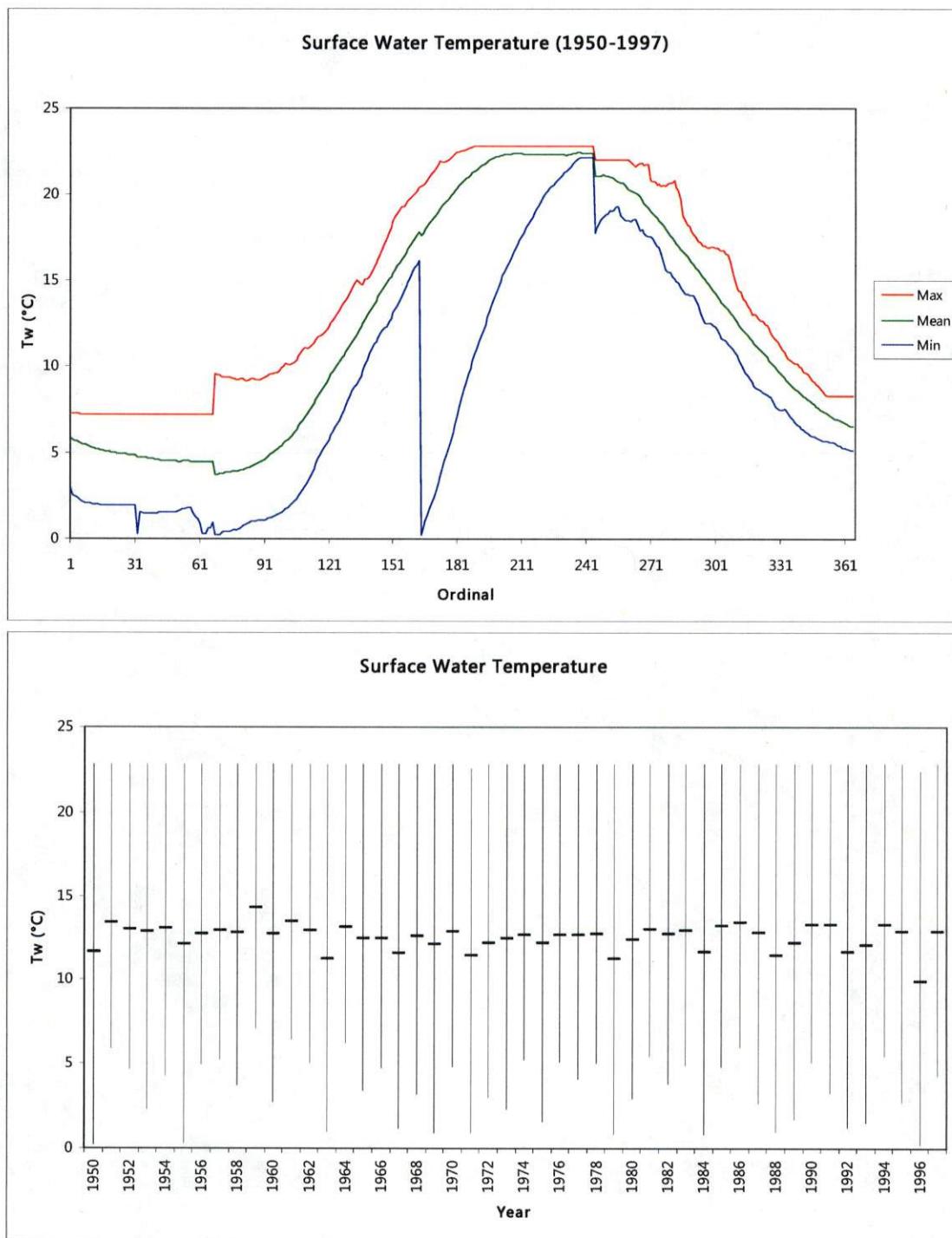


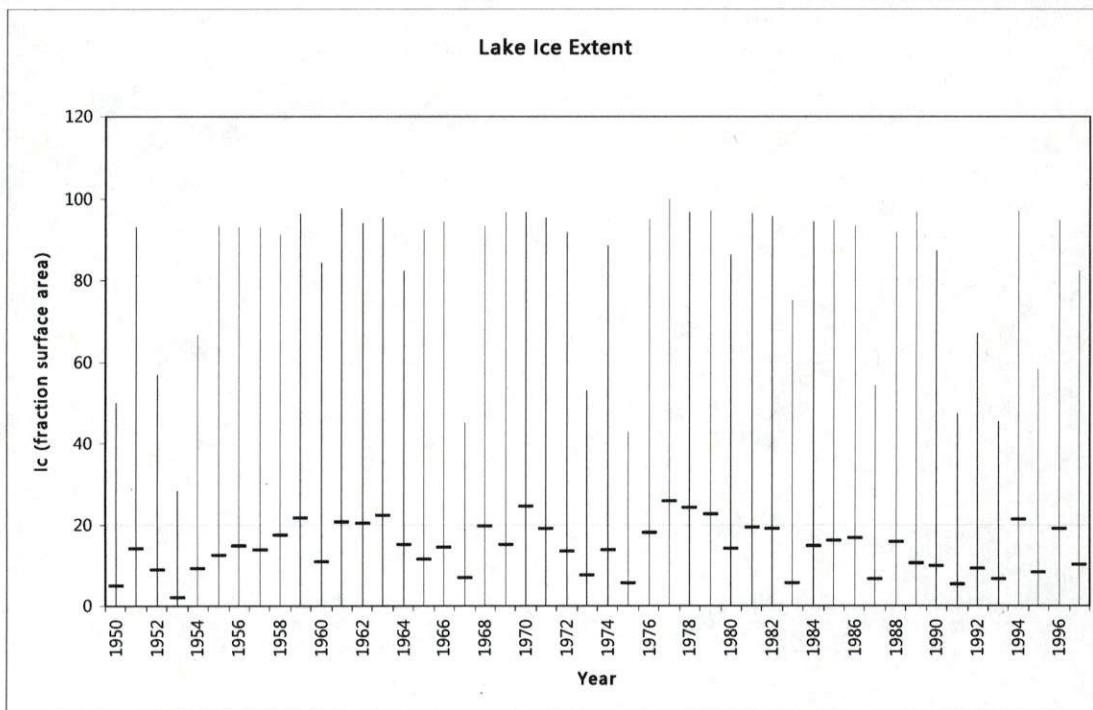
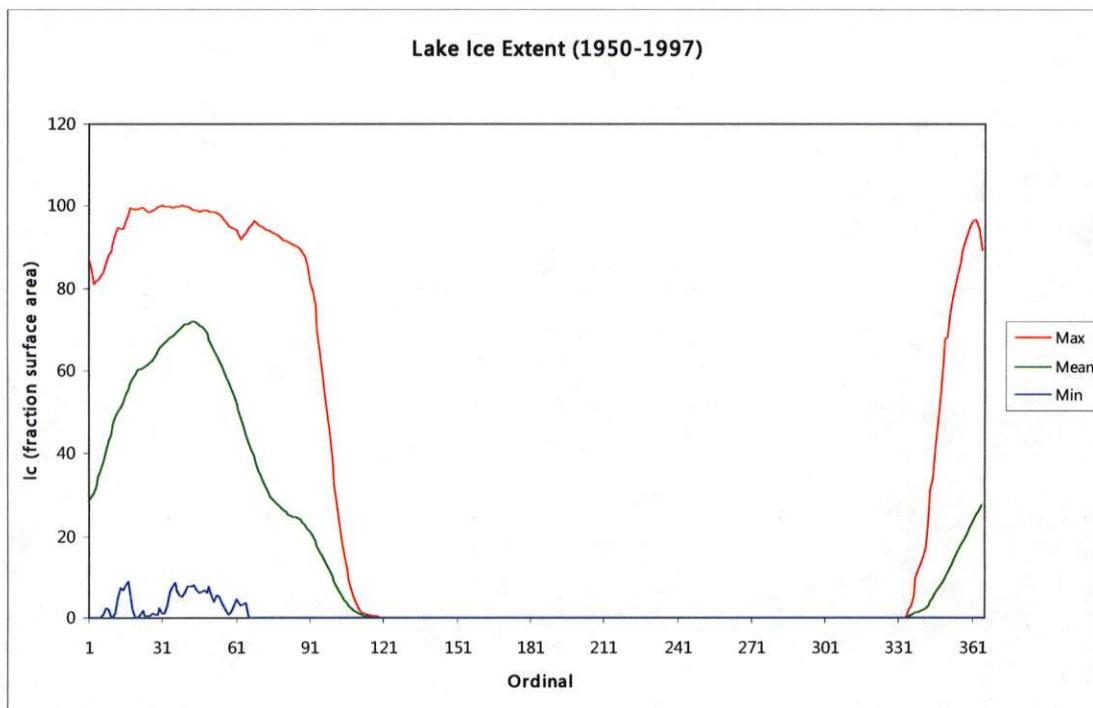




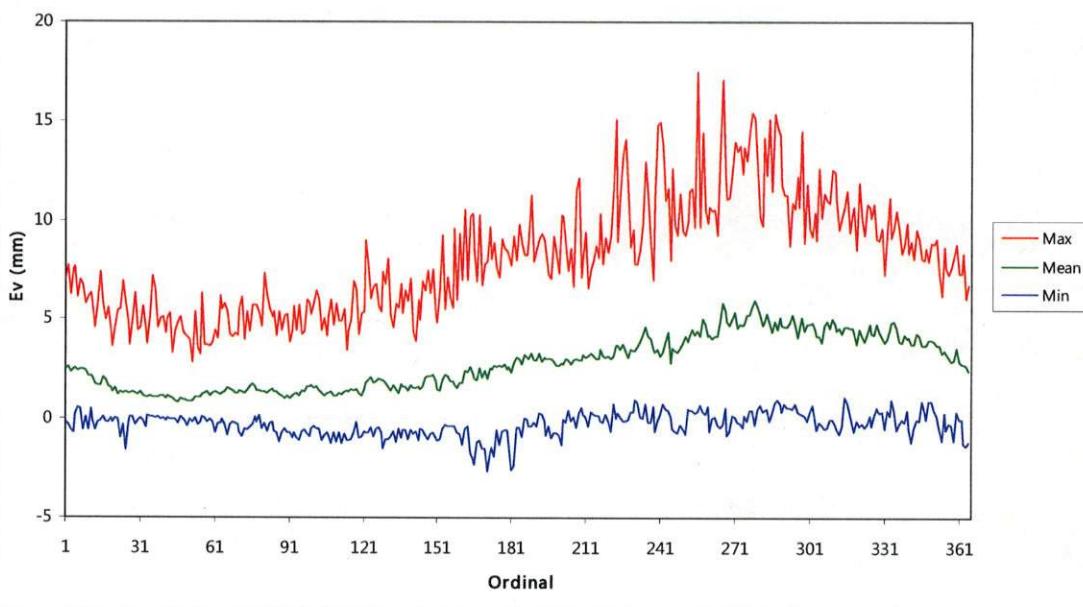




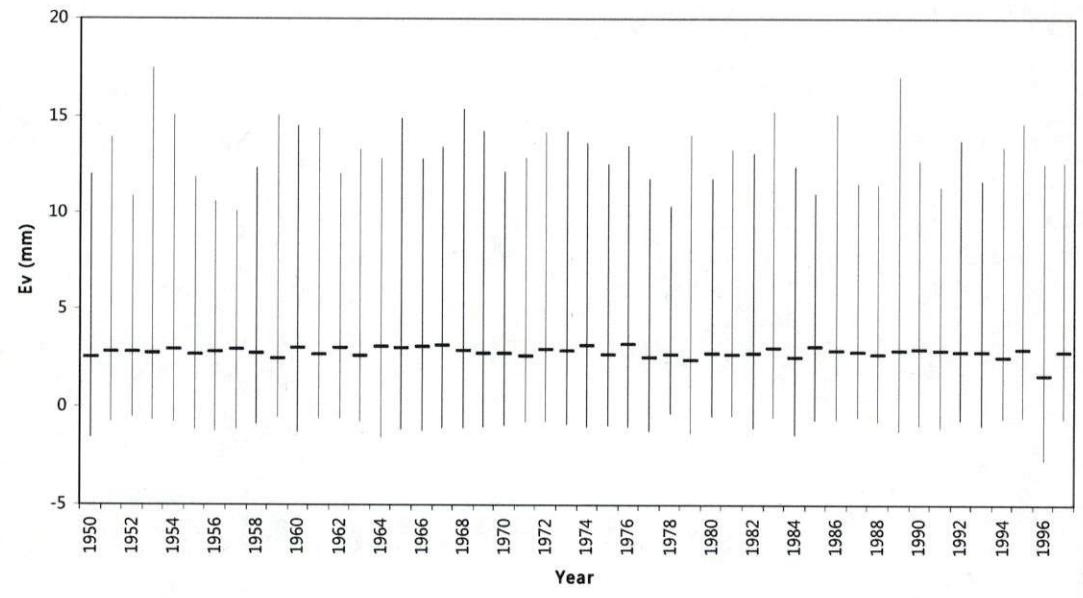


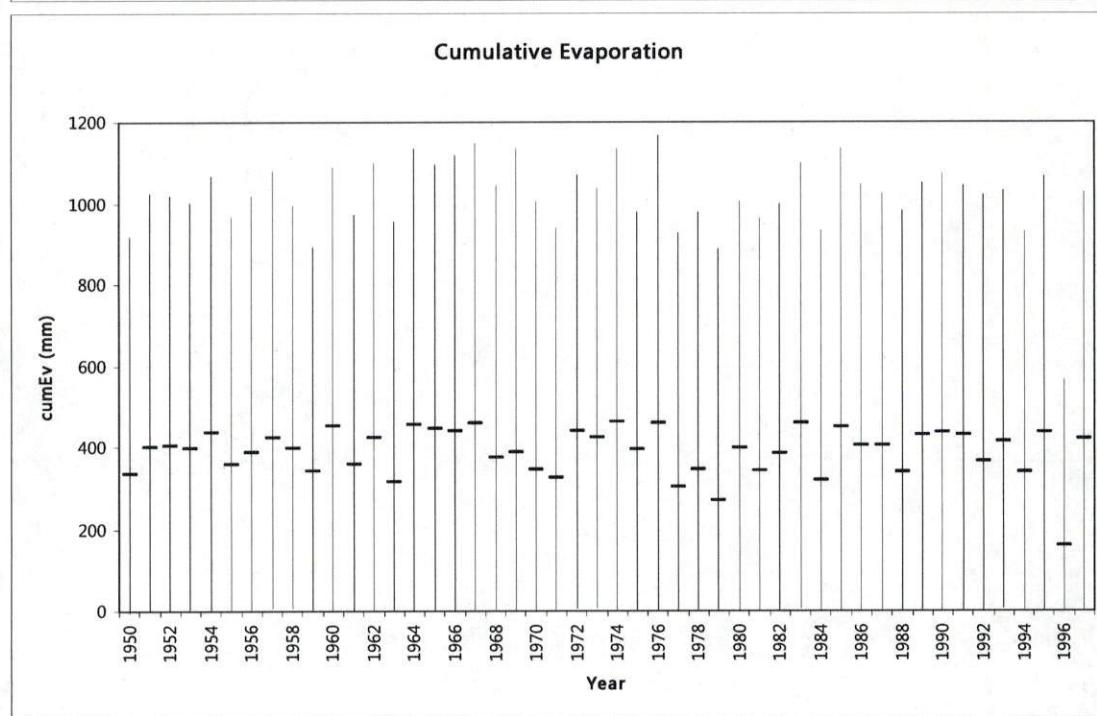
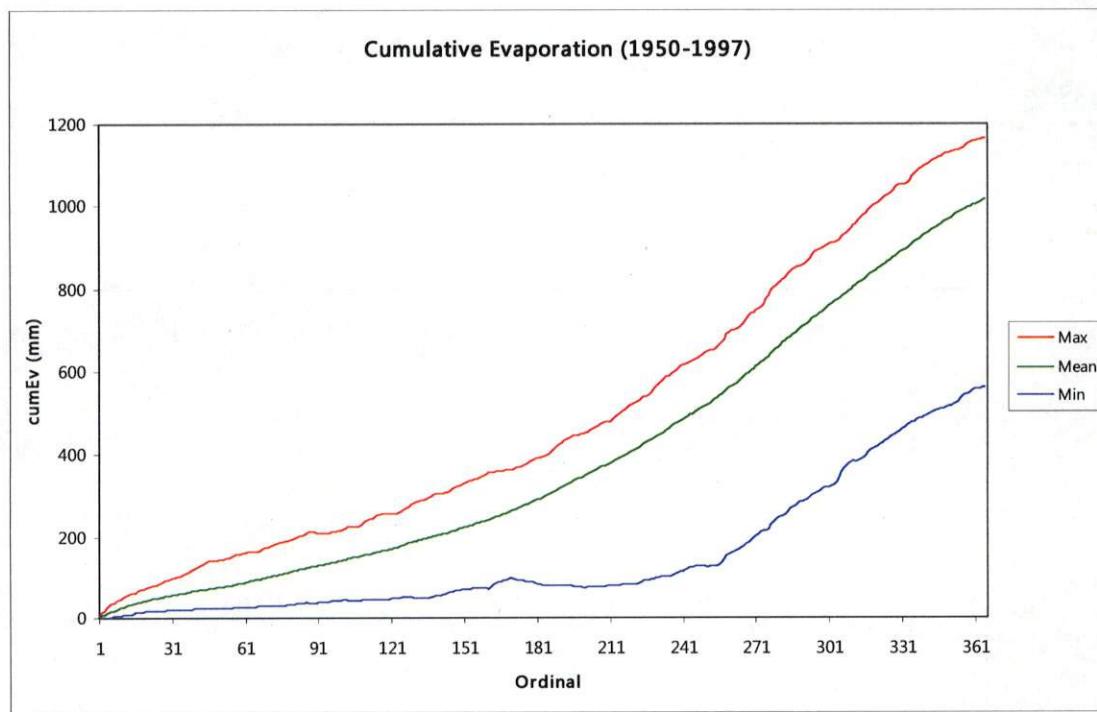


Daily Evaporation (1950-1997)



