UVB And Ozone Trends From Edmonton-Stony Plain Data

Alberta Environment

UVB AND OZONE TRENDS FROM

EDMONTON-STONY PLAIN DATA

Prepared by:

Samuel S. Shen

Intech. Inc.
510 Buchanan Road
Edmonton, Alberta T6R 2B5

for

Science and Standards
Alberta Environment
9820 – 106 Street
Edmonton, Alberta T5K 2J6

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Any comments, questions, or suggestions regarding the content of this document may be directed to:

Science and Standards Branch
Alberta Environment
4th Floor, Oxbridge Place
9820 – 106th Street
Edmonton, Alberta T5K 2J6
Fax: (780) 422-4192

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Information Centre
Alberta Environment
Main Floor, Great West Life Building
9920 – 108th Street
Edmonton, Alberta T5K 2M4
Phone: (780) 944-0313
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FOREWORD

There is significant health and ecological concern regarding any high level of UVB (radiation with wavelength in the 290-315 nm range) reaching the Earth's surface in any particular location. Excessive exposure to UVB can cause skin cancer in humans and has adverse effects on the ecosystem via damages at the molecular (DNA) level.

Since UVB levels at the surface are dependent on many factors, there is considerable spatial and temporal variation. However, much of the UVB is absorbed by ozone in the atmosphere and at locations where both UVB and ozone are measured, it is possible to study their trends given sufficiently long records. Kerr and McElroy (1993) studied the UVB and ozone trends in Toronto and concluded that there was a causal relationship between decreasing ozone and increasing UVB. The purpose of this project is to analyze the UVB and ozone data at the Stony Plain station near Edmonton to see if trends exist, and if so, how different these are from the Toronto study.

Raymond Wong, Ph.D.
Project Coordinator

ACKNOWLEDGEMENTS

The data used in this study were obtained from the WMO World Ozone and Ultraviolet Radiation Data Center (WOUDC) in Toronto. Dr. Raymond Wong of Alberta Environment made substantial contributions to this project by facilitating data preparation and literature search and providing technical advice. Bin Shen wrote all the computer programs, processed the data, and prepared all the figures.

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SUMMARY

Trend analysis was performed using ultraviolet-B (UVB) data from the Edmonton-Stony Plain station for the period from March 19, 1992 to December 31, 1996. During this period, total integrated irradiation (TotCIE) decreased by 21% in summer (May through August) but increased by 4% in the winter months (November through February), while there was a 11% decrease in the other months (Mar, Apr, Sep, Oct). The UVB data for different wavelengths showed a decreasing trend in winter, except for irradiation at wavelengths of 315, 320, and 325 µm (Tot315, Tot320, and Tot325, respectively). Increases of 12% in Tot320 and 8% in Tot325 in winter contribute to the 4% increase in TotCIE in winter. The trends found are spatially inhomogeneous. The standard deviation of UVB data is about 30% of the 4-year mean.

The ozone data for the same 4-year period exhibited an increasing trend in all months except July (1% decrease) and December (6% decrease). The standard deviation of total ozone is about 10% of the 4-year mean. The winter (December) decrease in total ozone may be related to the winter increase in UVB.

1.0 INTRODUCTION

In this report, ultraviolet (UV) radiation refers to solar radiation with wavelengths in the range 220-400 µm. Ultraviolet radiation is classified in three subranges: UVA (wavelength 315-400 µm), UVB (wavelength 290-315 µm), and UVC (wavelength 240-290 µm). The stratospheric ozone layer effectively blocks all of the UVC and allows only a small fraction of UVA to reach the troposphere below. Although UVB constitutes just 1% of solar radiation, most of which is absorbed in the upper atmosphere, UVB reaching the earth's surface can have negative health and ecological effects. Therefore, UVB monitoring has come to be recognized as a priority by many concerned organizations, including the World Meteorological Organization (WMO), U.S. Department of Agriculture (USDA), National Oceanographic and Atmospheric Administration (NOAA), National Aeronautics and Space Administration (NASA), Environmental Protection Agency (EPA), and, in Canada, the Atmospheric Environment Service (AES). Information on UVB radiation and atmospheric ozone can now be accessed on a number of internet websites.

Because of depletion of stratospheric ozone, it is expected that the amount of UVB being transmitted to the earth's surface has increased. A 1% reduction in ozone is estimated to result in a 2% increase in UVB penetration (Epstein, 1996). However, data from satellites and surface monitoring stations do not support the existence of a universal increasing trend in UVB radiation on the earth's surface. Studies of UV or UVB radiation at various observation stations indicate spatial inhomogeneity in the trend. Some studies found upward trends of UV radiation (e.g., Kerr and McElroy, 1993); others found evidence of decreasing levels of UV radiation (e.g., Justus and Murphey, 1994); while still others found no trend at all (Basher et al., 1994). Globally, from Nimbus-7/TOMS (total ozone mapping spectrometer) satellite data, it is generally believed that the global stratospheric ozone has been depleted and, consequently, UVB radiation has increased. (Herman et al., 1986; Lublin and Jensen, 1995).

Because of the spatial inhomogeneity of UVB trends, it is of interest to examine the data for specific locations. At the same time, it is also necessary to obtain reliable assessments of significant background noises, which include diurnal and seasonal cycles, instrumental error, altitude variations of observation stations, effects of aerosol concentrations, and local pollution levels. The present study uses statistical methods to analyze UVB data from the Edmonton station, located at Stony Plain (N53.55º, W114.10º). The objective is to determine any trend in the UVB data and to compare that with observed variation in atmospheric ozone.

2.0 DATA

2.1 UVB Data

The WMO World Ozone and Ultraviolet Radiation Data Center (WOUDC) located in Toronto is one of seven recognized world data centers. The WOUDC archives data for UVB stations in Canada and elsewhere. The Canadian stations are listed in Table 1. The Edmonton-Stony Plain station started operation on March 19, 1992. The days with missing data are listed in Table 2. The data were obtained using a Brewer spectrophotometer with a temporal resolution of 0.5-1.0 h.

Table 1 UVB Observation Stations in Canada

WMO Stn. No.	Stn. Name	WOUDC No.	Lat. (N)	Long. (W)	Elev. (m)	IC	Inst.
71638	Toronto	65	43.78	79.47	198	01	14
71866	Saskatoon	291	52.11	106.71	550	01	11
71917	Eureka*	315	79.98	85.93	10	01	69
72395	Halifax	321	44.74	63.67	31	01	84
72473	Saturna	290	48.78	123.13	178	01	19
72627	Montreal	319	45.48	73.75	24	01	79
72816	Goose*	76	53.19	60.23	44	01	18
72852	Winnipeg	320	49.90	97.24	239	01	83
72863	Regina	338	50.21	104.71	592	01	71
72919	Churchill	77	58.45	94.04	35	01	26
72924	Resolute	24	74.43	94.59	64	01	31
74082	Alert	18	82.30	62.20	62	01	12
74119	Edmonton	21	53.55	114.10	766	01	13

Notes: * denotes stations that do not have data in the WOUDC archive.
IC indicates instrument type, a Brewer spectrophotometer in all cases.
INST is the observation code.

Table 2 Summary of missing days at Edmonton-Stony Plain

Year	Total Missing Days (Specific days in Julian Year, 1-365 or 