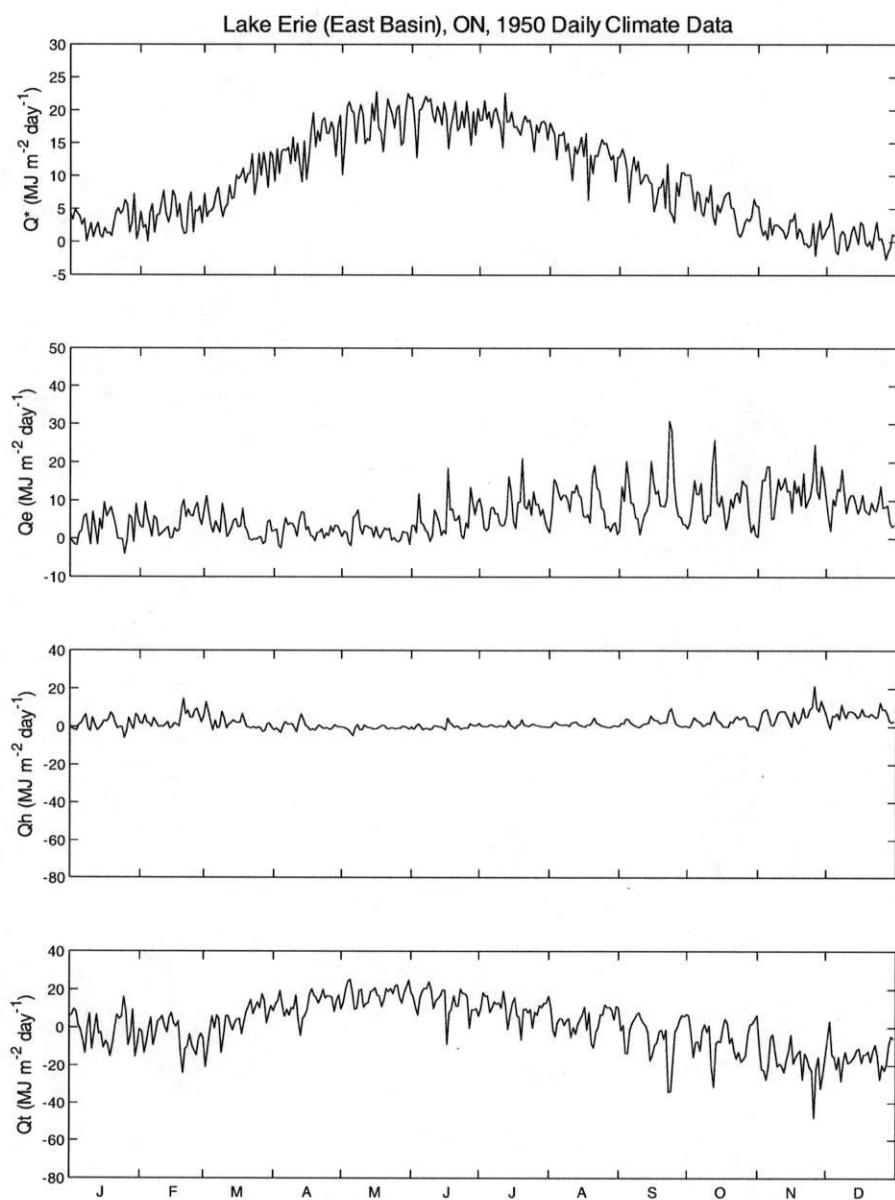
Daily Evaporation

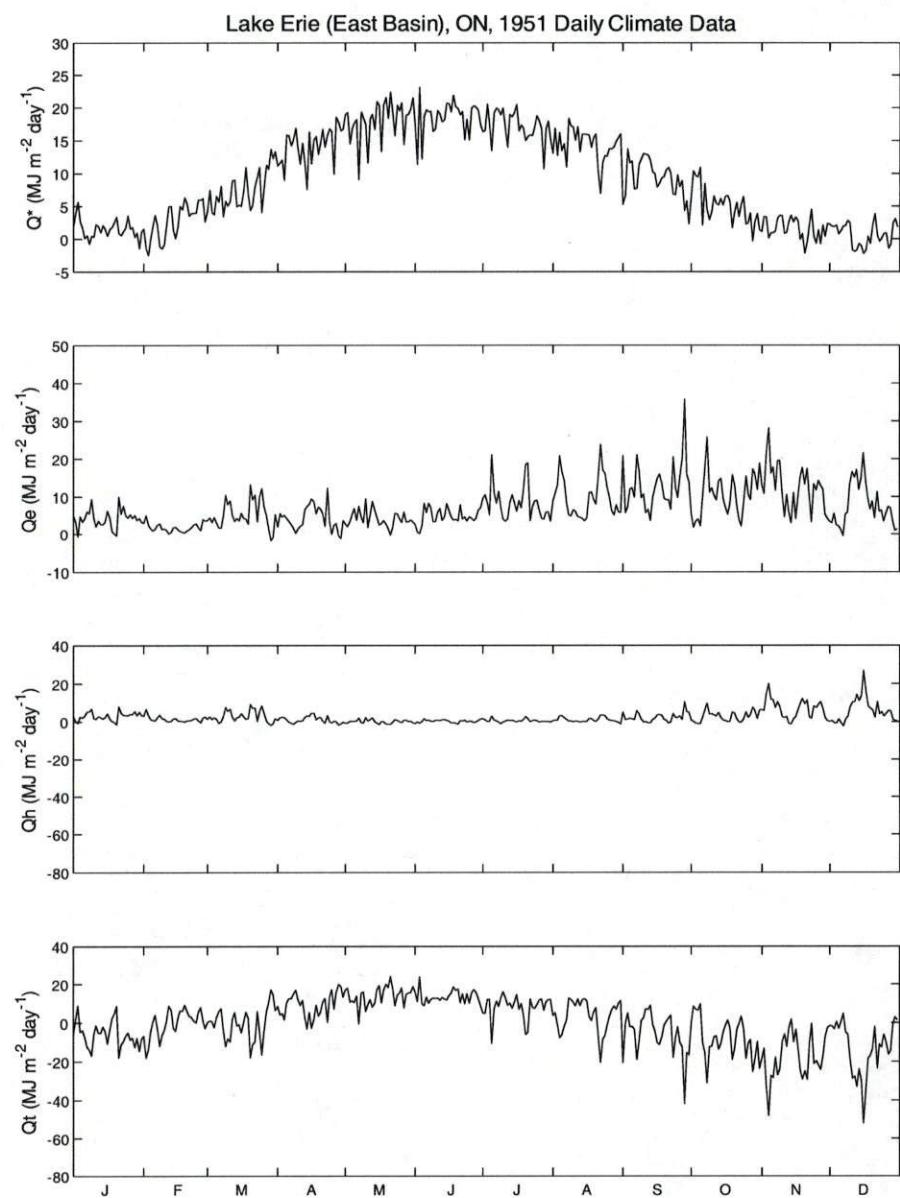


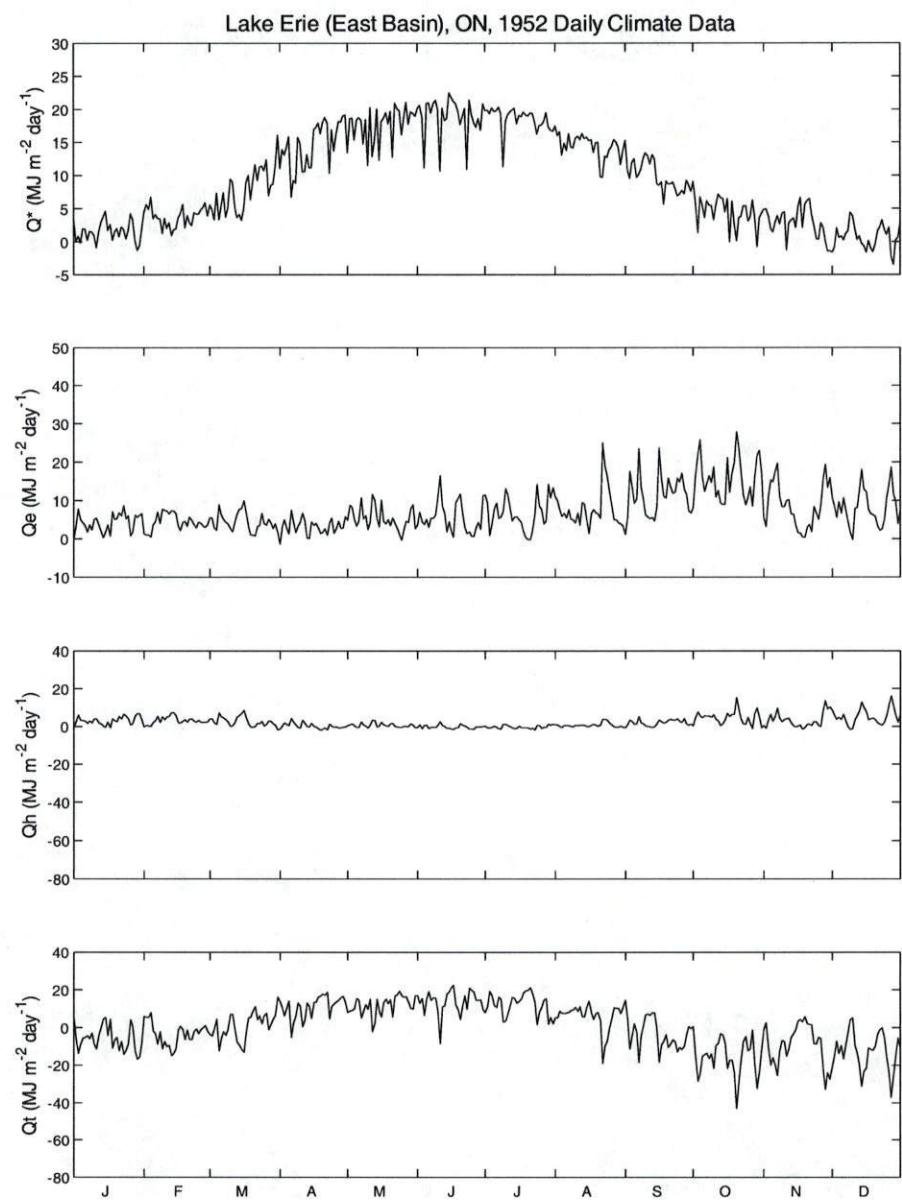


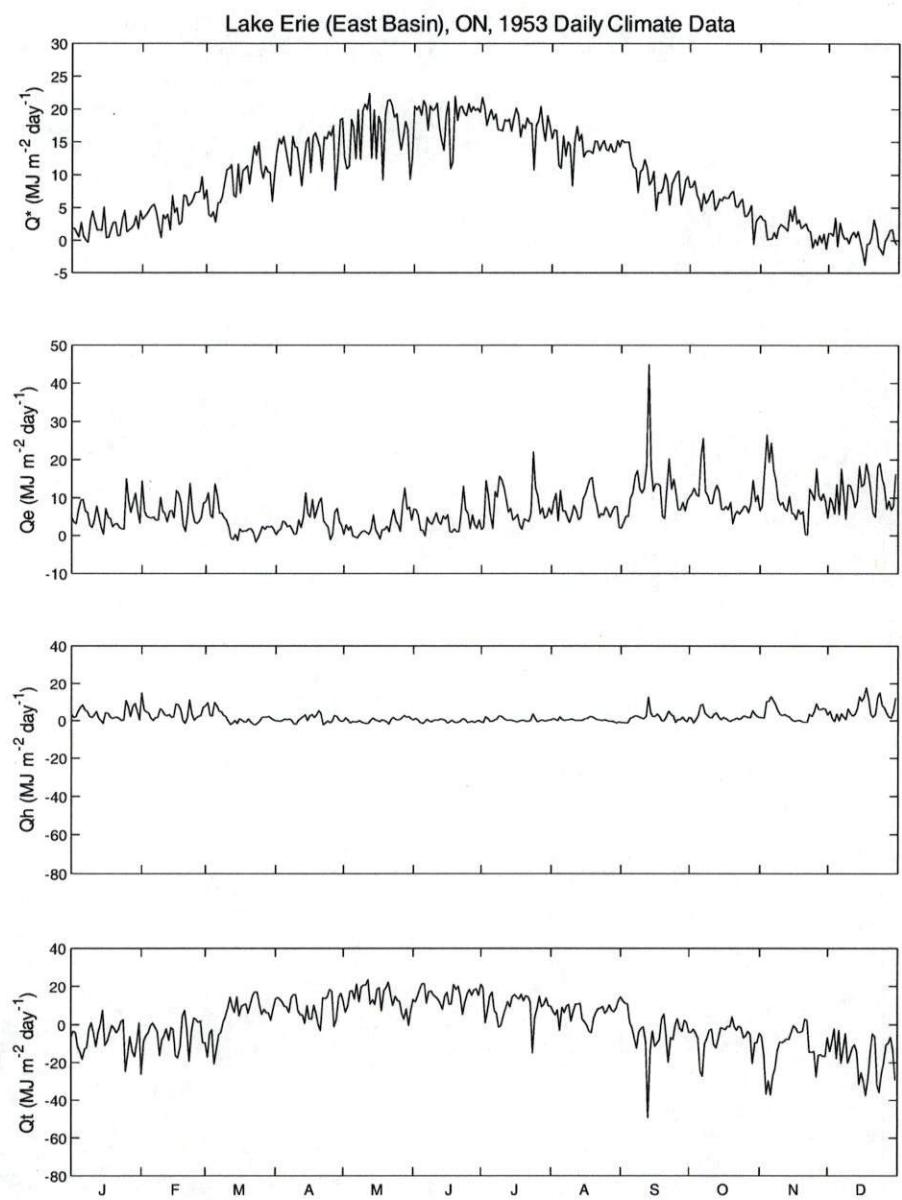
Appendix 2

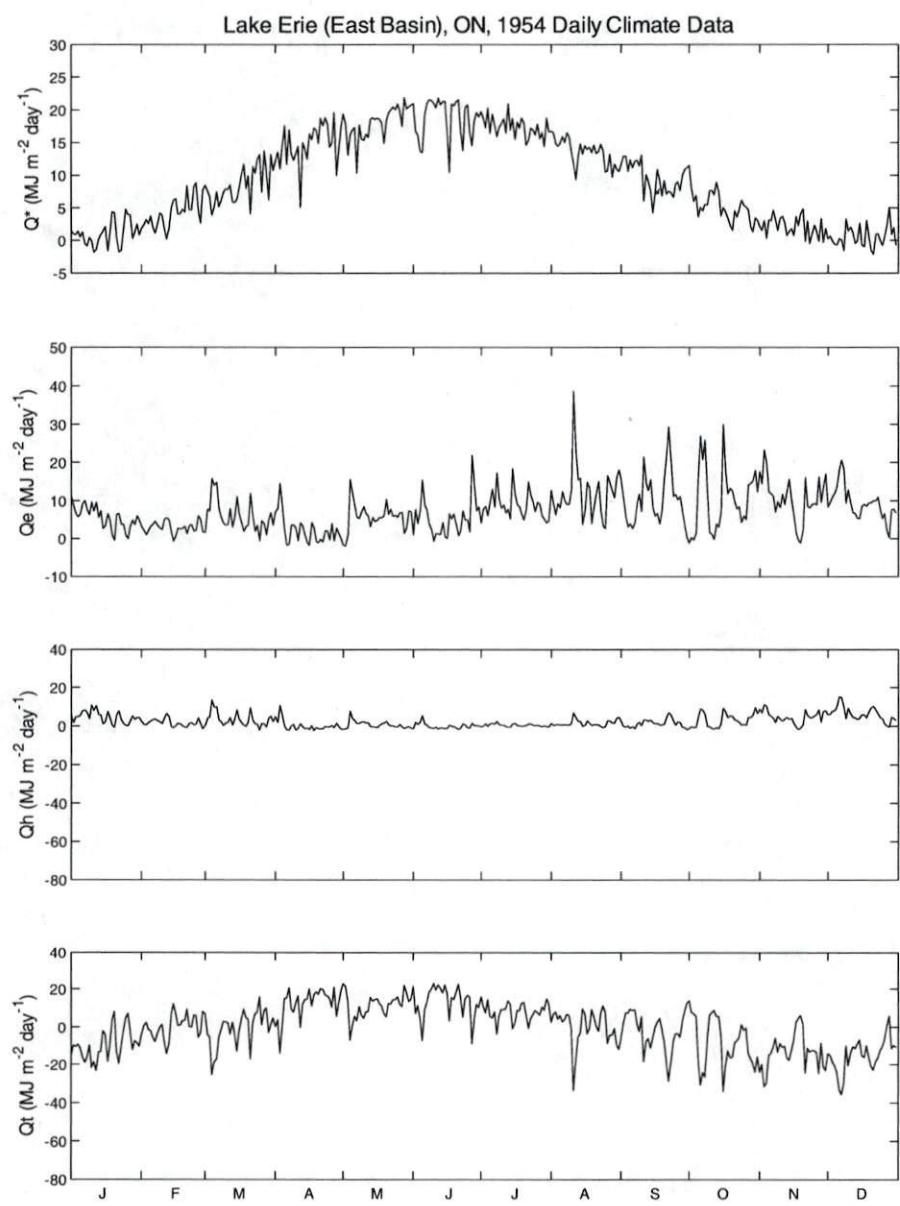
Heat Fluxes

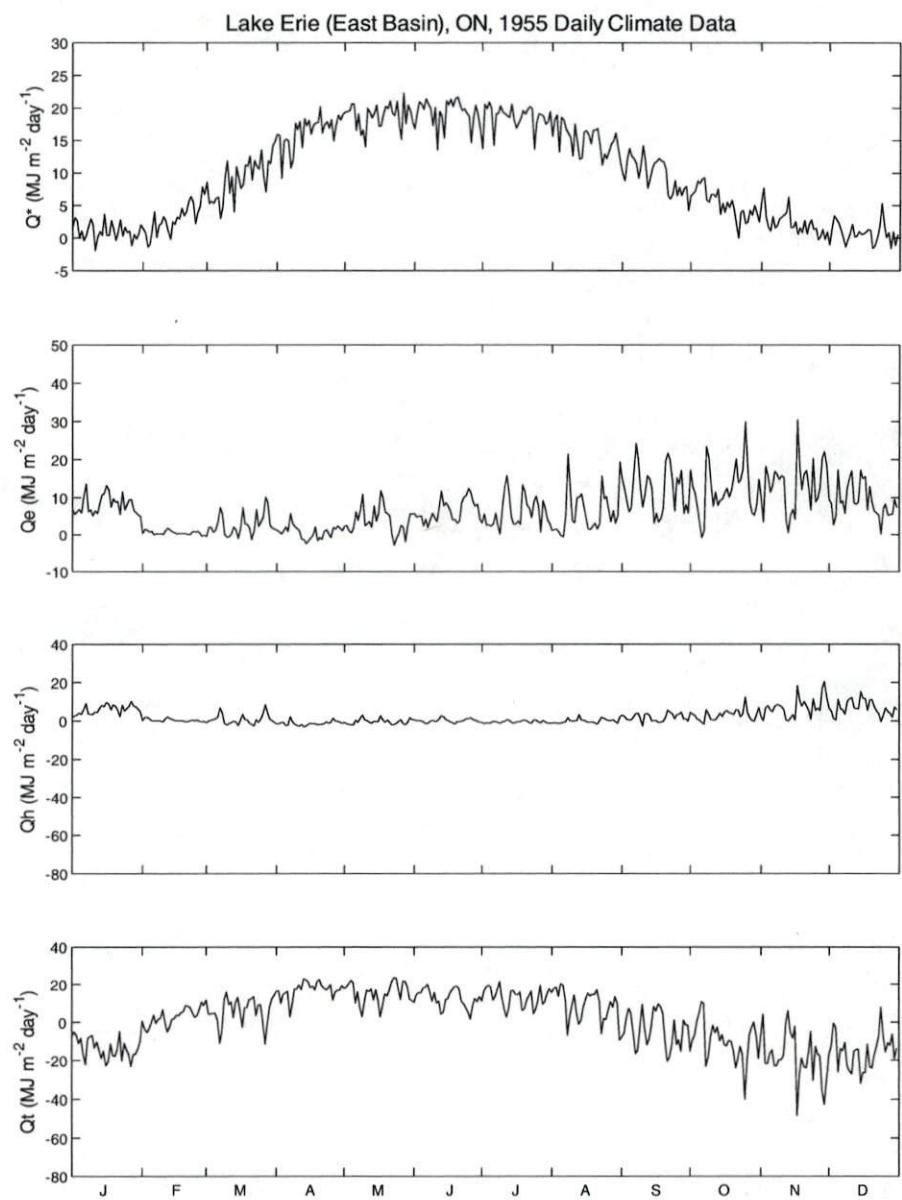


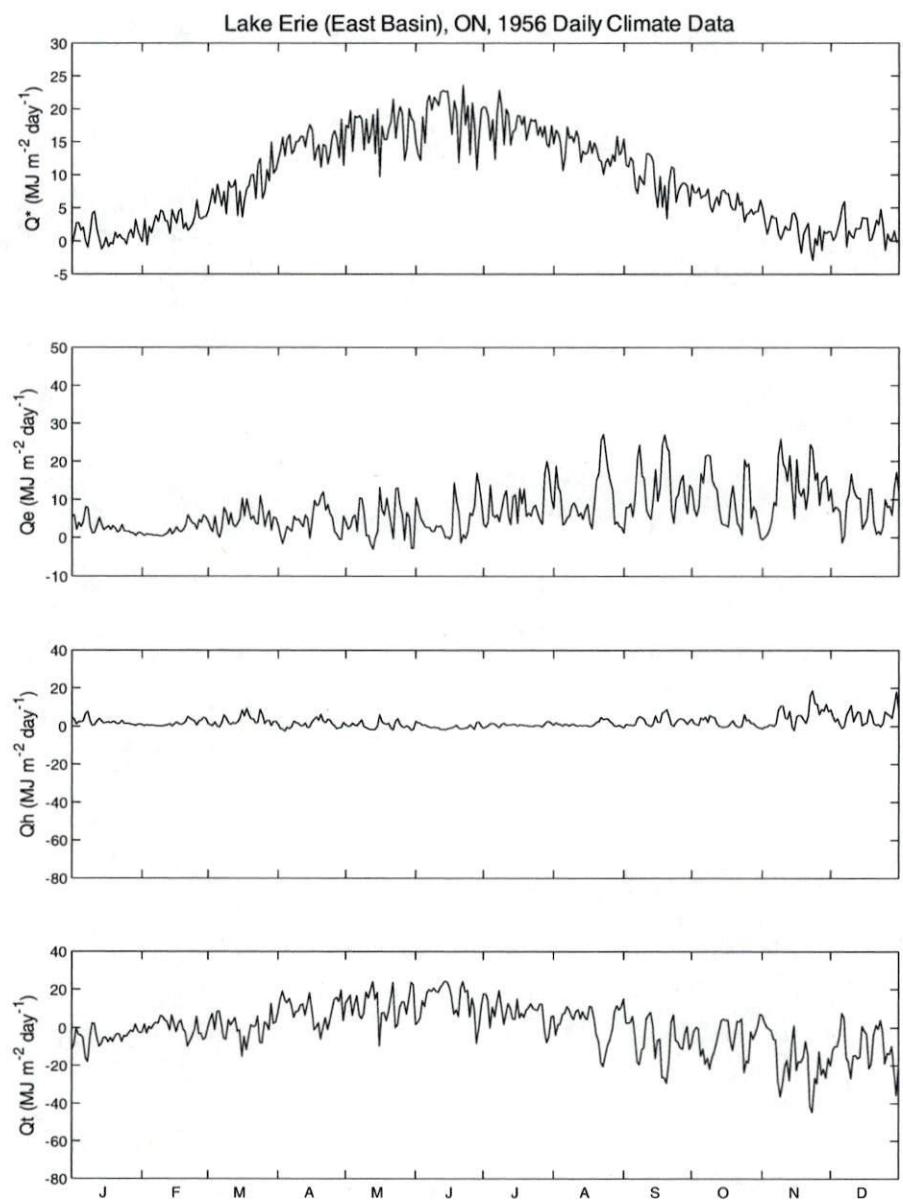


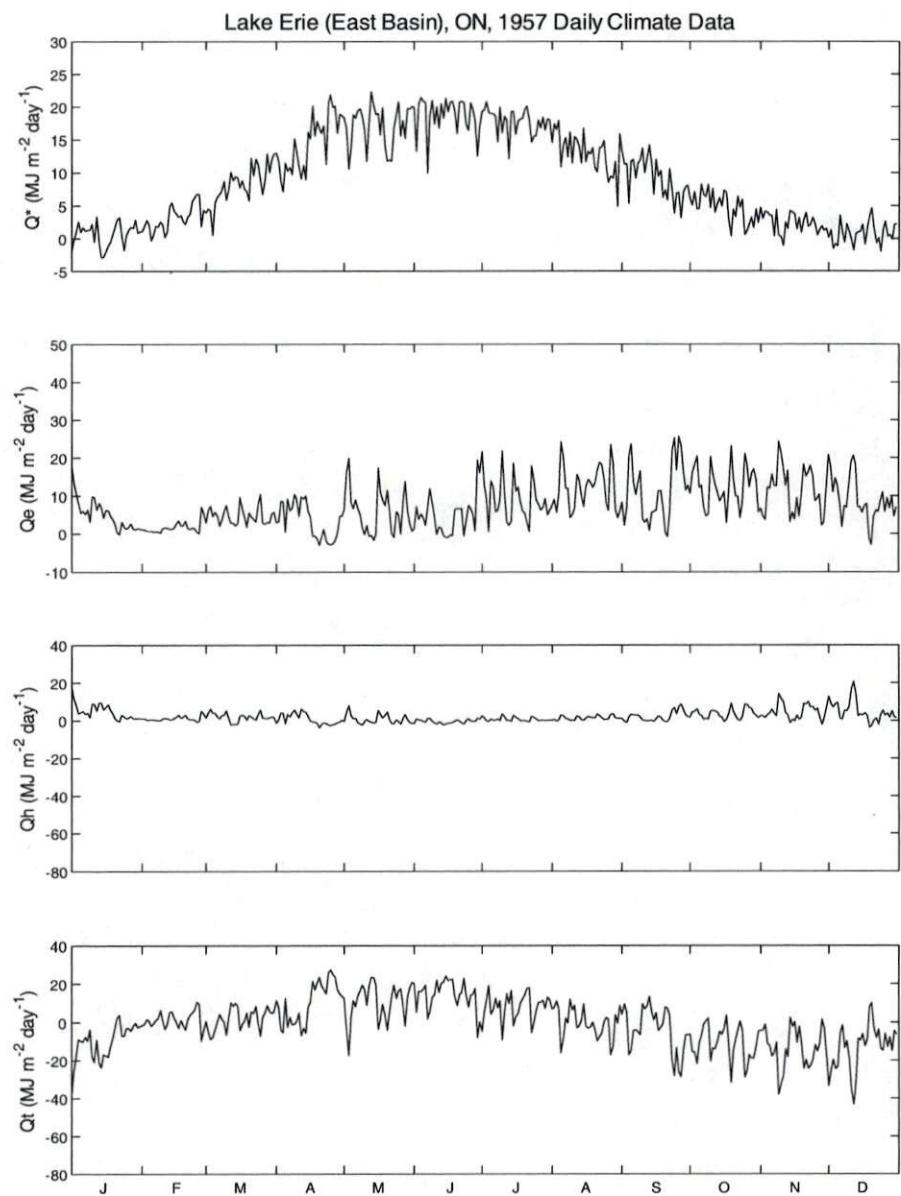


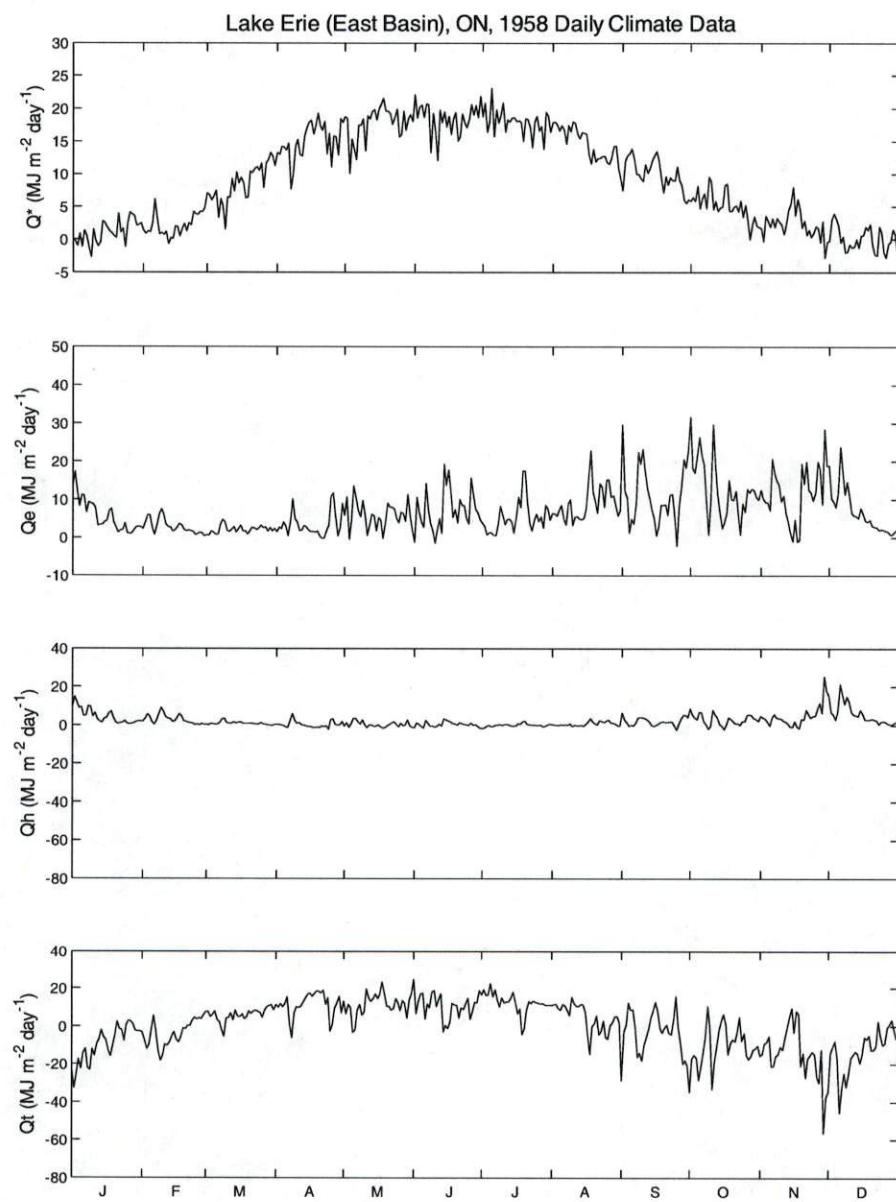


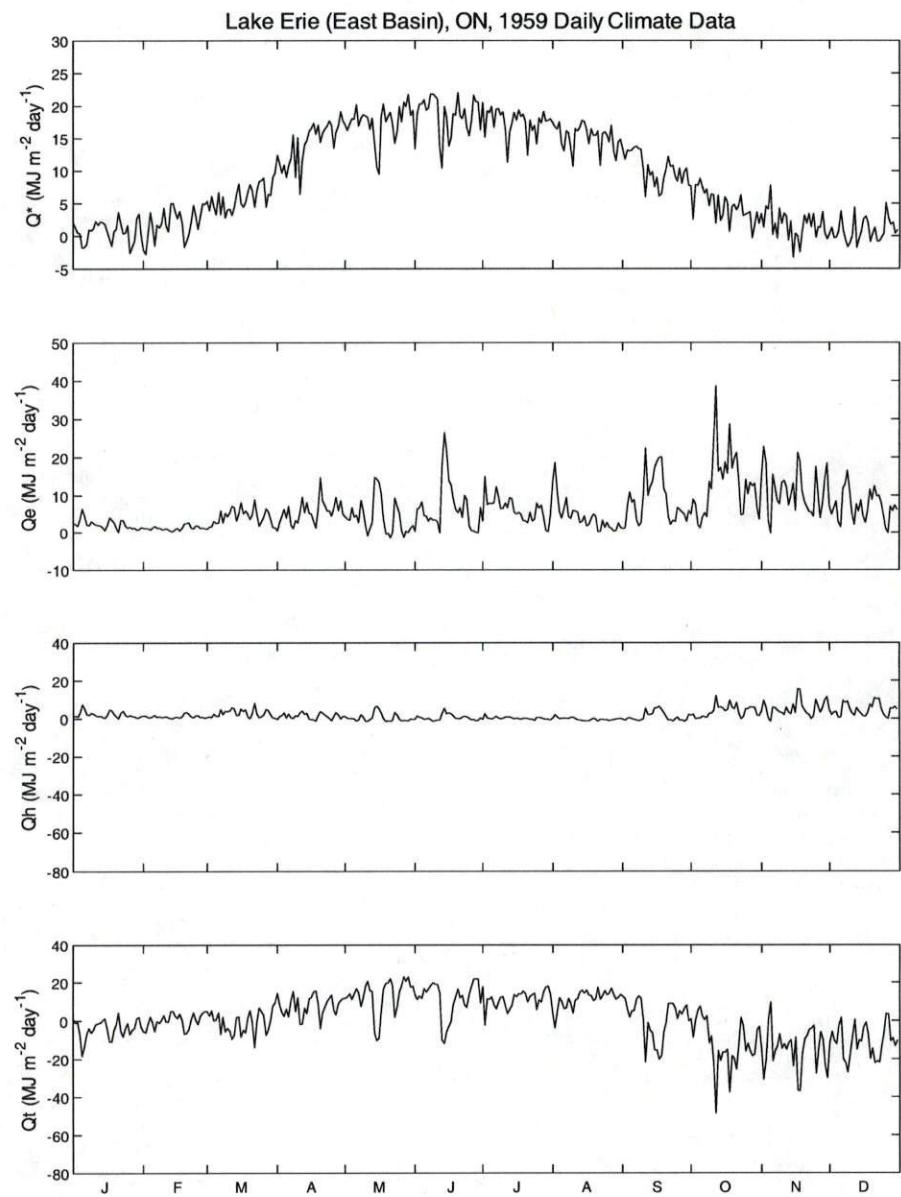


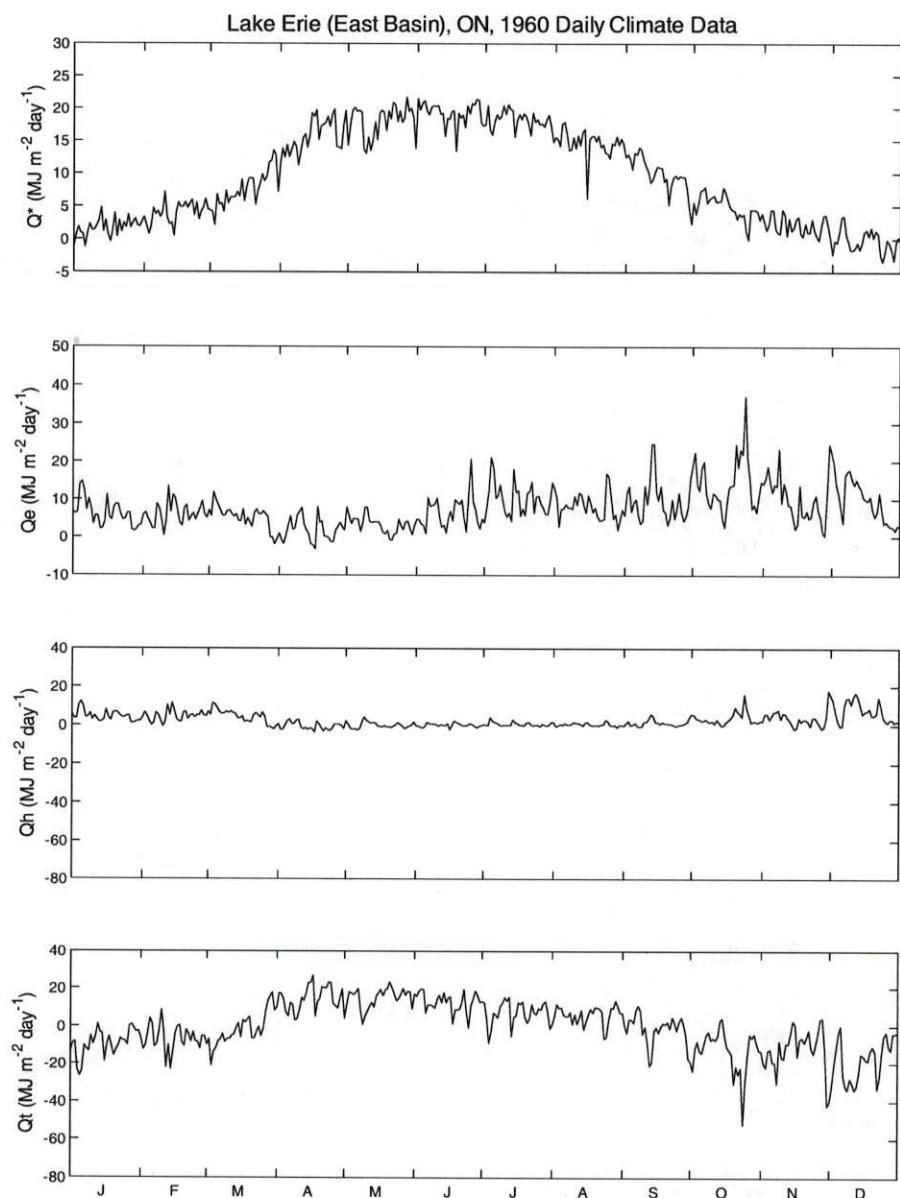


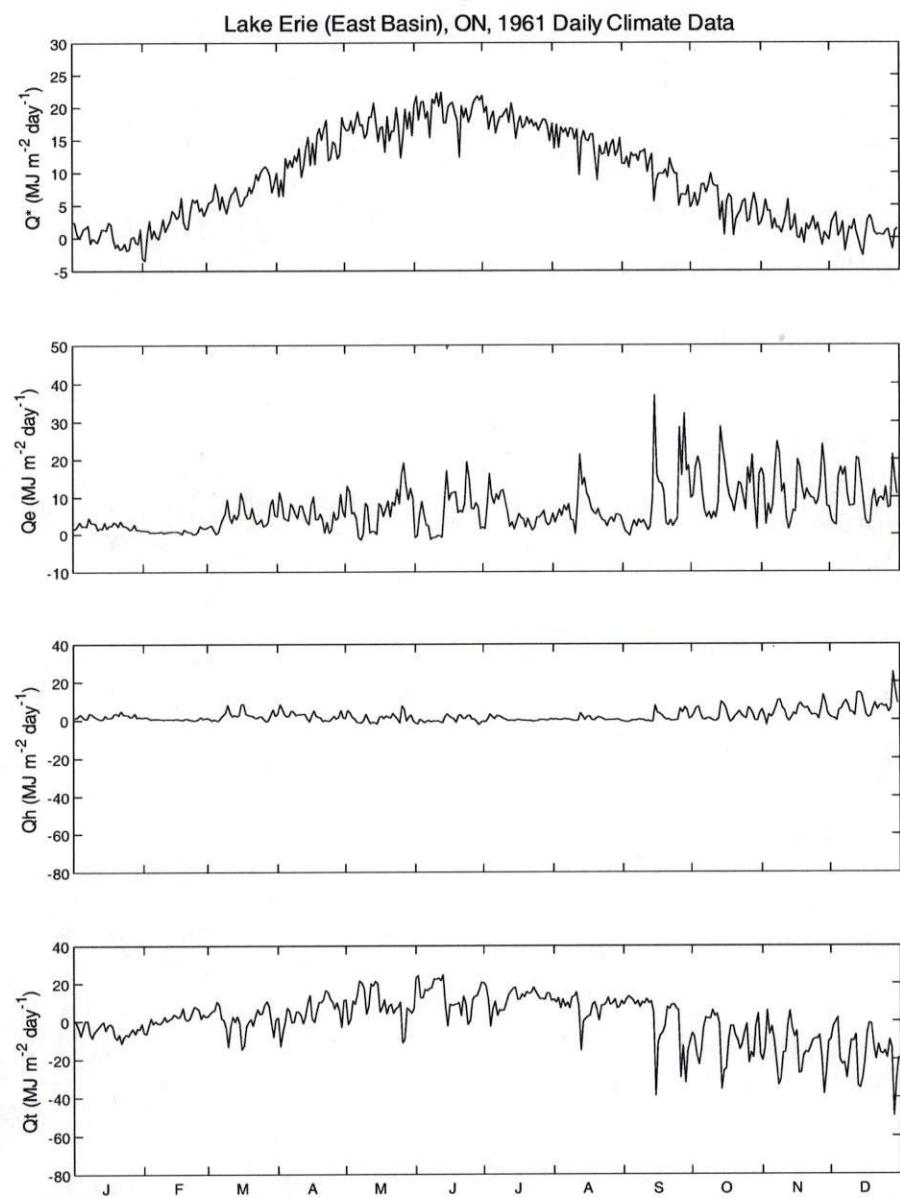


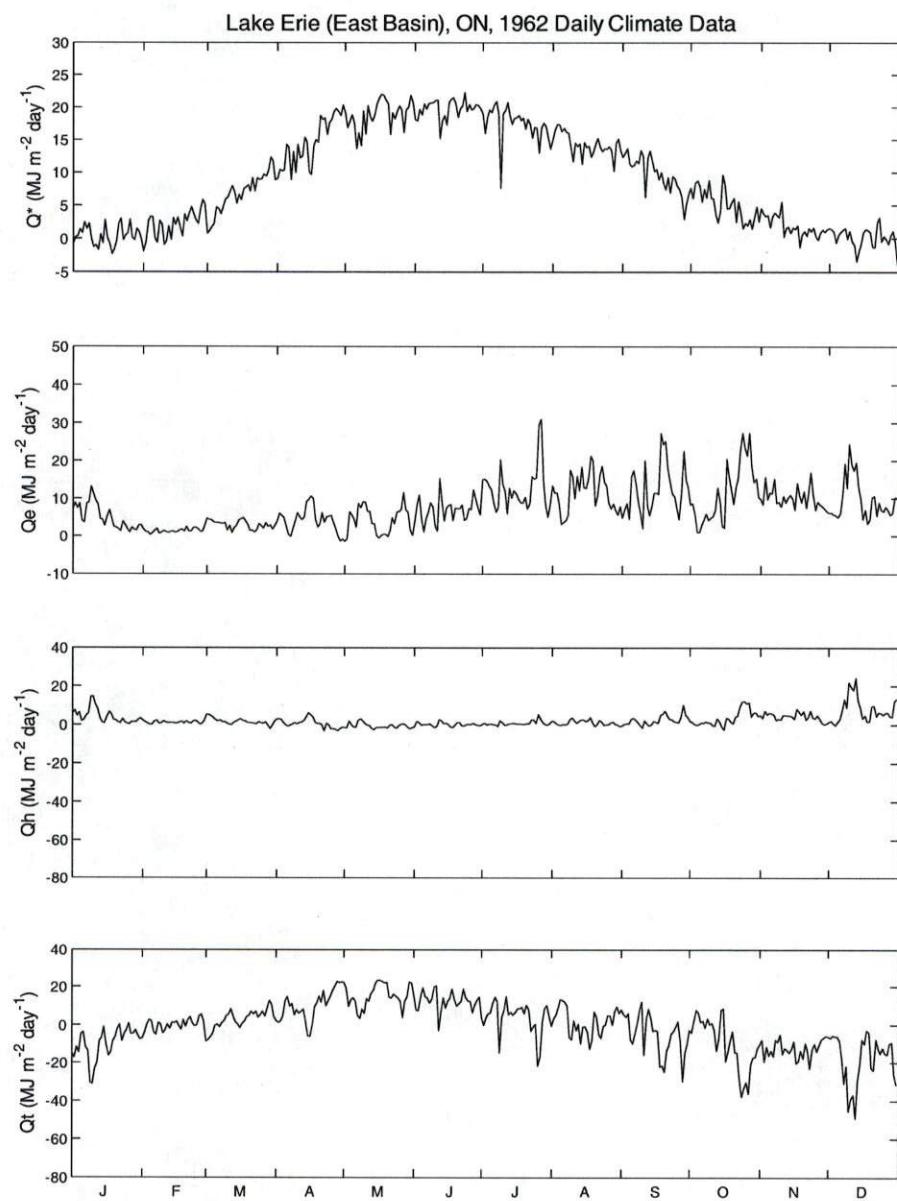


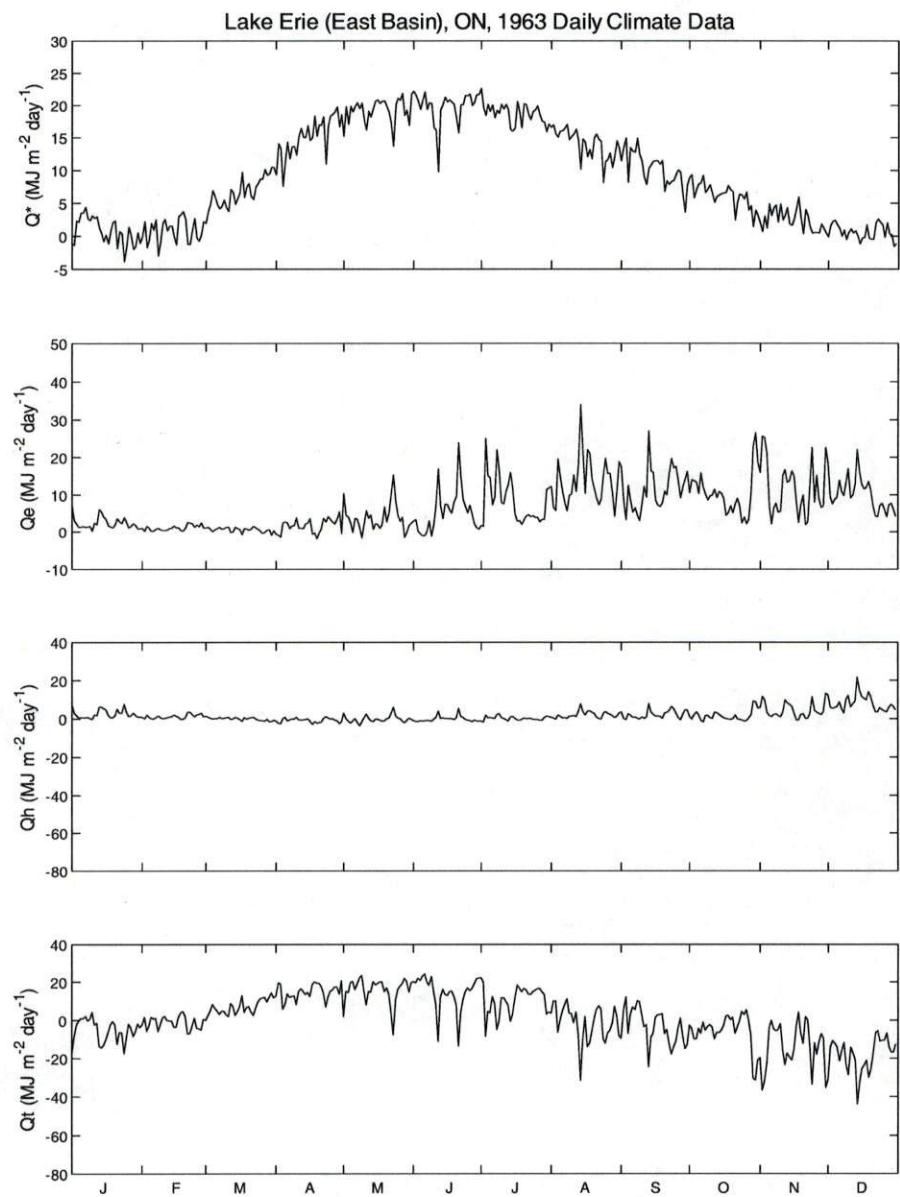


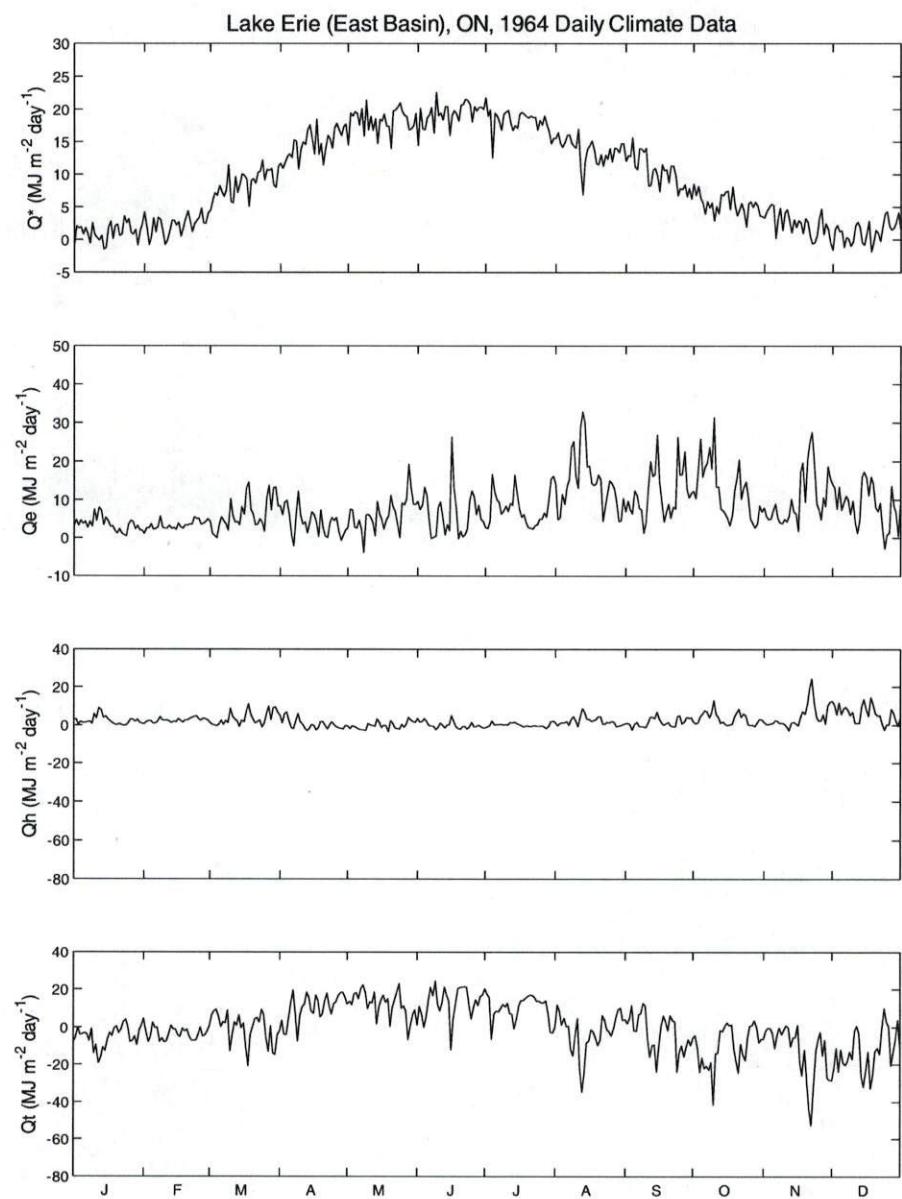


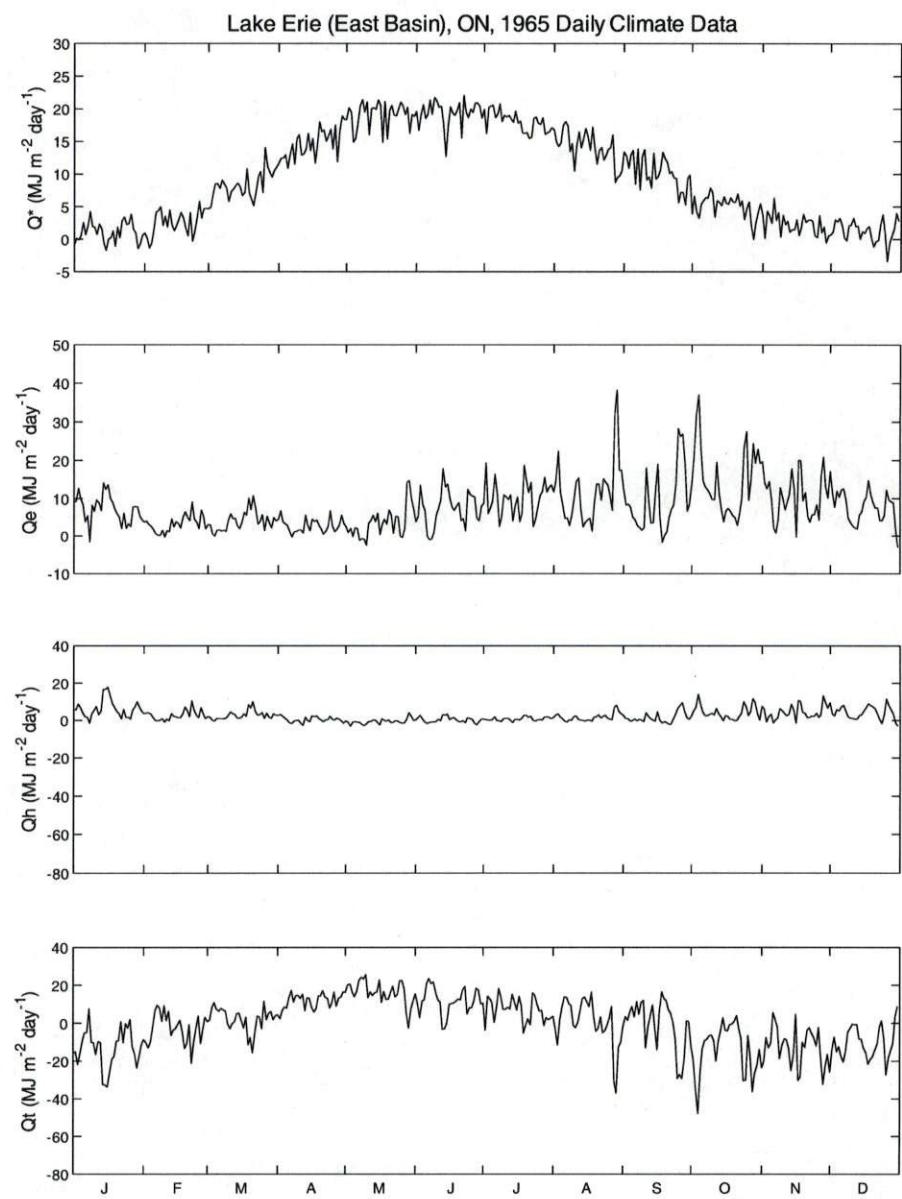


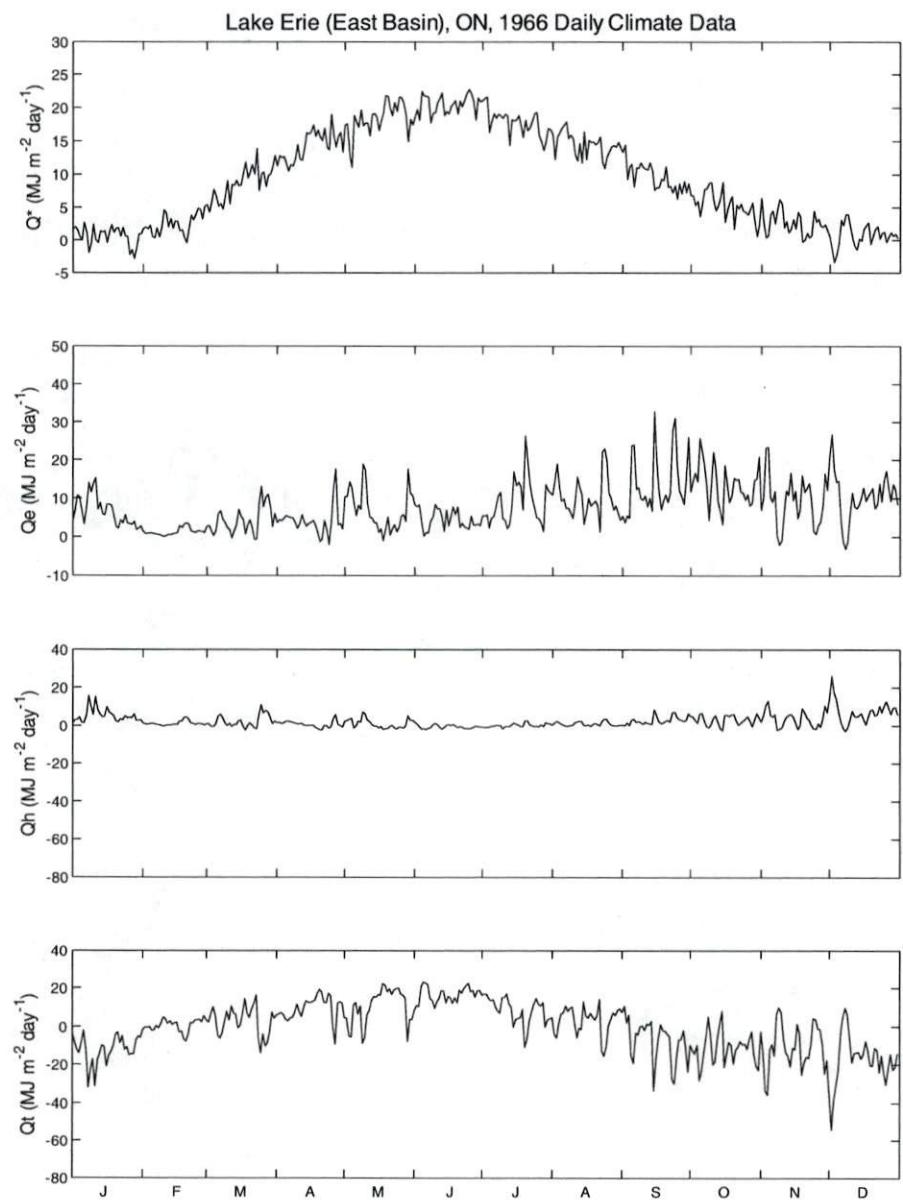


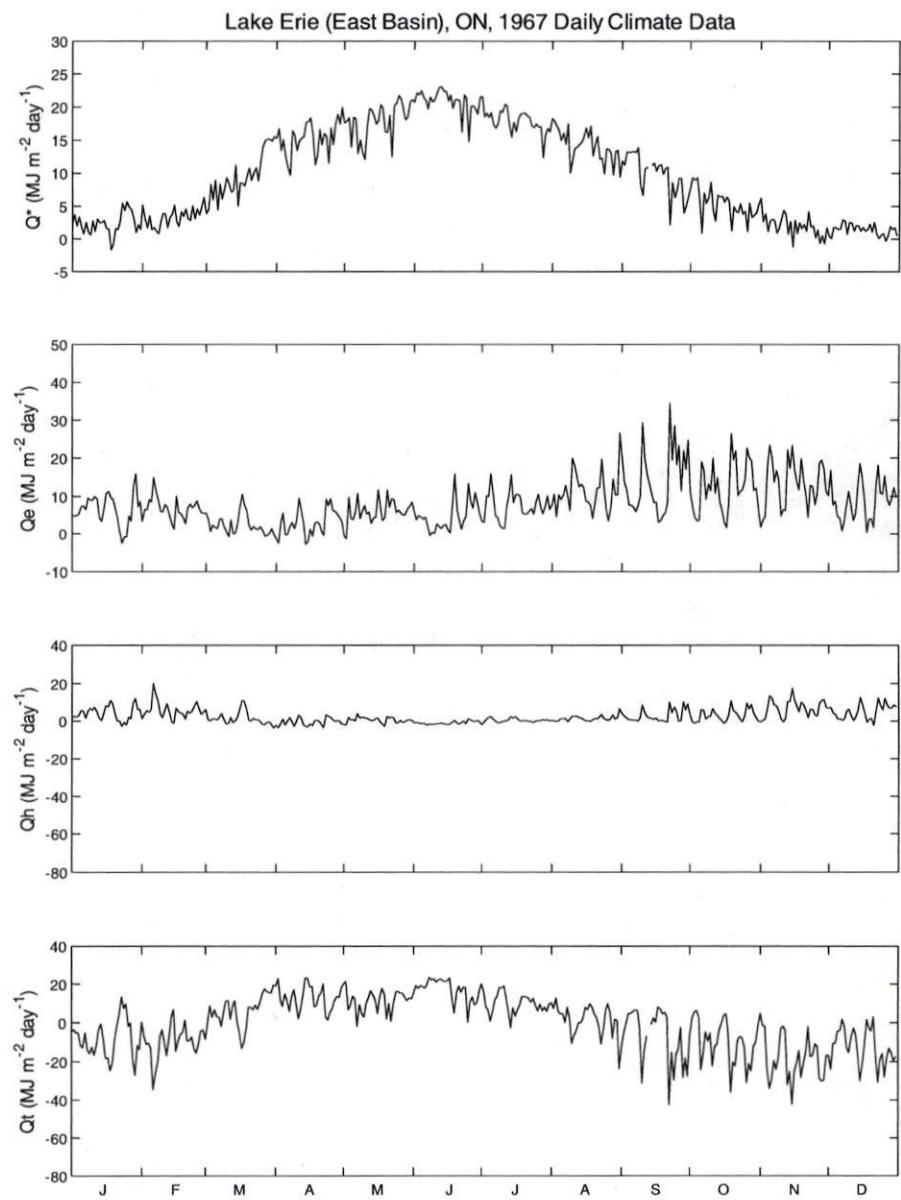


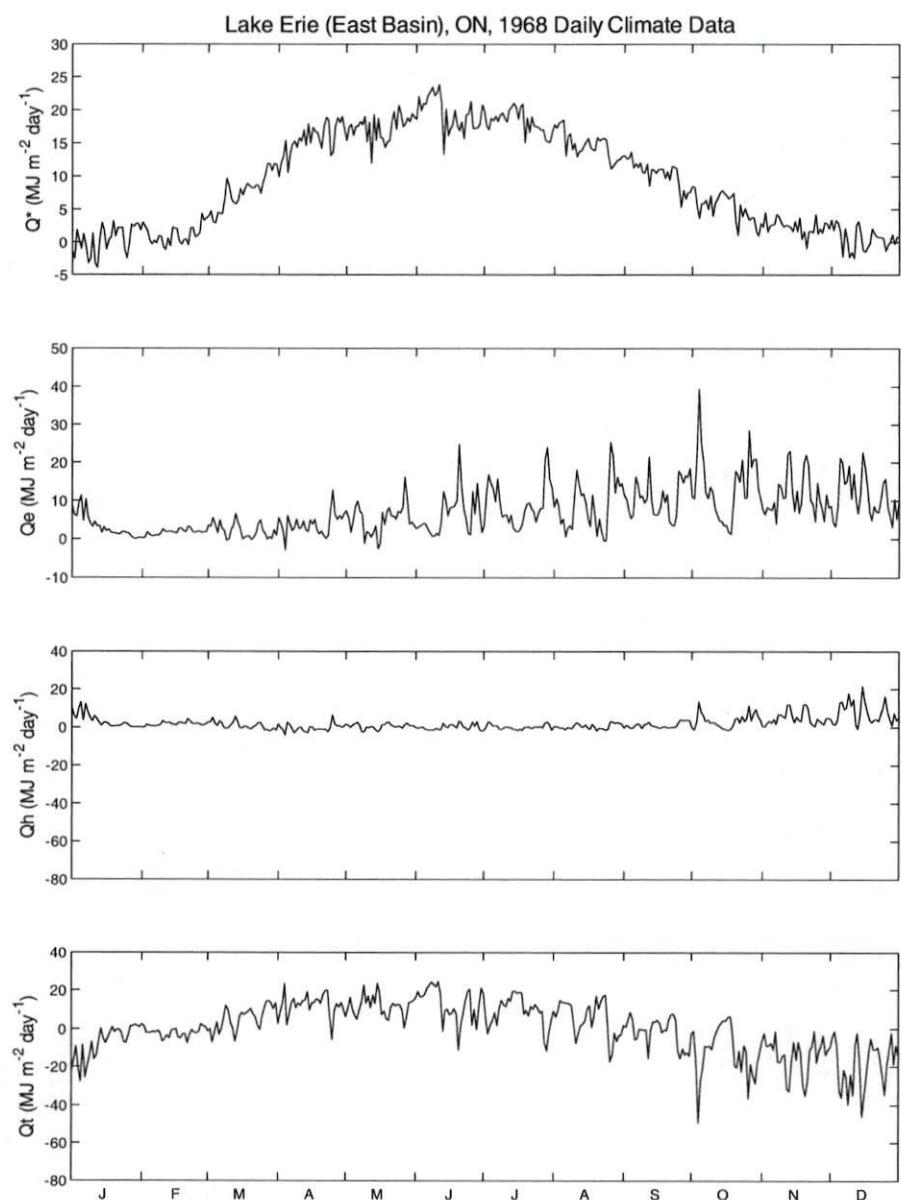


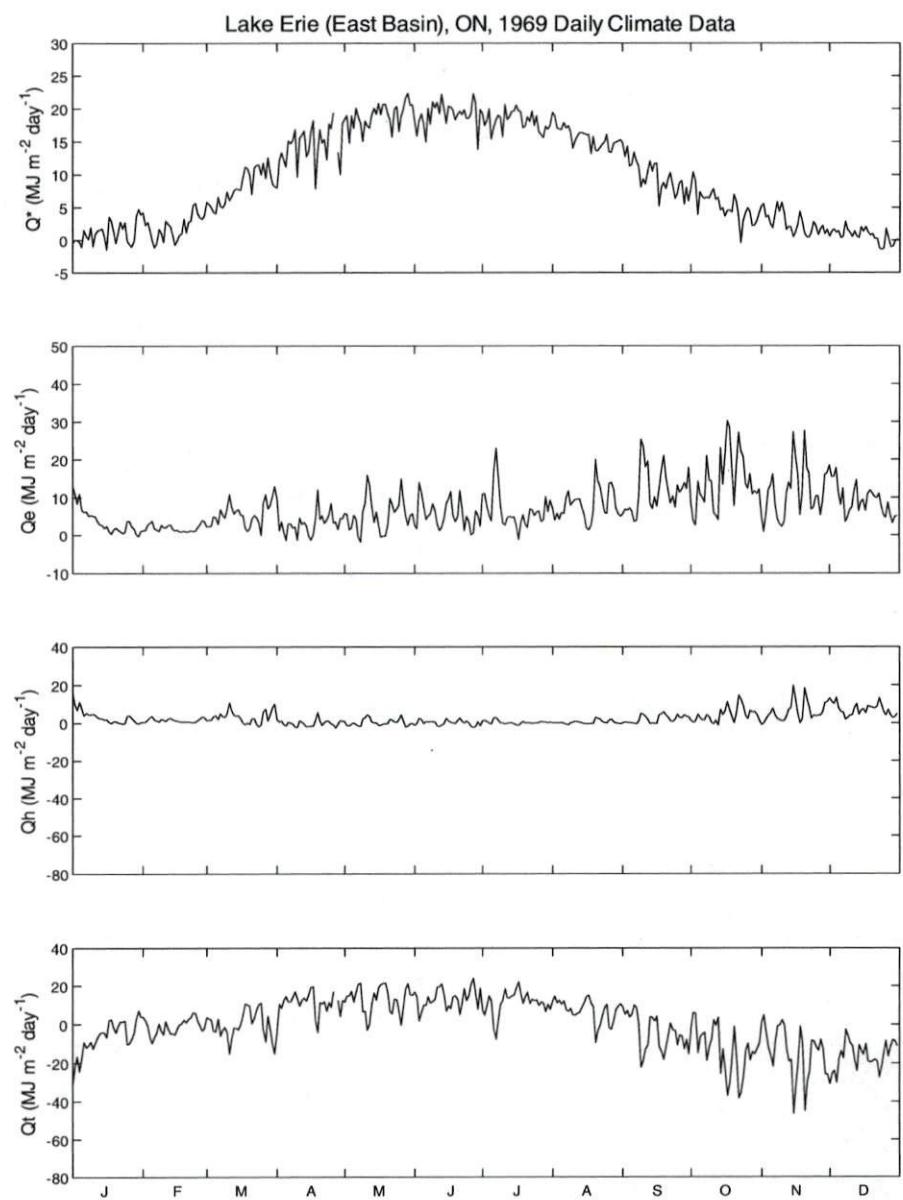


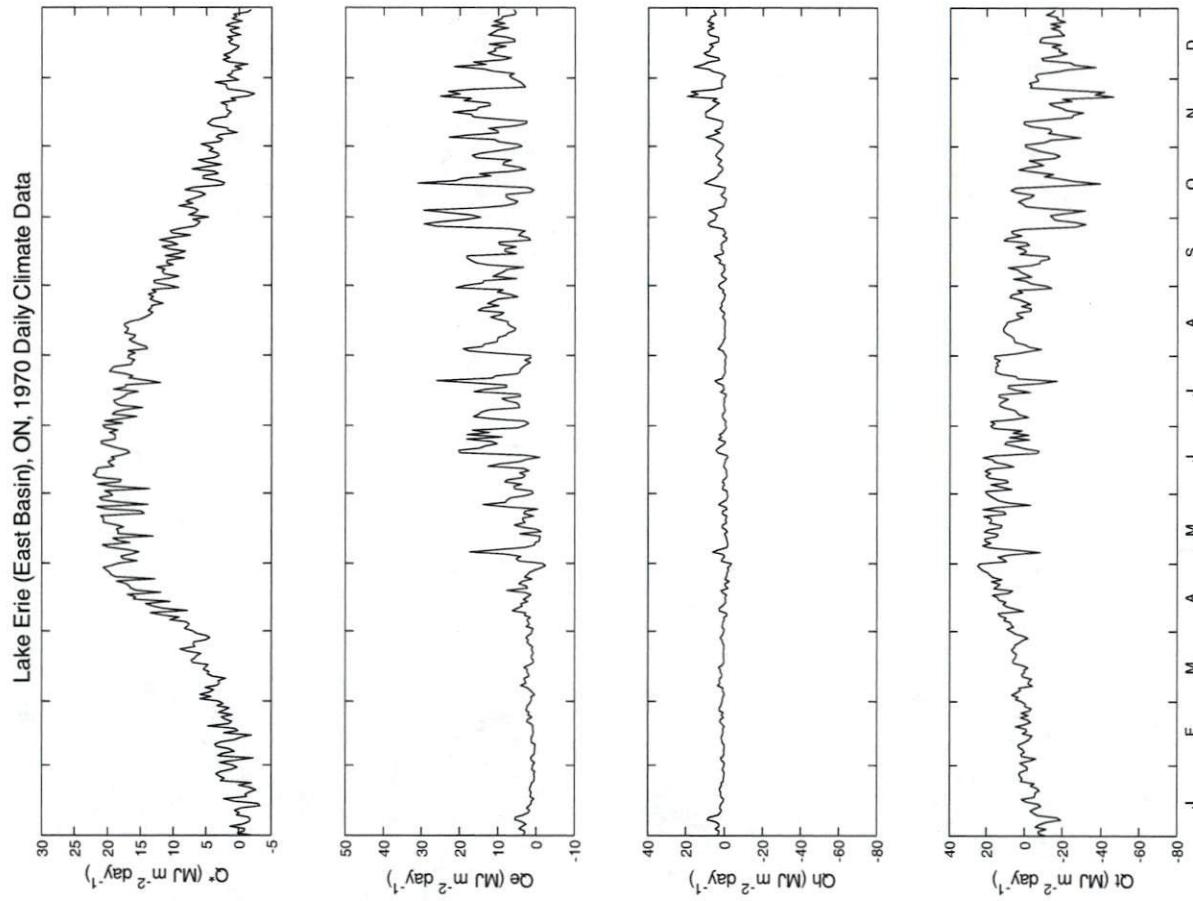


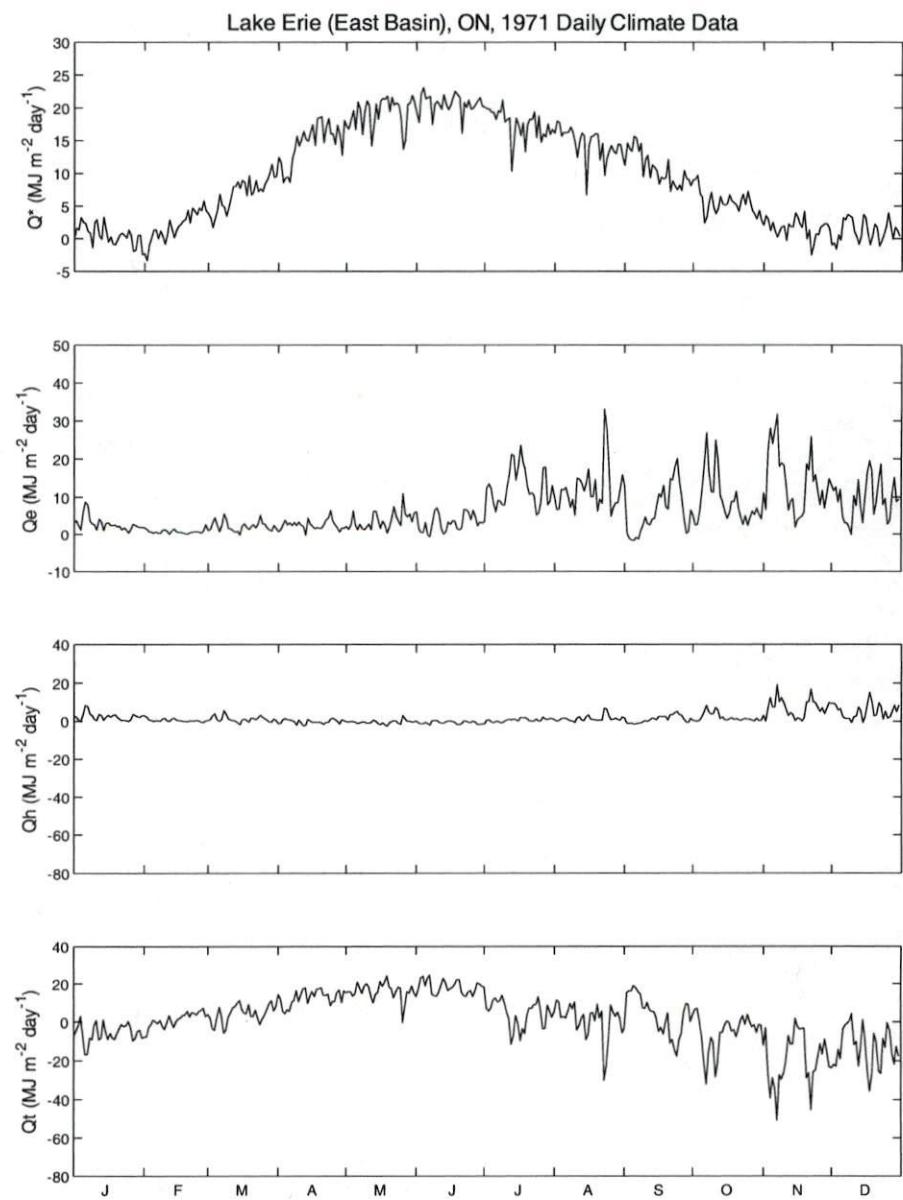


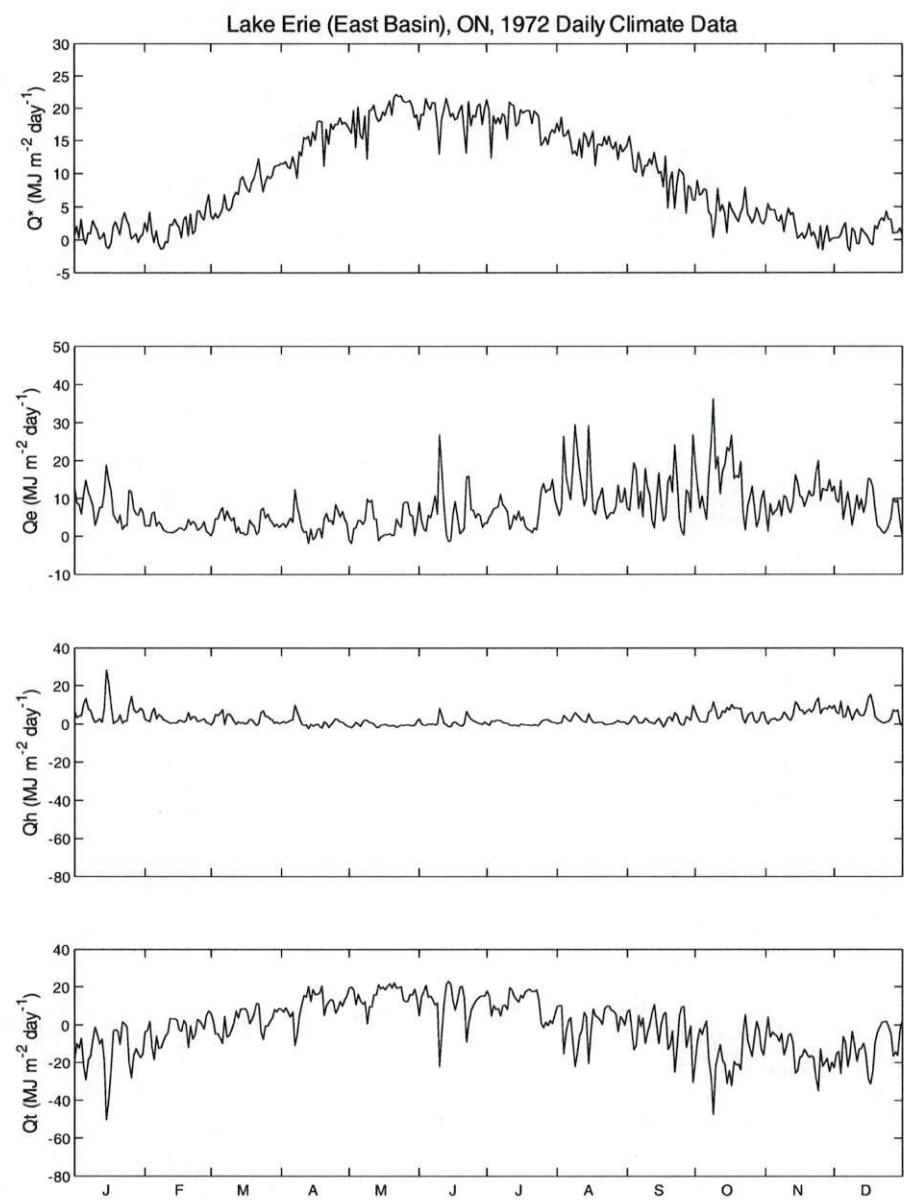


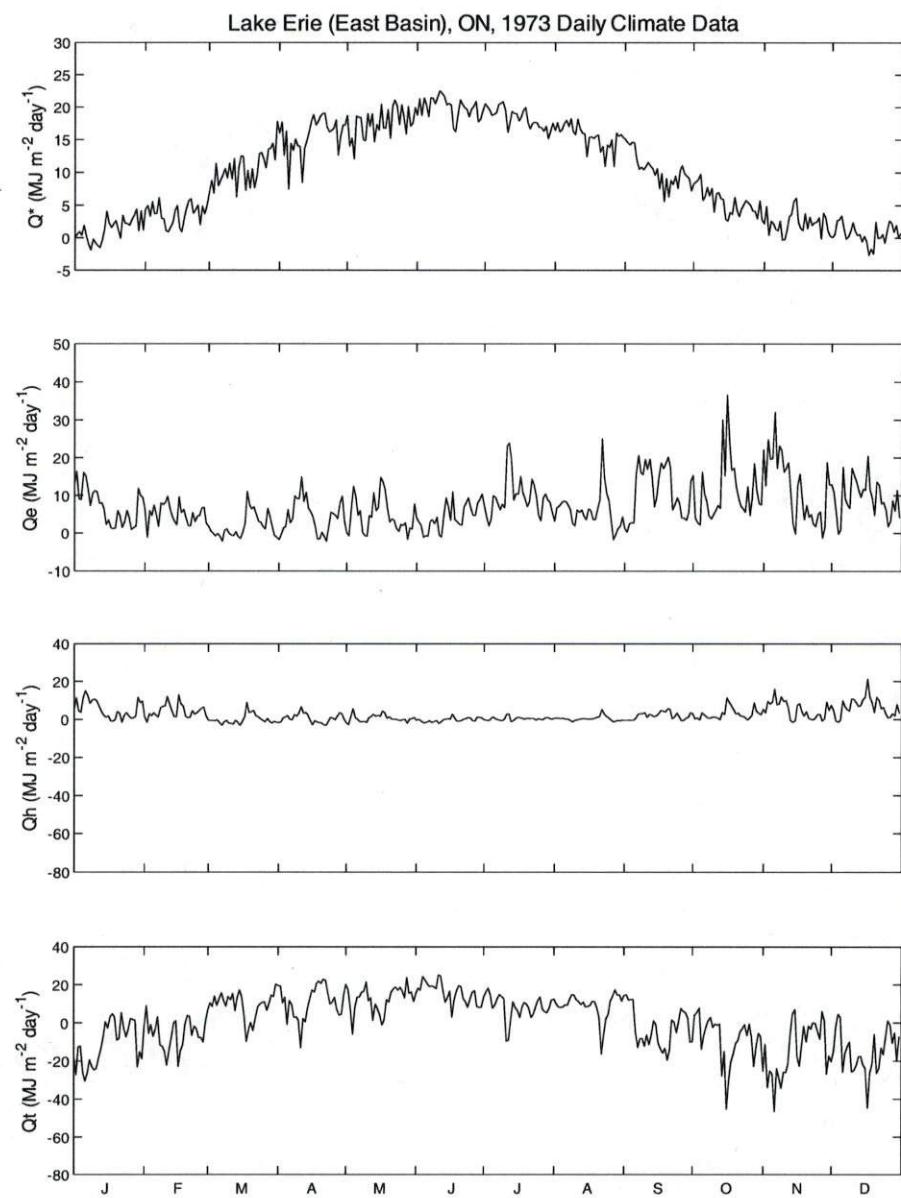


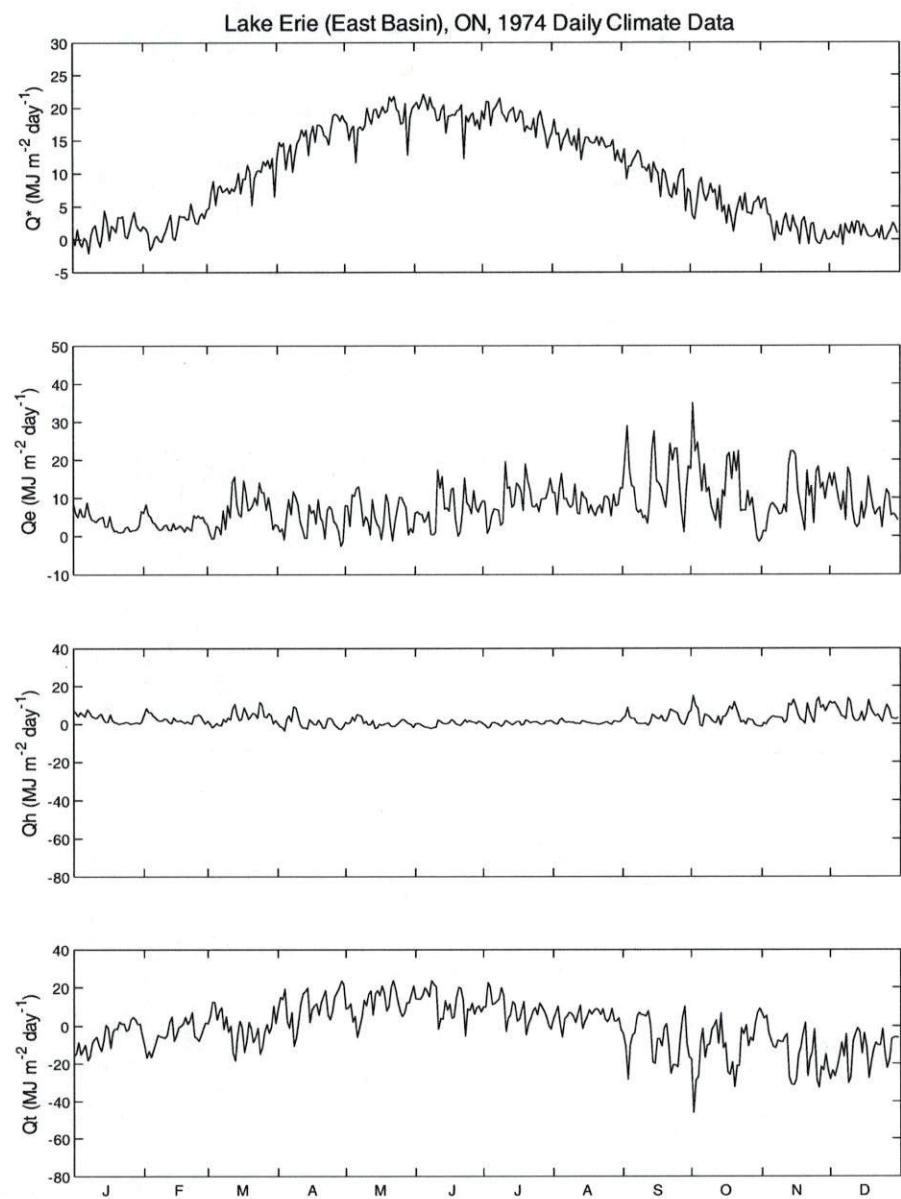


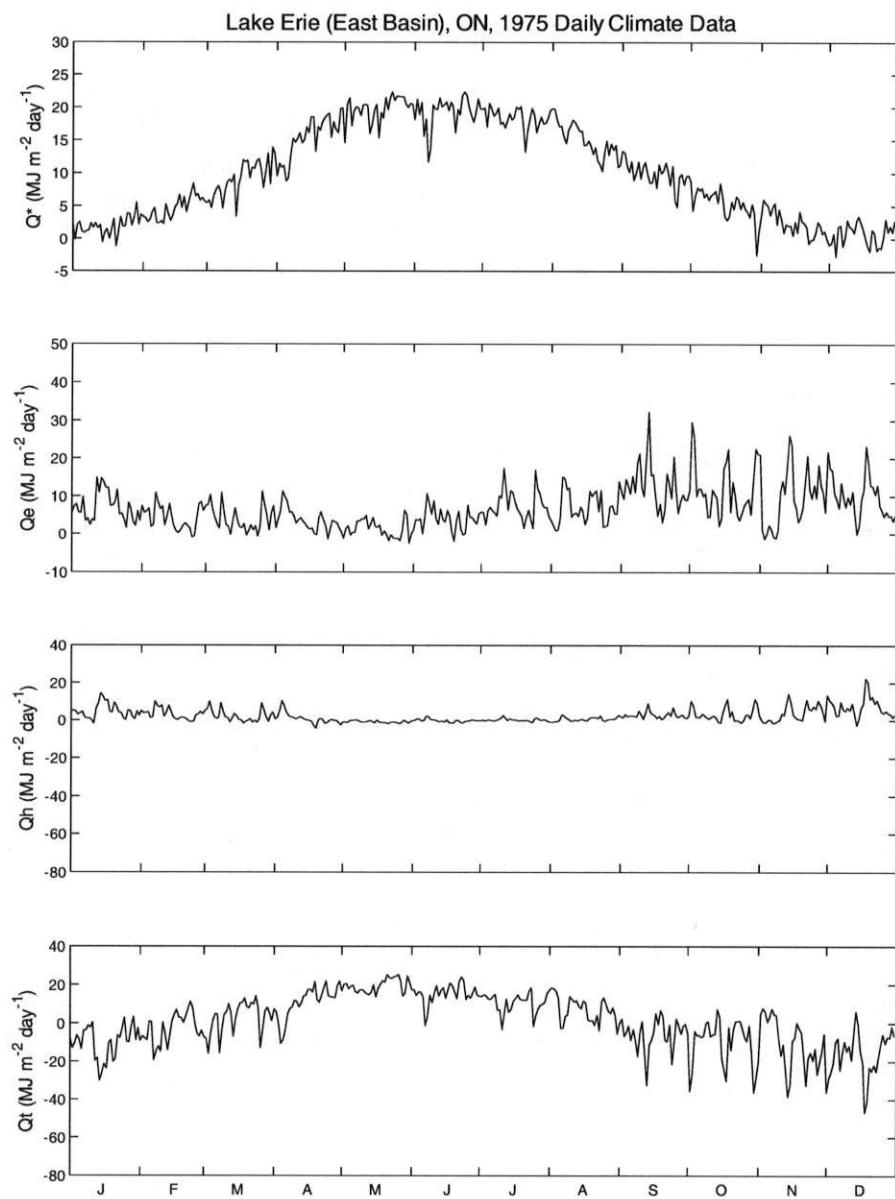


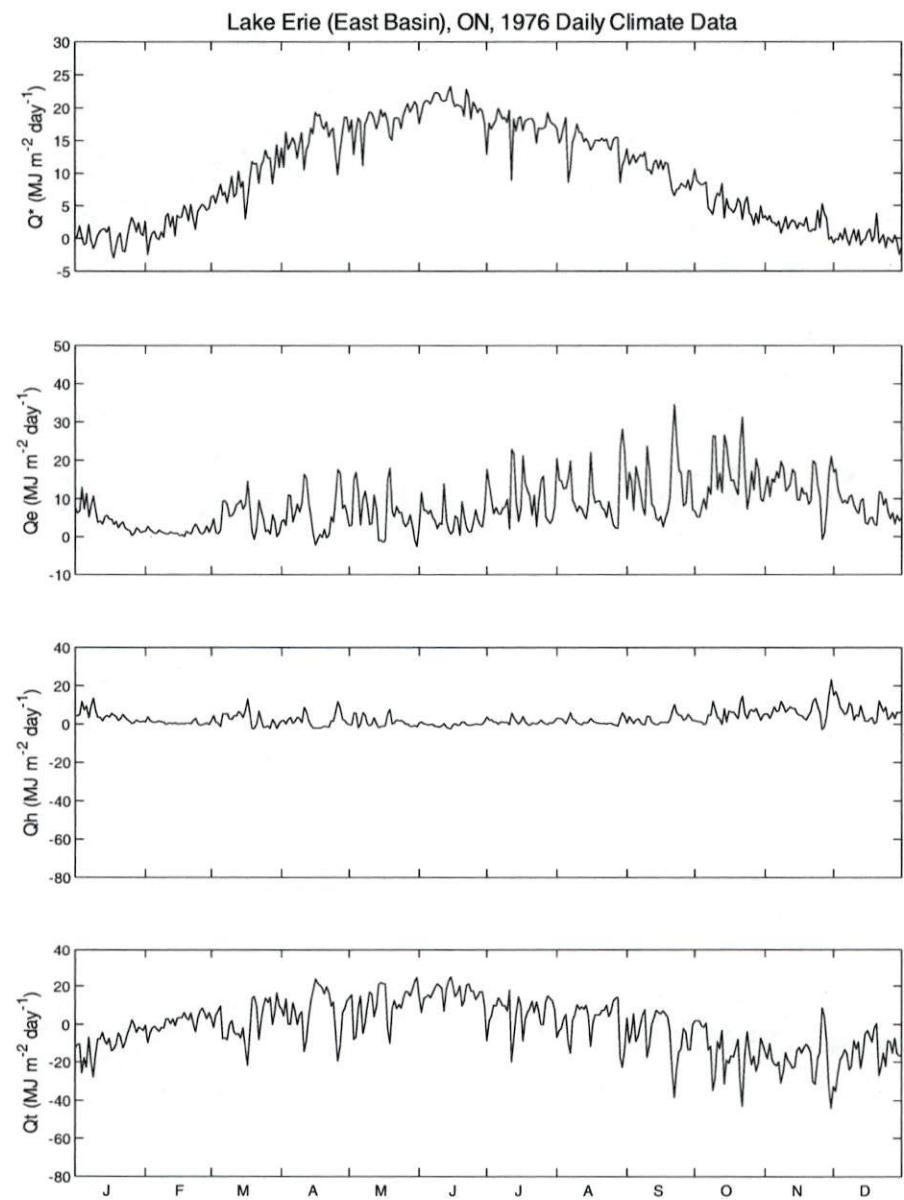


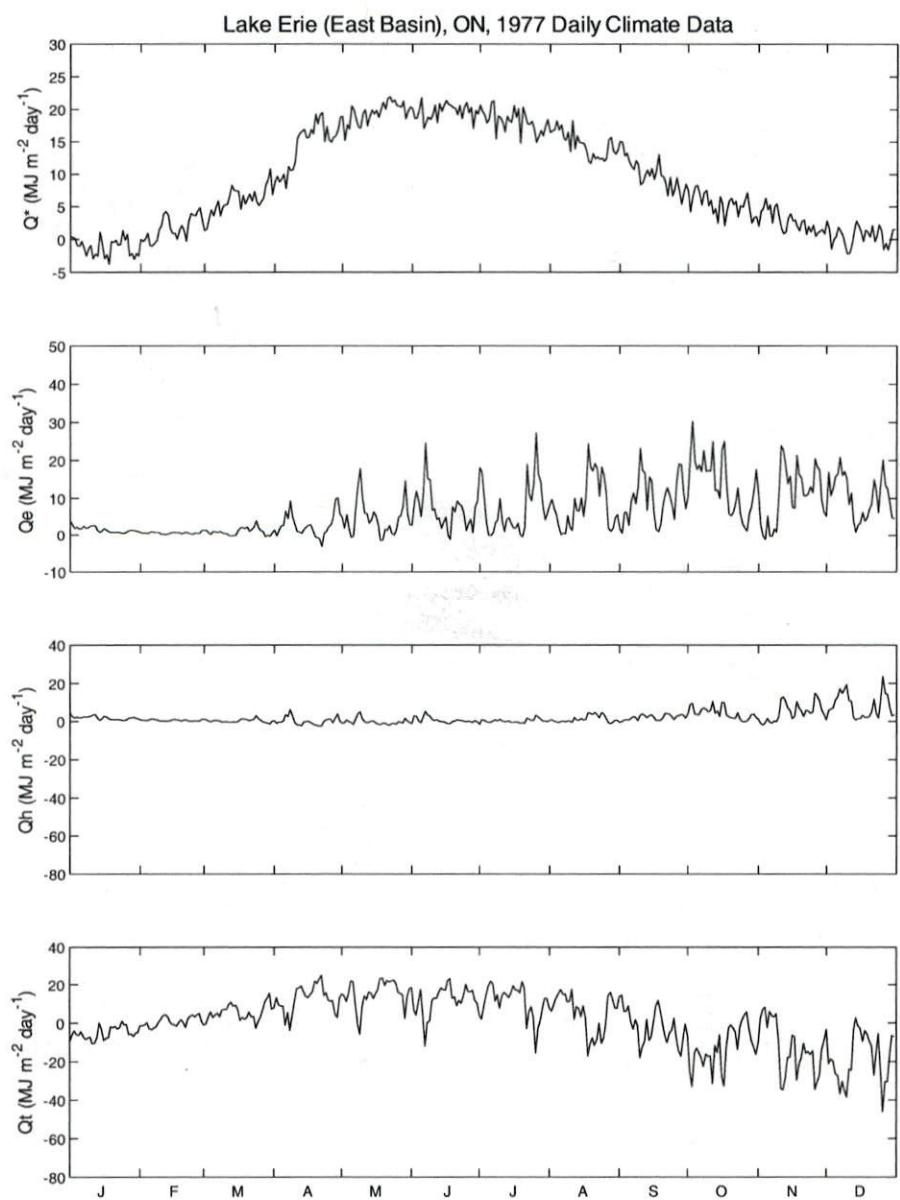


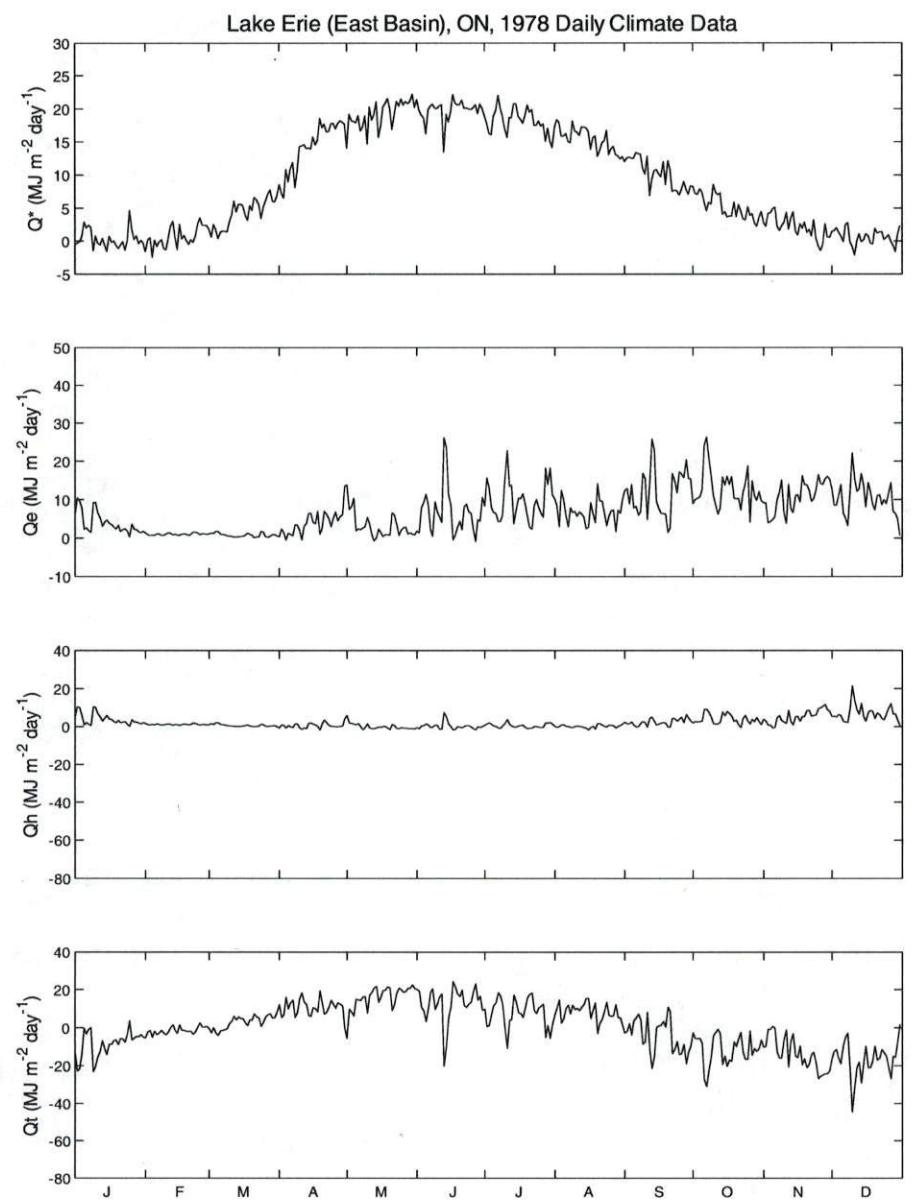


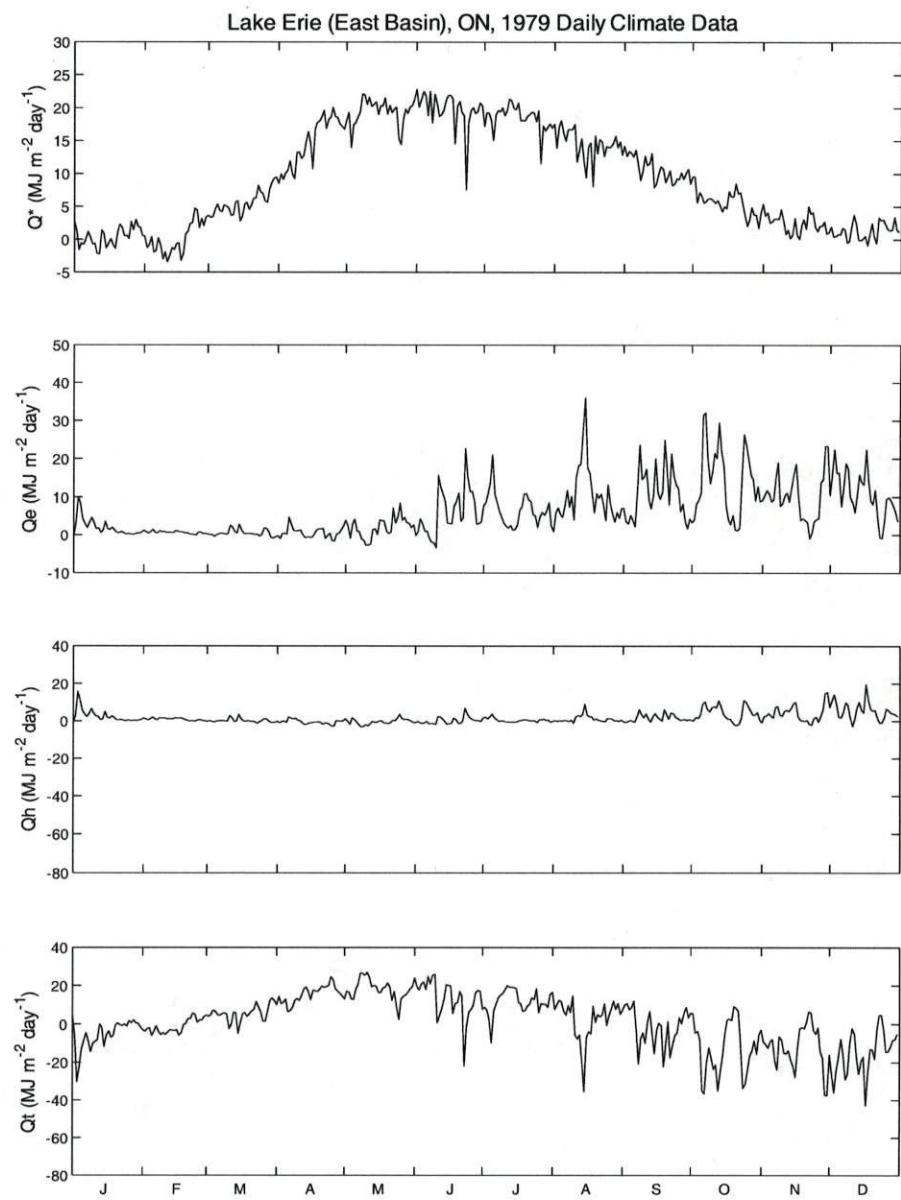


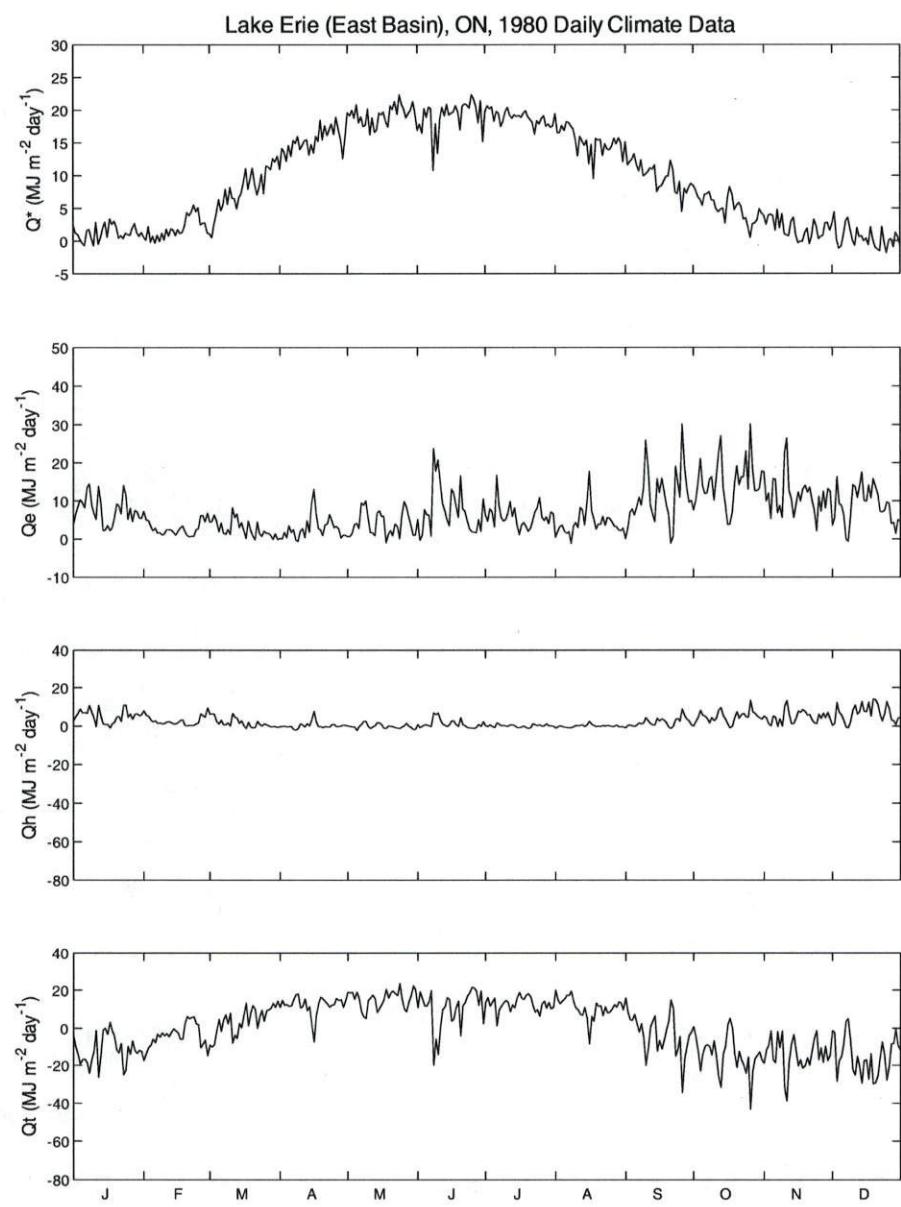


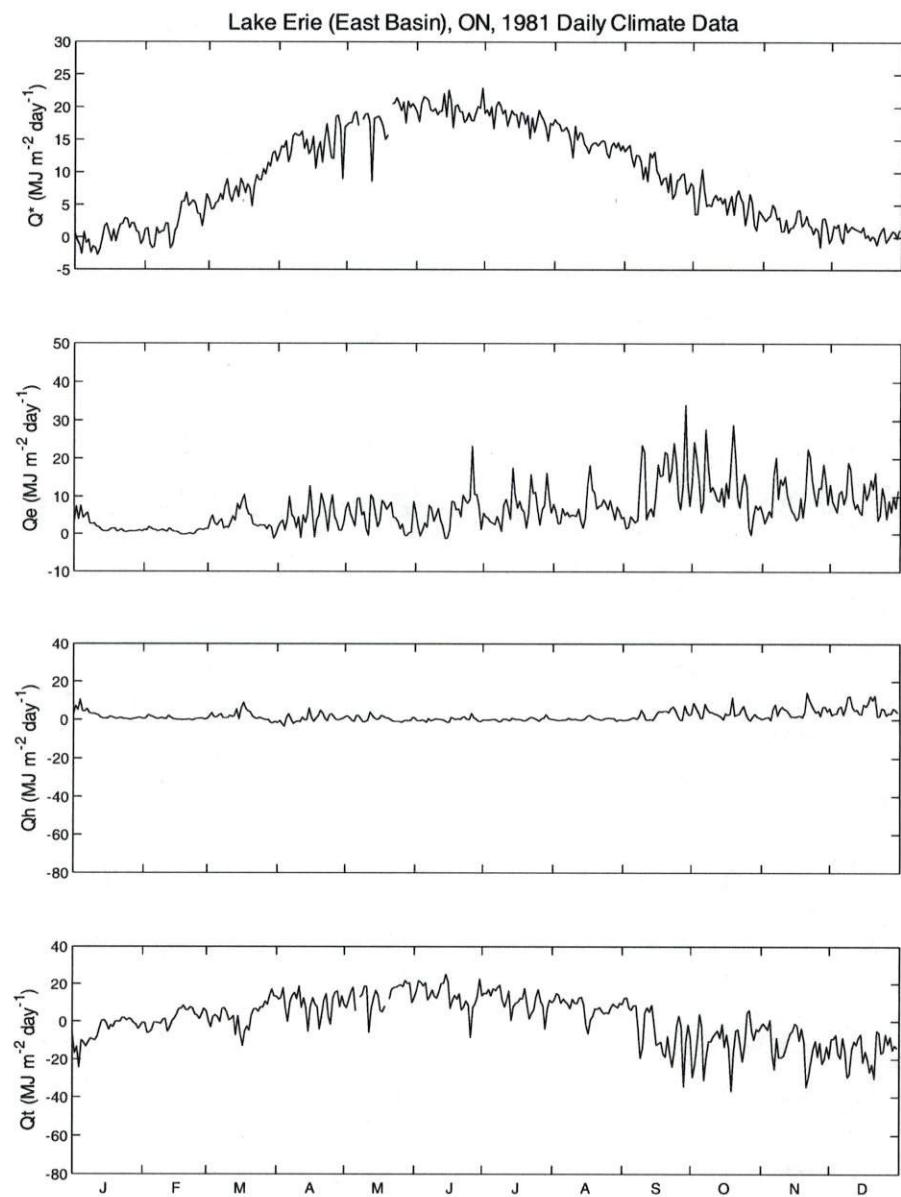


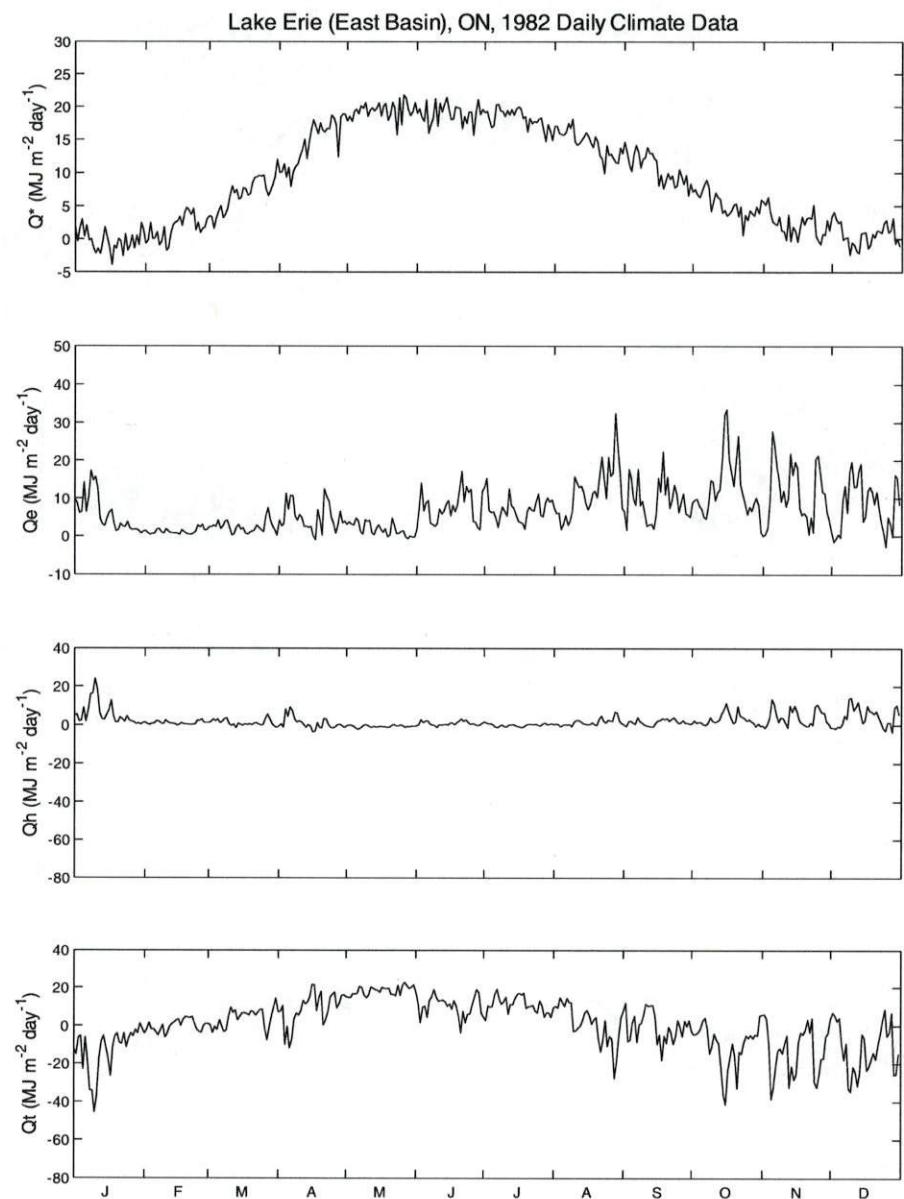


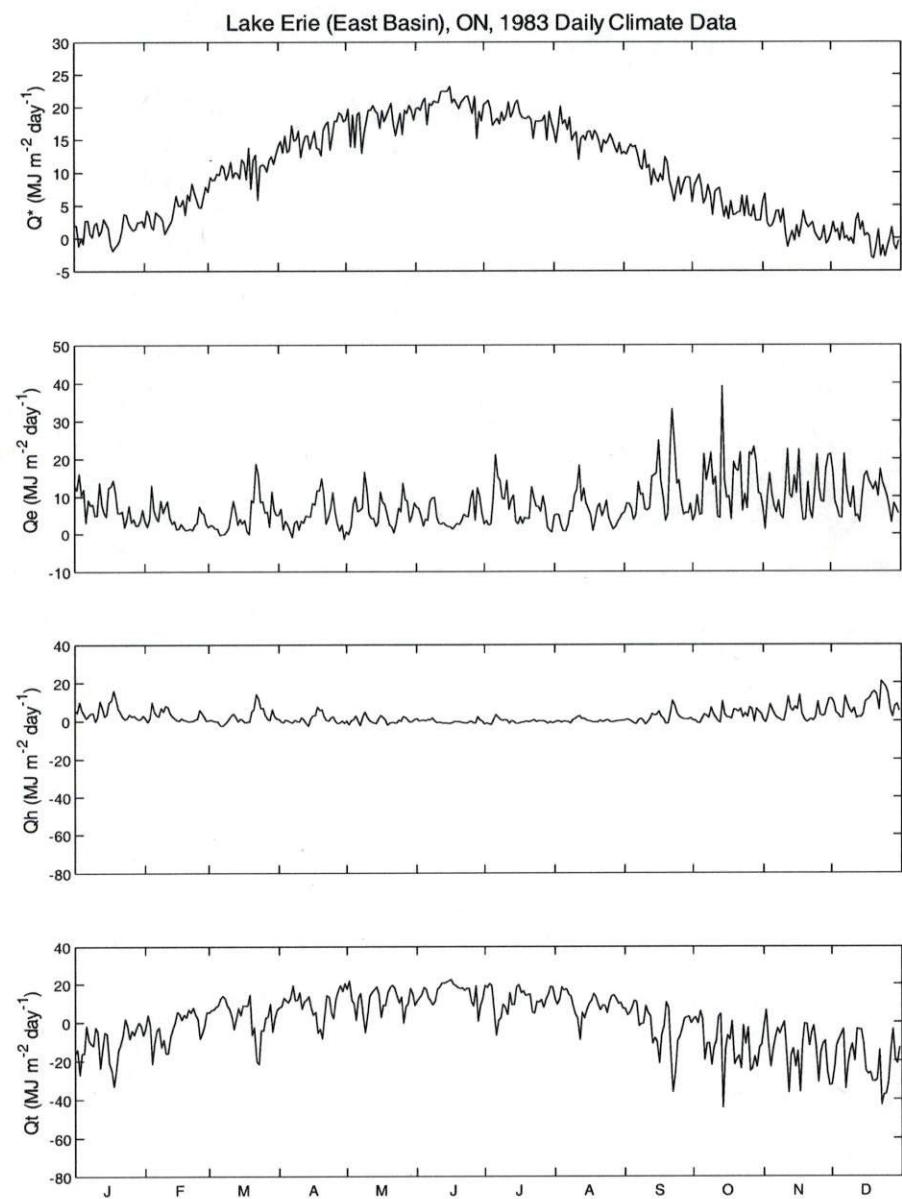


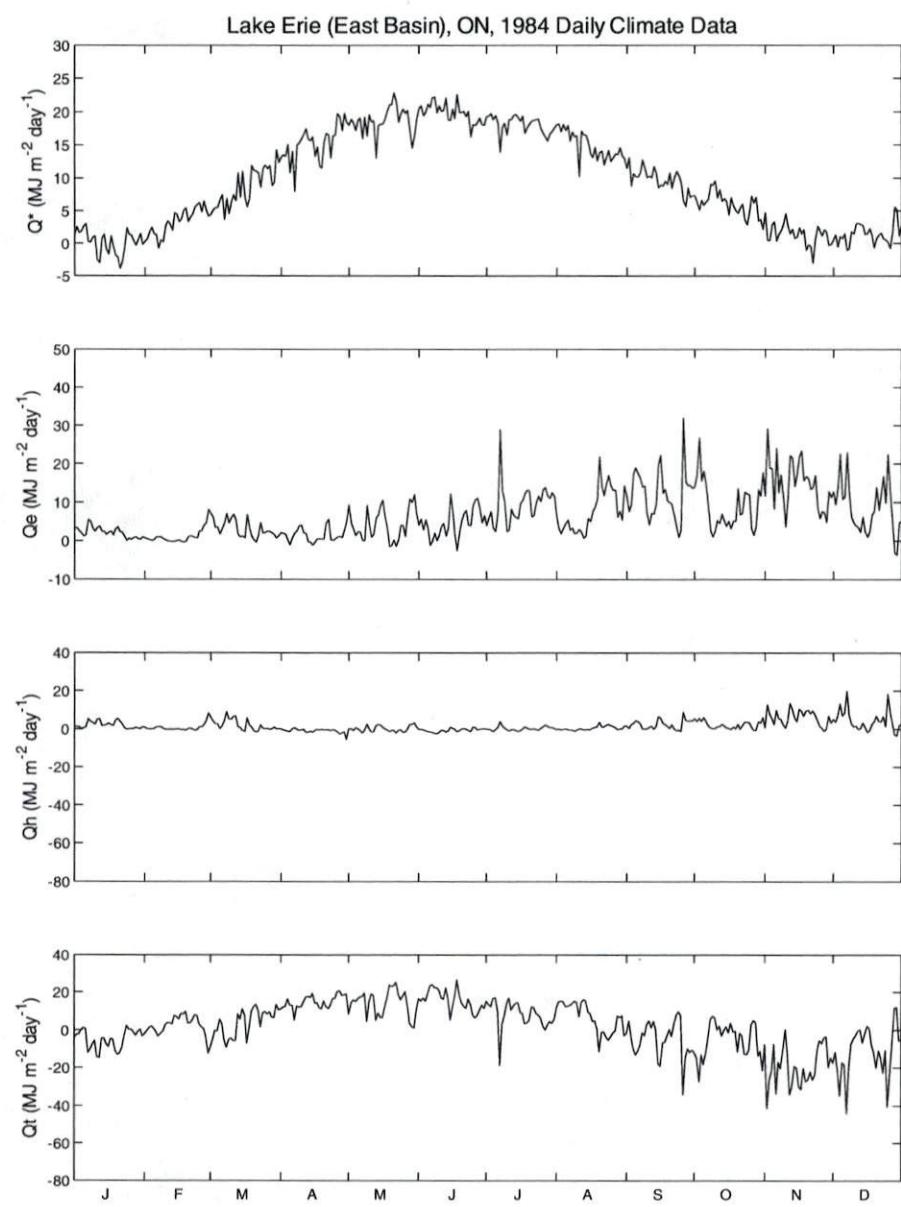


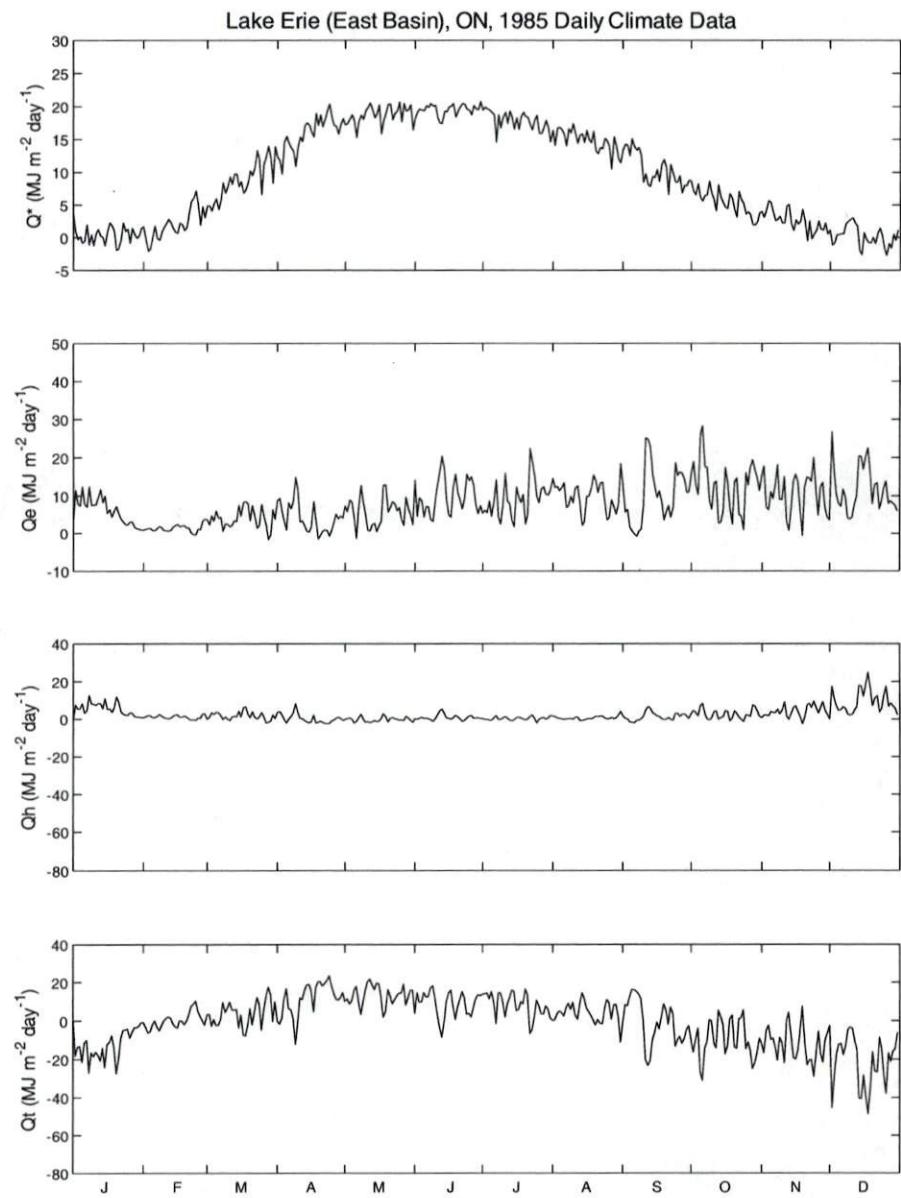


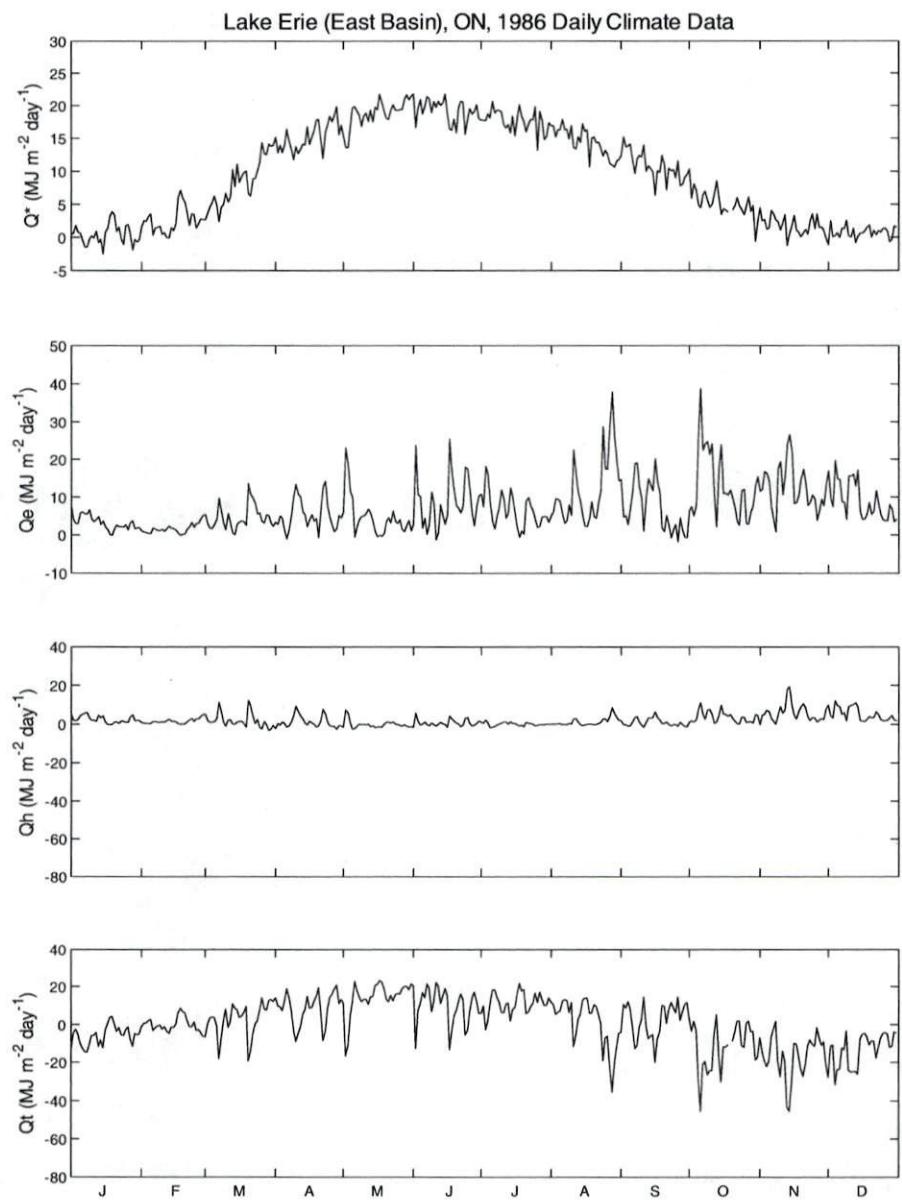


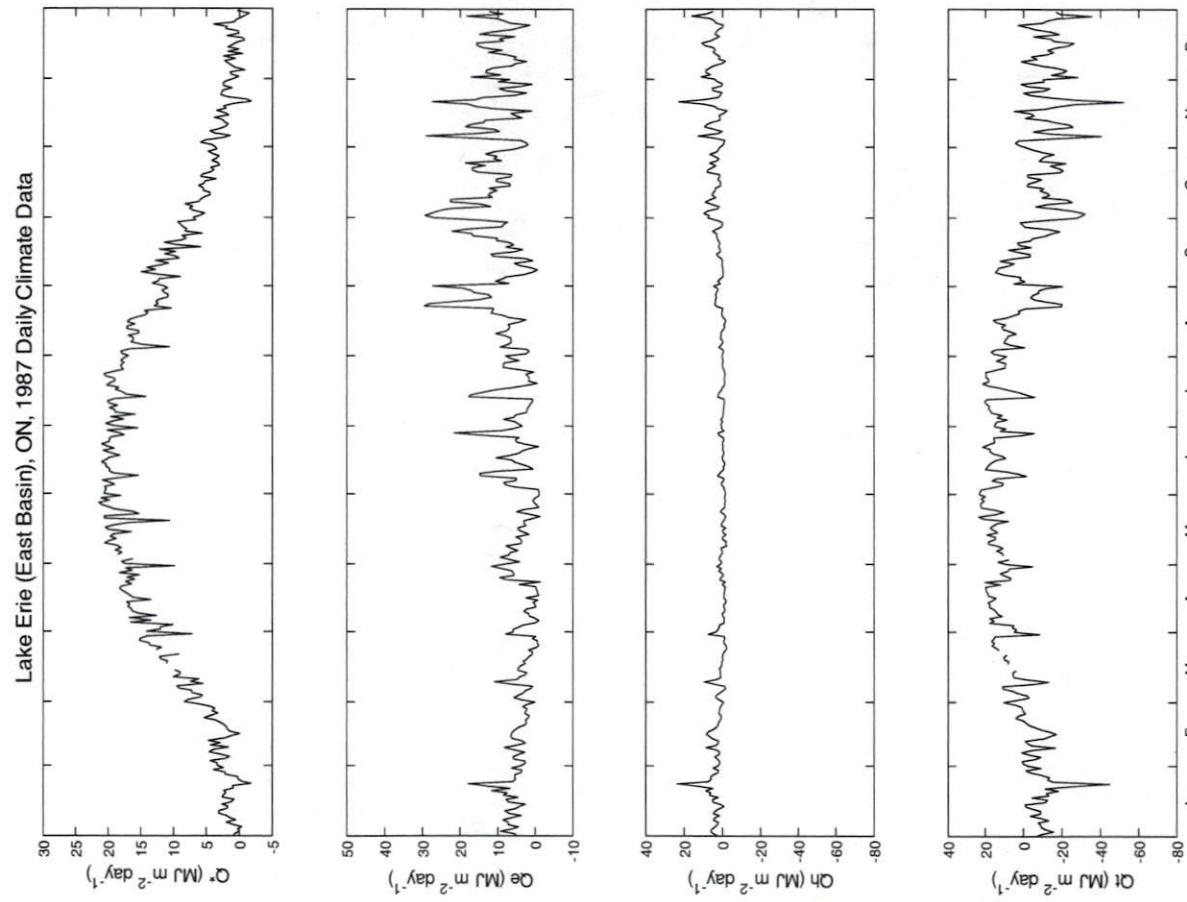


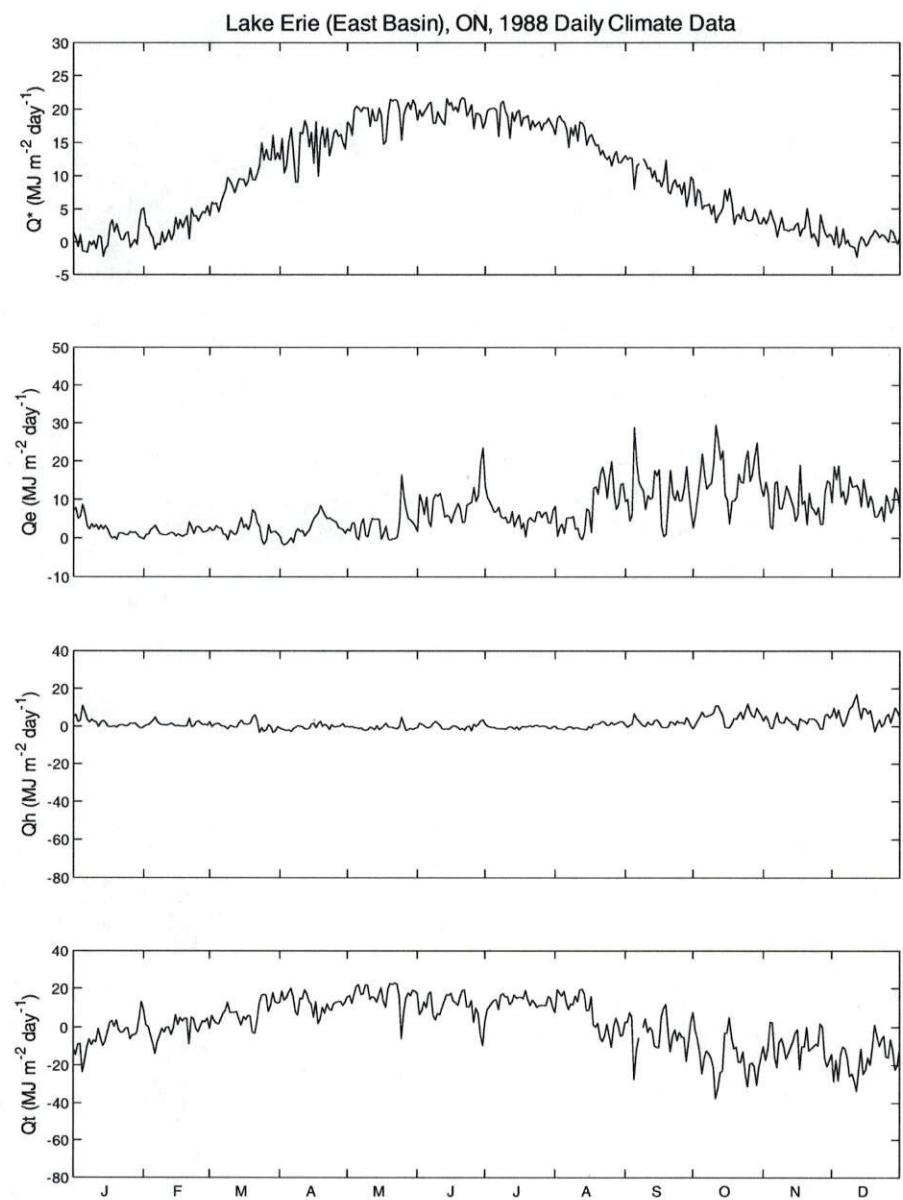


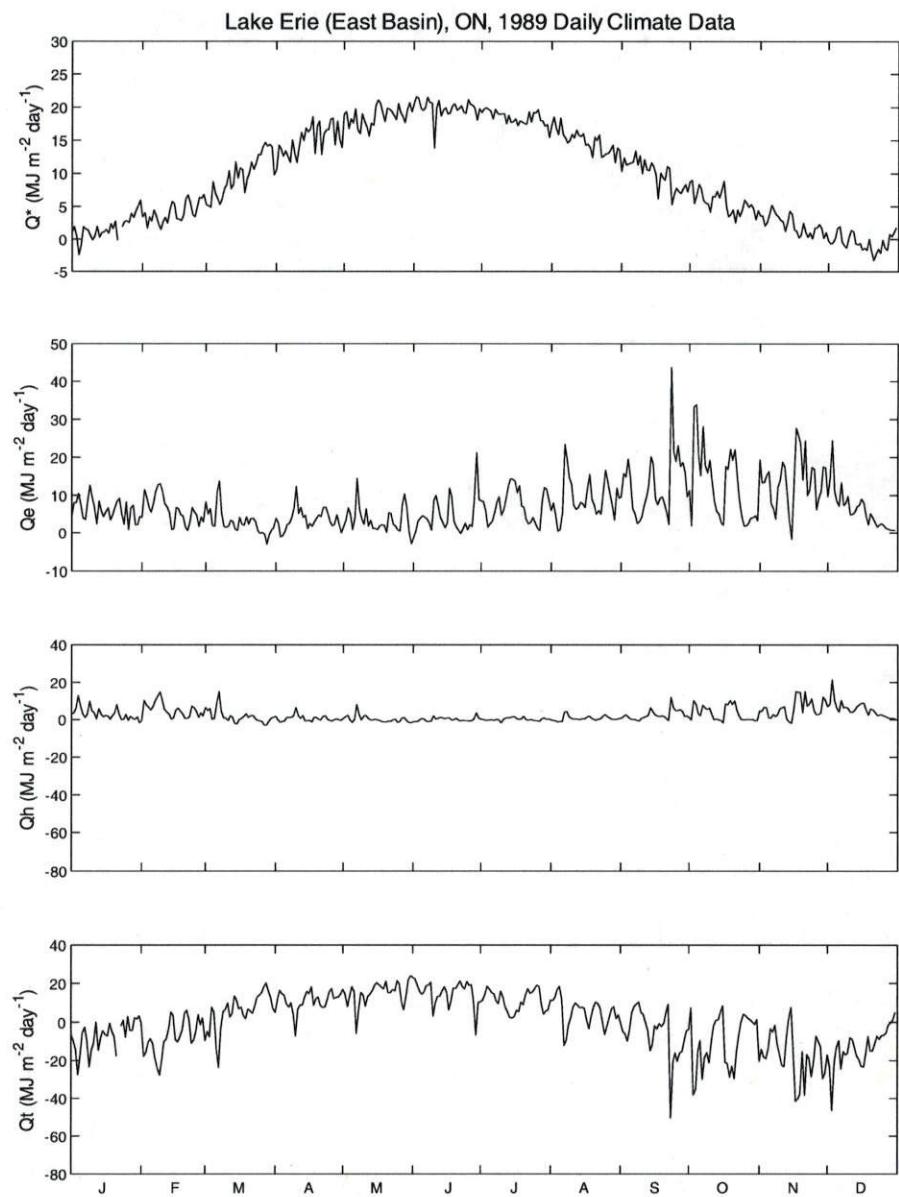


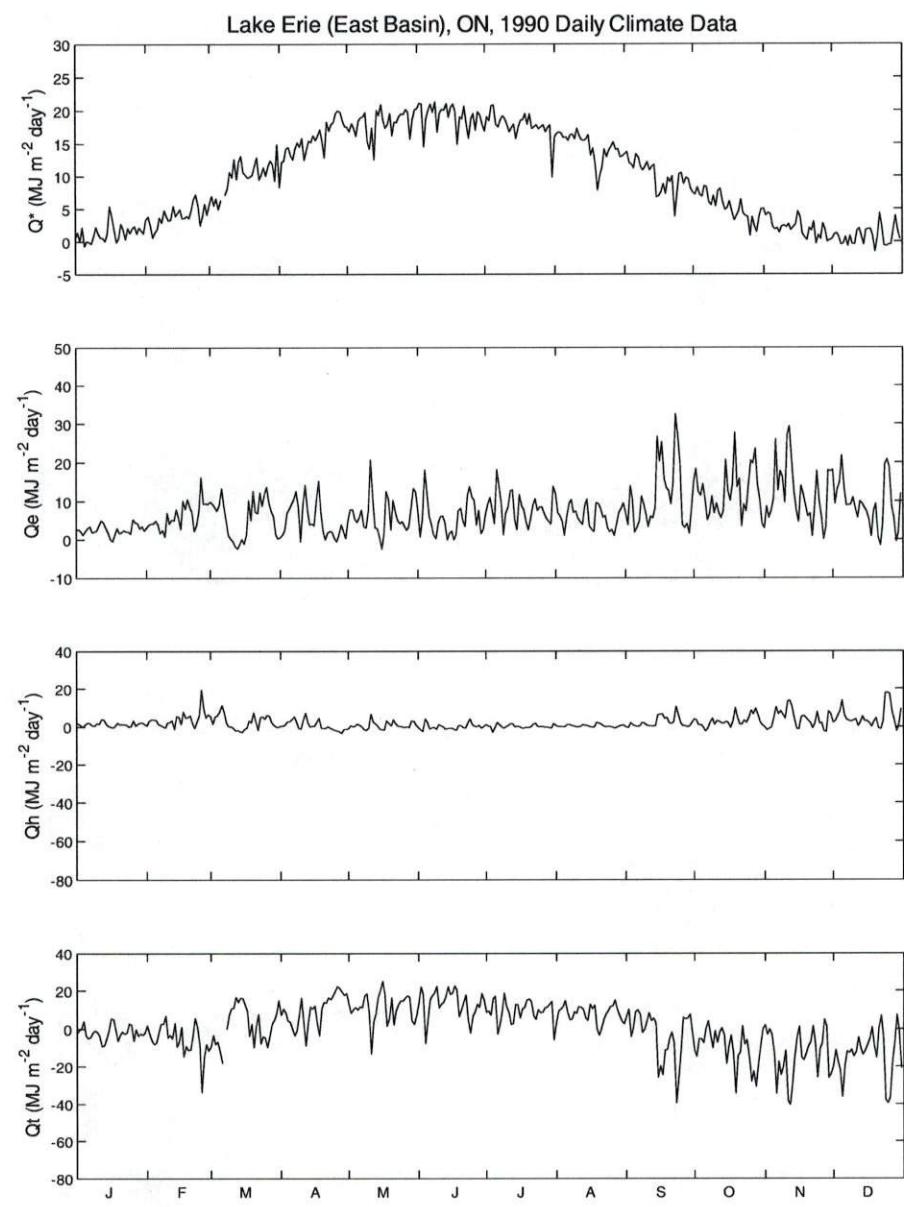


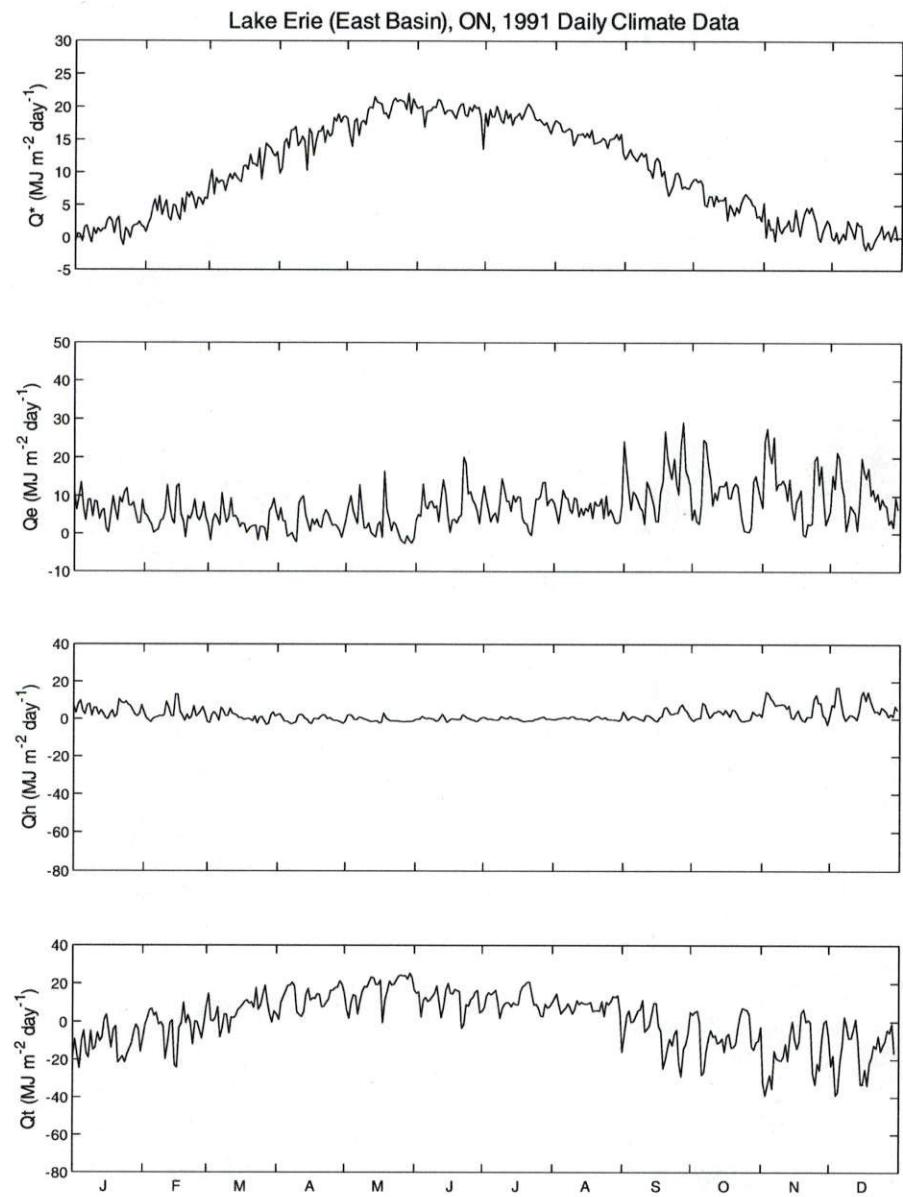


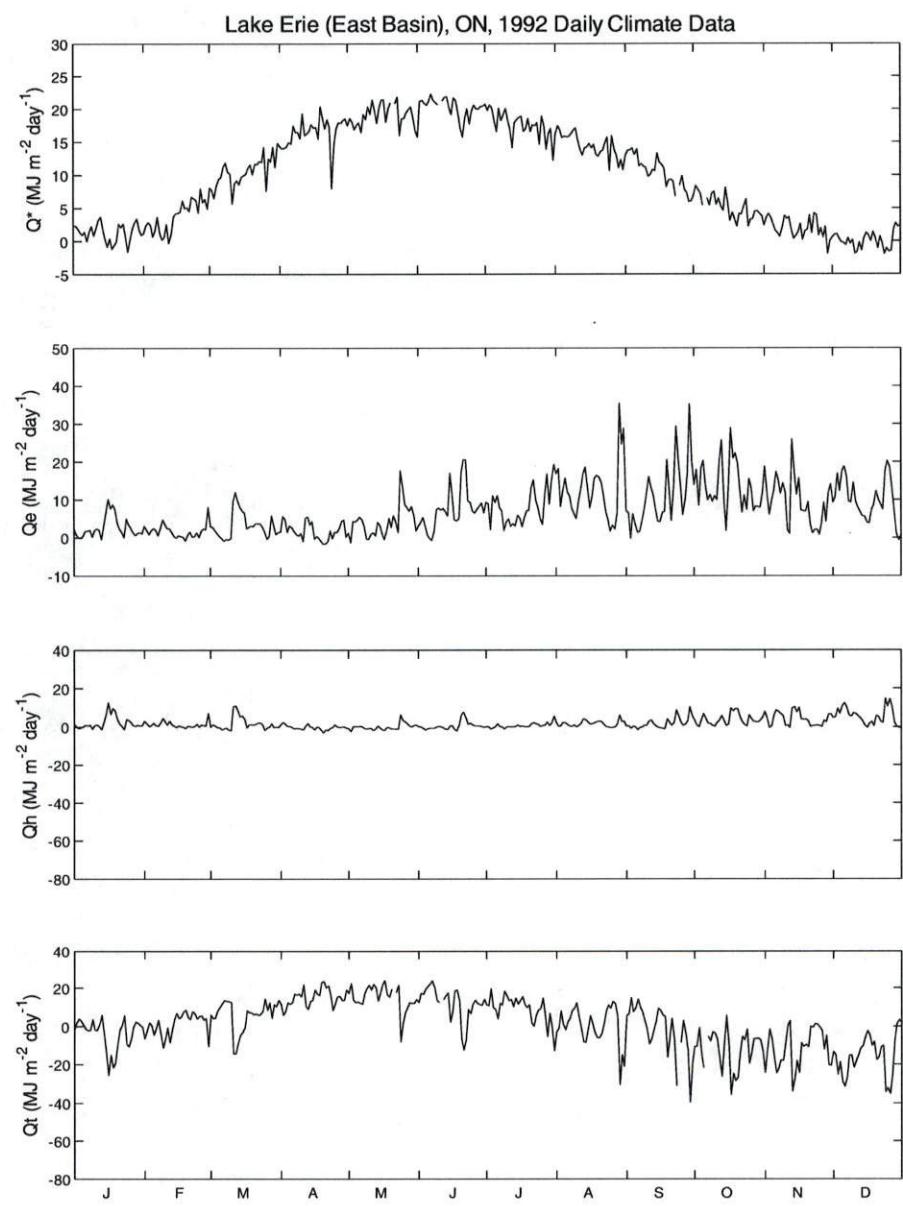


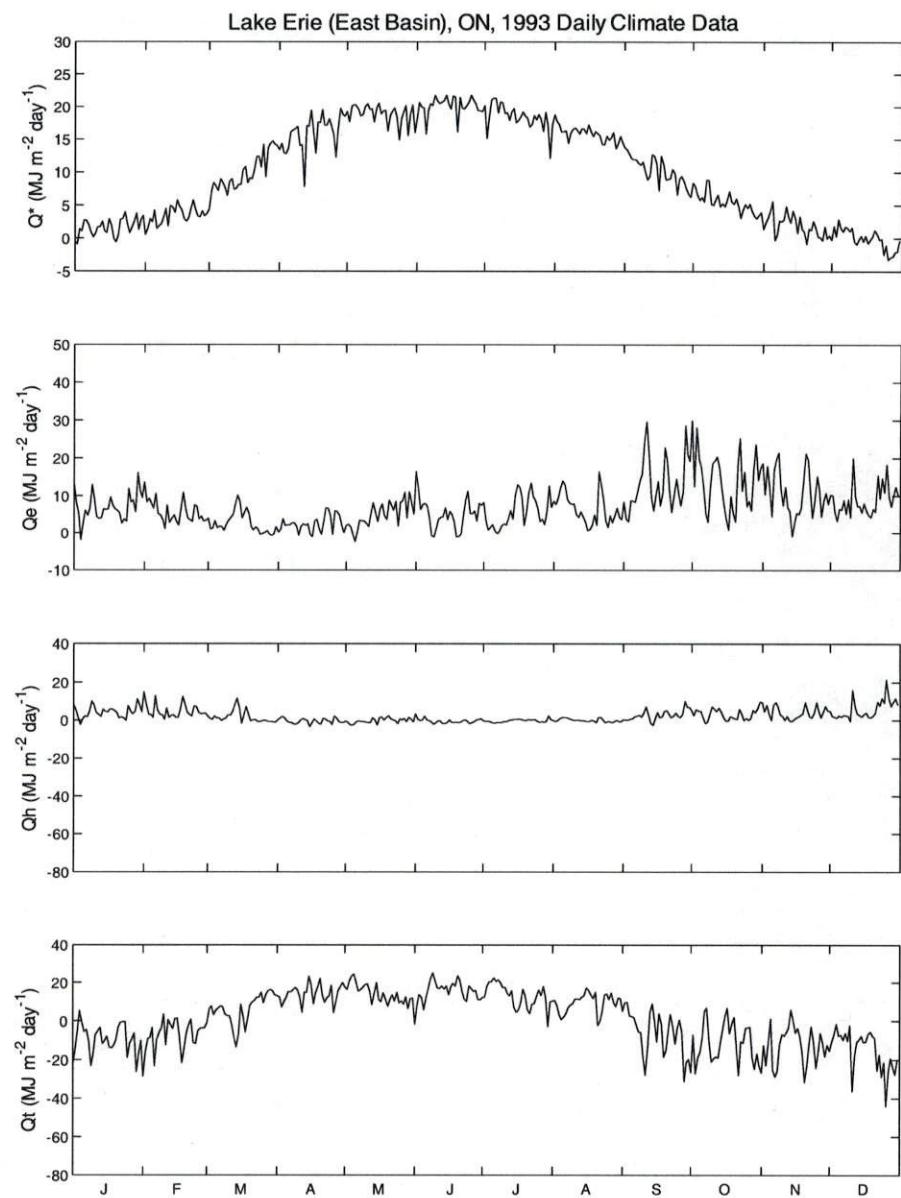


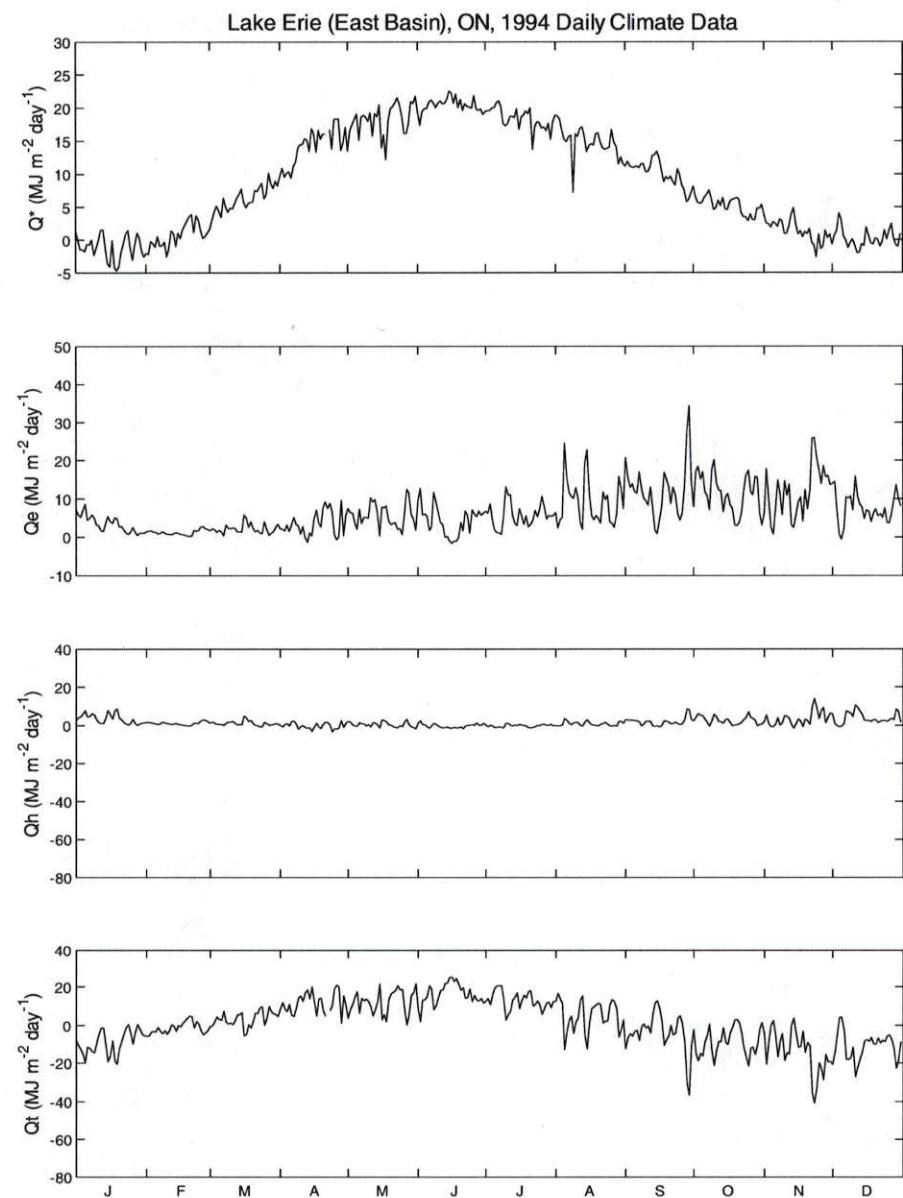


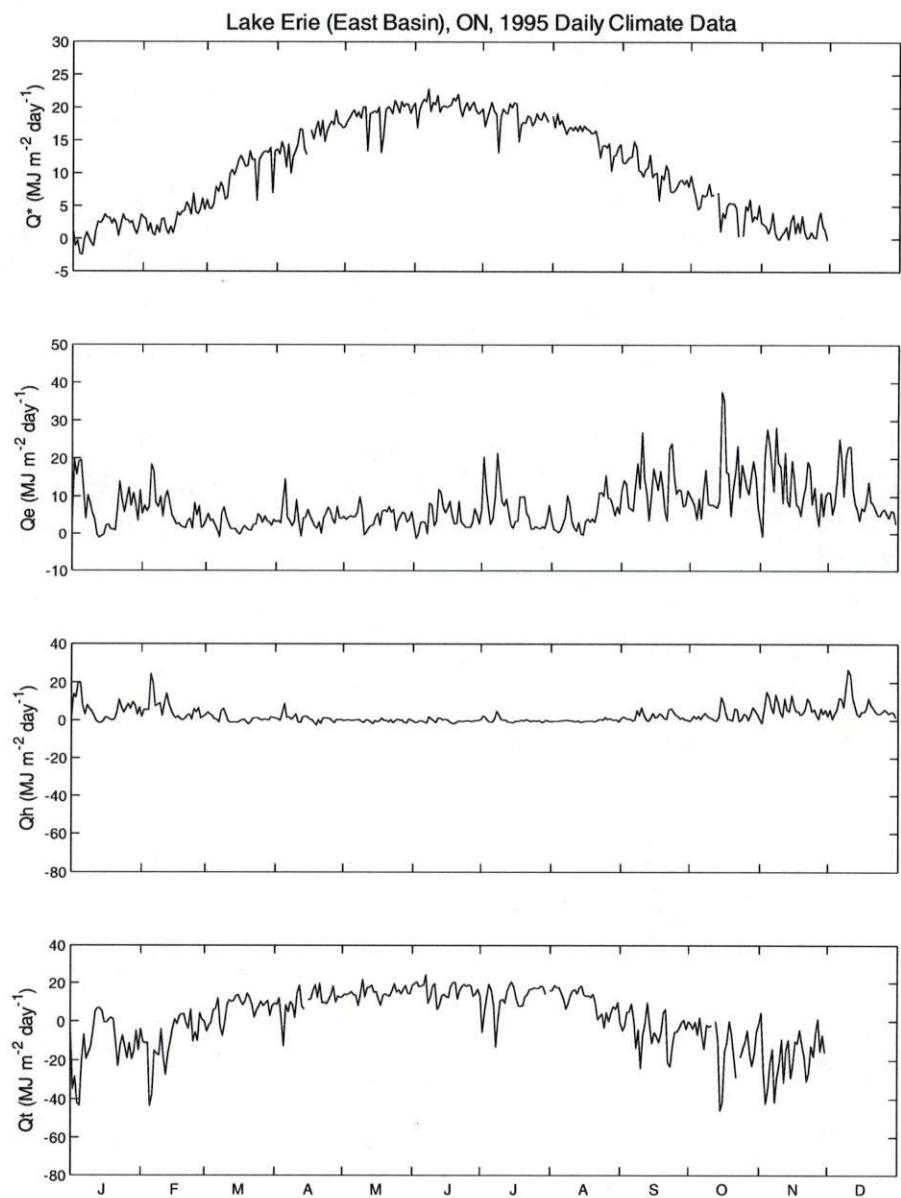


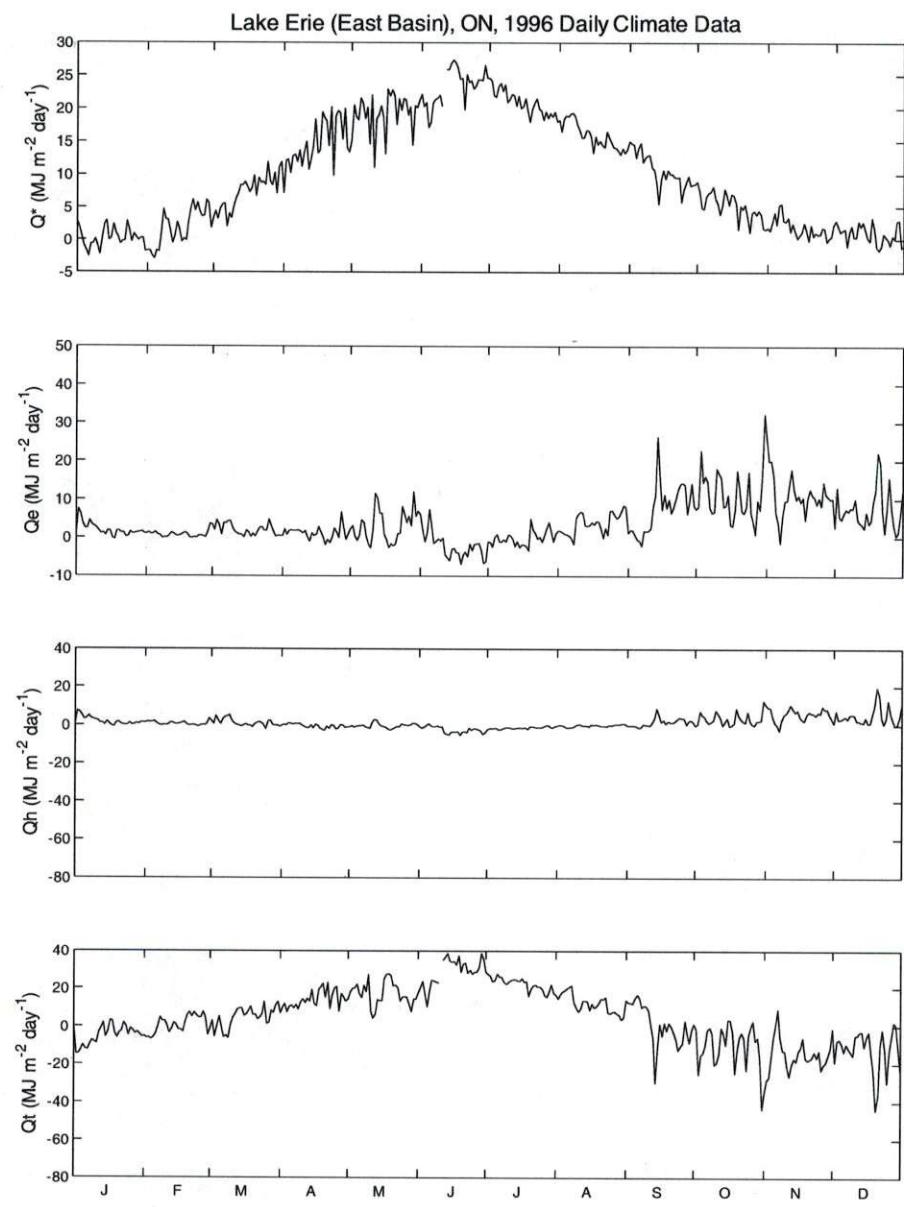


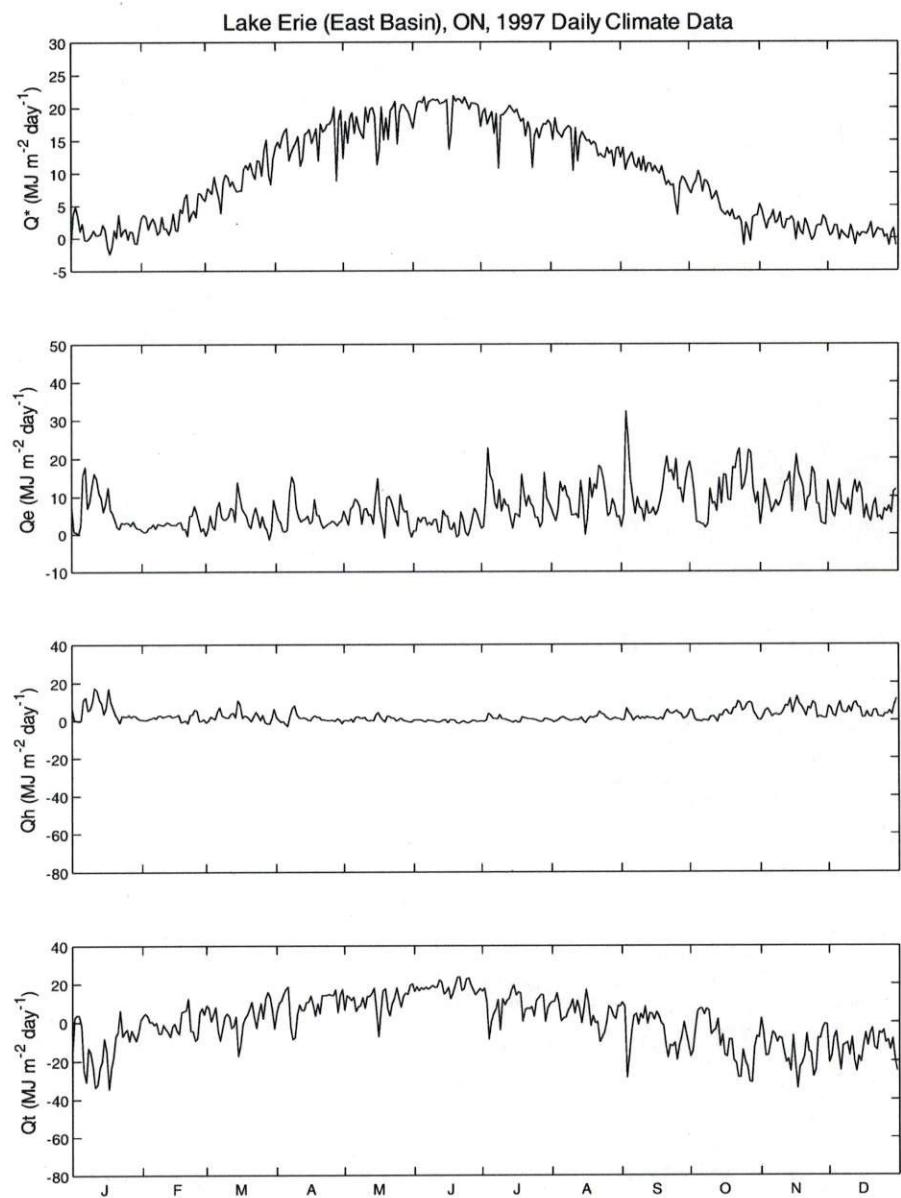






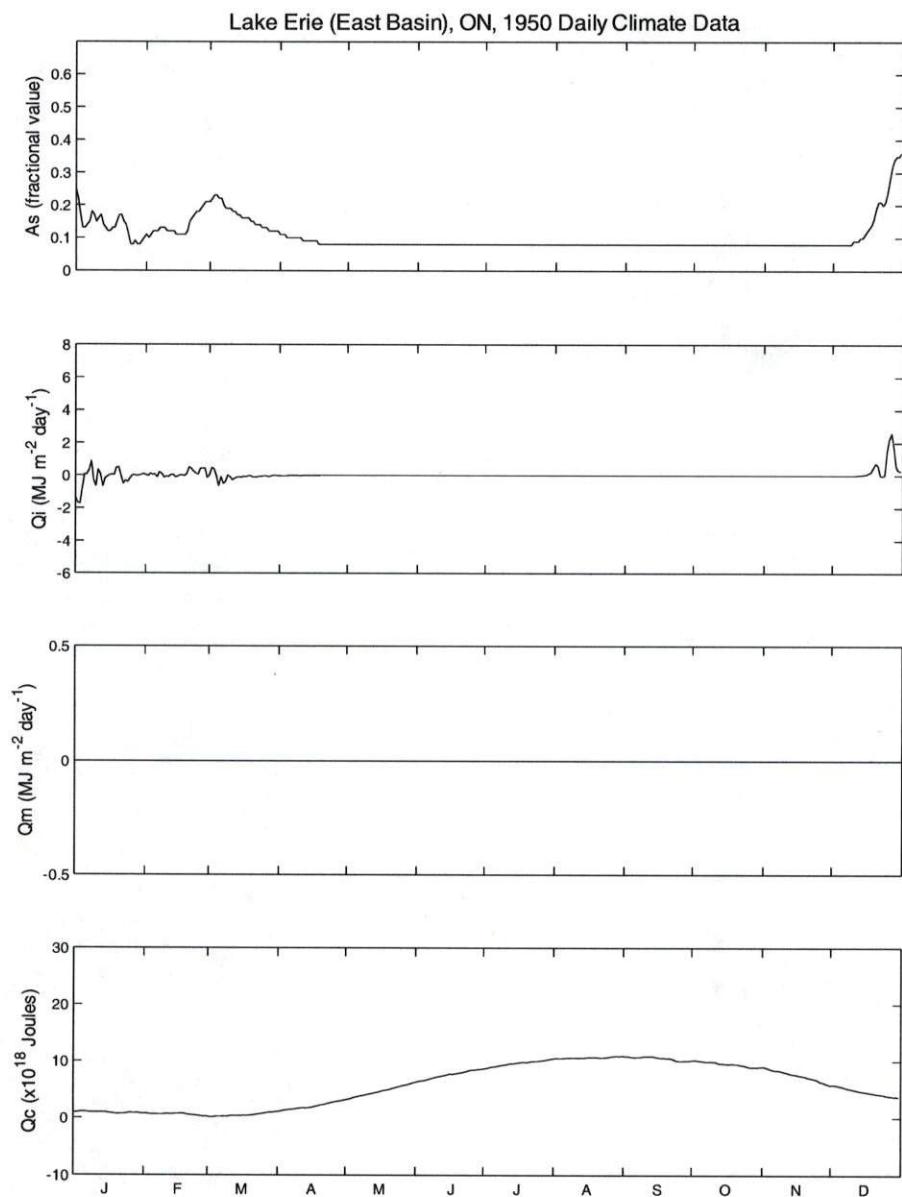


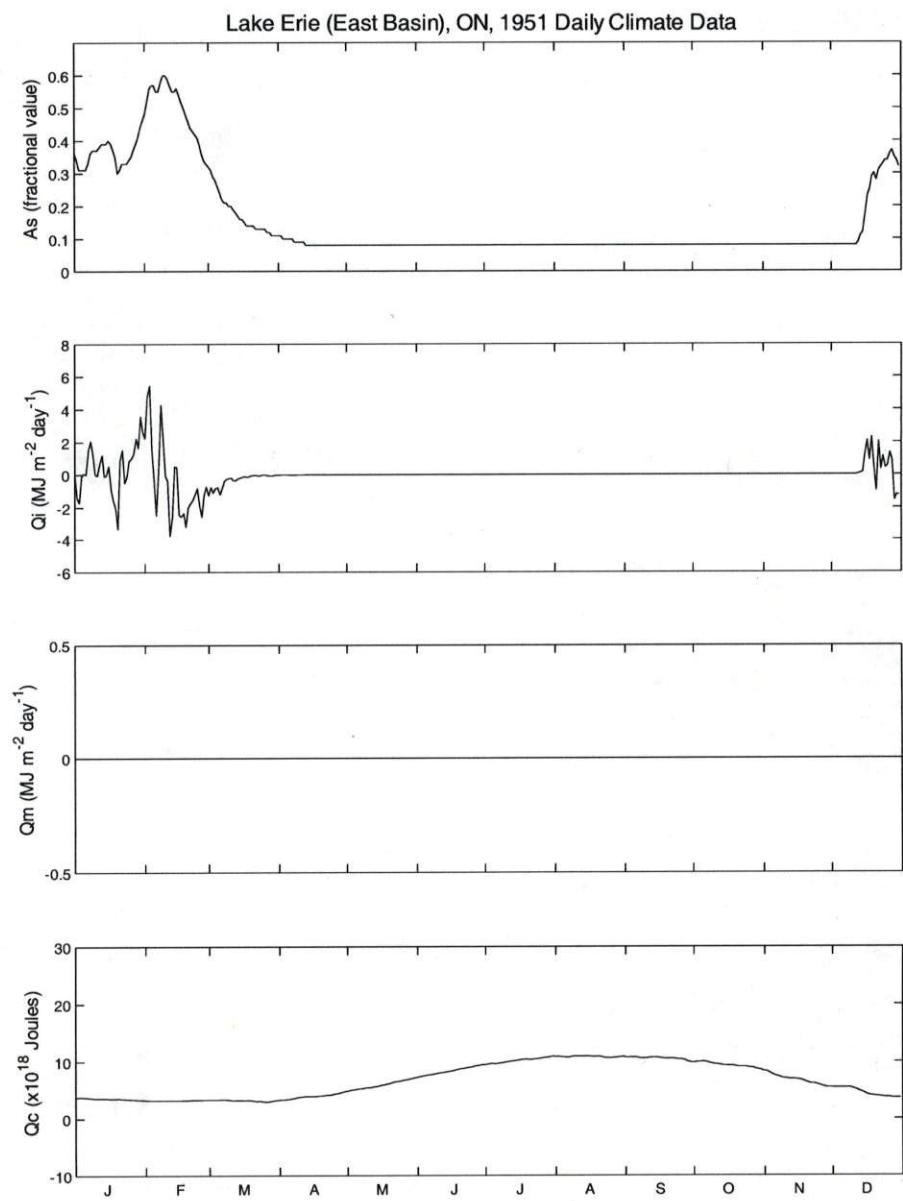




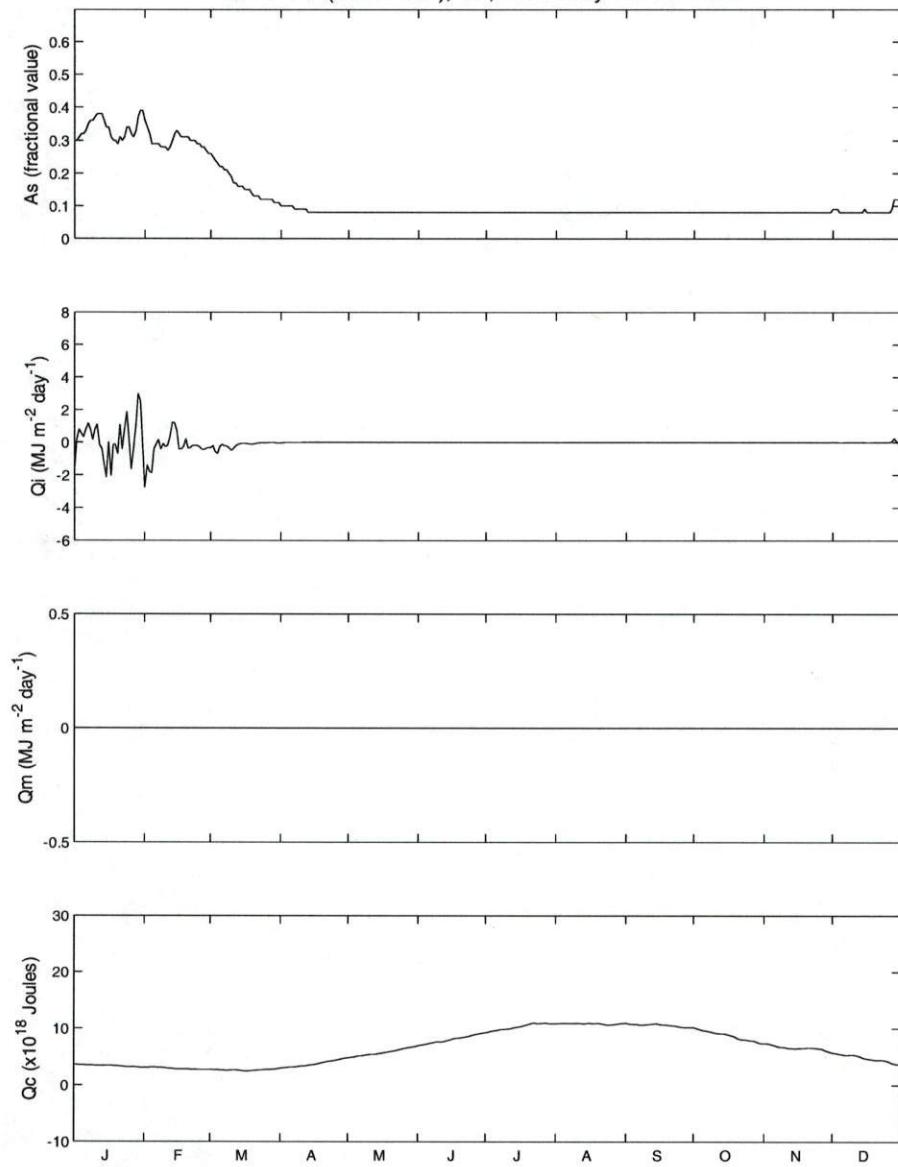
Appendix 3

Other Fluxes

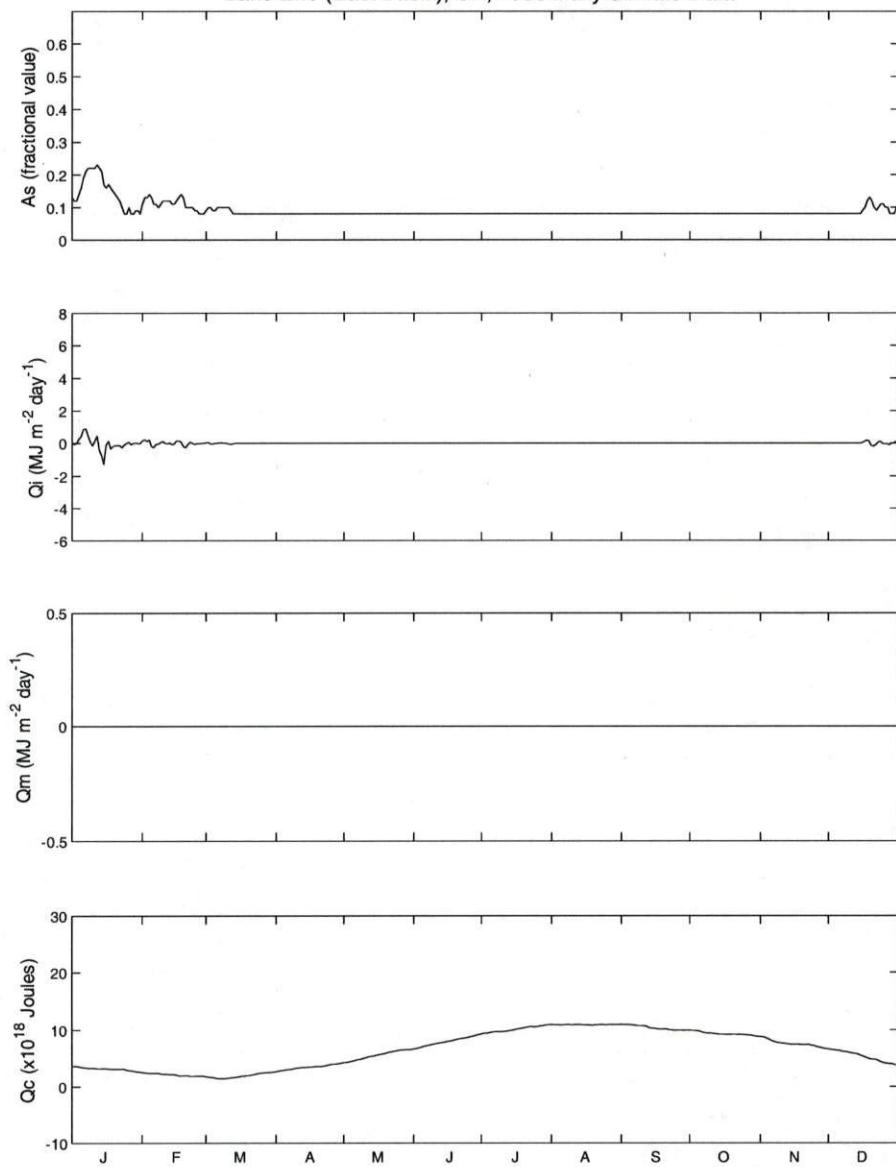




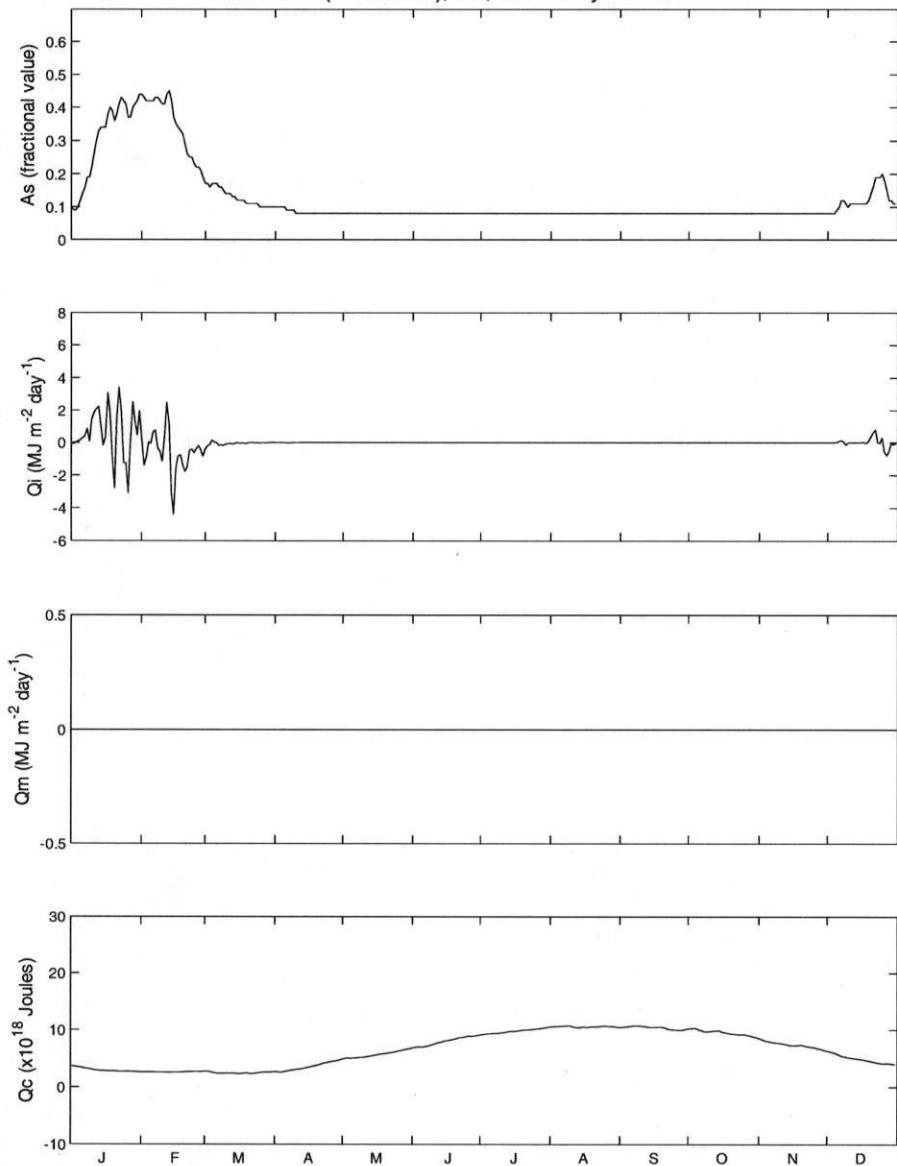
Lake Erie (East Basin), ON, 1952 Daily Climate Data

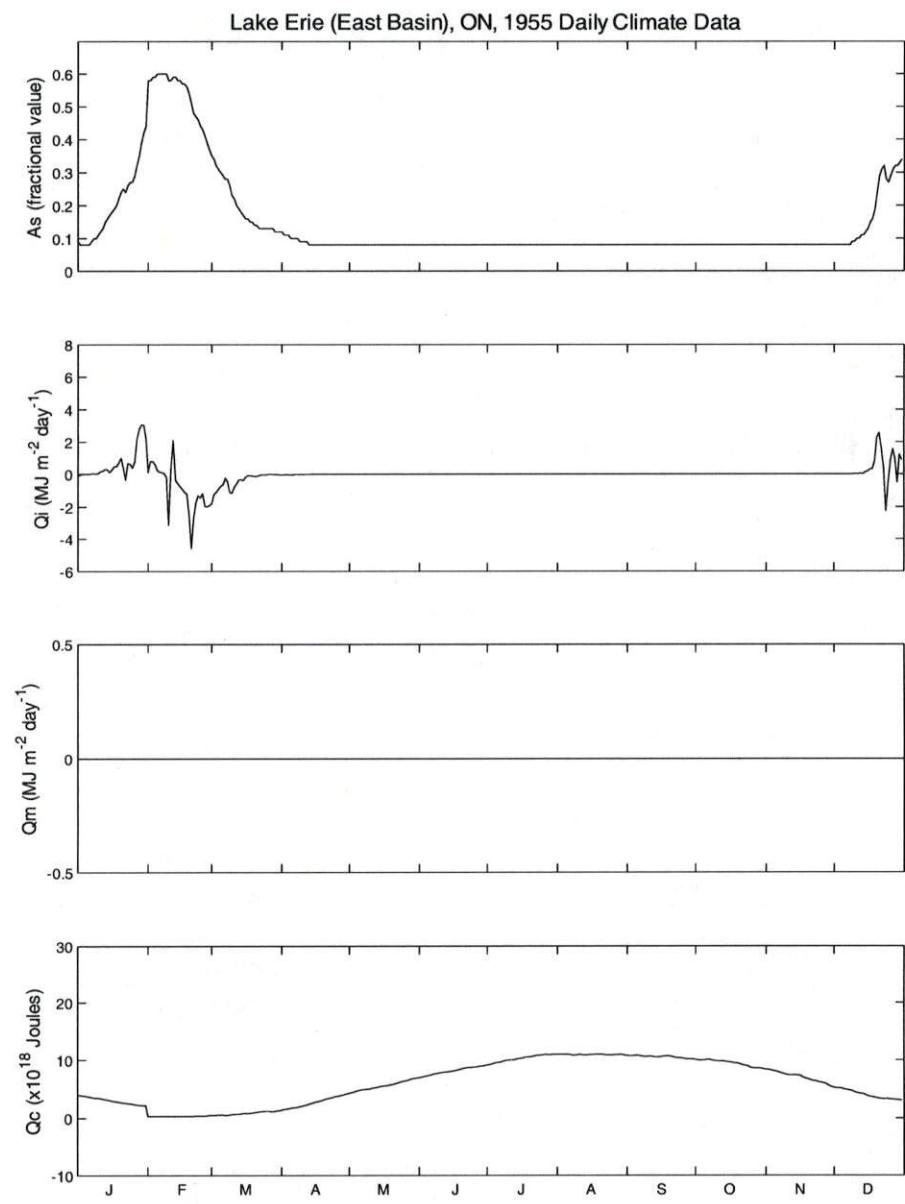


Lake Erie (East Basin), ON, 1953 Daily Climate Data

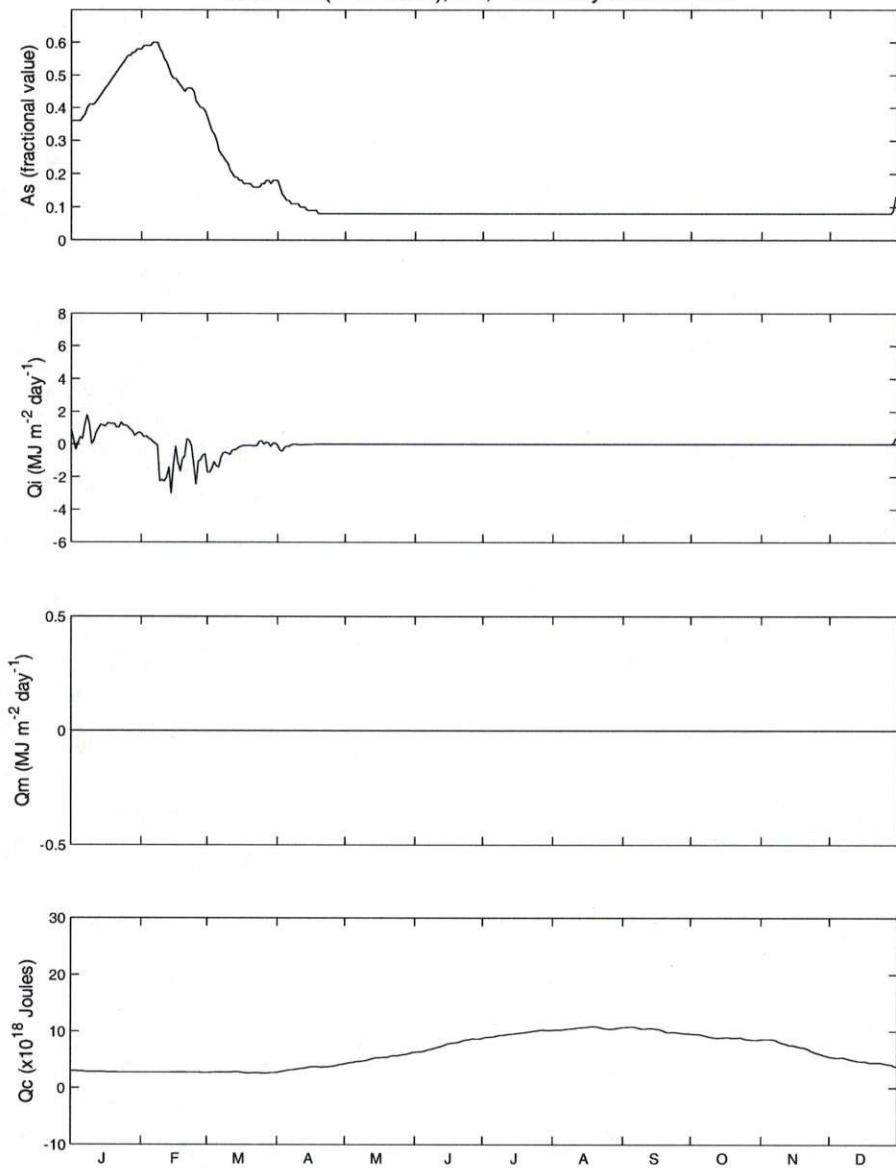


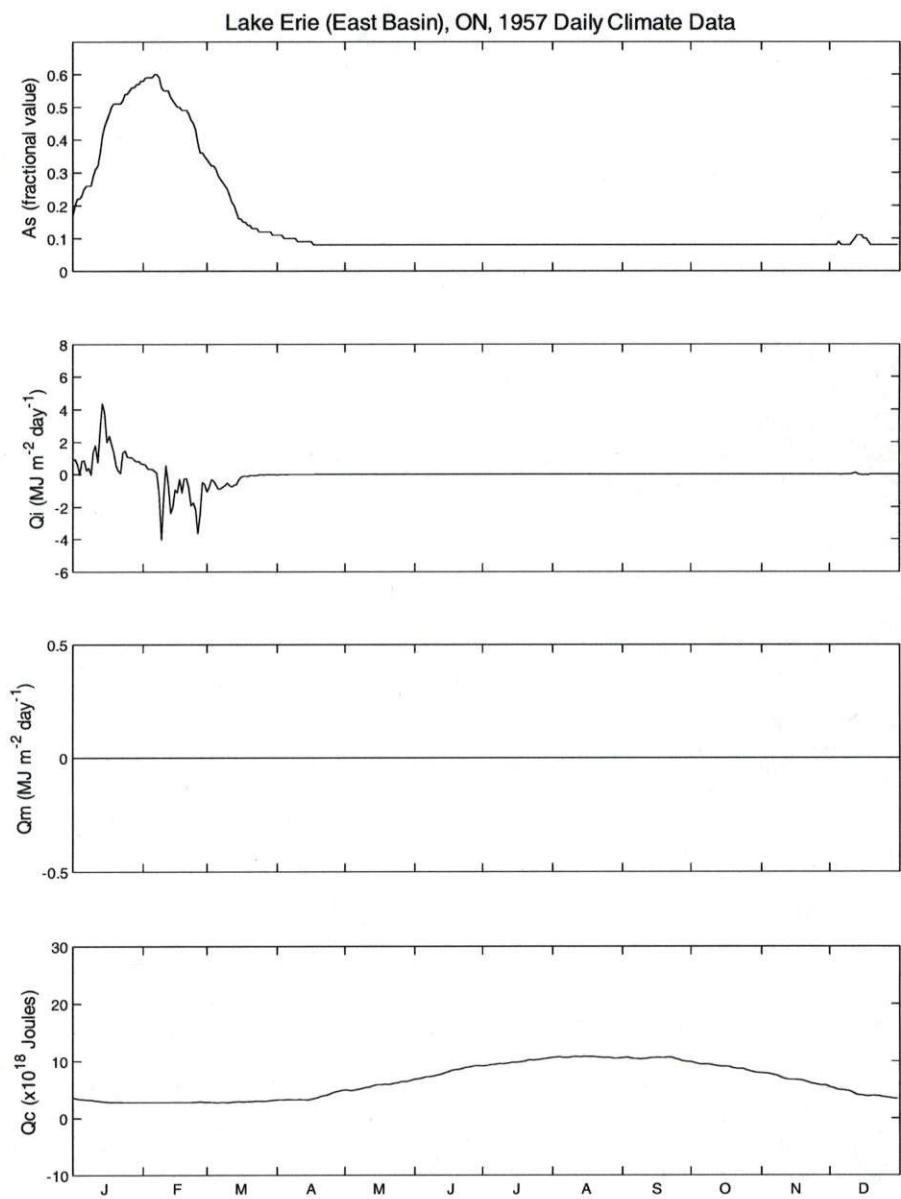
Lake Erie (East Basin), ON, 1954 Daily Climate Data

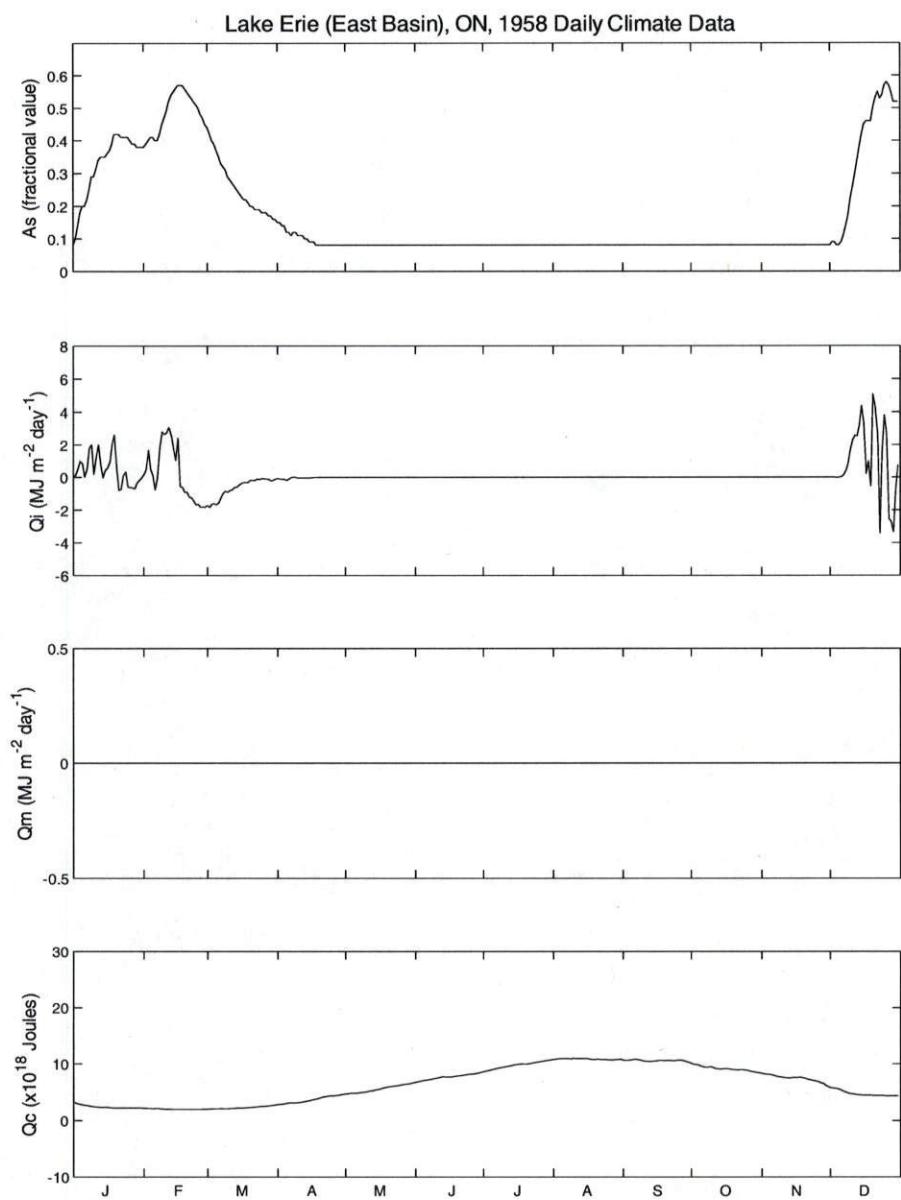


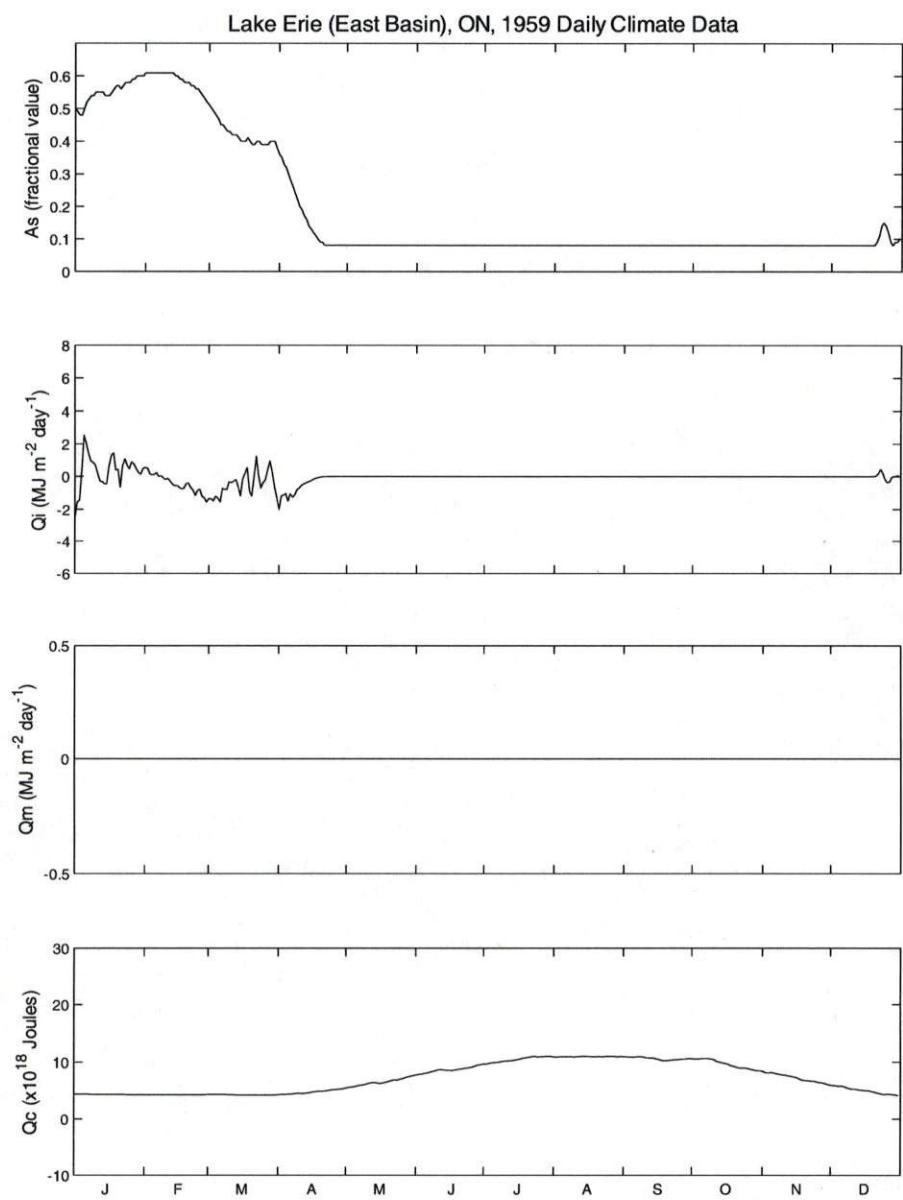


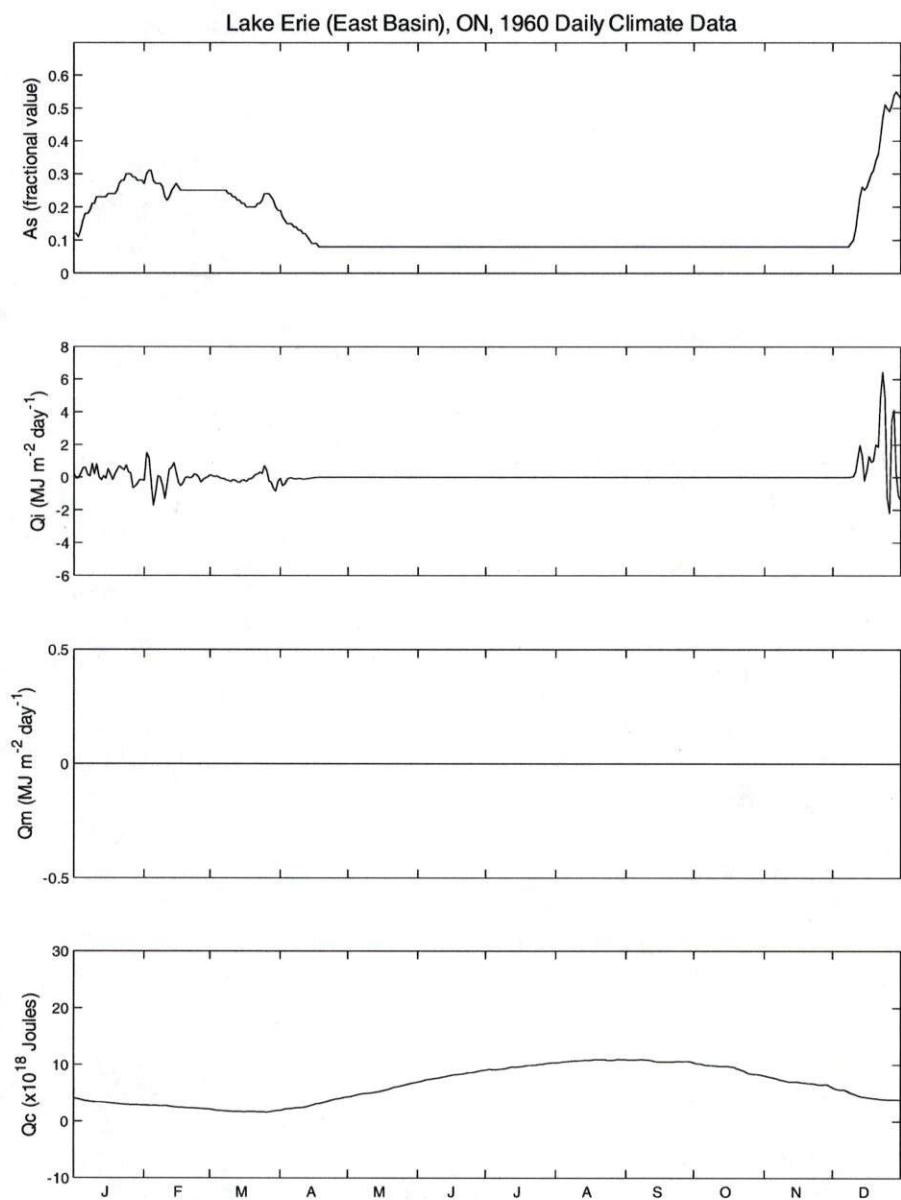
Lake Erie (East Basin), ON, 1956 Daily Climate Data

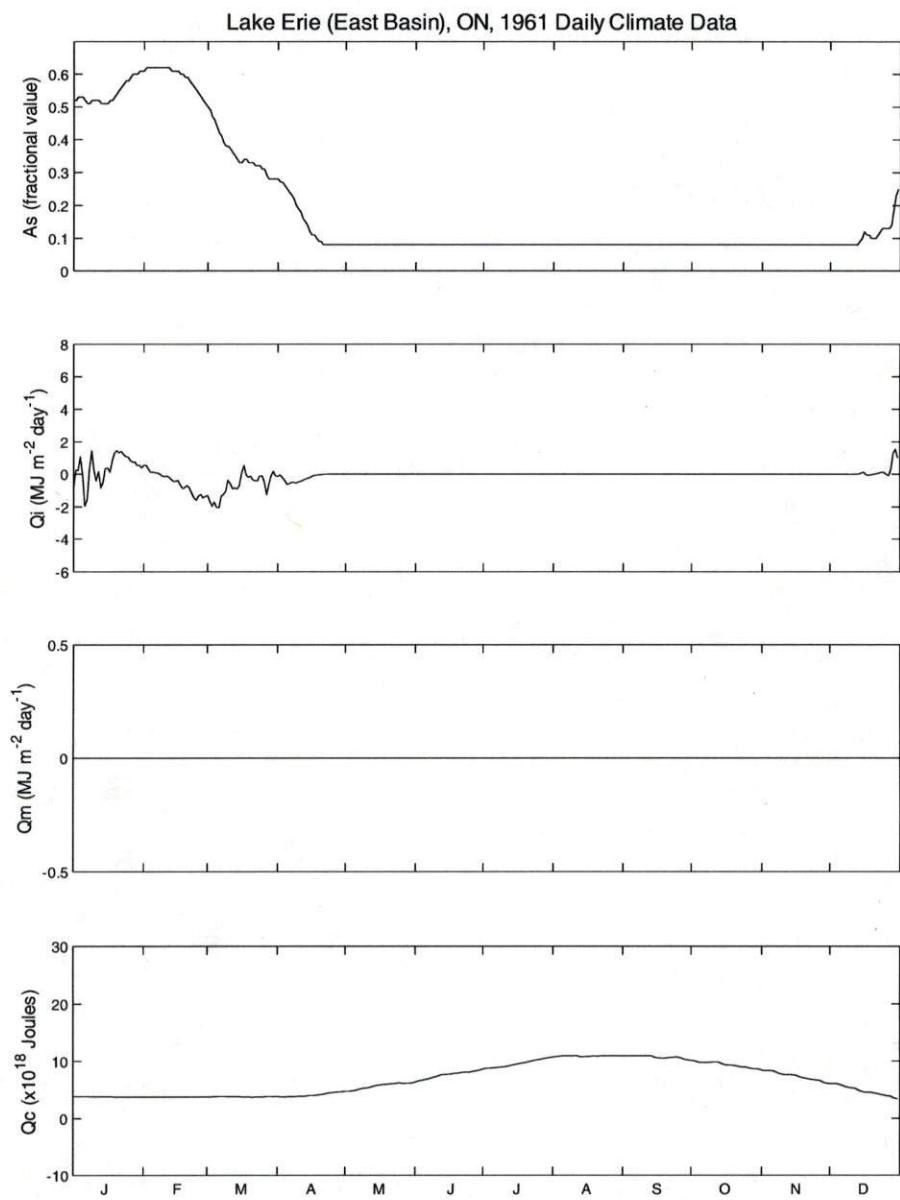


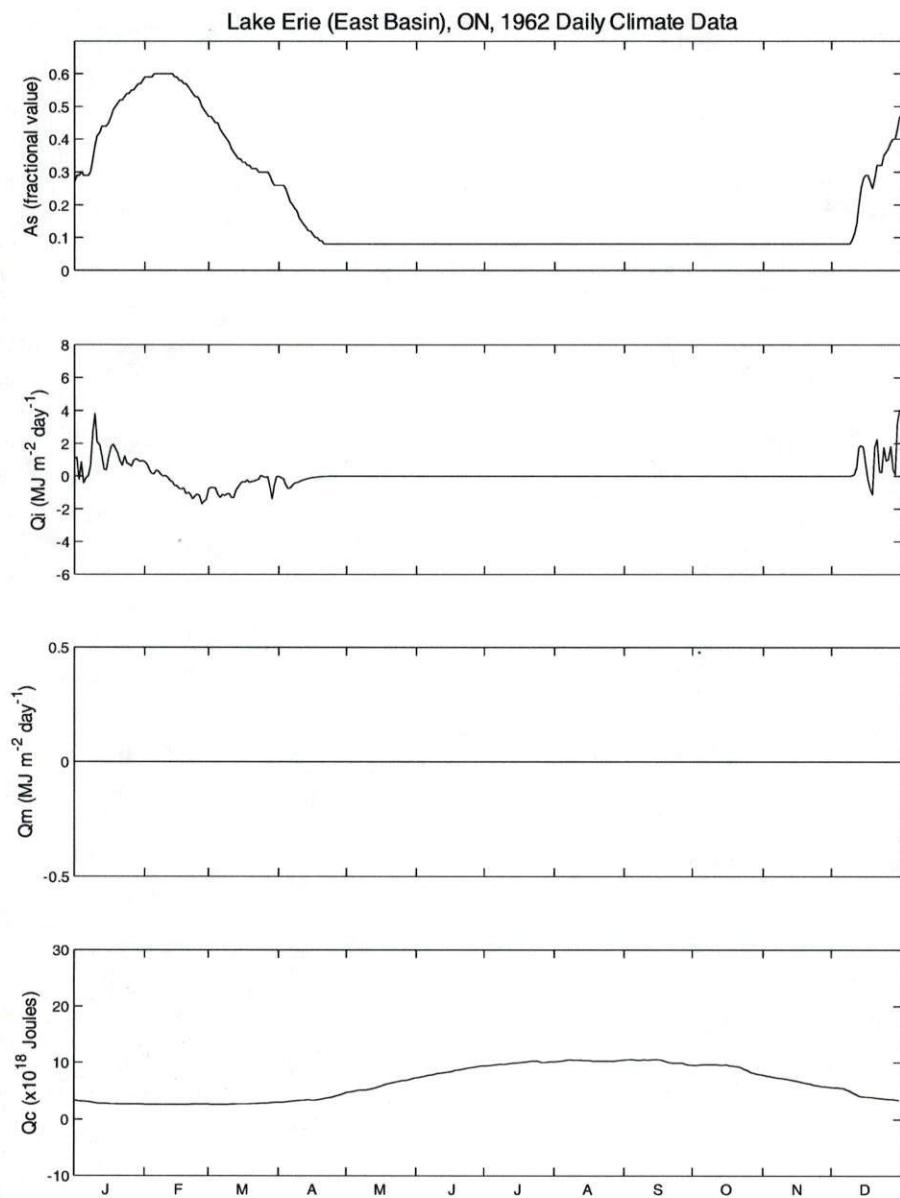


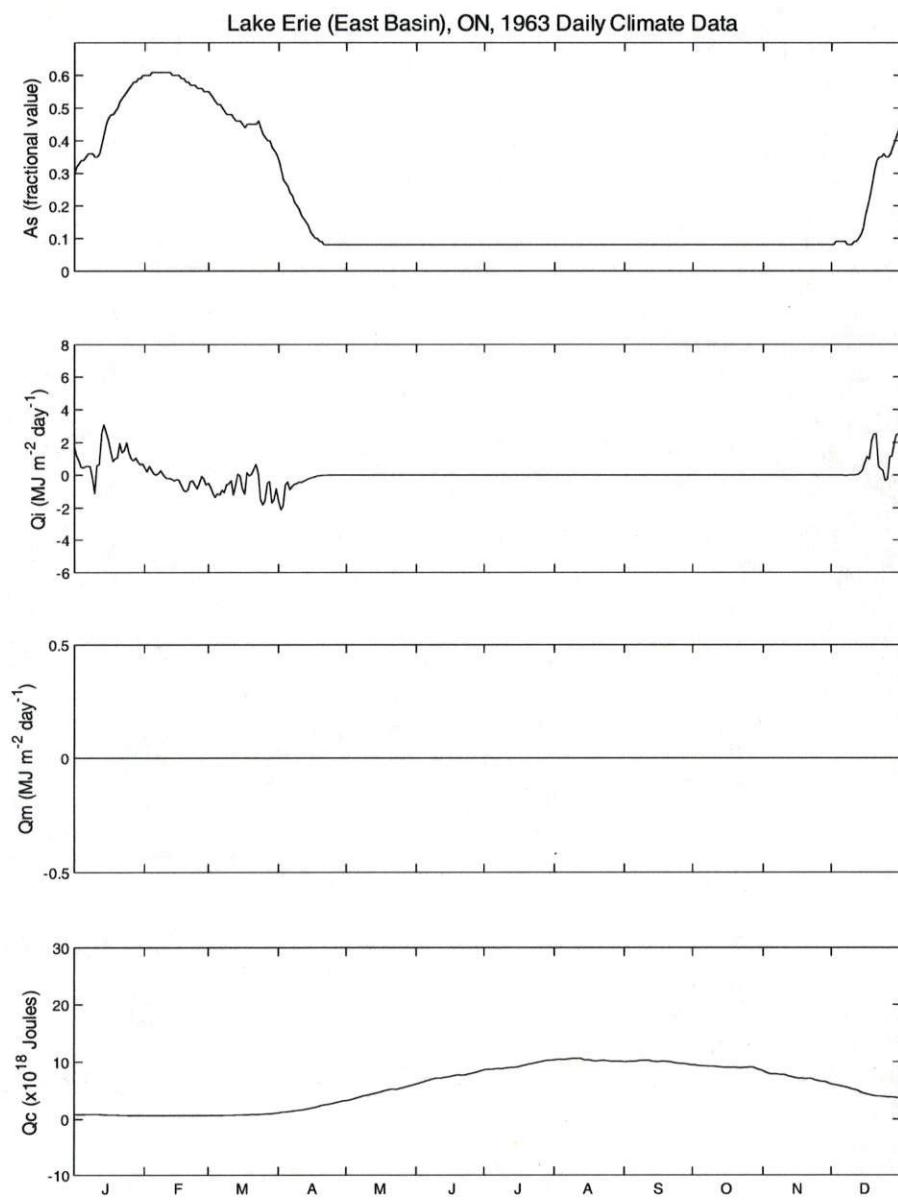




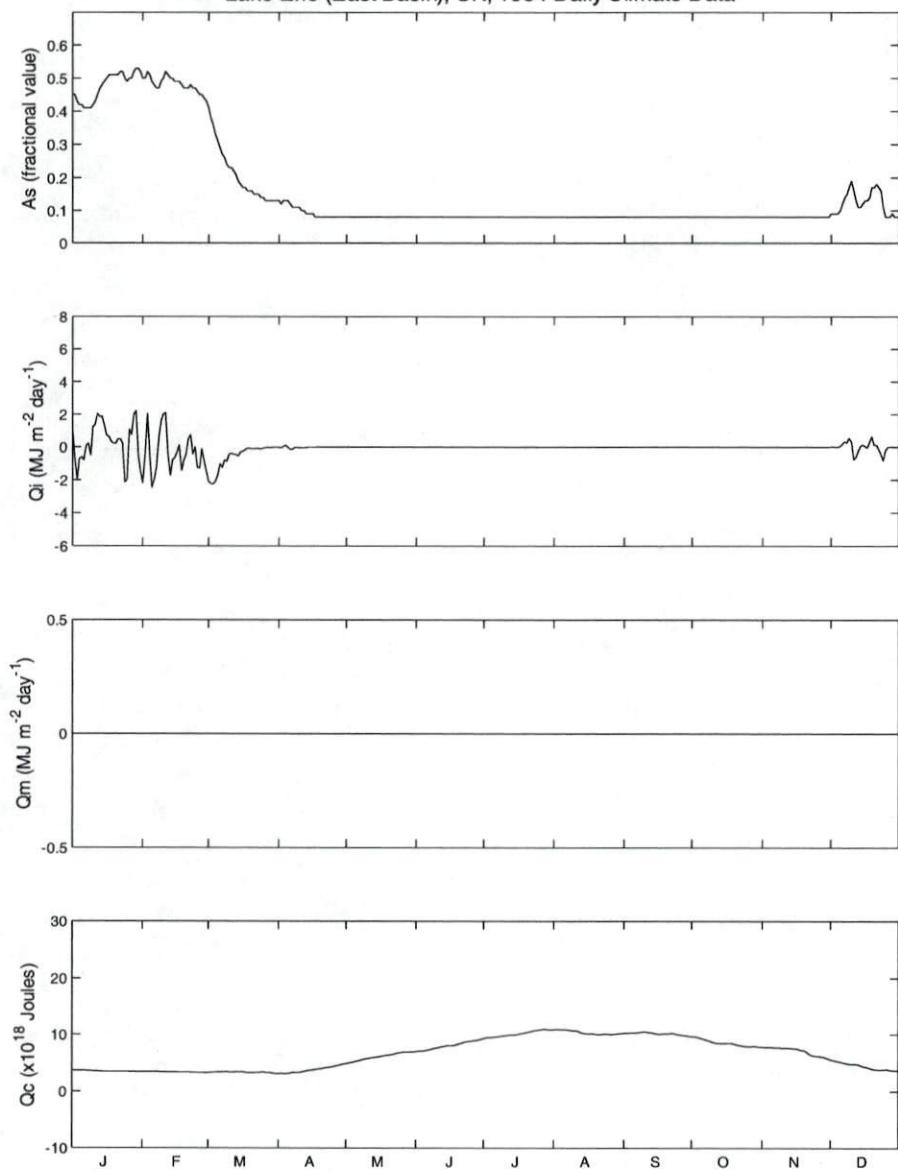




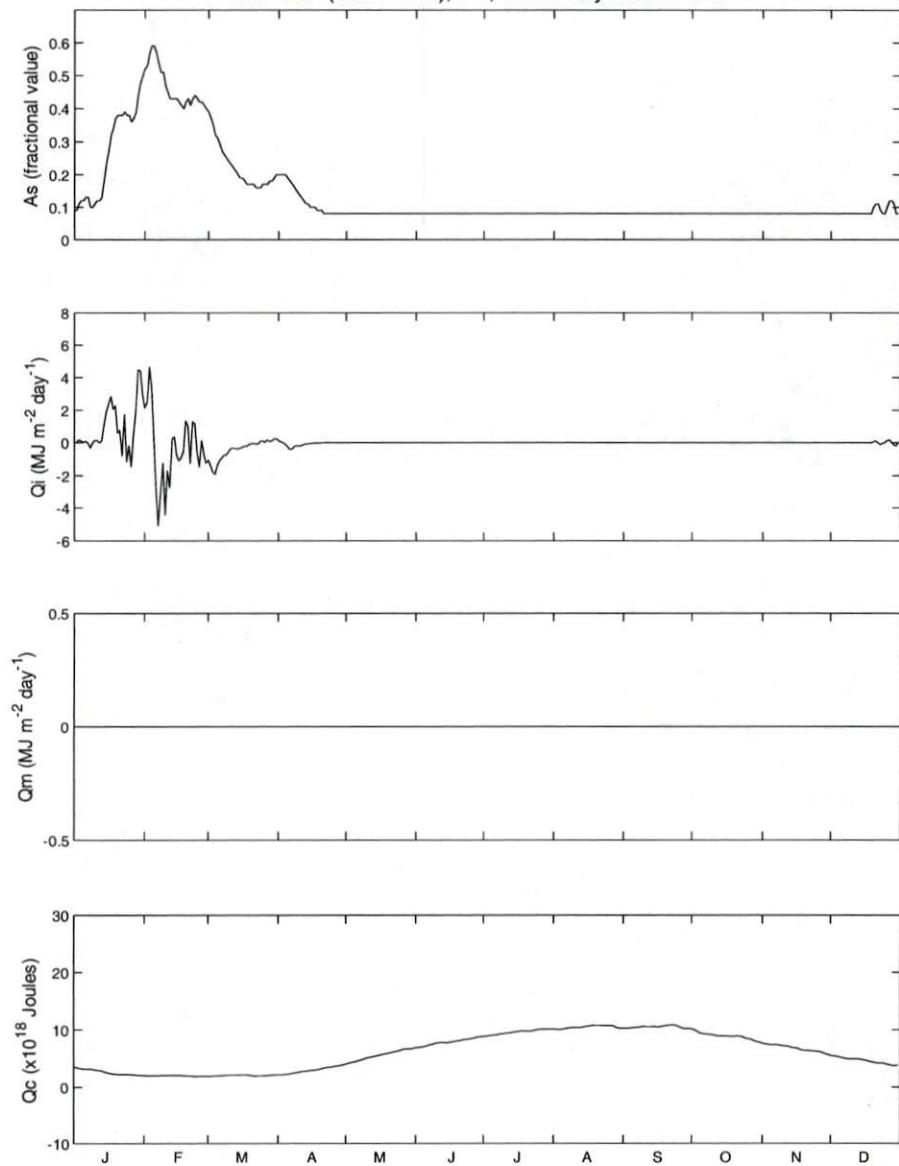




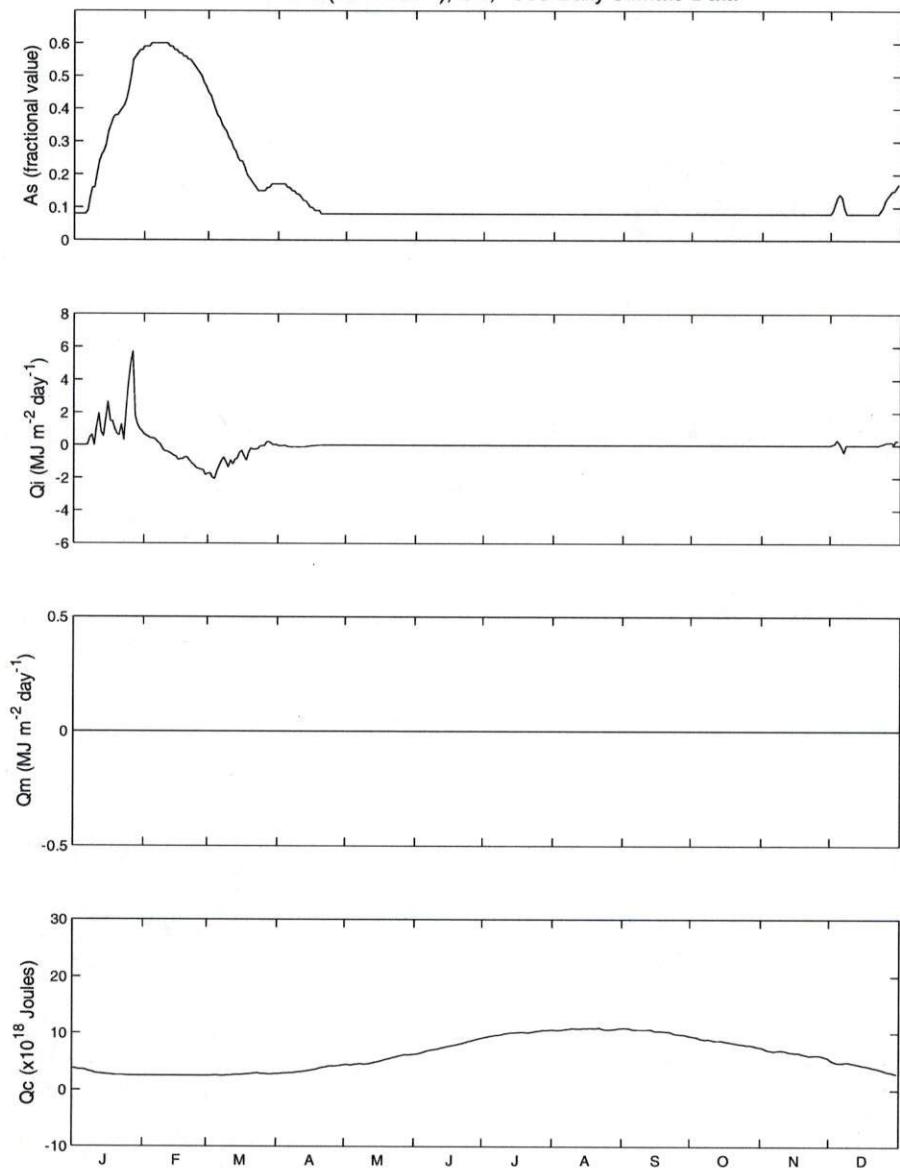
Lake Erie (East Basin), ON, 1964 Daily Climate Data

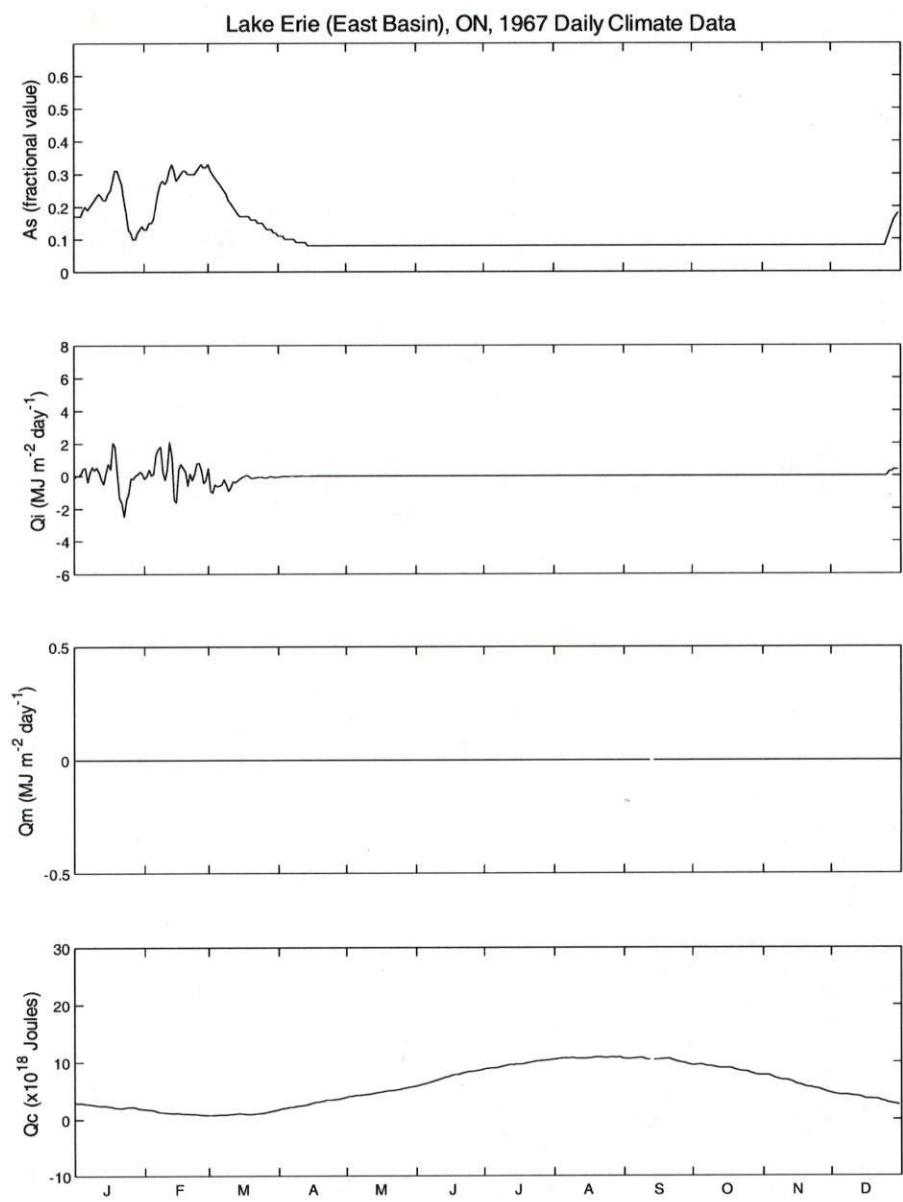


Lake Erie (East Basin), ON, 1965 Daily Climate Data

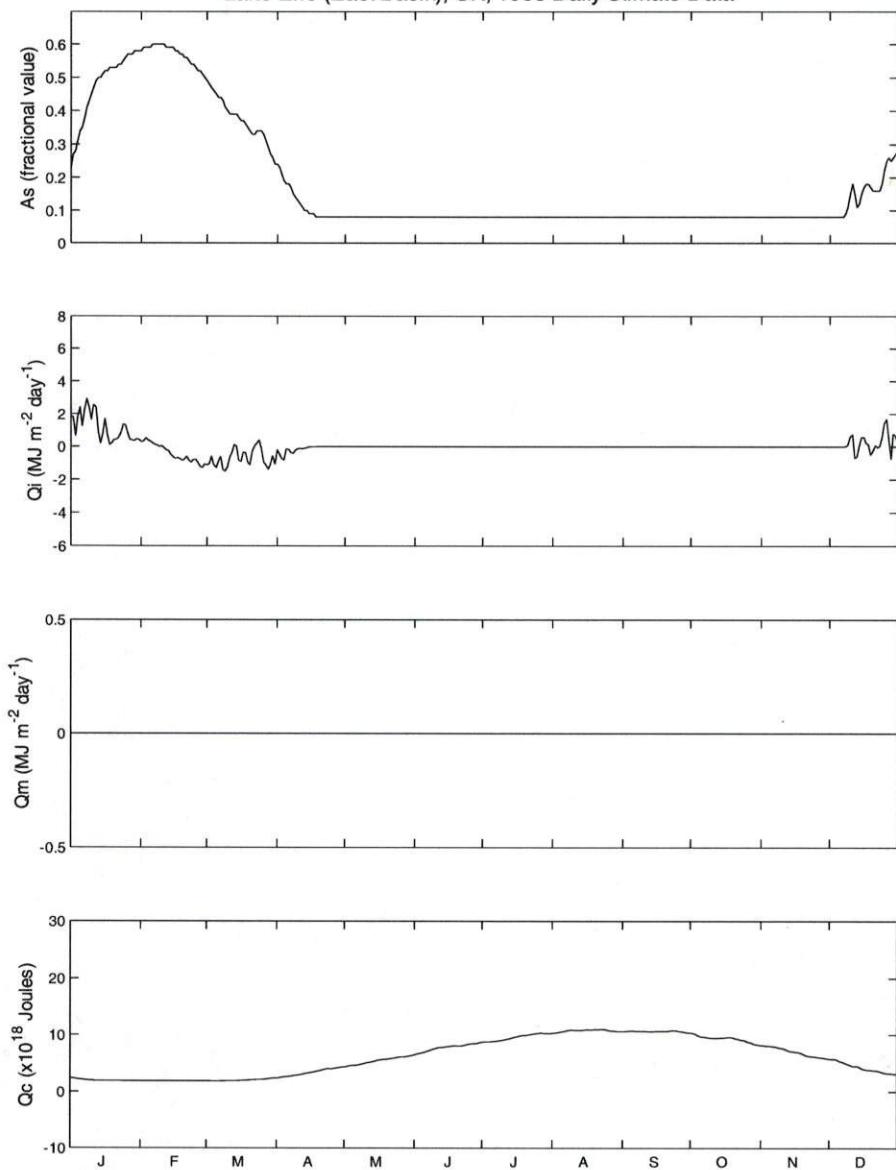


Lake Erie (East Basin), ON, 1966 Daily Climate Data

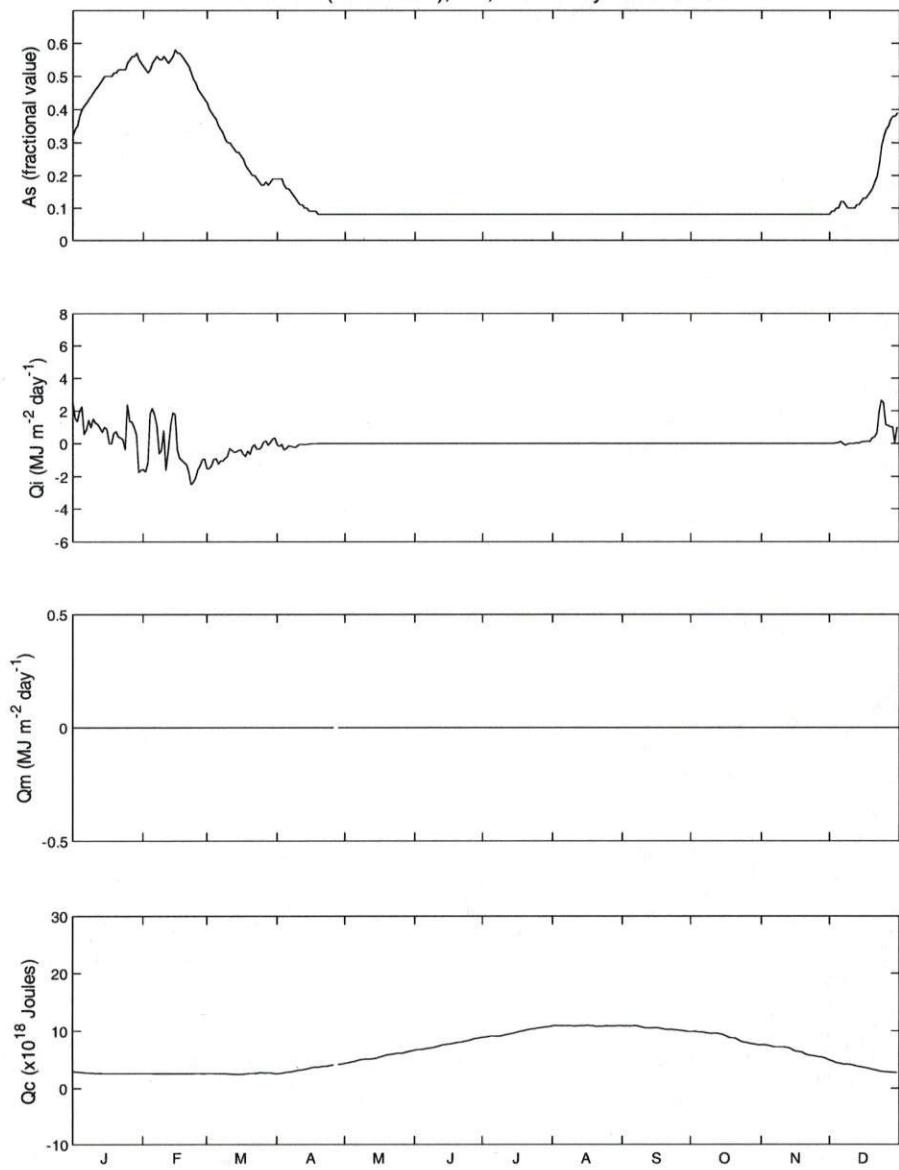


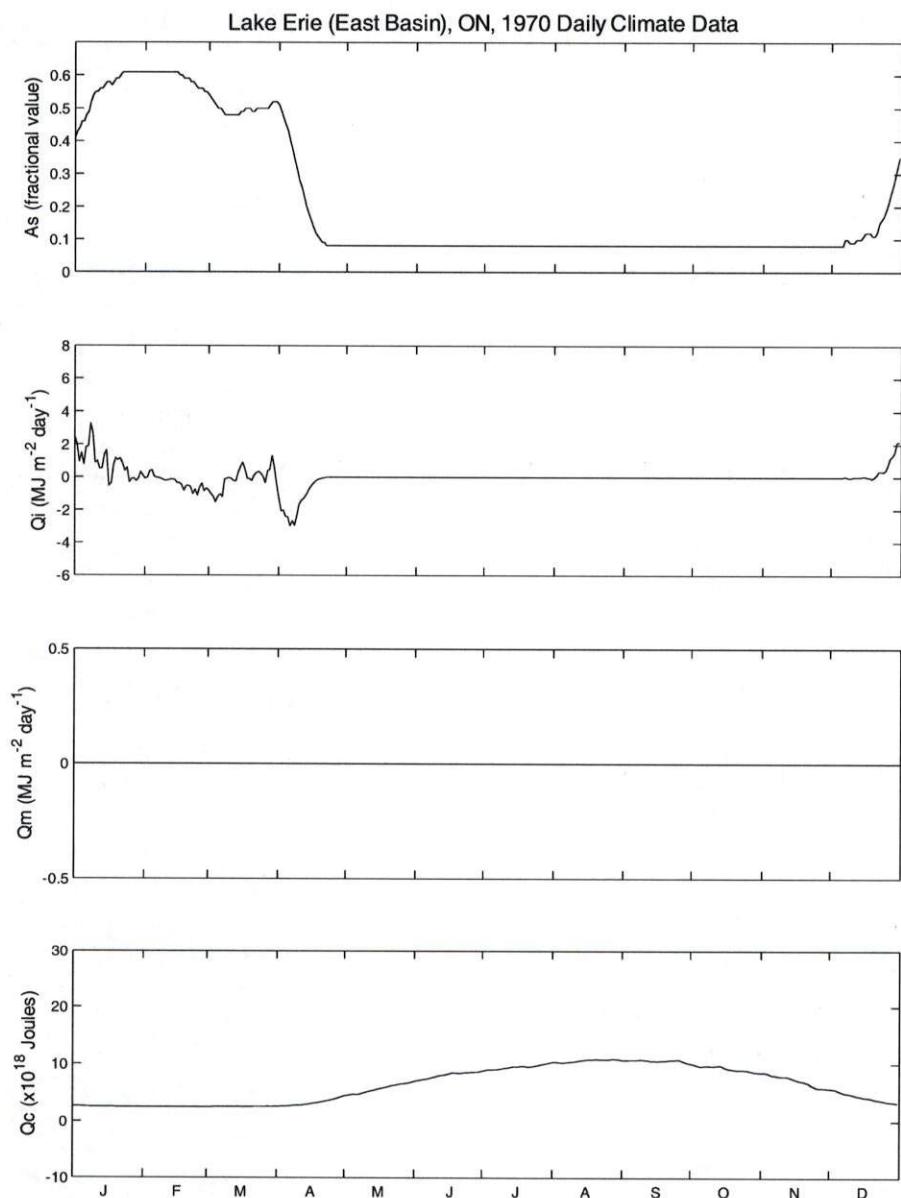


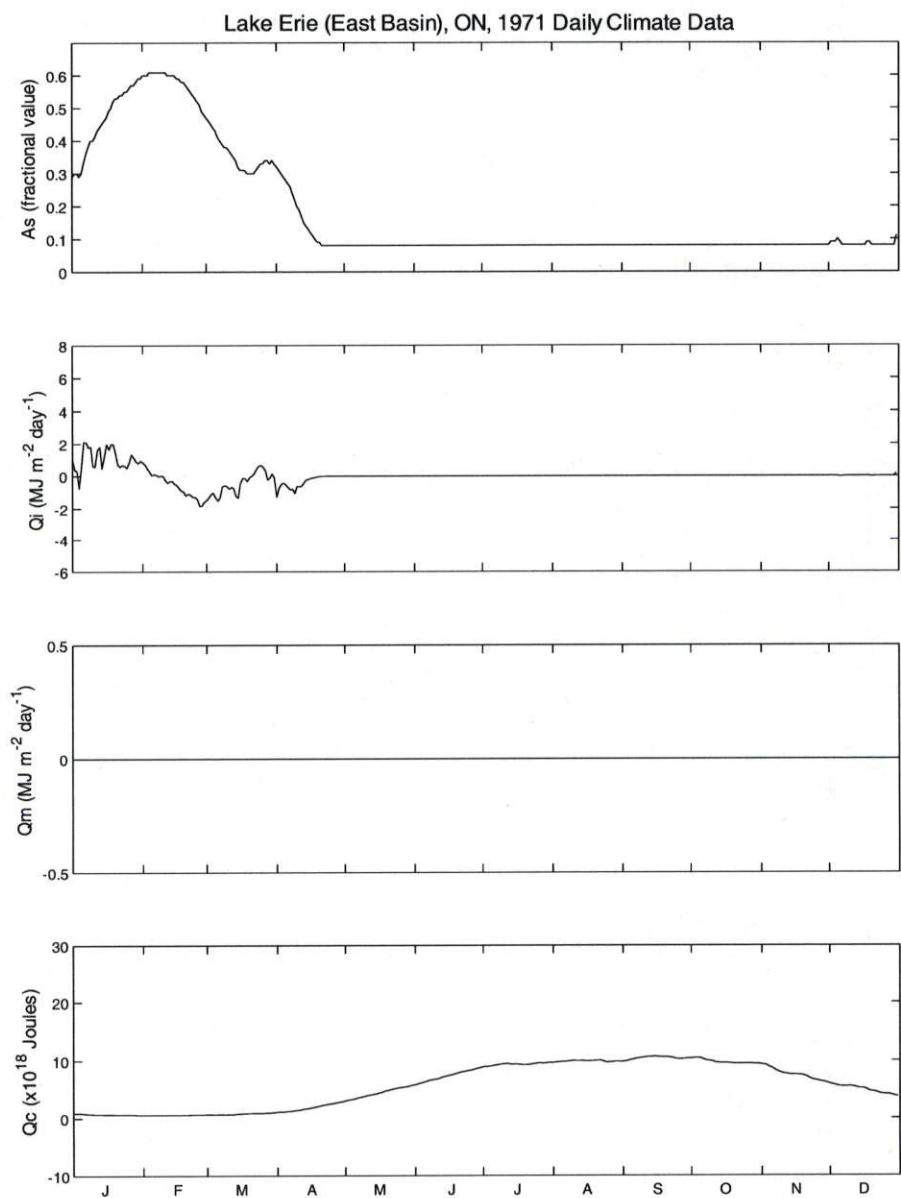
Lake Erie (East Basin), ON, 1968 Daily Climate Data

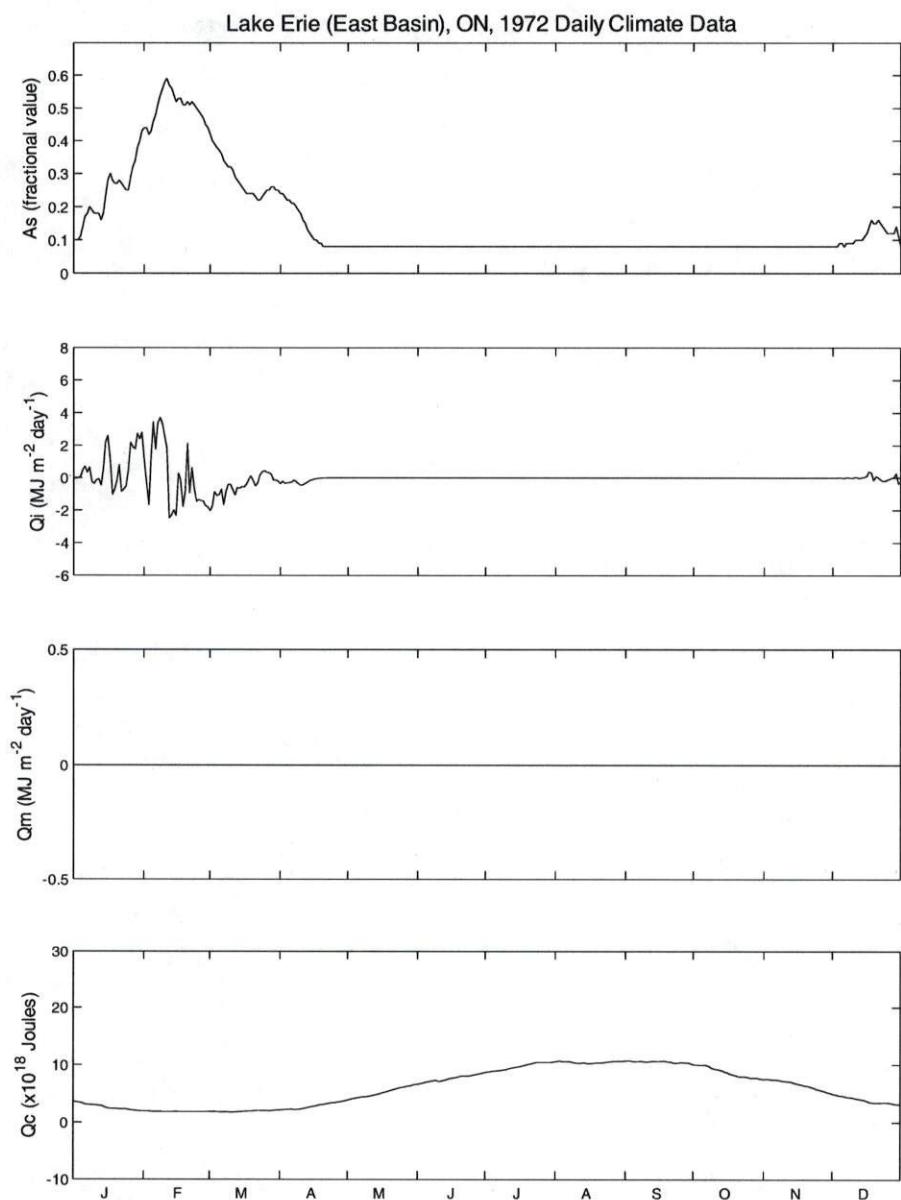


Lake Erie (East Basin), ON, 1969 Daily Climate Data

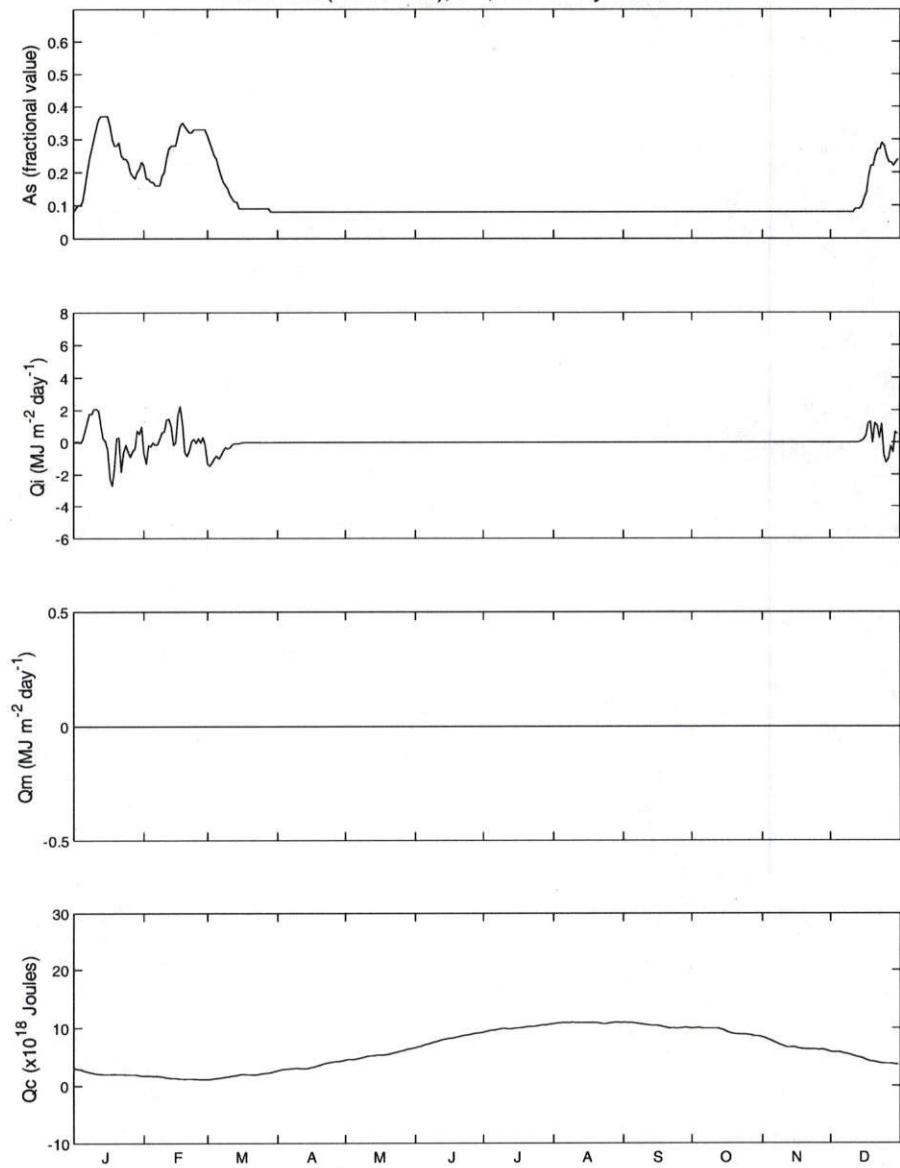




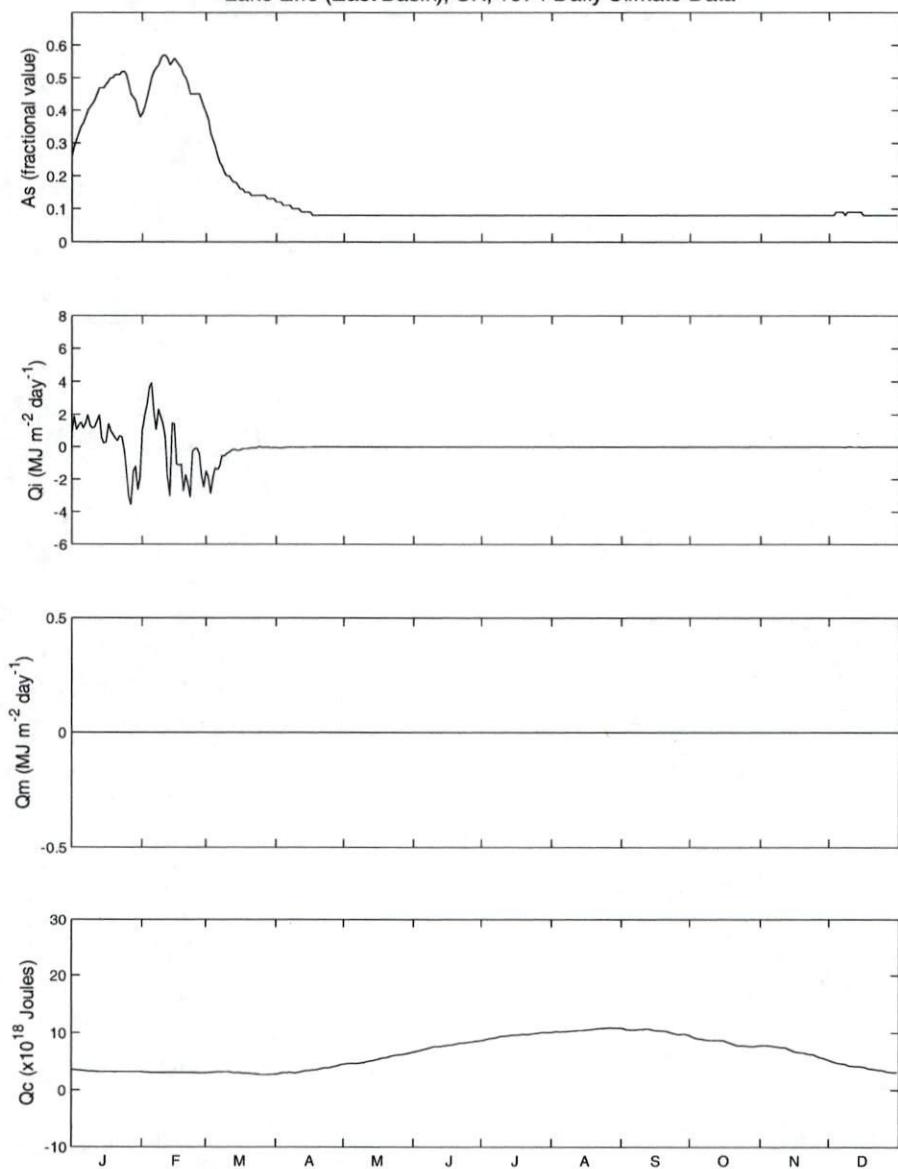




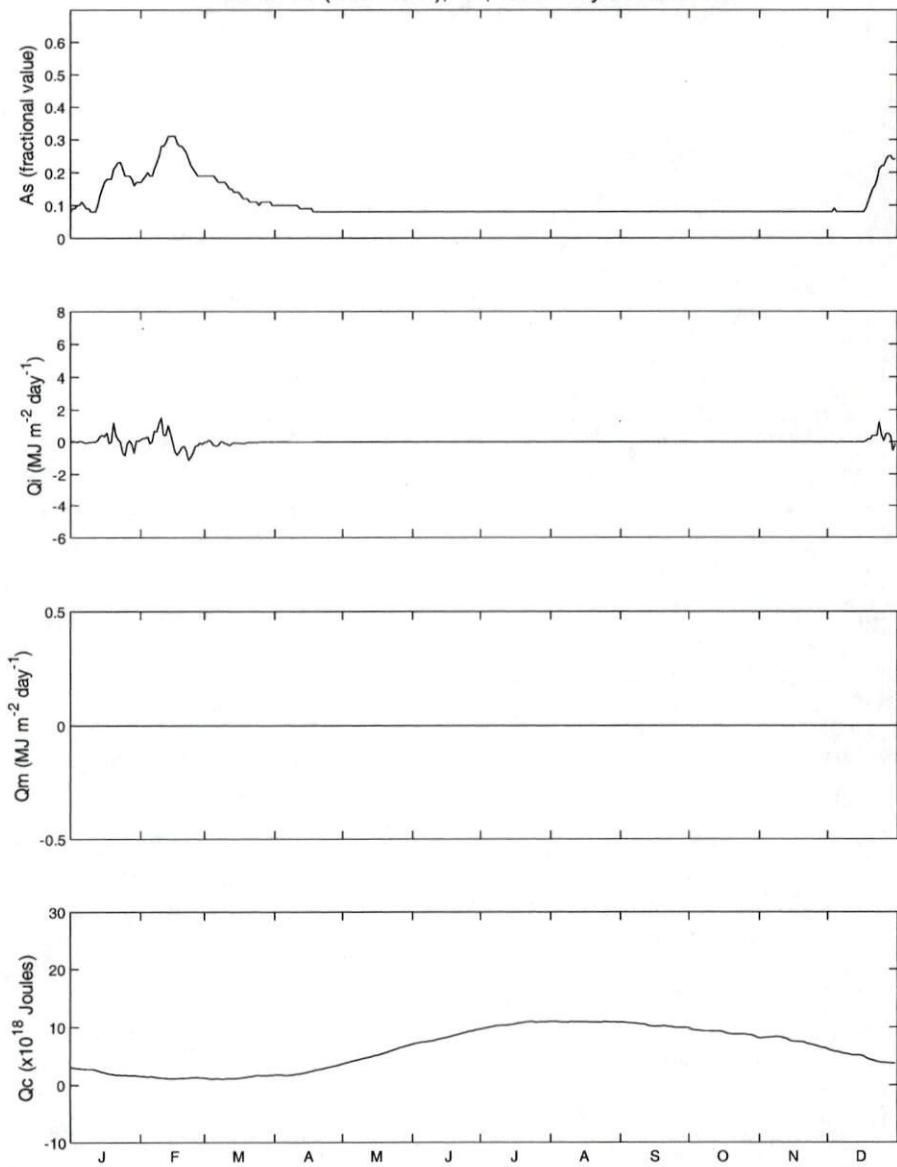
Lake Erie (East Basin), ON, 1973 Daily Climate Data



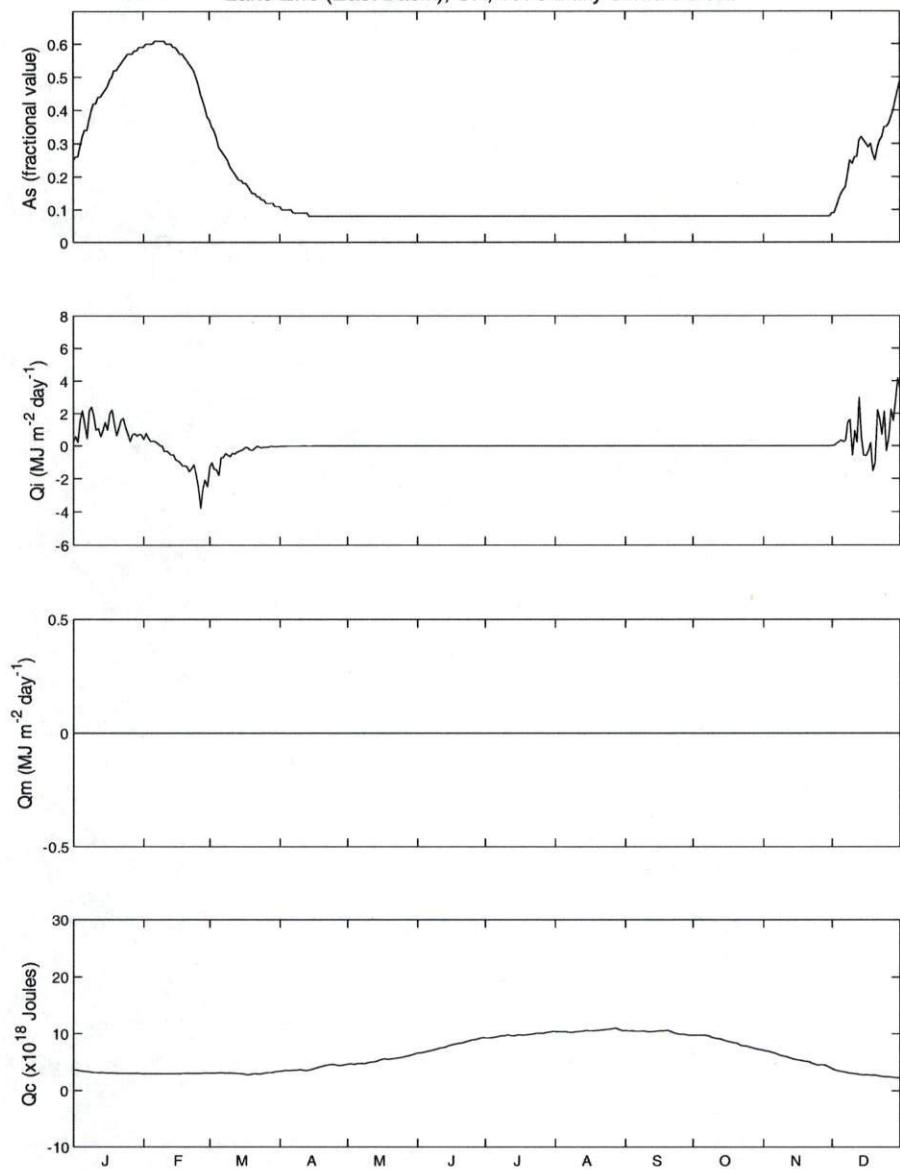
Lake Erie (East Basin), ON, 1974 Daily Climate Data



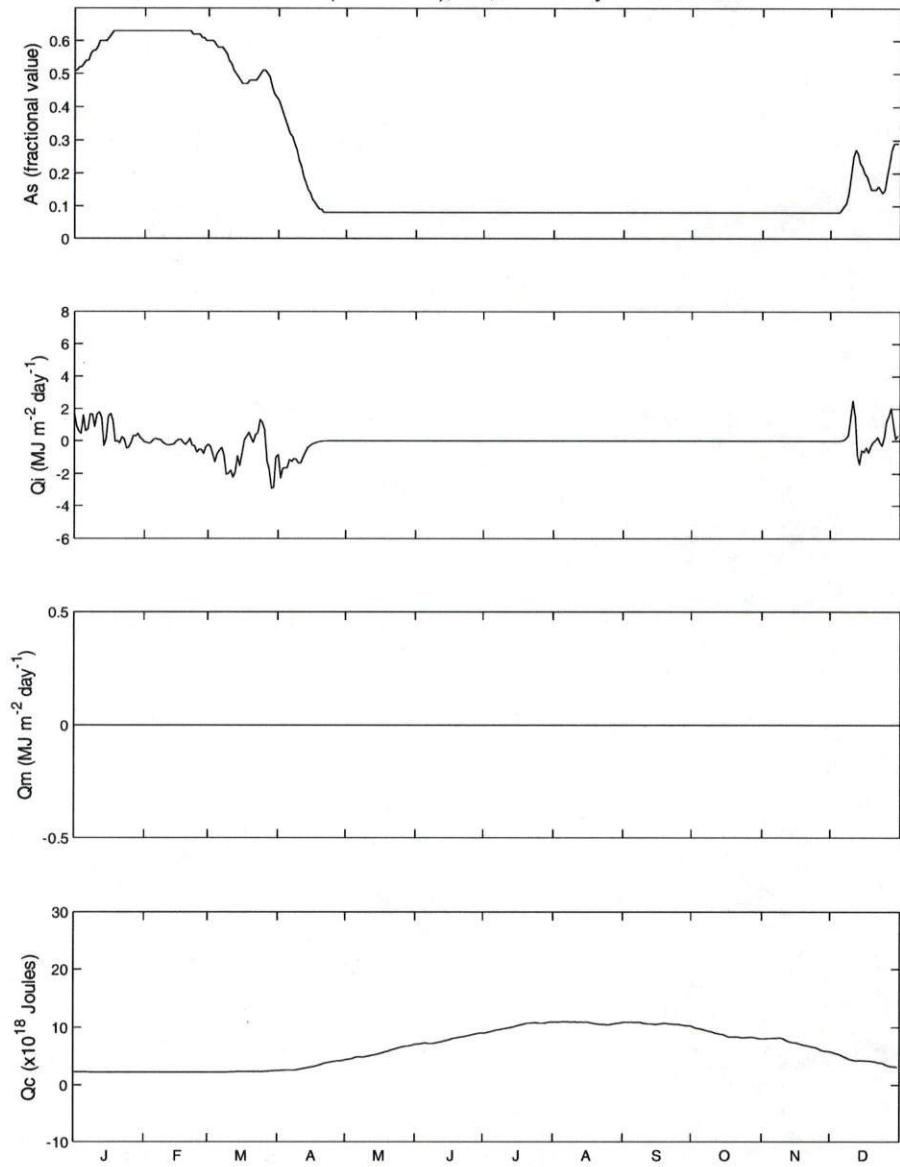
Lake Erie (East Basin), ON, 1975 Daily Climate Data

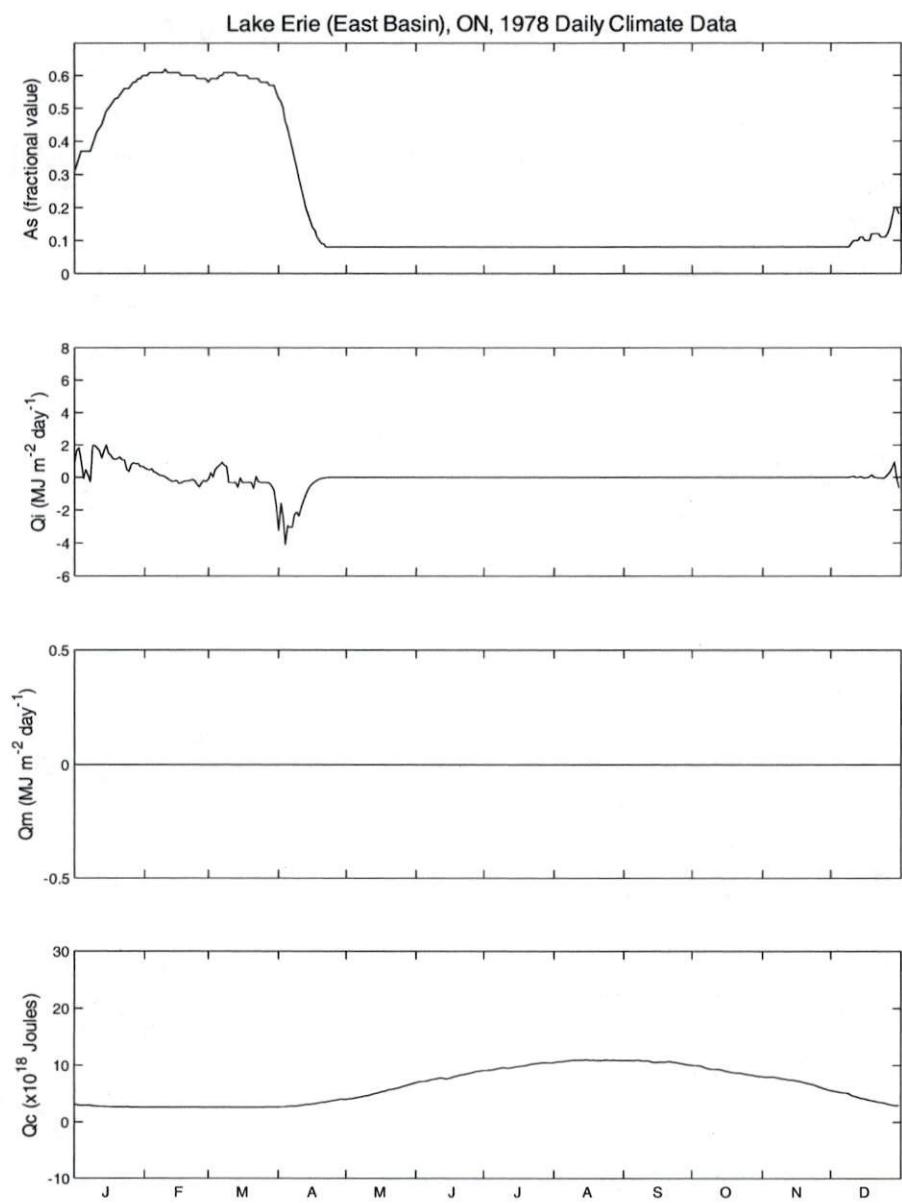


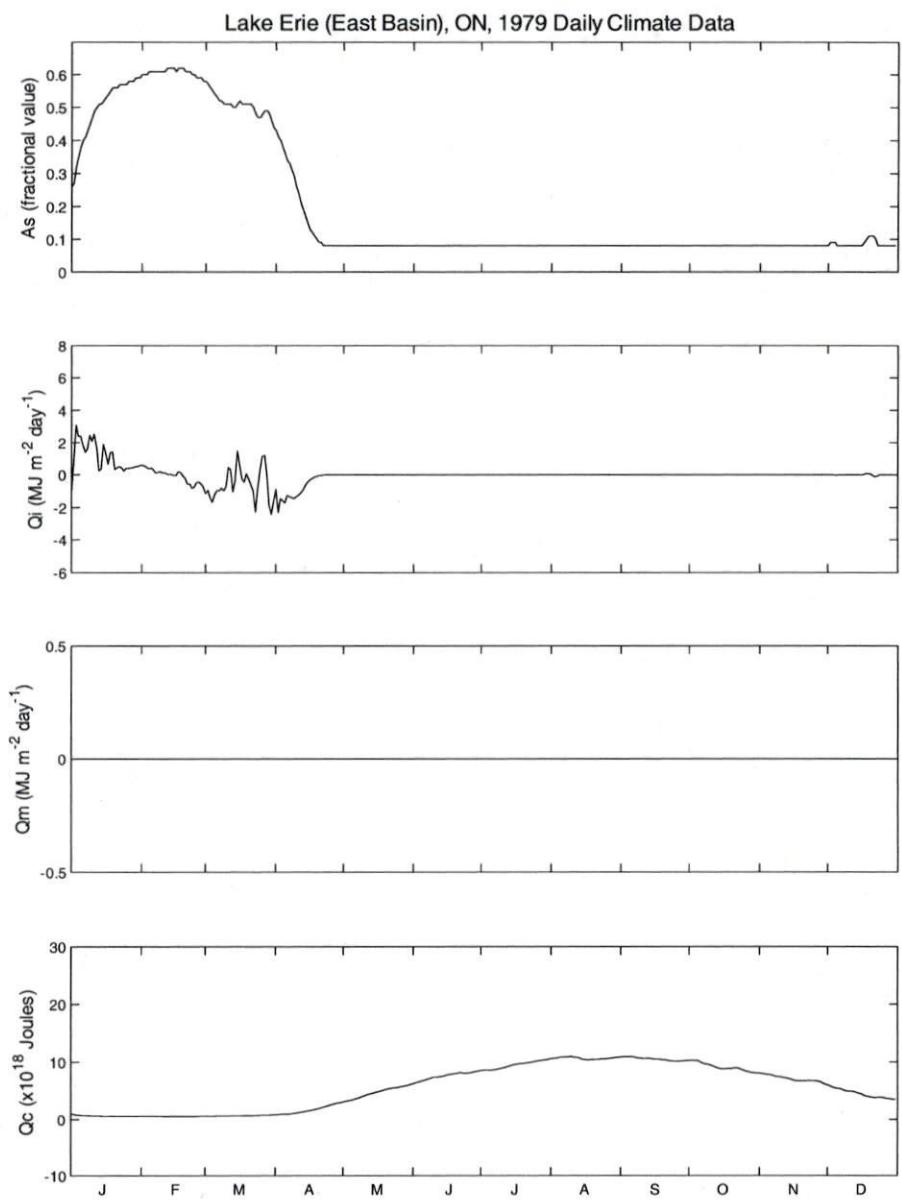
Lake Erie (East Basin), ON, 1976 Daily Climate Data



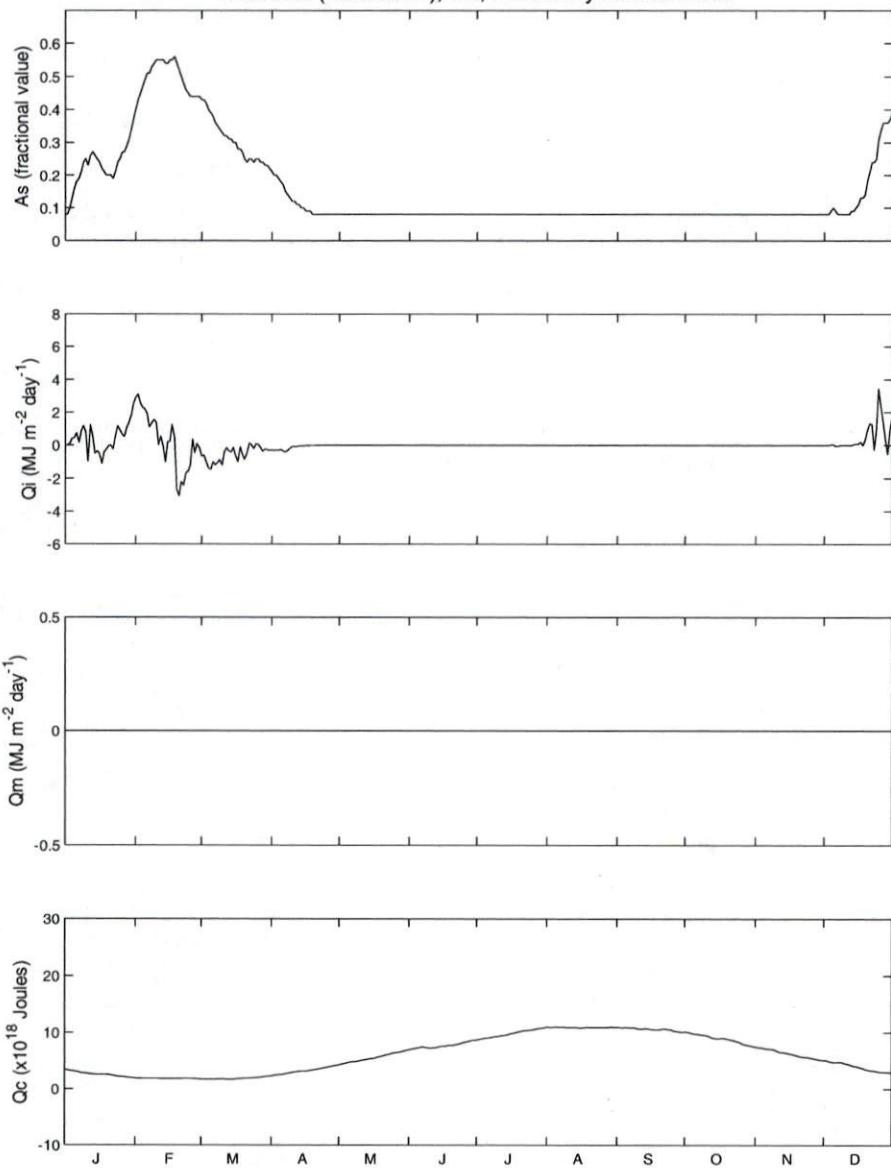
Lake Erie (East Basin), ON, 1977 Daily Climate Data

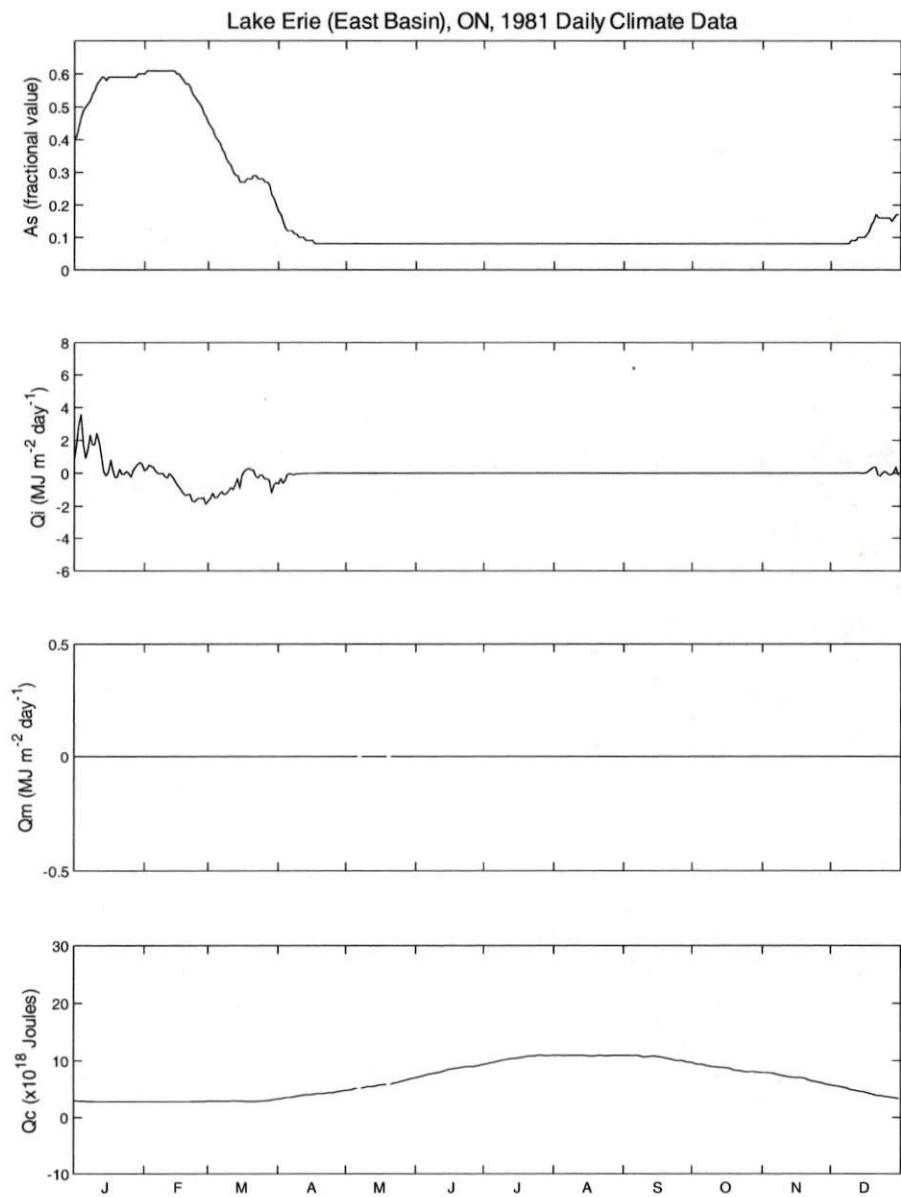




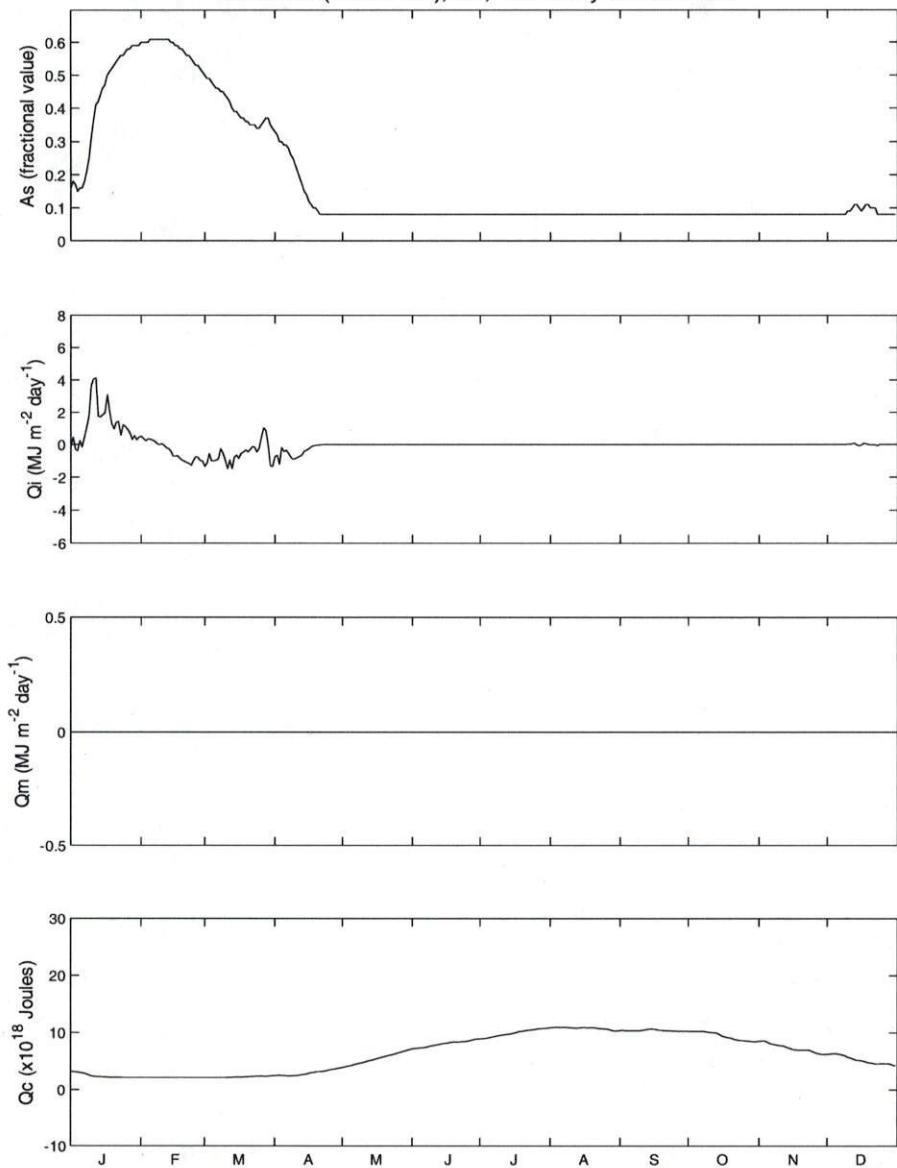


Lake Erie (East Basin), ON, 1980 Daily Climate Data

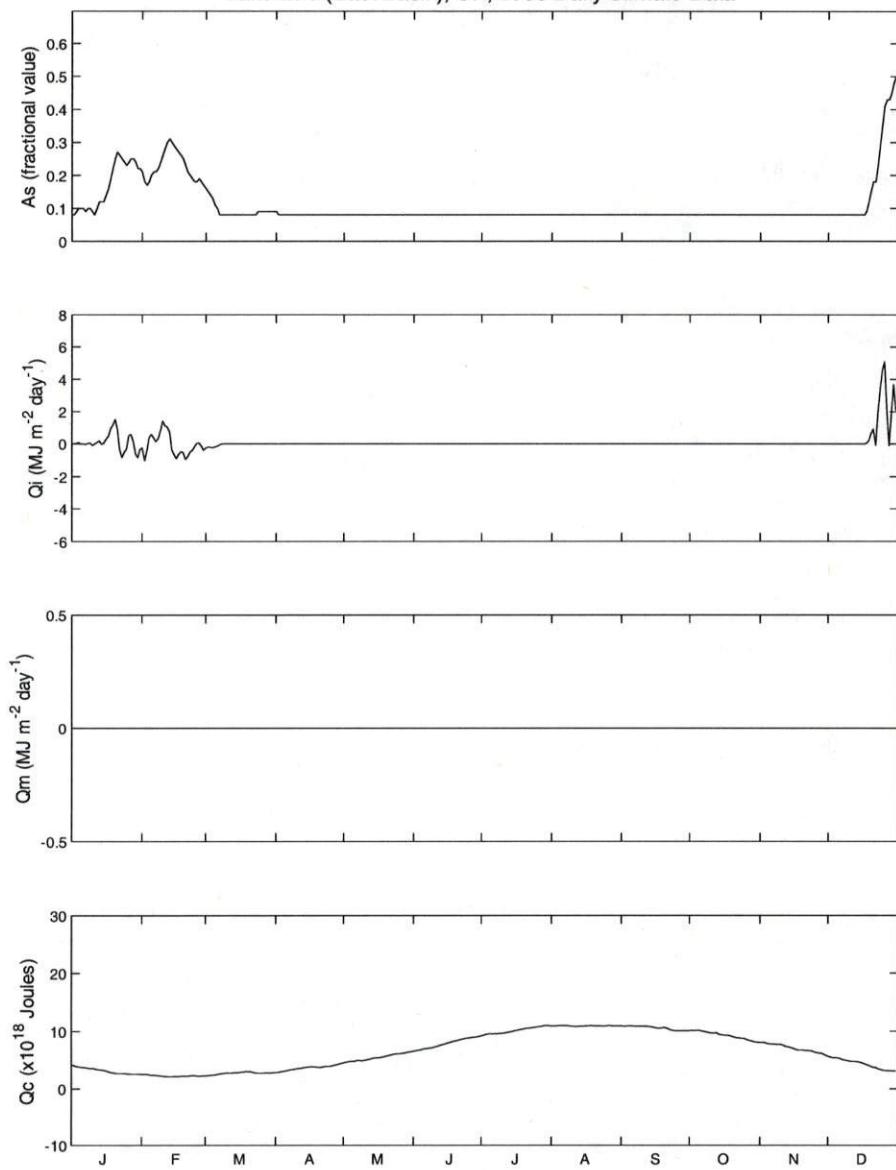


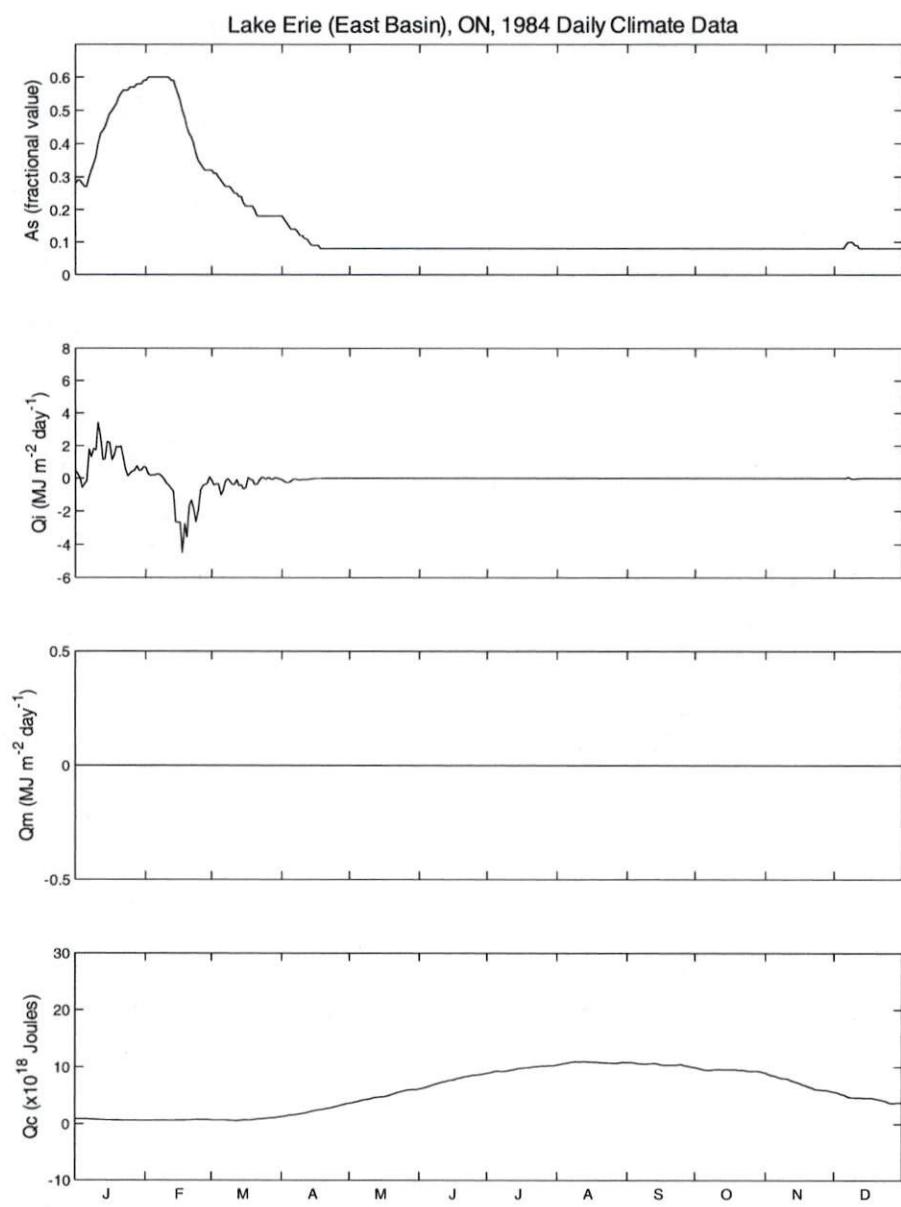


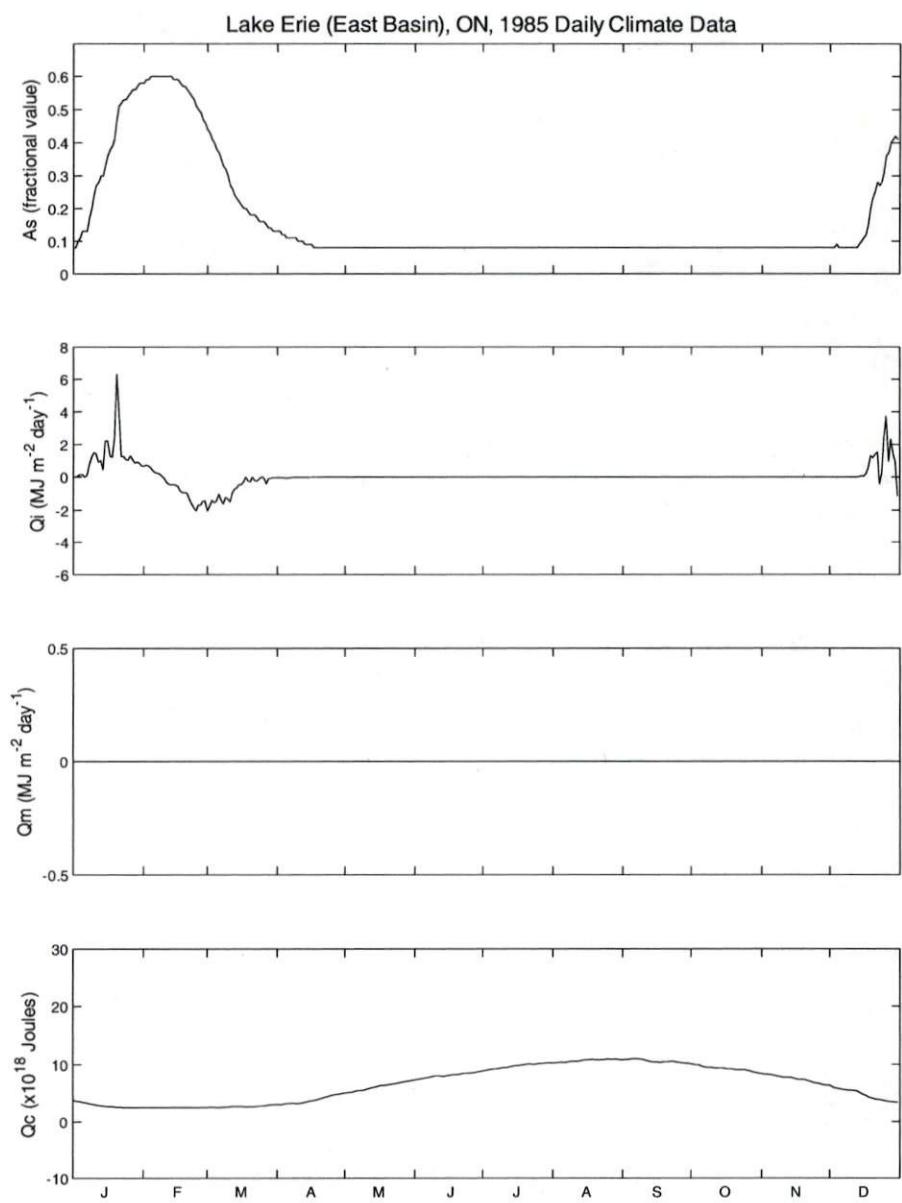
Lake Erie (East Basin), ON, 1982 Daily Climate Data



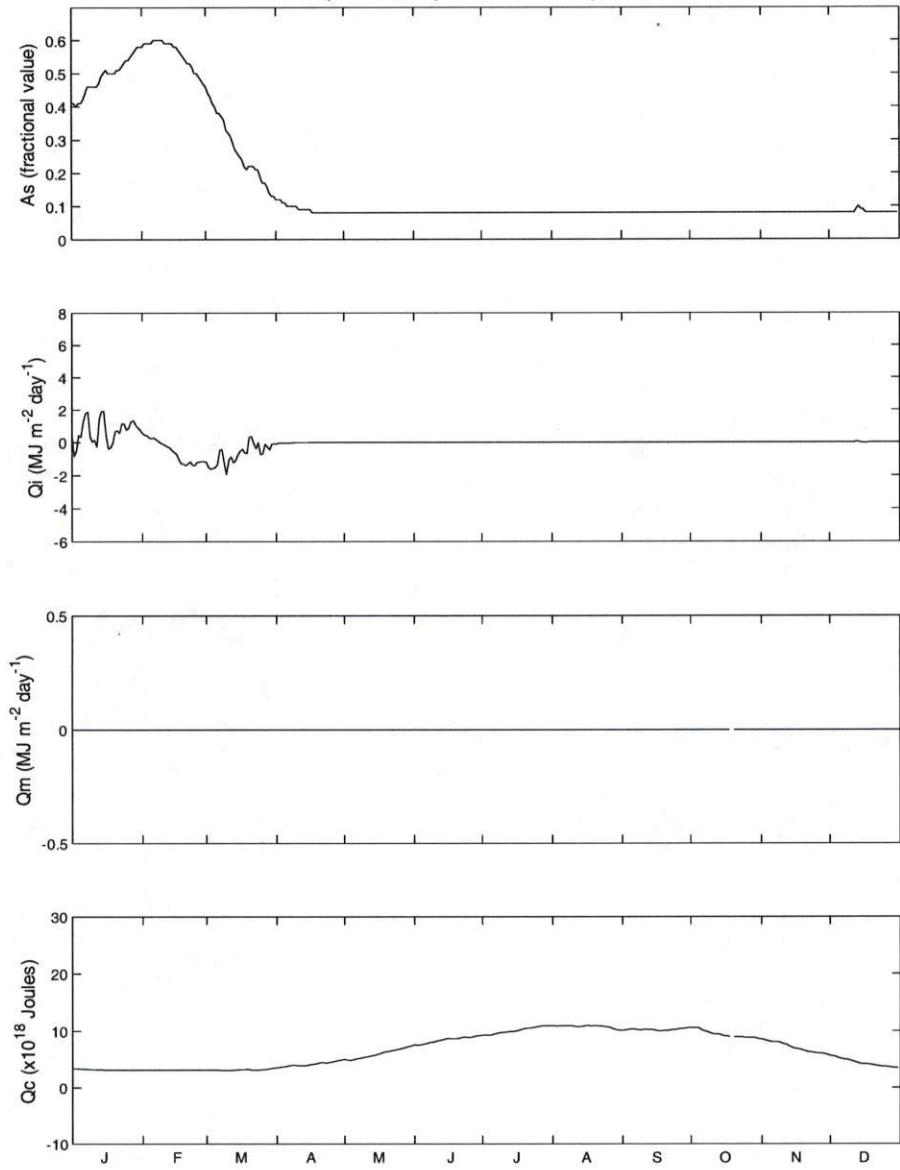
Lake Erie (East Basin), ON, 1983 Daily Climate Data



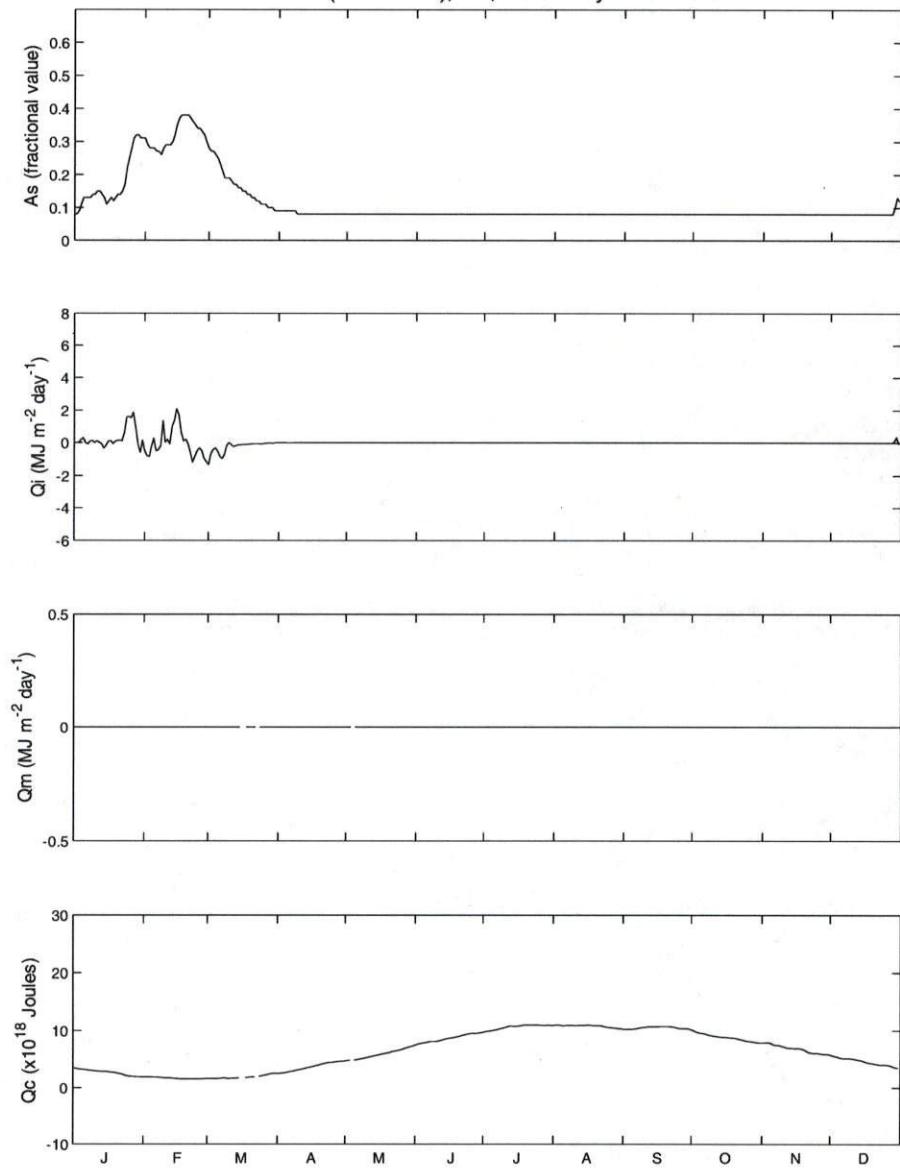




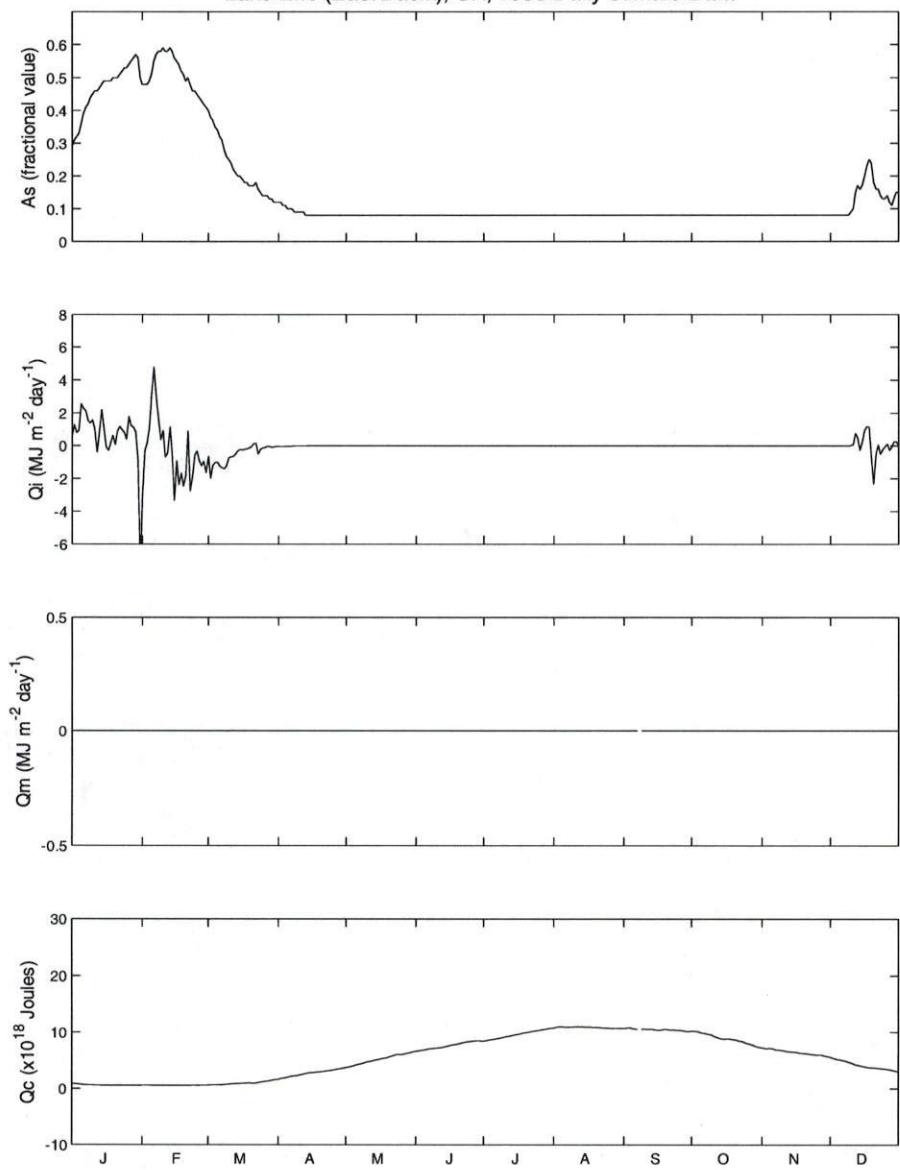
Lake Erie (East Basin), ON, 1986 Daily Climate Data



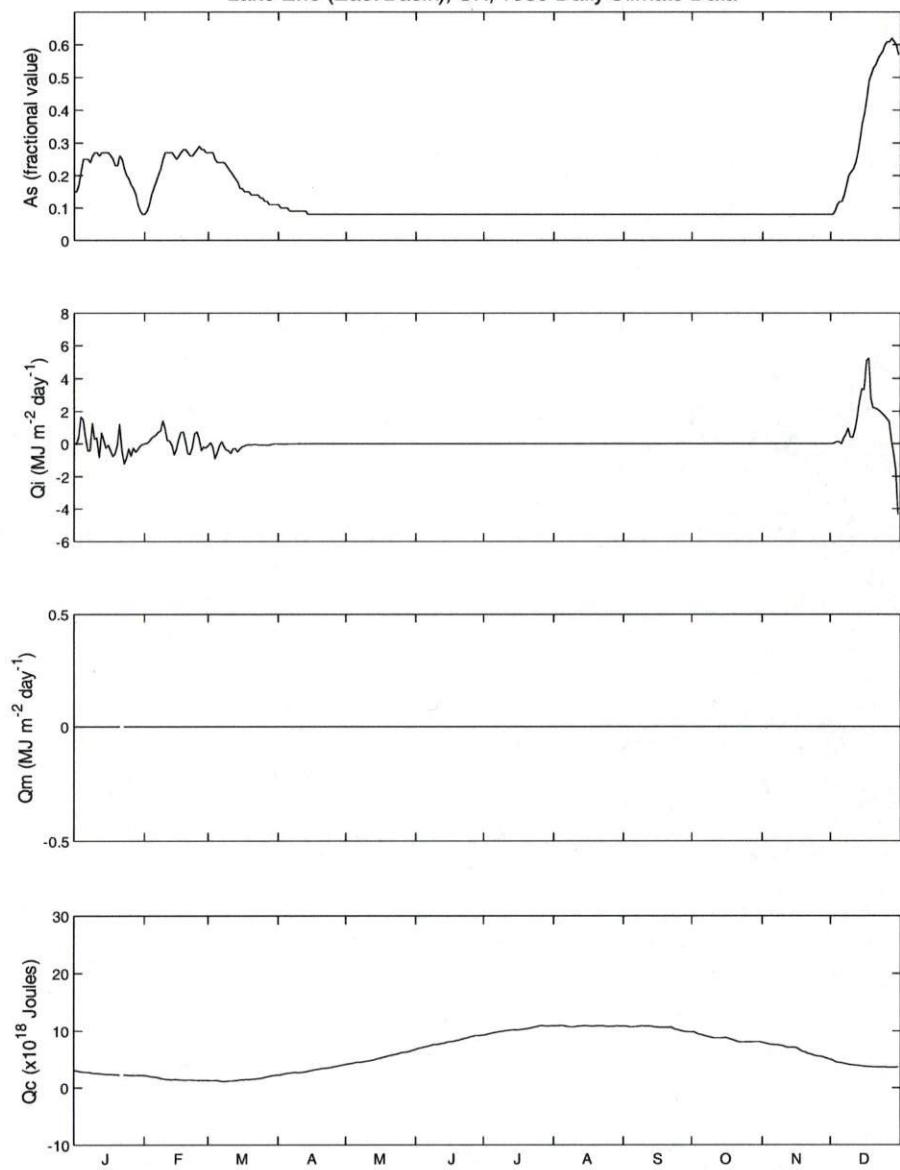
Lake Erie (East Basin), ON, 1987 Daily Climate Data



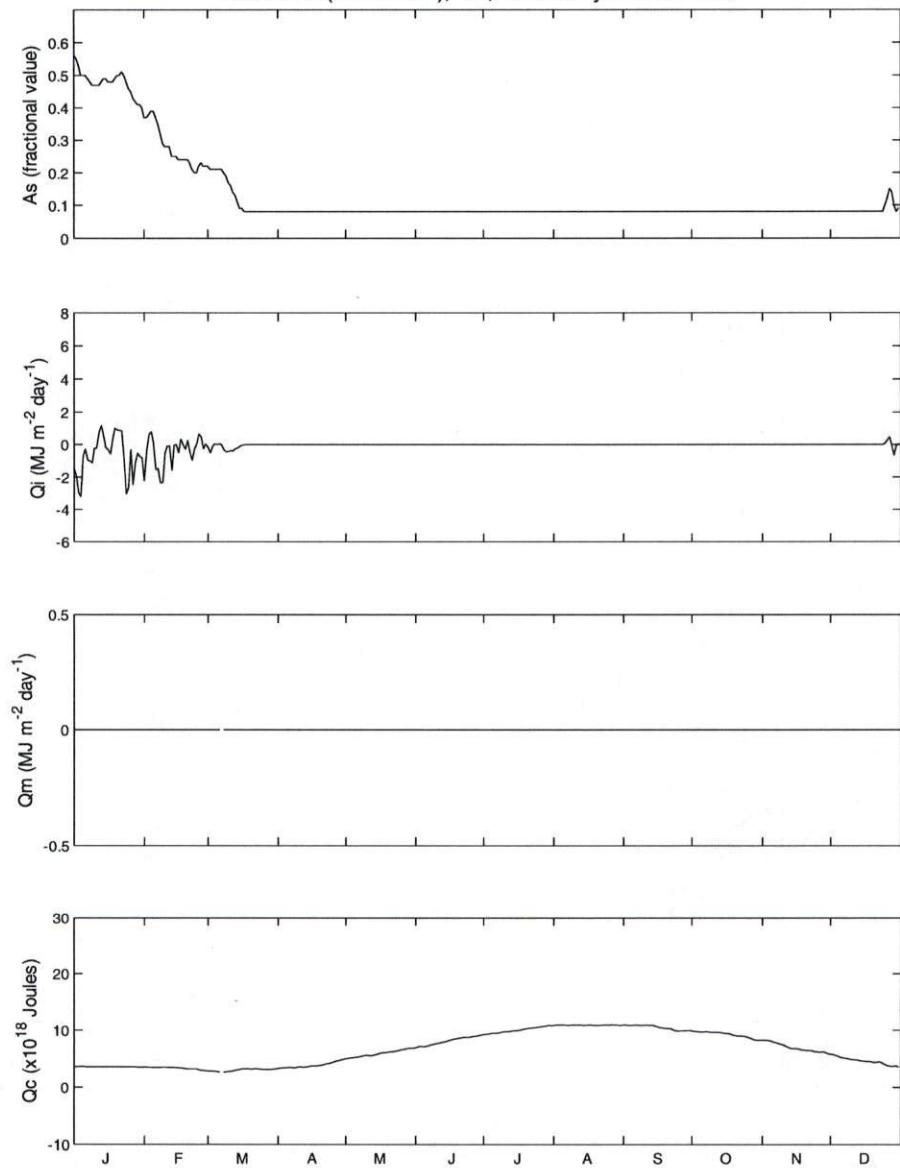
Lake Erie (East Basin), ON, 1988 Daily Climate Data



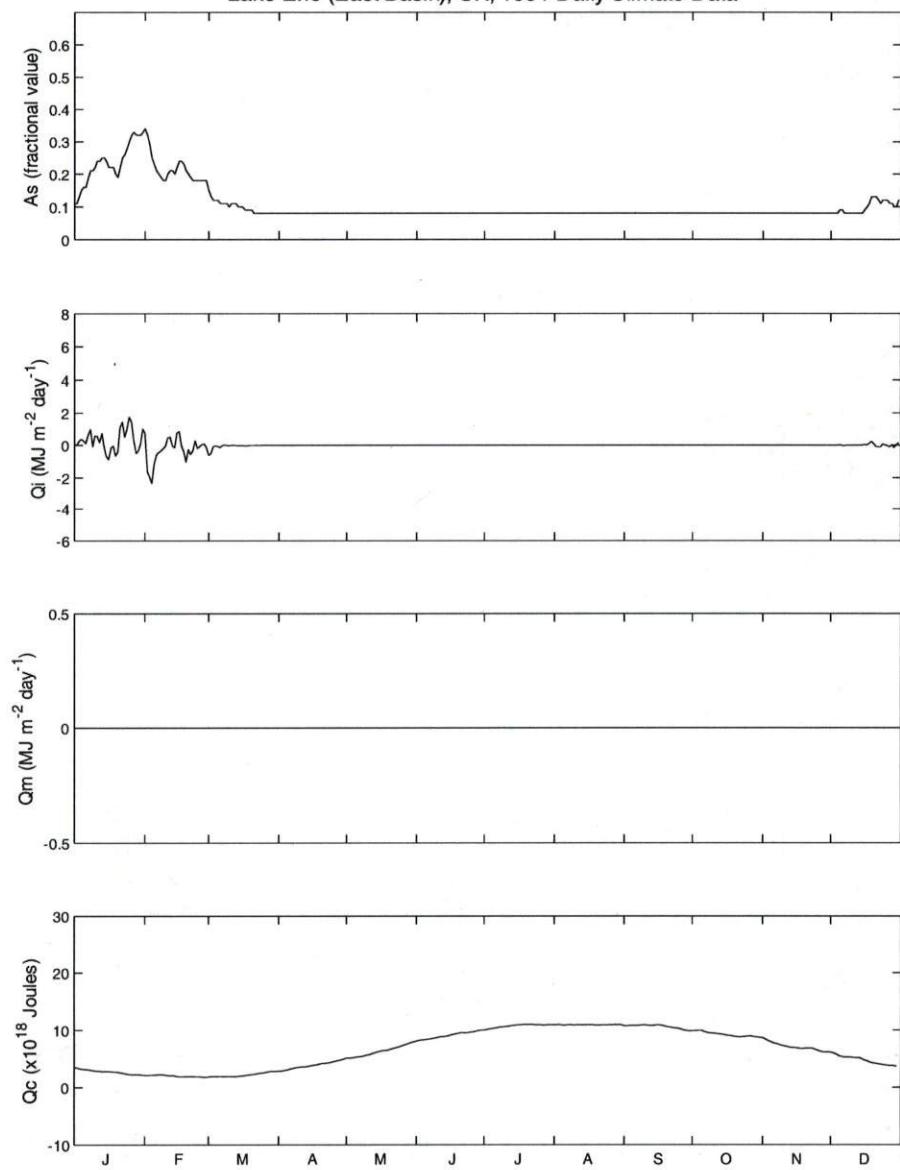
Lake Erie (East Basin), ON, 1989 Daily Climate Data



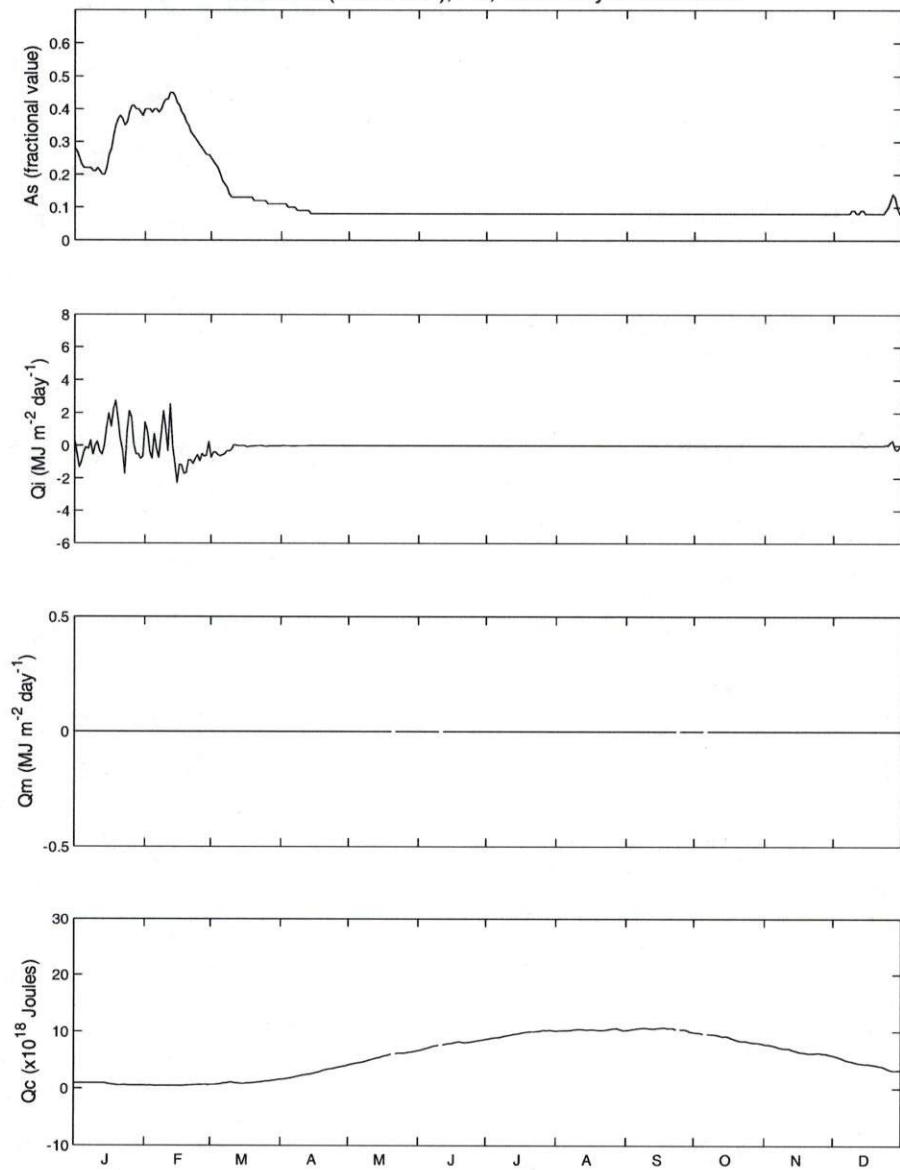
Lake Erie (East Basin), ON, 1990 Daily Climate Data



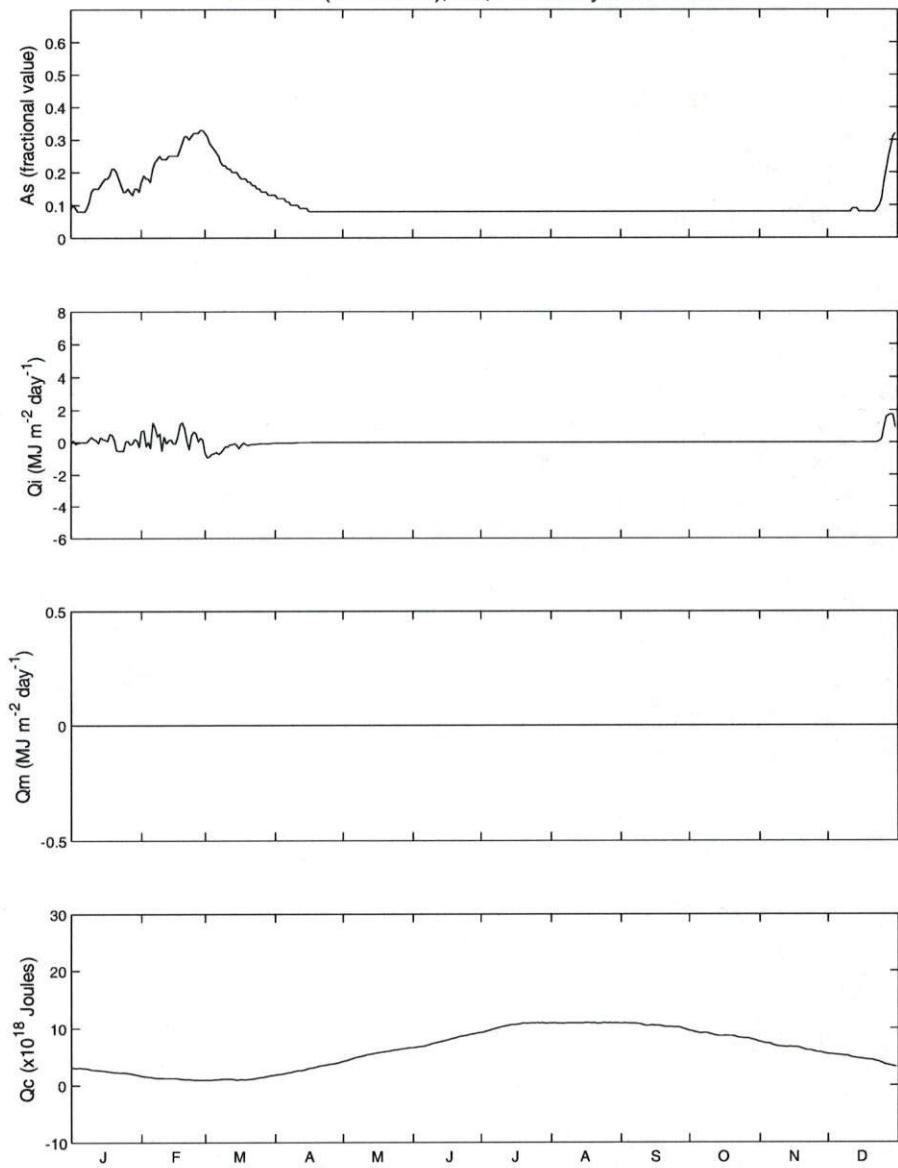
Lake Erie (East Basin), ON, 1991 Daily Climate Data



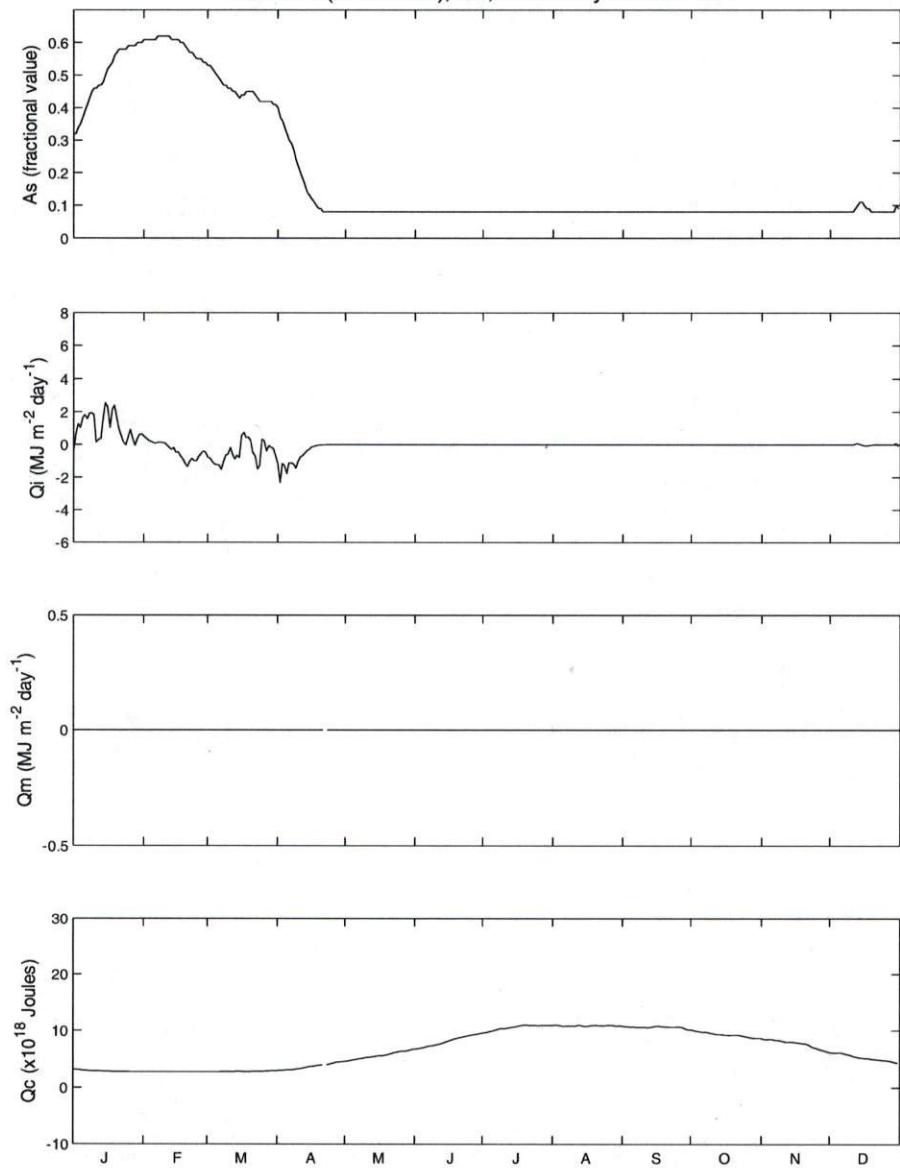
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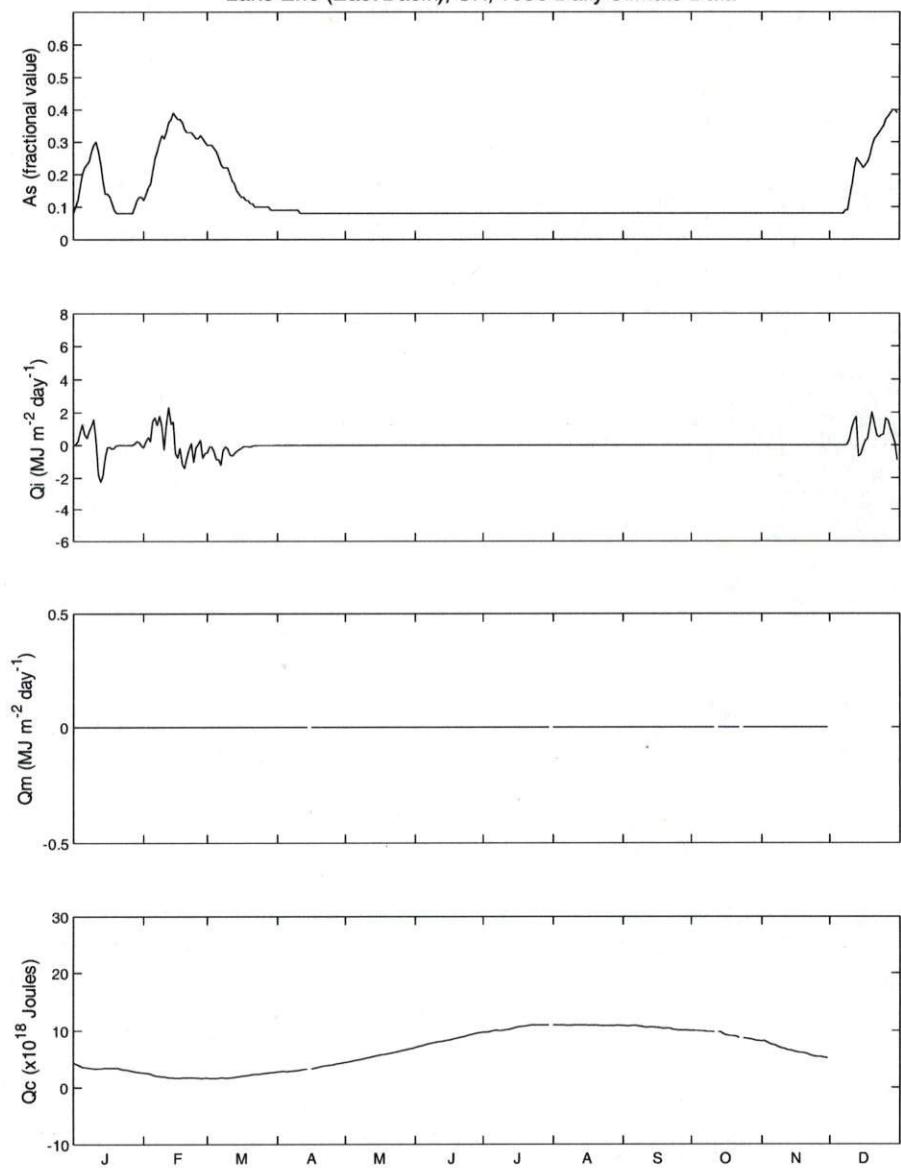
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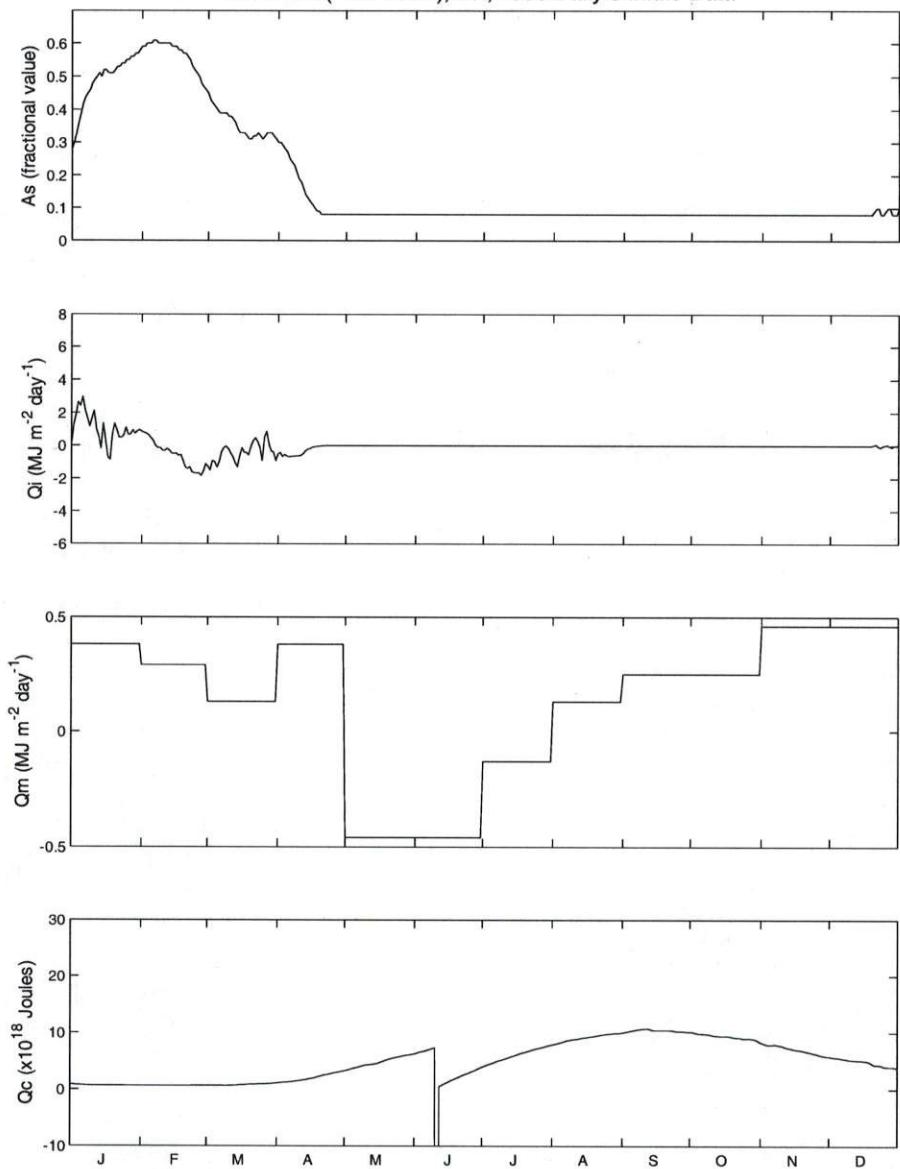
Lake Erie (East Basin), ON, 1994 Daily Climate Data



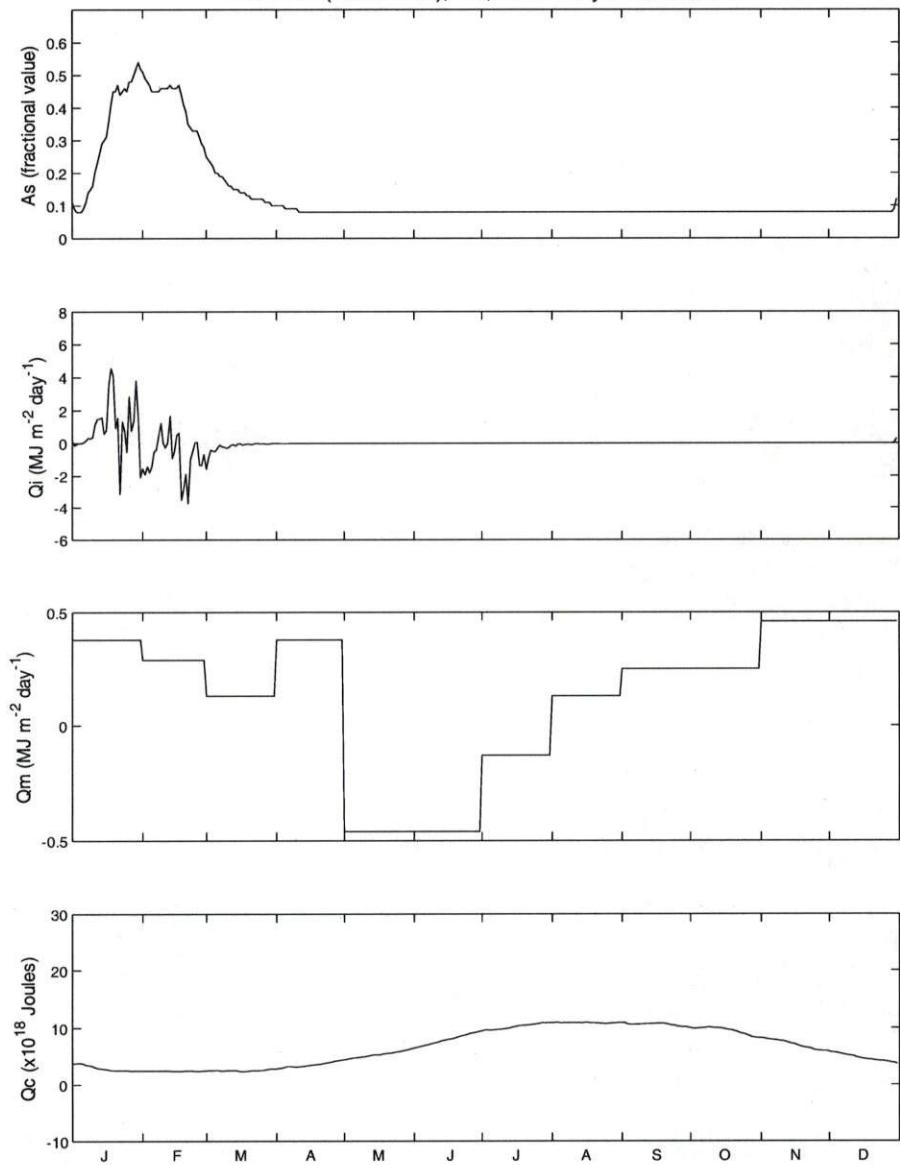
Lake Erie (East Basin), ON, 1995 Daily Climate Data



Lake Erie (East Basin), ON, 1996 Daily Climate Data

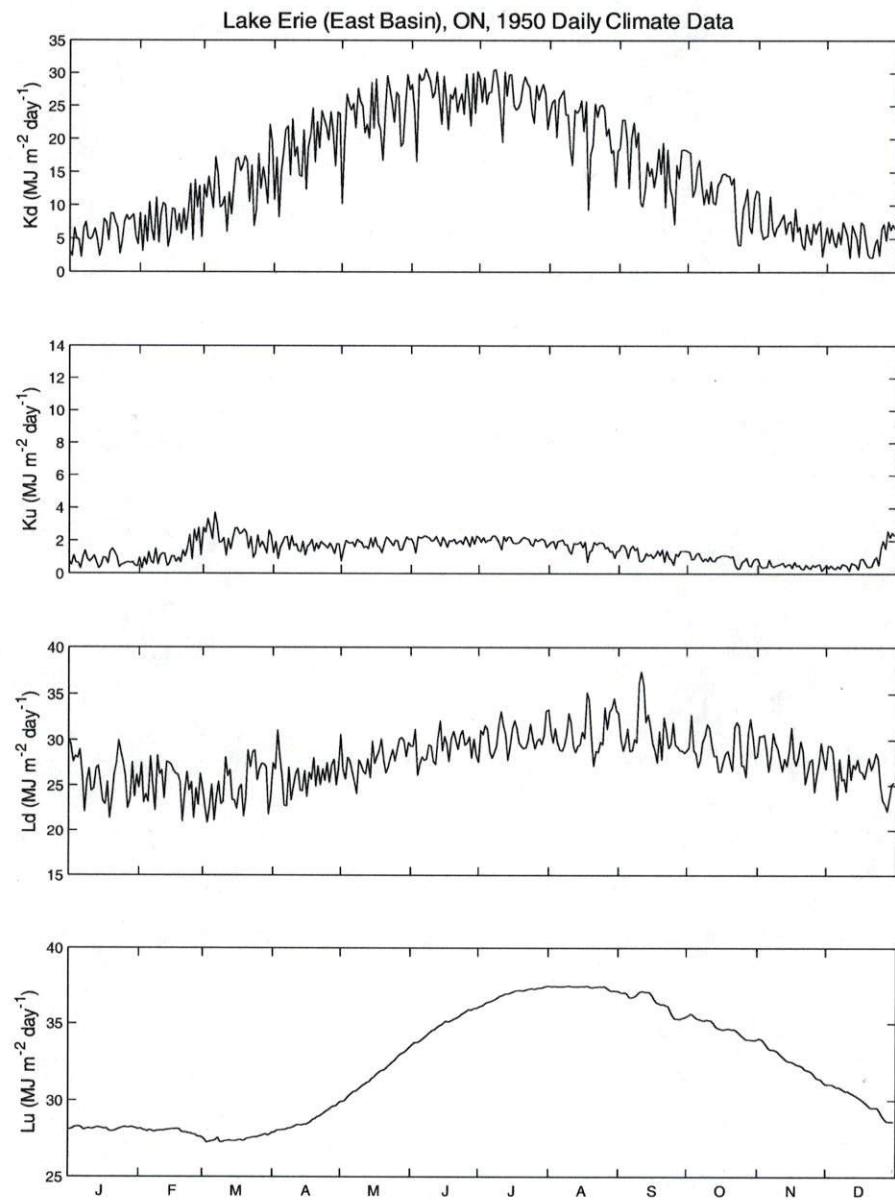


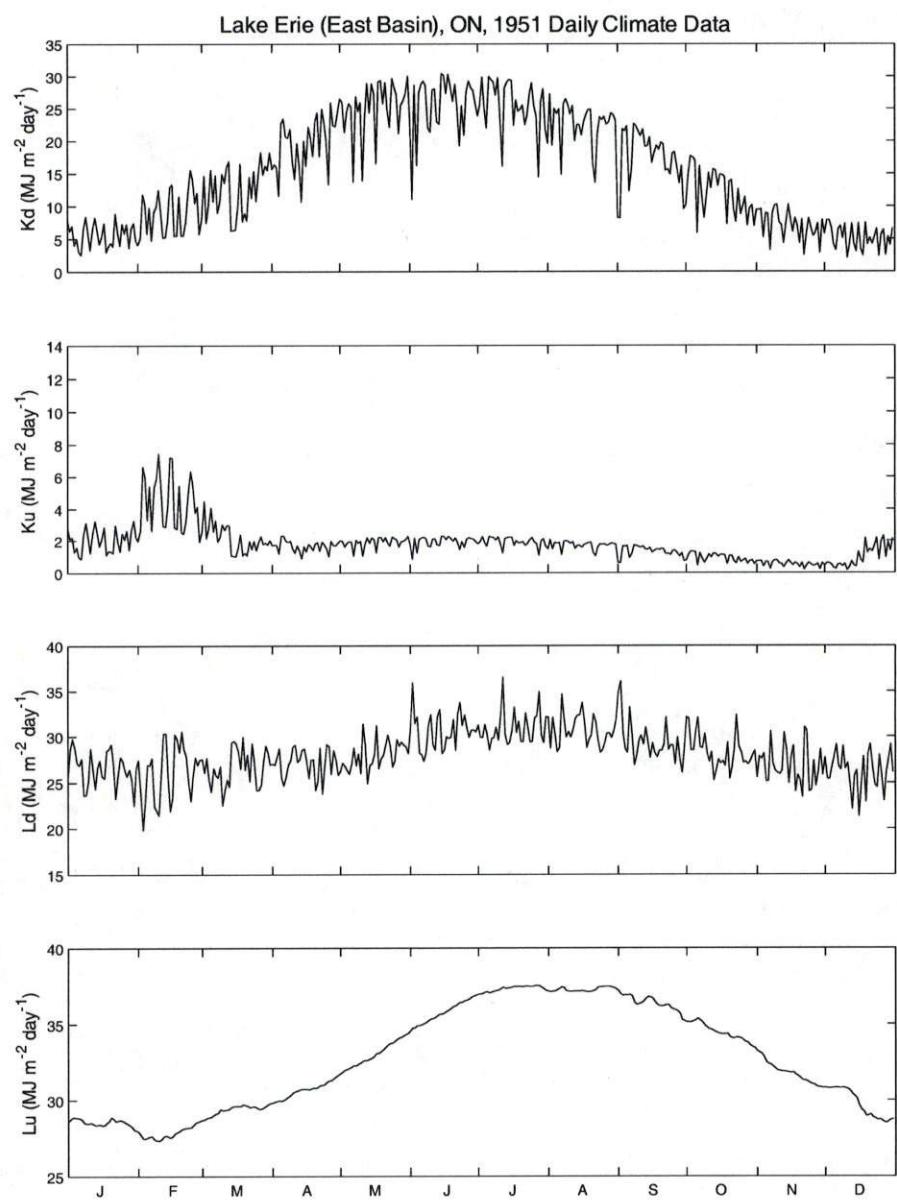
Lake Erie (East Basin), ON, 1997 Daily Climate Data

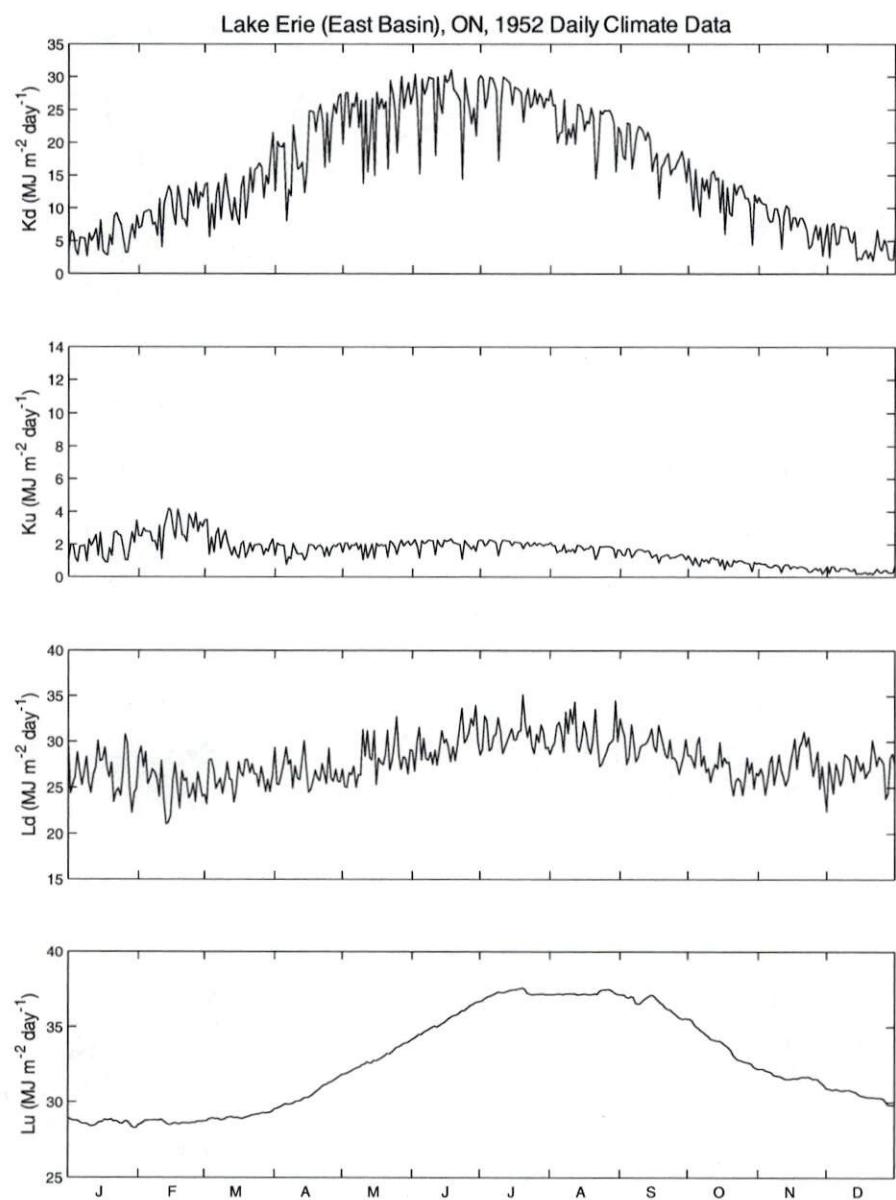


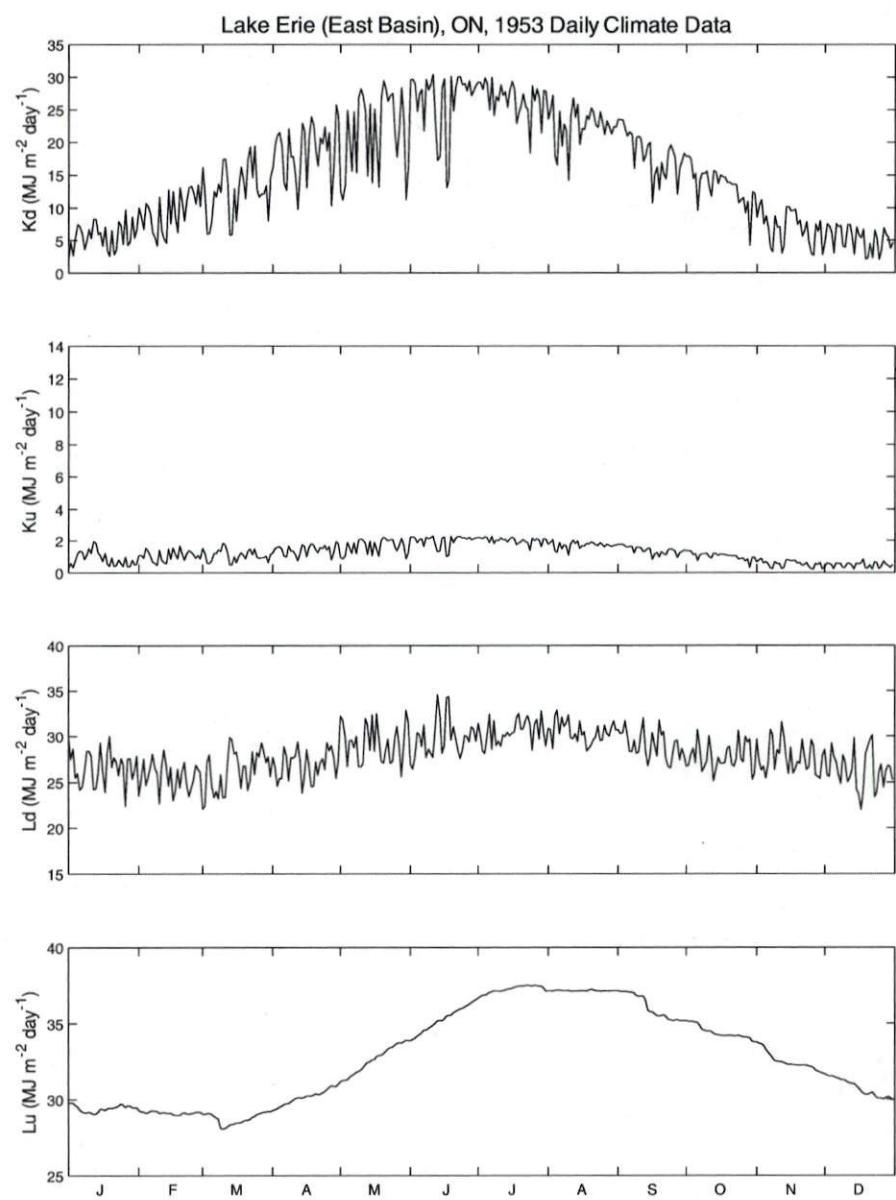
Appendix 4

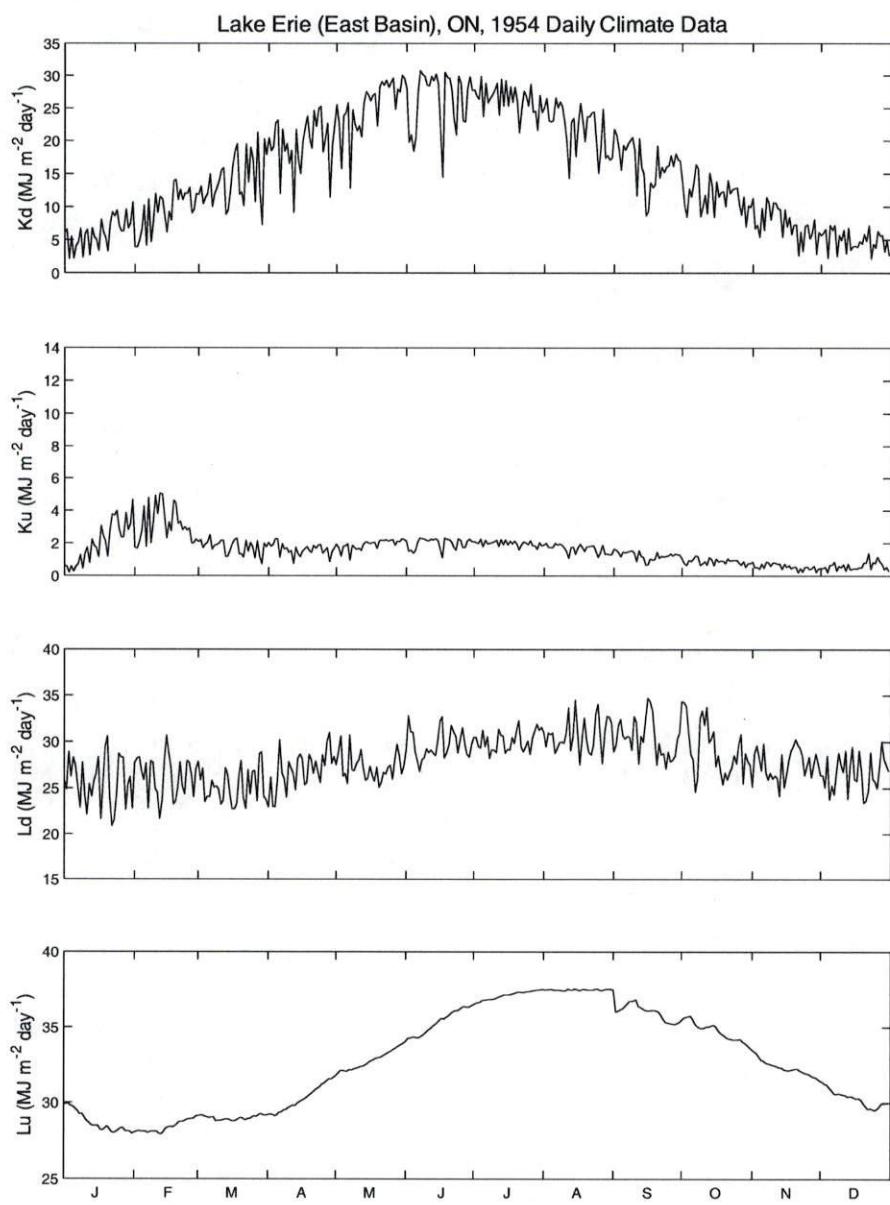
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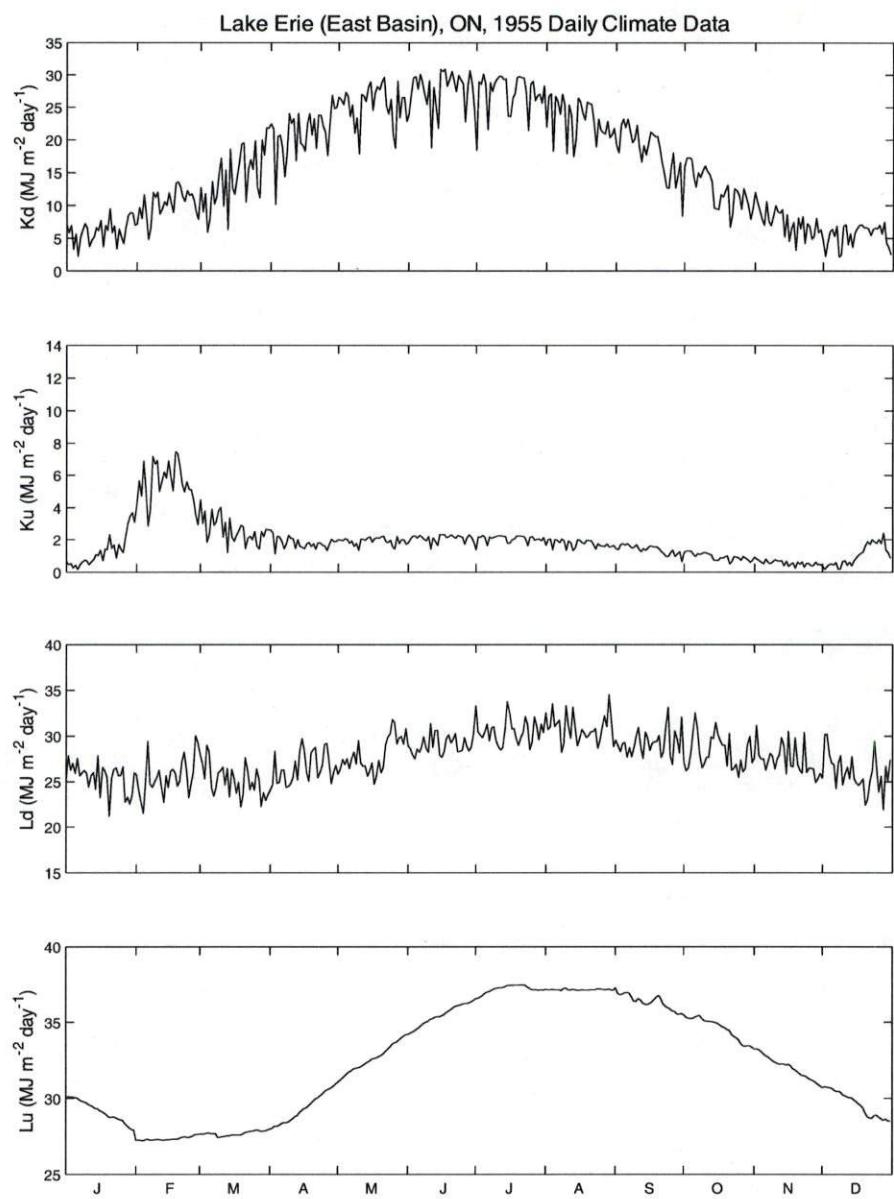


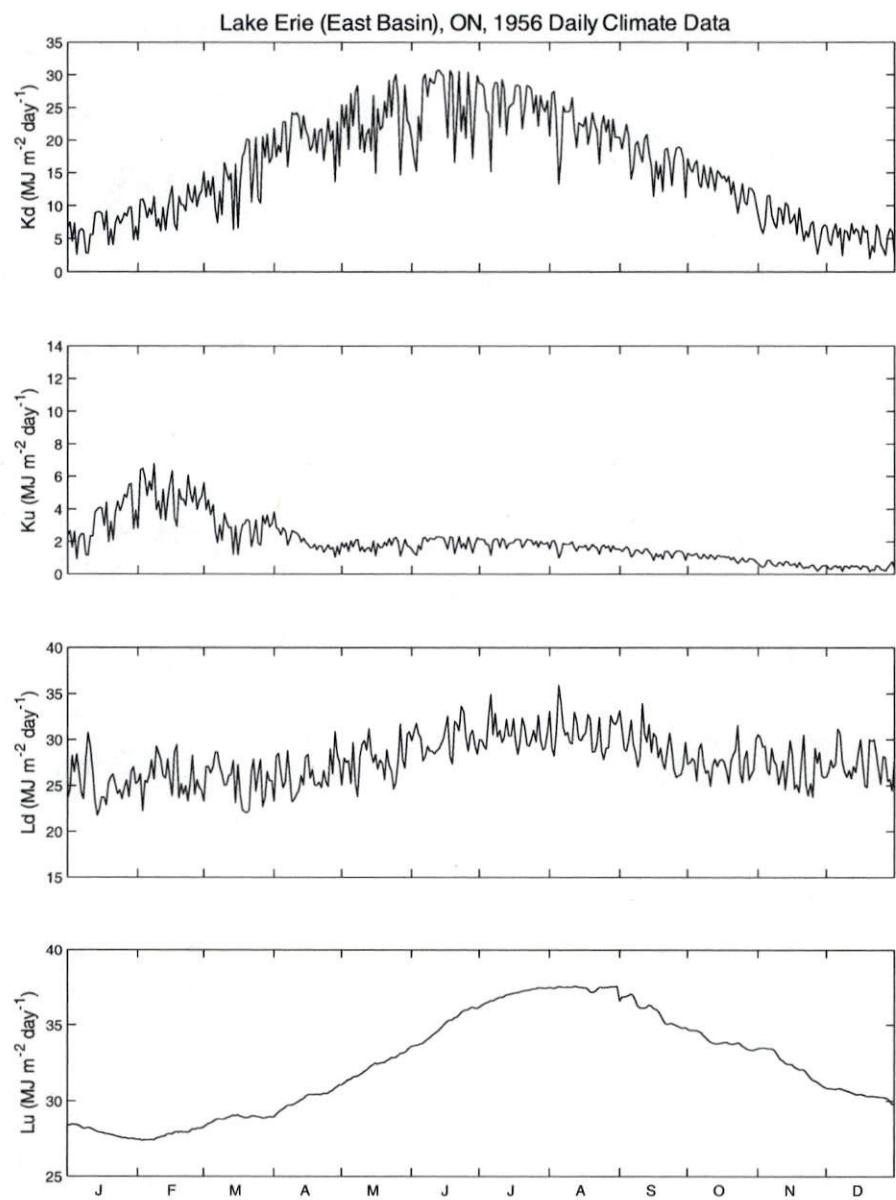


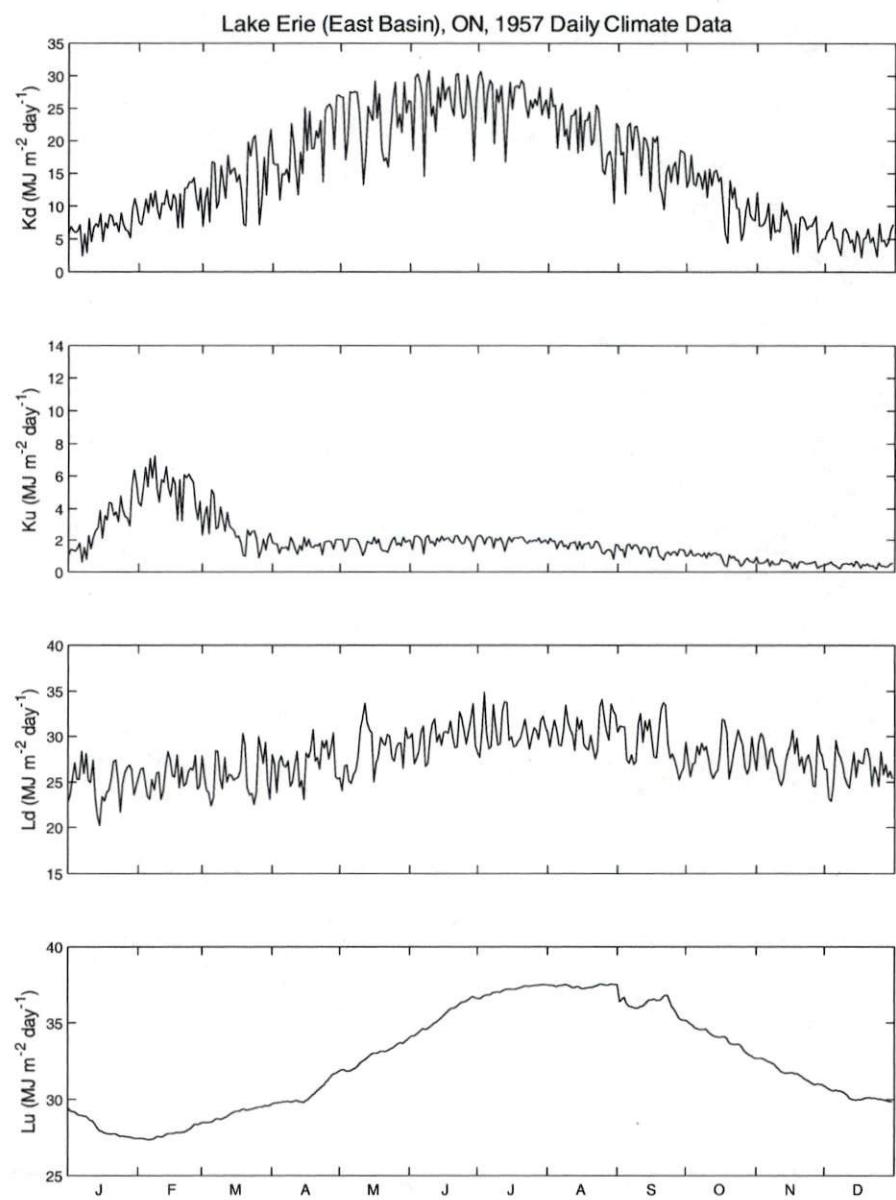


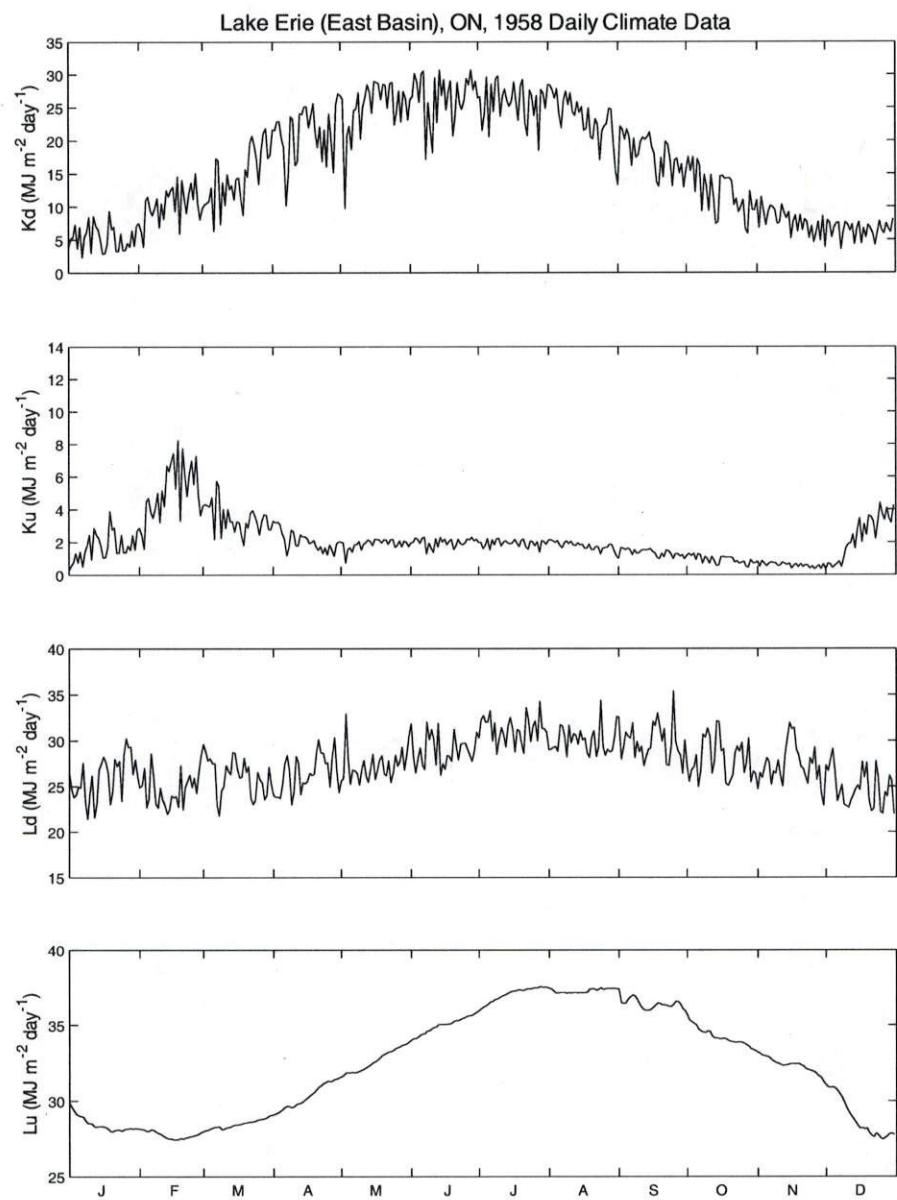


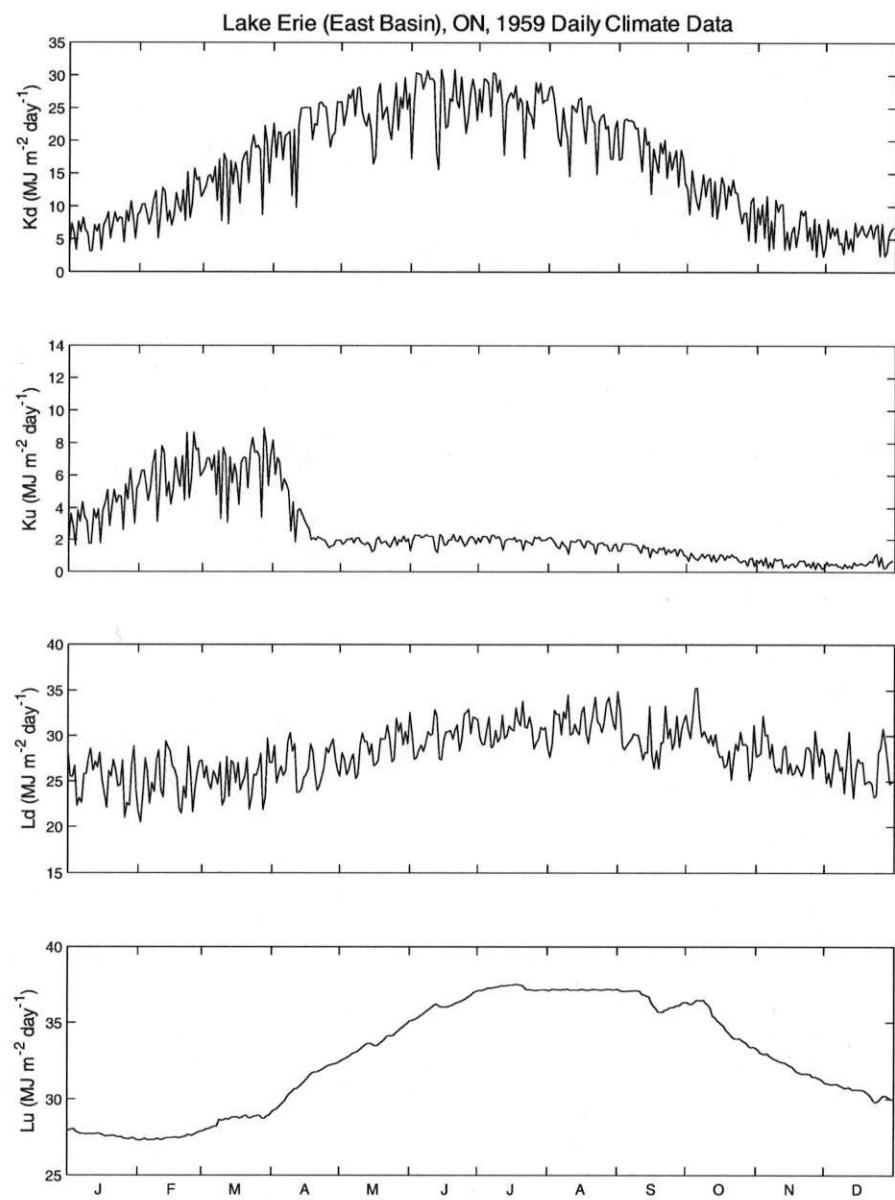


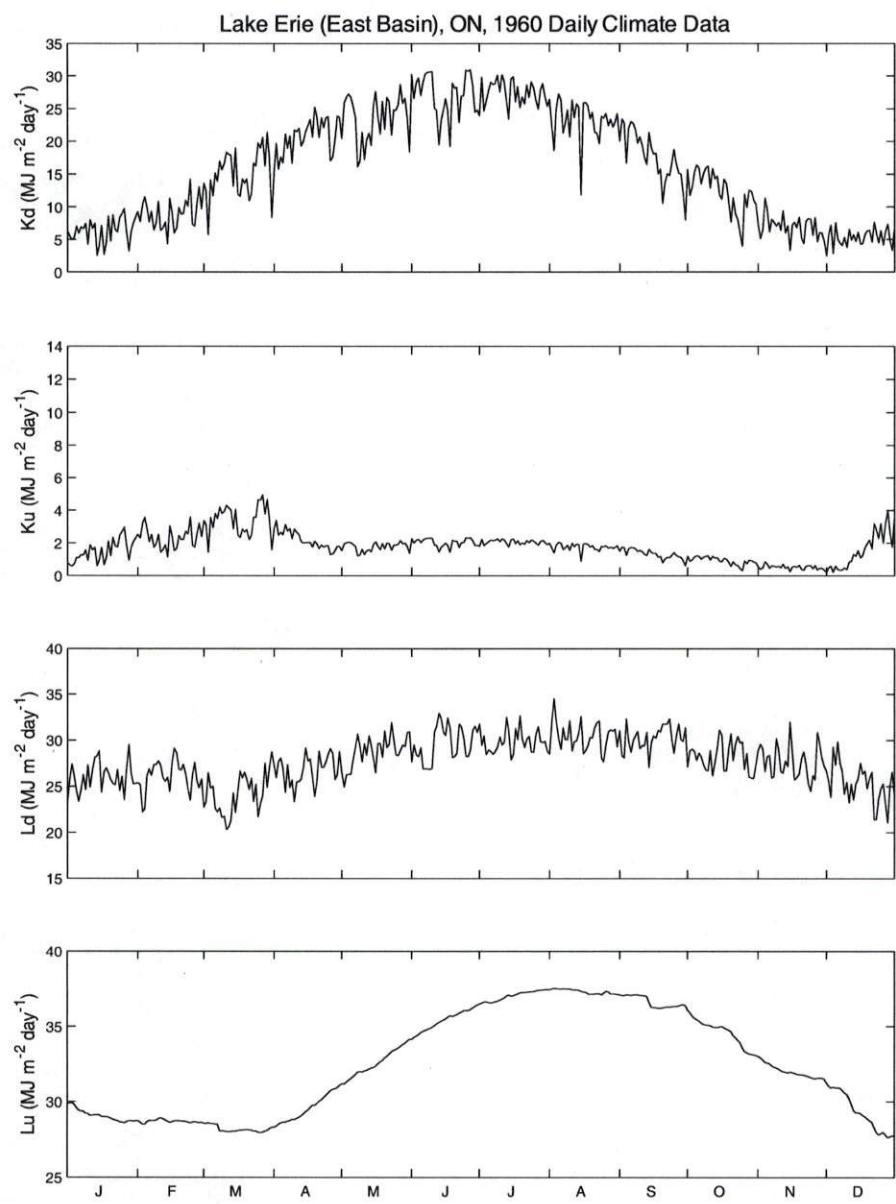


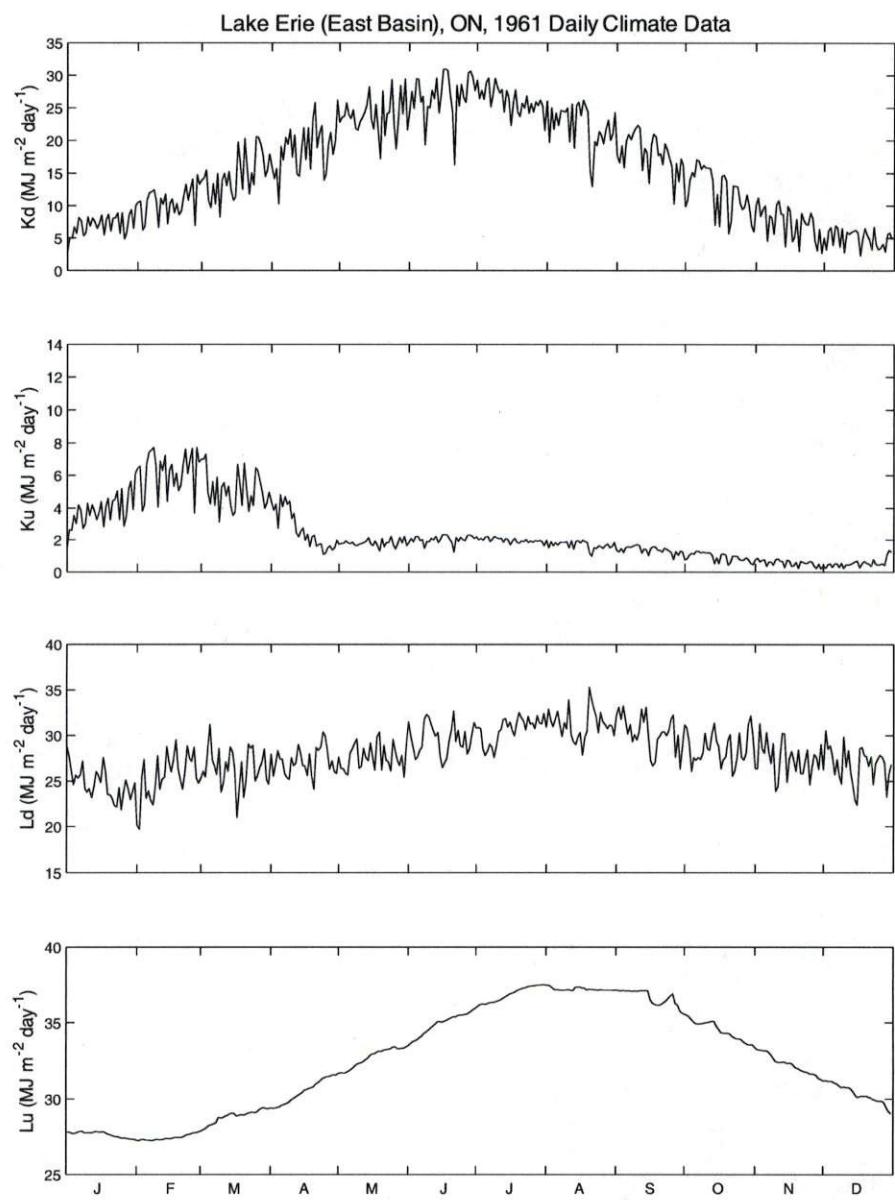


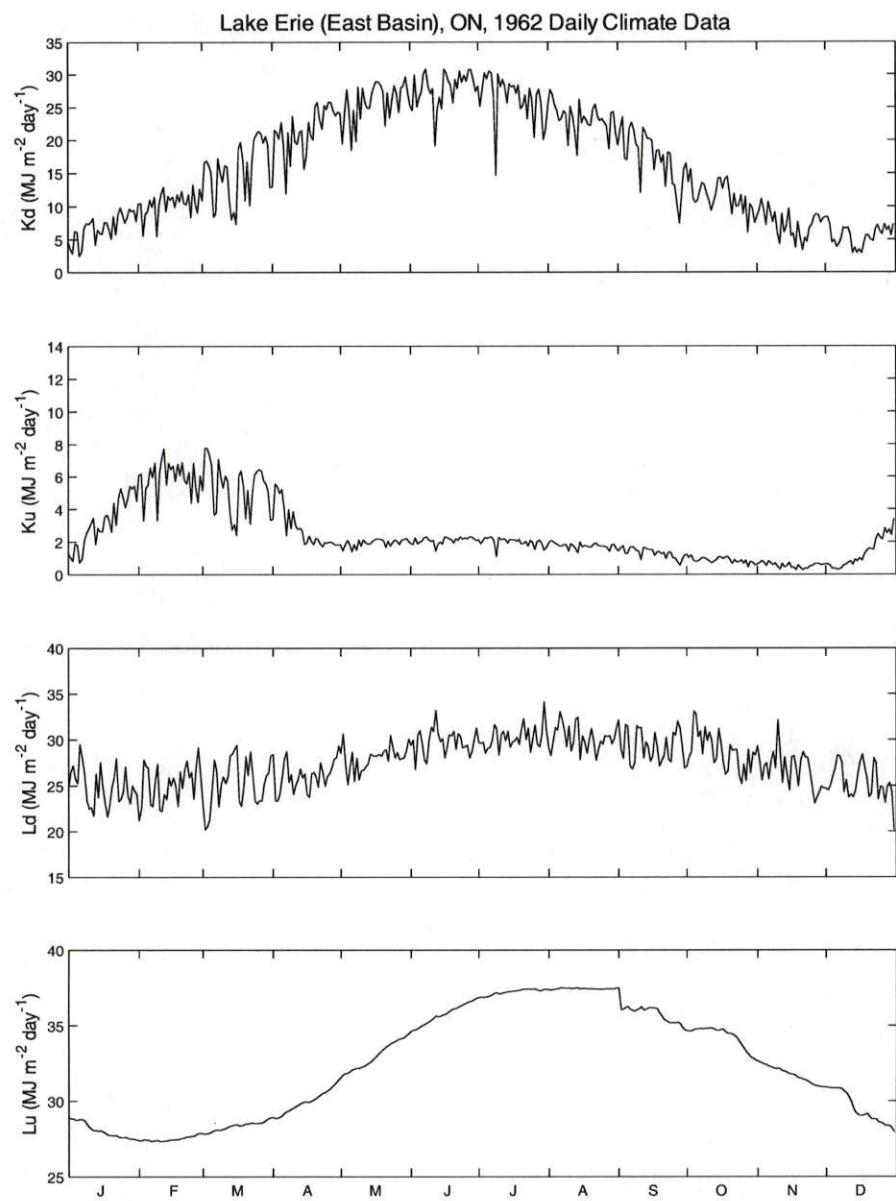


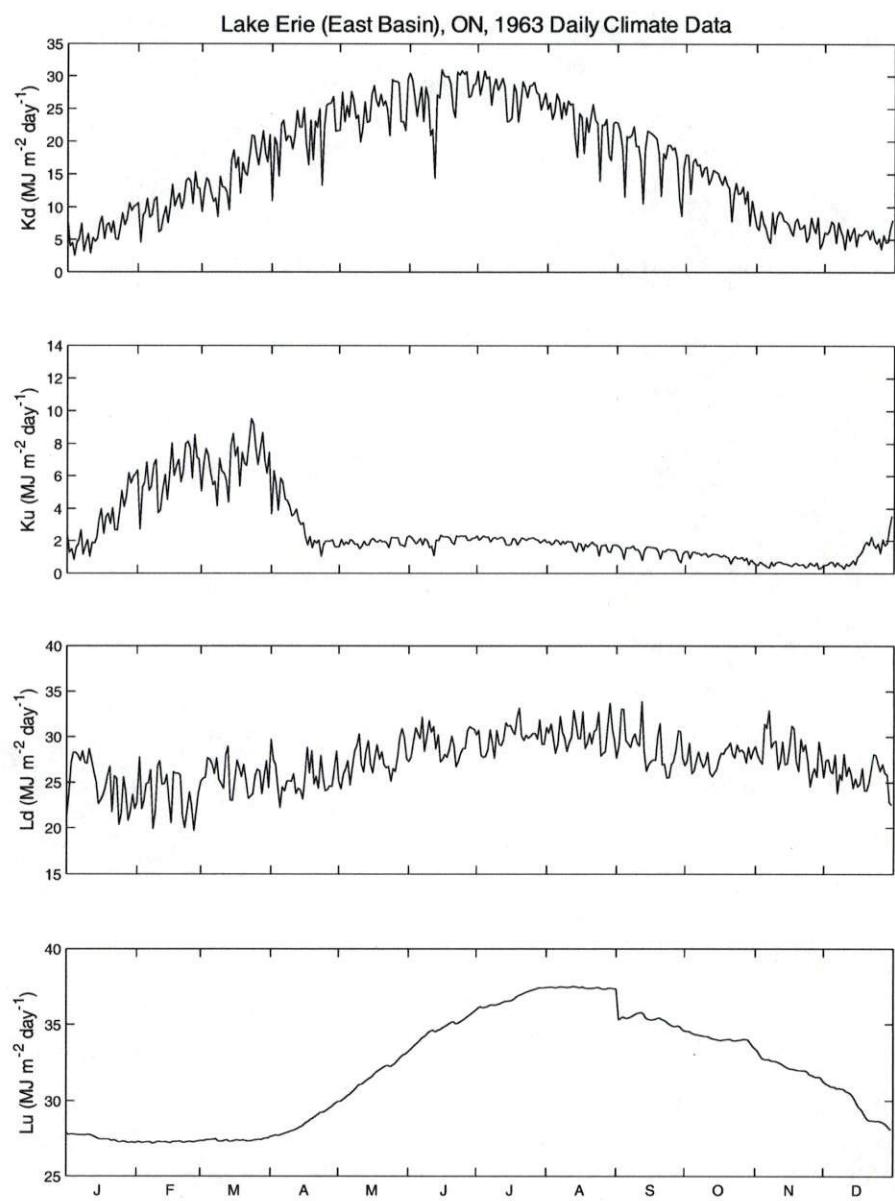


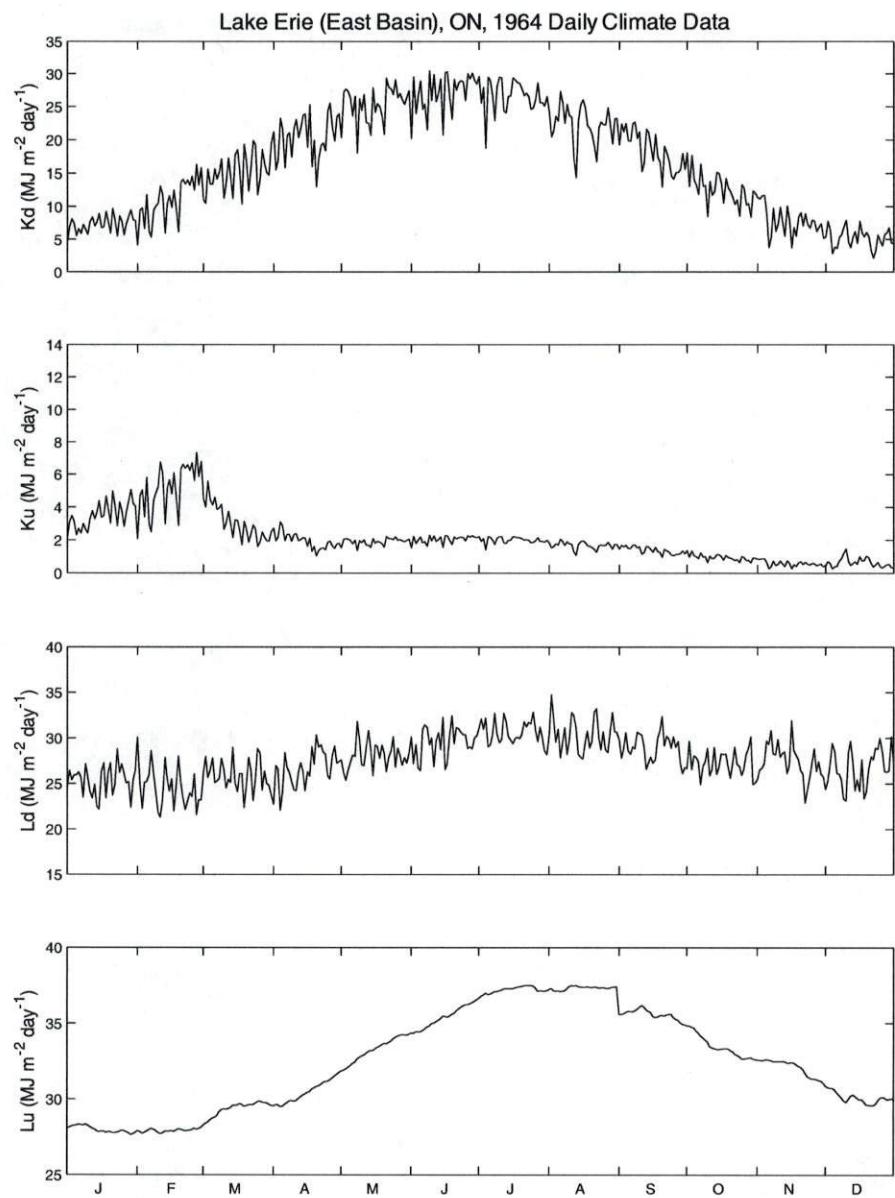


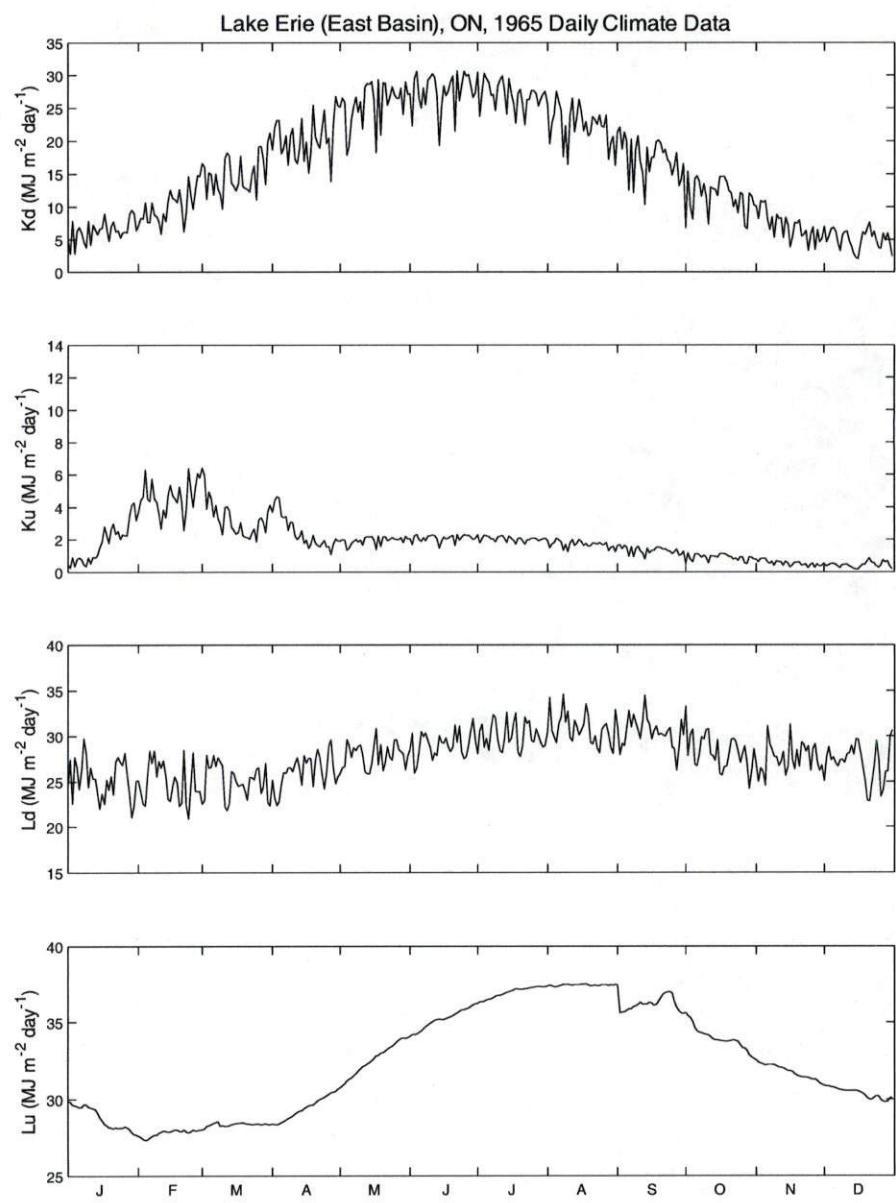


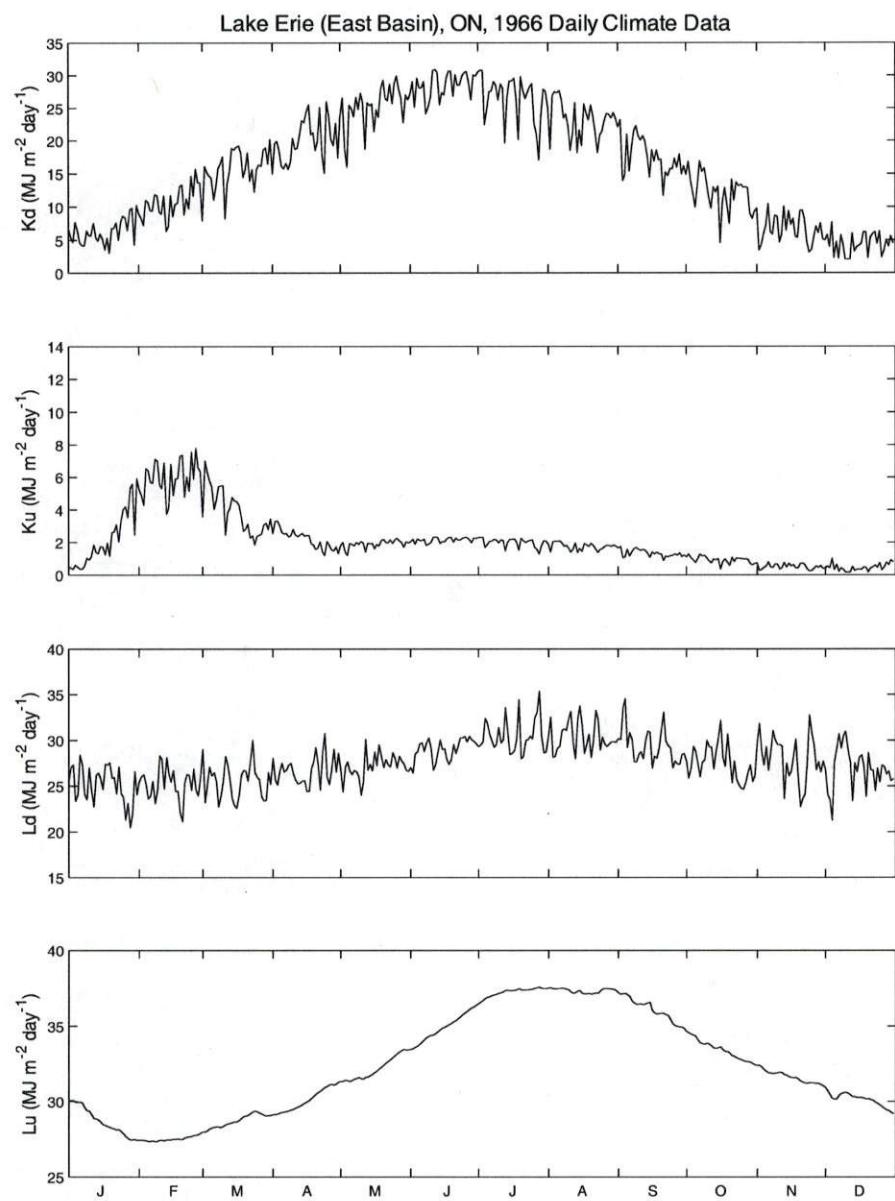


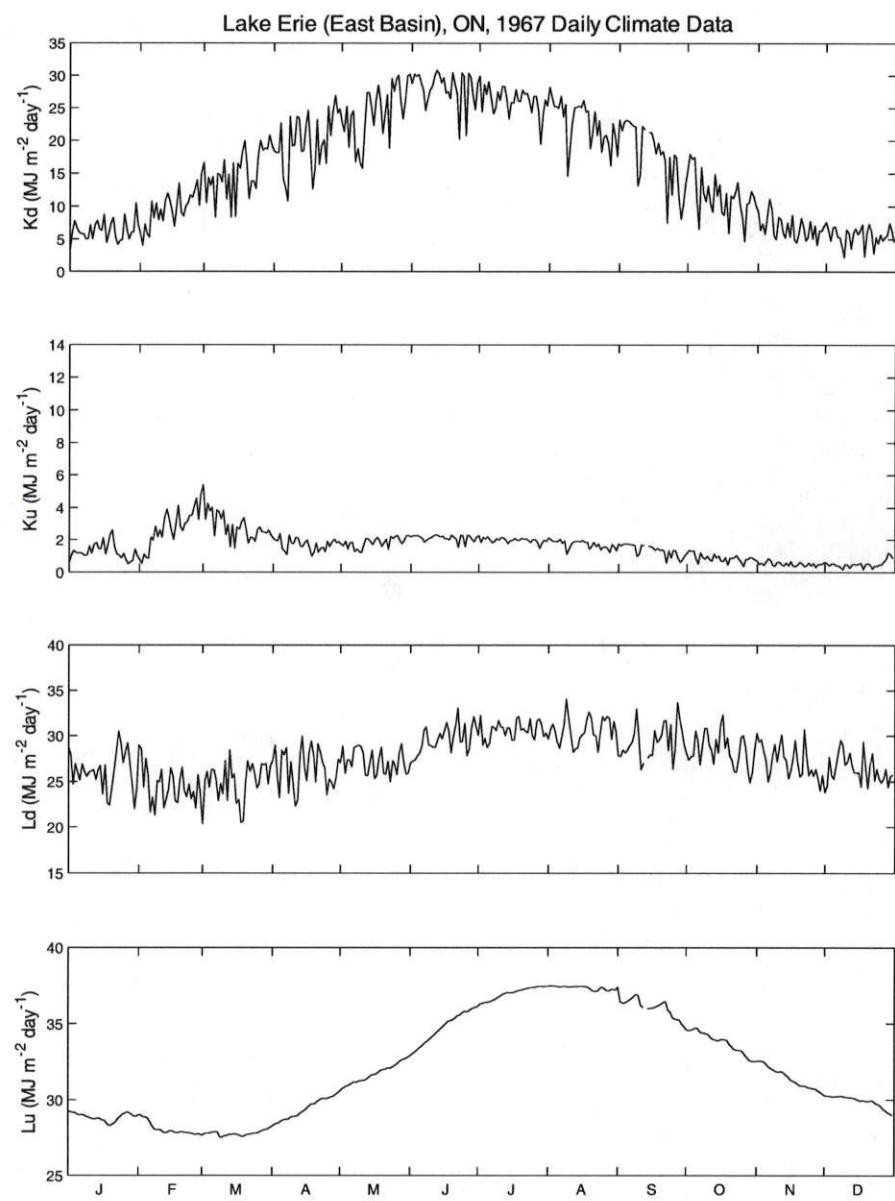


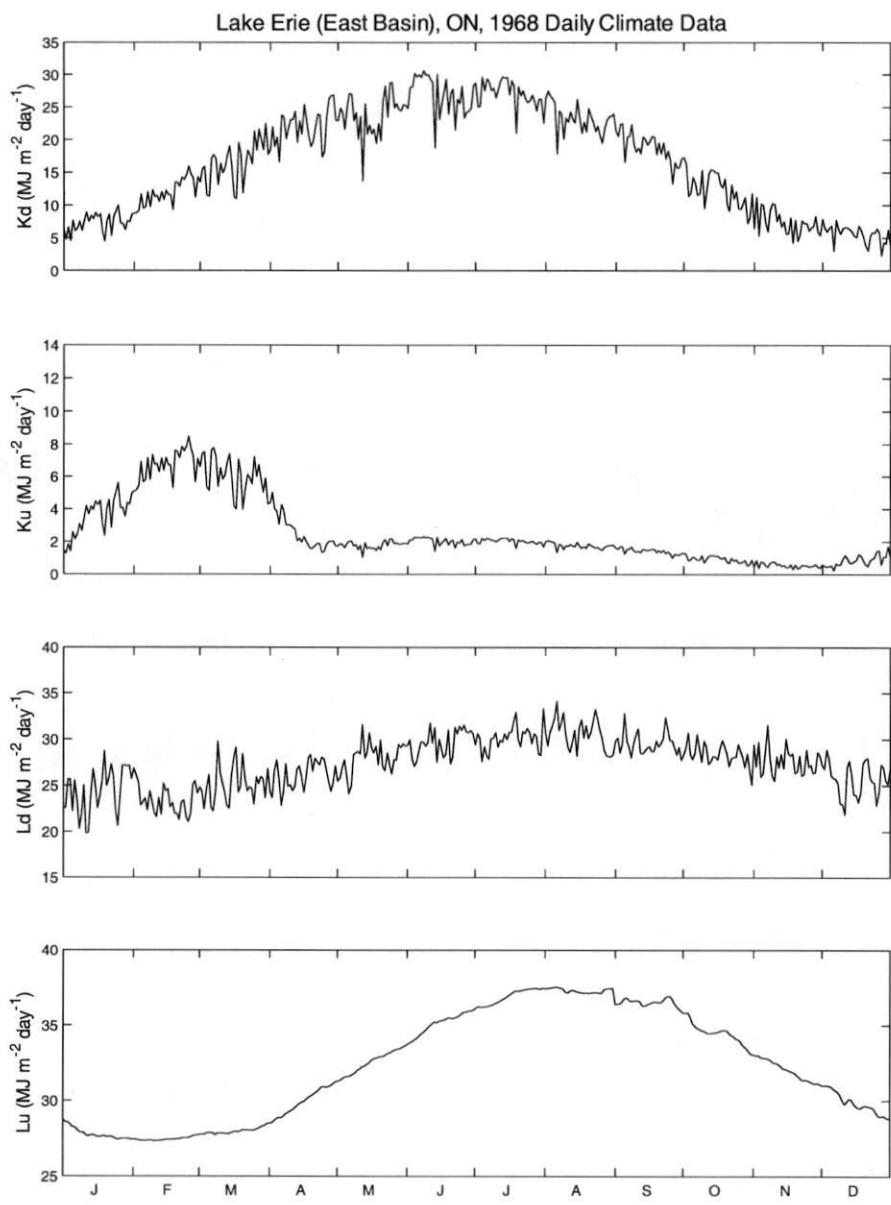


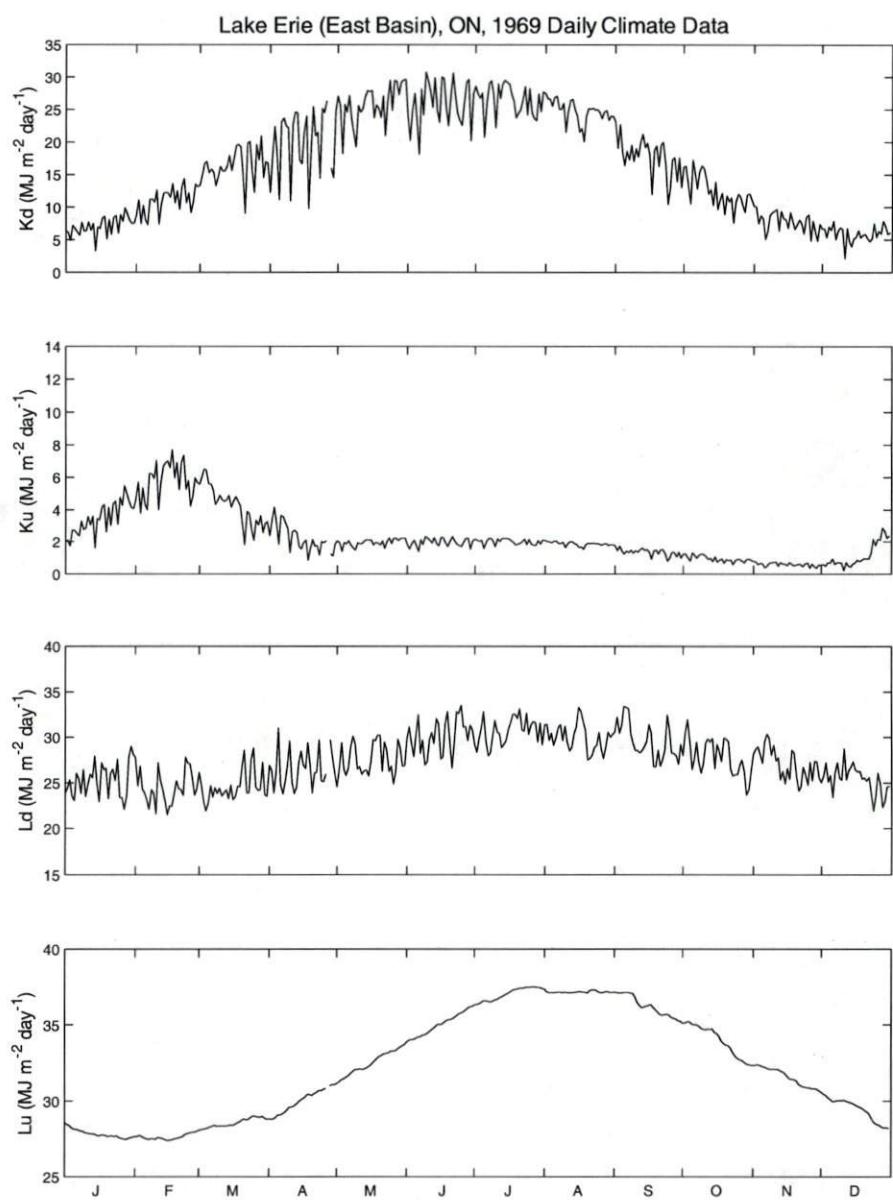


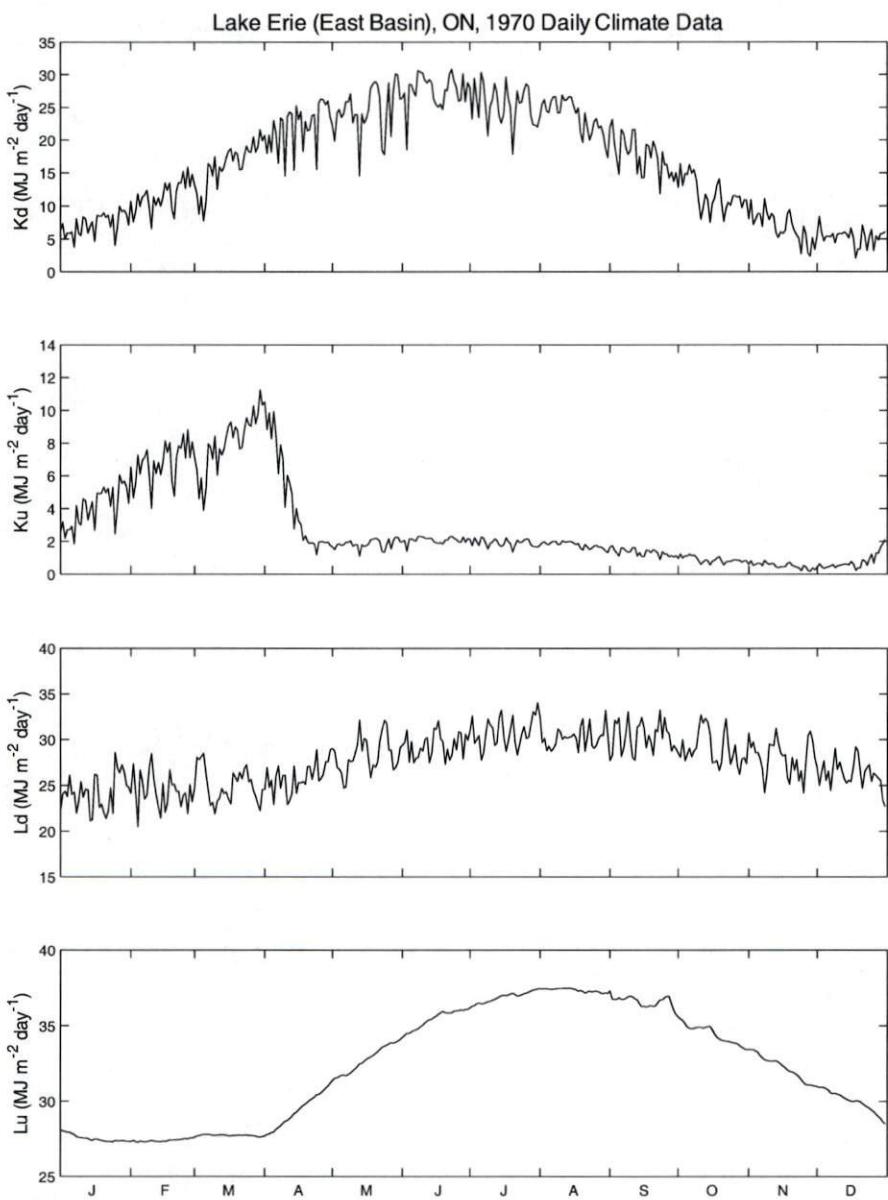




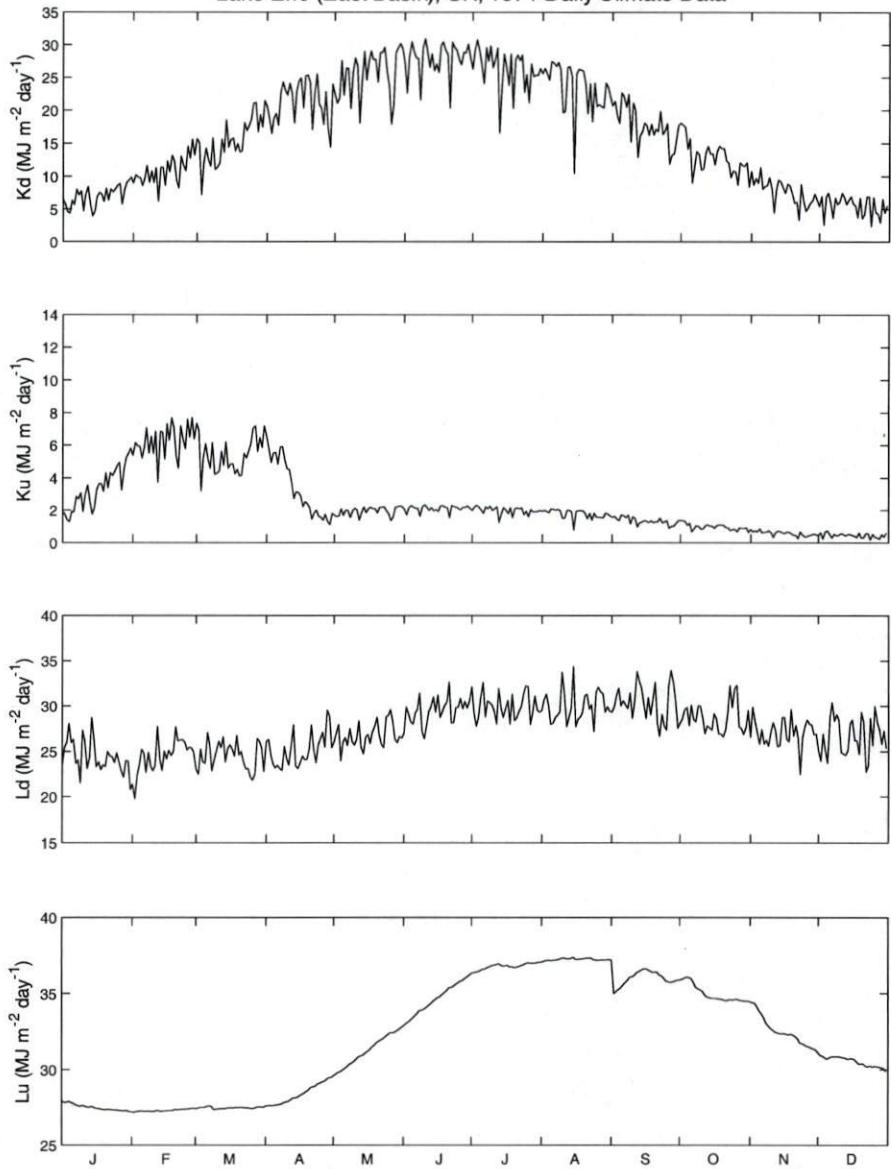


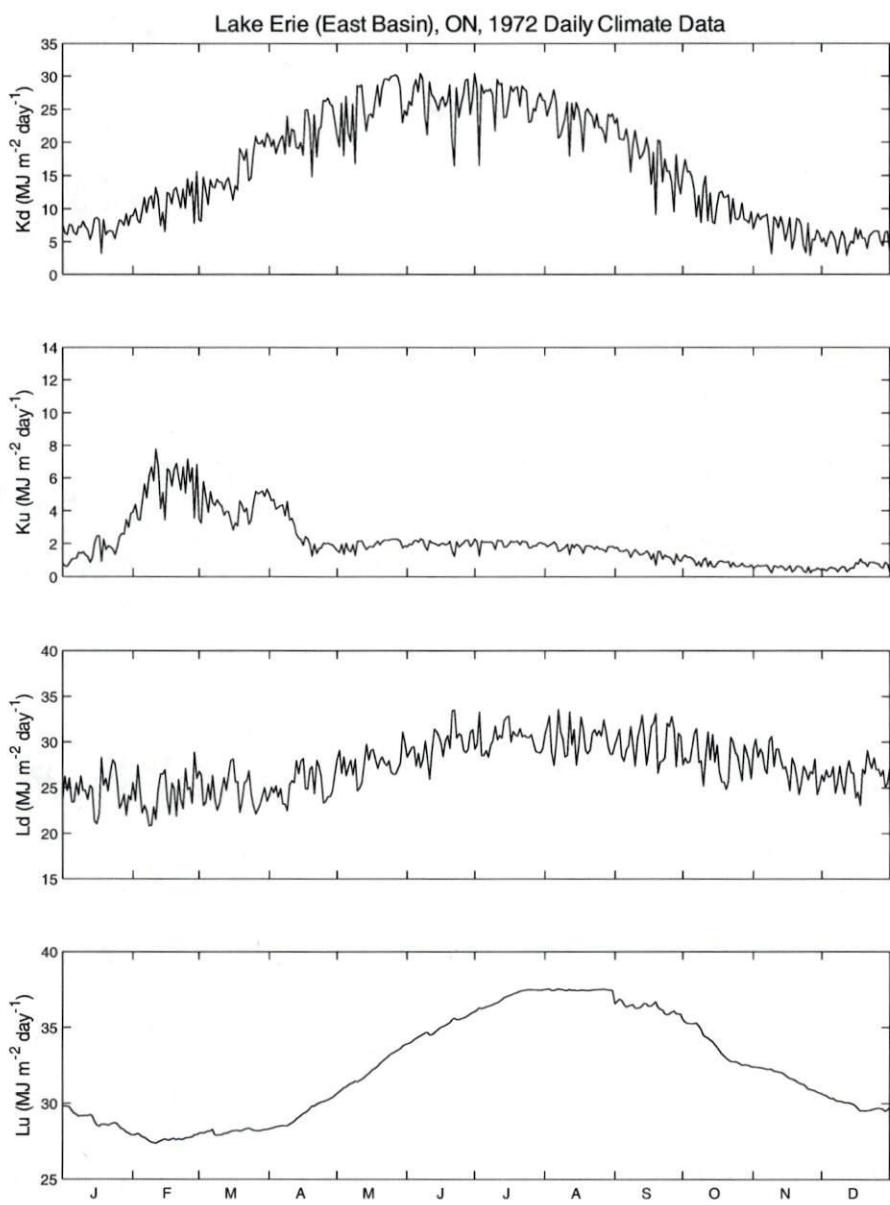




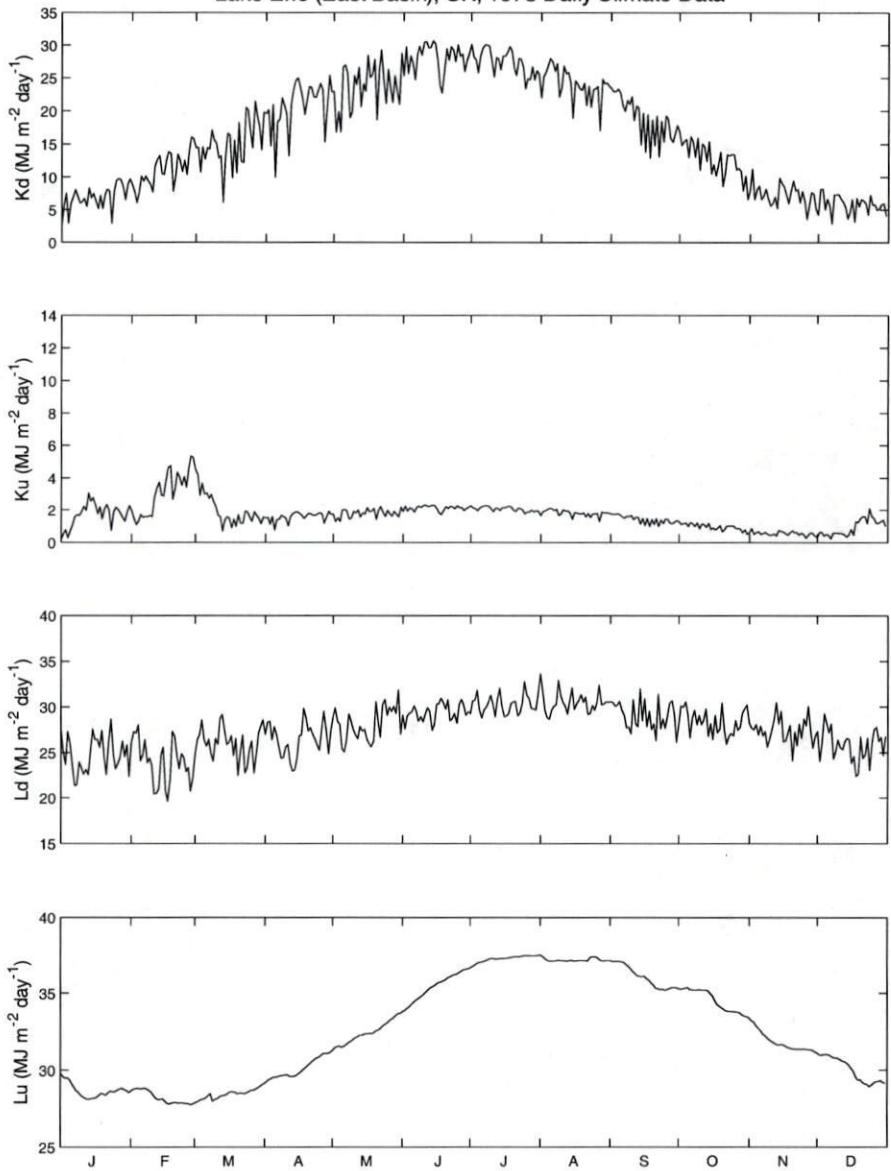


Lake Erie (East Basin), ON, 1971 Daily Climate Data

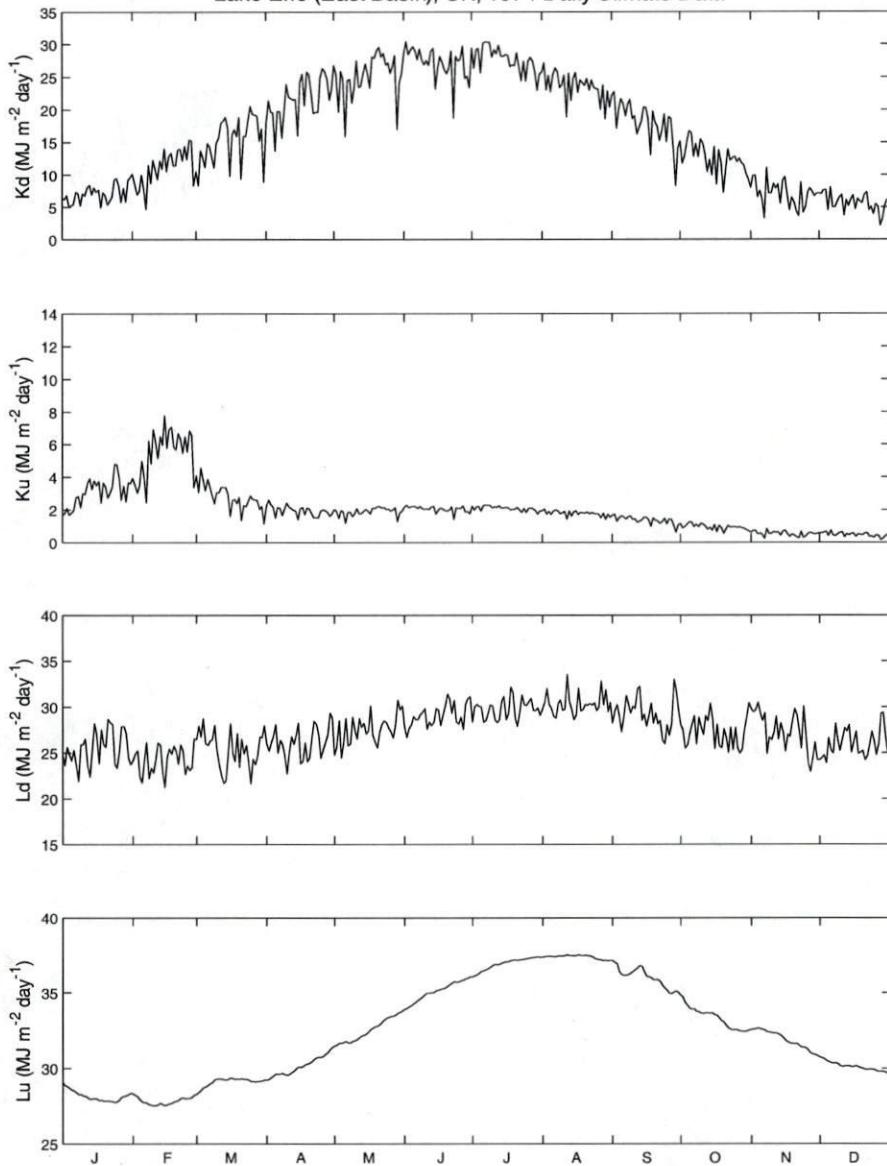


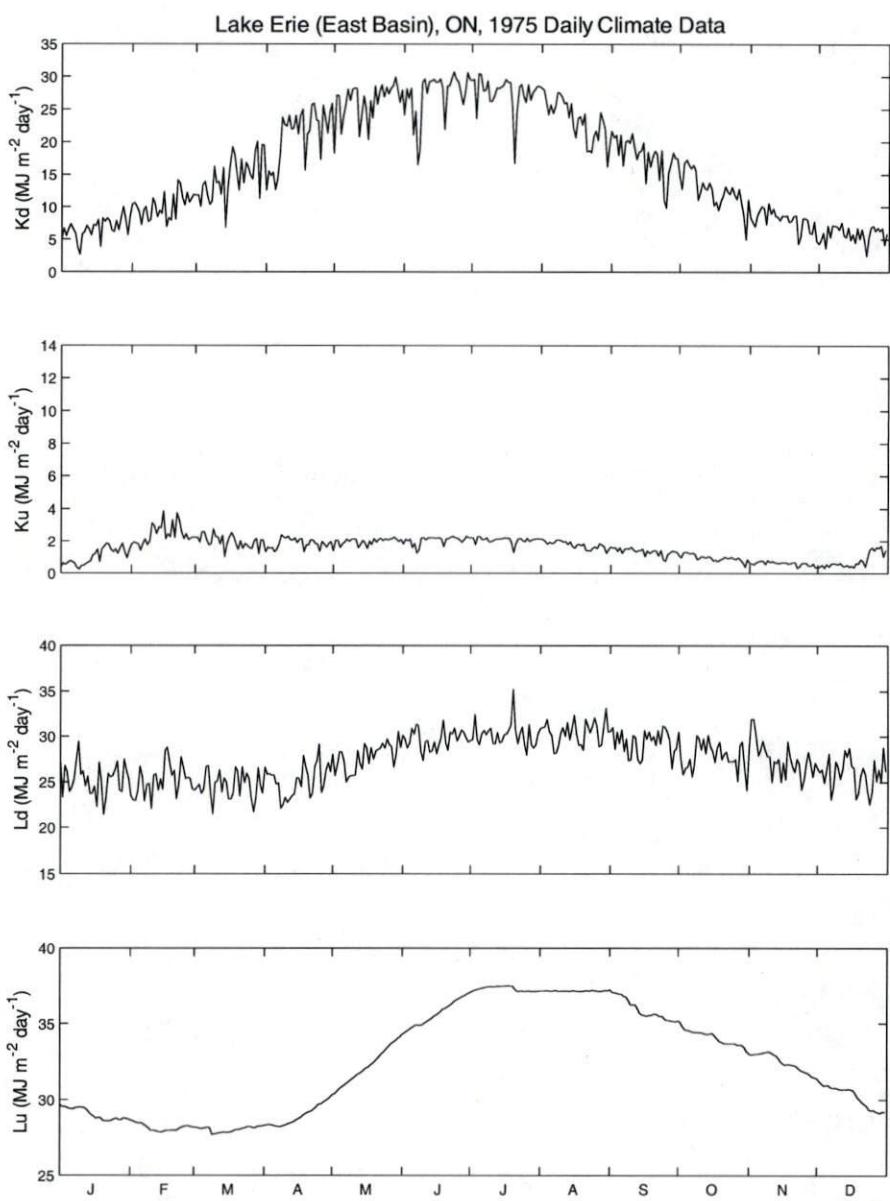


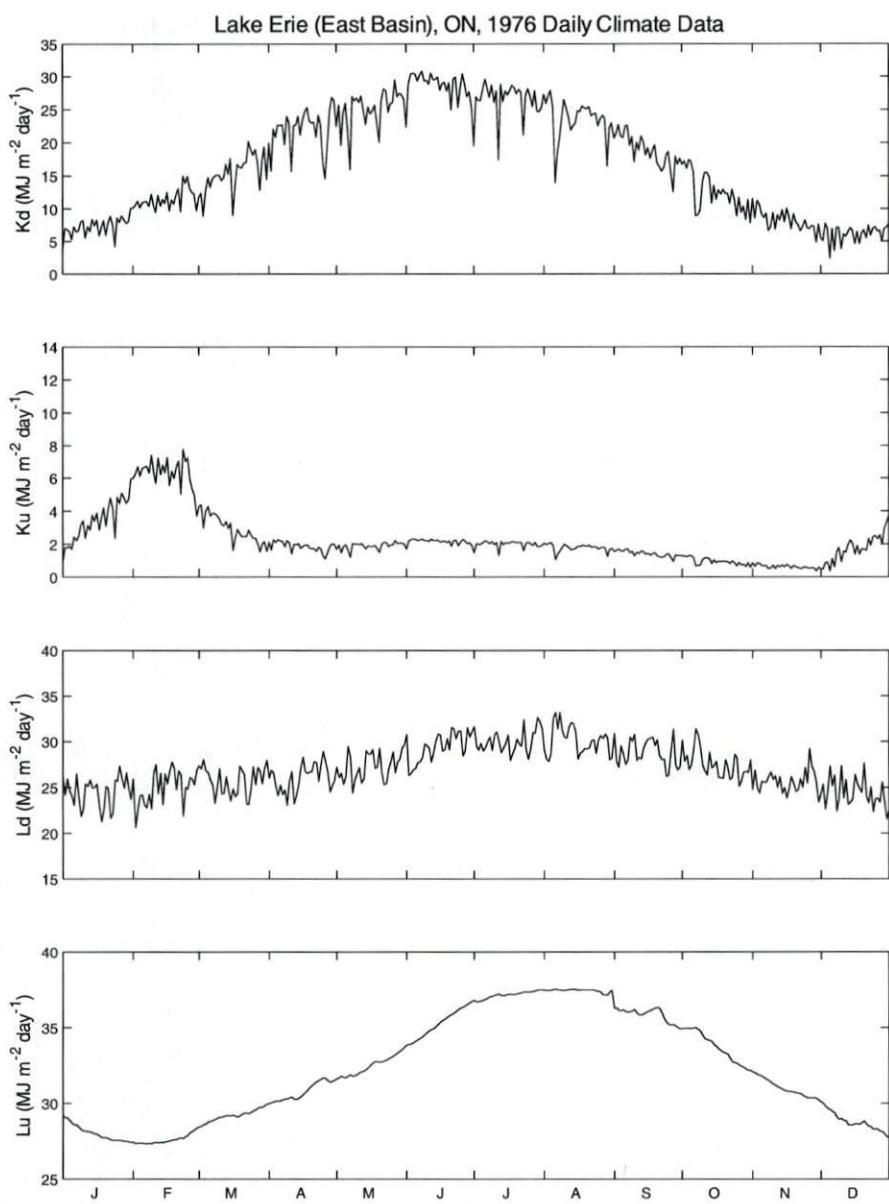
Lake Erie (East Basin), ON, 1973 Daily Climate Data

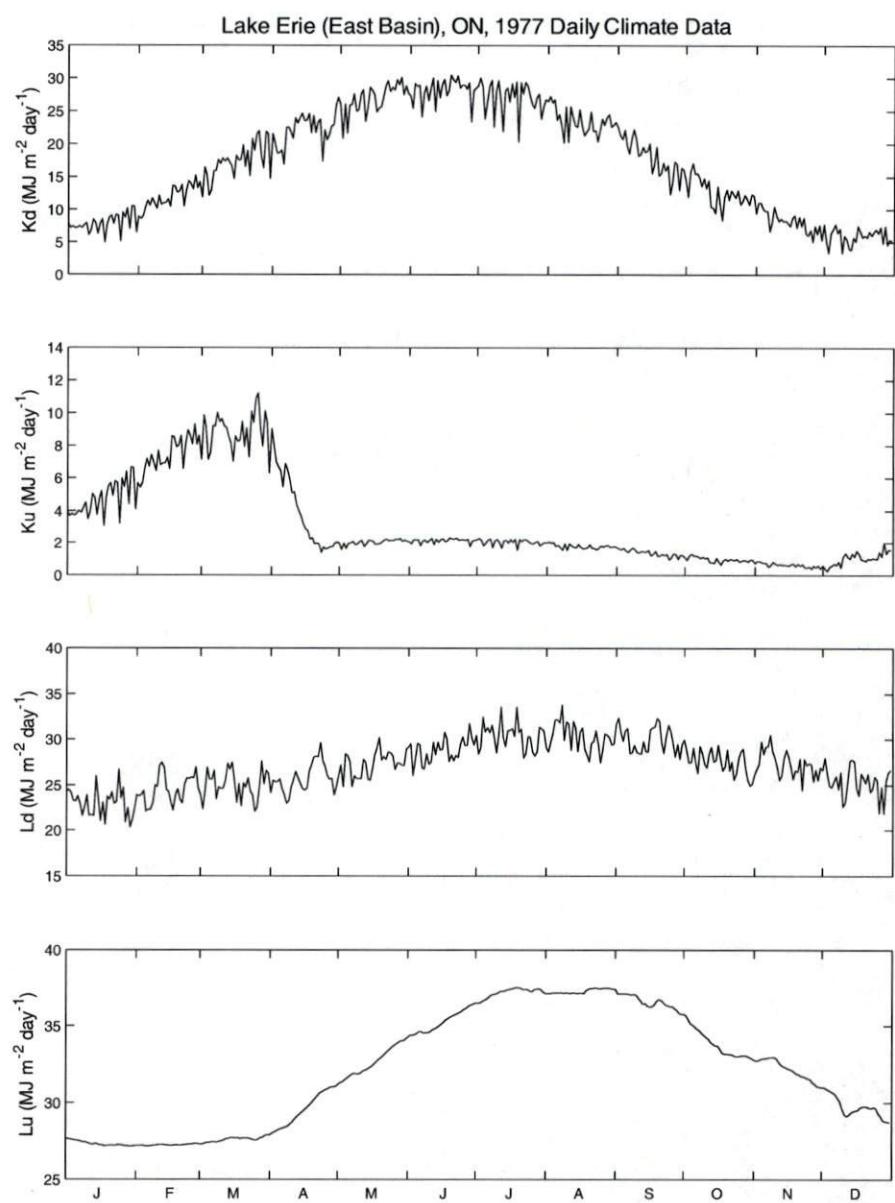


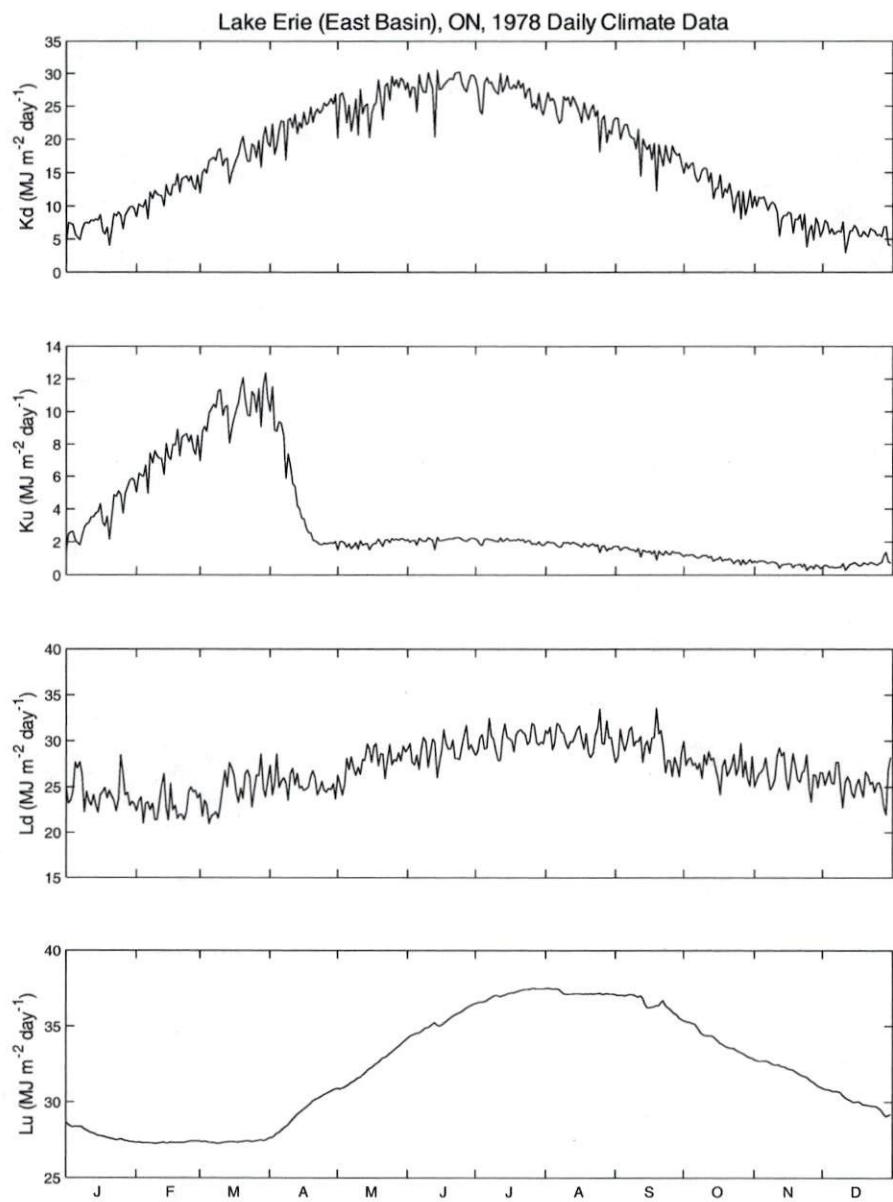
Lake Erie (East Basin), ON, 1974 Daily Climate Data

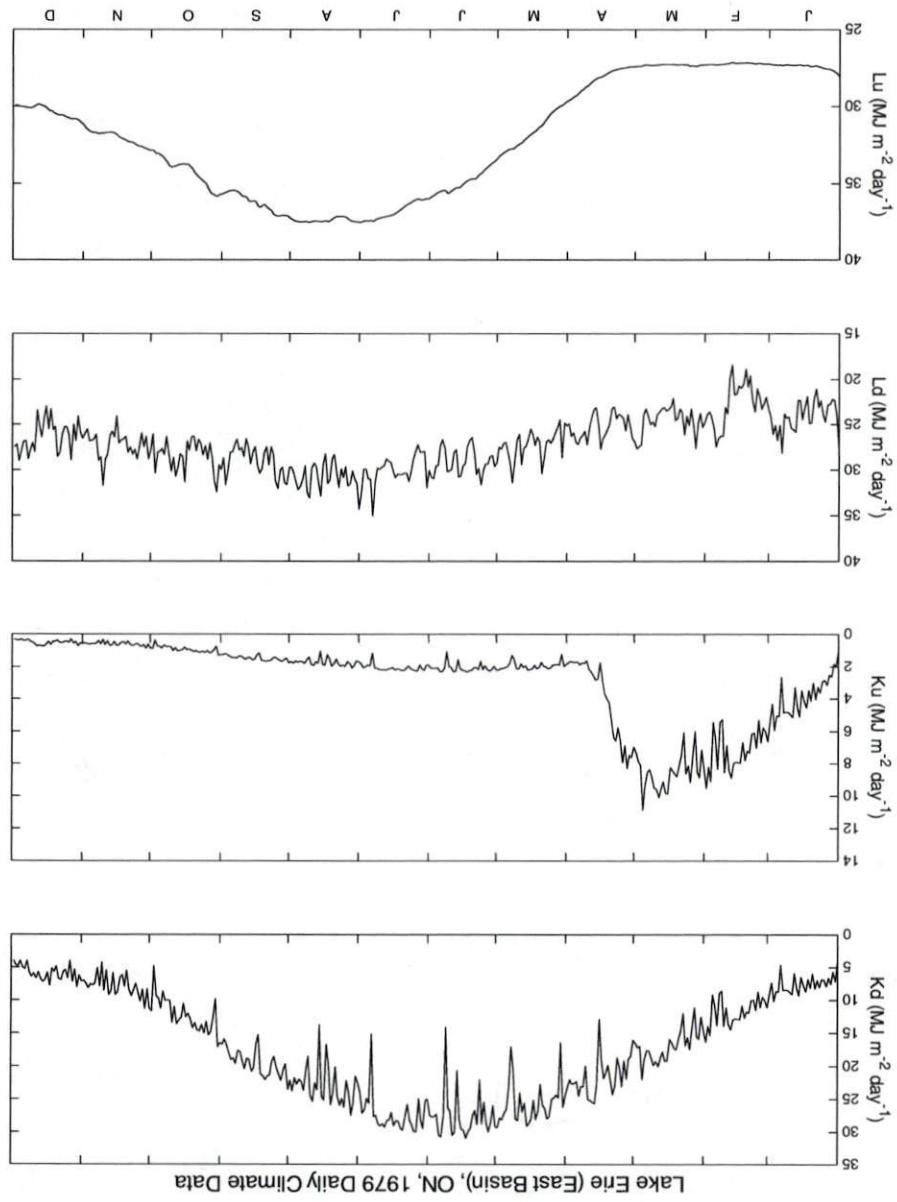


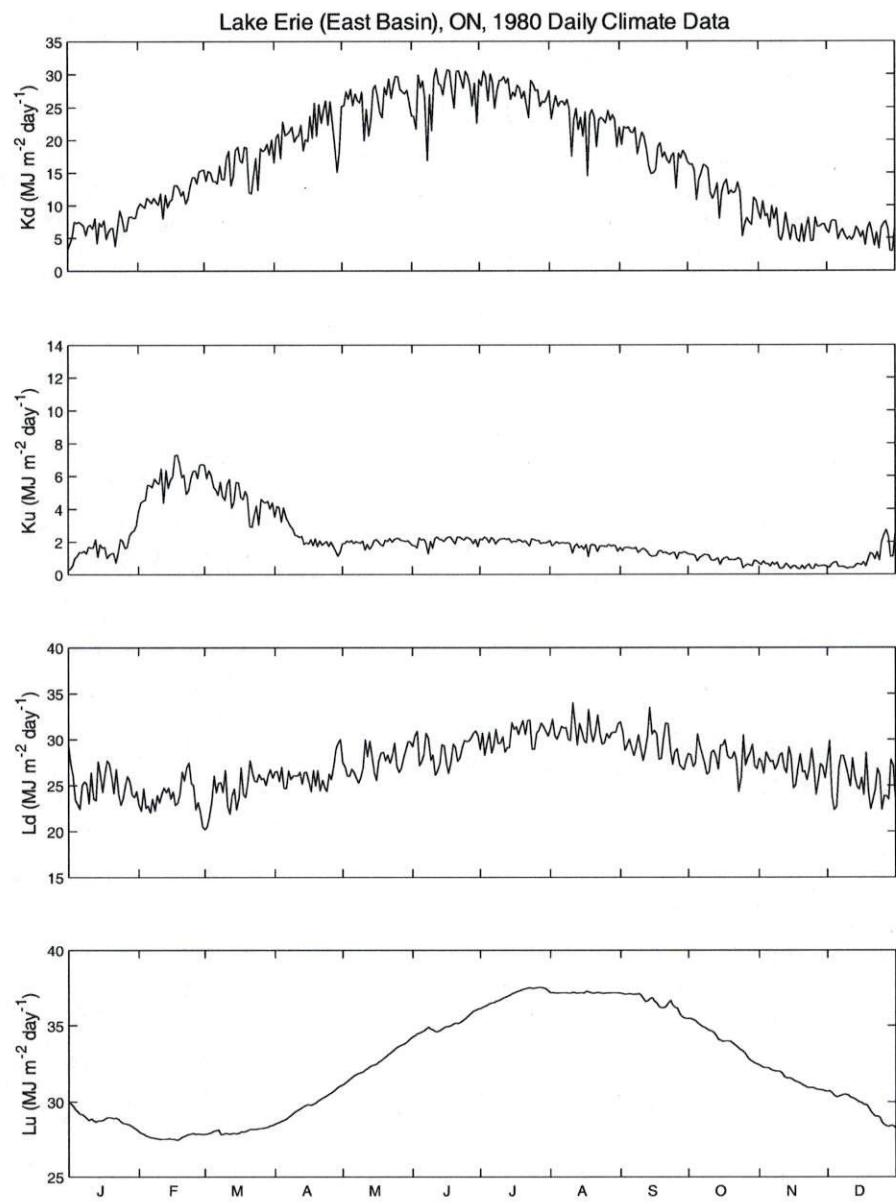


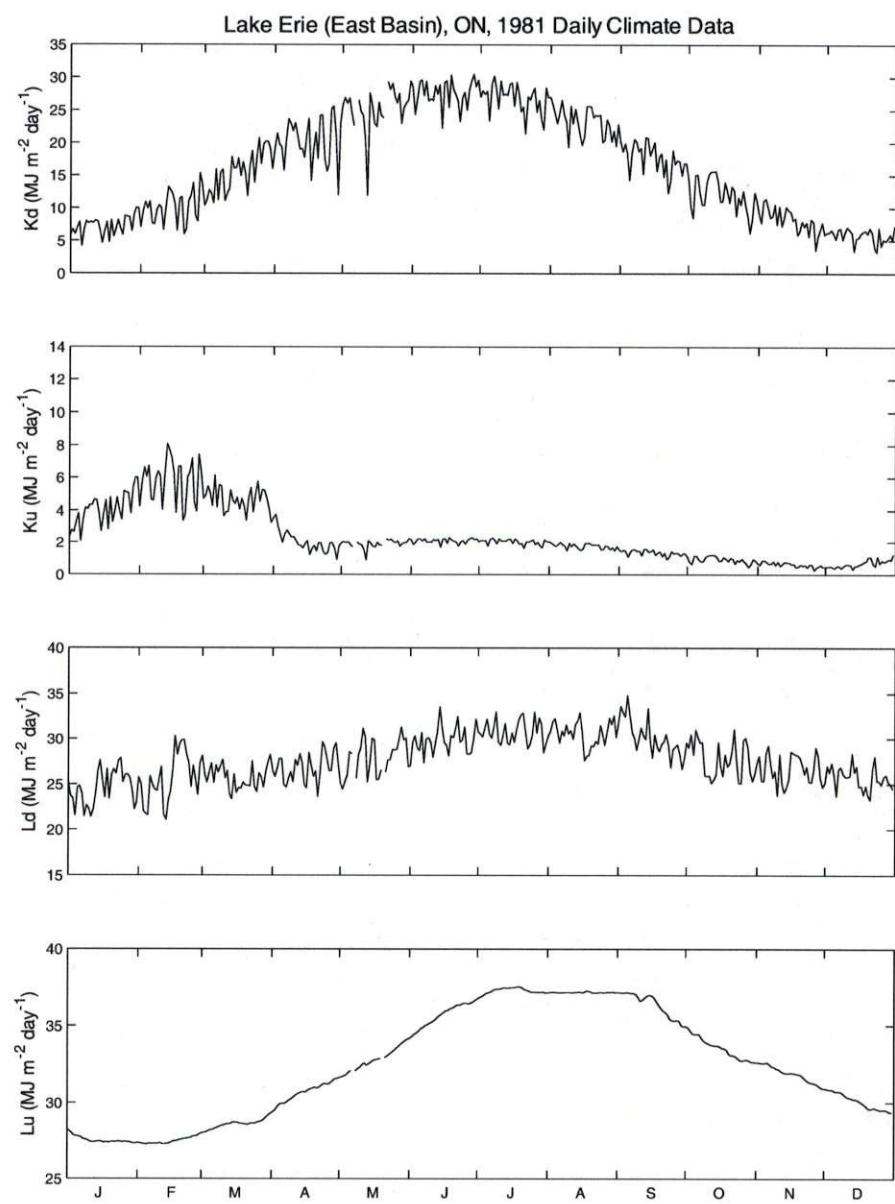


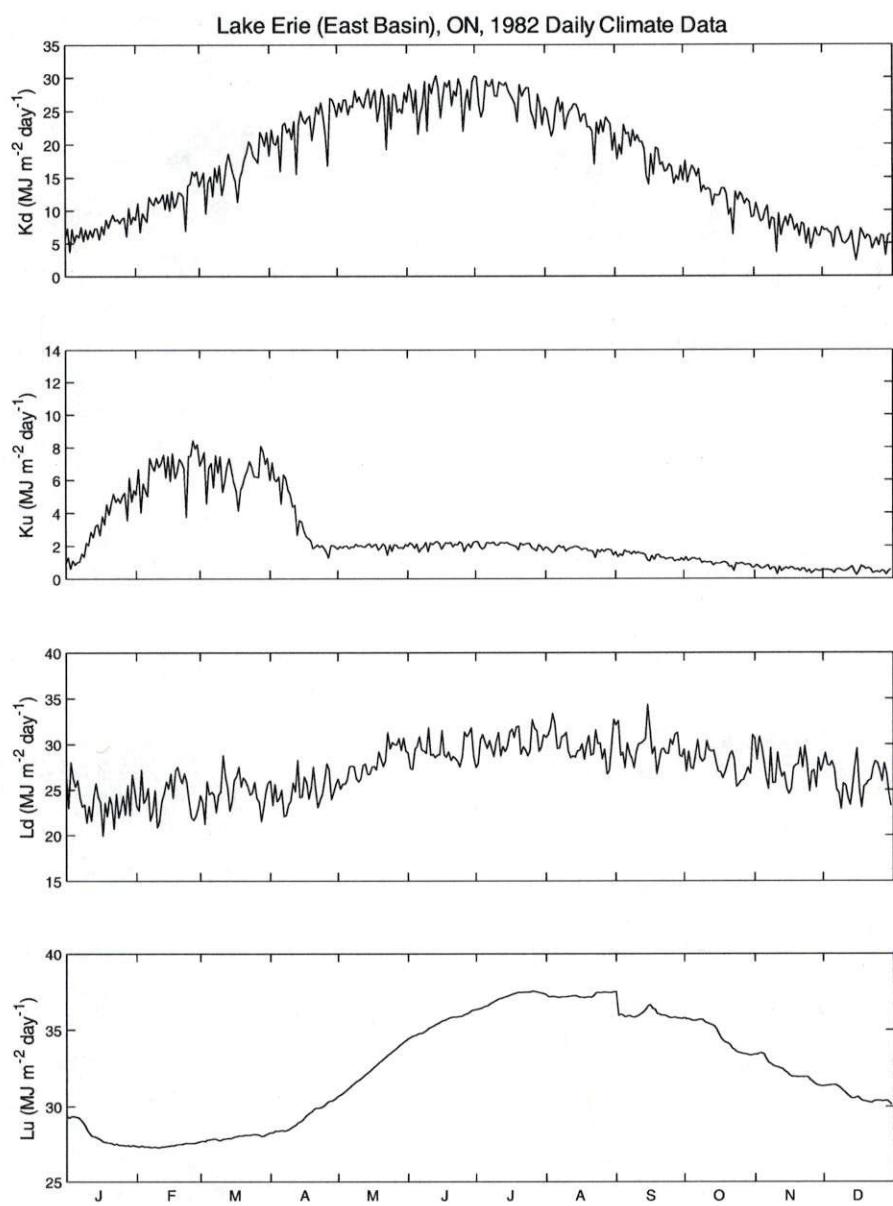


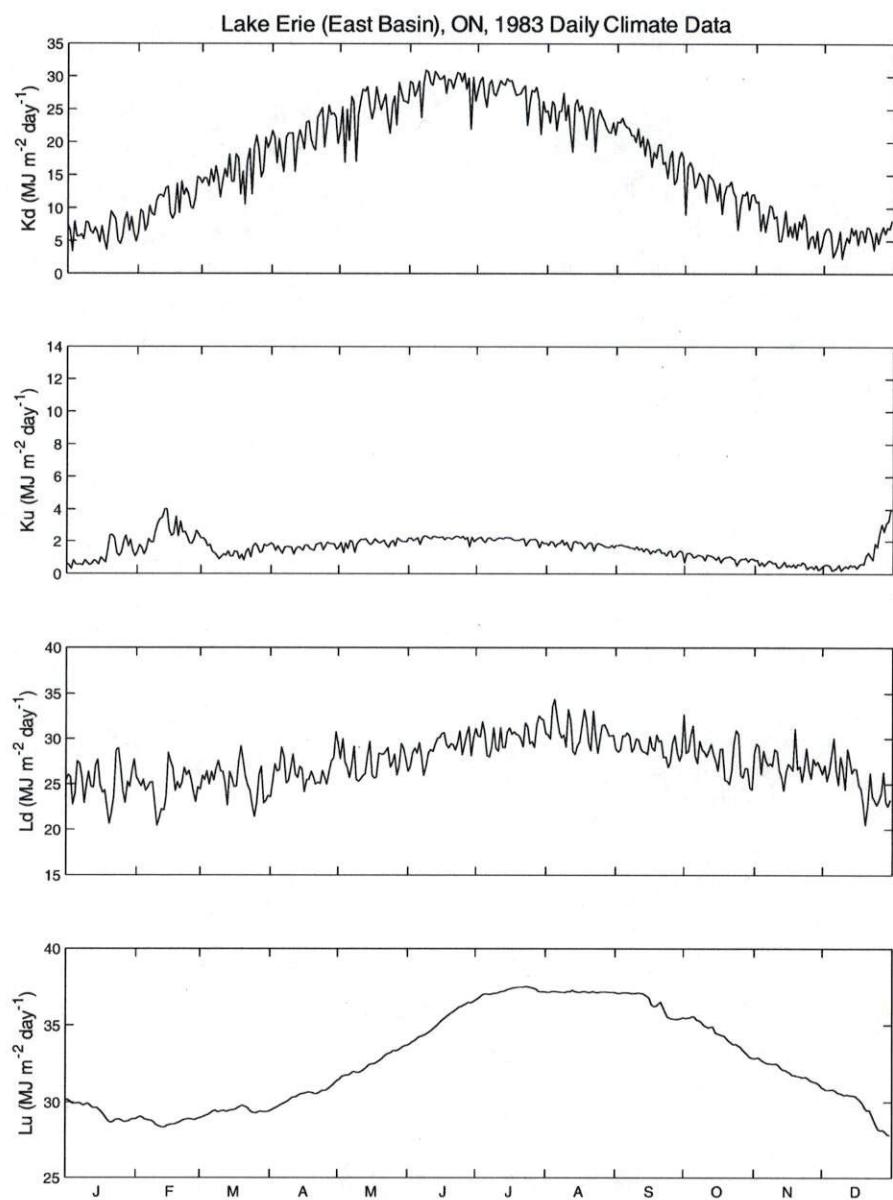


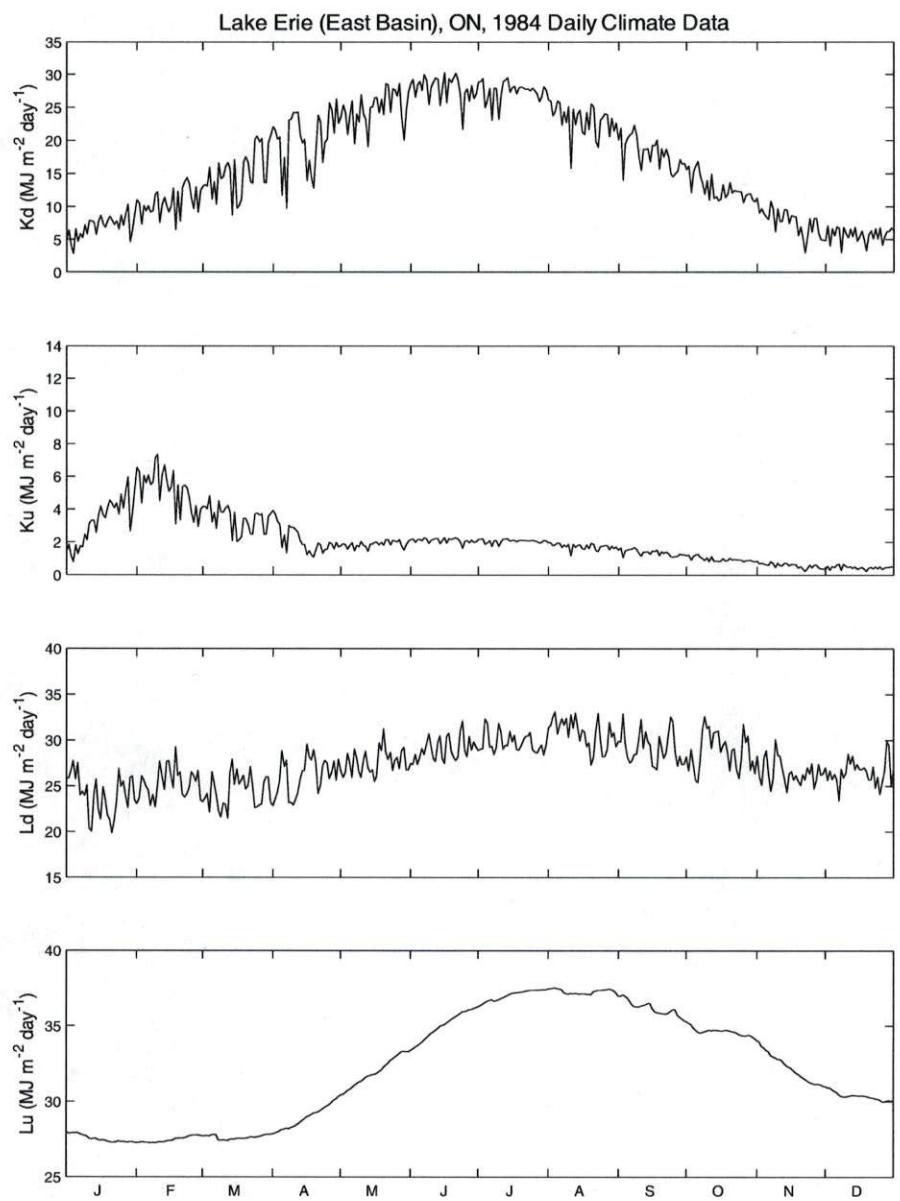


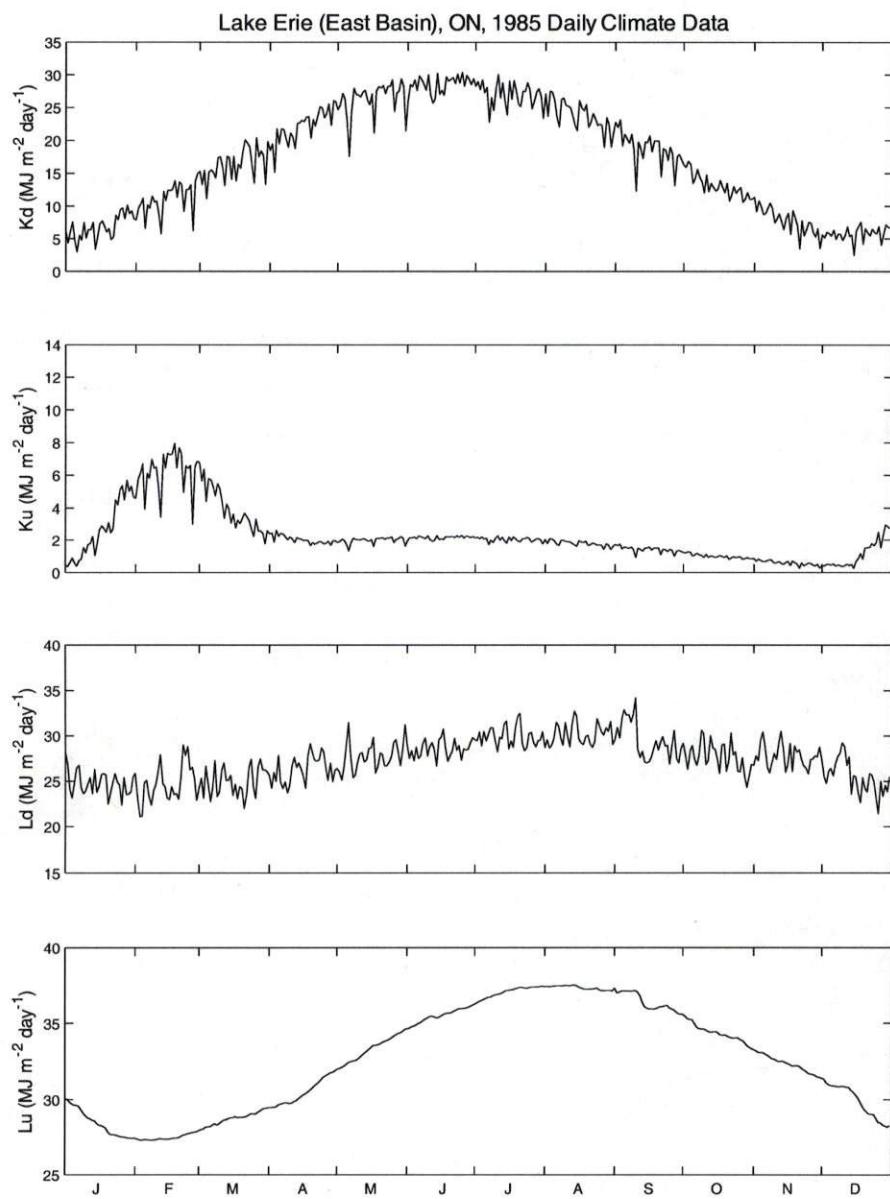


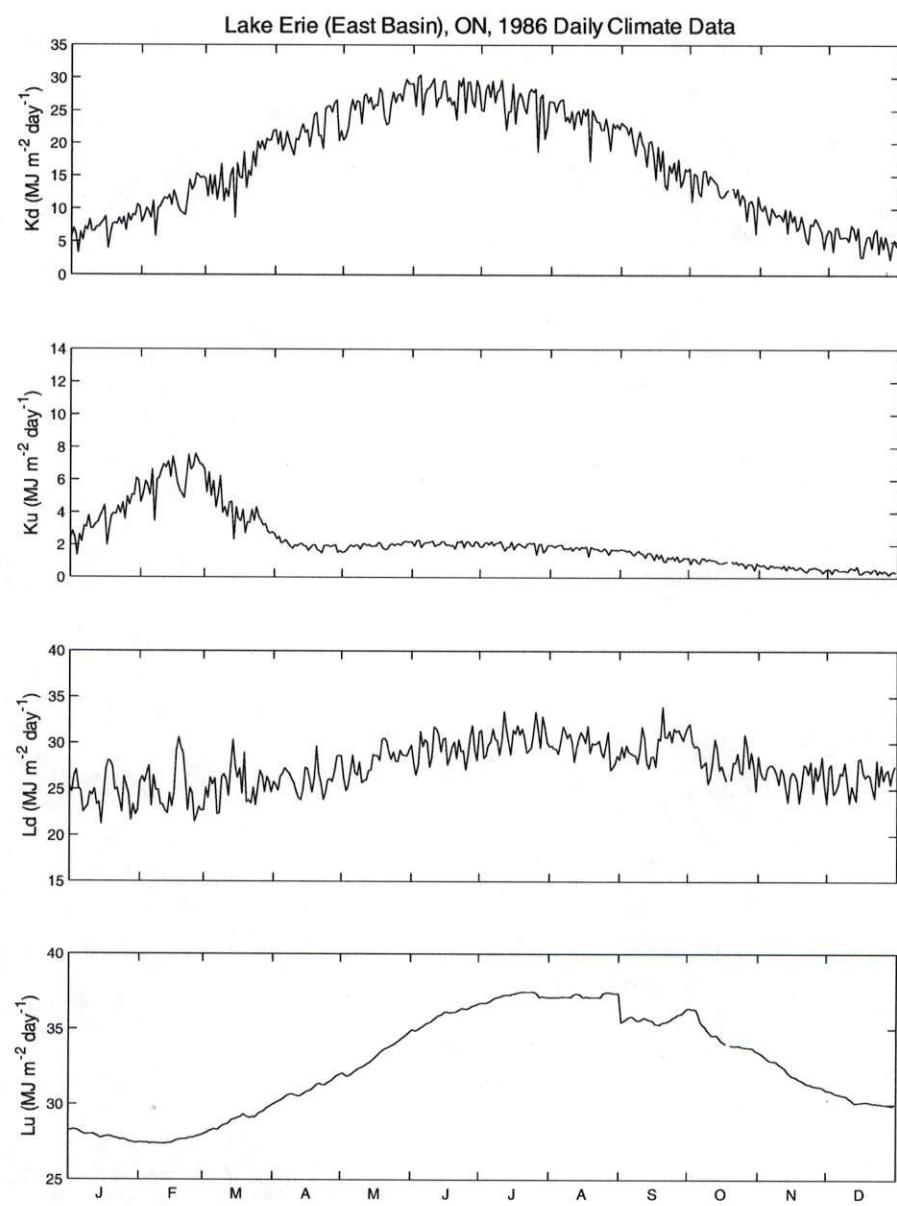


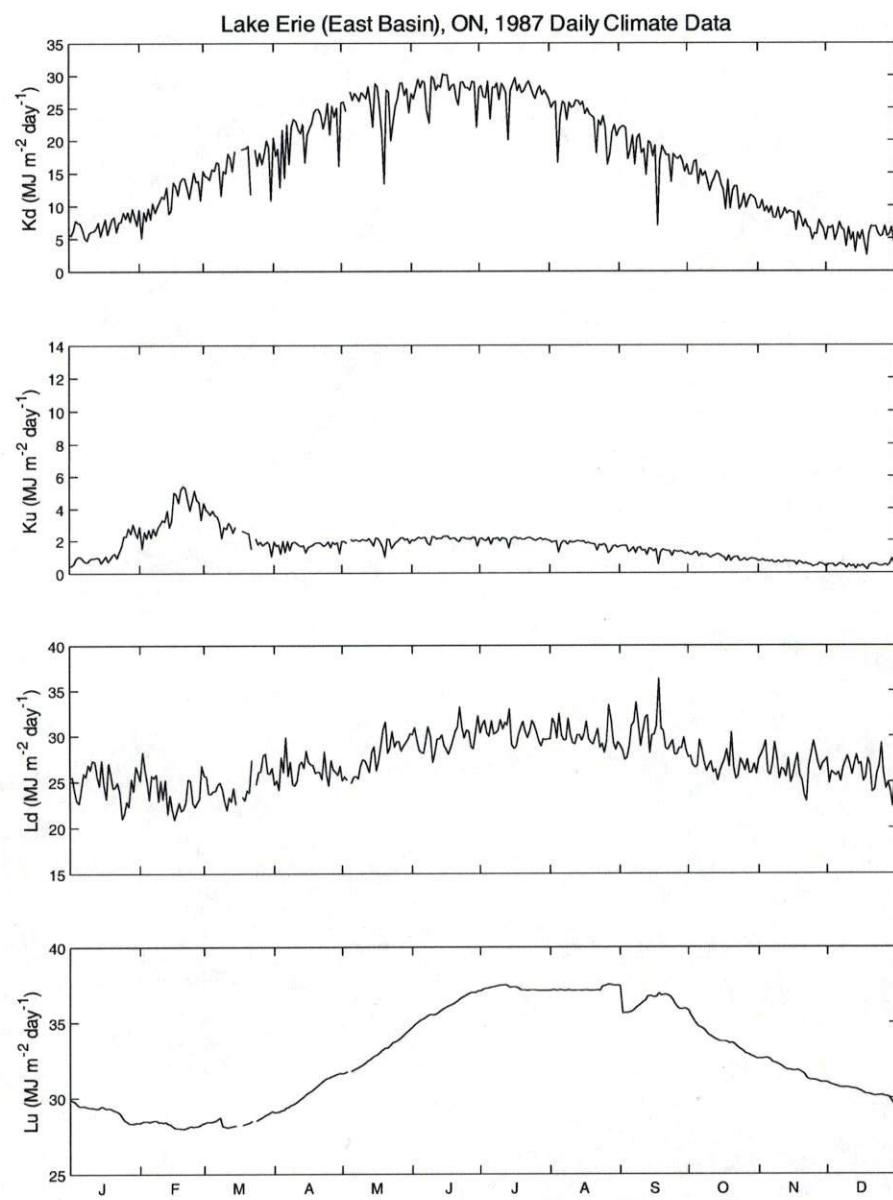


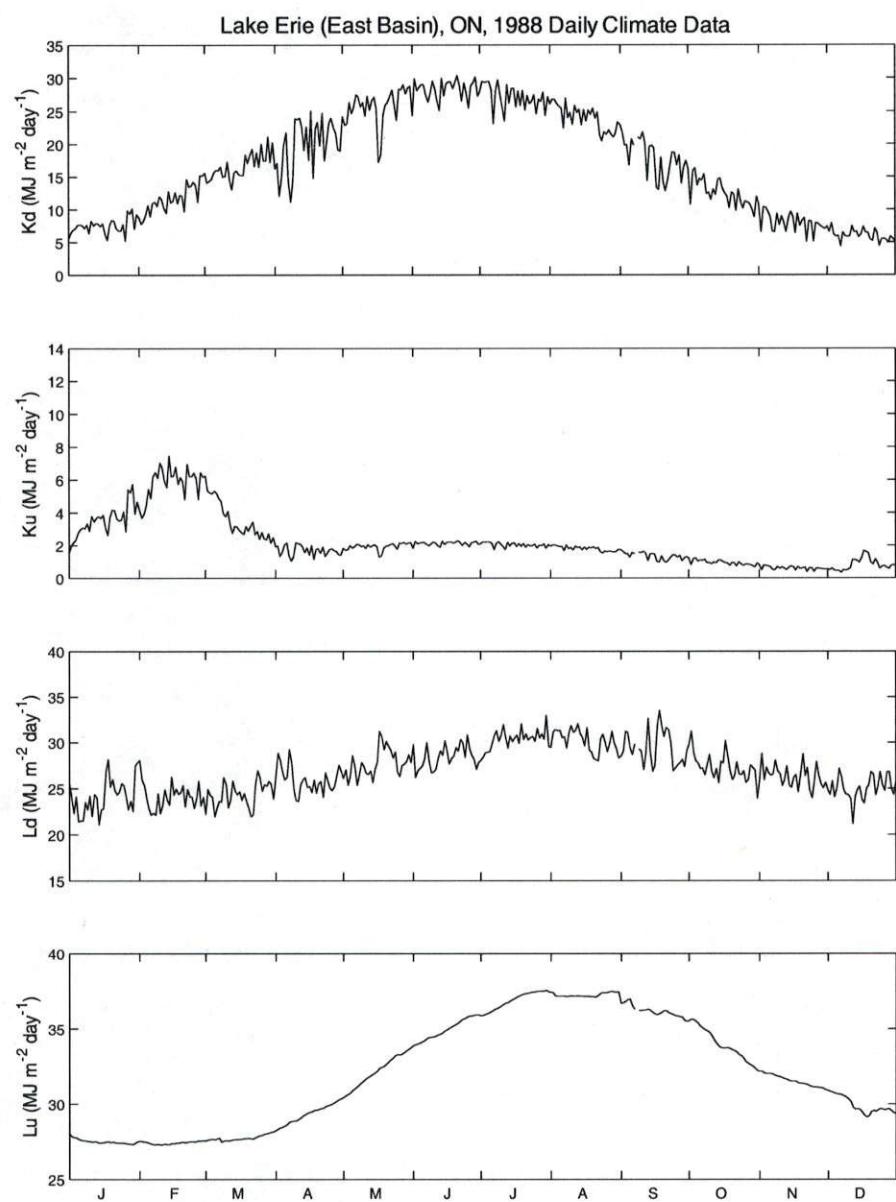


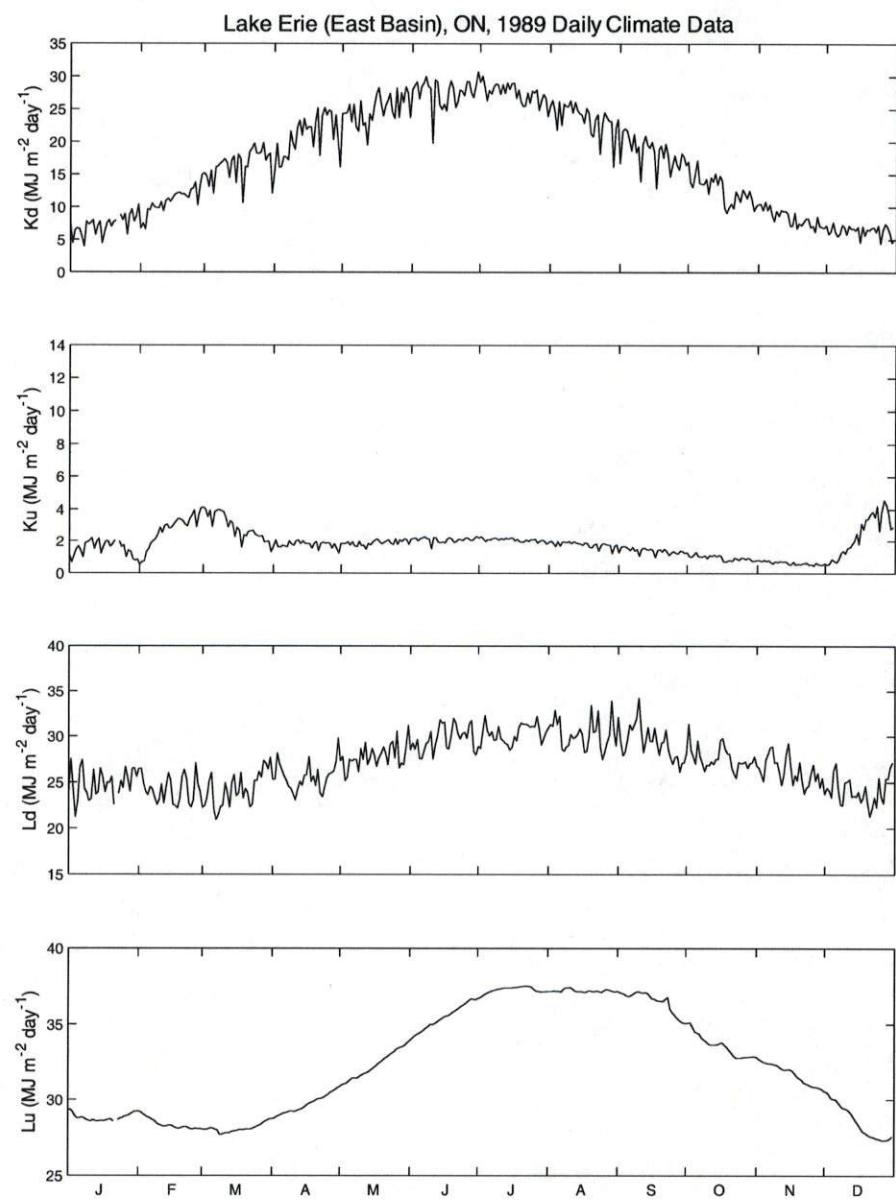


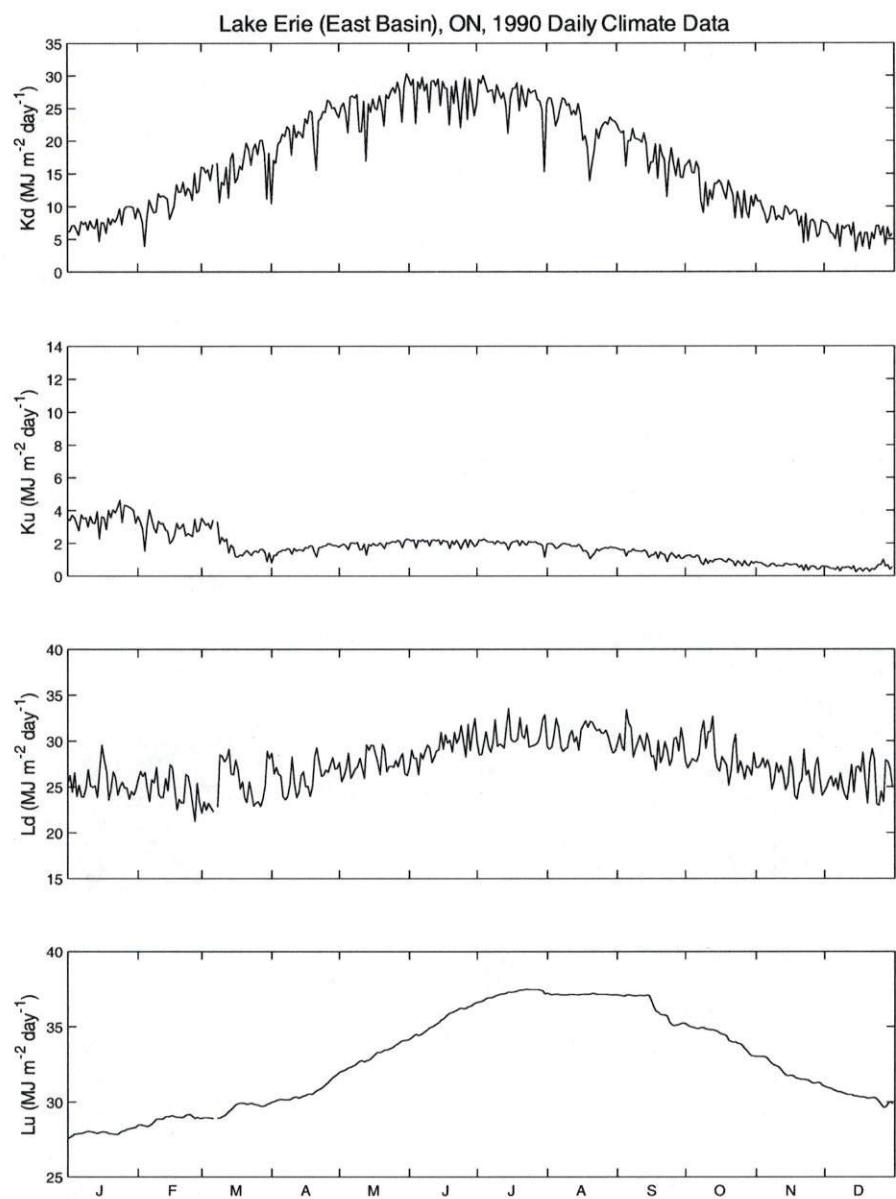


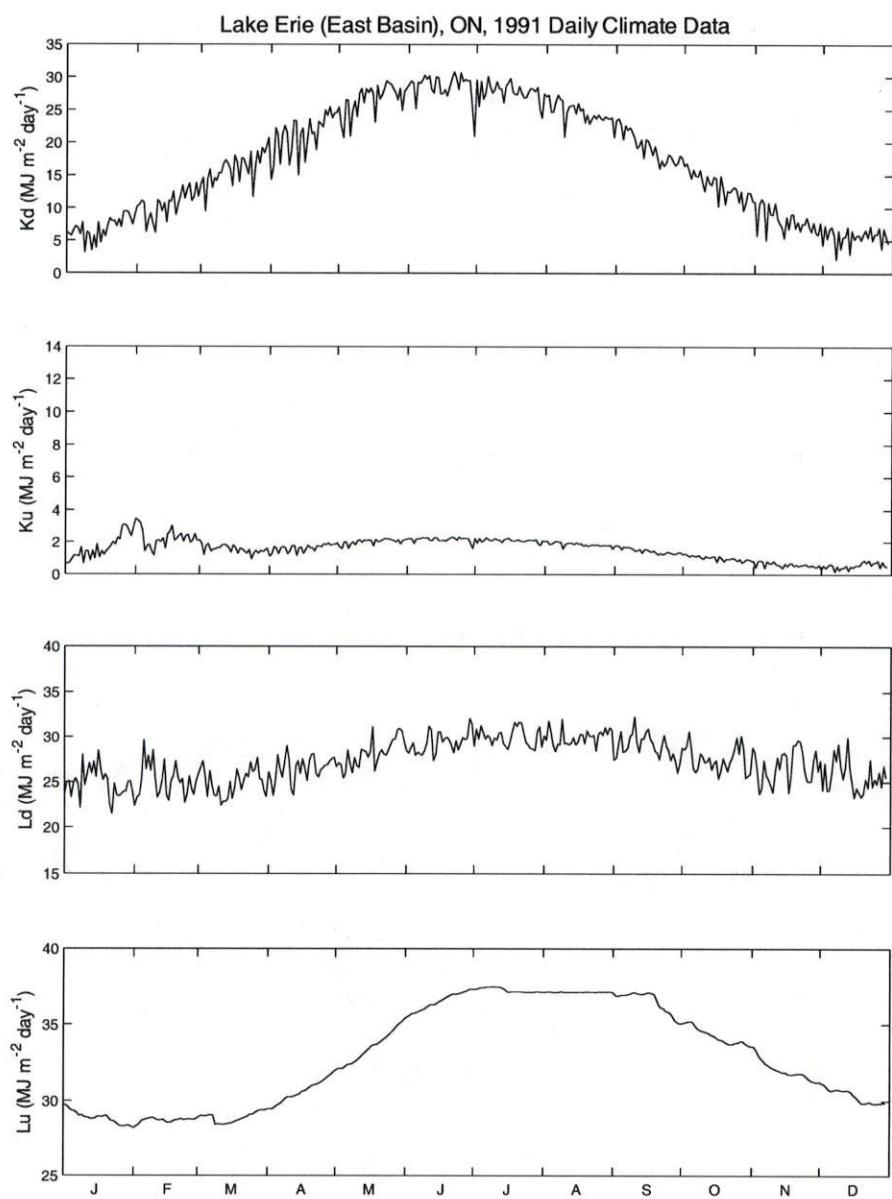


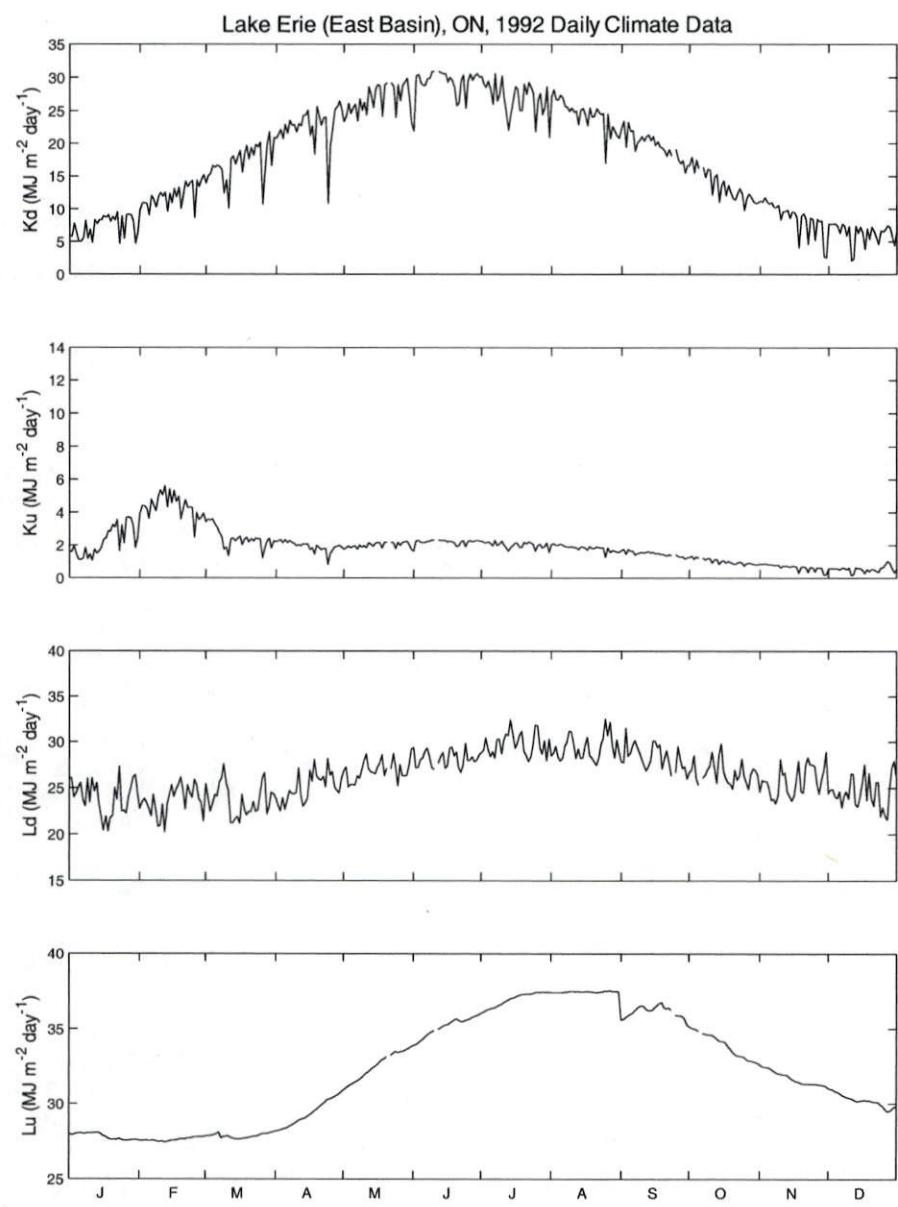


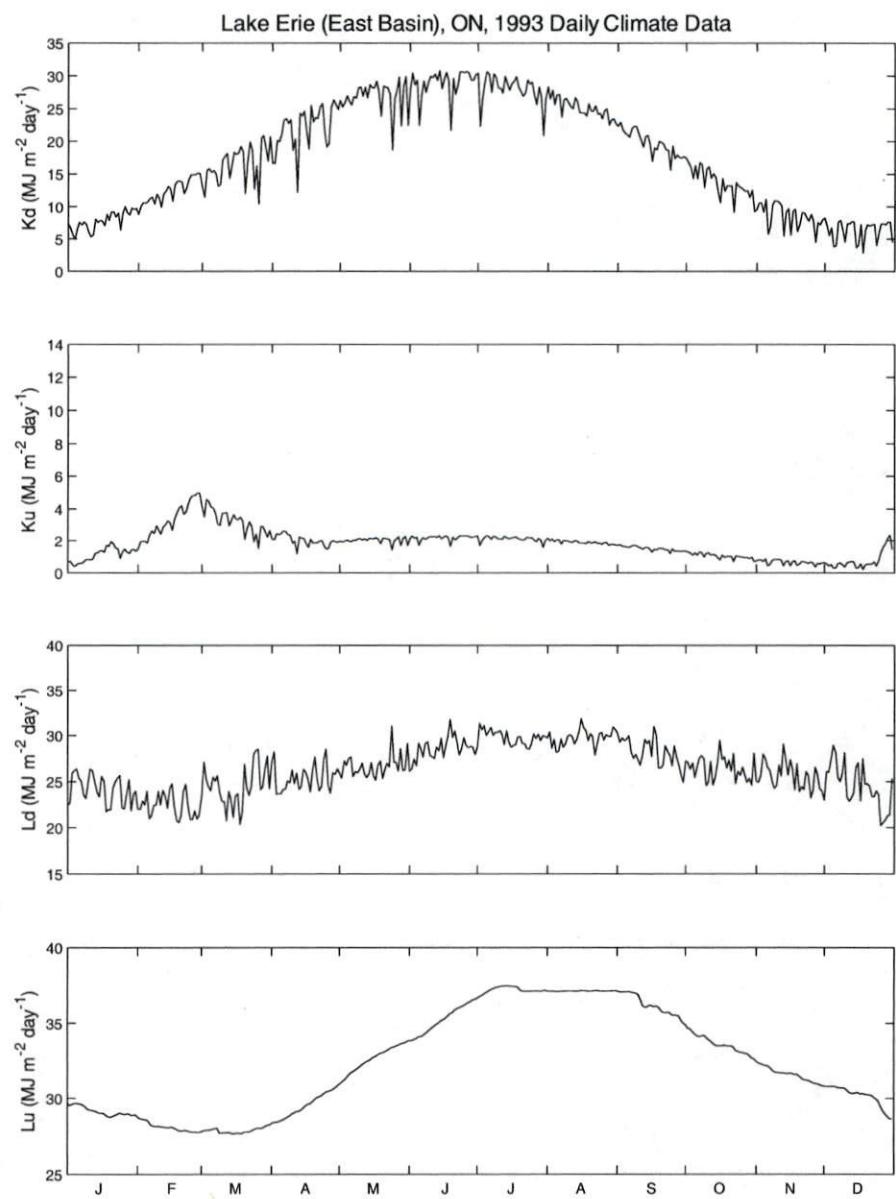


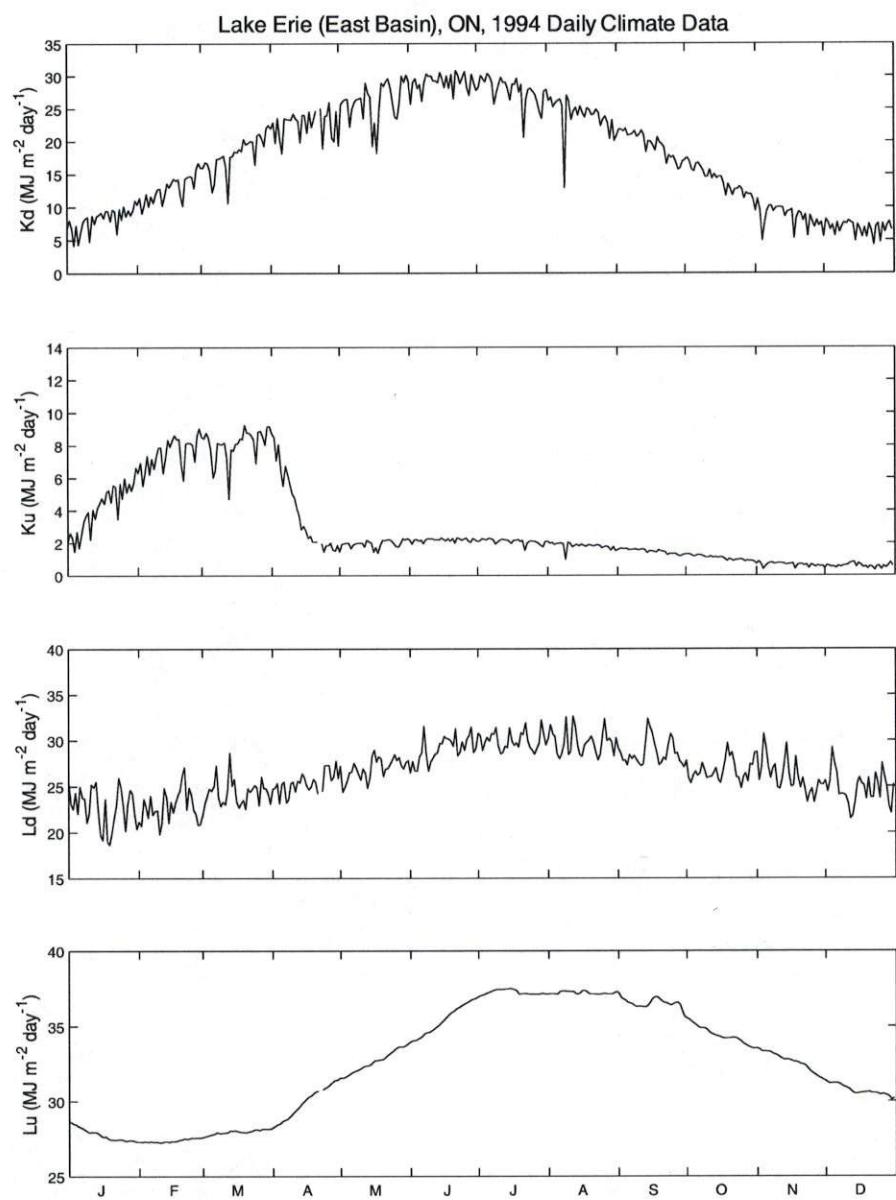


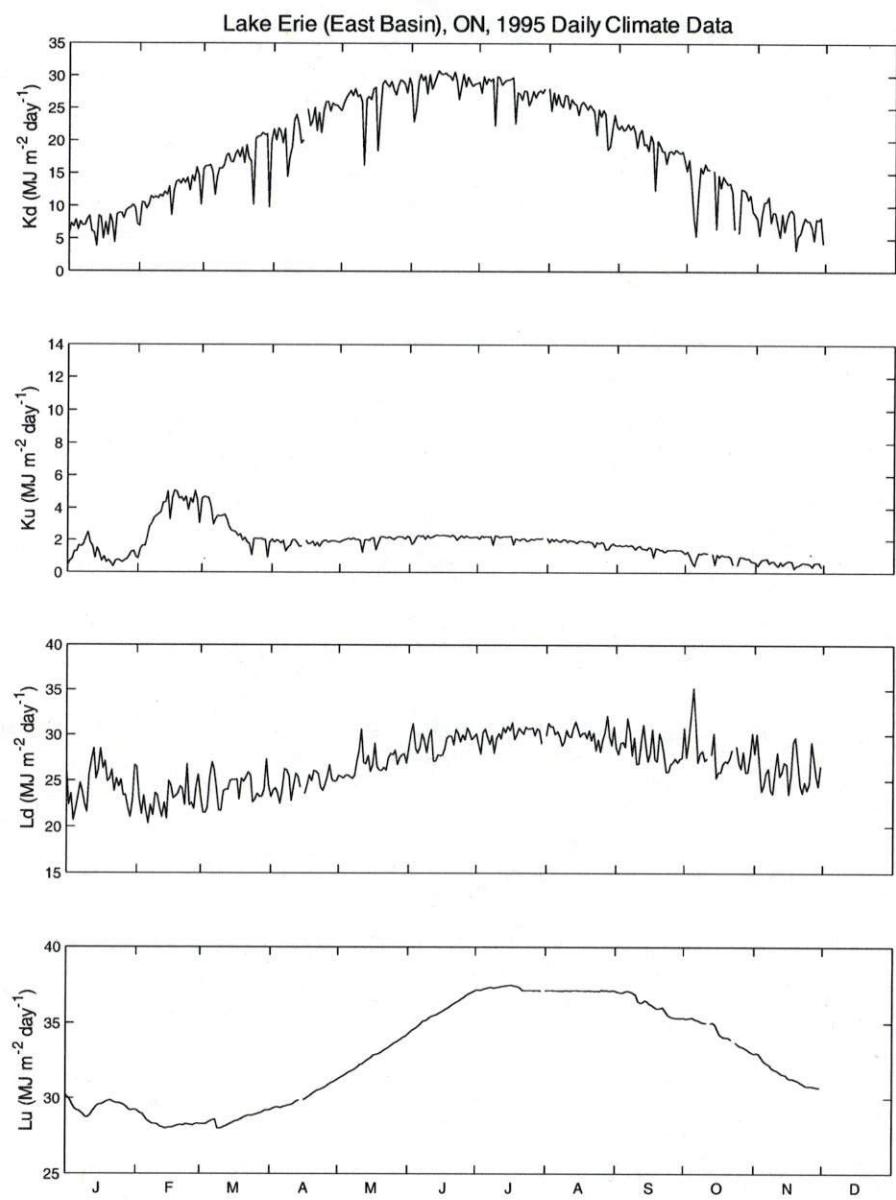


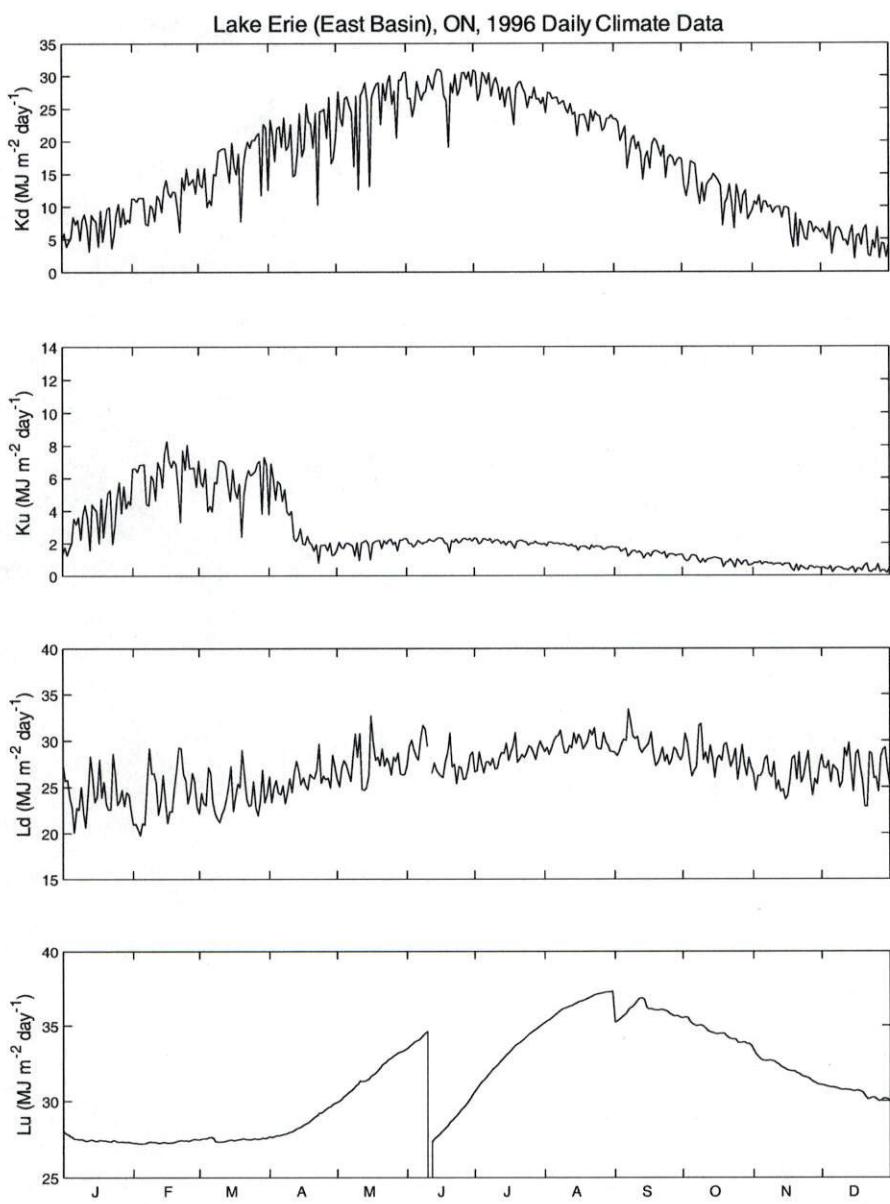


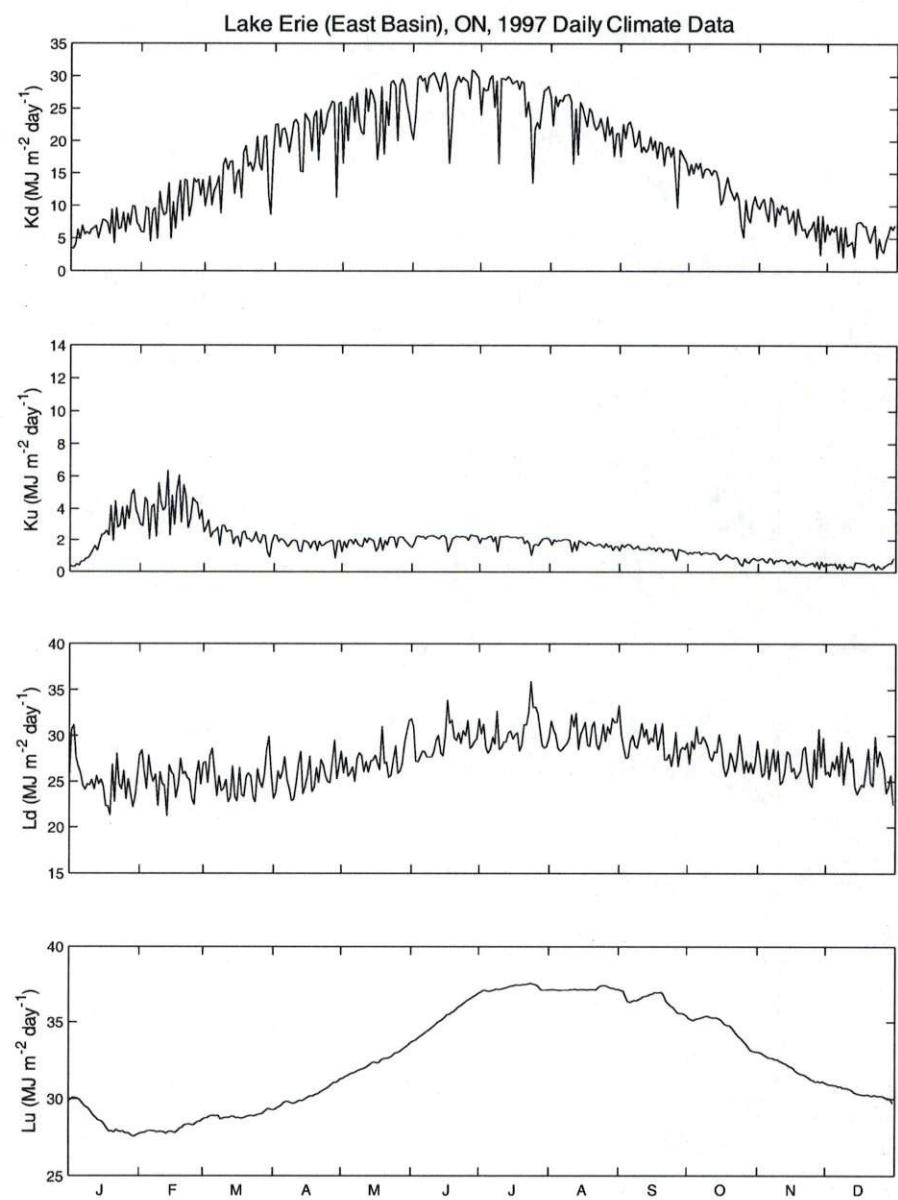






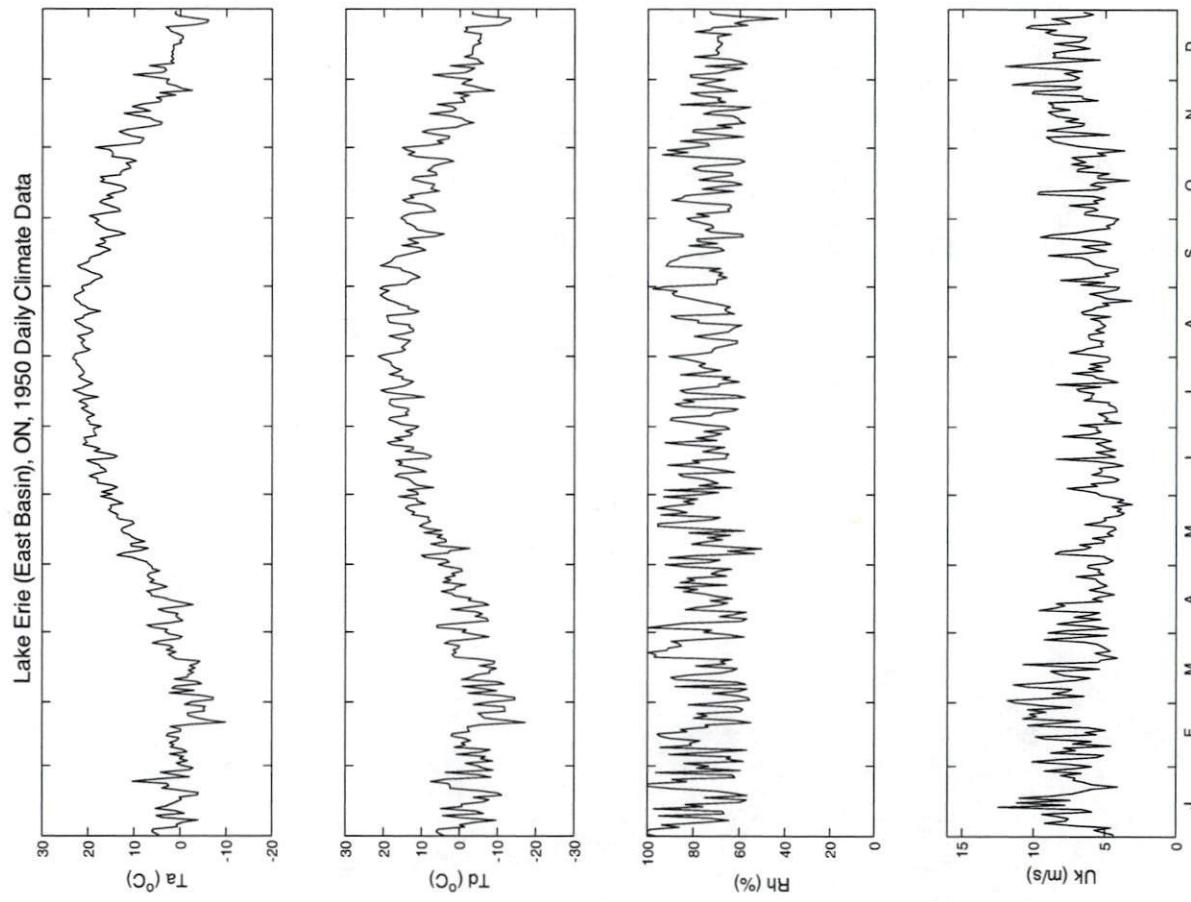


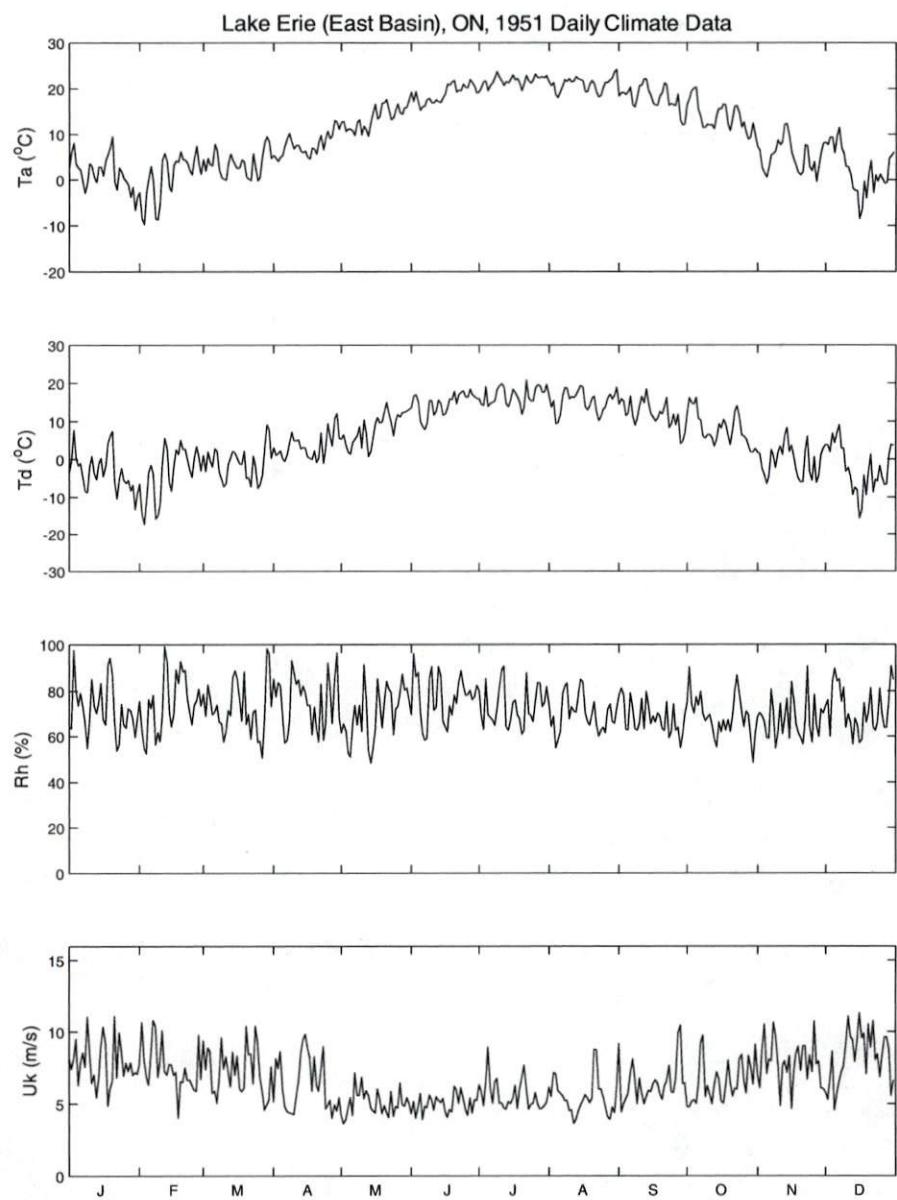


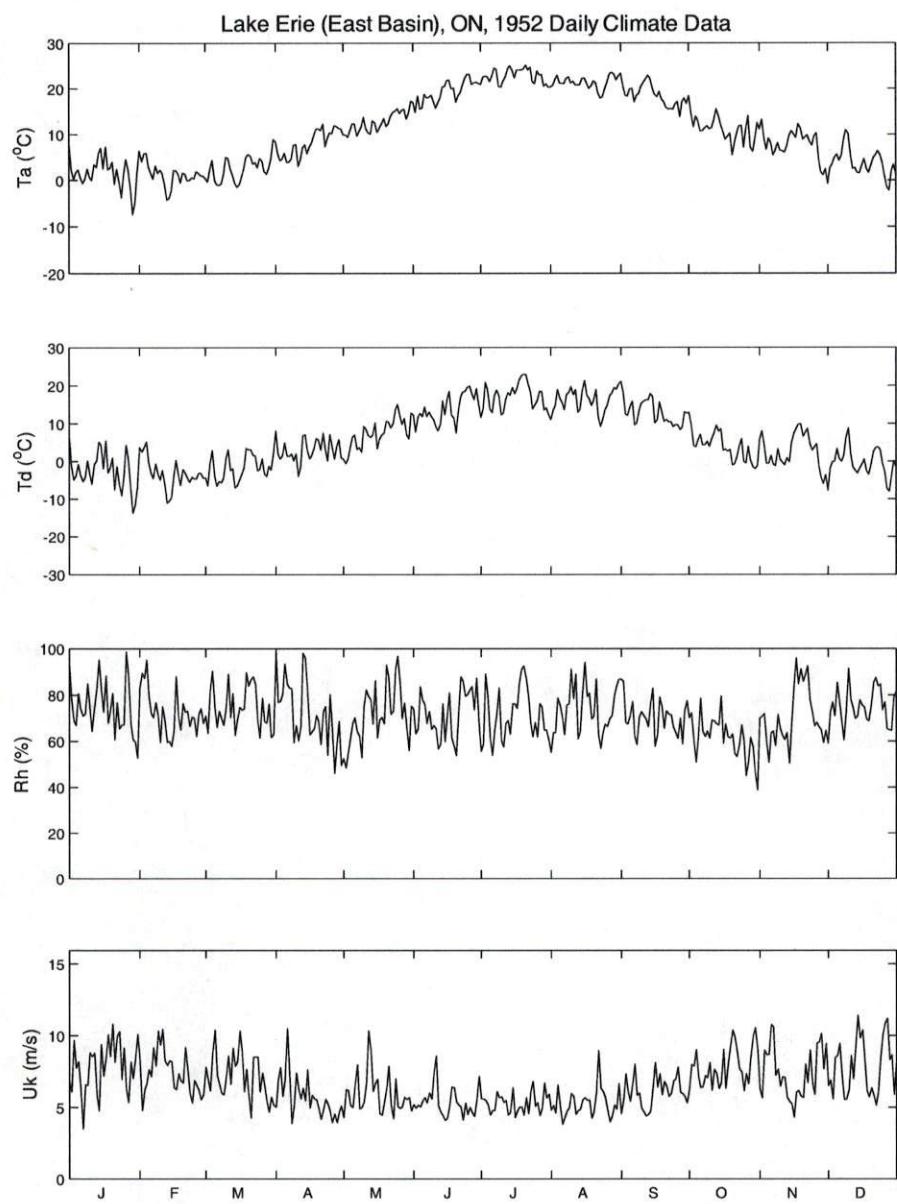


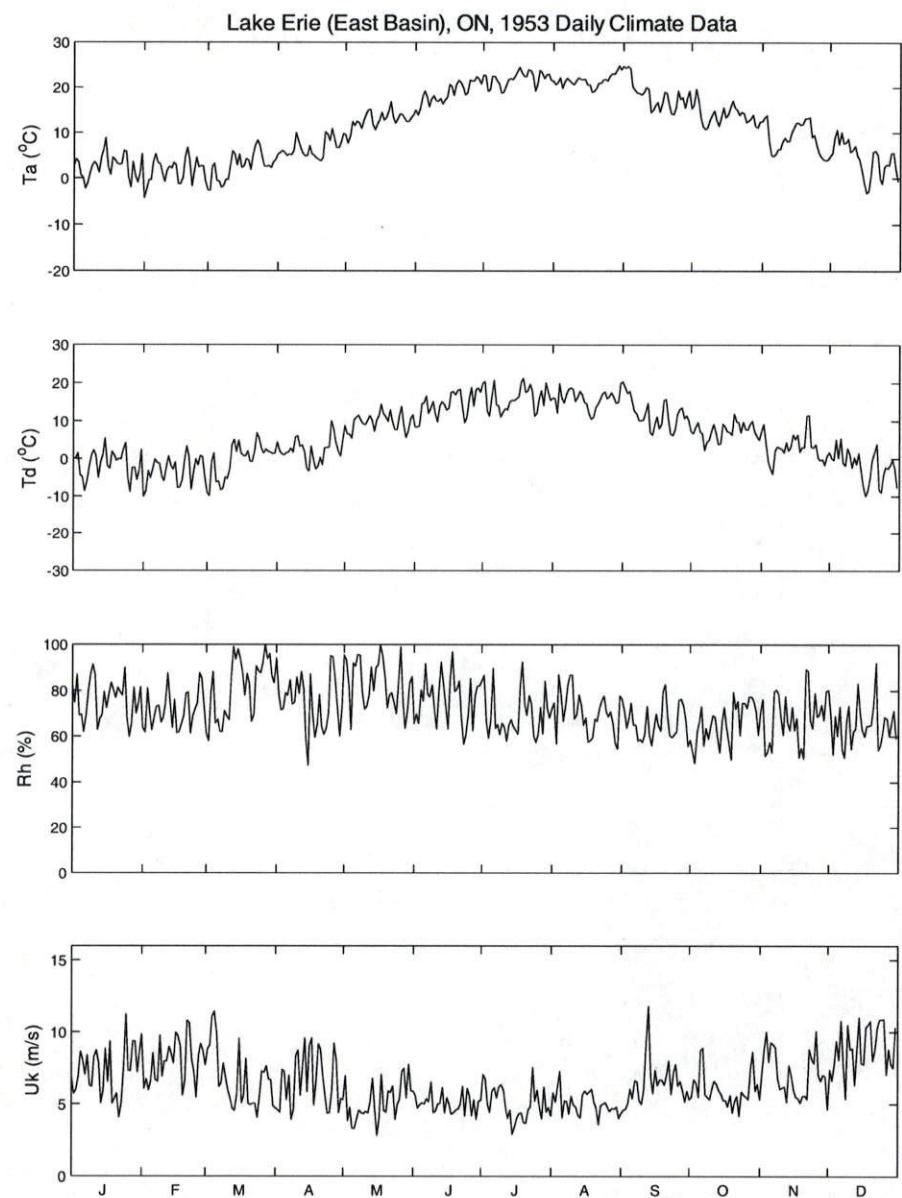
Appendix 5

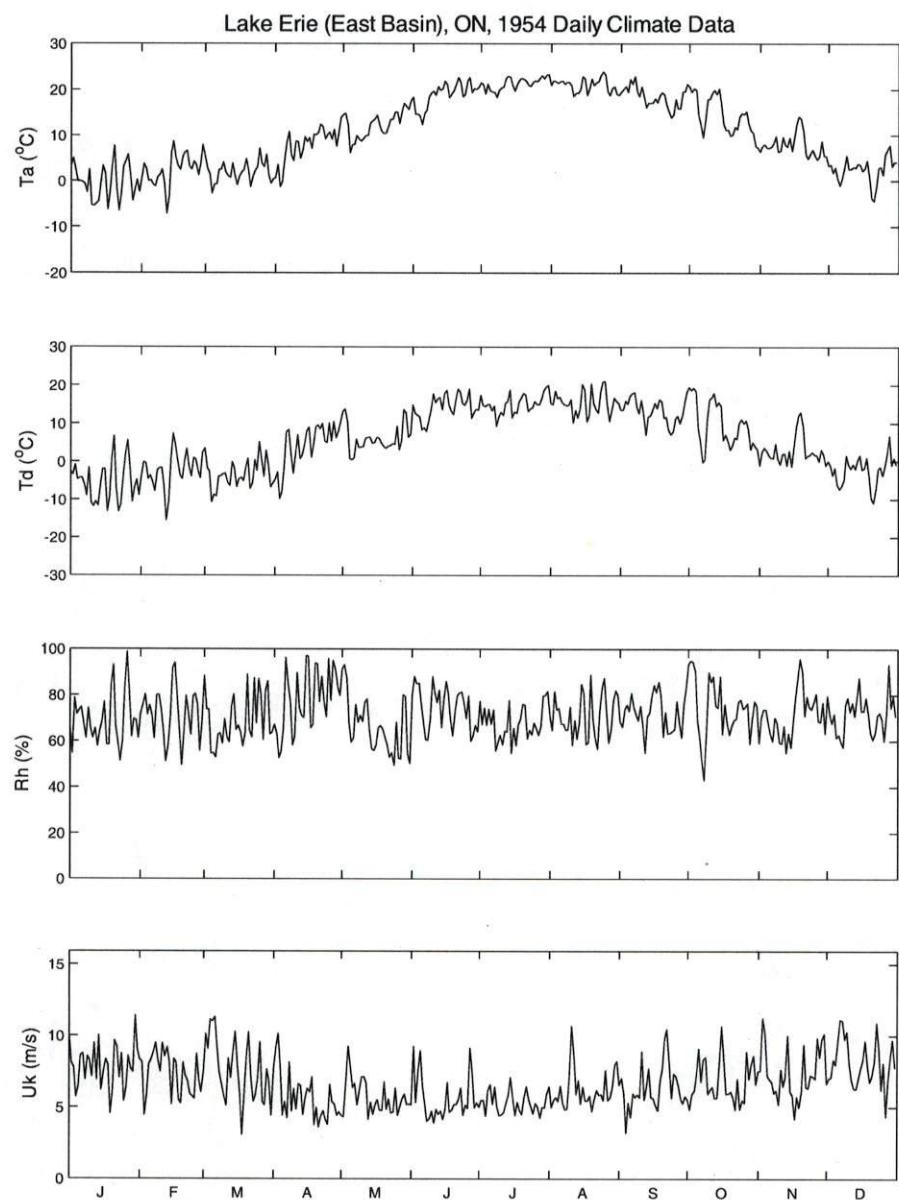
Meteorological

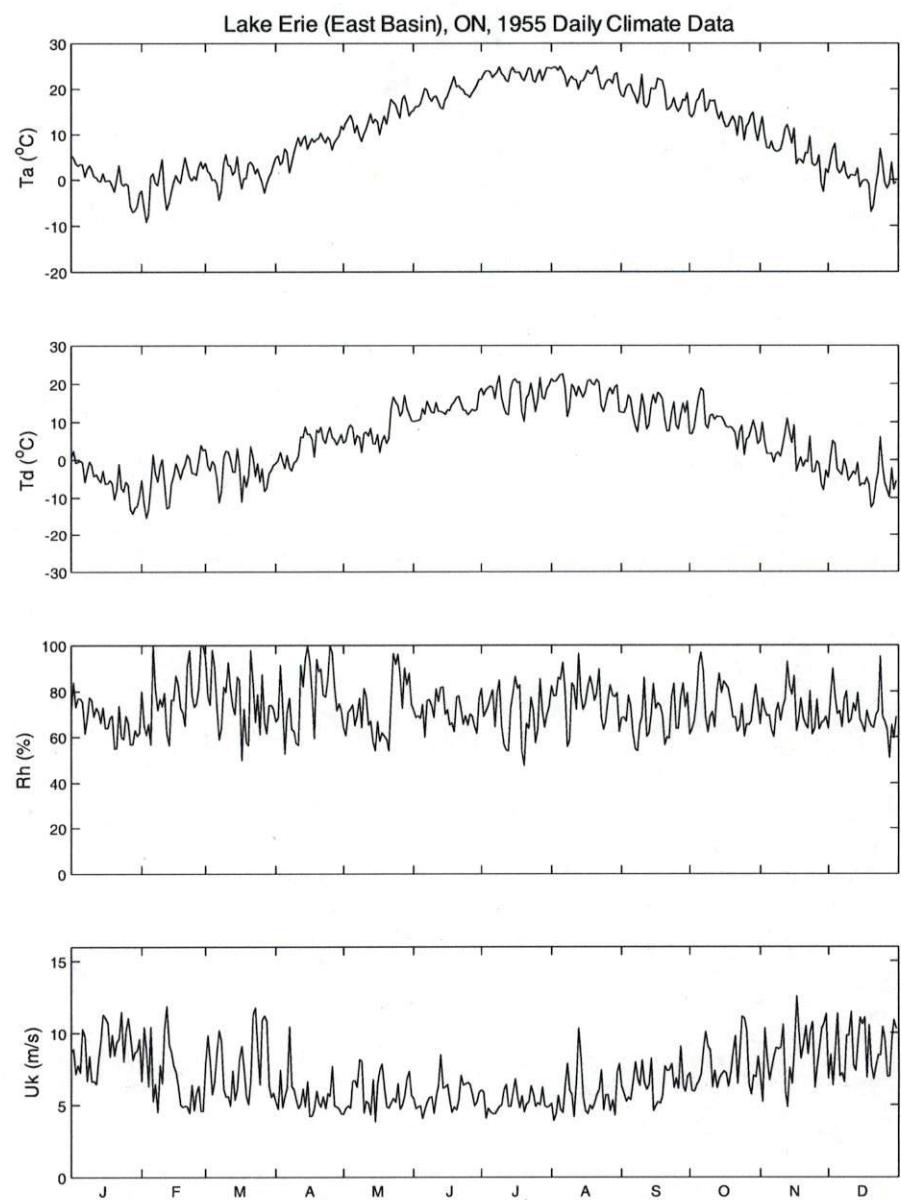


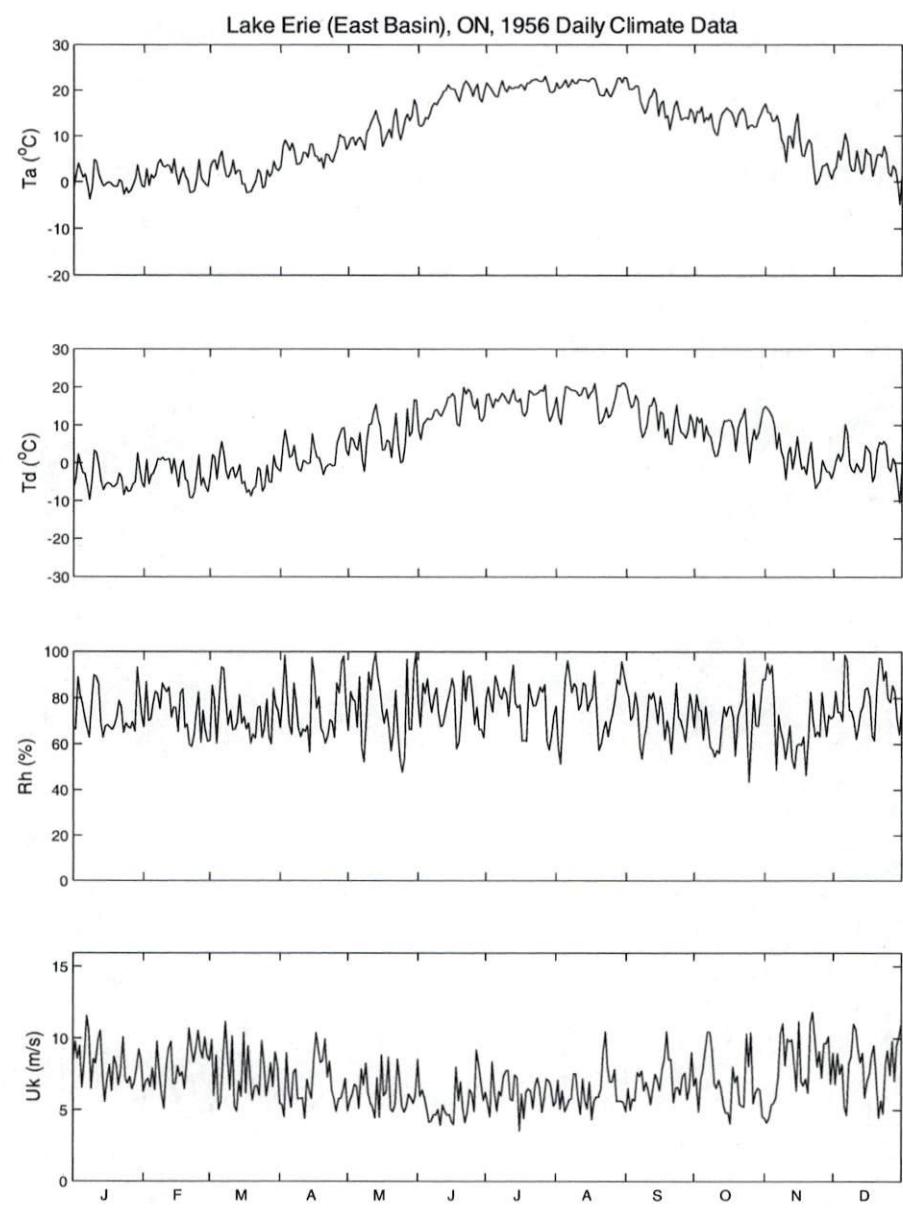


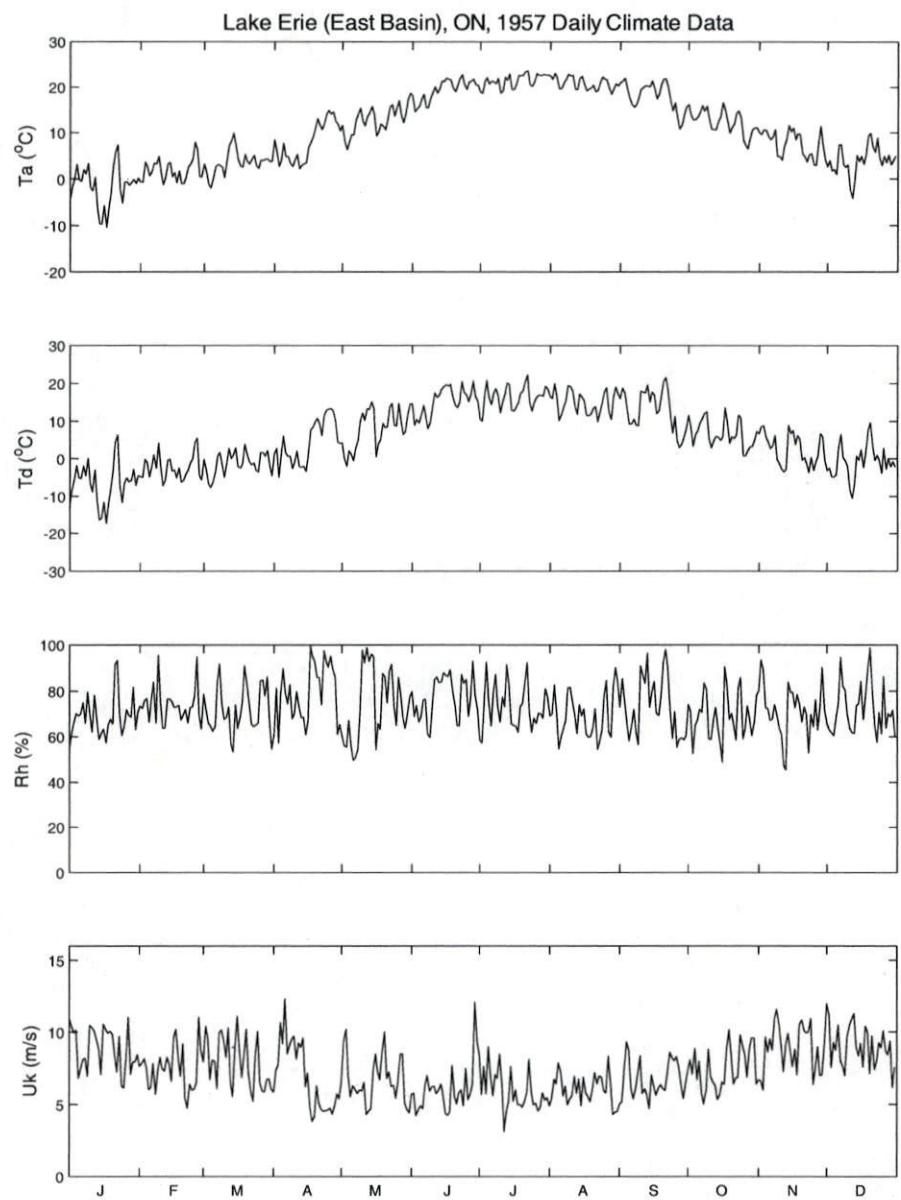


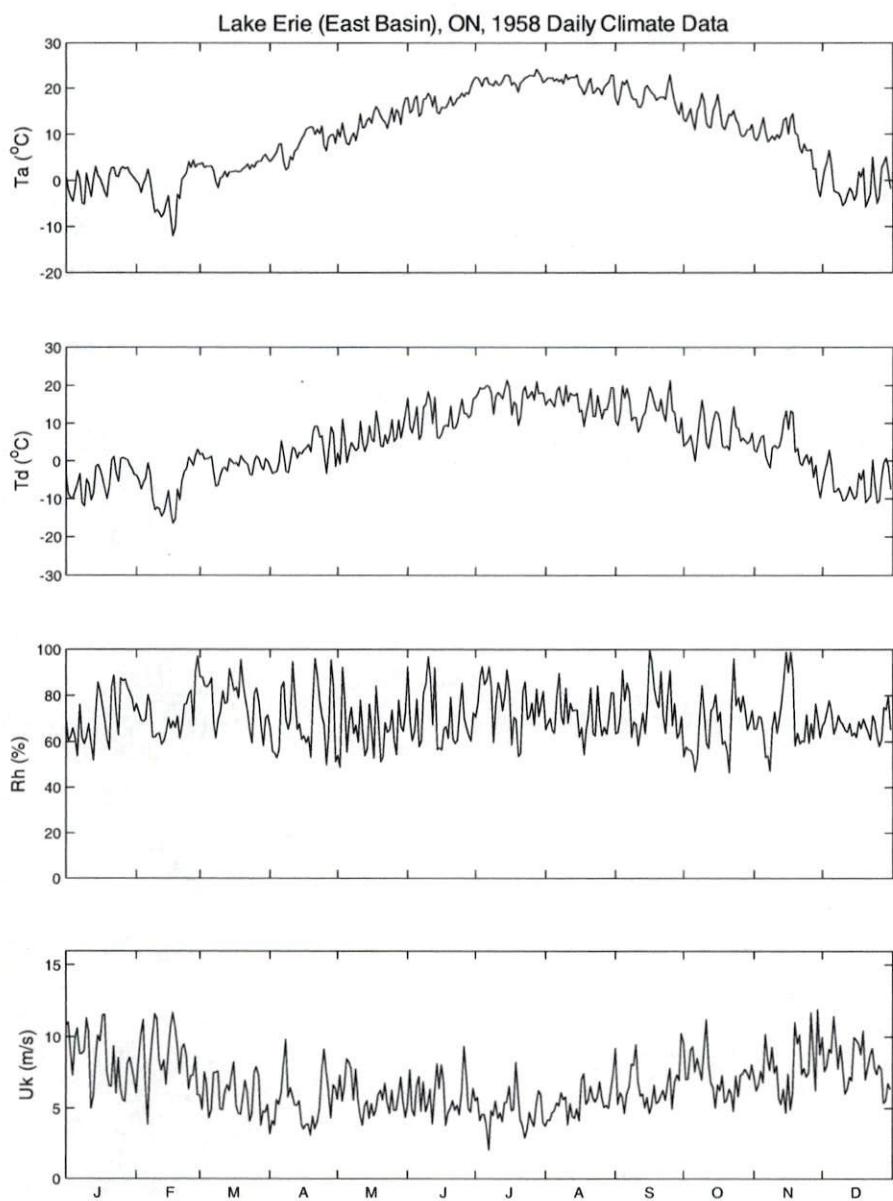


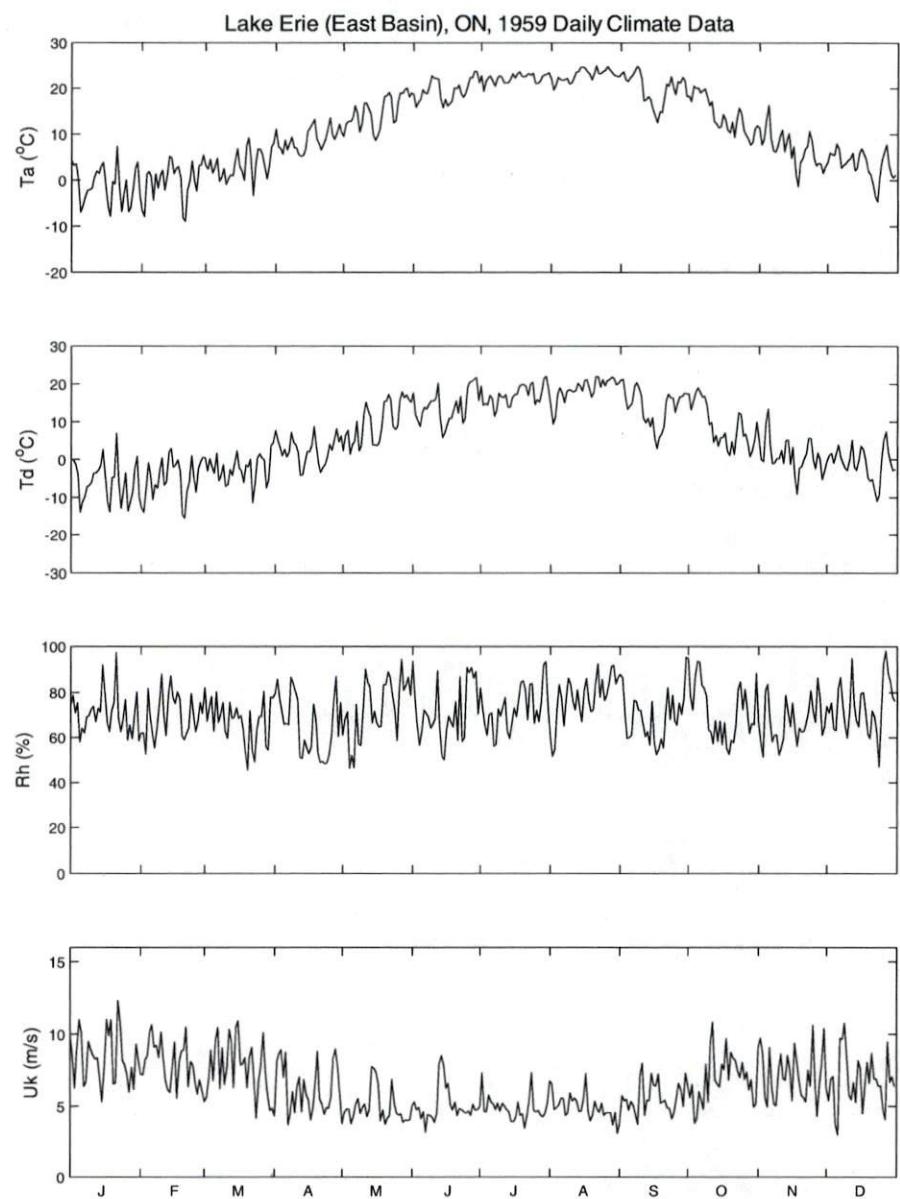


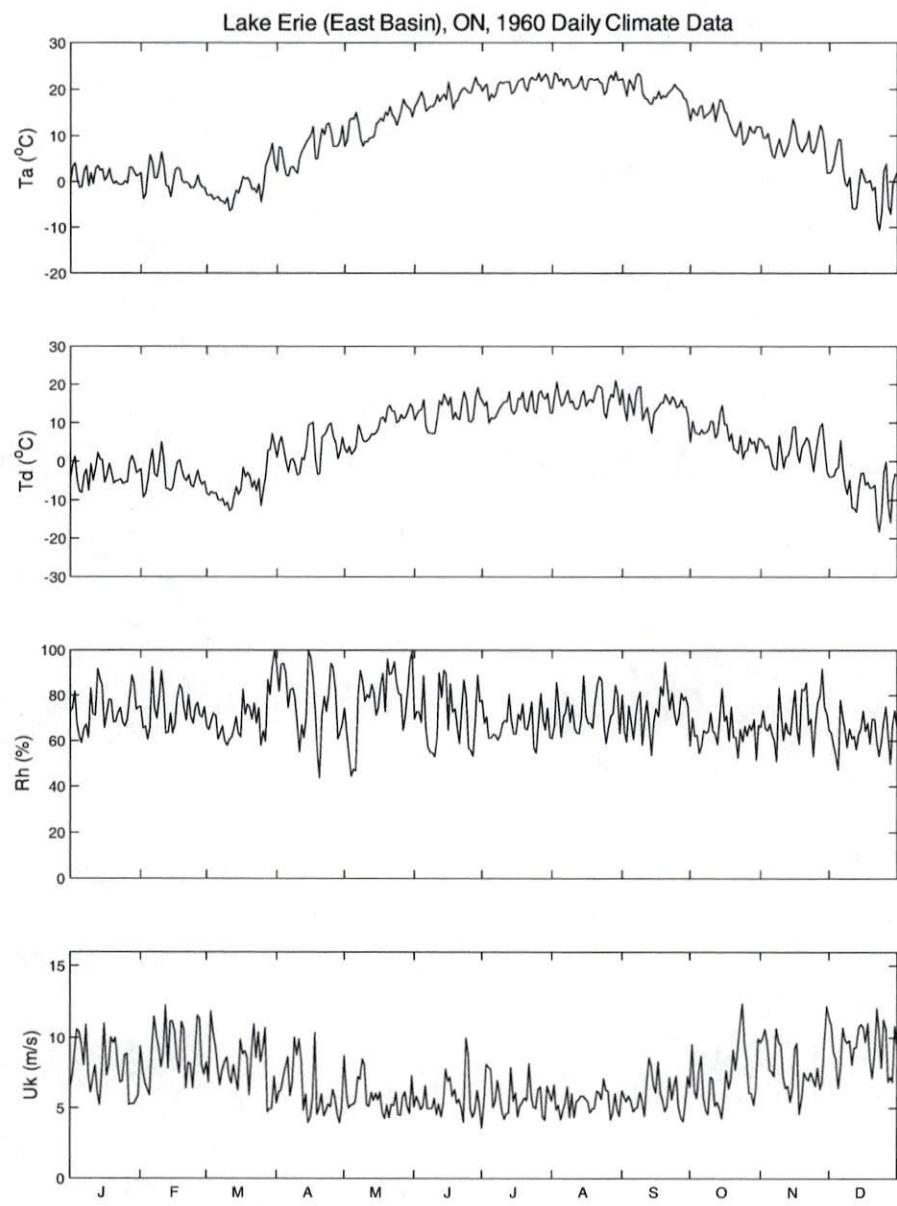


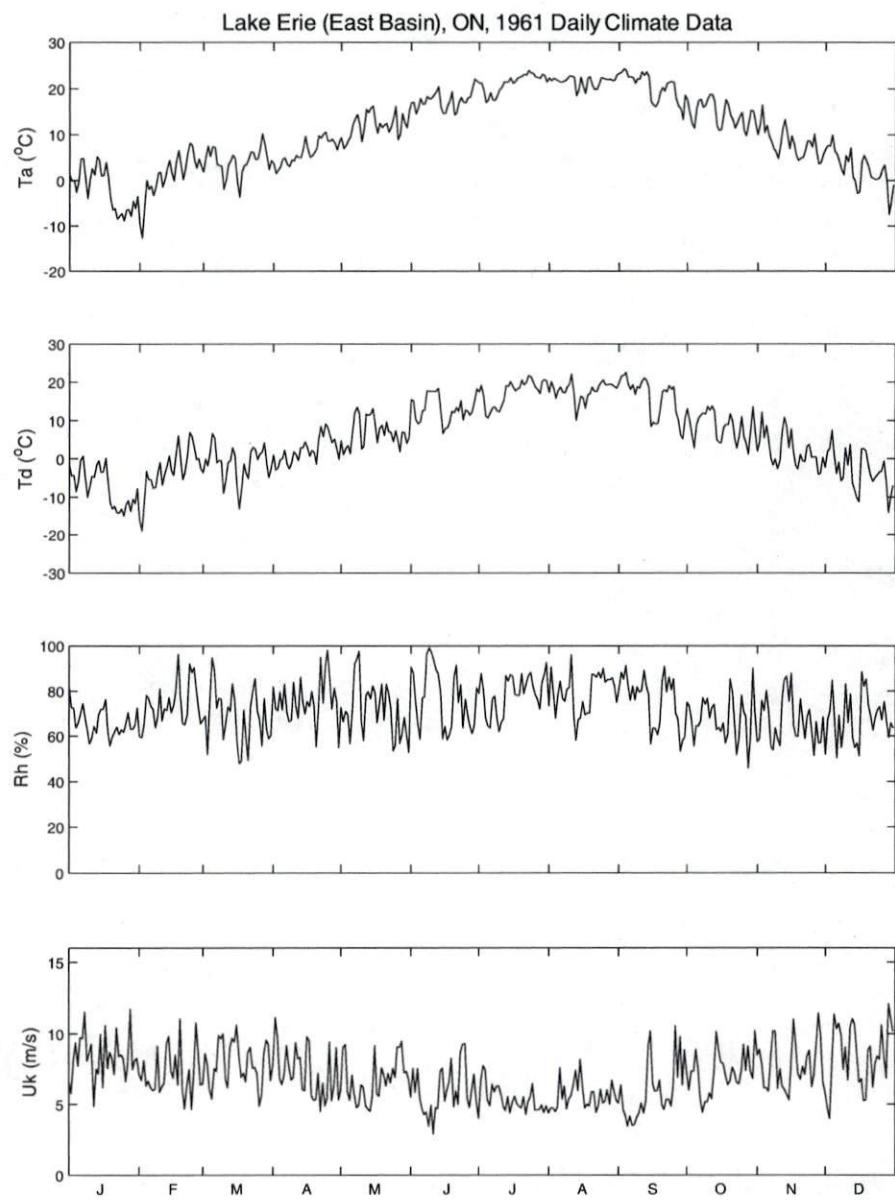


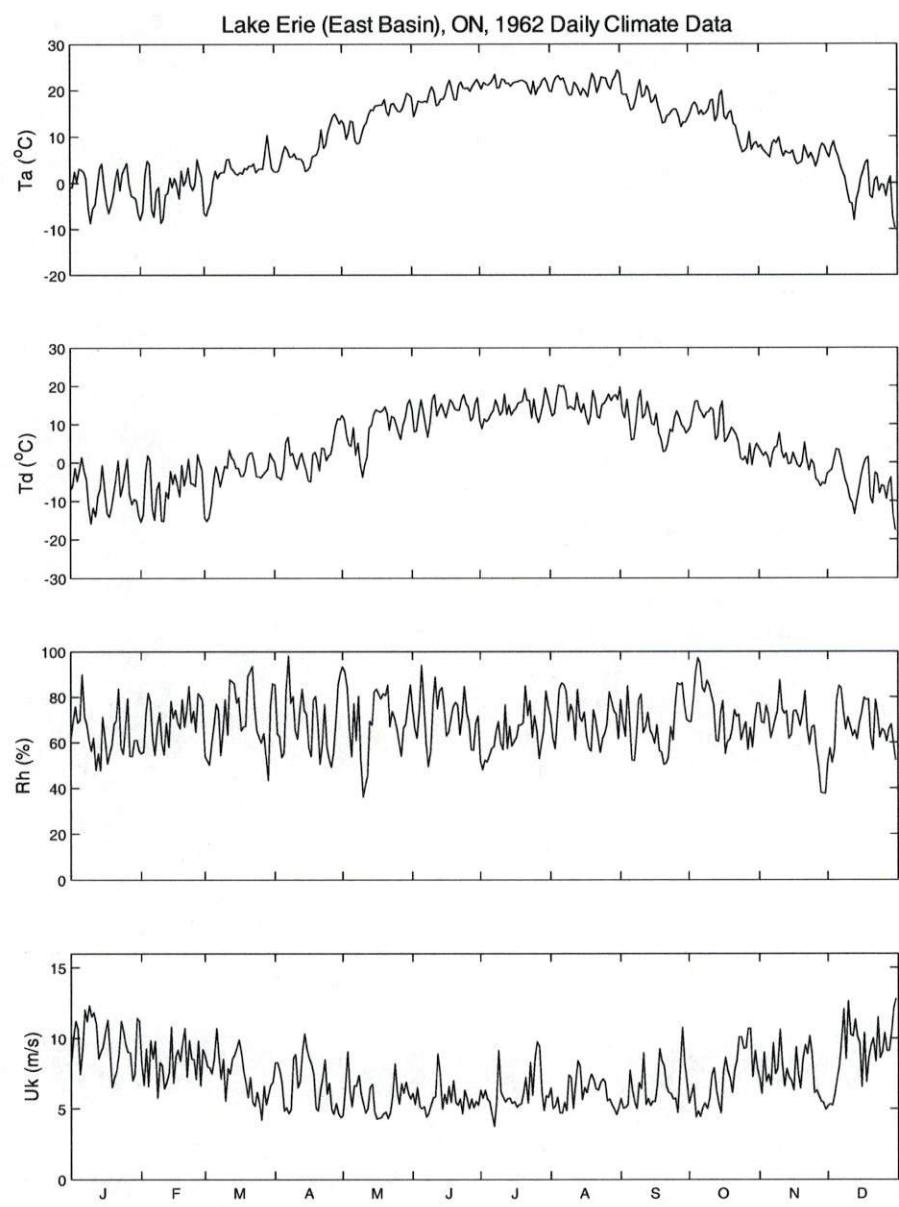


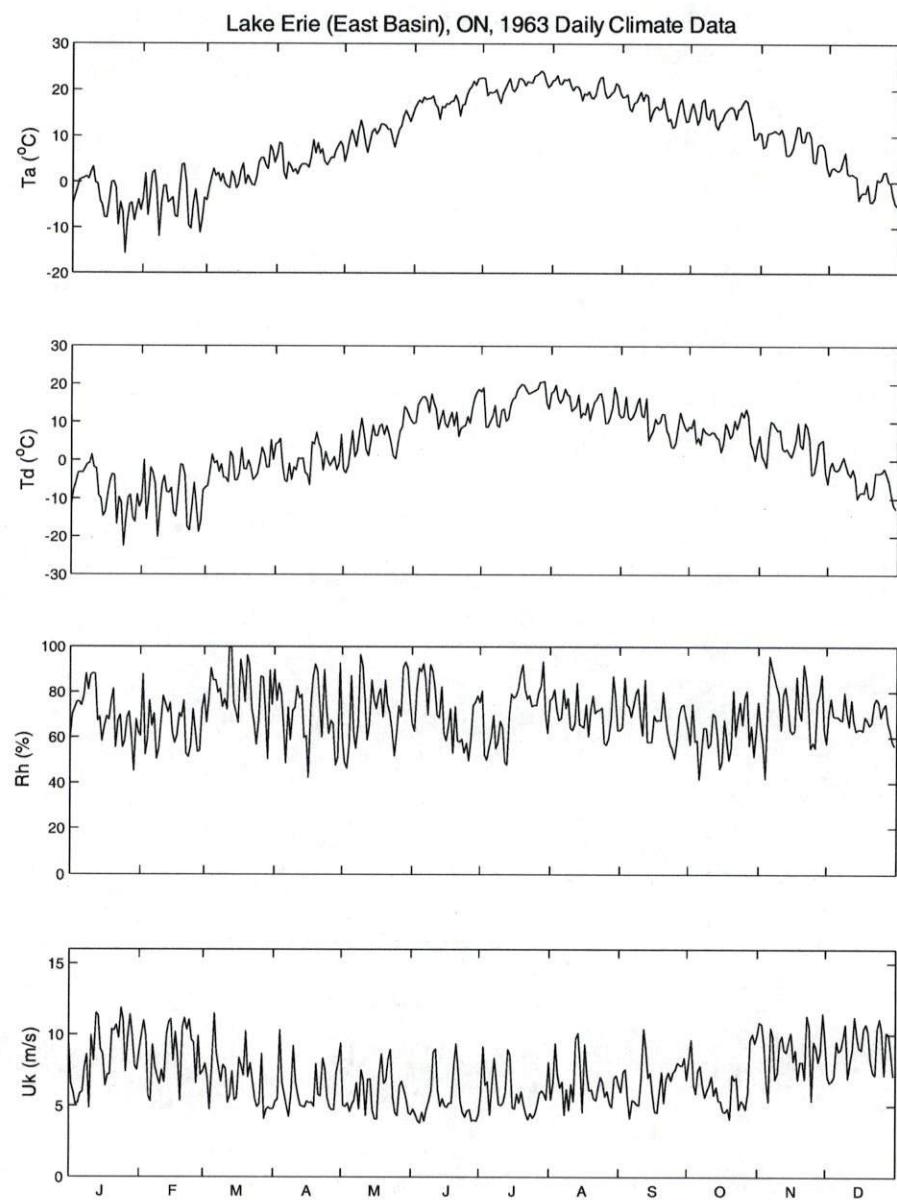


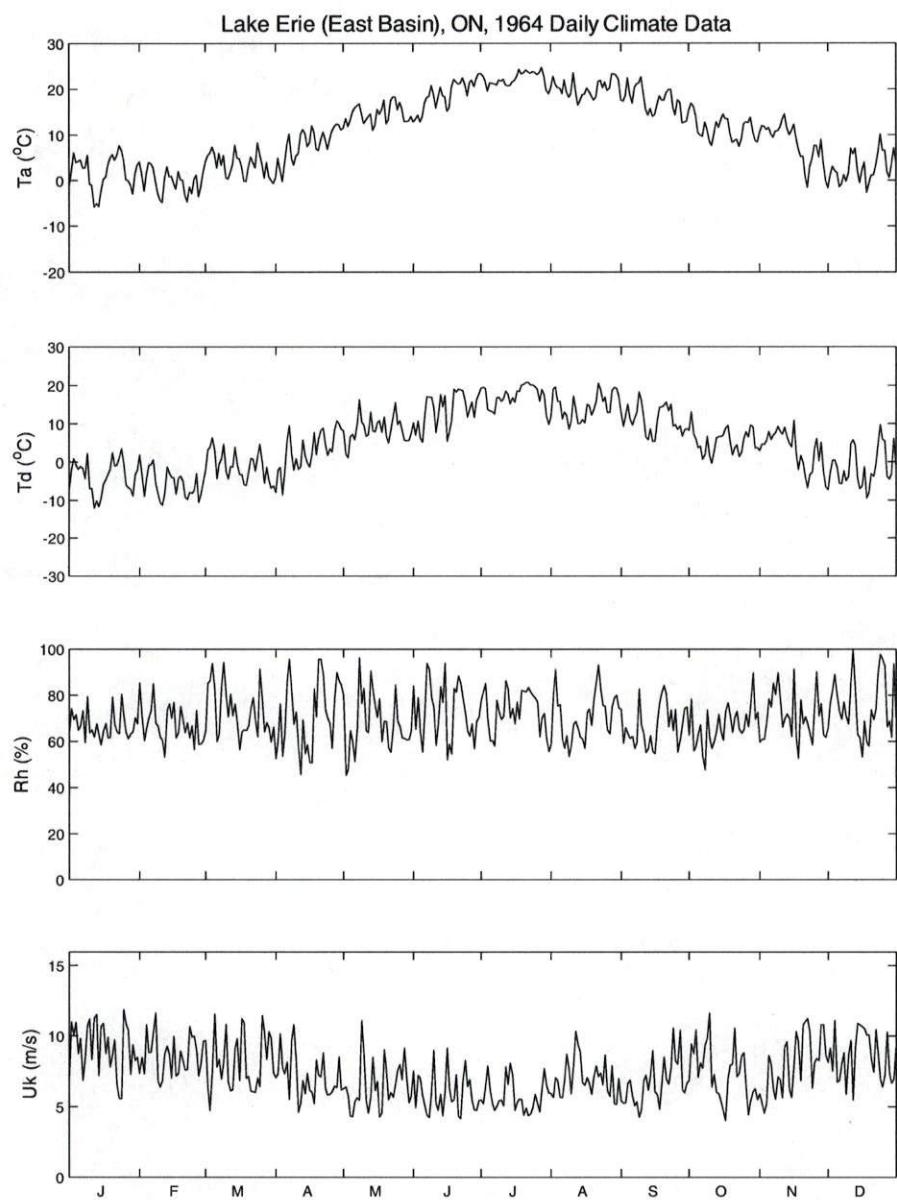


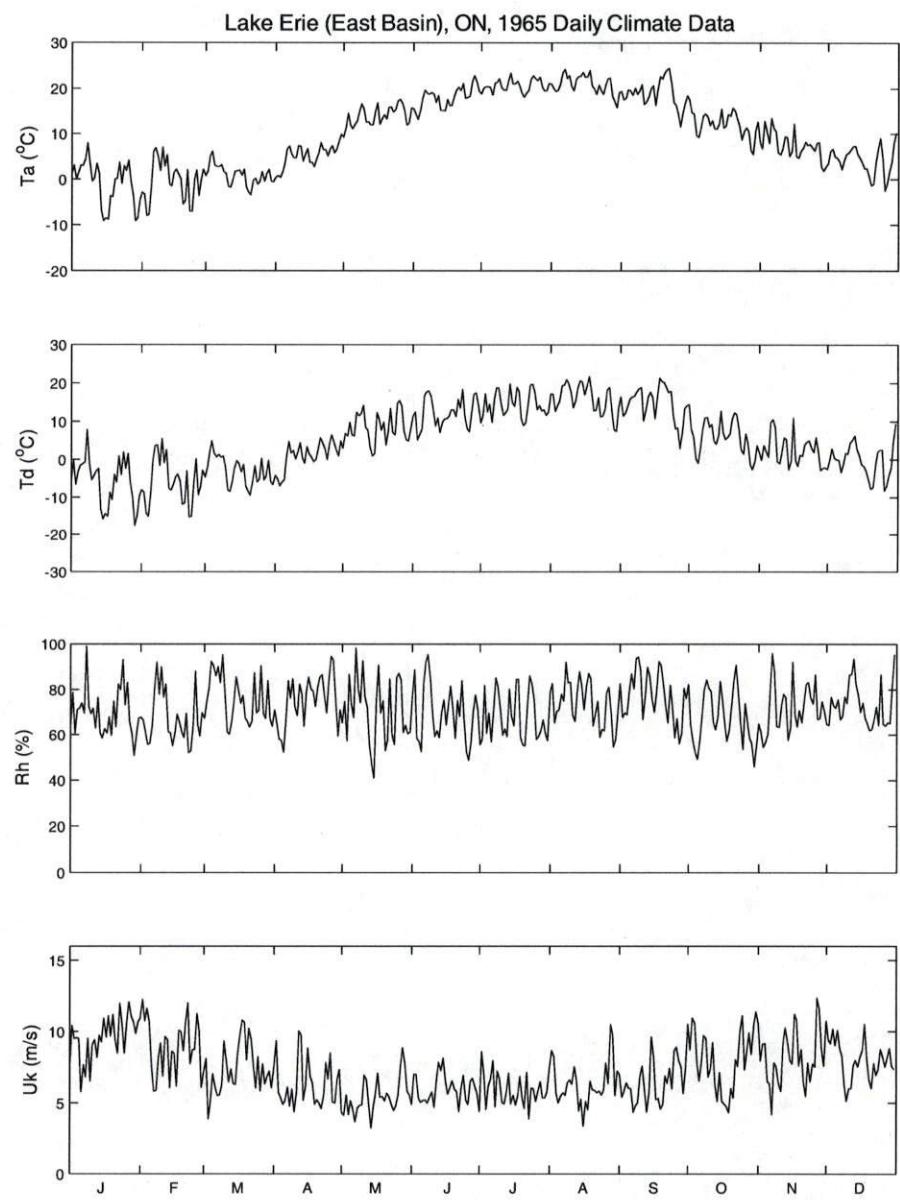


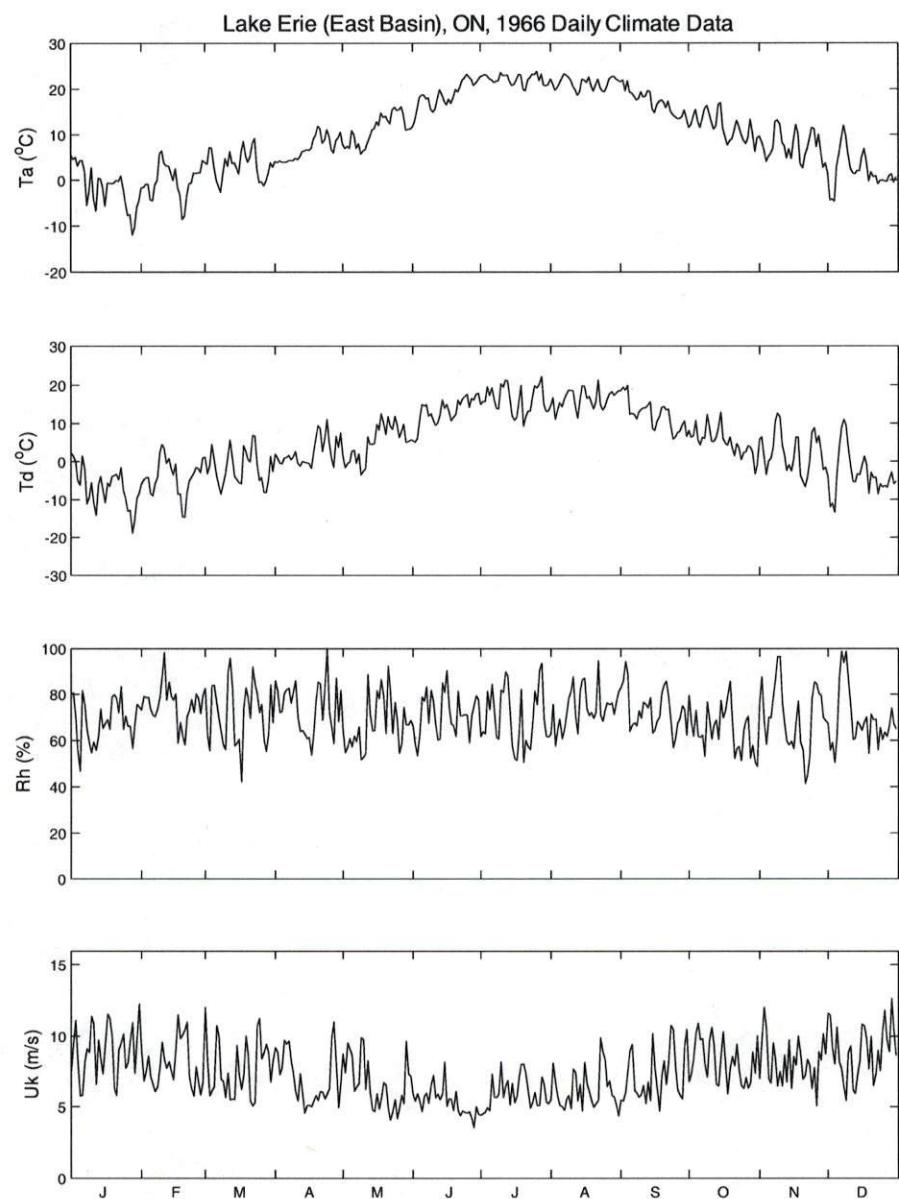


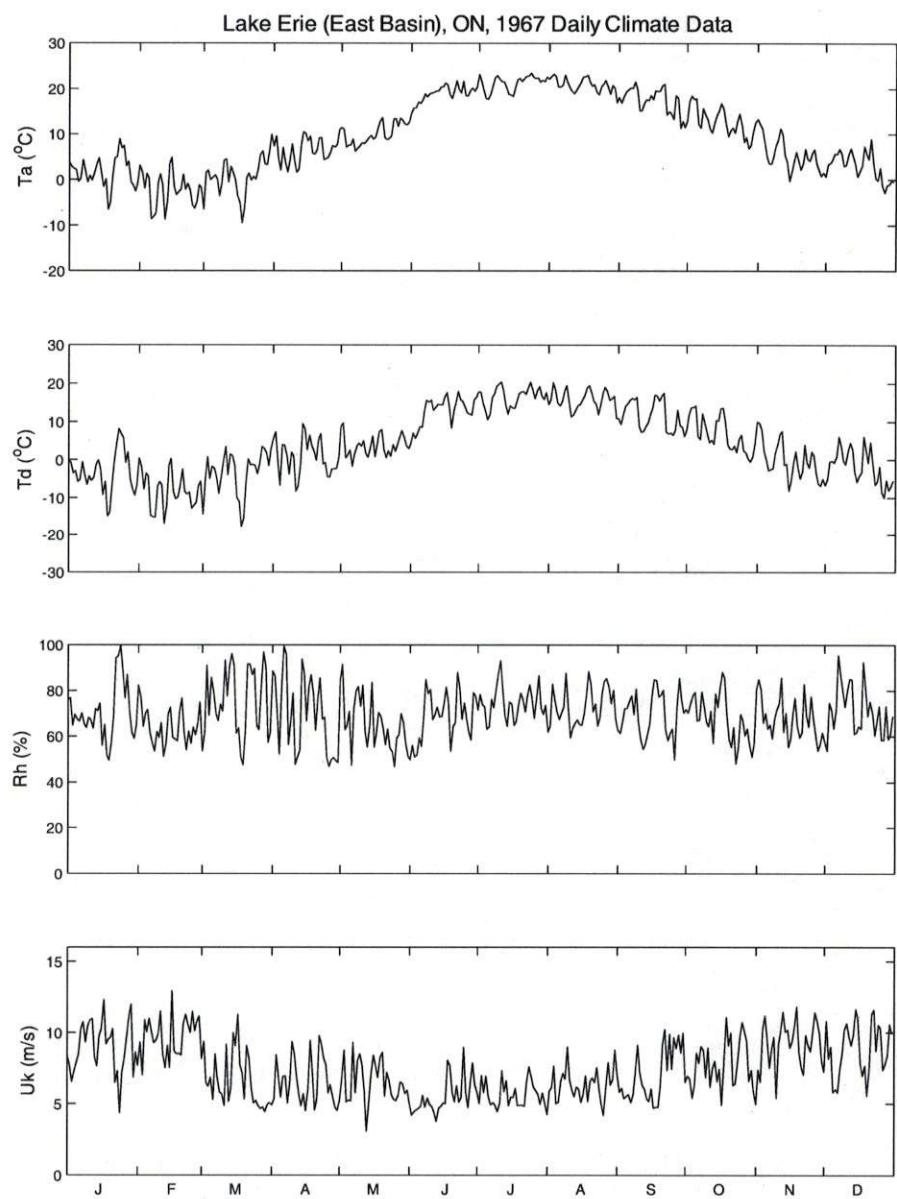


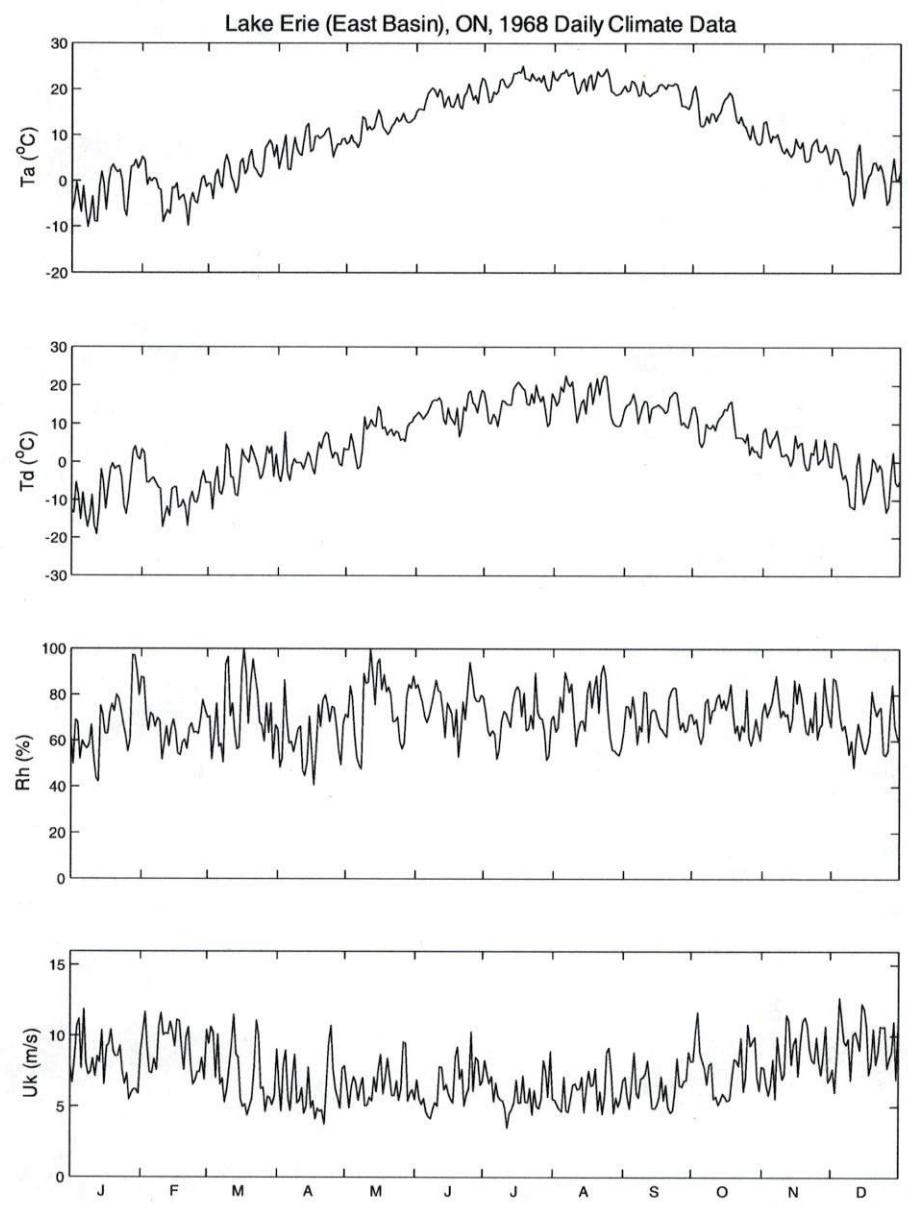


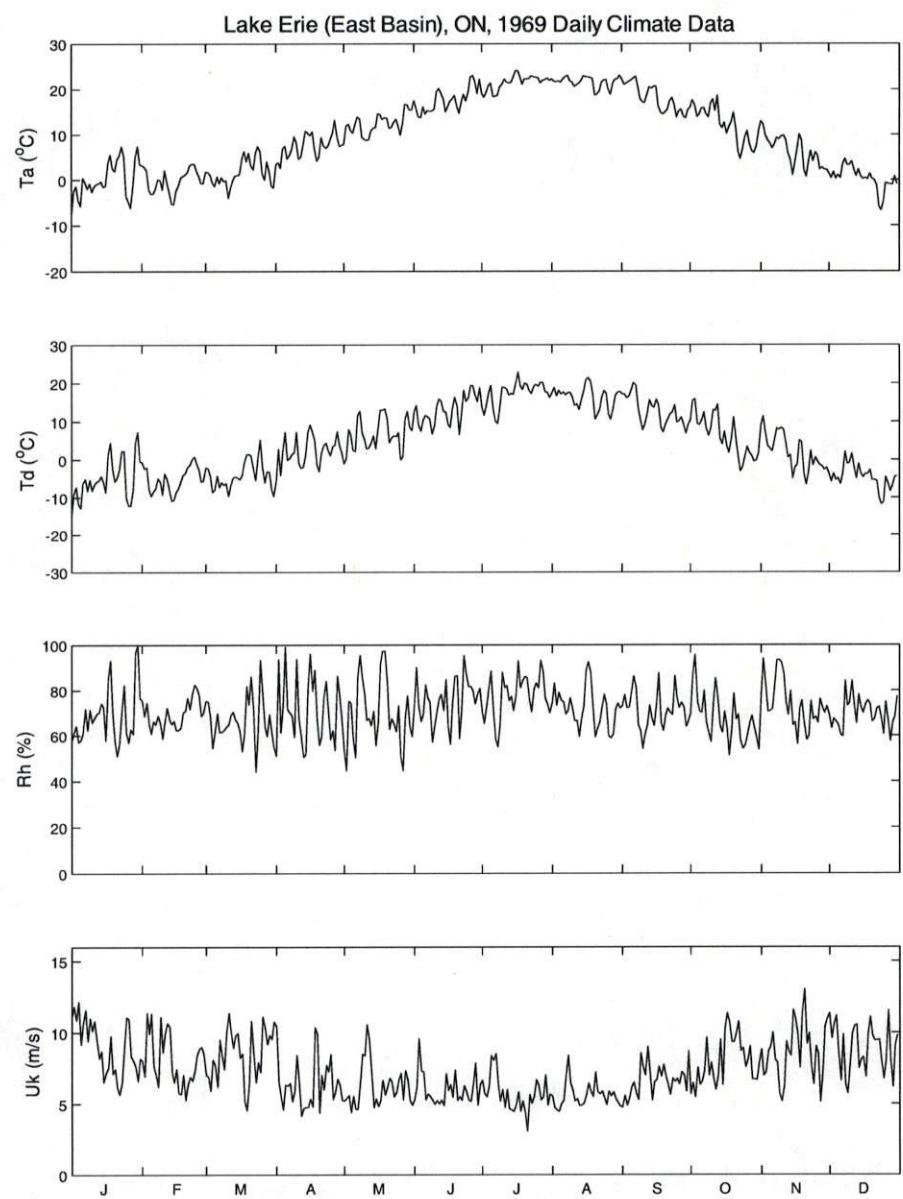


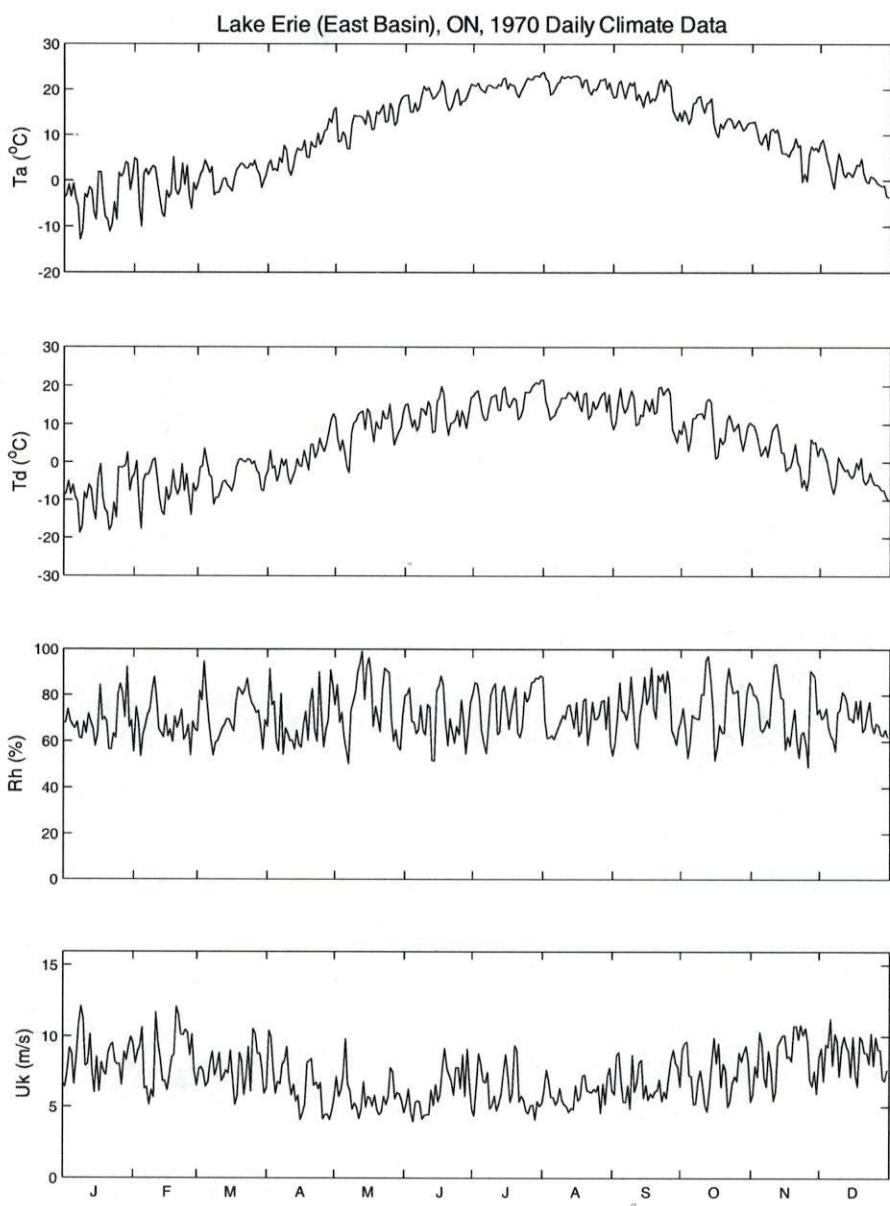


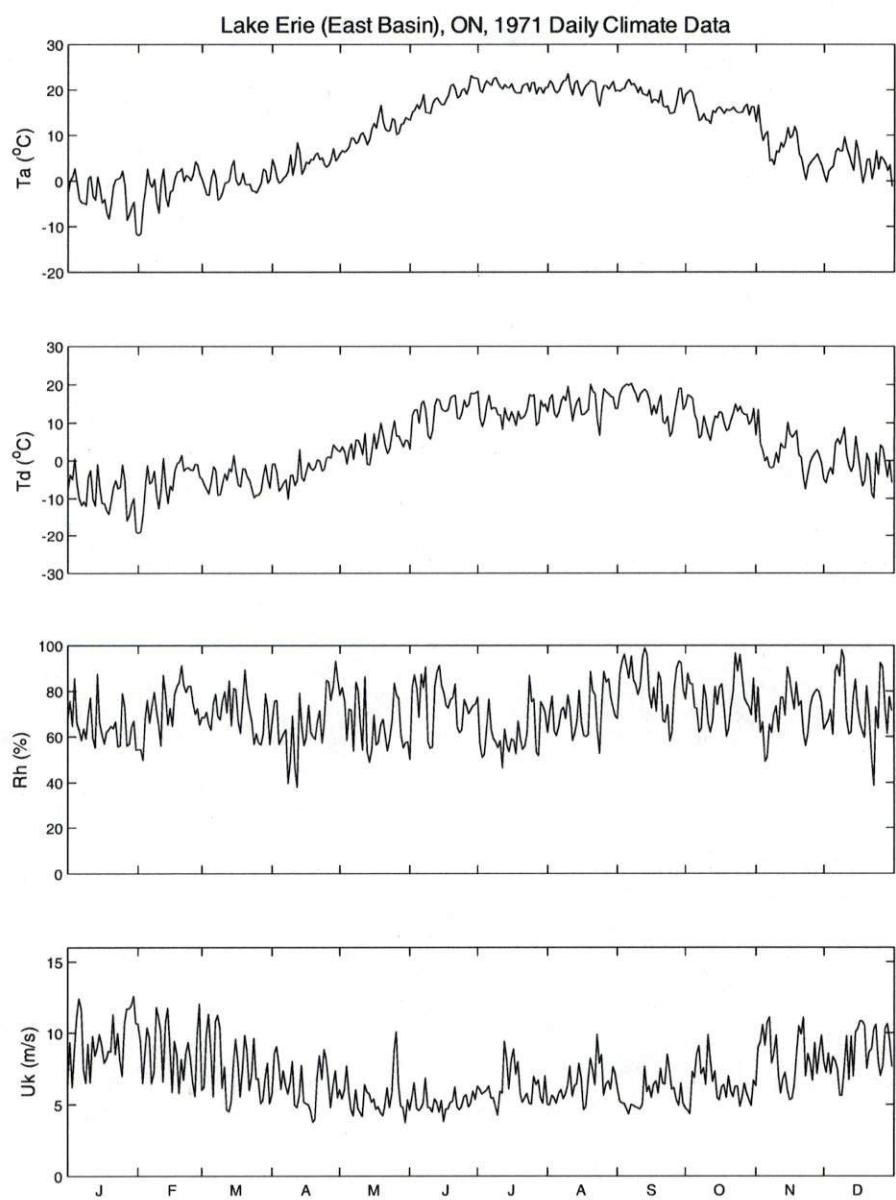


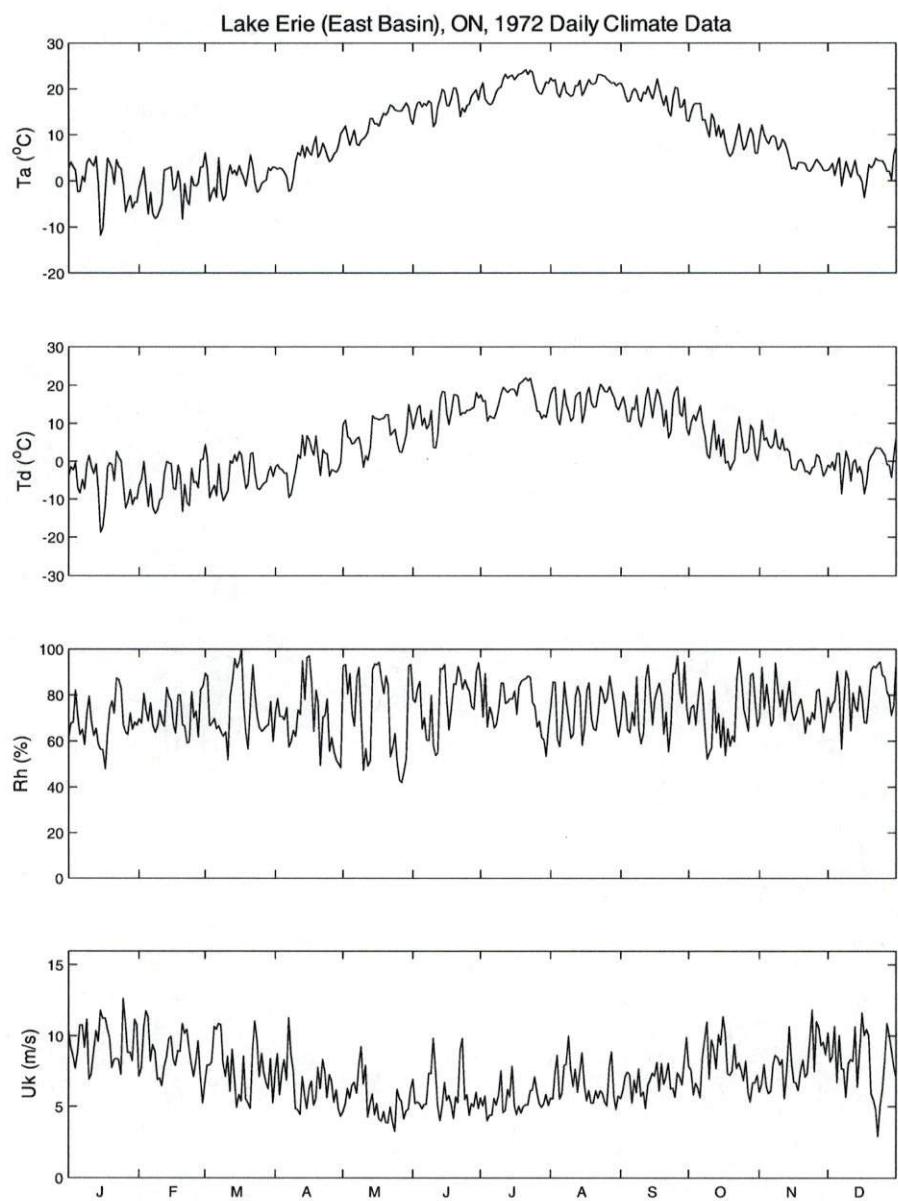


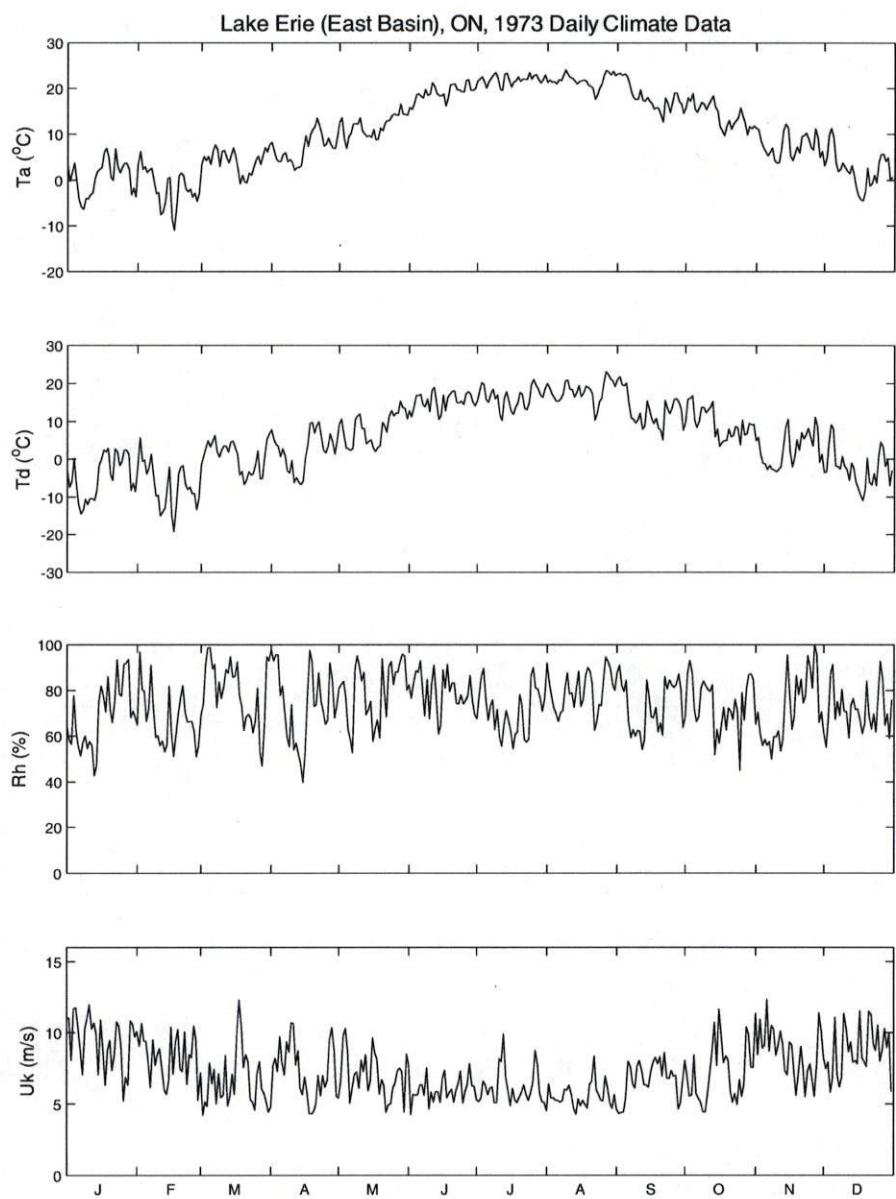


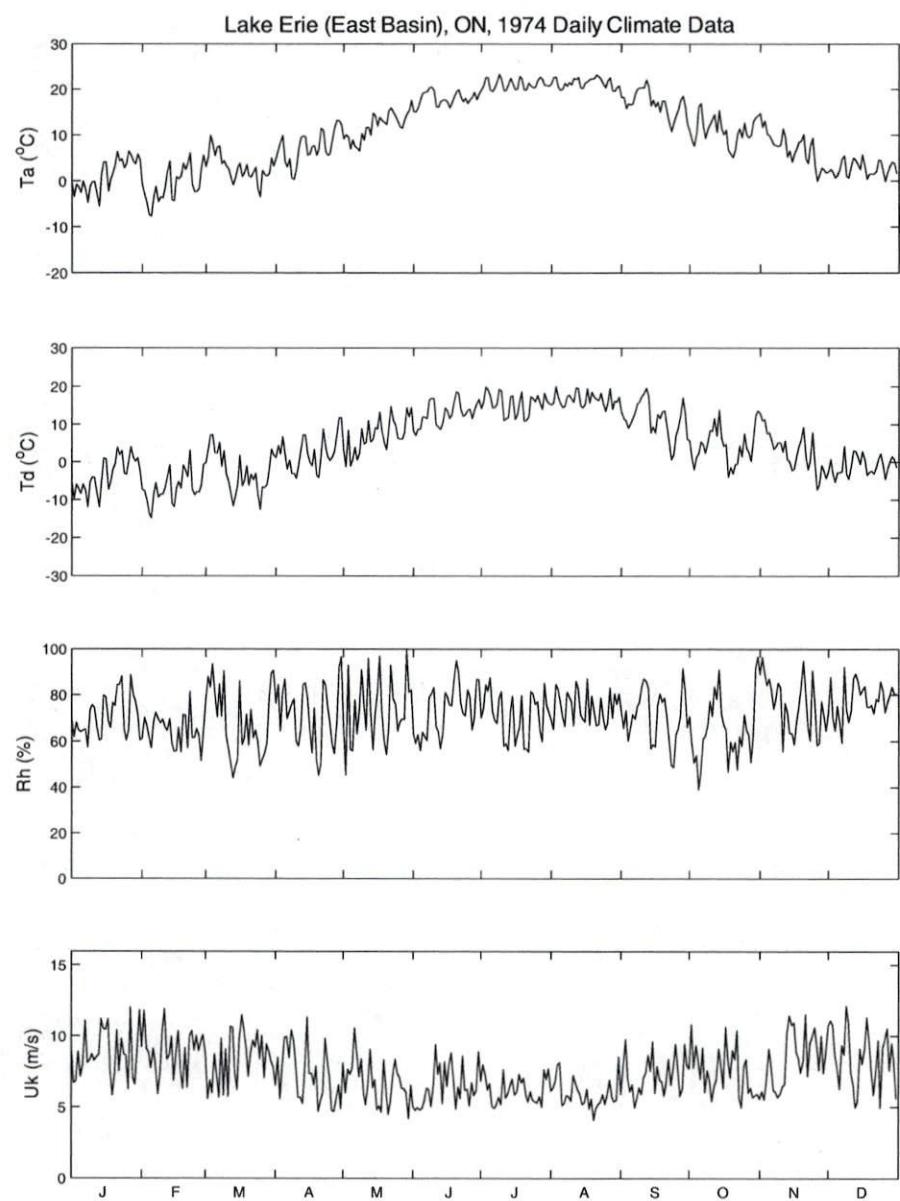


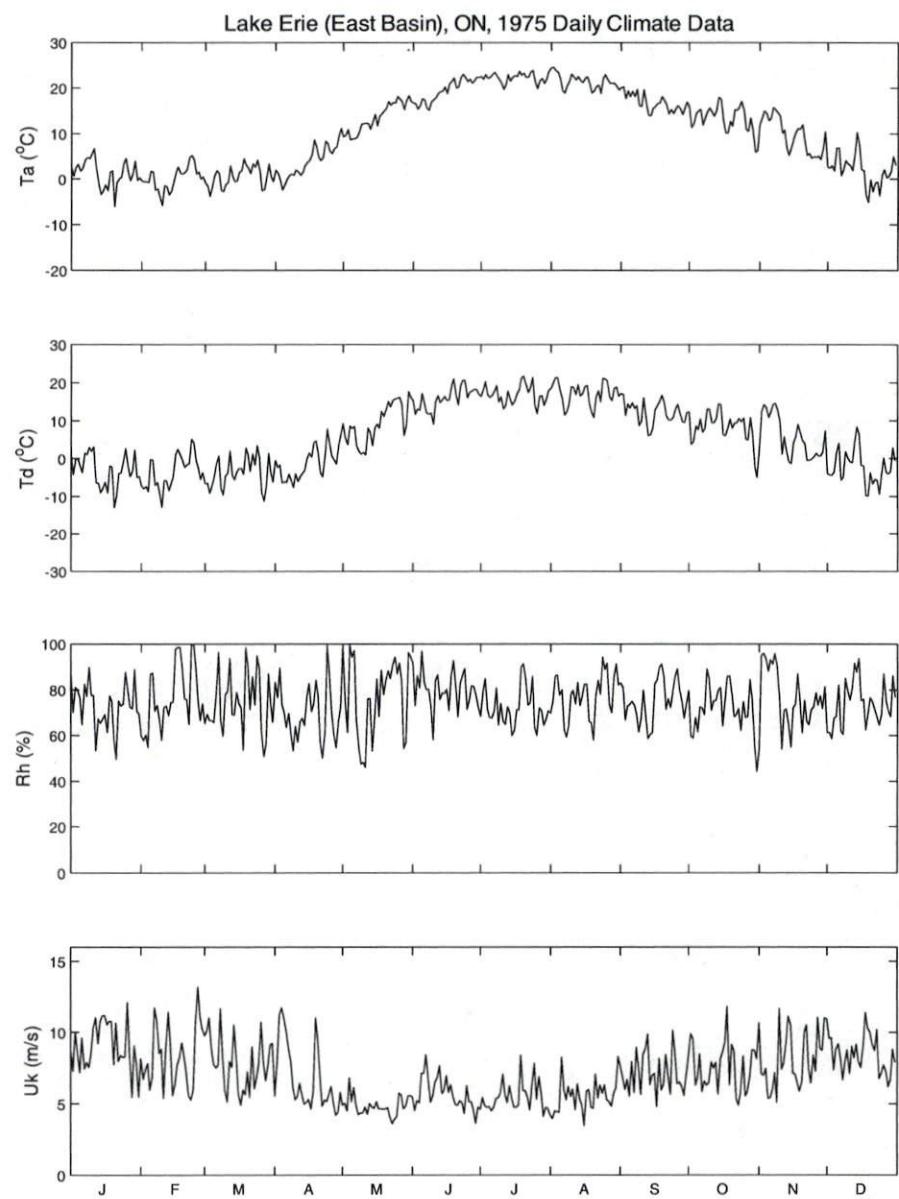


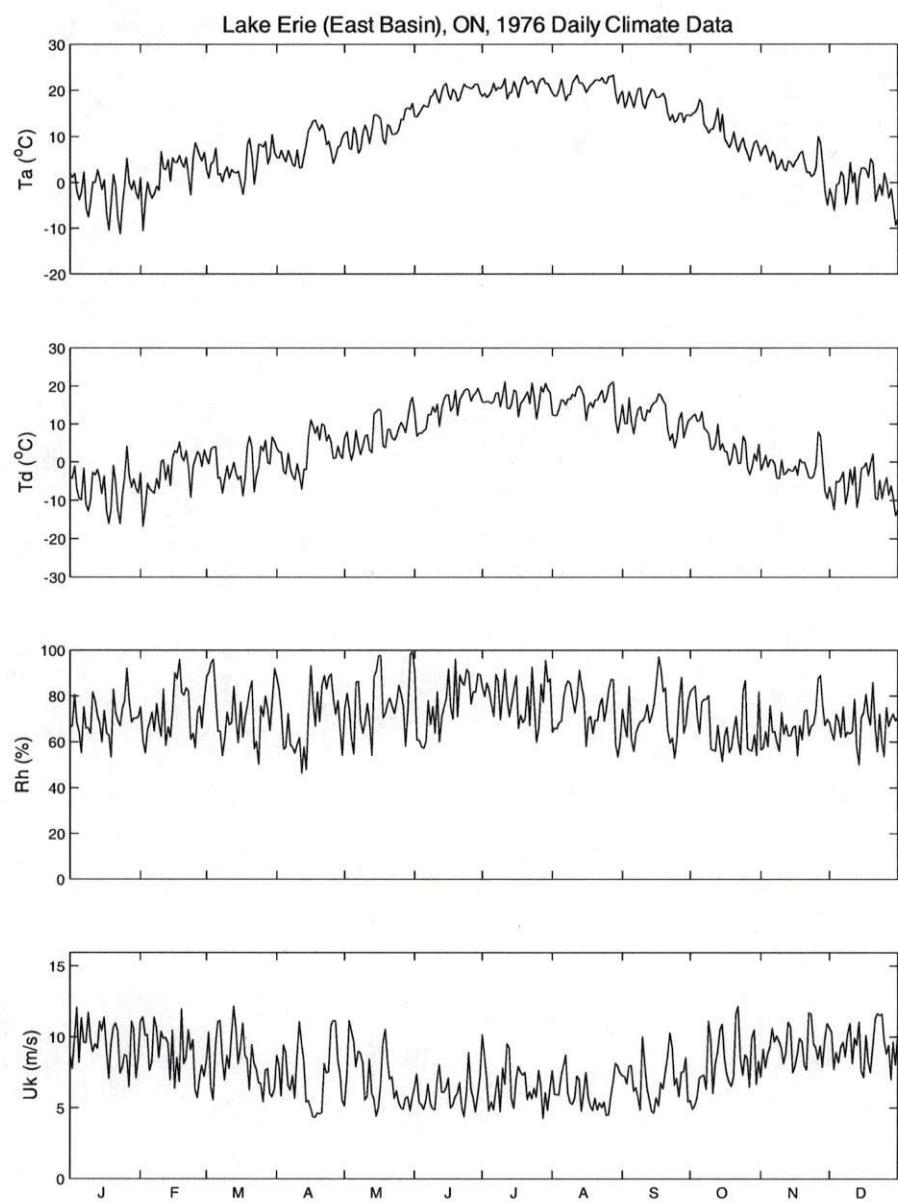


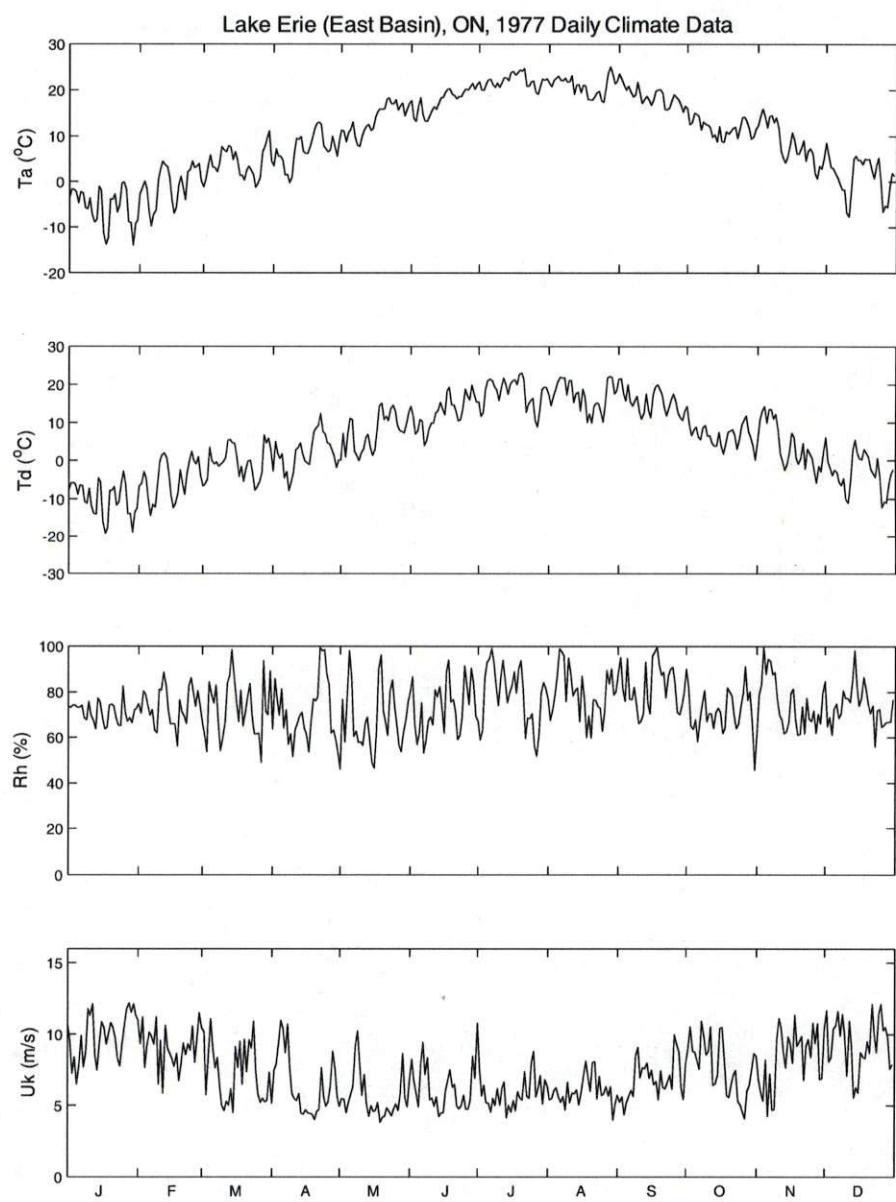


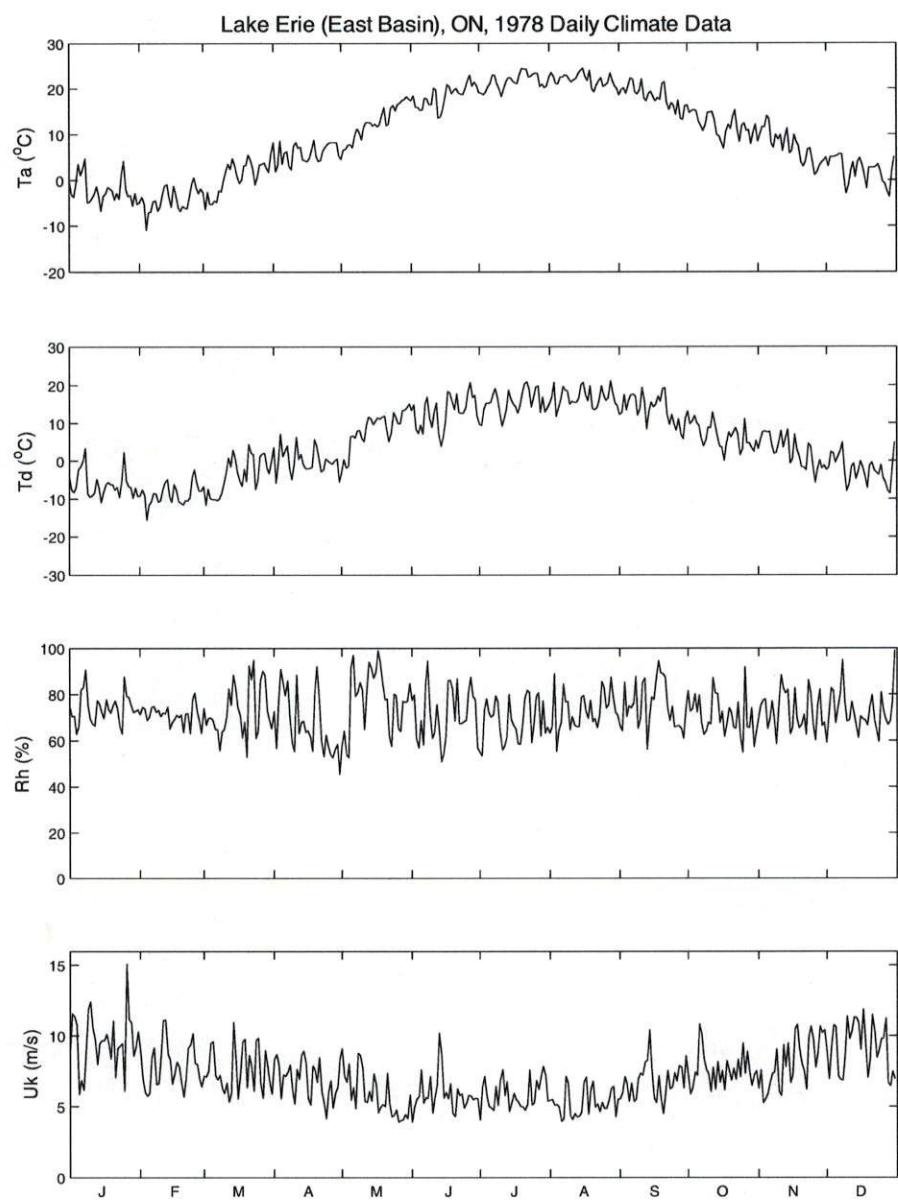


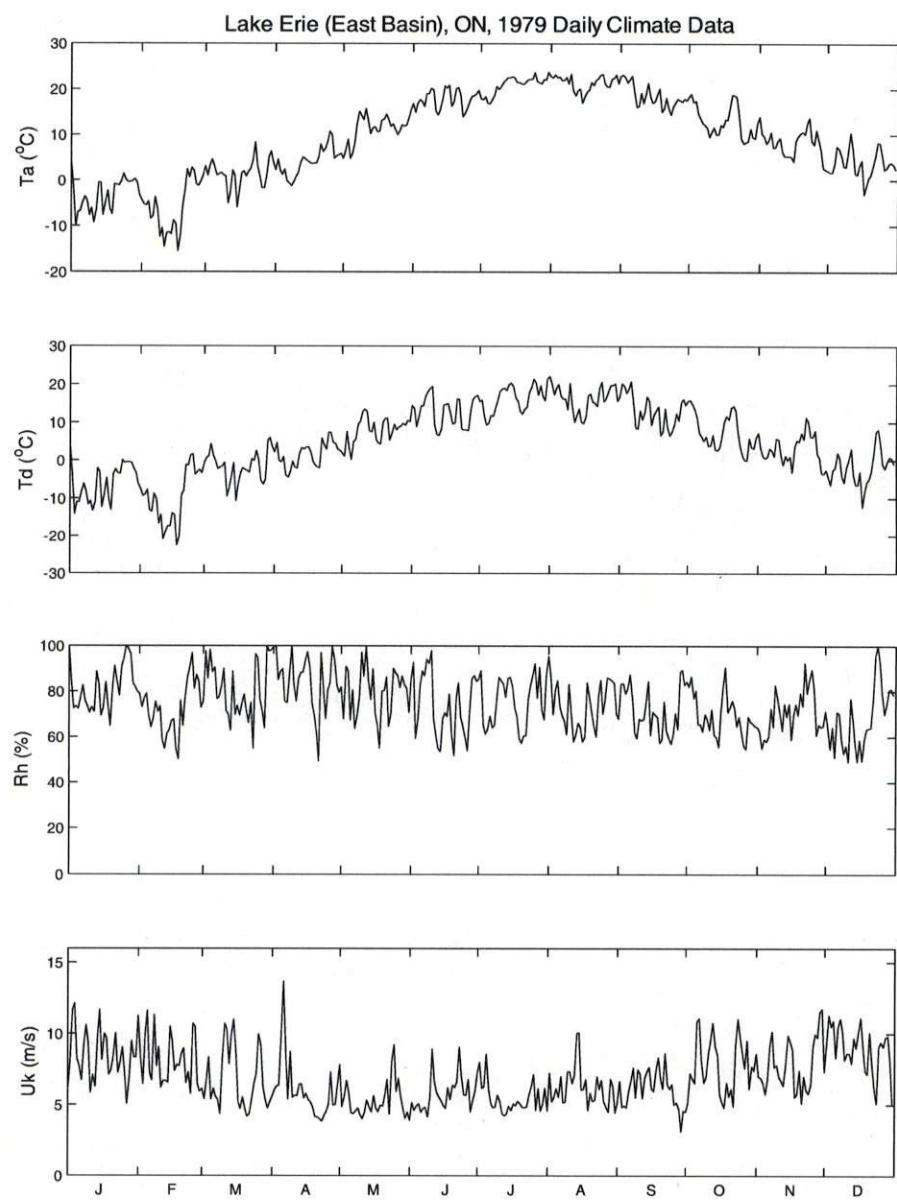


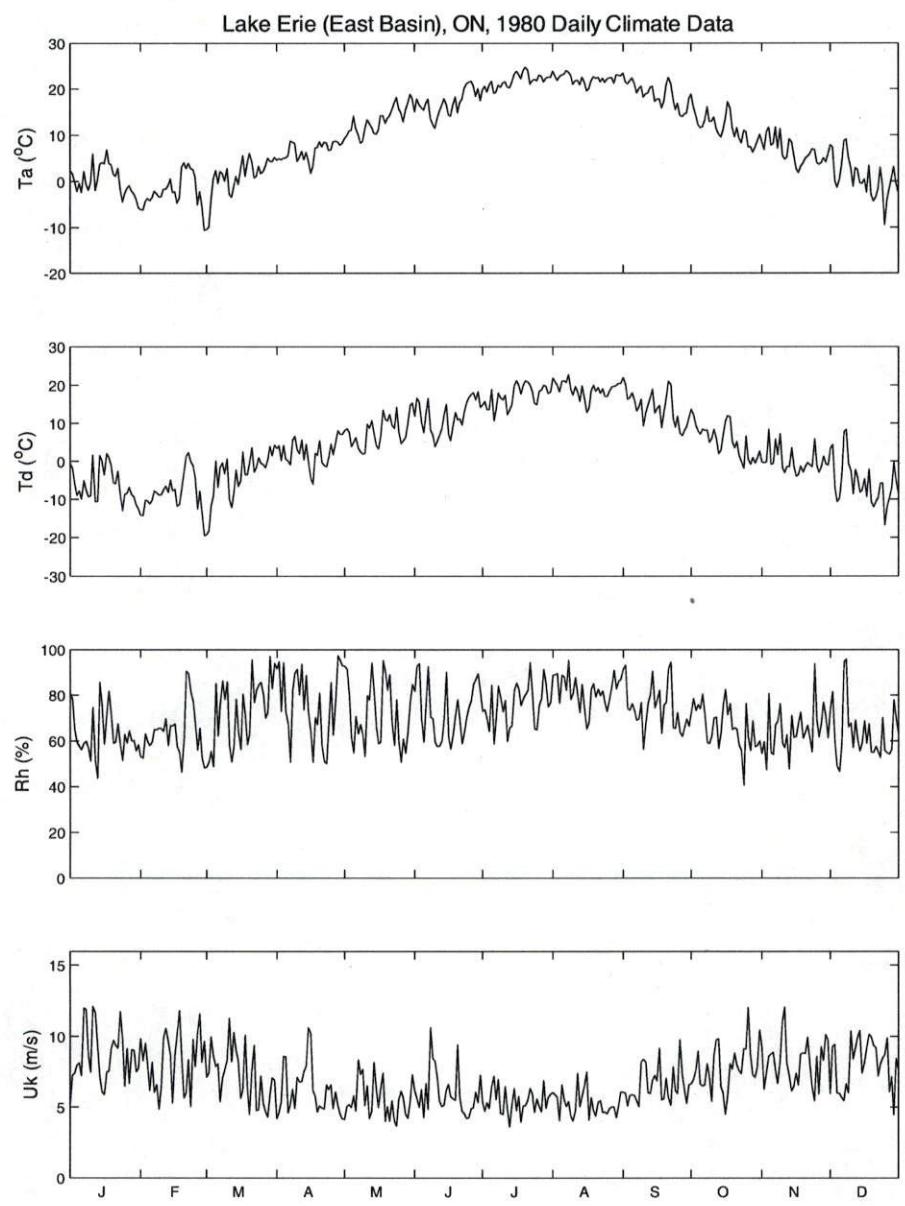


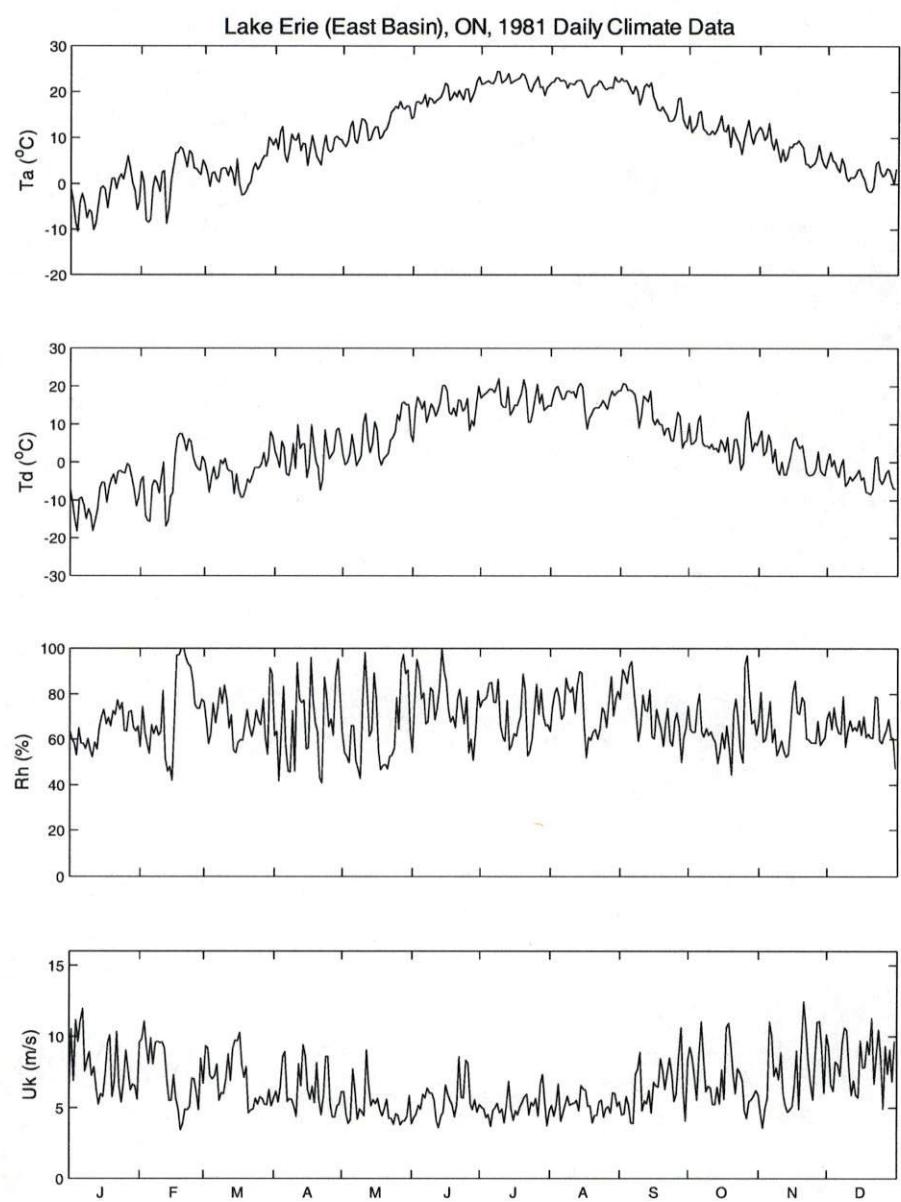


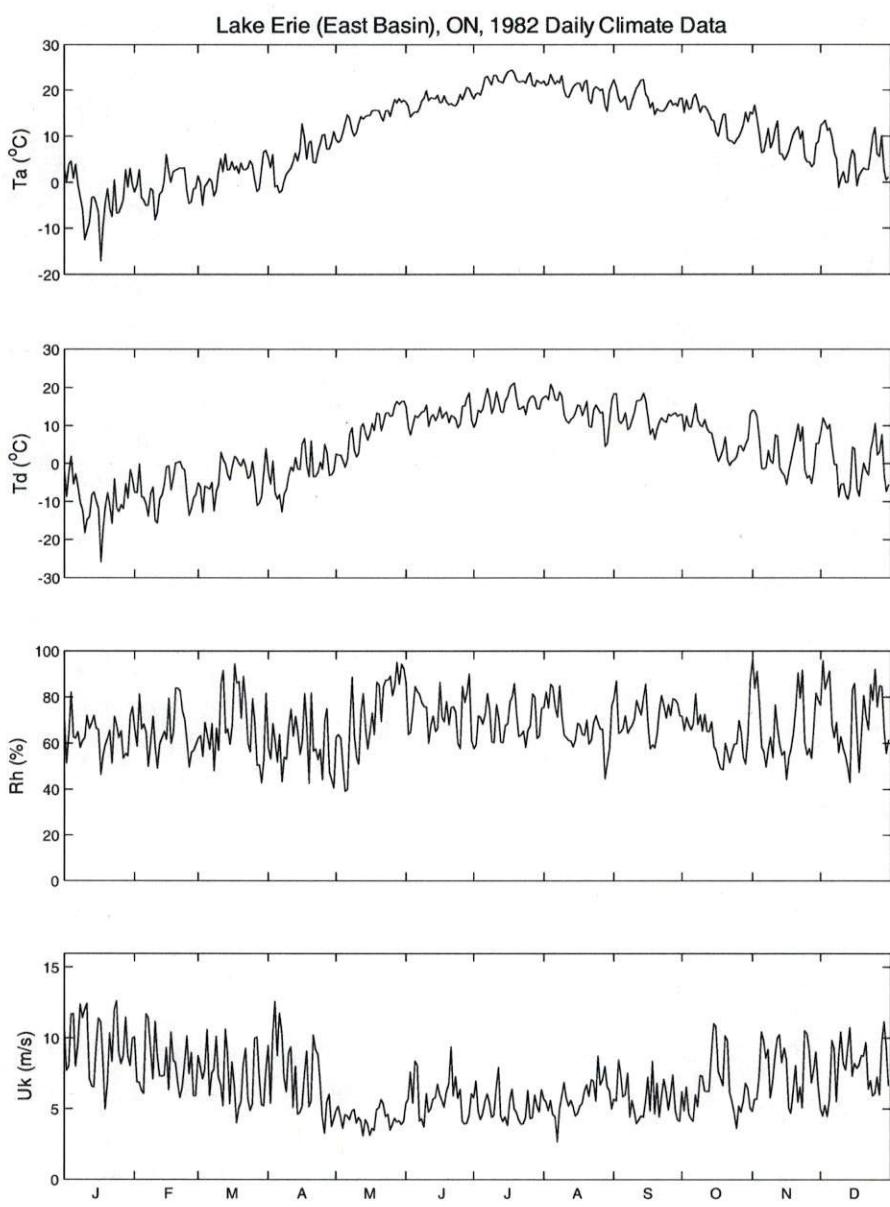


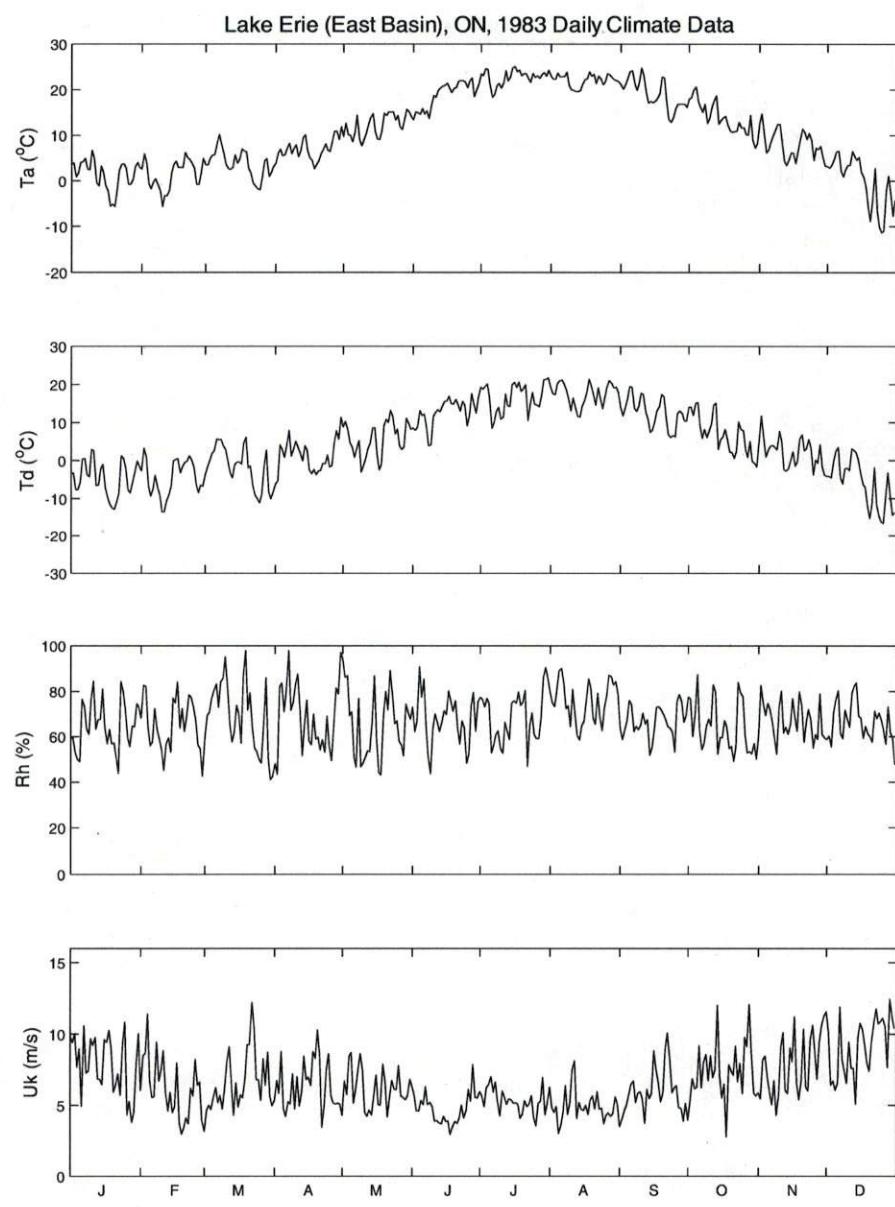


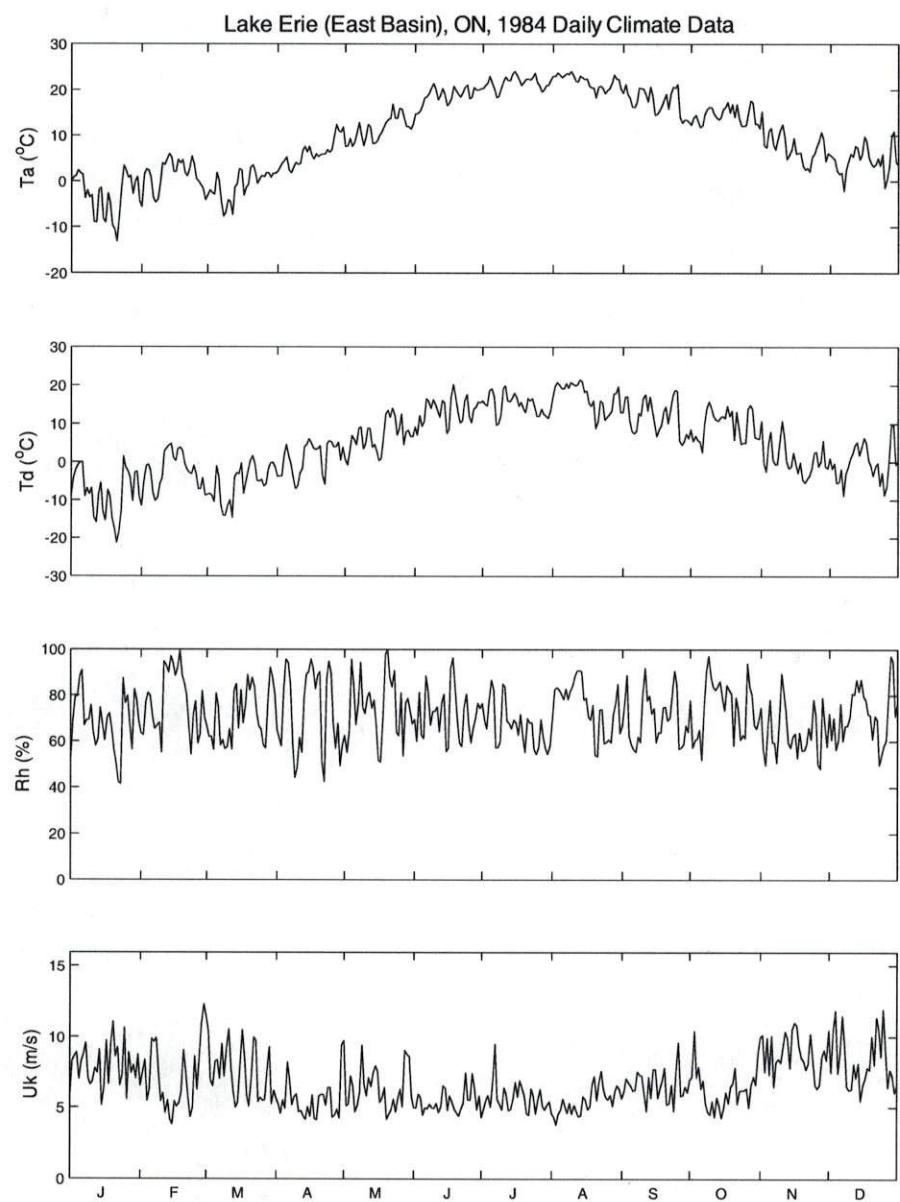


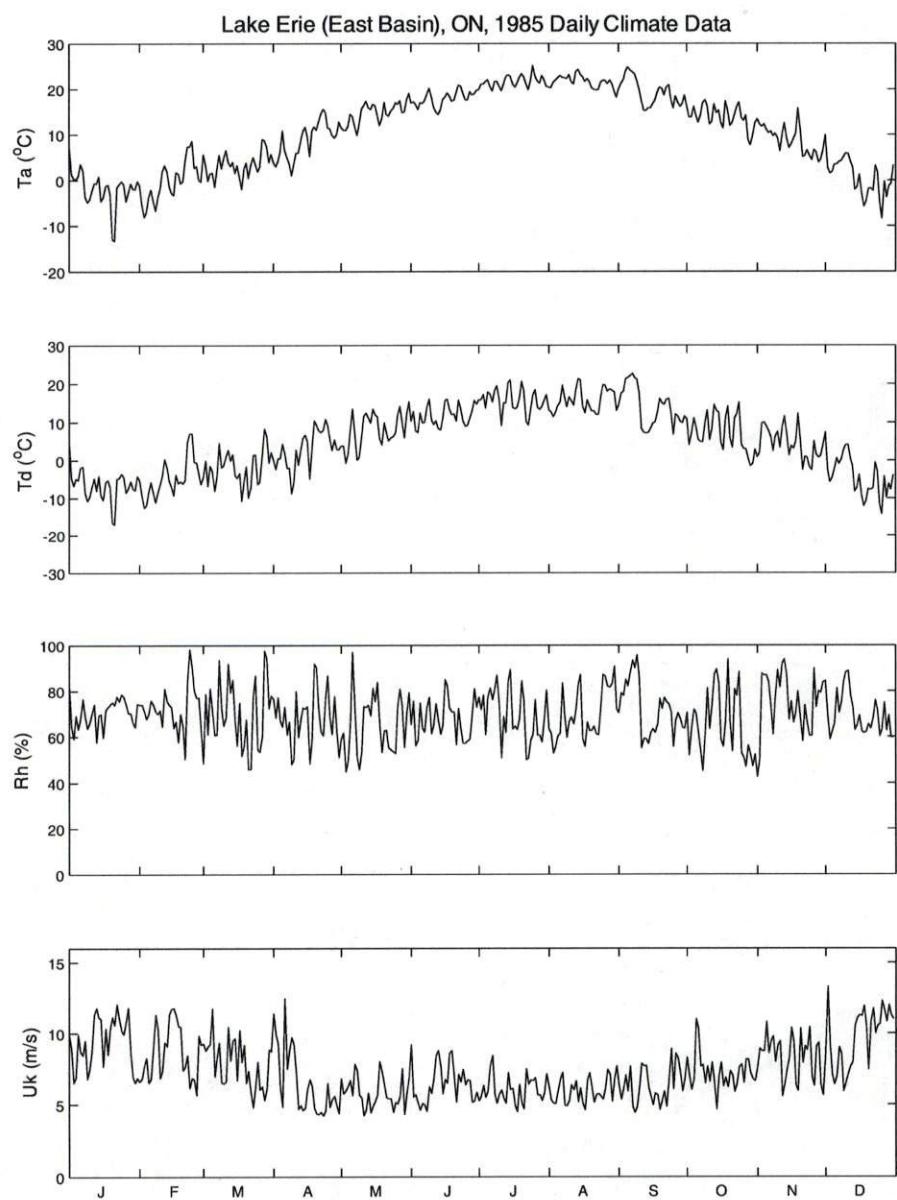


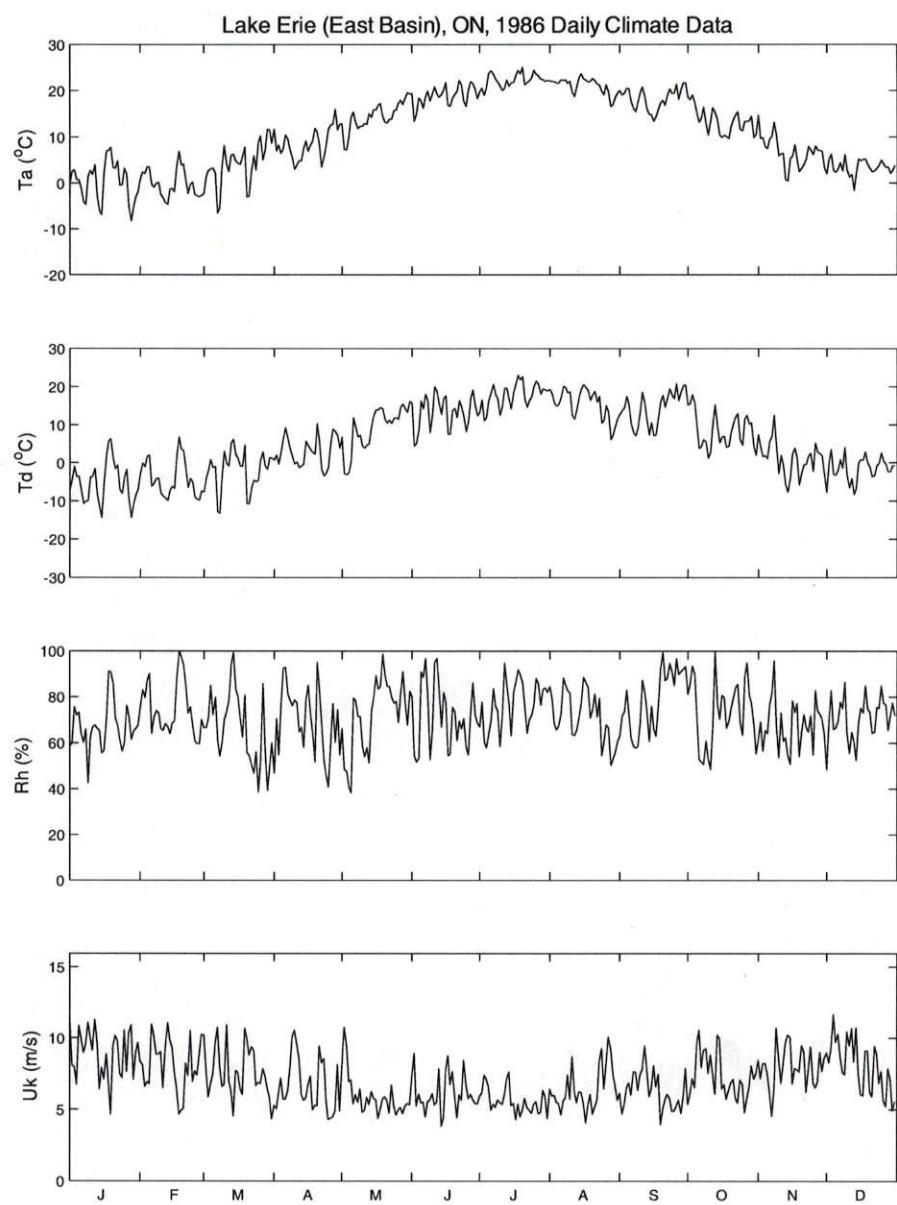


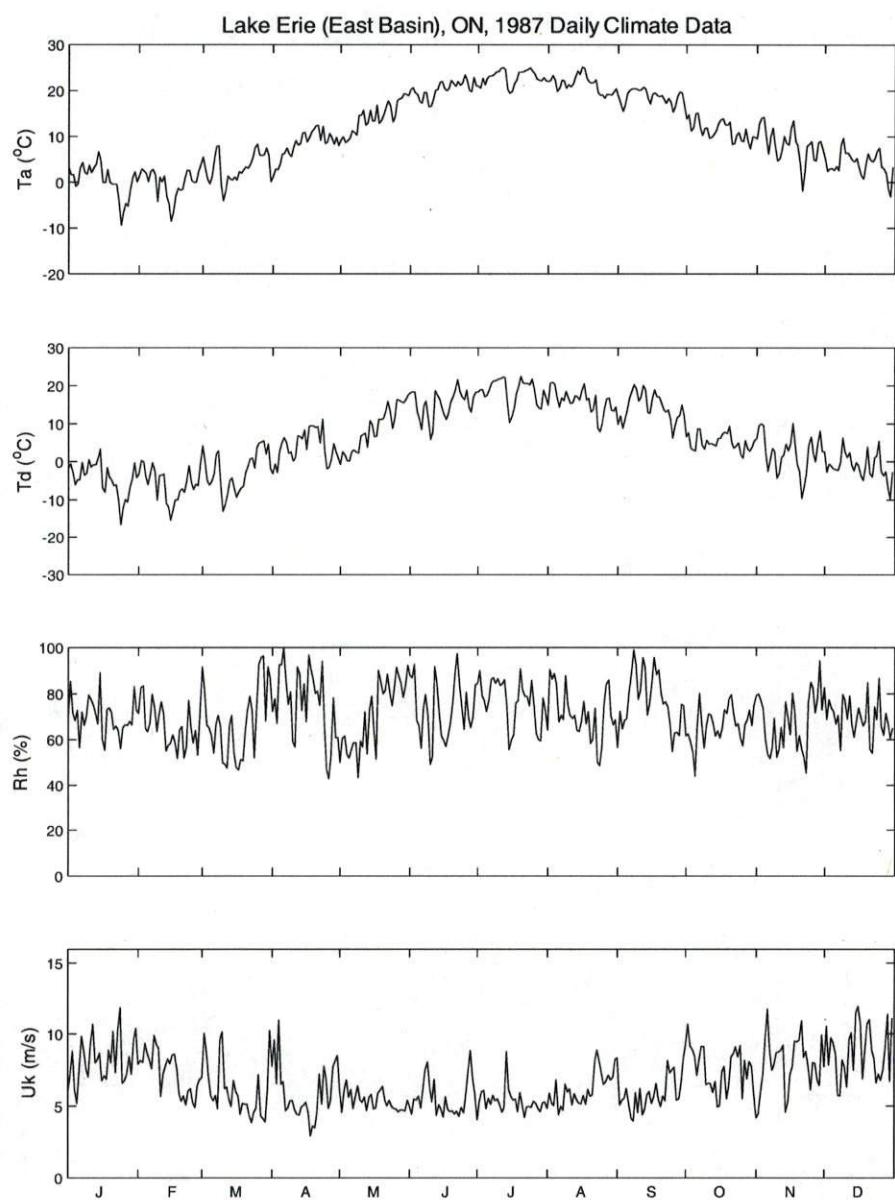


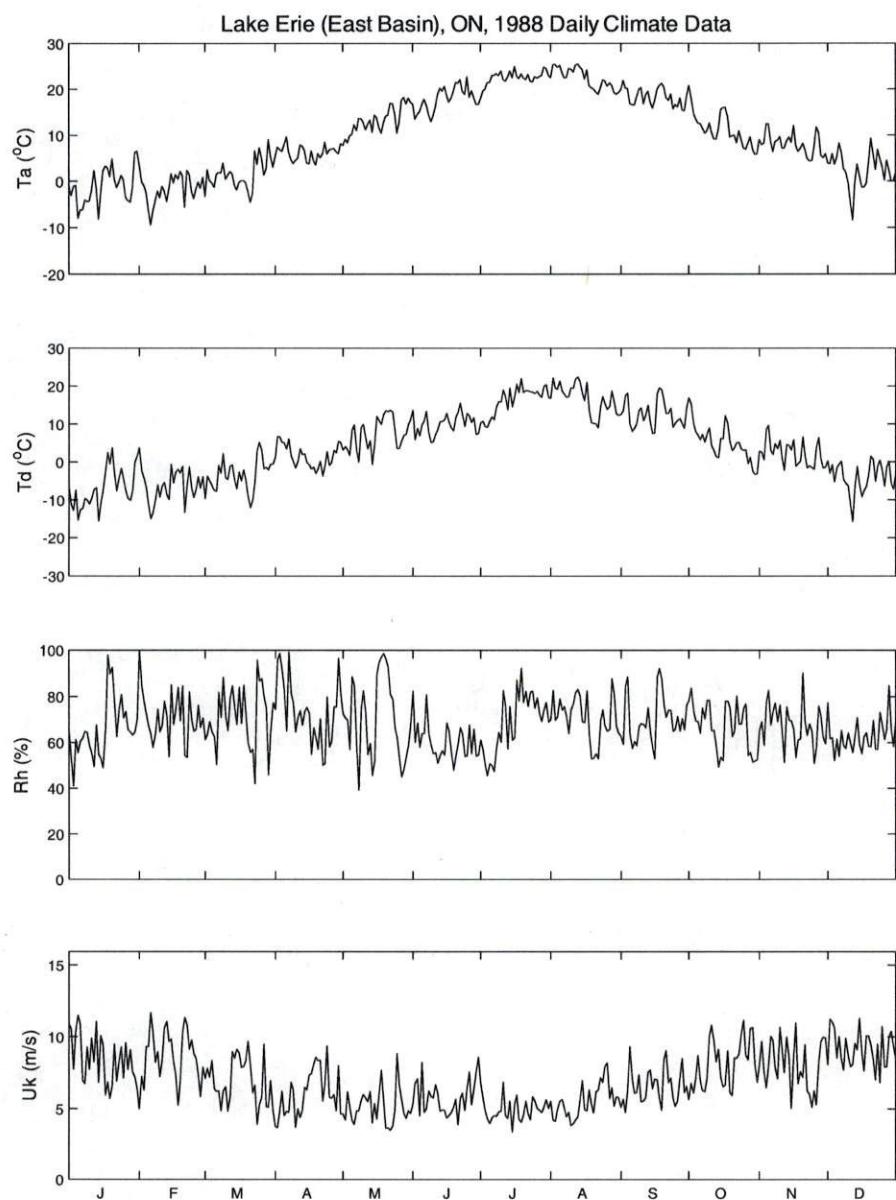


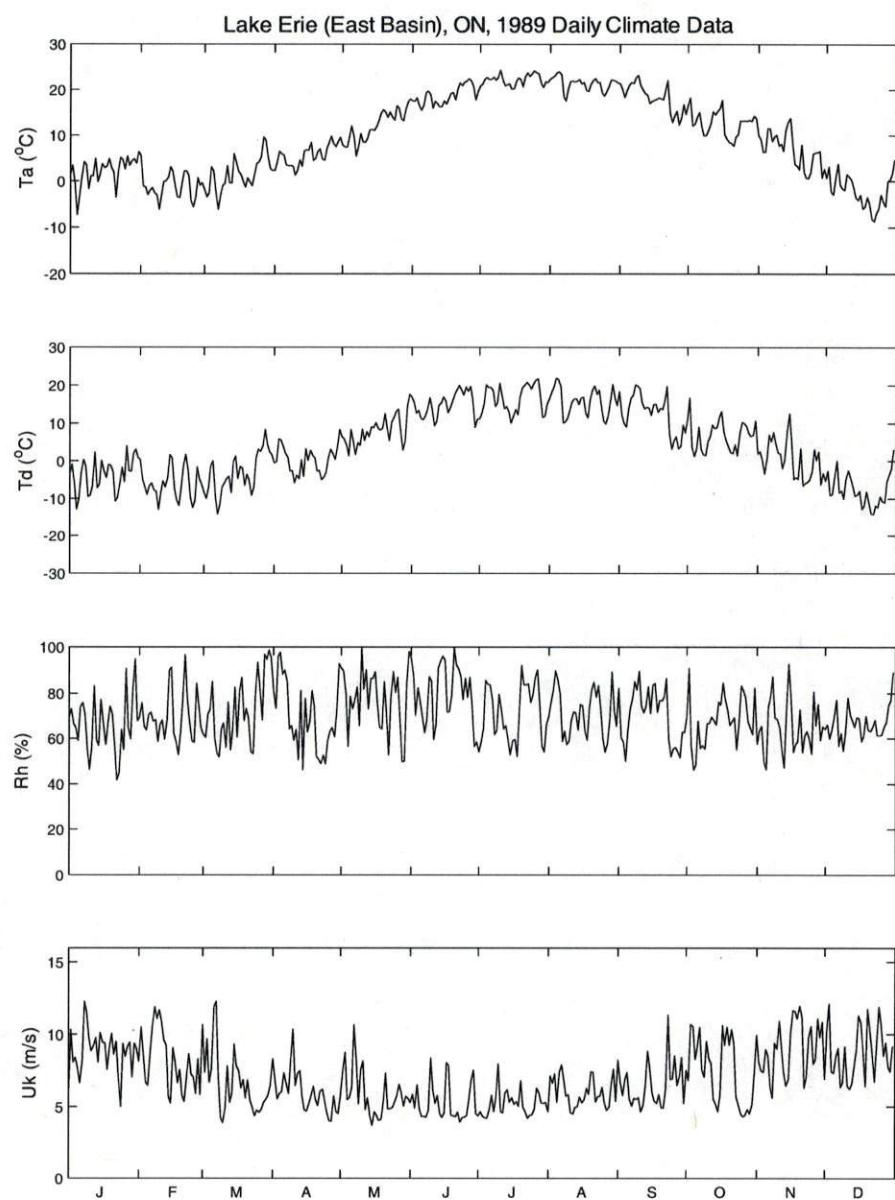


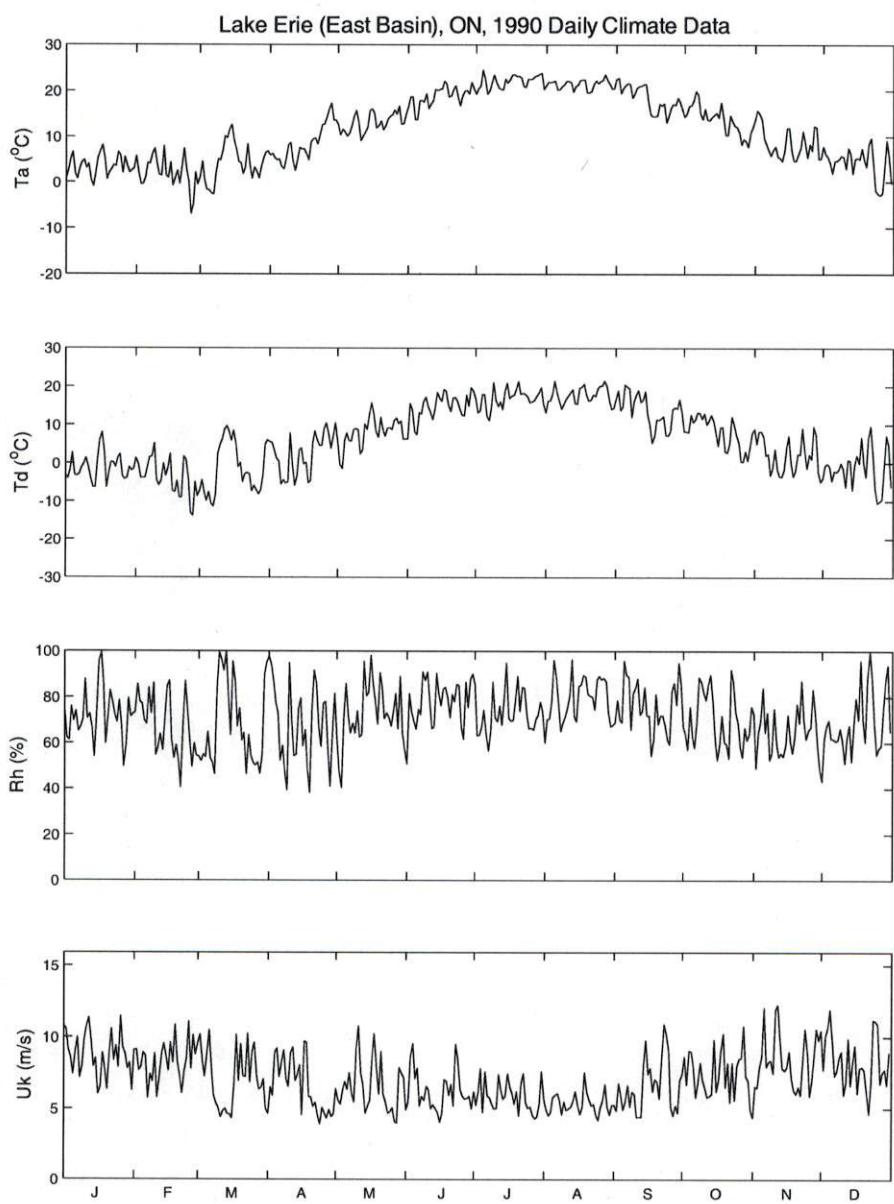


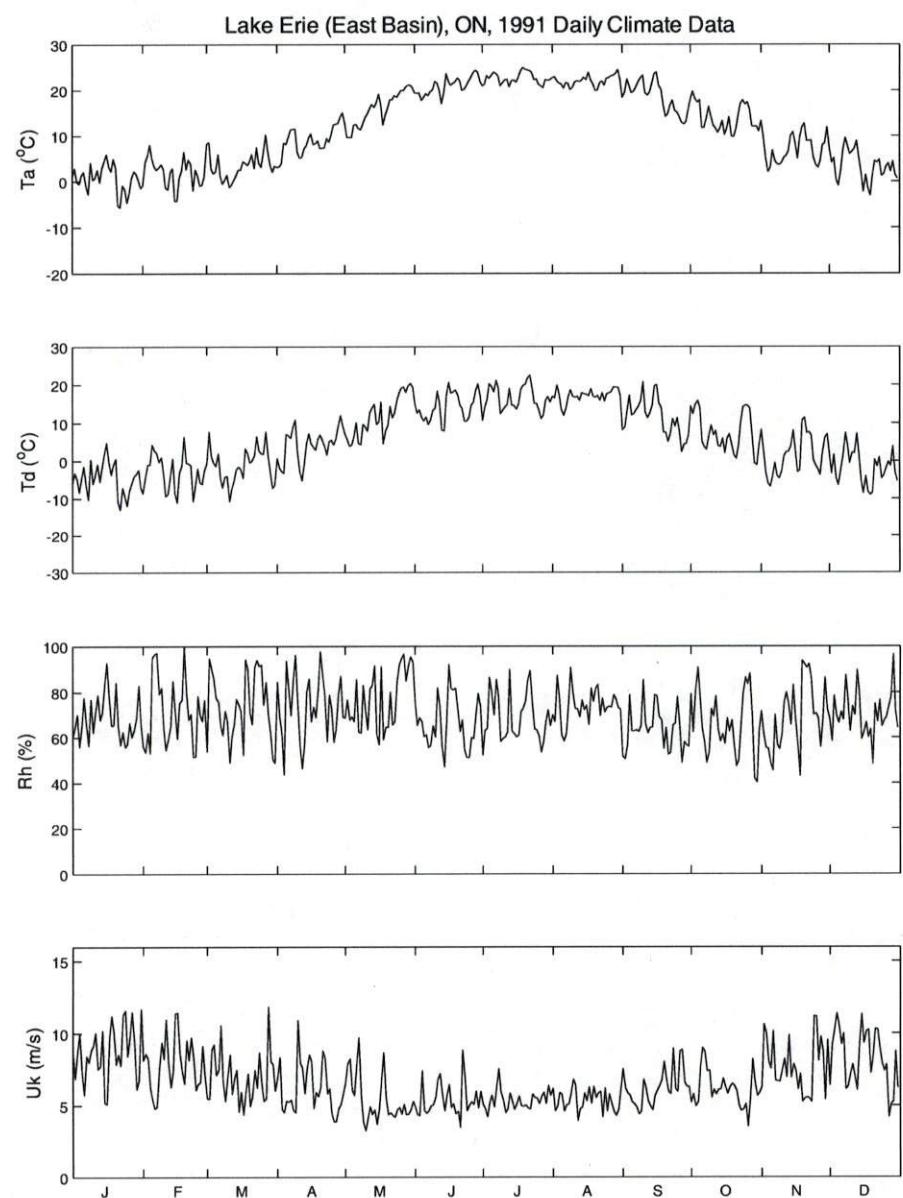


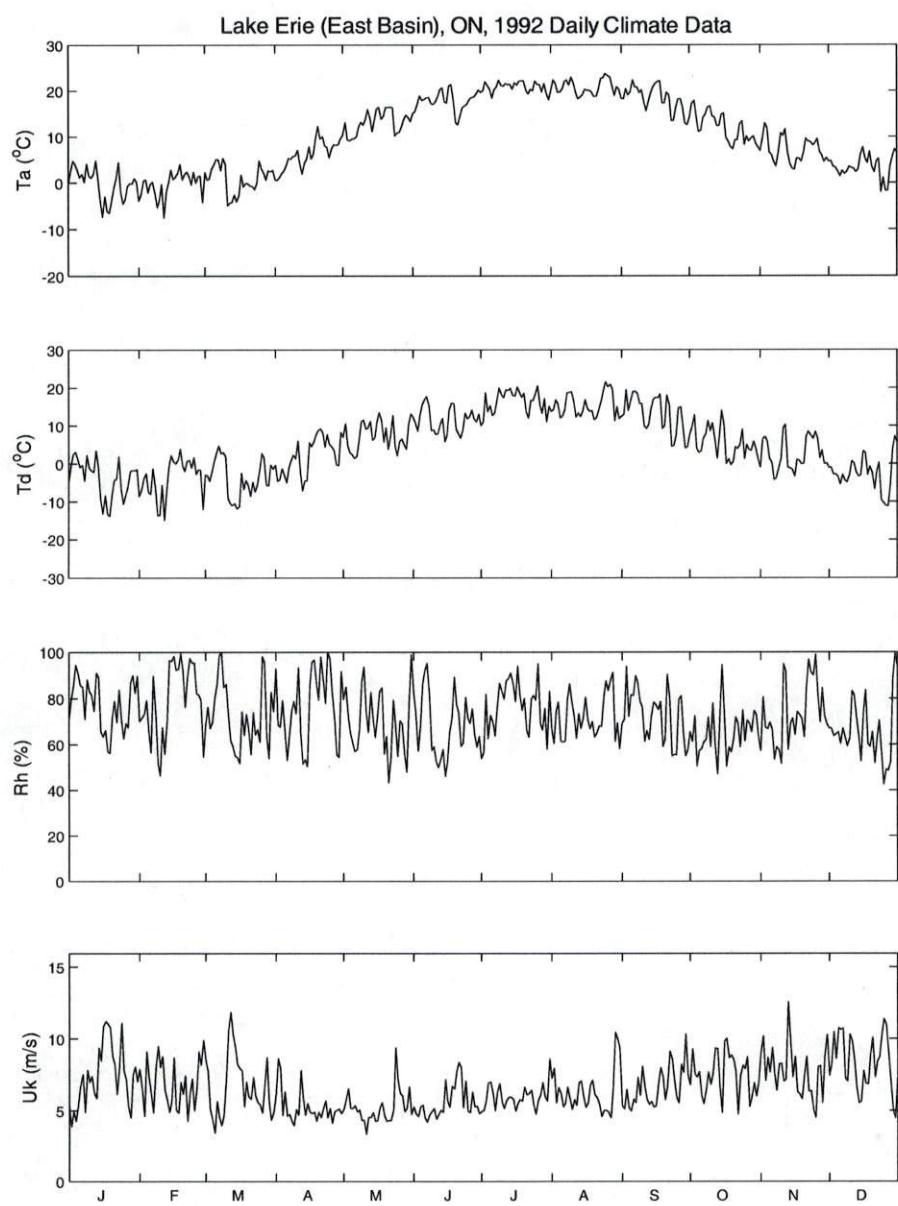


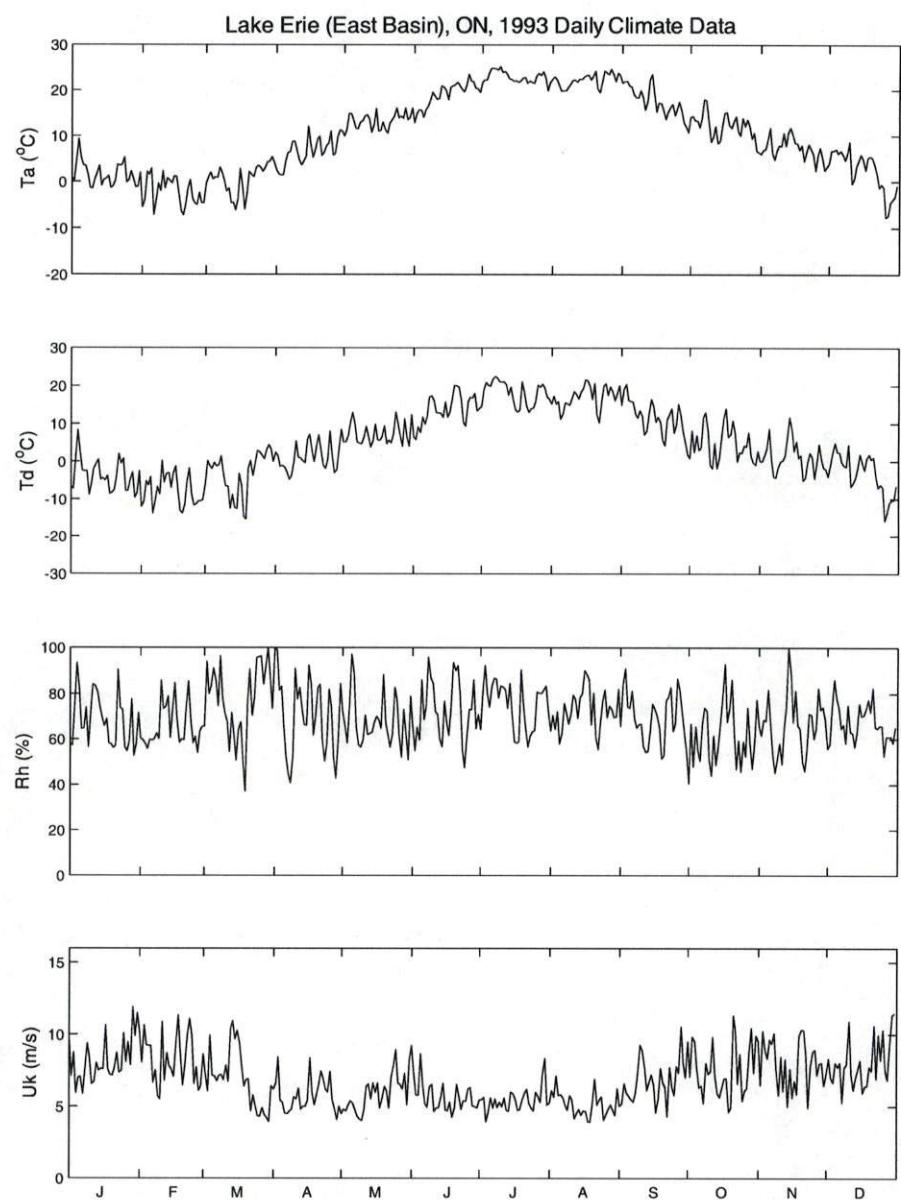


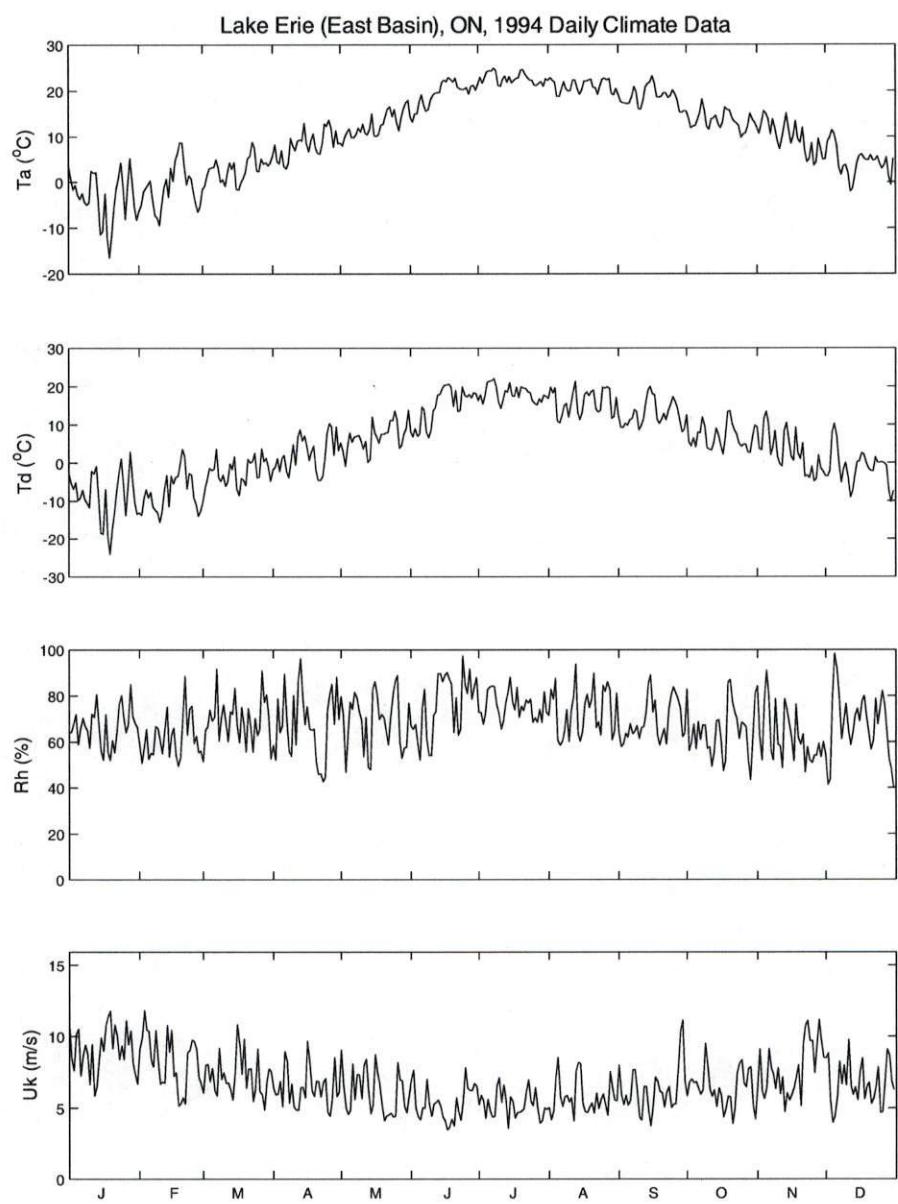


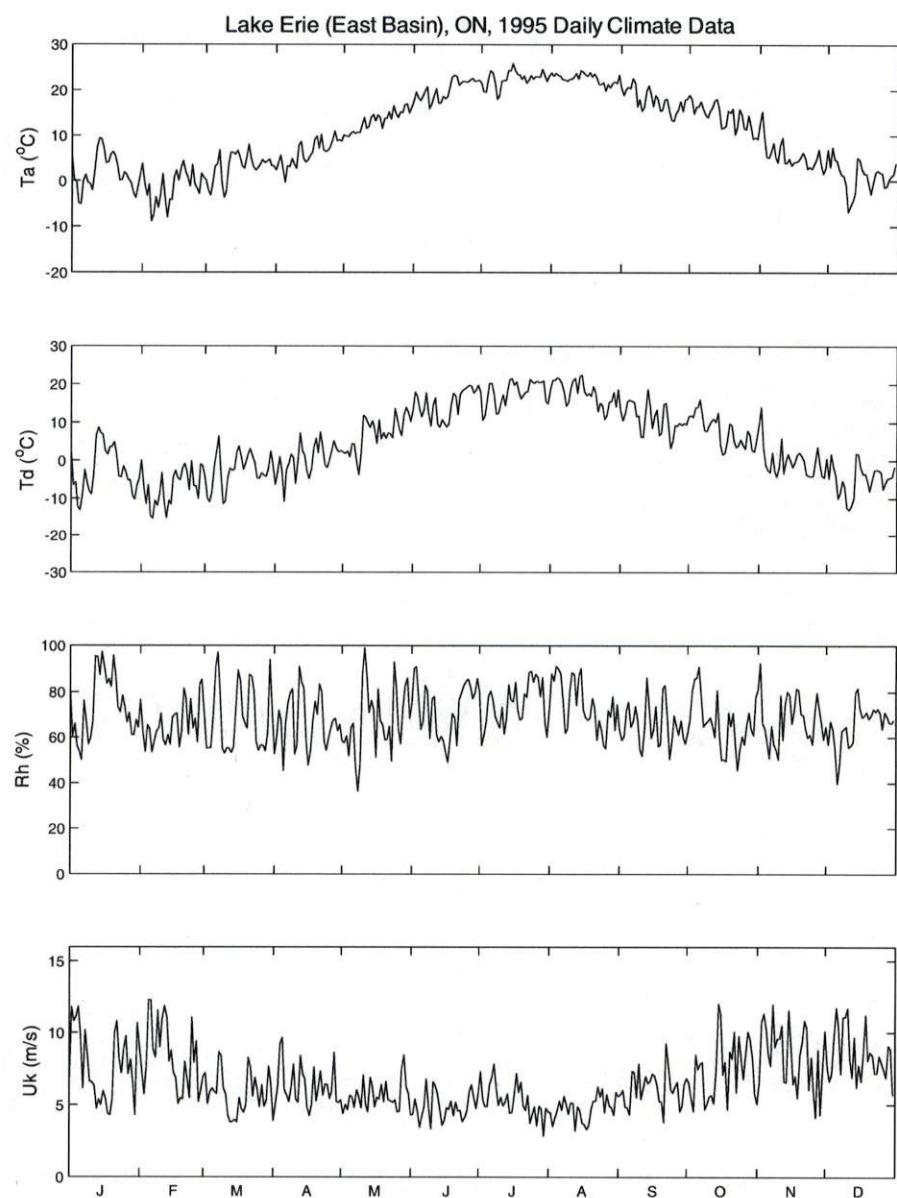


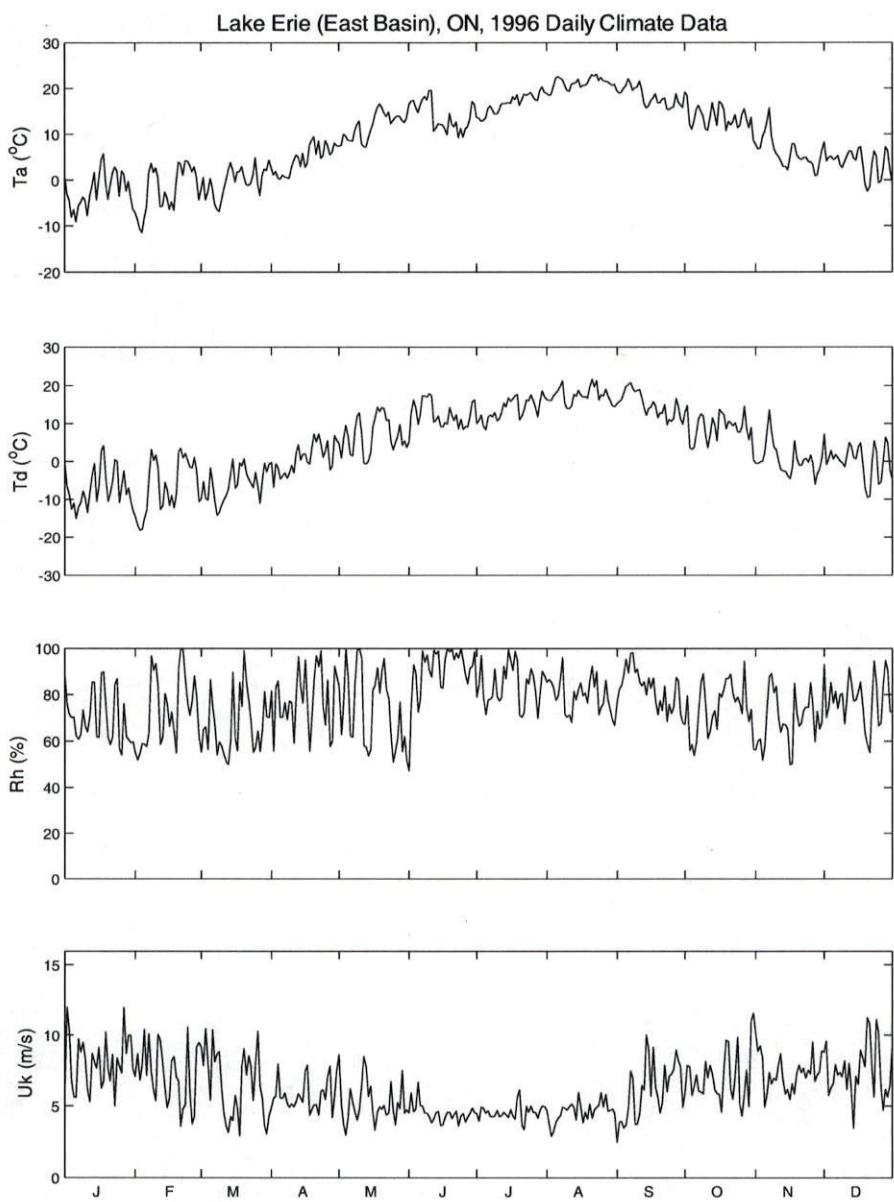


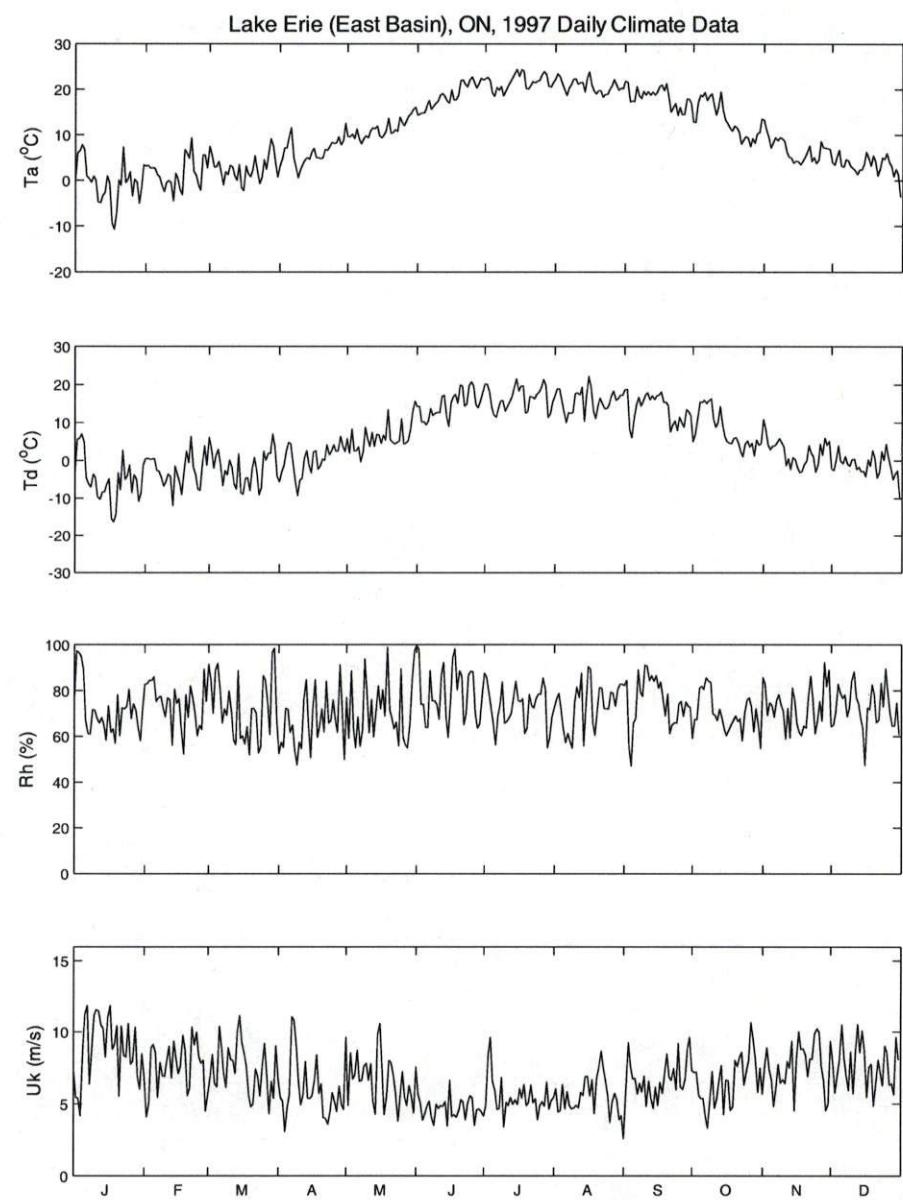




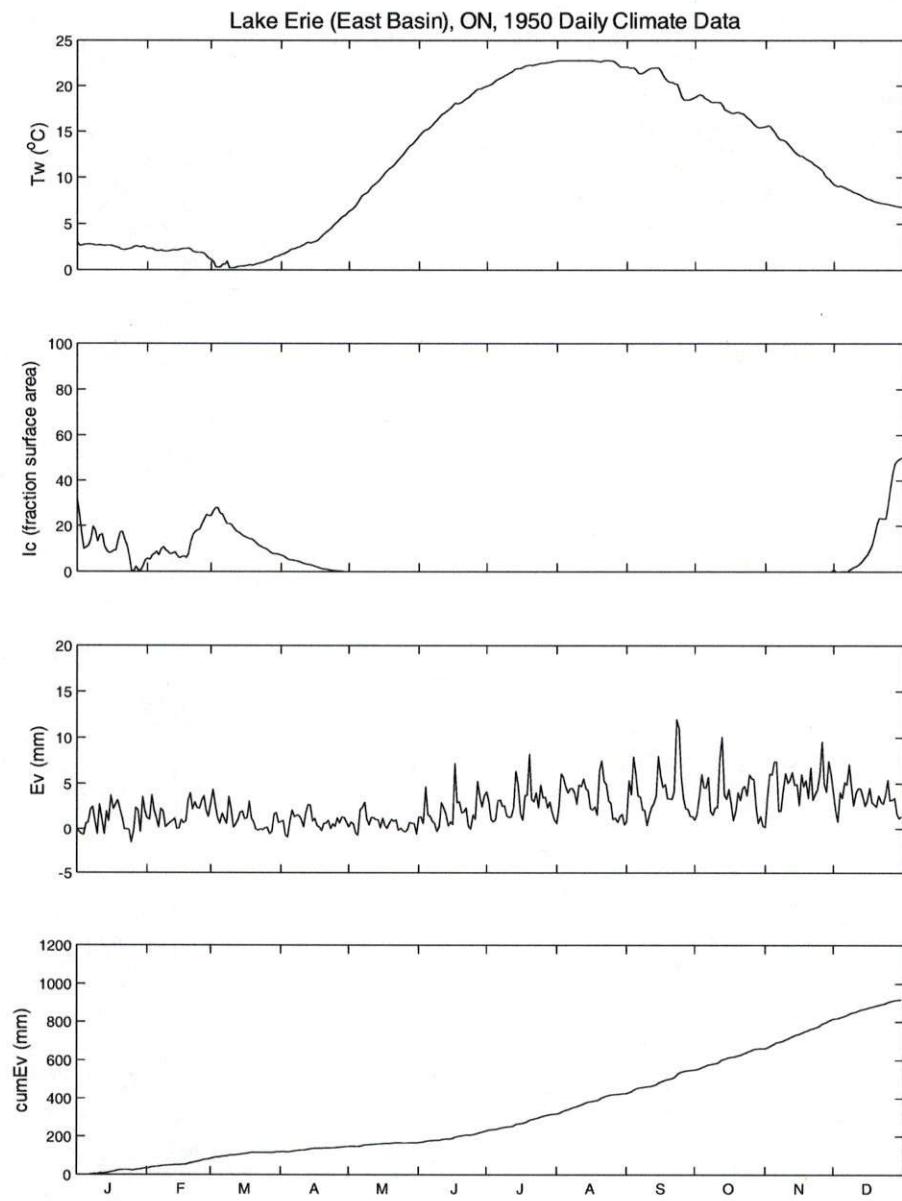


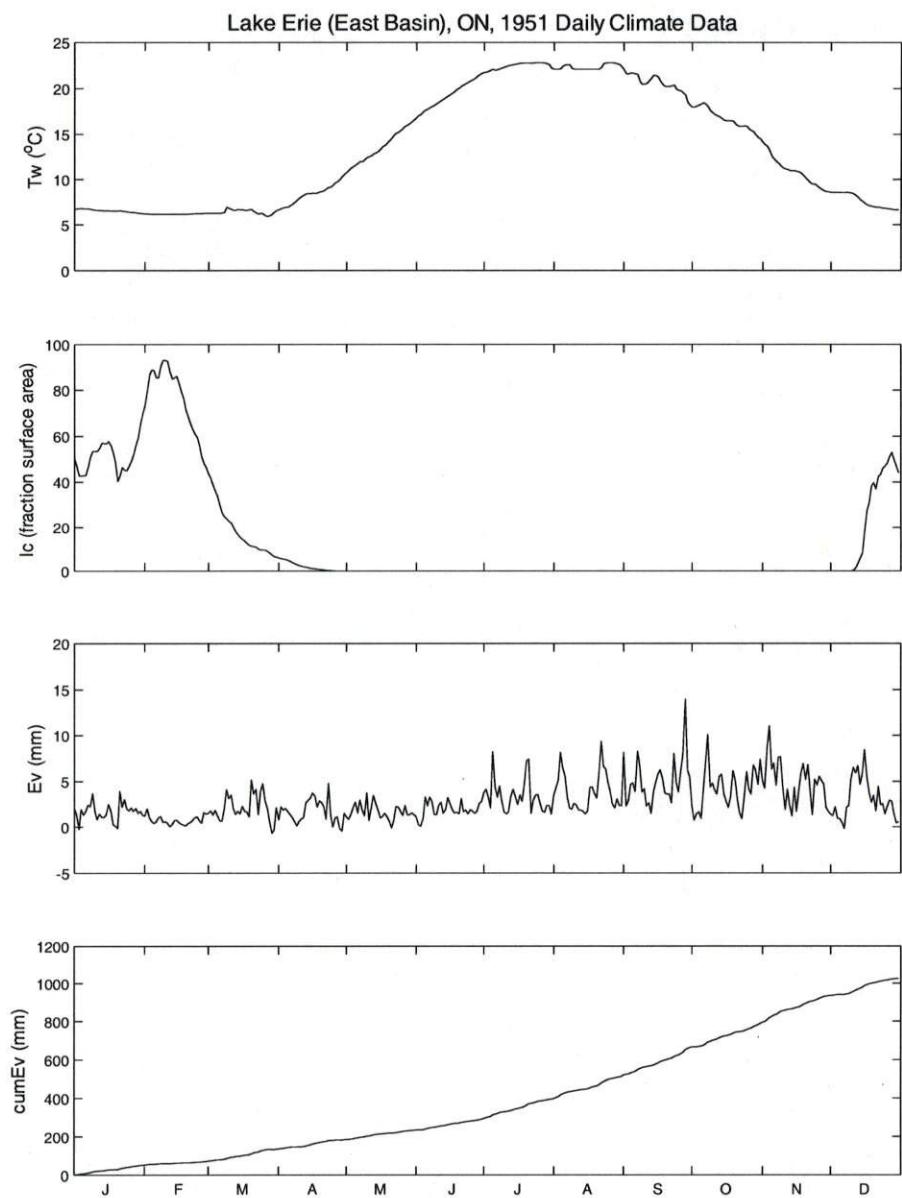


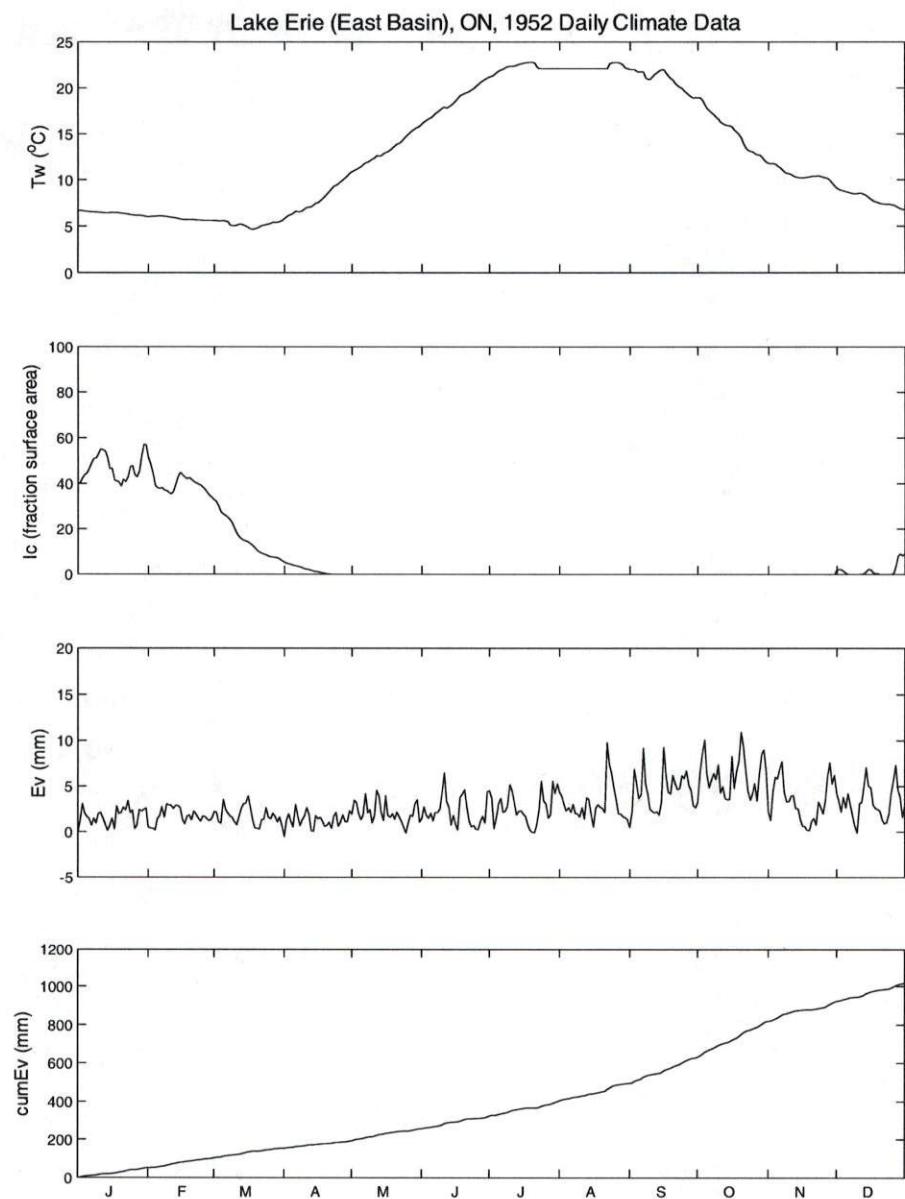




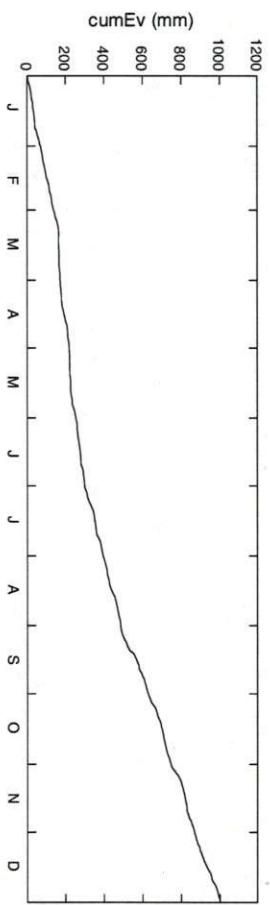
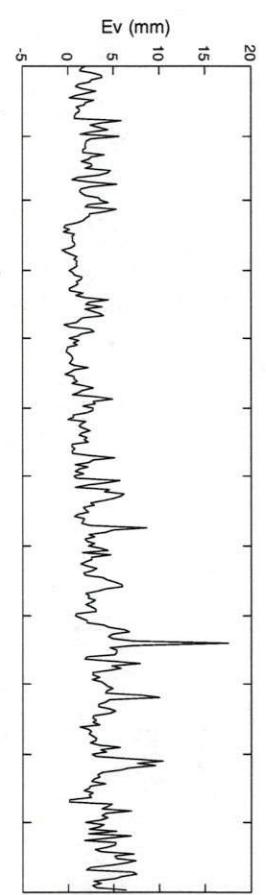
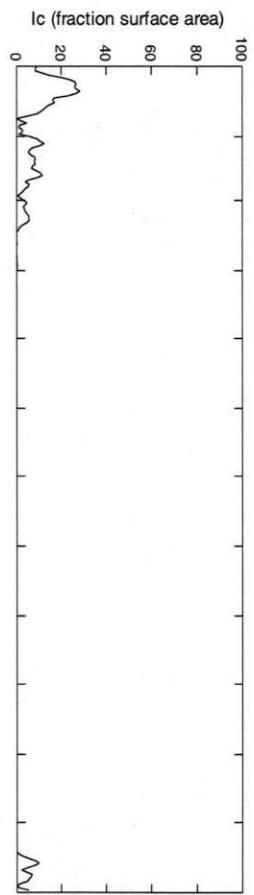
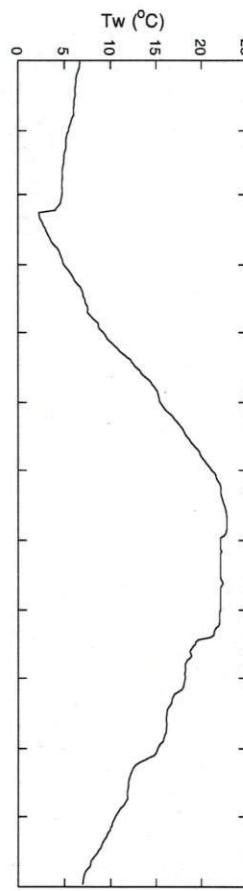
Appendix 6 Evaporation

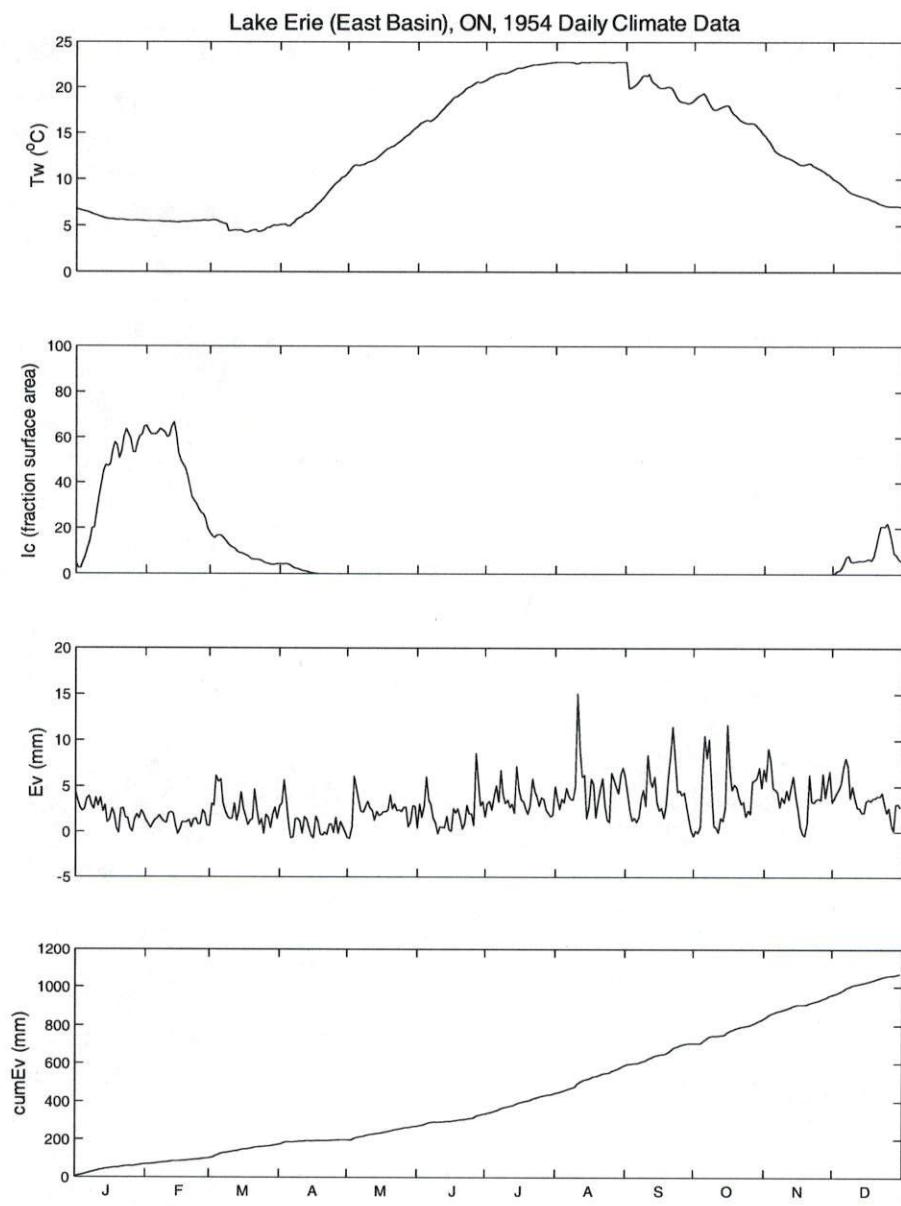


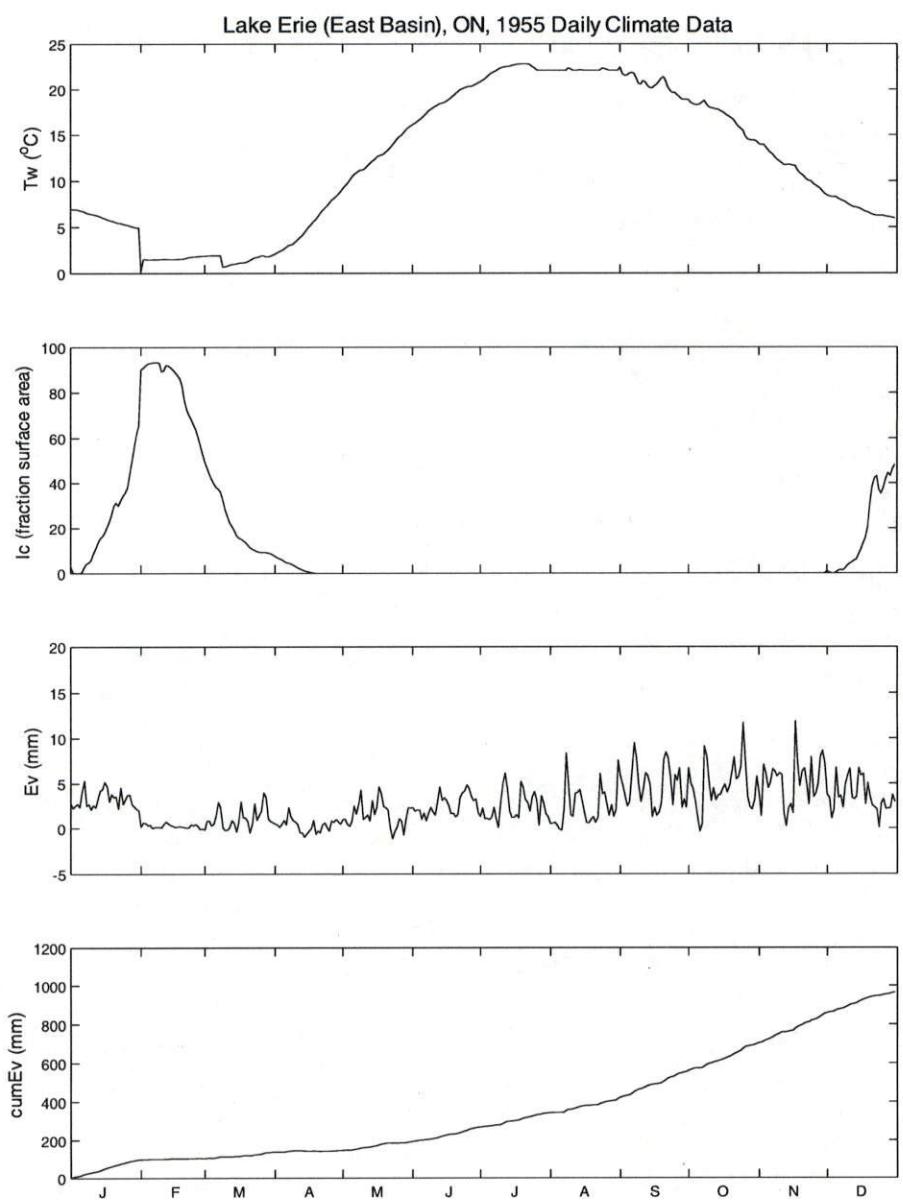


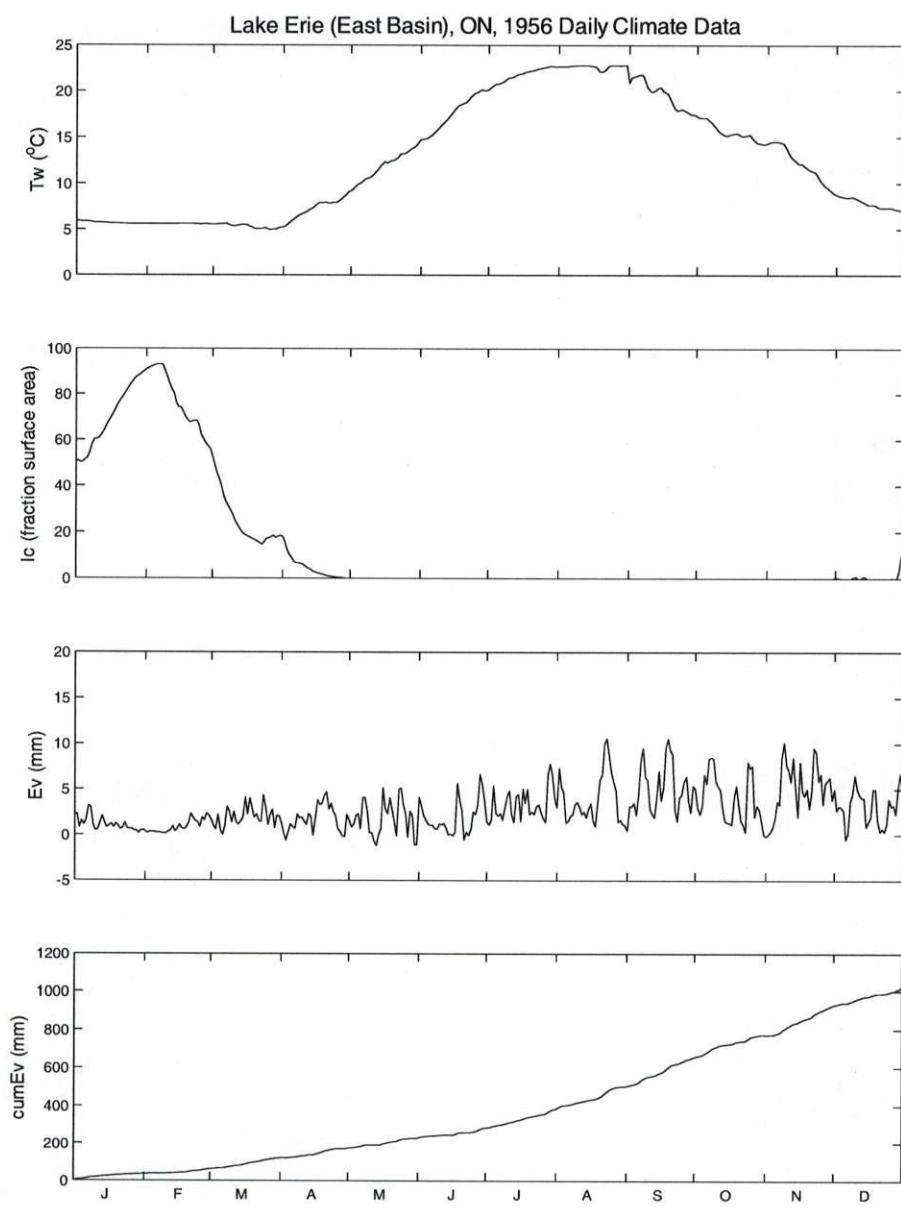


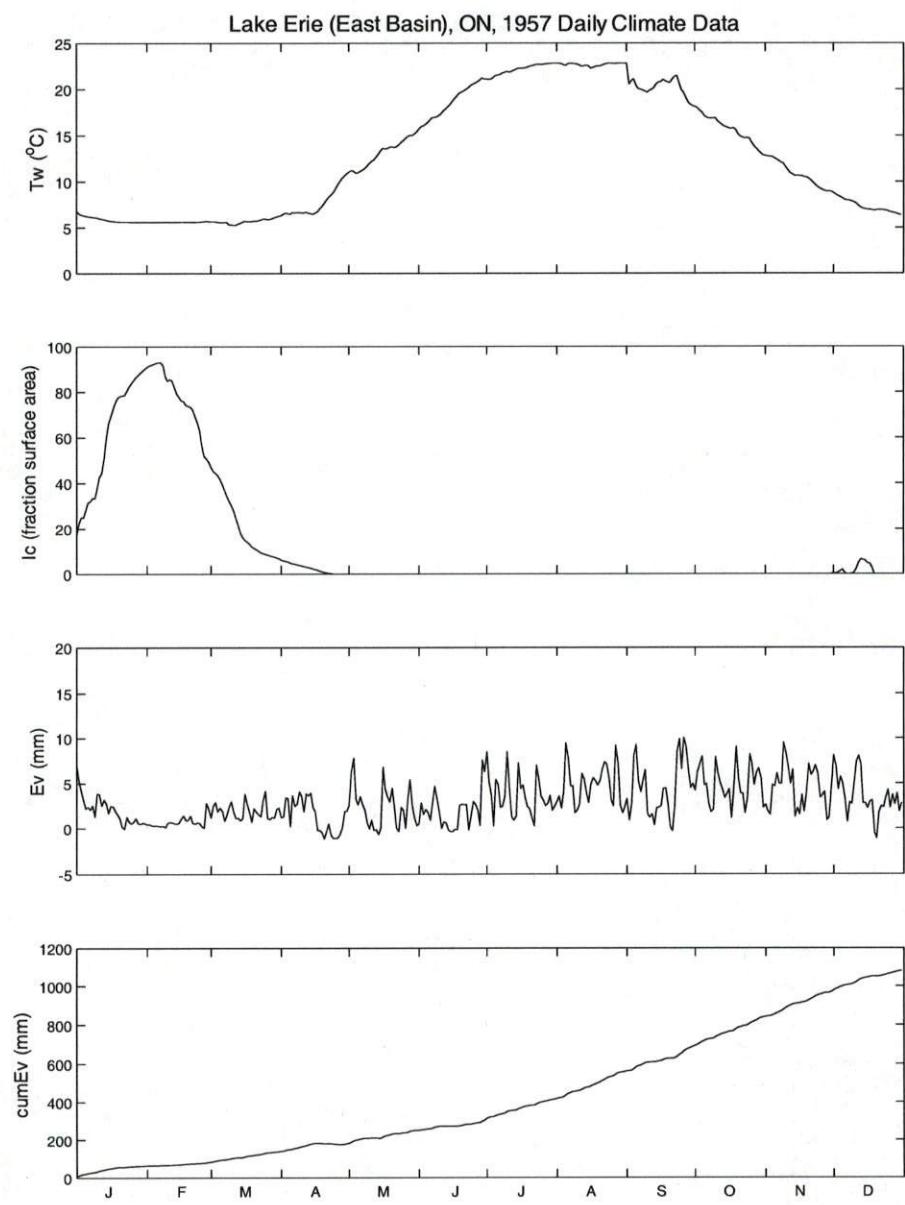
Lake Erie (East Basin), ON, 1953 Daily Climate Data

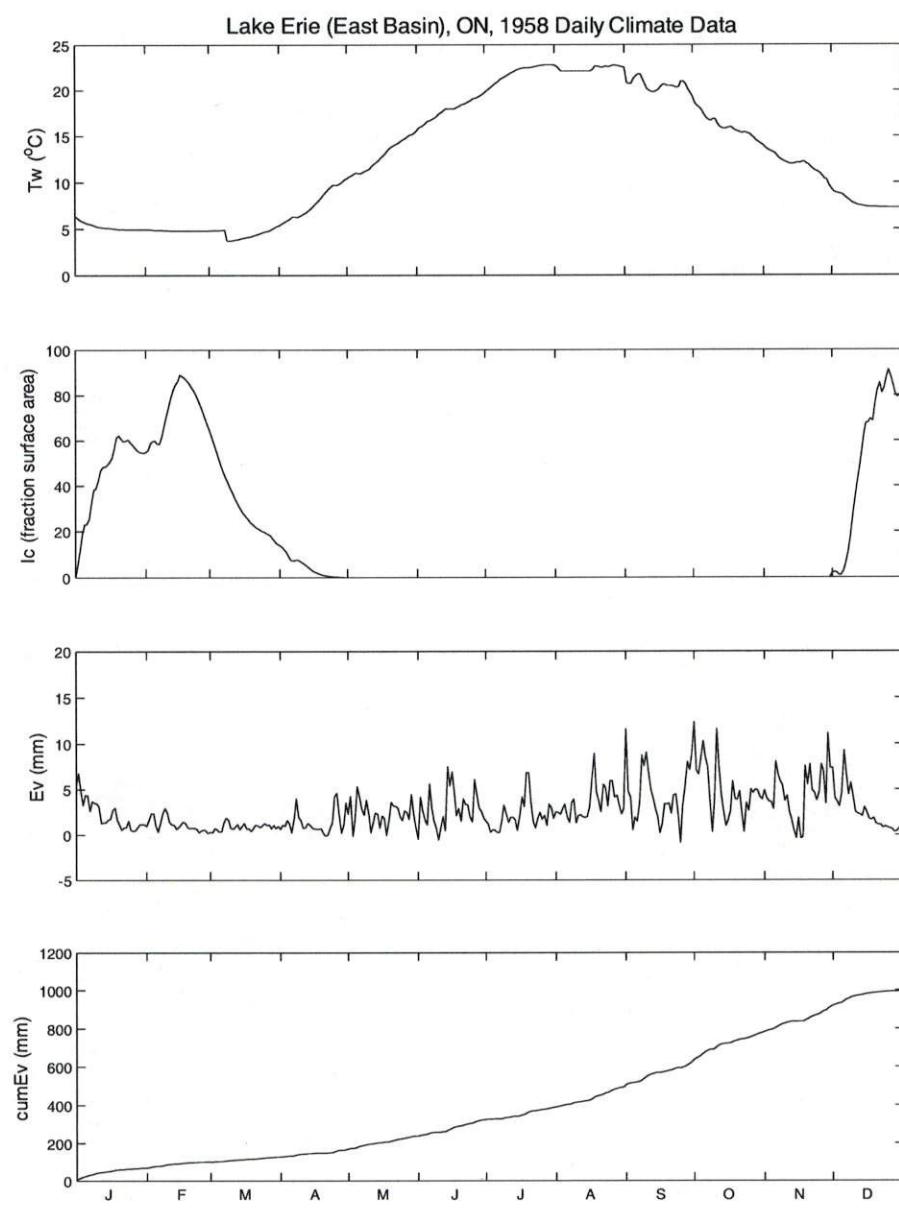


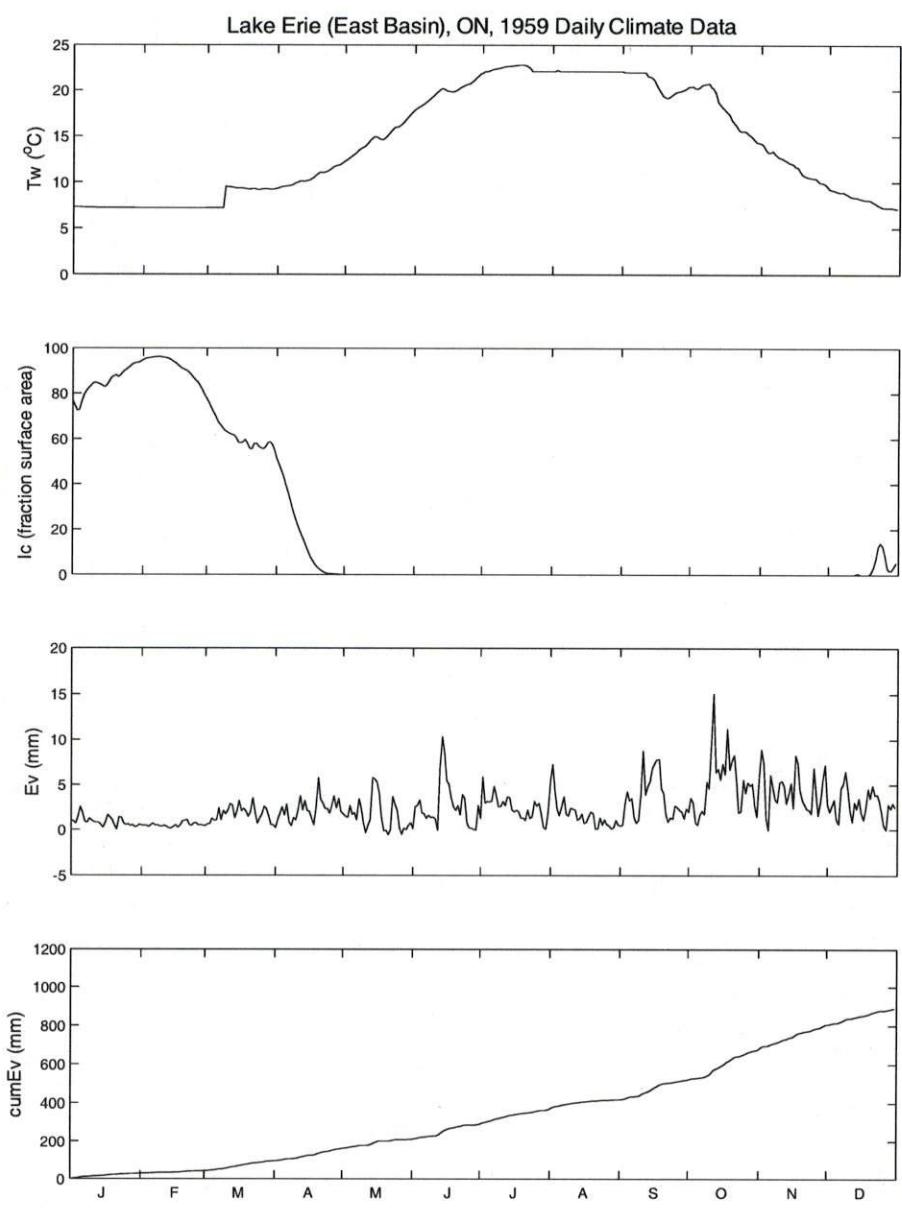


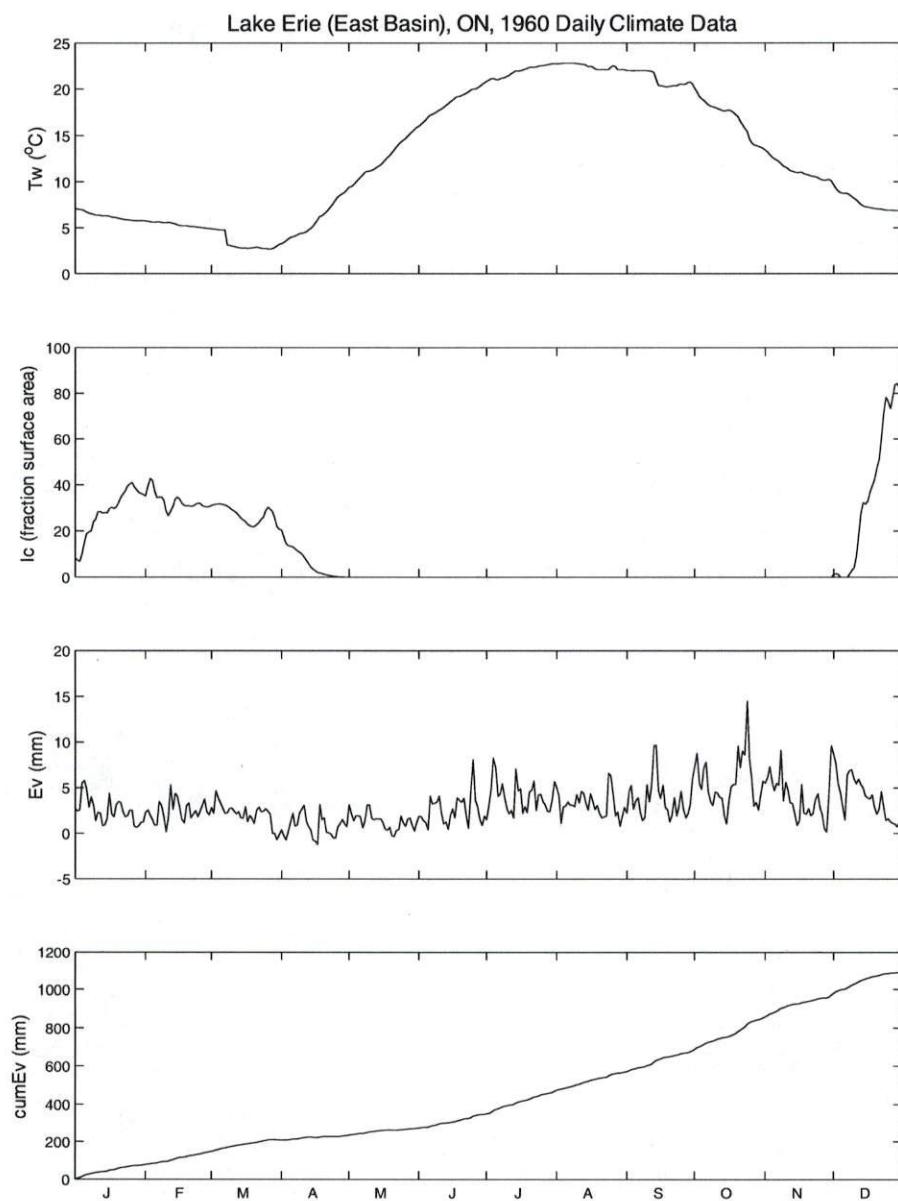


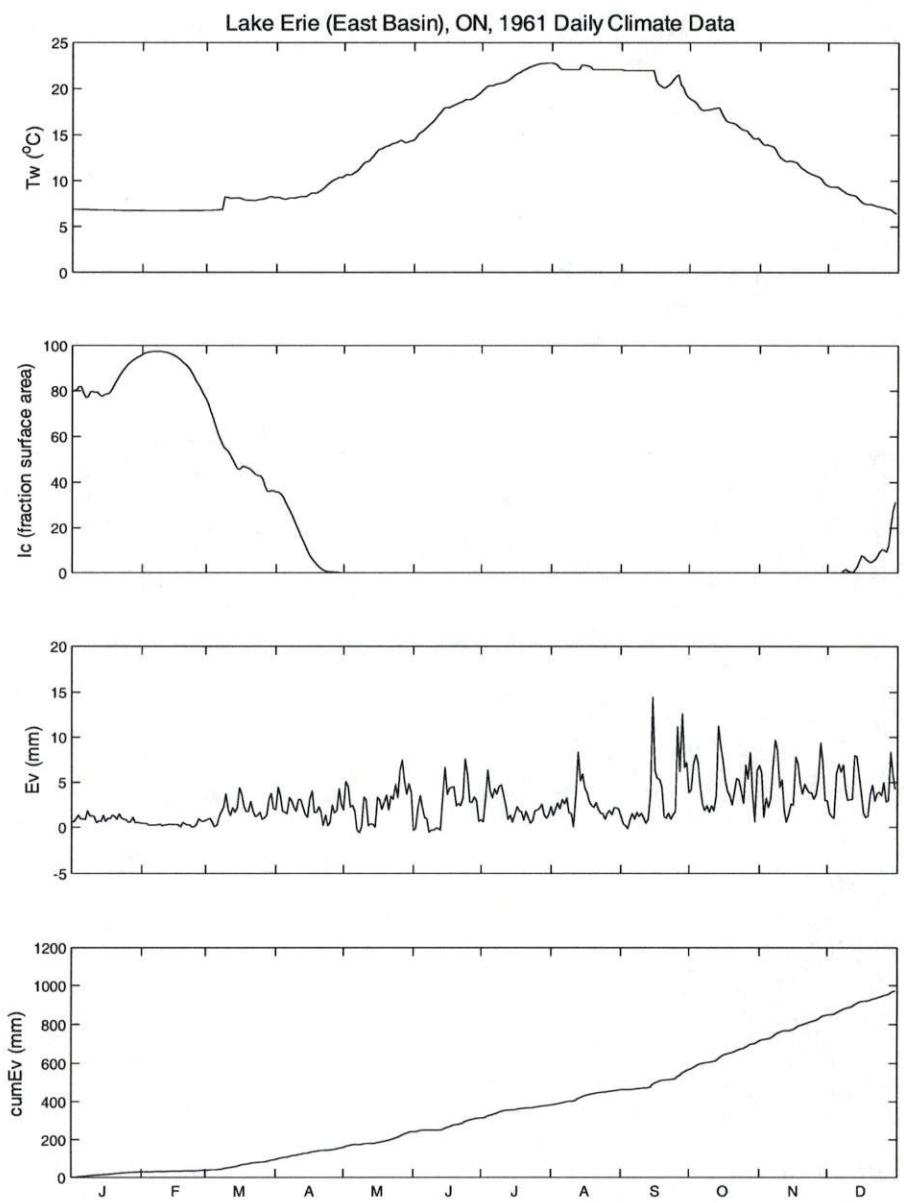


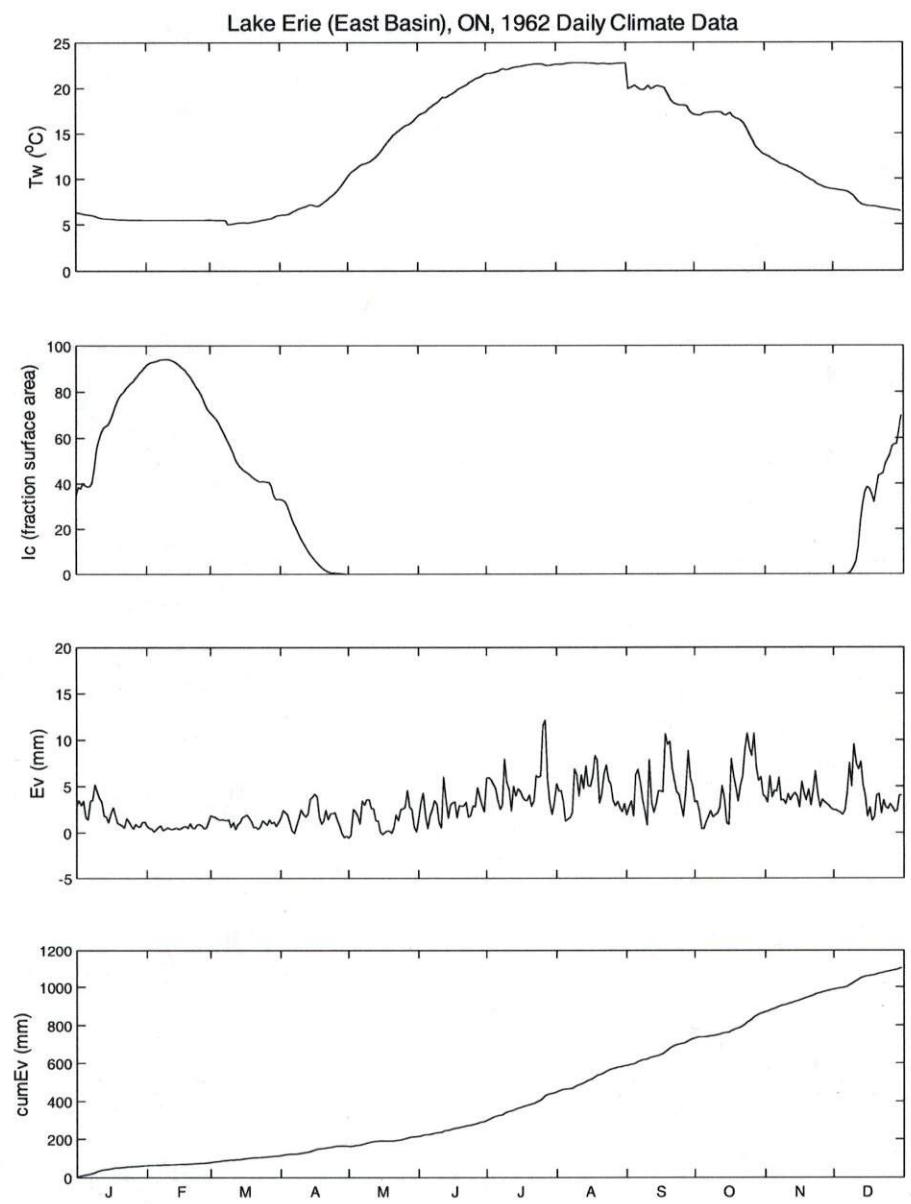


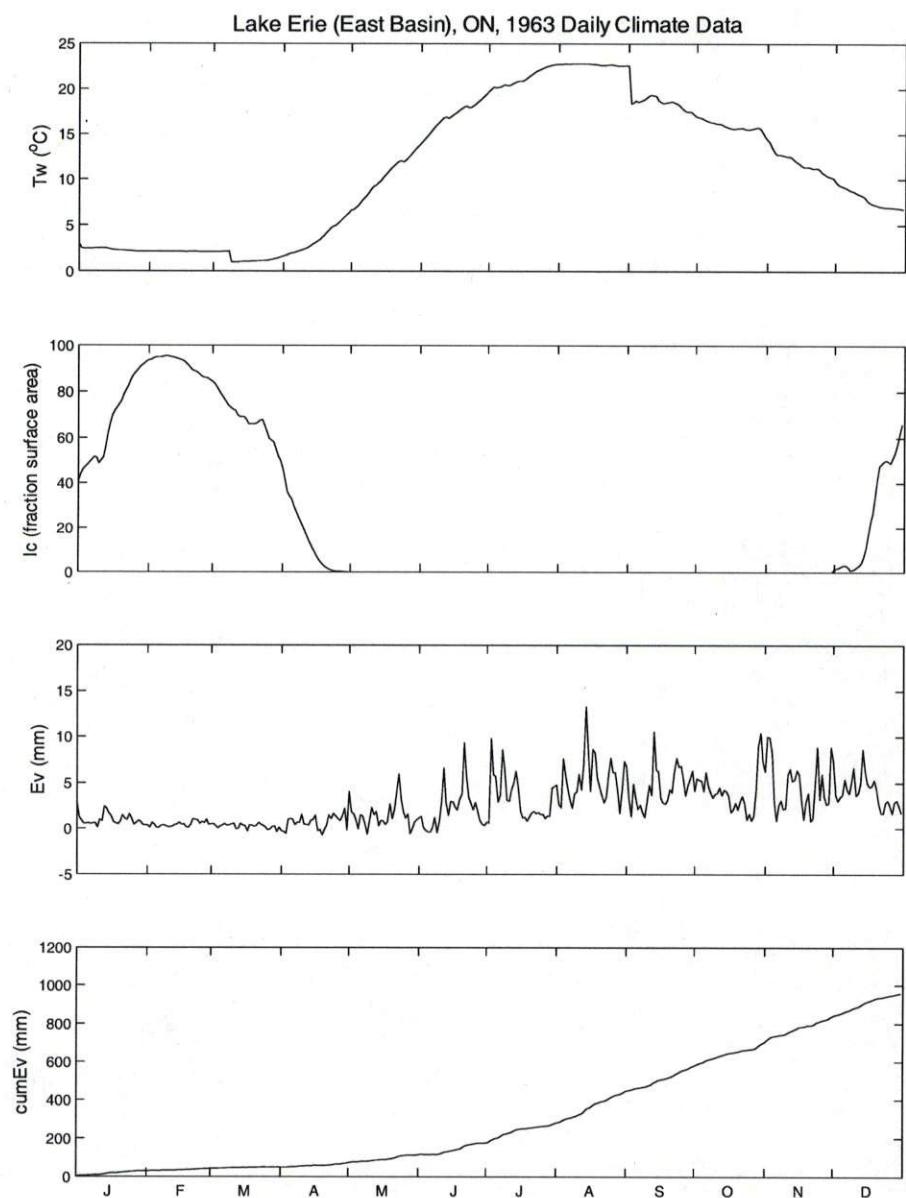


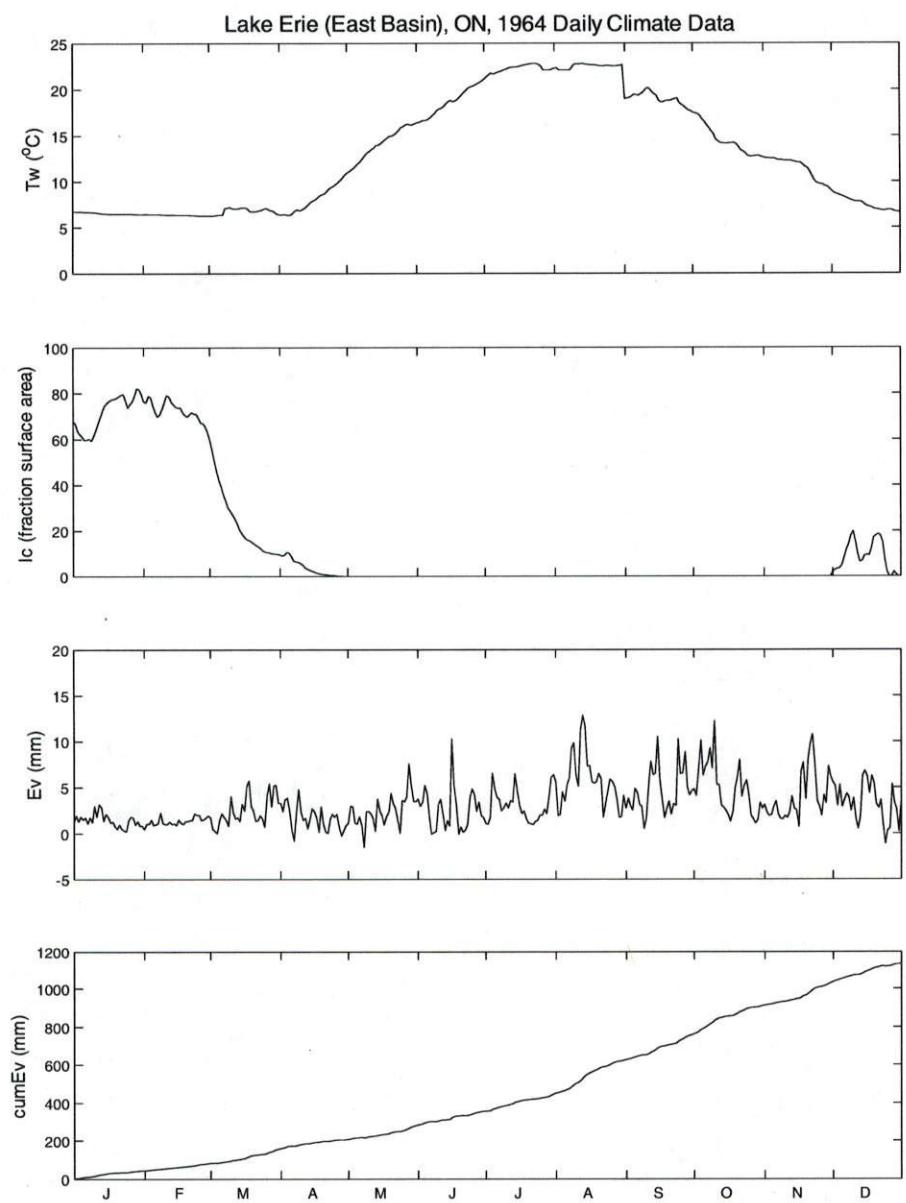


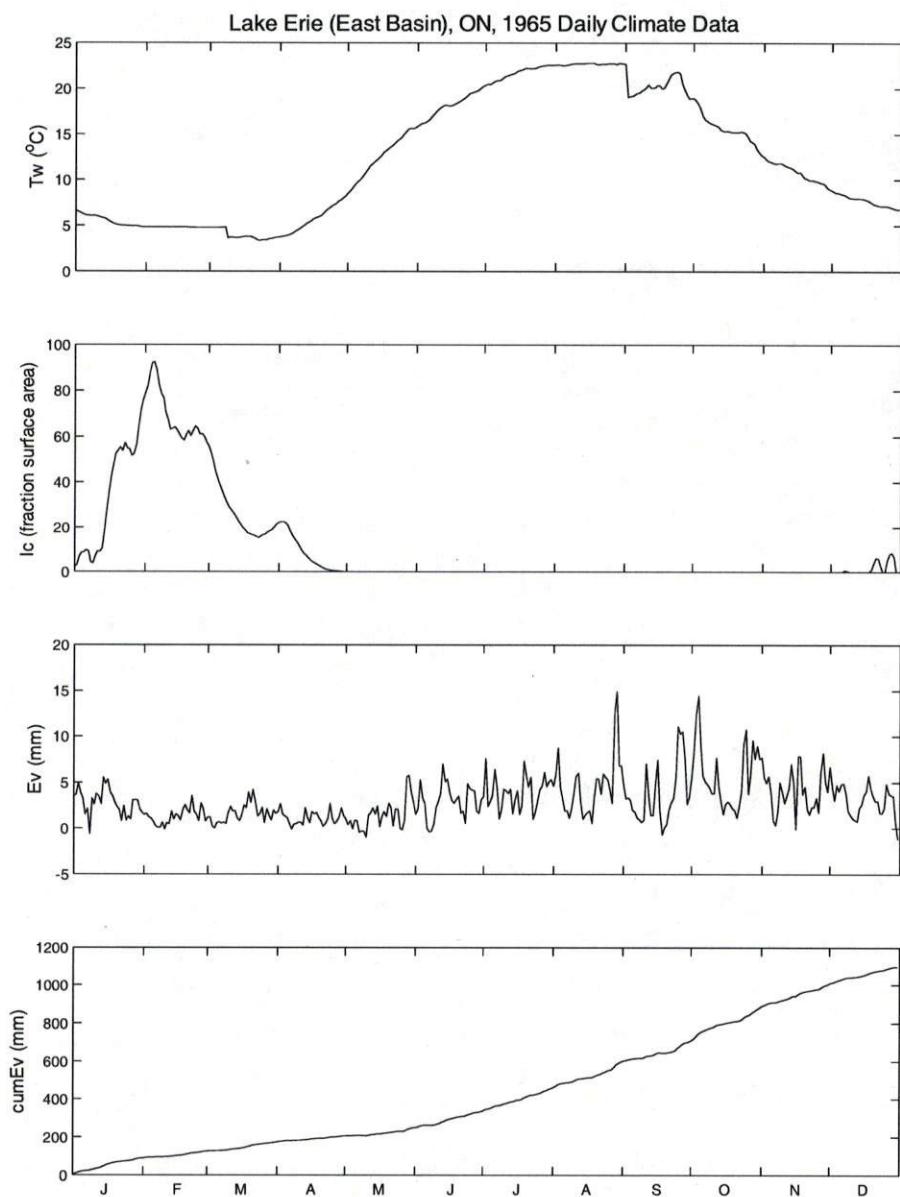


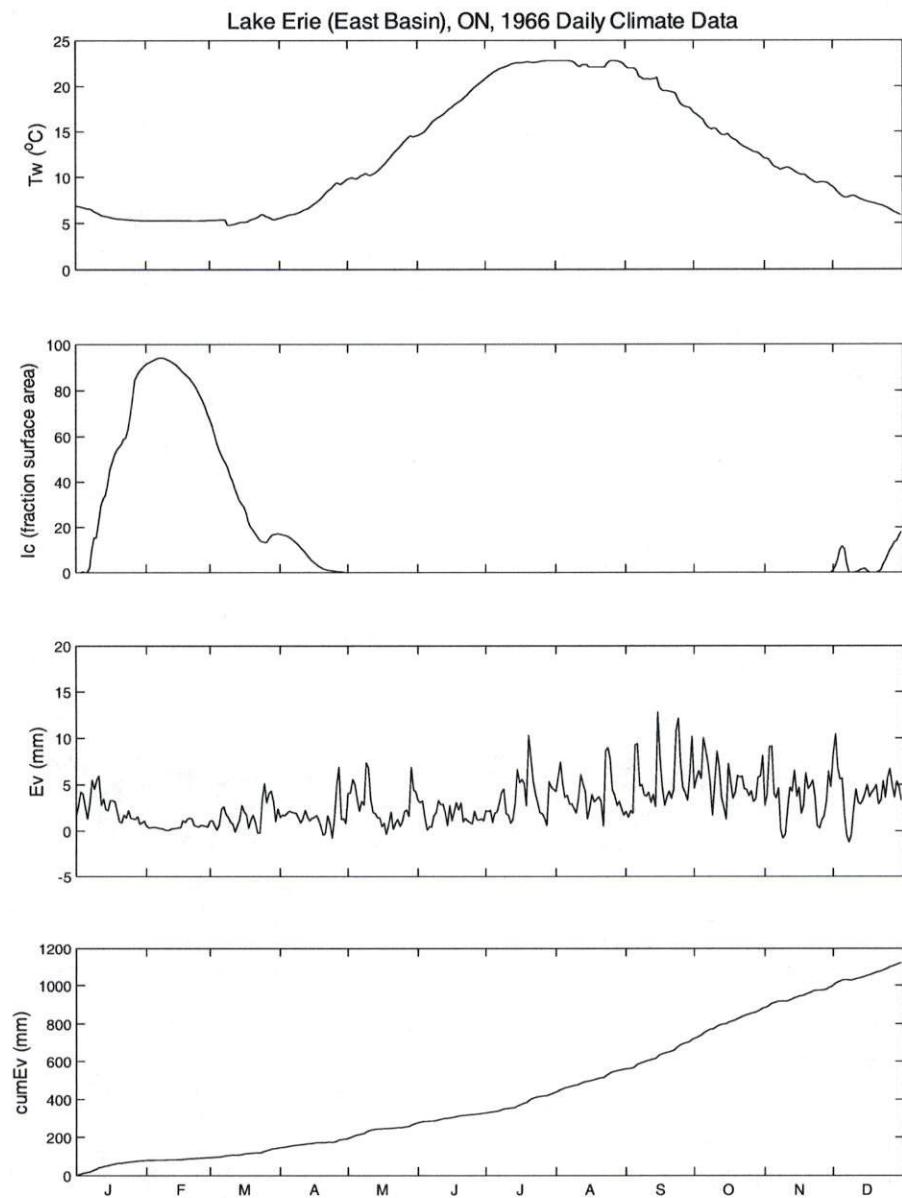


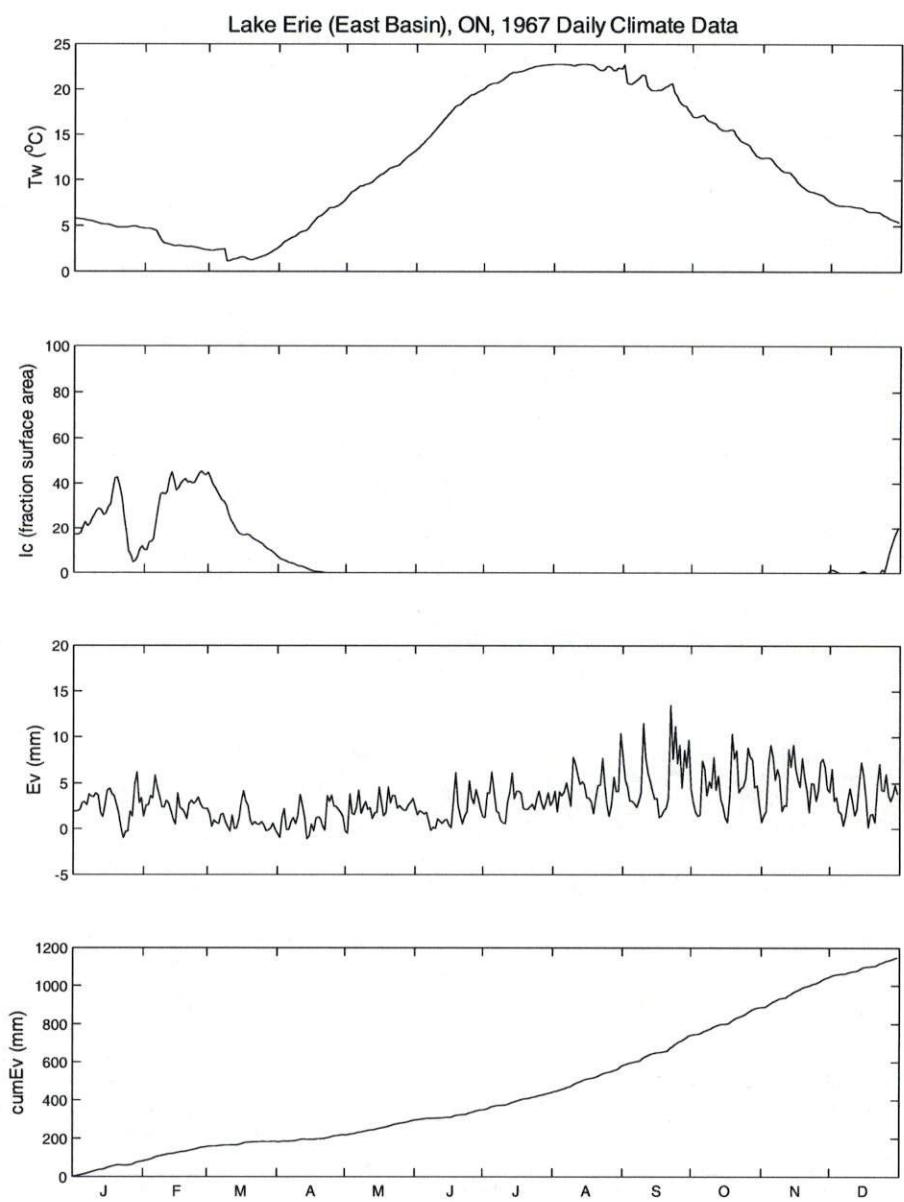


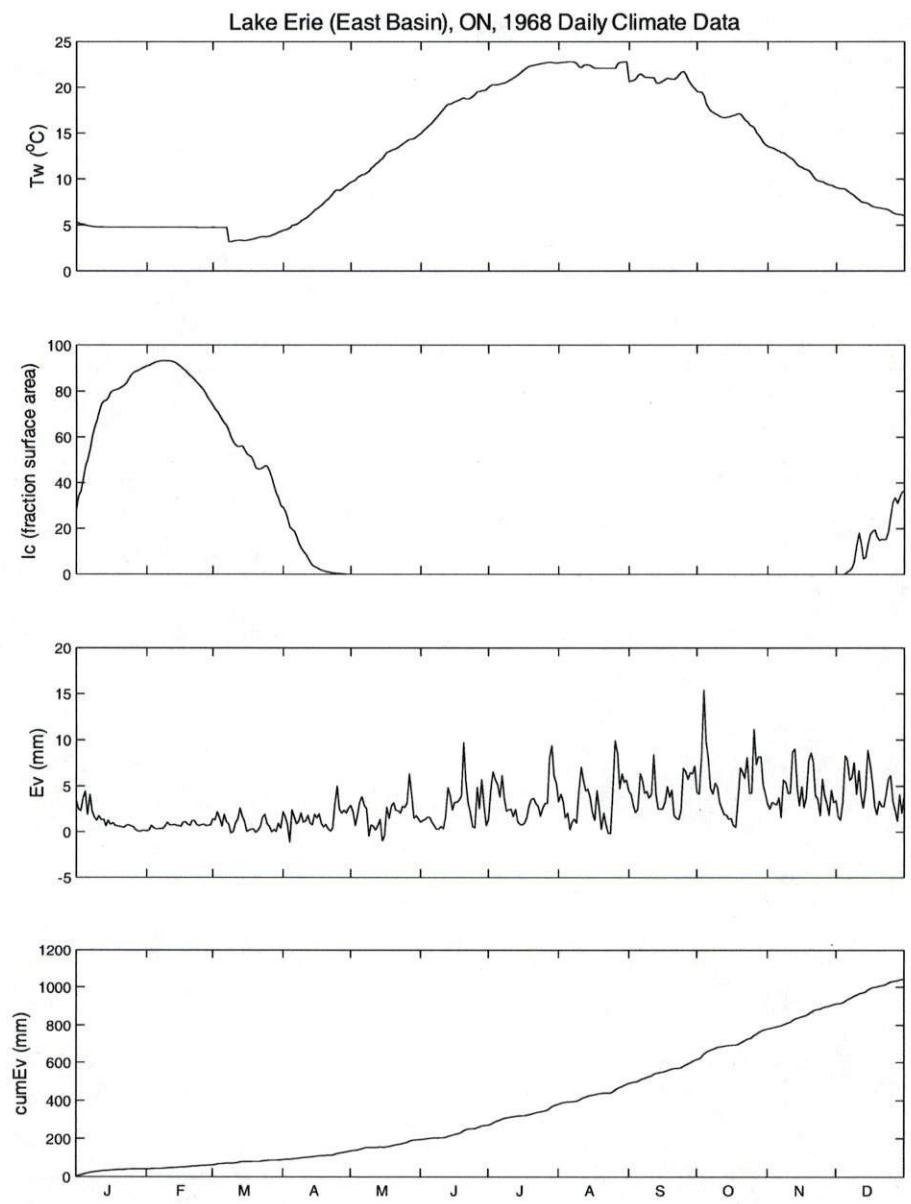


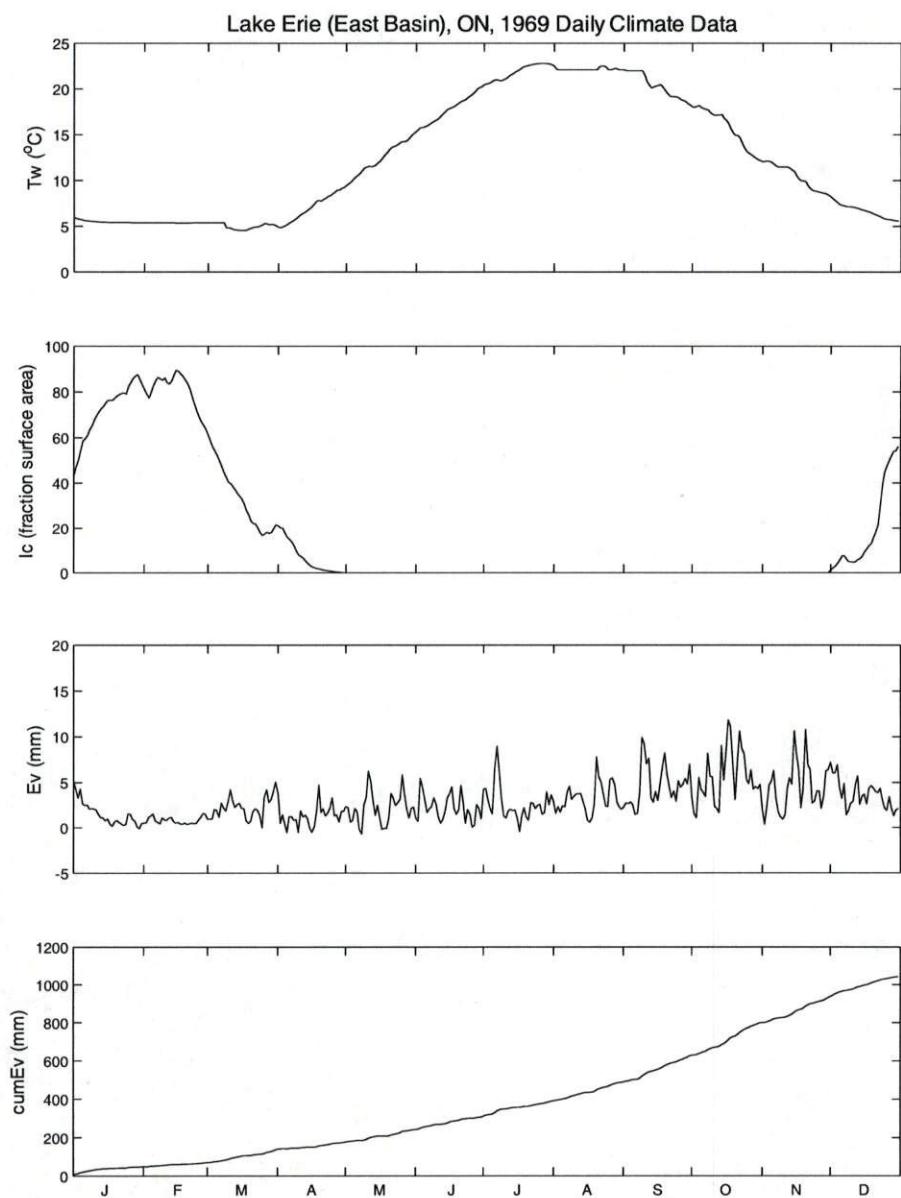


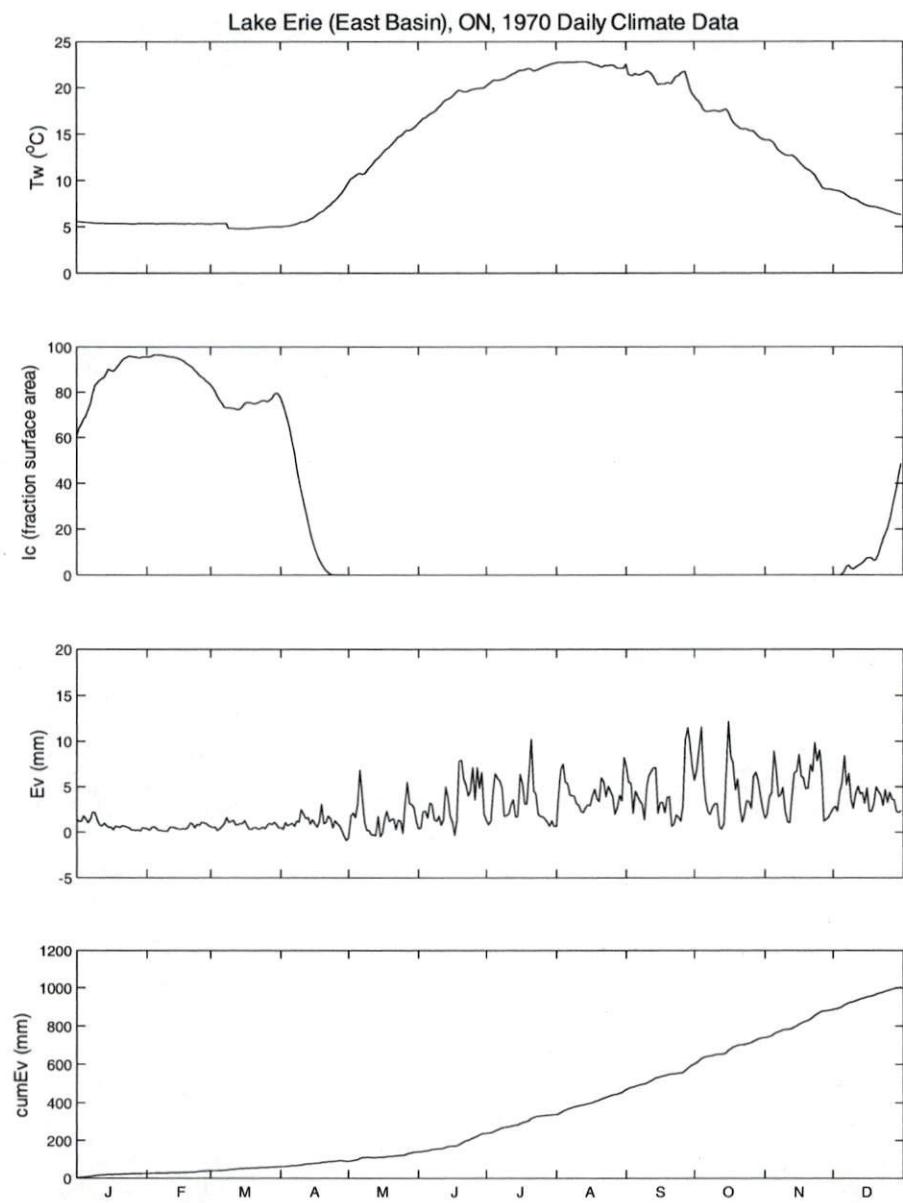


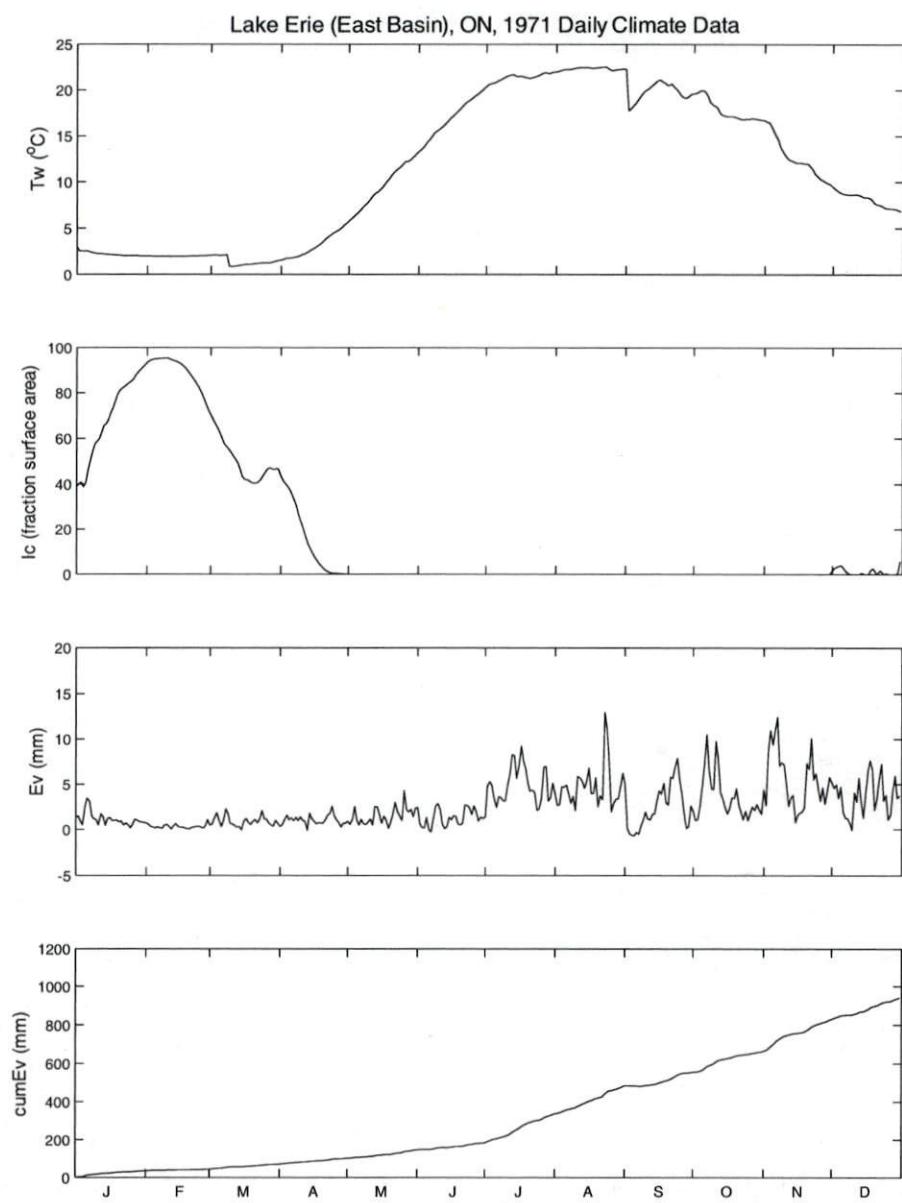


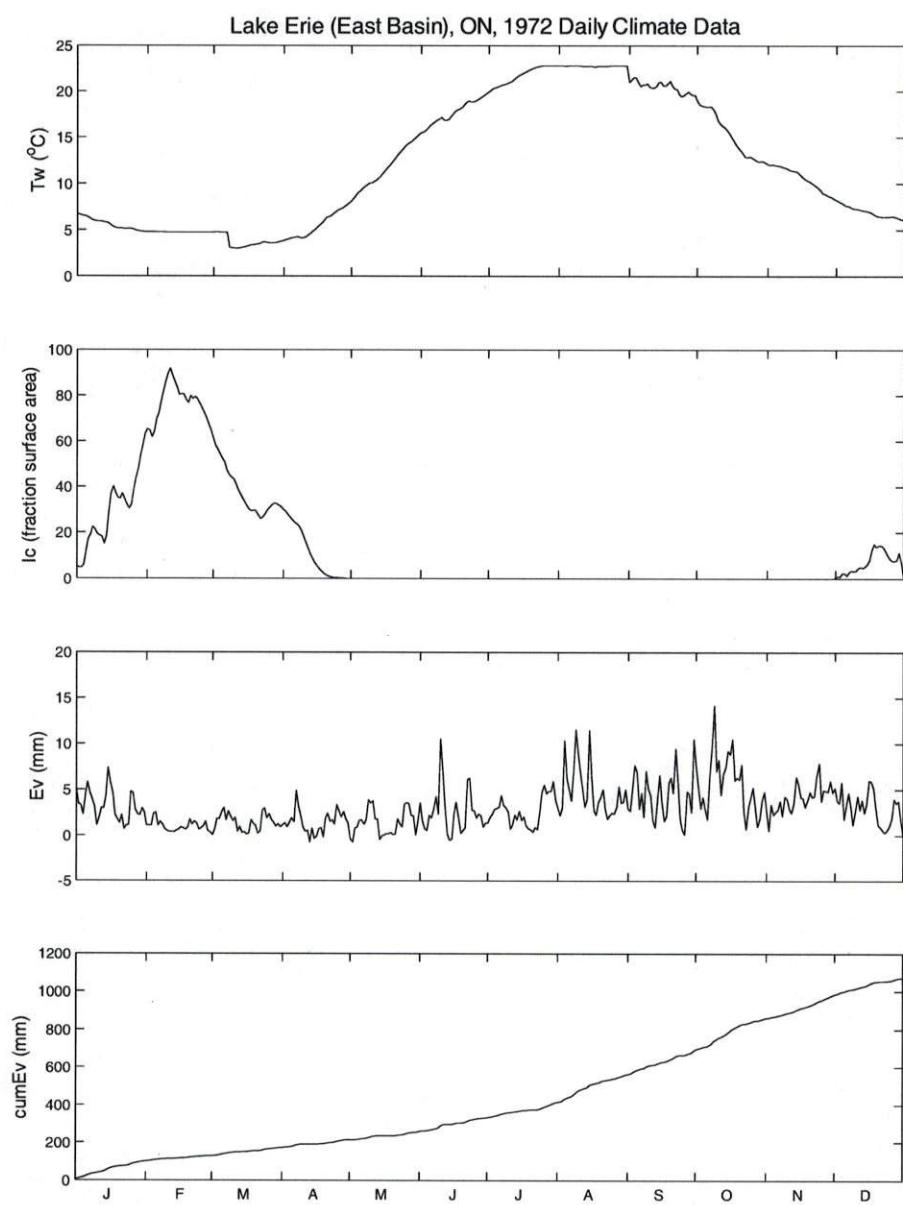


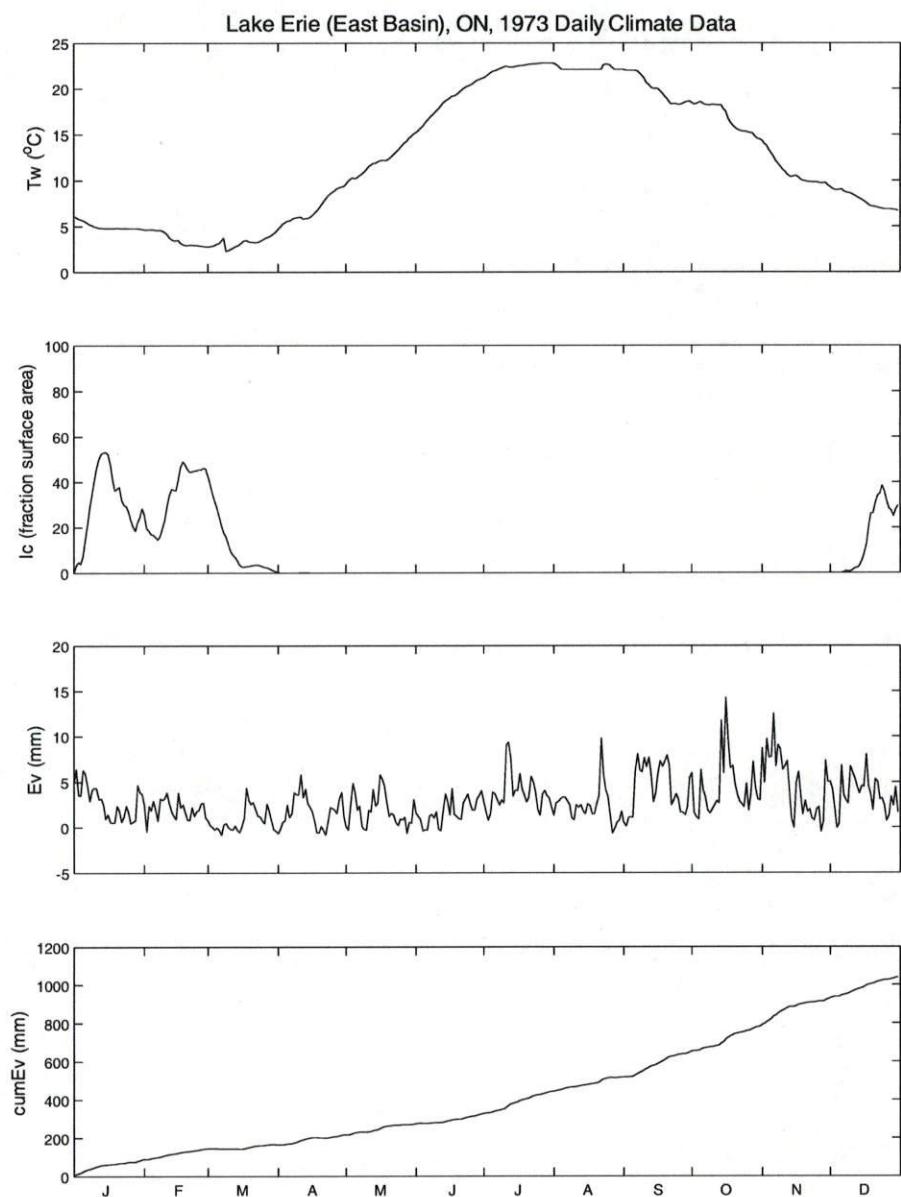


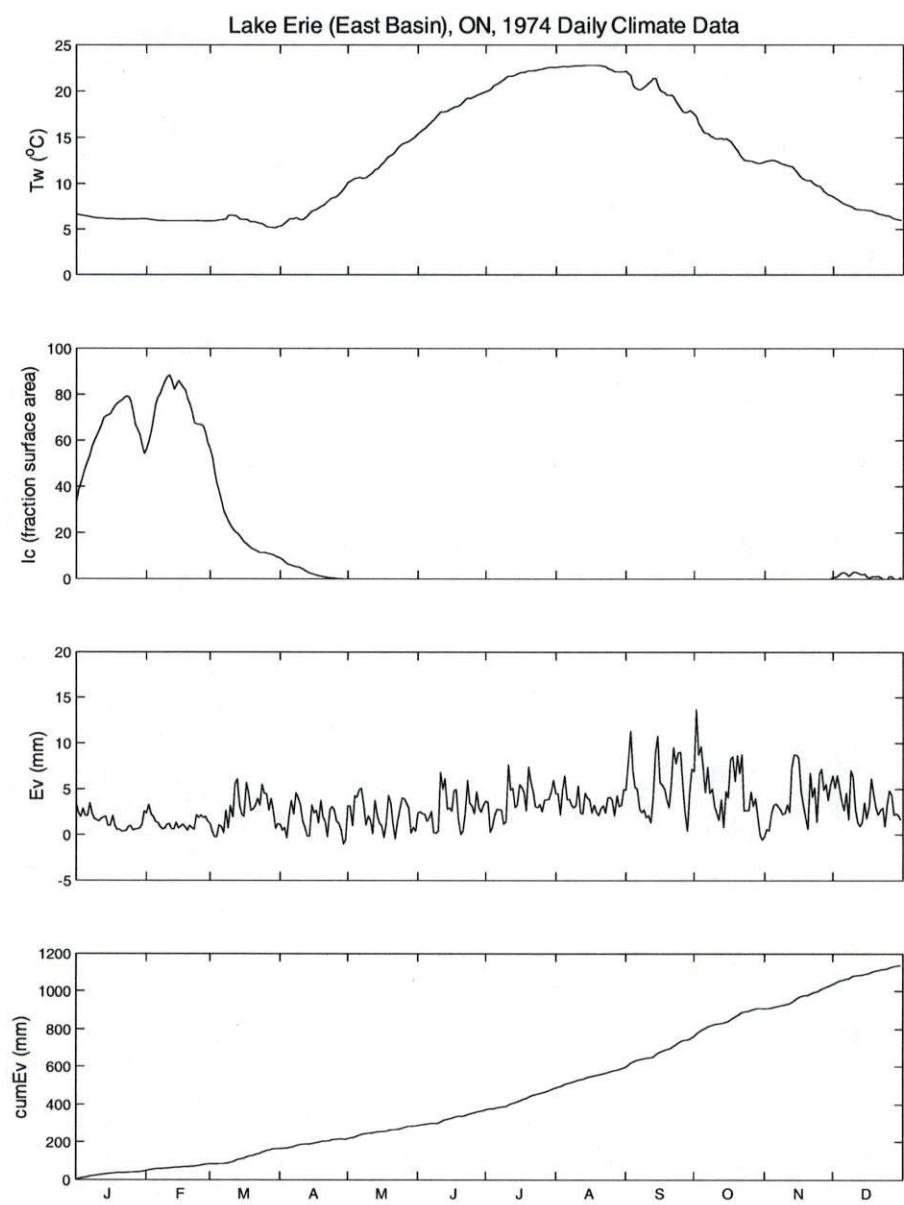


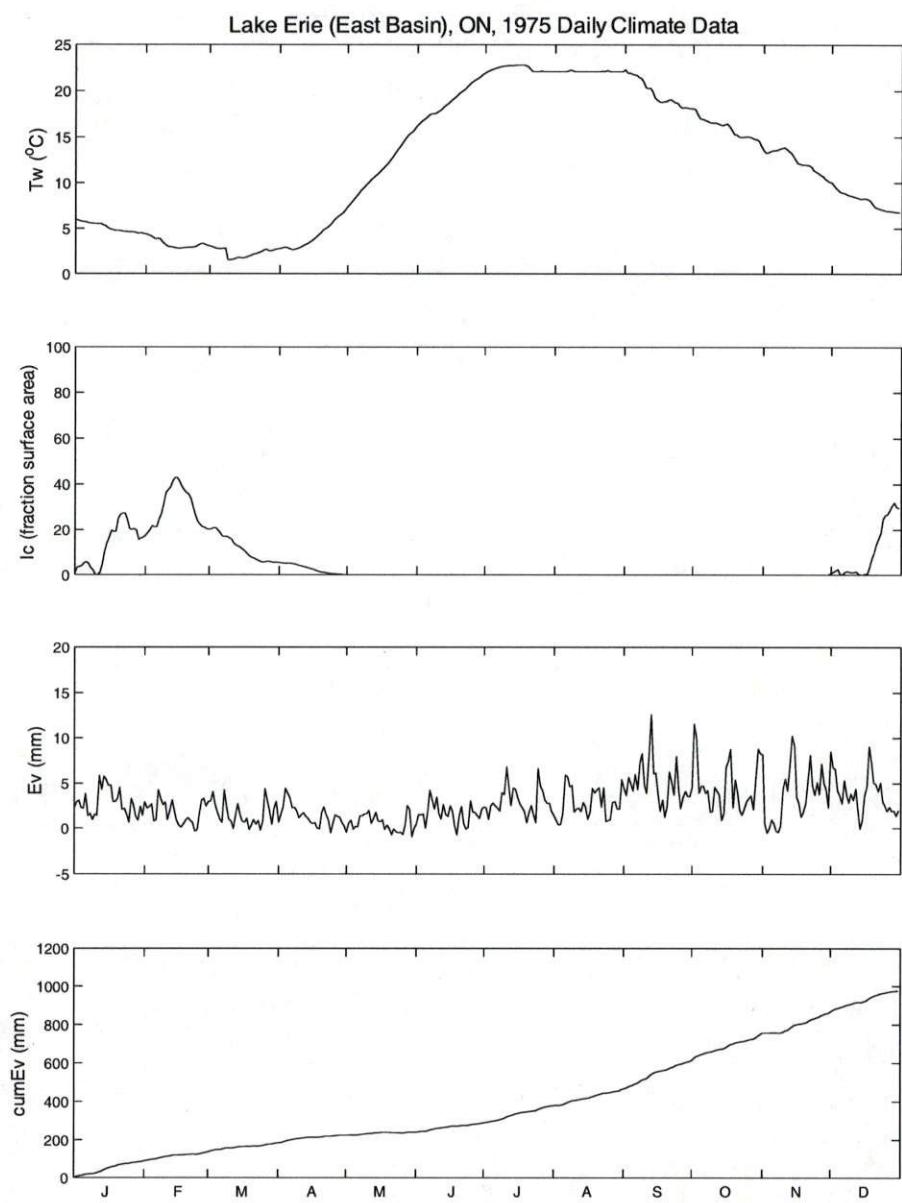


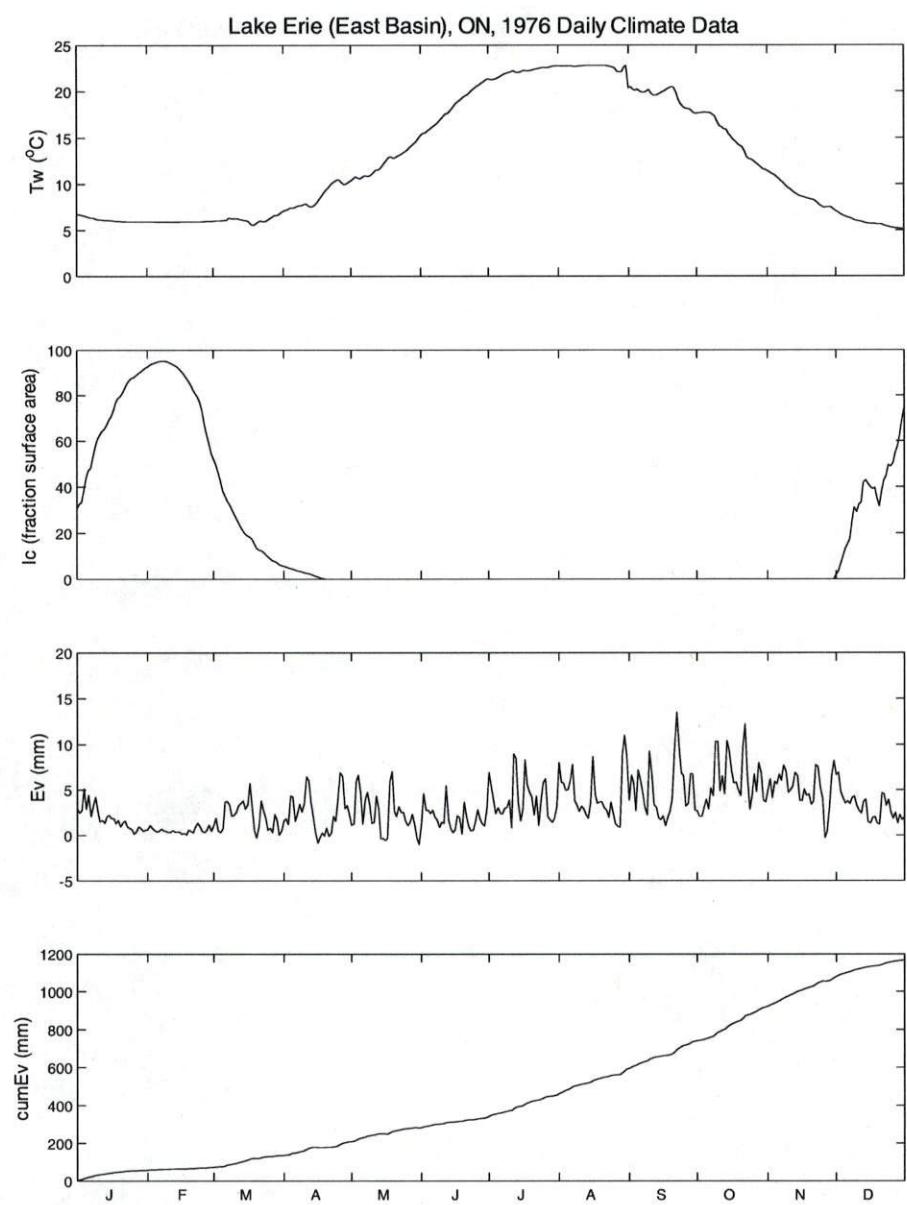


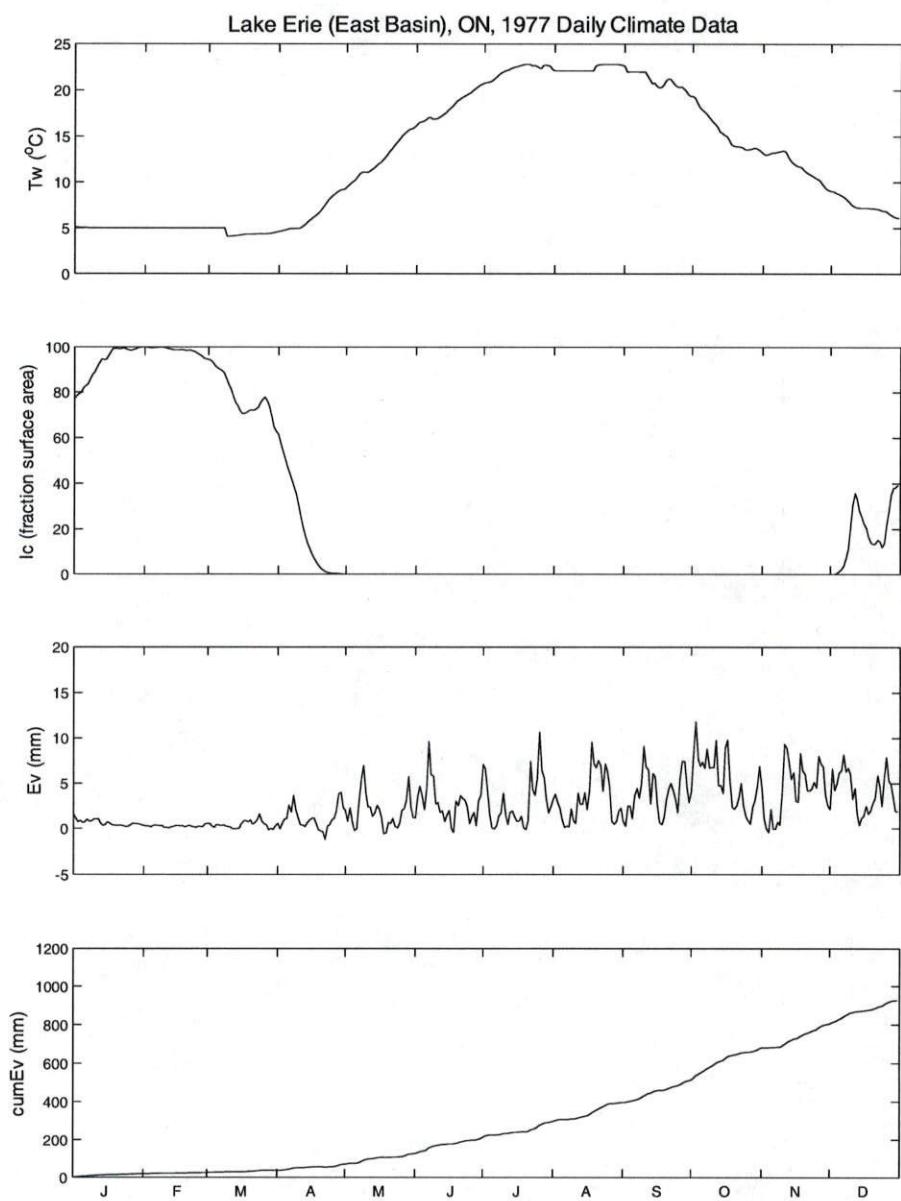




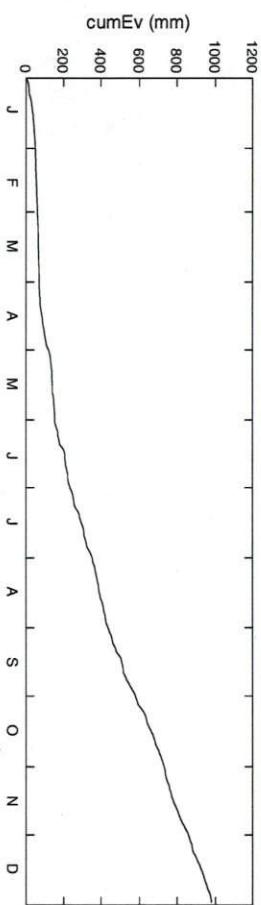
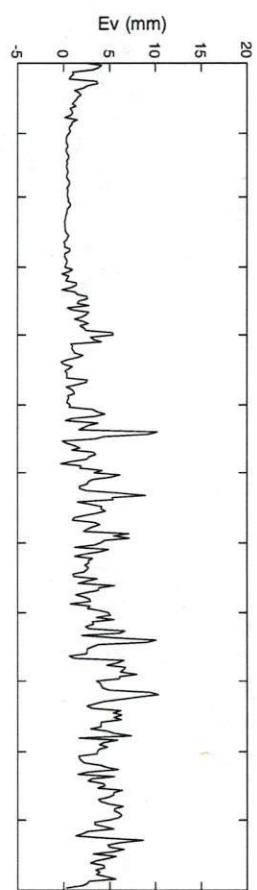
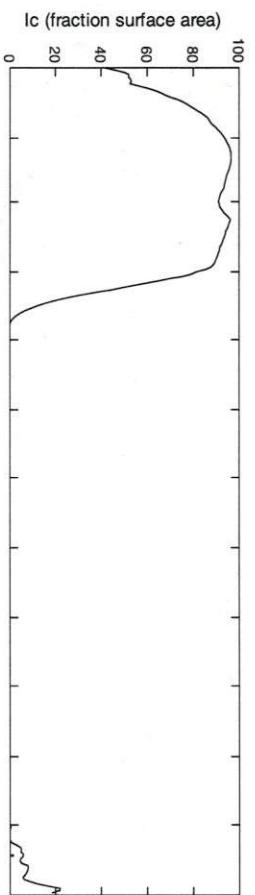
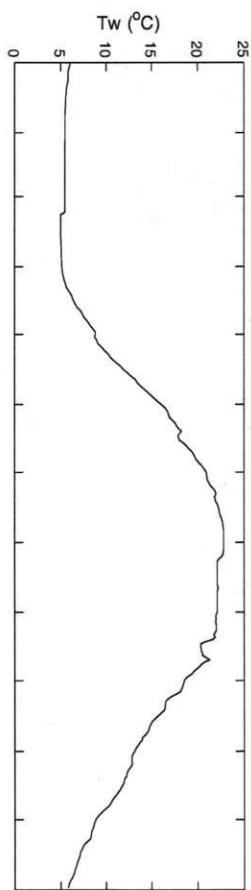


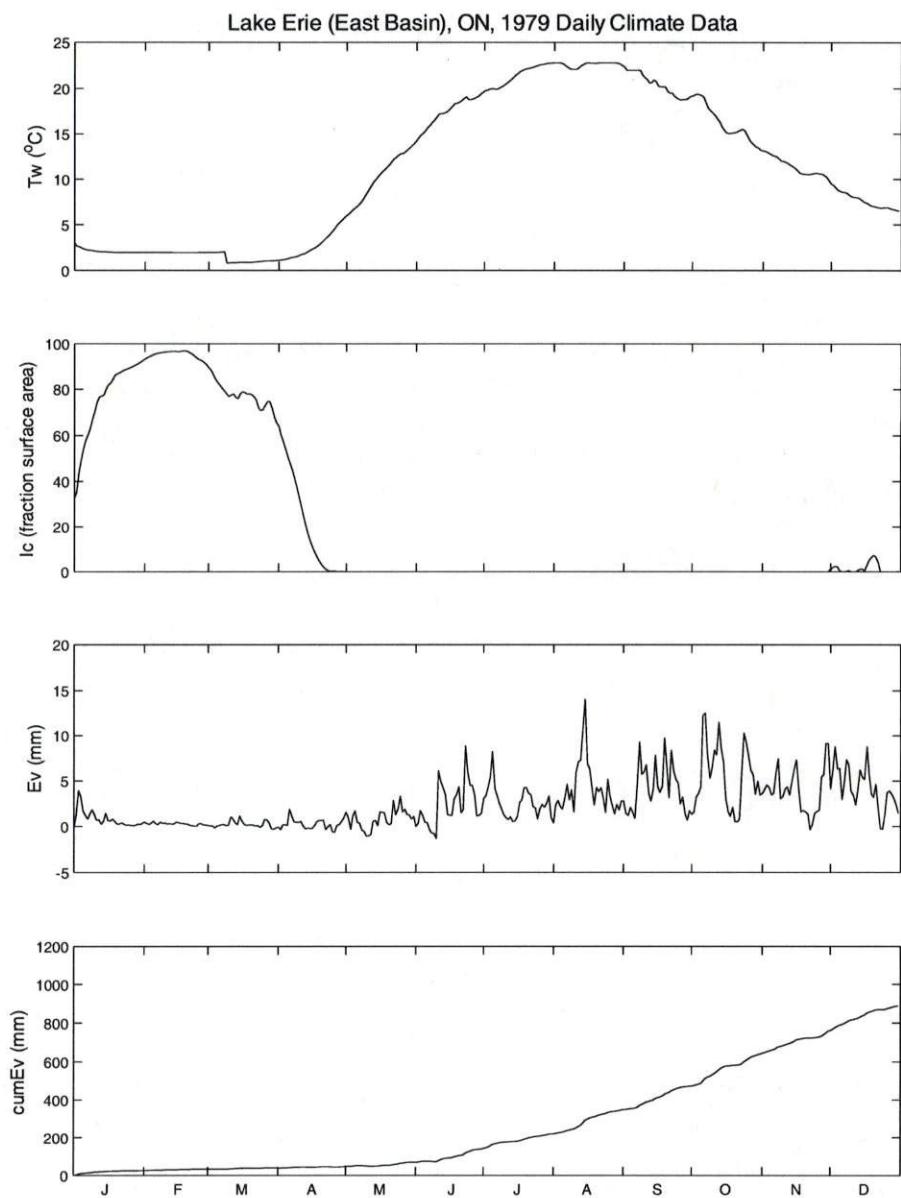


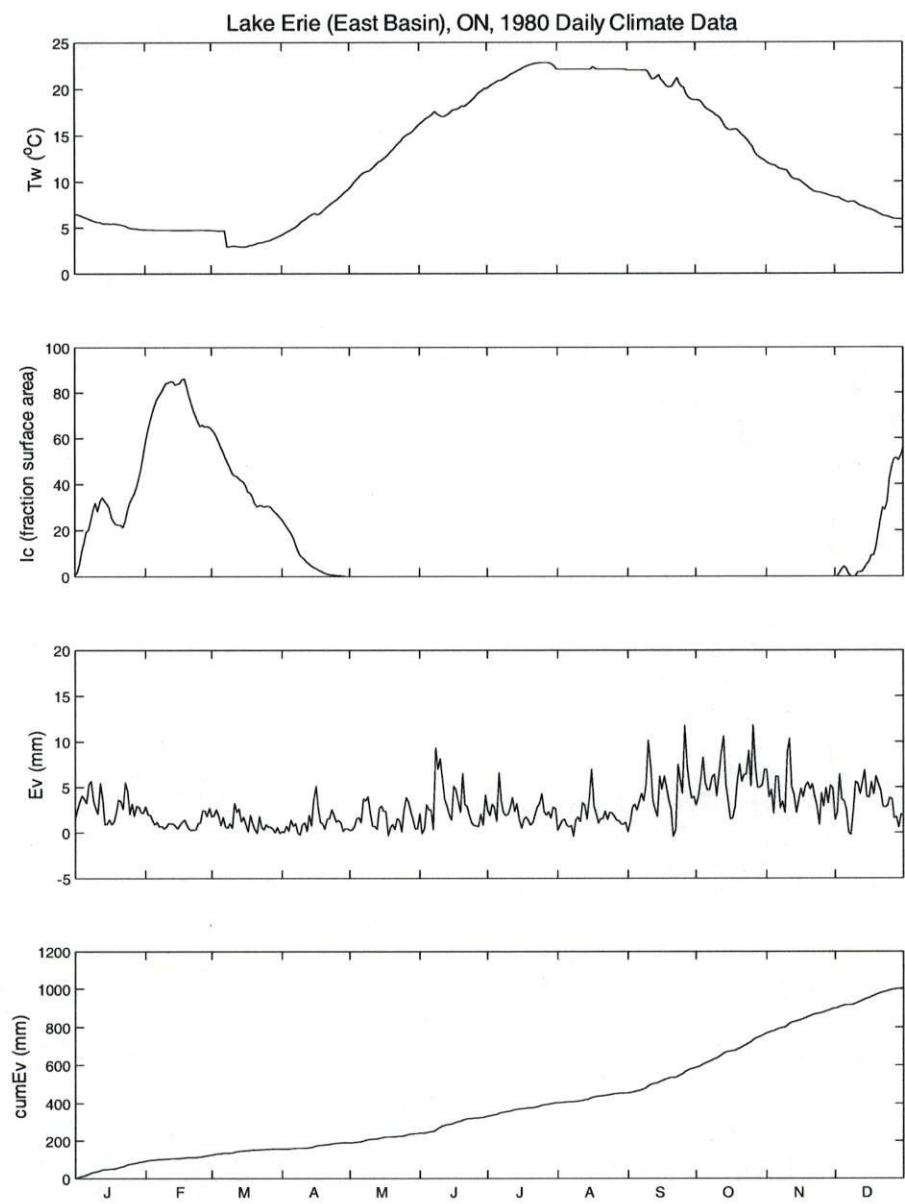


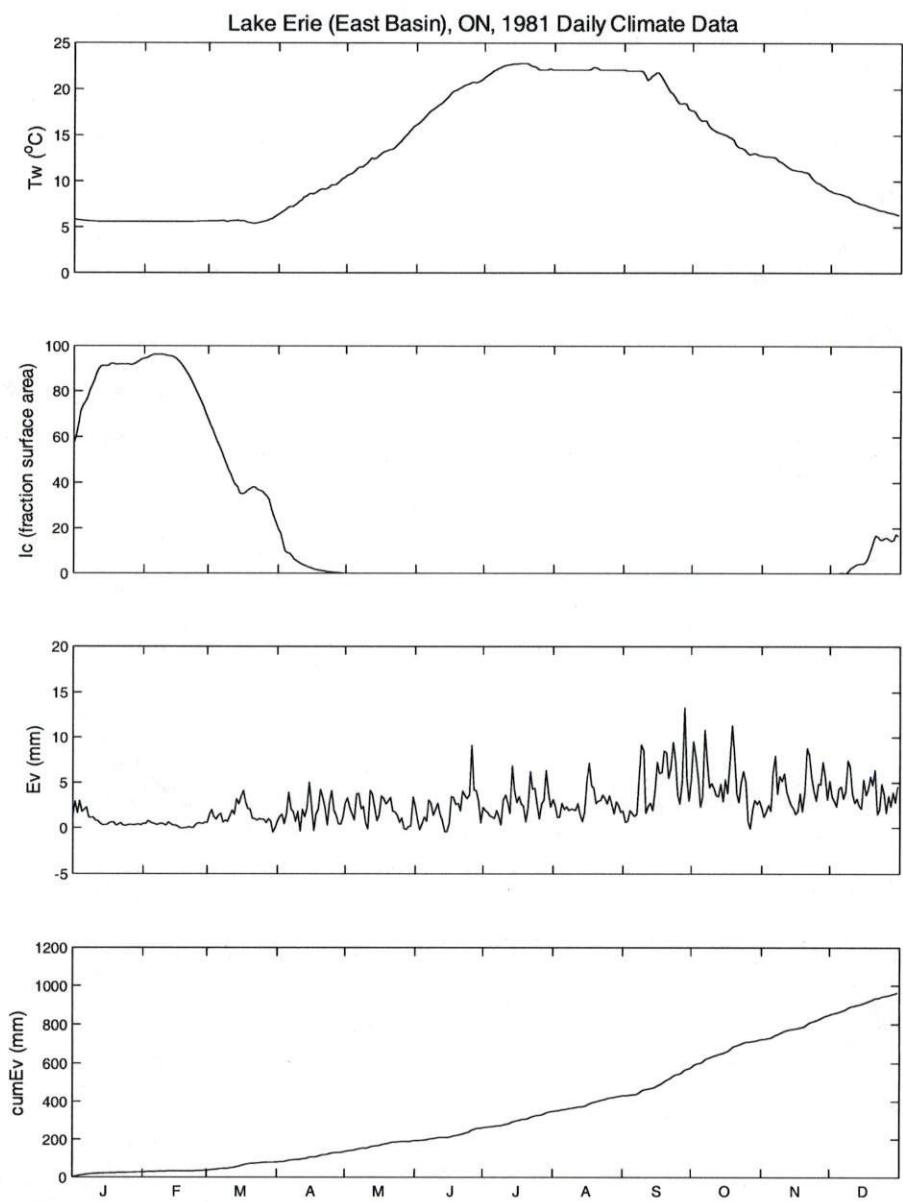


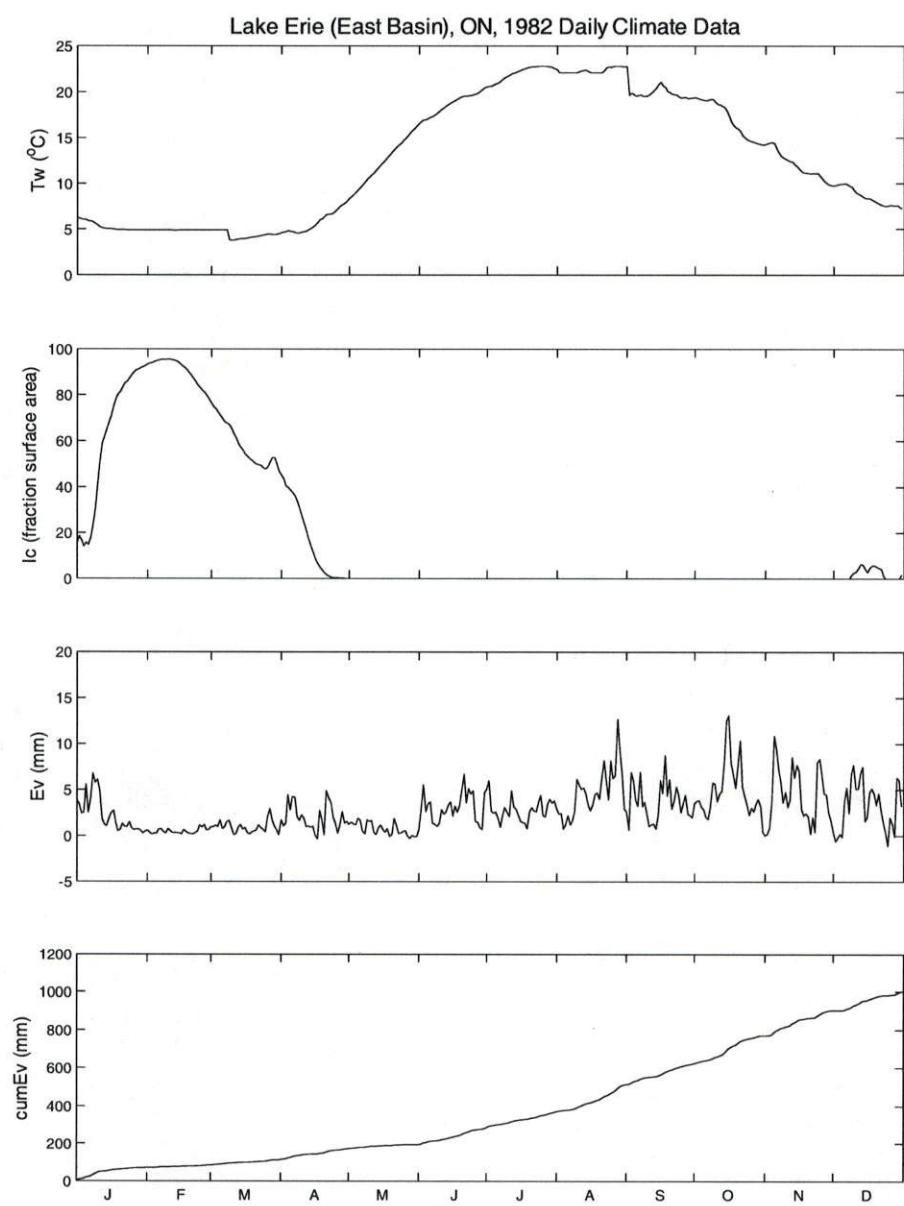
Lake Erie (East Basin), ON, 1978 Daily Climate Data

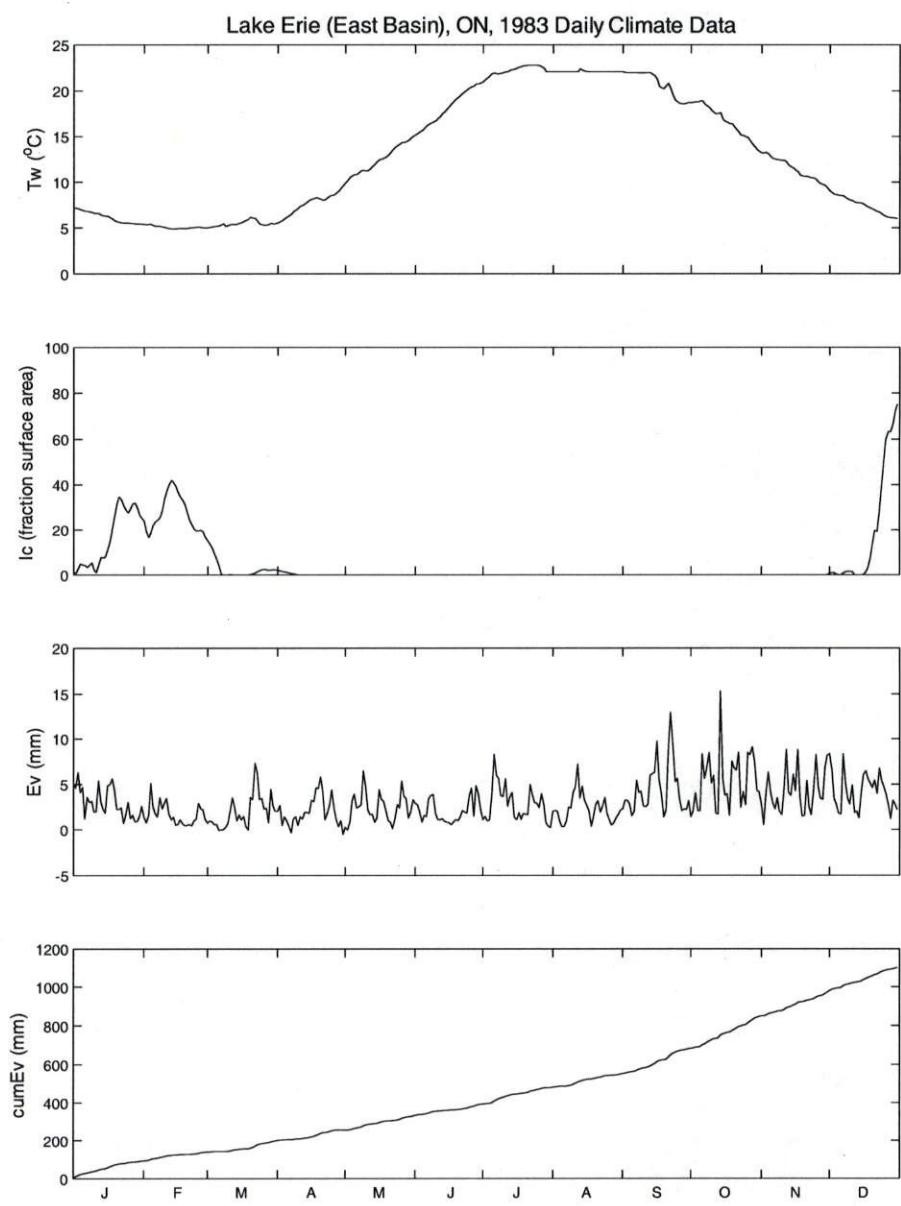


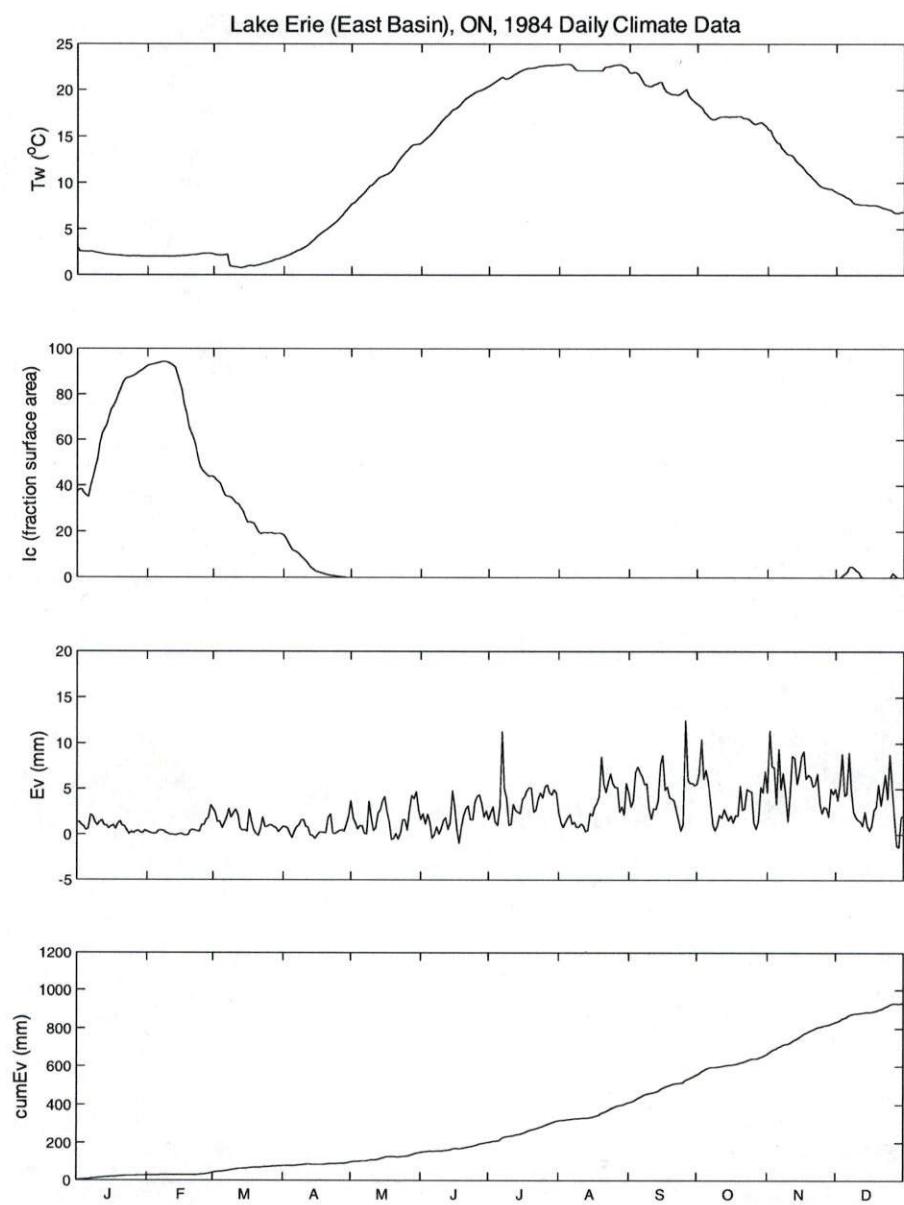


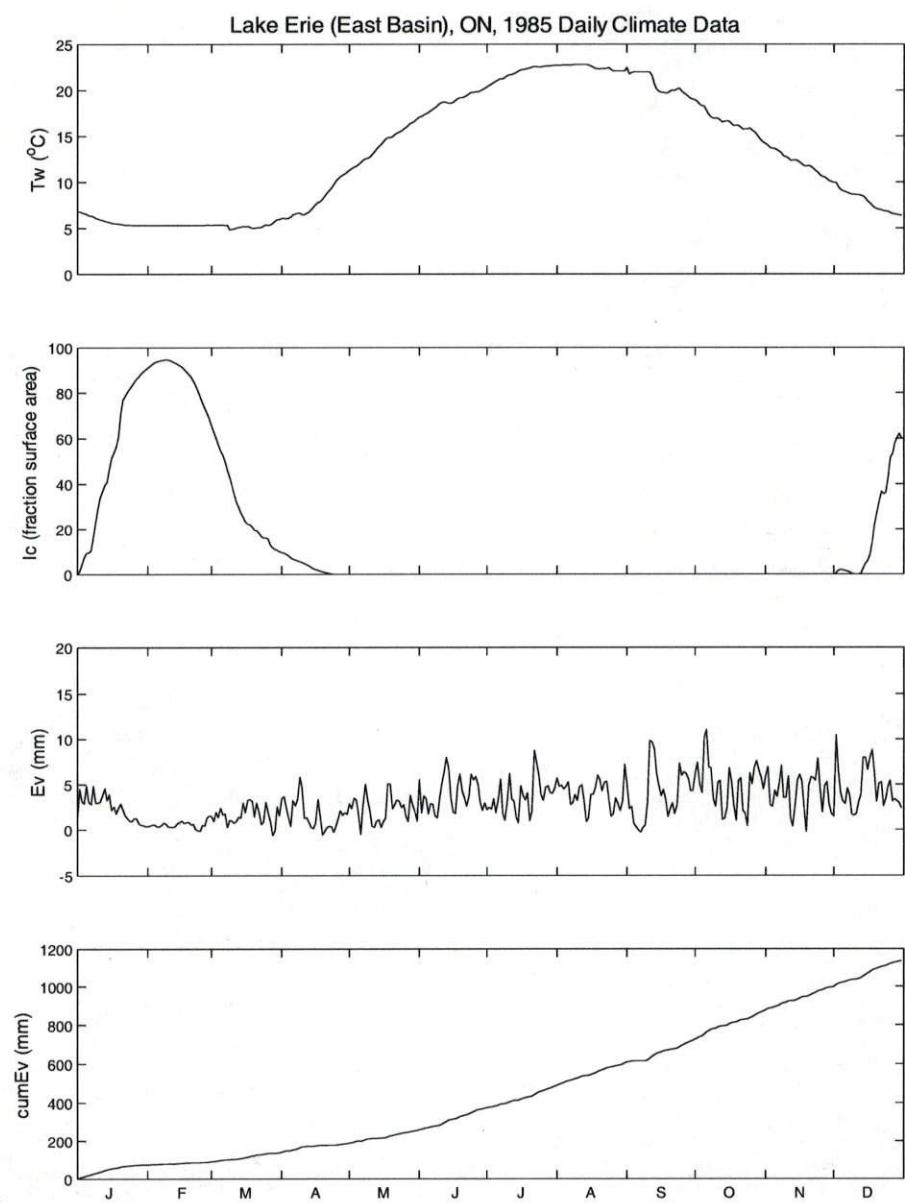


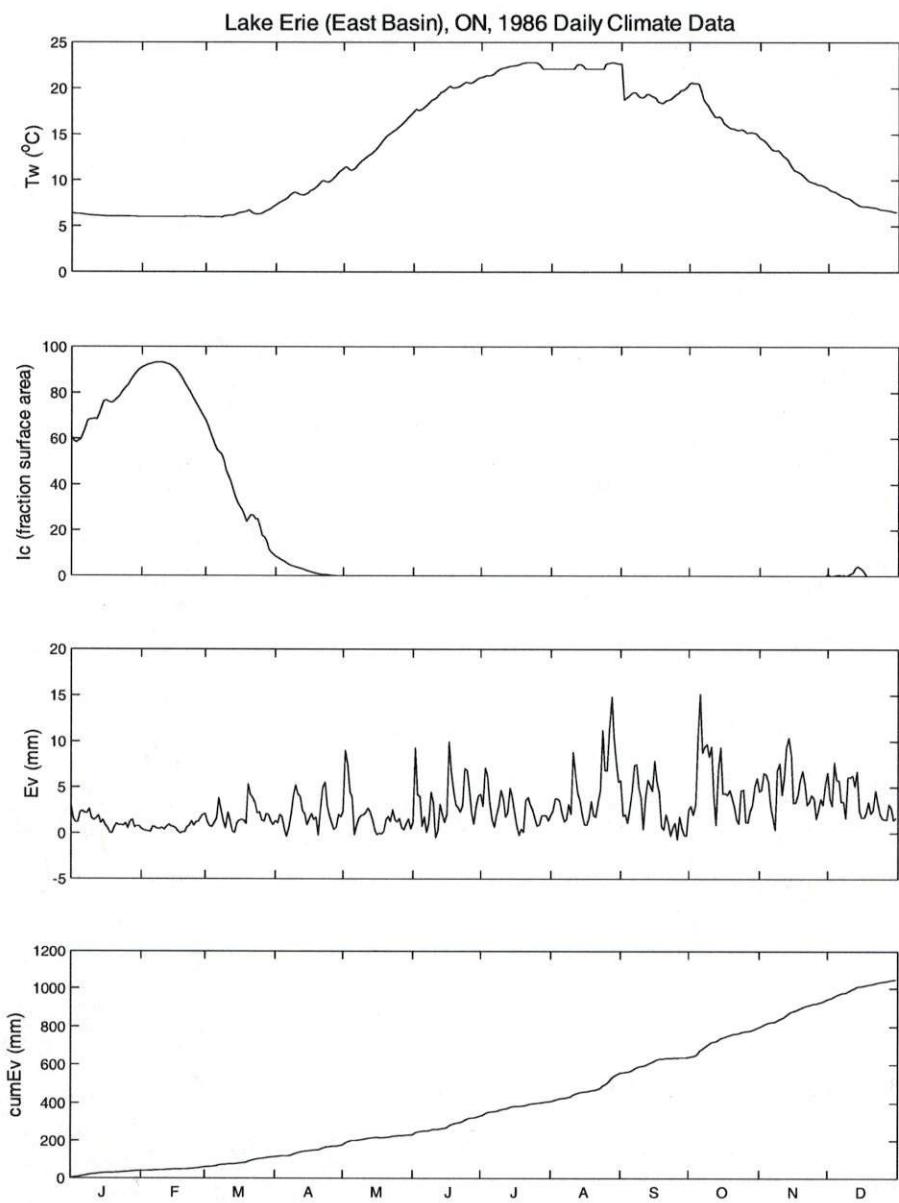


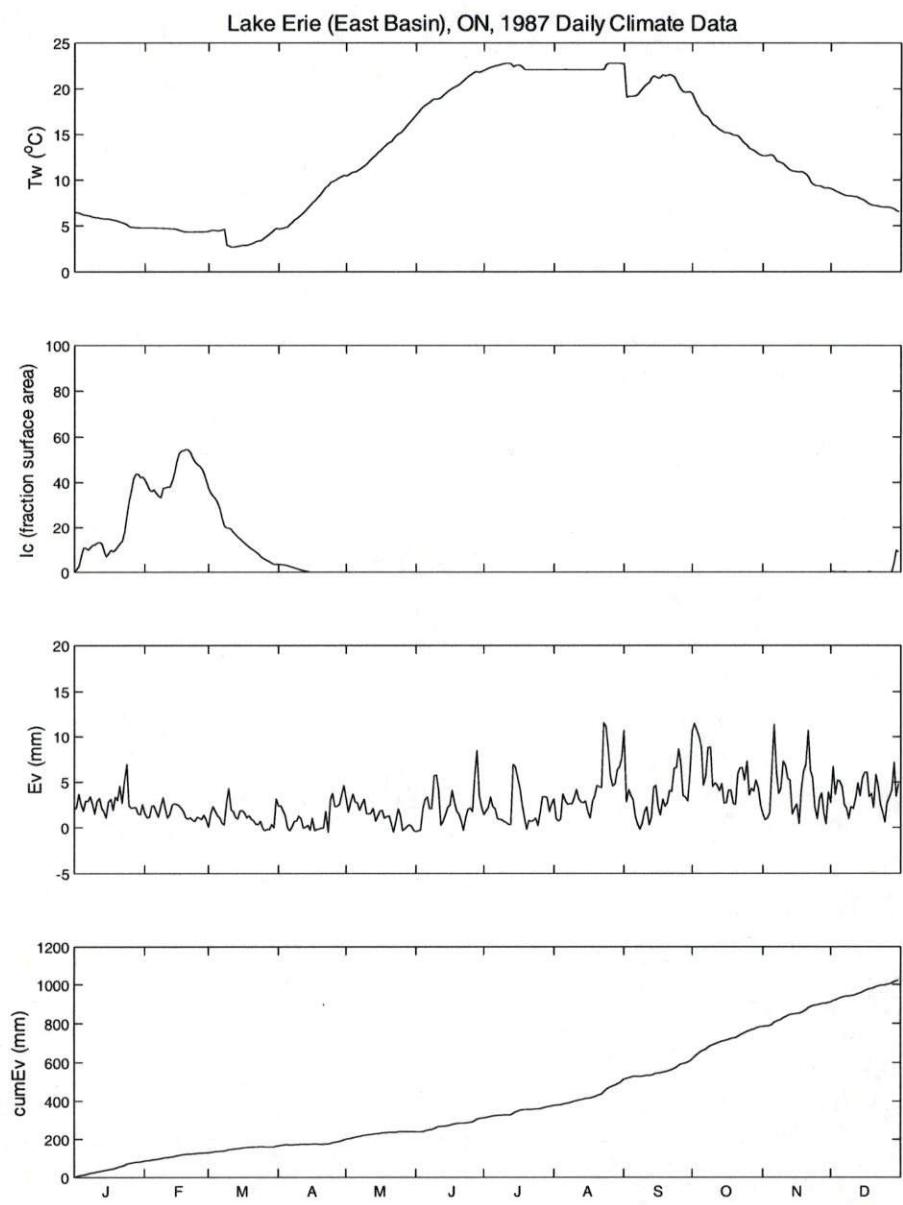


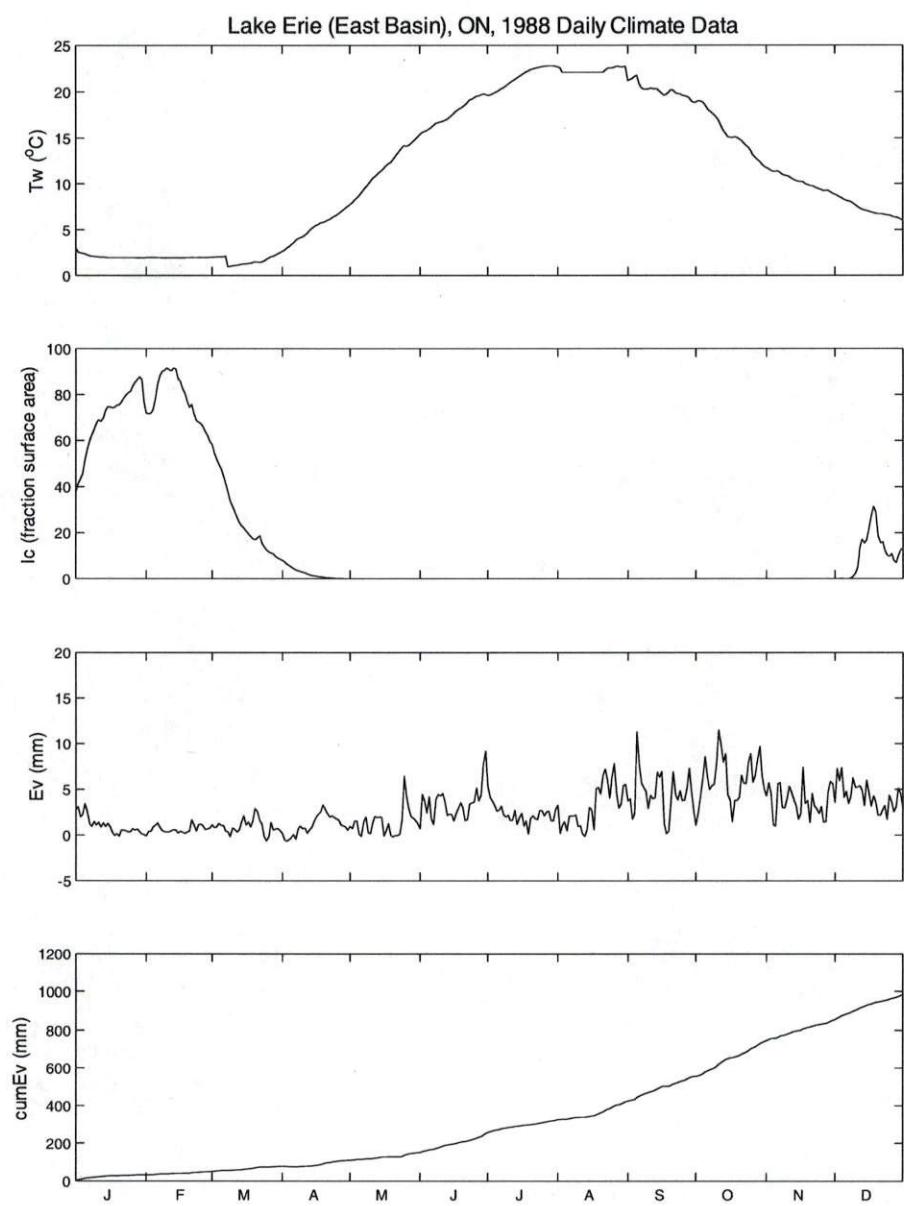


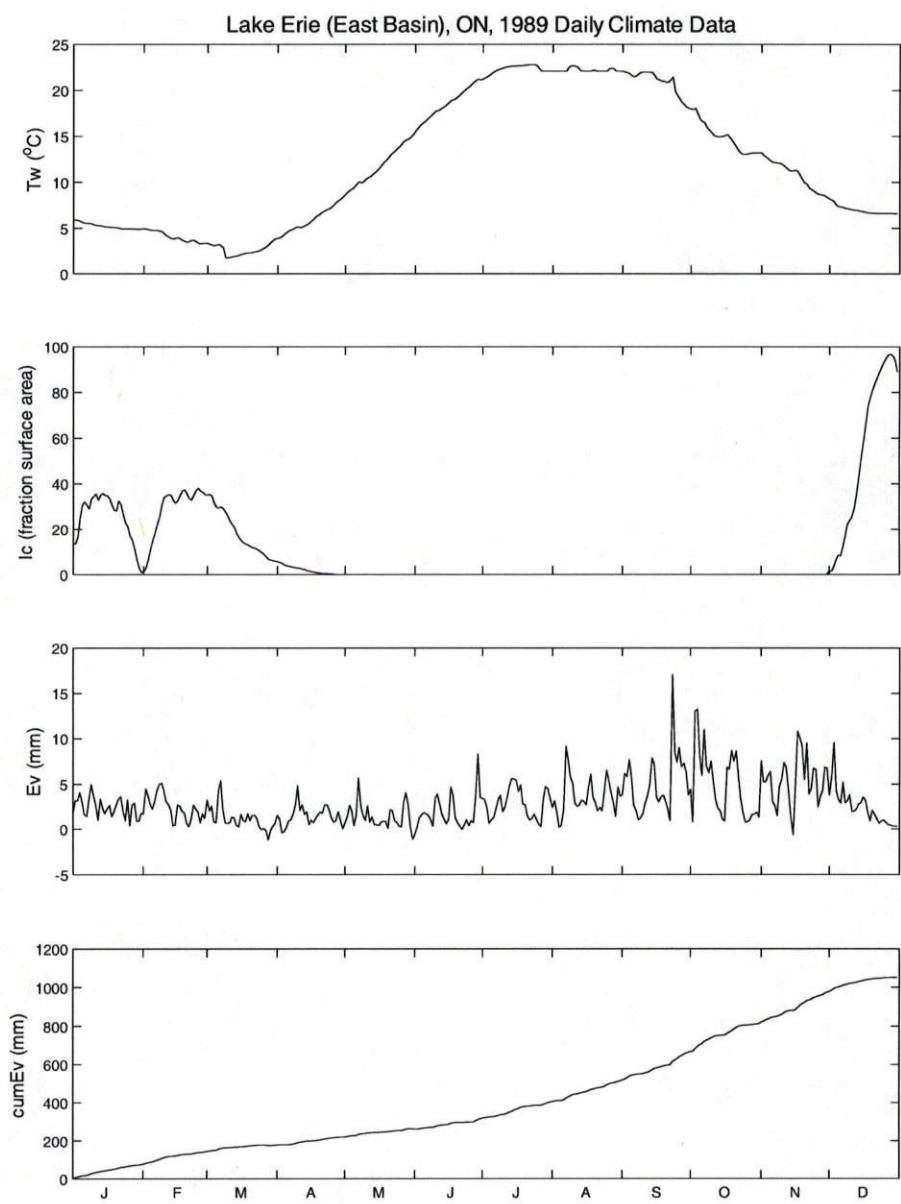


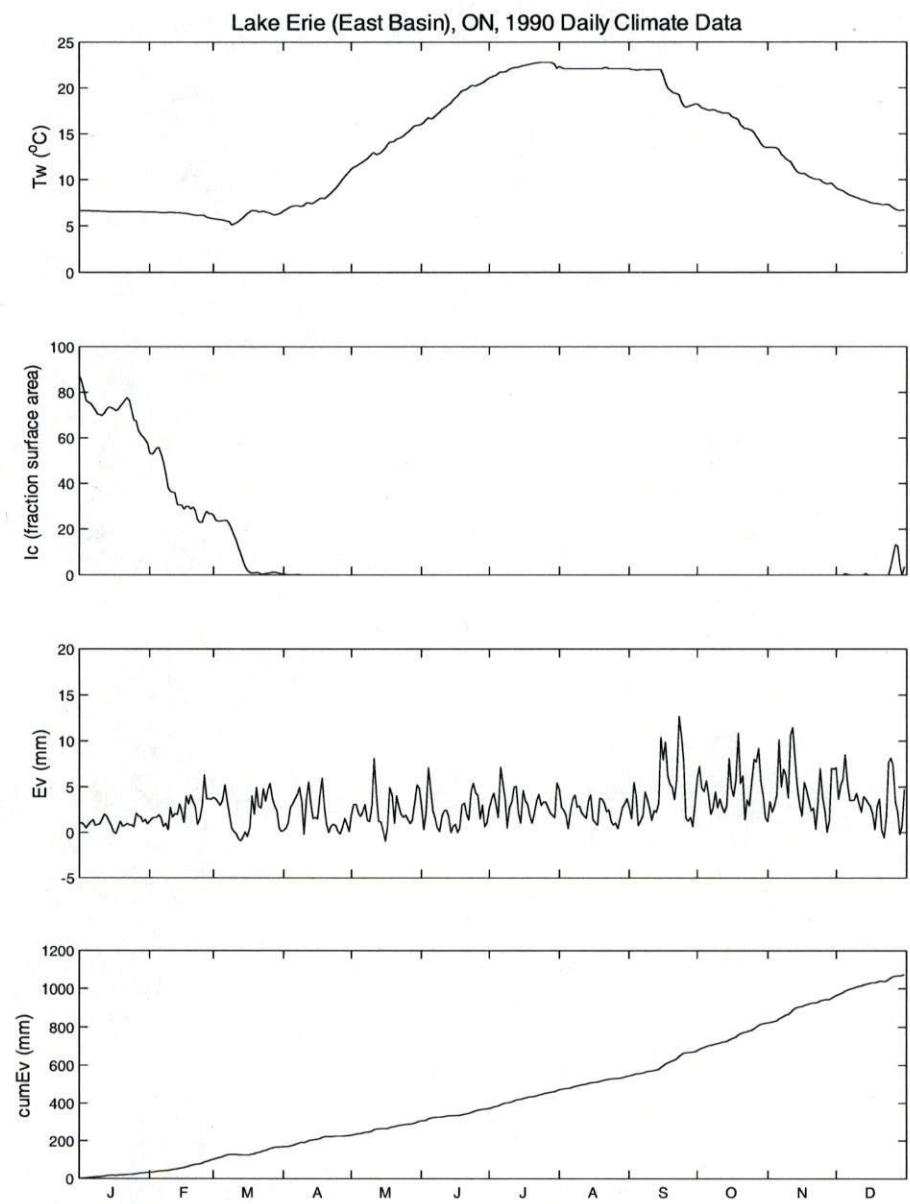


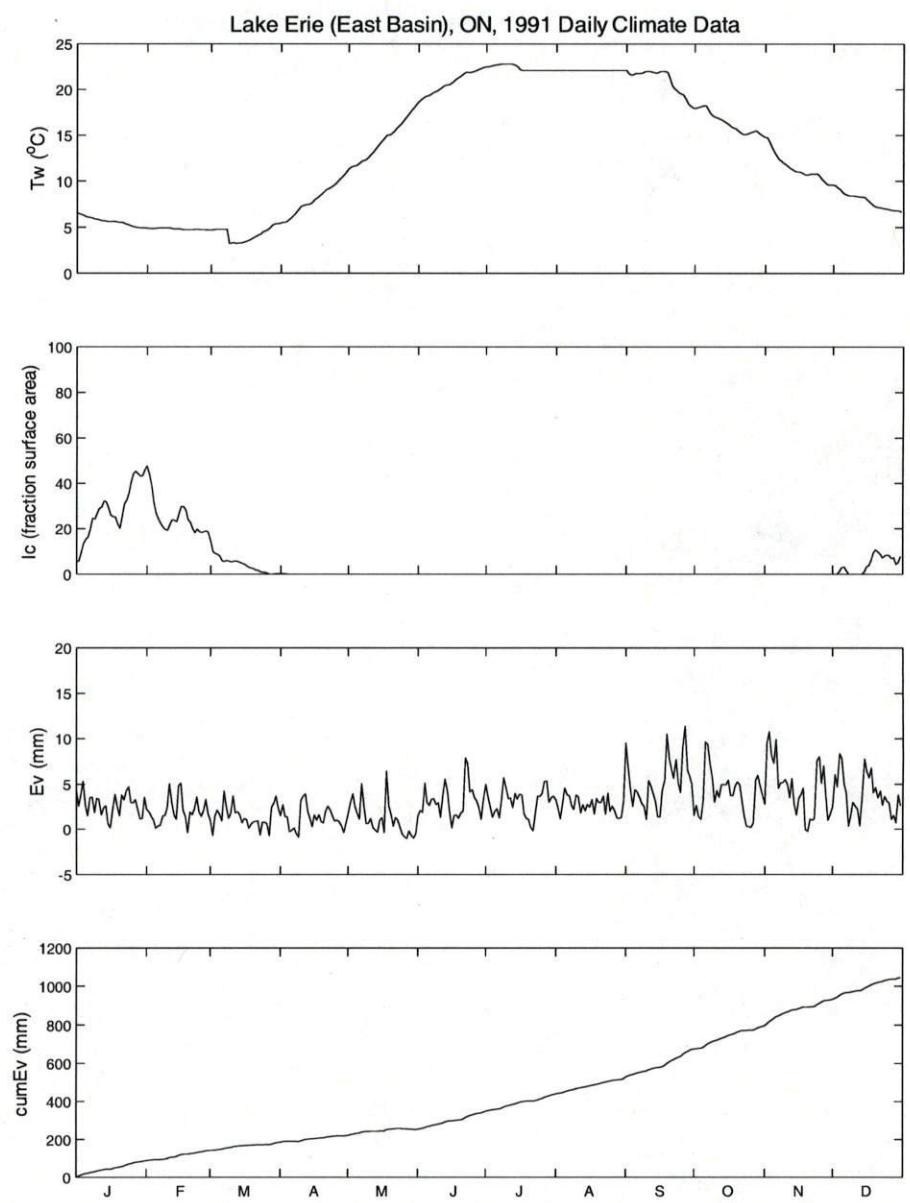


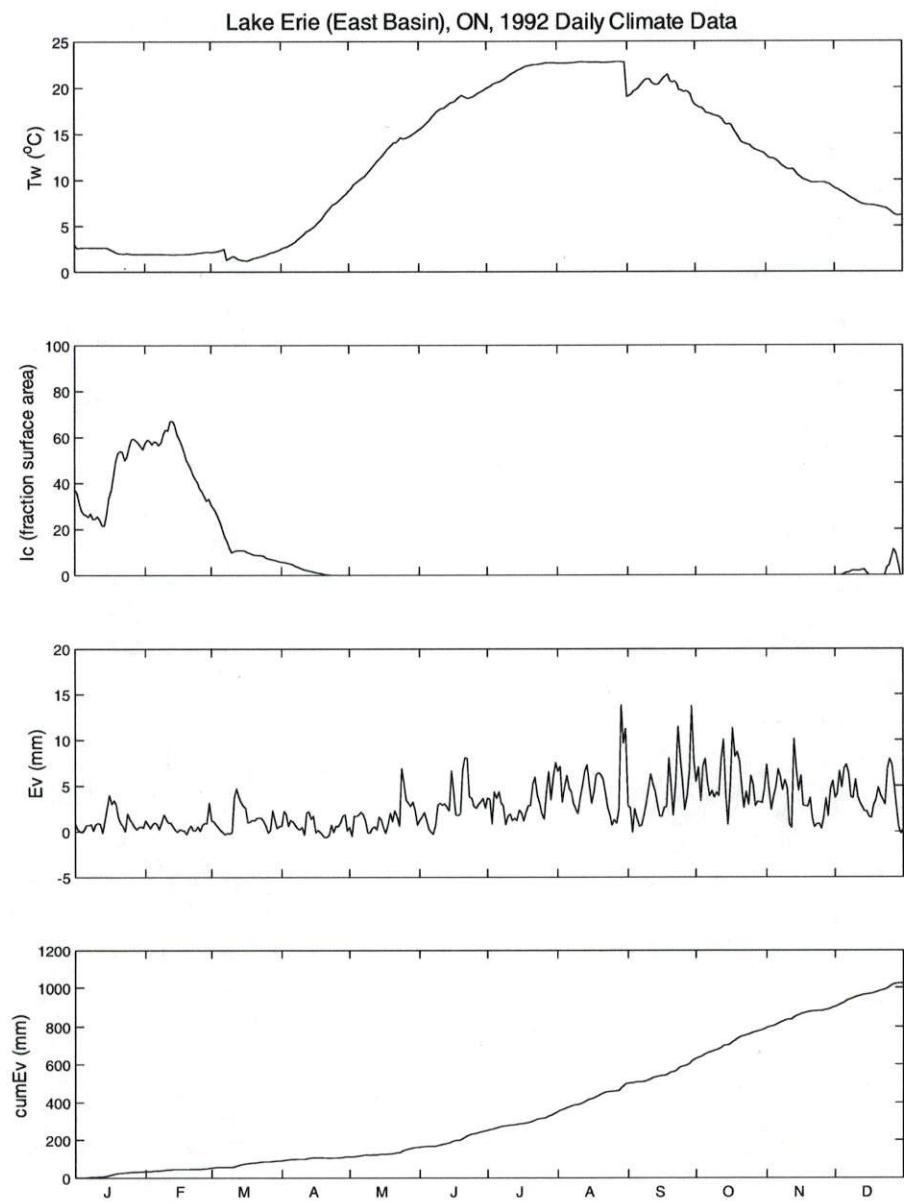


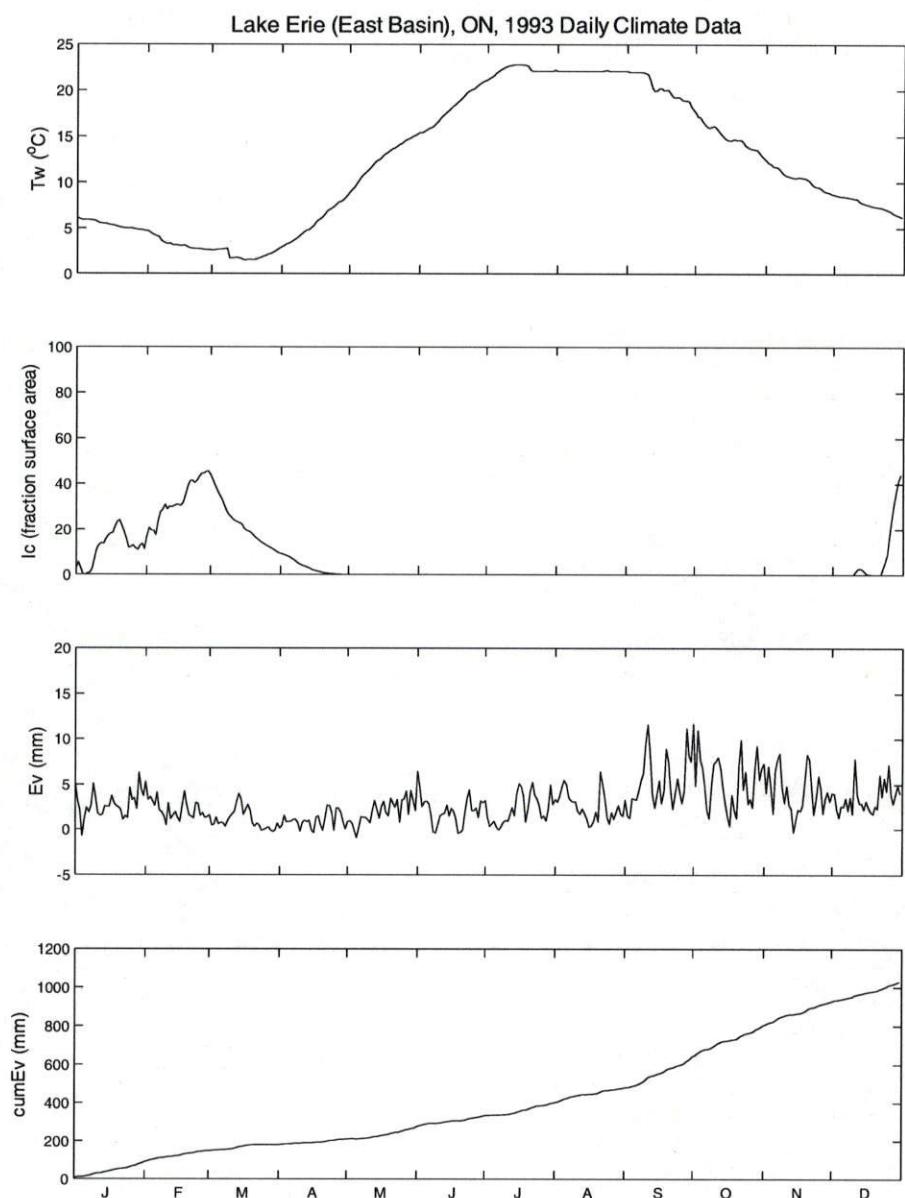


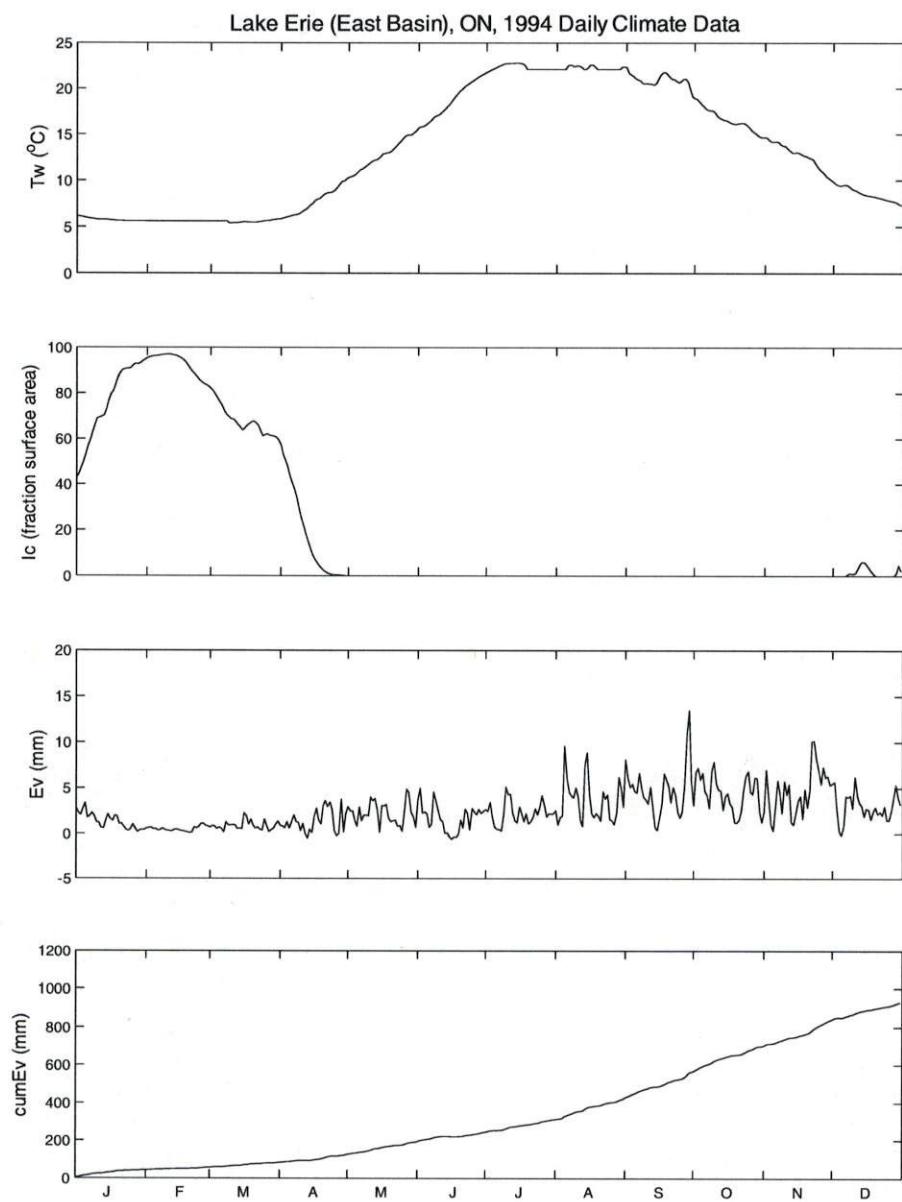


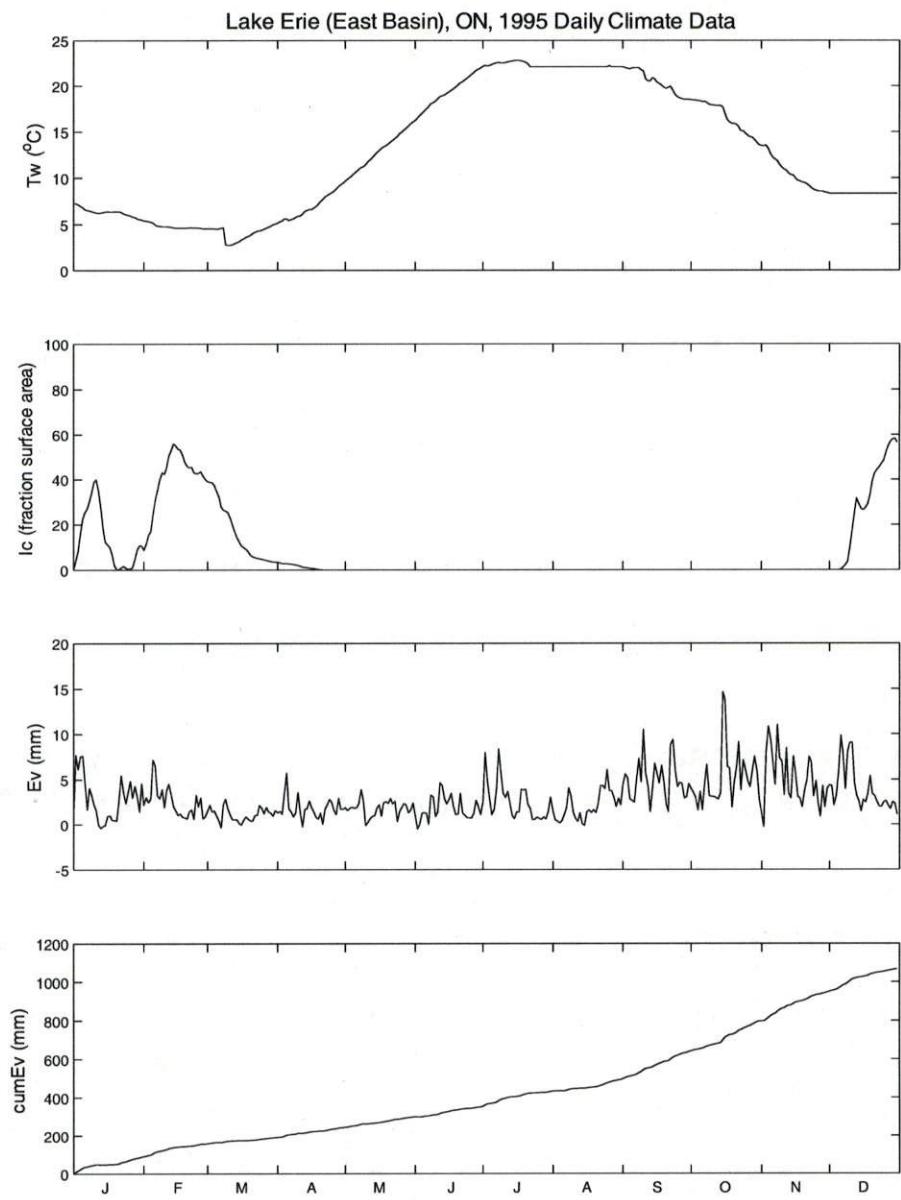




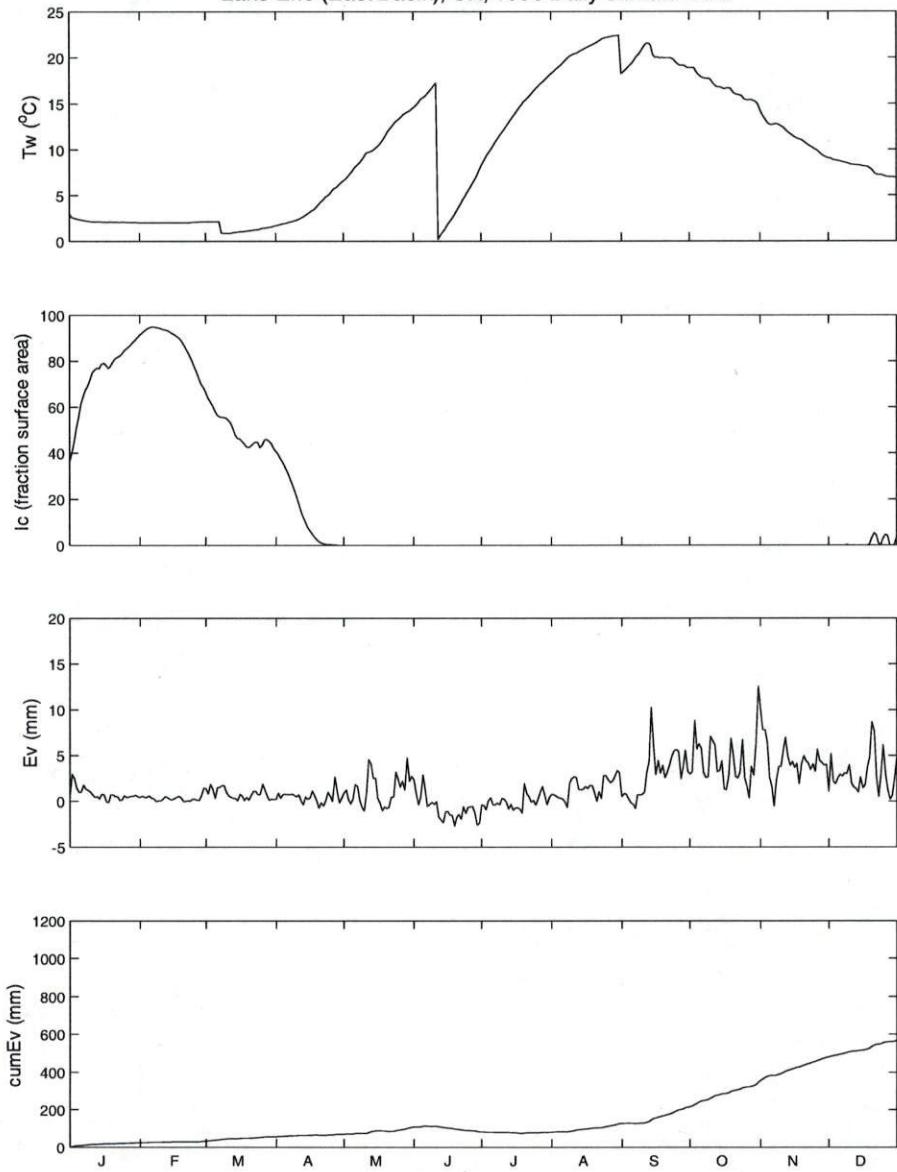


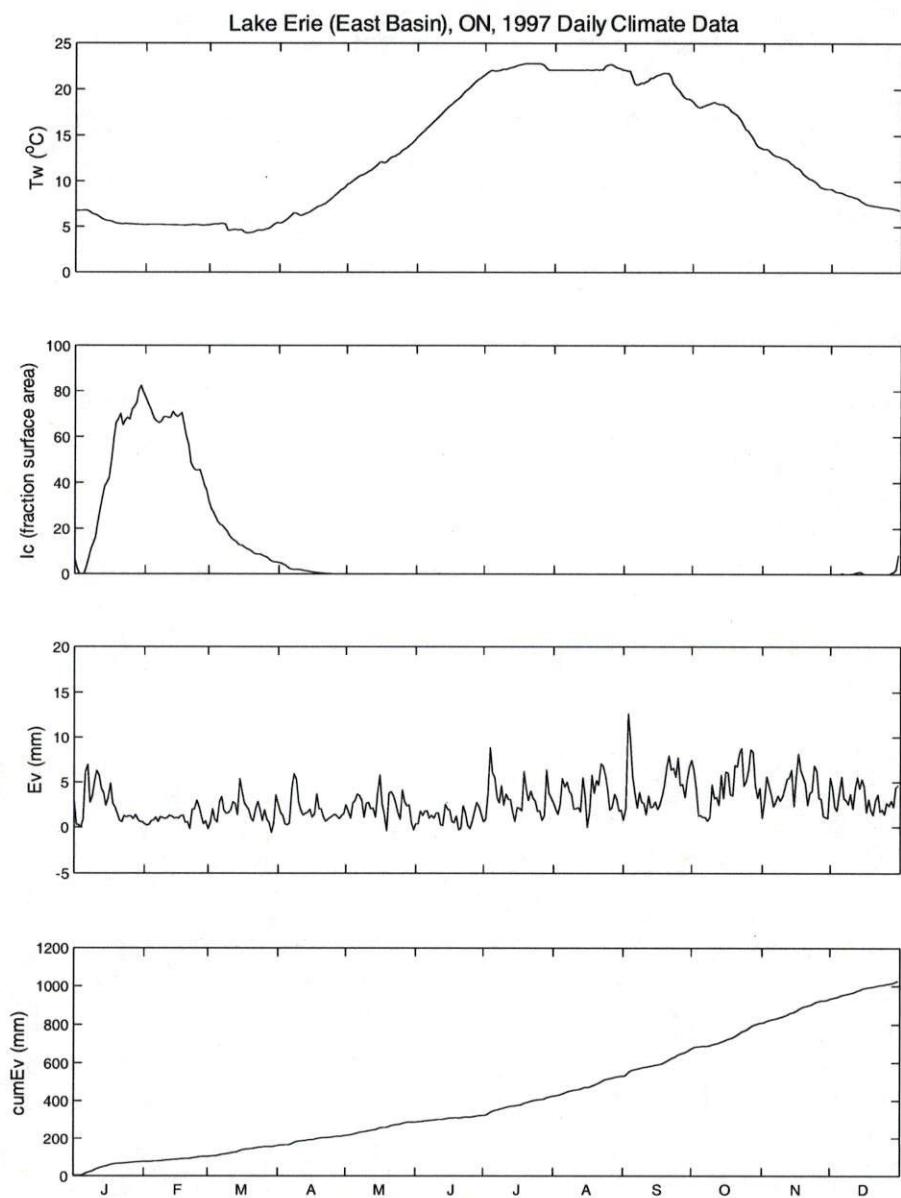






Lake Erie (East Basin), ON, 1996 Daily Climate Data





Appendix 7

MATLAB Scripts

ConvertErie_EB.m

Reads data from the original data files and generates a MATLAB compatible data files (one per year). These files are formatted to be compatible the "textread" function (comma delimited ASCII files). This script also generates a Cumulative Evaporation value. This conversion is done to simplify the process of reading in information and to greatly speed up the plotting of the data.

```
%For plotting Lake Erie (East Basin) Data
%    Years 1950 - 1997

close all
clear all

year=0;
for PlotYear = 1950: 1: 1997
close all

%Internal parameters
%PlotYear = 1965;

if ((PlotYear >= 1950) & (PlotYear <= 1995))
    InFile = 'ebf5095.dat';
else
    InFile = 'ebf9697.dat';
end

OutFile = sprintf('L_Erie_EB_%d.txt', PlotYear);
PrintFile = sprintf('L_Erie_EB_%d', PlotYear)

%Read the file; reformat it; save it in its new textread friendly format.
fid=fopen(InFile,'r');
fid_out=fopen(OutFile,'w');
%Print a header row
fprintf(fid_out,'year, ordinal, Kd, Ku, Ld, Lu, Q*, Uk, Ta, Td, Rh, Tw, As, Qh, Qe, Ev, Qi,
Ic, Qm, Qt, Qc, cumEv\r\n');
count=0;
linecount=0;
SkipLine=0;
clear cumEv;
cumEv=0;
while (~feof(fid) & year <= PlotYear)
```

```

line=fgetl(fid);

clear matches;
matches=findstr(line,'*****');
MatchCount=length(matches);
if (MatchCount > 0)
    SkipLine=1;
end

count=count+1;
if (count>3)
    clear c1 c2 c3 c4 c5 c6 c7 c8
    linecount=linecount+1;
    switch linecount
        case 1
            [year,month,day,ordinal,id]=strread(line, ' %d %d %d %d %d');
        case 2
            if ((MatchCount == 0) & (year == PlotYear))
                [Kd,Ku,Ld,Lu,Q,Uk,Ta,Td]=strread(line, ' %f %f %f %f %f %f %f %f');
            end
        case 3
            if ((MatchCount == 0) & (year == PlotYear))
                [Rh,Tw,As,Qh,Qe,Ev,Qi,Ic]=strread(line, ' %f %f %f %f %f %f %f %f');
                if (Ev ~= -999.99)
                    if (count == 6)
                        cumEv = Ev;
                    else
                        cumEv = cumEv + Ev;
                    end
                else
                    Ev = NaN;
                end
            end
        otherwise
            if ((MatchCount == 0) & (year == PlotYear))
                [Qm,Qt,Qc]=strread(line, ' %f %f %f');
            end

            linecount=0;
            if (SkipLine==0)
                if (year==PlotYear)
                    fprintf(fid_out,'%d, %d, %f, %f, %f, %f, %f, %f, %f, %f, %f, %f,
%f, %f, %f, %f, %f, %f, %f\r\n',...

```

```

year,ordinal,Kd,Ku,Ld,Lu,Q,Uk,Ta,Td,Rh,Tw,As,Qh,Qe,Ev,Qi,Ic,Qm,Qt,Qc,cumEv);

    end

    end

    SkipLine=0;

end

else

    linecount=0;

end

end

fclose(fid);

fclose(fid_out);

end

```

ErieMonthly EB.m

This script reads data from the converted yearly files and generates three comma delimited (.csv) files containing monthly Max, Min and Mean values (1950 through 1997).

% Script To generate Monthly summaries.

```
StartYear = 1950;  
EndYear = 1997;  
OutFile_Mean = 'L_Erie_EB_Monthly_Mean.csv'  
OutFile_Max = 'L_Erie_EB_Monthly_Max.csv';  
OutFile_Min = 'L_Erie_EB_Monthly_Min.csv';
```

Define a data structure.

```
ds = struct('Year',{},'Data',{});
```

* Read in the data.

```
for PlotYear = StartYear: 1: EndYear  
    close all
```

```
InFile = sprintf('L_Erie_EB_%d.txt', PlotYear);
```

```

clear year ordinal Kd Ku Ld Lu Q Uk Ta Td Rh Tw As Qh Qe Ev Qi Ic Qm Qt Qc cumEv;
end

%Initialize the results file.
fid_mean=fopen(OutFile_Mean,'w');
fid_max=fopen(OutFile_Max,'w');
fid_min=fopen(OutFile_Min,'w');

%Print a header row
fprintf(fid_mean,'year, month, Kd, Ku, Ld, Lu, Q*, Uk, Ta, Td, Rh, Tw, As, Qh, Qe, Ev, Qi,
Ic, Qm, Qt, Qc, cumEv\r\n');
fprintf(fid_max,'year, month, Kd, Ku, Ld, Lu, Q*, Uk, Ta, Td, Rh, Tw, As, Qh, Qe, Ev, Qi,
Ic, Qm, Qt, Qc, cumEv\r\n');
fprintf(fid_min,'year, month, Kd, Ku, Ld, Lu, Q*, Uk, Ta, Td, Rh, Tw, As, Qh, Qe, Ev, Qi,
Ic, Qm, Qt, Qc, cumEv\r\n');

%Calculate the Monthly means.
for PlotYear = StartYear: 1: EndYear    %Loop through the years.
    clear MMean MMax MMin;

    %Determine the start and ends ordinal date for each month.
    IsLeap = mod(PlotYear,4);
    if (IsLeap == 0)      %0 represents a leap year.
        Month_Start = [1 32 61 92 122 153 183 214 245 275 306 336];
        Month_End = [31 60 91 121 152 182 213 244 274 305 335 366];
    else
        Month_Start = [1 32 60 91 121 152 182 213 244 274 305 335];
        Month_End = [31 59 90 120 151 181 212 243 273 304 334 365];
    end

    for i = 1: 1: 12    %Loop through the months.
        %Kd
        clear FD Filtered ii
        FD = ds(PlotYear).Data(Month_Start(i):Month_End(i),3);
        [ii] = find(FD ~= -999.99);
        Filtered = FD(ii);
        if (size(Filtered) > 0)
            MMean(i,3) = mean(Filtered);
            MMax(i,3) = max(Filtered);
            MMin(i,3) = min(Filtered);
        else
            MMean(i,3) = -999.99;
            MMax(i,3) = -999.99;
        end
    end

```

```

    MMin(i,3) = -999.99;
end
%Ku
clear FD Filtered ii
FD = ds(PlotYear).Data(Month_Start(i):Month_End(i),4);
[ii] = find(FD ~= -999.99);
Filtered = FD(ii);
if (size(Filtered) > 0)
    MMean(i,4) = mean(Filtered);
    MMax(i,4) = max(Filtered);
    MMin(i,4) = min(Filtered);
else
    MMean(i,4) = -999.99;
    MMax(i,4) = -999.99;
    MMin(i,4) = -999.99;
end
%Ld
clear FD Filtered ii
FD = ds(PlotYear).Data(Month_Start(i):Month_End(i),5);
[ii] = find(FD ~= -999.99);
Filtered = FD(ii);
if (size(Filtered) > 0)
    MMean(i,5) = mean(Filtered);
    MMax(i,5) = max(Filtered);
    MMin(i,5) = min(Filtered);
else
    MMean(i,5) = -999.99;
    MMax(i,5) = -999.99;
    MMin(i,5) = -999.99;
end
%Lu
clear FD Filtered ii
FD = ds(PlotYear).Data(Month_Start(i):Month_End(i),6);
[ii] = find(FD ~= -999.99);
Filtered = FD(ii);
if (size(Filtered) > 0)
    MMean(i,6) = mean(Filtered);
    MMax(i,6) = max(Filtered);
    MMin(i,6) = min(Filtered);
else
    MMean(i,6) = -999.99;
    MMax(i,6) = -999.99;
    MMin(i,6) = -999.99;

```

```

end
%Q
clear FD Filtered ii
FD = ds(PlotYear).Data(Month_Start(i):Month_End(i),7);
[ii] = find(FD ~= -999.99);
Filtered = FD(ii);
if (size(Filtered) > 0)
    MMean(i,7) = mean(Filtered);
    MMax(i,7) = max(Filtered);
    MMin(i,7) = min(Filtered);
else
    MMean(i,7) = -999.99;
    MMax(i,7) = -999.99;
    MMin(i,7) = -999.99;
end
%Uk
clear FD Filtered ii
FD = ds(PlotYear).Data(Month_Start(i):Month_End(i),8);
[ii] = find(FD ~= -999.99);
Filtered = FD(ii);
if (size(Filtered) > 0)
    MMean(i,8) = mean(Filtered);
    MMax(i,8) = max(Filtered);
    MMin(i,8) = min(Filtered);
else
    MMean(i,8) = -999.99;
    MMax(i,8) = -999.99;
    MMin(i,8) = -999.99;
end
%Ta
clear FD Filtered ii
FD = ds(PlotYear).Data(Month_Start(i):Month_End(i),9);
[ii] = find(FD ~= -999.99);
Filtered = FD(ii);
if (size(Filtered) > 0)
    MMean(i,9) = mean(Filtered);
    MMax(i,9) = max(Filtered);
    MMin(i,9) = min(Filtered);
else
    MMean(i,9) = -999.99;
    MMax(i,9) = -999.99;
    MMin(i,9) = -999.99;
end

```

```

%Td
clear FD Filtered ii
FD = ds(PlotYear).Data(Month_Start(i):Month_End(i),10);
[ii] = find(FD ~= -999.99);
Filtered = FD(ii);
if (size(Filtered) > 0)
    MMean(i,10) = mean(Filtered);
    MMax(i,10) = max(Filtered);
    MMin(i,10) = min(Filtered);
else
    MMean(i,10) = -999.99;
    MMax(i,10) = -999.99;
    MMin(i,10) = -999.99;
end
%Rh
clear FD Filtered ii
FD = ds(PlotYear).Data(Month_Start(i):Month_End(i),11);
[ii] = find(FD ~= -999.99);
Filtered = FD(ii);
if (size(Filtered) > 0)
    MMean(i,11) = mean(Filtered);
    MMax(i,11) = max(Filtered);
    MMin(i,11) = min(Filtered);
else
    MMean(i,11) = -999.99;
    MMax(i,11) = -999.99;
    MMin(i,11) = -999.99;
end
%Tw
clear FD Filtered ii
FD = ds(PlotYear).Data(Month_Start(i):Month_End(i),12);
[ii] = find(FD ~= -999.99);
Filtered = FD(ii);
if (size(Filtered) > 0)
    MMean(i,12) = mean(Filtered);
    MMax(i,12) = max(Filtered);
    MMin(i,12) = min(Filtered);
else
    MMean(i,12) = -999.99;
    MMax(i,12) = -999.99;
    MMin(i,12) = -999.99;
end
%As

```

```

clear FD Filtered ii
FD = ds(PlotYear).Data(Month_Start(i):Month_End(i),13);
[ii] = find(FD ~= -999.99);
Filtered = FD(ii);
if (size(Filtered) > 0)
    MMean(i,13) = mean(Filtered);
    MMax(i,13) = max(Filtered);
    MMin(i,13) = min(Filtered);
else
    MMean(i,13) = -999.99;
    MMax(i,13) = -999.99;
    MMin(i,13) = -999.99;
end
%Qh
clear FD Filtered ii
FD = ds(PlotYear).Data(Month_Start(i):Month_End(i),14);
[ii] = find(FD ~= -999.99);
Filtered = FD(ii);
if (size(Filtered) > 0)
    MMean(i,14) = mean(Filtered);
    MMax(i,14) = max(Filtered);
    MMin(i,14) = min(Filtered);
else
    MMean(i,14) = -999.99;
    MMax(i,14) = -999.99;
    MMin(i,14) = -999.99;
end
%Qe
clear FD Filtered ii
FD = ds(PlotYear).Data(Month_Start(i):Month_End(i),15);
[ii] = find(FD ~= -999.99);
Filtered = FD(ii);
if (size(Filtered) > 0)
    MMean(i,15) = mean(Filtered);
    MMax(i,15) = max(Filtered);
    MMin(i,15) = min(Filtered);
else
    MMean(i,15) = -999.99;
    MMax(i,15) = -999.99;
    MMin(i,15) = -999.99;
end
%Ev
clear FD Filtered ii

```

```

FD = ds(PlotYear).Data(Month_Start(i):Month_End(i),16);
[ii] = find(FD ~= -999.99);
Filtered = FD(ii);
if (size(Filtered) > 0)
    MMean(i,16) = mean(Filtered);
    MMax(i,16) = max(Filtered);
    MMin(i,16) = min(Filtered);
else
    MMean(i,16) = -999.99;
    MMax(i,16) = -999.99;
    MMin(i,16) = -999.99;
end
%Qi
clear FD Filtered ii
FD = ds(PlotYear).Data(Month_Start(i):Month_End(i),17);
[ii] = find(FD ~= -999.99);
Filtered = FD(ii);
if (size(Filtered) > 0)
    MMean(i,17) = mean(Filtered);
    MMax(i,17) = max(Filtered);
    MMin(i,17) = min(Filtered);
else
    MMean(i,17) = -999.99;
    MMax(i,17) = -999.99;
    MMin(i,17) = -999.99;
end
%Ic
clear FD Filtered ii
FD = ds(PlotYear).Data(Month_Start(i):Month_End(i),18);
[ii] = find(FD ~= -999.99);
Filtered = FD(ii);
if (size(Filtered) > 0)
    MMean(i,18) = mean(Filtered);
    MMax(i,18) = max(Filtered);
    MMin(i,18) = min(Filtered);
else
    MMean(i,18) = -999.99;
    MMax(i,18) = -999.99;
    MMin(i,18) = -999.99;
end
%Qm
clear FD Filtered ii
FD = ds(PlotYear).Data(Month_Start(i):Month_End(i),19);

```

```

[ii] = find(FD ~= -999.99);
Filtered = FD(ii);
if (size(Filtered) > 0)
    MMean(i,19) = mean(Filtered);
    MMax(i,19) = max(Filtered);
    MMin(i,19) = min(Filtered);
else
    MMean(i,19) = -999.99;
    MMax(i,19) = -999.99;
    MMin(i,19) = -999.99;
end
%Qt
clear FD Filtered ii
FD = ds(PlotYear).Data(Month_Start(i):Month_End(i),20);
[ii] = find(FD ~= -999.99);
Filtered = FD(ii);
if (size(Filtered) > 0)
    MMean(i,20) = mean(Filtered);
    MMax(i,20) = max(Filtered);
    MMin(i,20) = min(Filtered);
else
    MMean(i,20) = -999.99;
    MMax(i,20) = -999.99;
    MMin(i,20) = -999.99;
end
%Qc
clear FD Filtered ii
FD = ds(PlotYear).Data(Month_Start(i):Month_End(i),21);
[ii] = find(FD ~= -999.99);
Filtered = FD(ii);
if (size(Filtered) > 0)
    MMean(i,21) = mean(Filtered);
    MMax(i,21) = max(Filtered);
    MMin(i,21) = min(Filtered);
else
    MMean(i,21) = -999.99;
    MMax(i,21) = -999.99;
    MMin(i,21) = -999.99;
end
%cumEv
clear FD Filtered ii
FD = ds(PlotYear).Data(Month_Start(i):Month_End(i),22);
[ii] = find(FD ~= -999.99);

```

```

        Filtered = FD(ii);

        if (size(Filtered) > 0)
            MMean(i,22) = mean(Filtered);
            MMax(i,22) = max(Filtered);
            MMin(i,22) = min(Filtered);
        else
            MMean(i,22) = -999.99;
            MMax(i,22) = -999.99;
            MMin(i,22) = -999.99;
        end

        %Save the results to the output file.

        fprintf(fid_mean,' %d, %d, %f, %f,
        %f, %f, %f, %f, %f\r\n',...
        PlotYear, i, MMean(i,3:22));

        fprintf(fid_max,' %d, %d, %f, %f,
        %f, %f, %f, %f, %f\r\n',...
        PlotYear, i, MMax(i,3:22));

        fprintf(fid_min,' %d, %d, %f, %f,
        %f, %f, %f, %f, %f\r\n',...
        PlotYear, i, MMin(i,3:22));

    end
end

fclose all;

```

Erie_EB_Summary.m

This script generate a comma delimited (.csv) file containing daily Max, Min, Mean and Median values for the 1950 through 1997 years (i.e., maximum temperature for ordinal day 1, over the 48 year span).

```

% Script for stats gathering of daily met data.

StartYear = 1950;
EndYear = 1997;
OutFile = 'L_Erie_EB_Summary.csv';

% Define a data structure.
ds = struct('Year',{},'Data', {});

% Read in the data,
for PlotYear = StartYear: 1: EndYear
    close all

    InFile = sprintf('L_Erie_EB_%d.txt', PlotYear);

```



```

Filtered = Kd(ii);
DataMax(Day,3) = max(Filtered);
DataMin(Day,3) = min(Filtered);
DataMean(Day,3) = mean(Filtered);
DataMedian(Day,3) = median(Filtered);

%Only look at non "missing number" numbers
clear Filtered;
[ii] = find(Ku(1,:) ~= -999.99);
Filtered = Ku(ii);
DataMax(Day,4) = max(Filtered);
DataMin(Day,4) = min(Filtered);
DataMean(Day,4) = mean(Filtered);
DataMedian(Day,4) = median(Filtered);

%Only look at non "missing number" numbers
clear Filtered;
[ii] = find(Ld(1,:) ~= -999.99);
Filtered = Ld(ii);
DataMax(Day,5) = max(Filtered);
DataMin(Day,5) = min(Filtered);
DataMean(Day,5) = mean(Filtered);
DataMedian(Day,5) = median(Filtered);

%Only look at non "missing number" numbers
clear Filtered;
[ii] = find(Lu(1,:) ~= -999.99);
Filtered = Lu(ii);
DataMax(Day,6) = max(Filtered);
DataMin(Day,6) = min(Filtered);
DataMean(Day,6) = mean(Filtered);
DataMedian(Day,6) = median(Filtered);

%Only look at non "missing number" numbers
clear Filtered;
[ii] = find(Q(1,:) ~= -999.99);
Filtered = Q(ii);
DataMax(Day,7) = max(Filtered);
DataMin(Day,7) = min(Filtered);
DataMean(Day,7) = mean(Filtered);
DataMedian(Day,7) = median(Filtered);

%Only look at non "missing number" numbers
clear Filtered;
[ii] = find(Uk(1,:) ~= -999.99);
Filtered = Uk(ii);

```

```

DataMax(Day,8) = max(Filtered);
DataMin(Day,8) = min(Filtered);
DataMean(Day,8) = mean(Filtered);
DataMedian(Day,8) = median(Filtered);
%Only look at non "missing number" numbers
clear Filtered;
[ii] = find(Ta(1,:) ~= -999.99);
Filtered = Ta(ii);
DataMax(Day,9) = max(Filtered);
DataMin(Day,9) = min(Filtered);
DataMean(Day,9) = mean(Filtered);
DataMedian(Day,9) = median(Filtered);
%Only look at non "missing number" numbers
clear Filtered;
[ii] = find(Td(1,:) ~= -999.99);
Filtered = Td(ii);
DataMax(Day,10) = max(Filtered);
DataMin(Day,10) = min(Filtered);
DataMean(Day,10) = mean(Filtered);
DataMedian(Day,10) = median(Filtered);
%Only look at non "missing number" numbers
clear Filtered;
[ii] = find(Rh(1,:) ~= -999.99);
Filtered = Rh(ii);
DataMax(Day,11) = max(Filtered);
DataMin(Day,11) = min(Filtered);
DataMean(Day,11) = mean(Filtered);
DataMedian(Day,11) = median(Filtered);
%Only look at non "missing number" numbers
clear Filtered;
[ii] = find(Tw(1,:) ~= -999.99);
Filtered = Tw(ii);
DataMax(Day,12) = max(Filtered);
DataMin(Day,12) = min(Filtered);
DataMean(Day,12) = mean(Filtered);
DataMedian(Day,12) = median(Filtered);
%Only look at non "missing number" numbers
clear Filtered;
[ii] = find(As(1,:) ~= -999.99);
Filtered = As(ii);
DataMax(Day,13) = max(Filtered);
DataMin(Day,13) = min(Filtered);
DataMean(Day,13) = mean(Filtered);

```

```

DataMedian(Day,13) = median(Filtered);
%Only look at non "missing number" numbers
clear Filtered;
[ii] = find(Qh(1,:) ~= -999.99);
Filtered = Qh(ii);
DataMax(Day,14) = max(Filtered);
DataMin(Day,14) = min(Filtered);
DataMean(Day,14) = mean(Filtered);
DataMedian(Day,14) = median(Filtered);
%Only look at non "missing number" numbers
clear Filtered;
[ii] = find(Qe(1,:) ~= -999.99);
Filtered = Qe(ii);
DataMax(Day,15) = max(Filtered);
DataMin(Day,15) = min(Filtered);
DataMean(Day,15) = mean(Filtered);
DataMedian(Day,15) = median(Filtered);
%Only look at non "missing number" numbers
clear Filtered;
[ii] = find(Ev(1,:) ~= -999.99);
Filtered = Ev(ii);
DataMax(Day,16) = max(Filtered);
DataMin(Day,16) = min(Filtered);
DataMean(Day,16) = mean(Filtered);
DataMedian(Day,16) = median(Filtered);
%Only look at non "missing number" numbers
clear Filtered;
[ii] = find(Qi(1,:) ~= -999.99);
Filtered = Qi(ii);
DataMax(Day,17) = max(Filtered);
DataMin(Day,17) = min(Filtered);
DataMean(Day,17) = mean(Filtered);
DataMedian(Day,17) = median(Filtered);
%Only look at non "missing number" numbers
clear Filtered;
[ii] = find(Ic(1,:) ~= -999.99);
Filtered = Ic(ii);
DataMax(Day,18) = max(Filtered);
DataMin(Day,18) = min(Filtered);
DataMean(Day,18) = mean(Filtered);
DataMedian(Day,18) = median(Filtered);
%Only look at non "missing number" numbers
clear Filtered;

```

```

[ii] = find(Qm(1,:) ~= -999.99);
Filtered = Qm(ii);
DataMax(Day,19) = max(Filtered);
DataMin(Day,19) = min(Filtered);
DataMean(Day,19) = mean(Filtered);
DataMedian(Day,19) = median(Filtered);
%Only look at non "missing number" numbers
clear Filtered;
[ii] = find(Qt(1,:) ~= -999.99);
Filtered = Qt(ii);
DataMax(Day,20) = max(Filtered);
DataMin(Day,20) = min(Filtered);
DataMean(Day,20) = mean(Filtered);
DataMedian(Day,20) = median(Filtered);
%Only look at non "missing number" numbers
clear Filtered;
[ii] = find(Qc(1,:) ~= -999.99);
Filtered = Qc(ii);
DataMax(Day,21) = max(Filtered);
DataMin(Day,21) = min(Filtered);
DataMean(Day,21) = mean(Filtered);
DataMedian(Day,21) = median(Filtered);
%Only look at non "missing number" numbers
clear Filtered;
[ii] = find(cumEv(1,:) ~= -999.99);
Filtered = cumEv(ii);
DataMax(Day,22) = max(Filtered);
DataMin(Day,22) = min(Filtered);
DataMean(Day,22) = mean(Filtered);
DataMedian(Day,22) = median(Filtered);

clear Kd Ku Ld Lu Q Uk Ta Td Rh Tw As Qh Qe Ev Qi Ic Qm Qt Qc cumEv;
end

%Save the results to a text file

fid_out=fopen(OutFile,'w');
%Print a header row
fprintf(fid_out,'ordinal, Kd, Ku, Ld, Lu, Q*, Uk, Ta, Td, Rh, Tw, As, Qh, Qe, Ev, Qi, Ic,
Qm, Qt, Qc, cumEv\r\n');
fprintf(fid_out,'Max (%d-%d)\r\n',StartYear,EndYear)
for Day = 1: 1: 365

```

```

        fprintf(fid_out,'%d, %f, %f,
        %f, %f, %f\r\n',...
        Day, ...

DataMax(Day,3),DataMax(Day,4),DataMax(Day,5),DataMax(Day,6),DataMax(Day,7),DataMax(Day,8),Da
taMax(Day,9),...

DataMax(Day,10),DataMax(Day,11),DataMax(Day,12),DataMax(Day,13),DataMax(Day,14),DataMax(Day,
15),DataMax(Day,16),...

DataMax(Day,17),DataMax(Day,18),DataMax(Day,19),DataMax(Day,20),DataMax(Day,21),DataMax(Day,
22));
end

fprintf(fid_out,'Min (%d-%d)\r\n',StartYear,EndYear);
for Day = 1: 1: 365
    fprintf(fid_out,'%d, %f, %f,
    %f, %f, %f\r\n',...
    Day, ...

DataMin(Day,3),DataMin(Day,4),DataMin(Day,5),DataMin(Day,6),DataMin(Day,7),DataMin(Day,8),Da
taMin(Day,9),...

DataMin(Day,10),DataMin(Day,11),DataMin(Day,12),DataMin(Day,13),DataMin(Day,14),DataMin(Day,
15),DataMin(Day,16),...

DataMin(Day,17),DataMin(Day,18),DataMin(Day,19),DataMin(Day,20),DataMin(Day,21),DataMin(Day,
22));
end

fprintf(fid_out,'Mean (%d-%d)\r\n',StartYear,EndYear);
for Day = 1: 1: 365
    fprintf(fid_out,'%d, %f, %f,
    %f, %f, %f\r\n',...
    Day, ...

DataMean(Day,3),DataMean(Day,4),DataMean(Day,5),DataMean(Day,6),DataMean(Day,7),DataMean(Day
,8),DataMean(Day,9),...

DataMean(Day,10),DataMean(Day,11),DataMean(Day,12),DataMean(Day,13),DataMean(Day,14),DataMea
n(Day,15),DataMean(Day,16),...

DataMean(Day,17),DataMean(Day,18),DataMean(Day,19),DataMean(Day,20),DataMean(Day,21),DataMea
n(Day,22));
end

fprintf(fid_out,'Median (%d-%d)\r\n',StartYear,EndYear);
for Day = 1: 1: 365
    fprintf(fid_out,'%d, %f, %f,
    %f, %f, %f\r\n',...
    Day, ...

DataMedian(Day,3),DataMedian(Day,4),DataMedian(Day,5),DataMedian(Day,6),DataMedian(Day,7),Da
taMedian(Day,8),DataMedian(Day,9),...

```



```

AxisLabelFontSize = 10;
TitleSize = 12;

IsLeap = mod(PlotYear,4);
if (IsLeap == 0) %0 represents a leap year.
    X_Ticks = [1 32 61 92 122 153 183 214 245 275 306 336];
    X_Labels = 'J|F|M|A|M|J|J|A|S|O|N|D';
else
    X_Ticks = [1 32 60 91 121 152 182 213 244 274 305 335];
    X_Labels = 'J|F|M|A|M|J|J|A|S|O|N|D';
end
X_Label_Ticks = [15 47 75 106 136 168 197 228 259 289 320 350];

%Set the data for the x-axis
x=data(:,2);
XMin=1;
XMax=366;

%=====
% Page 1 Plots
%
% Radiative Exchanges
% Kd (MJ m^-2 day^-1)
% Ku (MJ m^-2 day^-1)
% Ld (MJ m^-2 day^-1)
% Lu (MJ m^-2 day^-1)
%-----

close all
clear Y1 Y2 Y3 Y4

Y1 = data(:,3);
Y2 = data(:,4);
Y3 = data(:,5);
Y4 = data(:,6);

%-k' = Solid Black Line
subplot(4,1,1),plot(x,Y1,'-k');
orient tall;
title(PlotTitle,'fontsize',TitleSize);
set(gca,'fontsize',TickLabelFontSize);
ylabel('Kd (MJ m^{-2} day^{-1})','FontSize',AxisLabelFontSize);
%set the X and Y axis limits. Set Y axis to auto scaling.

```

```

axis([XMin XMax 0 35]);
XLim('Manual');
set(gca,'XTick',X_Ticks);
set(gca,'XTickLabel',[]);
%YLim('Auto');

subplot(4,1,2),plot(x,Y2,'-k')
set(gca,'fontsize',TickLabelFontSize);
ylabel('Ku (MJ m^{-2} day^{-1})','FontSize',AxisLabelFontSize);
%set the X and Y axis limits. Set Y axis to auto scaling.
axis([XMin XMax 0 14]);
XLim('Manual');
set(gca,'XTick',X_Ticks);
set(gca,'XTickLabel',[]);
%YLim('Auto');

subplot(4,1,3),plot(x,Y3,'-k')
set(gca,'fontsize',TickLabelFontSize);
ylabel('Ld (MJ m^{-2} day^{-1})','FontSize',AxisLabelFontSize);
%set the X and Y axis limits. Set Y axis to auto scaling.
axis([XMin XMax 15 40]);
XLim('Manual');
set(gca,'XTick',X_Ticks);
set(gca,'XTickLabel',[]);
%YLim('Auto');

subplot(4,1,4),plot(x,Y4,'-k')
set(gca,'fontsize',TickLabelFontSize);
ylabel('Lu (MJ m^{-2} day^{-1})','FontSize',AxisLabelFontSize);
%set the X and Y axis limits. Set Y axis to auto scaling.
axis([XMin XMax 25 40]);
XLim('Manual');
set(gca,'XTick',X_Ticks);
set(gca,'XTickLabel',[]);
%YLim('Auto');

% Plot a second Axis to place Months between tick marks.
ax1 = gca;
ax2 = axes('Position',get(ax1,'Position'), ...
    'XAxisLocation','bottom', 'YAxisLocation', 'left', ...
    'Color', 'none', ...
    'XColor', 'k', 'YColor', 'k');
set(ax2,'fontsize',TickLabelFontSize);

```

```

set(ax2,'XLim',get(ax1,'XLim'));
set(ax2,'YLim',get(ax1,'YLim'));
set(ax2,'XTick',X_Label_Ticks);
set(ax2,'XTickLabel',X_Labels);
set(ax2,'YTickLabel',[]);
set(ax2,'TickLength',[0 0]);

%Save the plot to a file.
PlotFile = ['Radiative_', PrintFile];
print('-dmeta', '-r600', PlotFile);

%=====
% Page 2 Plots
%
% Heat Fluxes
% Q* (MJ m^-2 day^-1)
% Qe (MJ m^-2 day^-1)
% Qh (MJ m^-2 day^-1)
% Qt (MJ m^-2 day^-1)
%-----

close all
clear Y1 Y2 Y3 Y4

Y1 = data(:,7);
Y2 = data(:,15);
Y3 = data(:,14);
Y4 = data(:,20);

%-k' = Solid Black Line
subplot(4,1,1),plot(x,Y1,'-k');
orient tall;
title(PlotTitle,'fontsize',TitleSize);
set(gca,'fontsize',TickLabelFontSize);
ylabel('Q* (MJ m^{-2} day^{-1})','FontSize',AxisLabelFontSize);
%set the X and Y axis limits. Set Y axis to auto scaling.
axis([XMin XMax -5 30])
XLim('Manual');
set(gca,'XTick',X_Ticks);
set(gca,'XTickLabel',[]);
%YLim('Auto');

```

```

subplot(4,1,2),plot(x,Y2,'-k')
set(gca,'fontsize',TickLabelFontSize);
ylabel('Qe (MJ m^{-2} day^{-1})','FontSize',AxisLabelFontSize);
%set the X and Y axis limits. Set Y axis to auto scaling.
axis([XMin XMax -10 50])
XLim('Manual');
set(gca,'XTick',X_Ticks);
set(gca,'XTickLabel',[]);
%YLim('Auto');

subplot(4,1,3),plot(x,Y3,'-k')
set(gca,'fontsize',TickLabelFontSize);
ylabel('Qh (MJ m^{-2} day^{-1})','FontSize',AxisLabelFontSize);
%set the X and Y axis limits. Set Y axis to auto scaling.
axis([XMin XMax -80 40])
XLim('Manual');
set(gca,'XTick',X_Ticks);
set(gca,'XTickLabel',[]);
%YLim('Auto');

subplot(4,1,4),plot(x,Y4,'-k')
set(gca,'fontsize',TickLabelFontSize)
ylabel('Qt (MJ m^{-2} day^{-1})','FontSize',AxisLabelFontSize);
%set the X and Y axis limits. Set Y axis to auto scaling.
axis([XMin XMax -80 40])
XLim('Manual');
set(gca,'XTick',X_Ticks);
set(gca,'XTickLabel',[]);
%YLim('Auto');

% Plot a second Axis to place Months between tick marks.
ax1 = gca;
ax2 = axes('Position',get(ax1,'Position'), ...
'XAxisLocation','bottom', 'YAxisLocation', 'left', ...
'Color', 'none', ...
'XColor', 'k', 'YColor', 'k');
set(ax2,'fontsize',TickLabelFontSize);
set(ax2,'XLim',get(ax1,'XLim'));
set(ax2,'YLim',get(ax1,'YLim'));
set(ax2,'XTick',X_Label_Ticks);
set(ax2,'XTickLabel',X_Labels);
set(ax2,'YTickLabel',[]);
set(ax2,'TickLength',[0 0]);

```

```

%Save the plot to a file.
PlotFile = ['HeatFluxes_', PrintFile];
print('-dmeta', '-r600', PlotFile);

%=====
% Page 3 Plots
%
% Meteorology
% Ta (Deg C)
% Td (Dec C)
% Rh (%)
% Uk (m/s)
%-----

close all
clear Y1 Y2 Y3 Y4

Y1 = data(:,9);
Y2 = data(:,10);
Y3 = data(:,11);
Y4 = data(:,8);

%-k' = Solid Black Line
subplot(4,1,1),plot(x,Y1,'-k');
orient tall;
title(PlotTitle,'fontsize',TitleSize);
set(gca,'fontsize',TickLabelFontSize);
ylabel('Ta (^oC)', 'FontSize', AxisLabelFontSize);
%set the X and Y axis limits. Set Y axis to auto scaling.
axis([XMin XMax -20 30])
XLim('Manual');
set(gca,'XTick',X_Ticks);
set(gca,'XTickLabel',[]);
%YLim('Auto');

subplot(4,1,2),plot(x,Y2,'-k')
set(gca,'fontsize',TickLabelFontSize);
ylabel('Td (^oC)', 'FontSize', AxisLabelFontSize);
%set the X and Y axis limits. Set Y axis to auto scaling.
axis([XMin XMax -30 30])
XLim('Manual');

```

```

set(gca,'XTick',X_Ticks);
set(gca,'XTickLabel',[]);
%YLim('Auto');

subplot(4,1,3),plot(x,Y3,'-k')
set(gca,'fontsize',TickLabelFontSize);
ylabel('Rh (%)','FontSize',AxisLabelFontSize);
%set the X and Y axis limits. Set Y axis to auto scaling.
axis([XMin XMax 0 100])
XLim('Manual');
set(gca,'XTick',X_Ticks);
set(gca,'XTickLabel',[]);
%YLim('Auto');

subplot(4,1,4),plot(x,Y4,'-k')
set(gca,'fontsize',TickLabelFontSize)
ylabel('Uk (m/s)','FontSize',AxisLabelFontSize);
%set the X and Y axis limits. Set Y axis to auto scaling.
axis([XMin XMax 0 16])
XLim('Manual');
set(gca,'XTick',X_Ticks);
set(gca,'XTickLabel',[]);
%YLim('Auto');

% Plot a second Axis to place Months between tick marks.
ax1 = gca;
ax2 = axes('Position',get(ax1,'Position'), ...
'XAxisLocation','bottom', 'YAxisLocation', 'left', ...
'Color', 'none', ...
'XColor', 'k', 'YColor', 'k');
set(ax2,'fontsize',TickLabelFontSize);
set(ax2,'XLim',get(ax1,'XLim'));
set(ax2,'YLim',get(ax1,'YLim'));
set(ax2,'XTick',X_Label_Ticks);
set(ax2,'XTickLabel',X_Labels);
set(ax2,'YTickLabel',[]);
set(ax2,'TickLength',[0 0]);

%Save the plot to a file.
PlotFile = ['Meteorology_', PrintFile];
print('-dmeta', '-r600', PlotFile);

```

```

%=====
% Page 4 Plots
%
% Other fluxes
% As (fraction)
% Qi (MJ/m^2/day)
% Qm (MJ/m^2/day)
% Qc (Exa Joules)
%-----

close all
clear Y1 Y2 Y3 Y4

Y1 = data(:,13);
Y2 = data(:,17);
Y3 = data(:,19);
Y4 = data(:,21);

%'-k' = Solid Black Line
subplot(4,1,1),plot(x,Y1,'-k');
orient tall;
title(PlotTitle,'fontsize',TitleSize);
set(gca,'fontsize',TickLabelFontSize);
ylabel('As (fractional value)','FontSize',AxisLabelFontSize);
%set the X and Y axis limits. Set Y axis to auto scaling.
axis([XMin XMax 0 0.7])
XLim('Manual');
set(gca,'XTick',X_Ticks);
set(gca,'XTickLabel',[]);
%YLim('Auto');

subplot(4,1,2),plot(x,Y2,'-k')
set(gca,'fontsize',TickLabelFontSize);
ylabel('Qi (MJ m^{-2} day^{-1})','FontSize',AxisLabelFontSize);
%set the X and Y axis limits. Set Y axis to auto scaling.
axis([XMin XMax -6 8])
XLim('Manual');
set(gca,'XTick',X_Ticks);
set(gca,'XTickLabel',[]);
%YLim('Auto');

subplot(4,1,3),plot(x,Y3,'-k')
set(gca,'fontsize',TickLabelFontSize);

```

```

ylabel('Qm (MJ m^{-2} day^{-1})','FontSize',AxisLabelFontSize);
%set the X and Y axis limits. Set Y axis to auto scaling.
axis([XMin XMax -0.5 0.5])
XLim('Manual');
set(gca,'XTick',X_Ticks);
set(gca,'XTickLabel',[]);
%YLim('Auto');

subplot(4,1,4),plot(x,Y4,'-k')
set(gca,'fontsize',TickLabelFontSize)
ylabel('Qc (x10^{18} Joules)','FontSize',AxisLabelFontSize);
%set the X and Y axis limits. Set Y axis to auto scaling.
axis([XMin XMax -10 30])
XLim('Manual');
set(gca,'XTick',X_Ticks);
set(gca,'XTickLabel',[]);
%YLim('Auto');

% Plot a second Axis to place Months between tick marks.
ax1 = gca;
ax2 = axes('Position',get(ax1,'Position'), ...
    'XAxisLocation','bottom', 'YAxisLocation', 'left', ...
    'Color', 'none', ...
    'XColor', 'k', 'YColor', 'k');
set(ax2,'fontsize',TickLabelFontSize);
set(ax2,'XLim',get(ax1,'XLim'));
set(ax2,'YLim',get(ax1,'YLim'));
set(ax2,'XTick',X_Label_Ticks);
set(ax2,'XTickLabel',X_Labels);
set(ax2,'YTickLabel',[]);
set(ax2,'TickLength',[0 0]);

%Save the plot to a file.
PlotFile = ['OtherFluxes_', PrintFile];
print('-dmeta', '-r600', PlotFile);

% =====
% Page 5 Plots
%
% Evaporation
% Tw (Deg C)
% Ic (fraction surface area)
% Ev (mm)

```

```

% cumEv (mm)
% -----
%
close all
clear Y1 Y2 Y3 Y4

Y1 = data(:,12);
Y2 = data(:,18);
Y3 = data(:,16);
Y4 = data(:,22);

%'-k' = Solid Black Line
subplot(4,1,1),plot(x,Y1,'-k');
orient tall;
title(PlotTitle,'fontsize',TitleSize);
set(gca,'fontsize',TickLabelFontSize);
ylabel('Tw (^oC)', 'FontSize', AxisLabelFontSize);
%set the X and Y axis limits. Set Y axis to auto scaling.
axis([XMin XMax 0 25])
XLim('Manual');
set(gca,'XTick',X_Ticks);
set(gca,'XTickLabel',[]);
%YLim('Auto');

subplot(4,1,2),plot(x,Y2,'-k')
set(gca,'fontsize',TickLabelFontSize);
ylabel('Ic (fraction surface area)', 'FontSize', AxisLabelFontSize);
%set the X and Y axis limits. Set Y axis to auto scaling.
axis([XMin XMax 0 100])
XLim('Manual');
set(gca,'XTick',X_Ticks);
set(gca,'XTickLabel',[]);
%YLim('Auto');

subplot(4,1,3),plot(x,Y3,'-k')
set(gca,'fontsize',TickLabelFontSize);
ylabel('Ev (mm)', 'FontSize', AxisLabelFontSize);
%set the X and Y axis limits. Set Y axis to auto scaling.
axis([XMin XMax -5 20])
XLim('Manual');
set(gca,'XTick',X_Ticks);
set(gca,'XTickLabel',[]);
%YLim('Auto');

```

```

subplot(4,1,4),plot(x,Y4,'-k')
set(gca,'fontsize',TickLabelFontSize)
ylabel('cumEv (mm)', 'FontSize', AxisLabelFontSize);
%set the X and Y axis limits. Set Y axis to auto scaling.
axis([XMin XMax 0 1200])
XLim('Manual');
set(gca,'XTick',X_Ticks);
set(gca,'XTickLabel',[]);
%YLim('Auto');

% Plot a second Axis to place Months between tick marks.
ax1 = gca;
ax2 = axes('Position',get(ax1,'Position'), ...
    'XAxisLocation','bottom', 'YAxisLocation', 'left', ...
    'Color', 'none', ...
    'XColor', 'k', 'YColor', 'k');
set(ax2,'fontsize',TickLabelFontSize);
set(ax2,'XLim',get(ax1,'XLim'));
set(ax2,'YLim',get(ax1,'YLim'));
set(ax2,'XTick',X_Label_Ticks);
set(ax2,'XTickLabel',X_Labels);
set(ax2,'YTickLabel',[]);
set(ax2,'TickLength',[0 0]);

%Save the plot to a file.
PlotFile = ['Evaporation_', PrintFile];
print('-dmeta', '-r600', PlotFile);

end

```

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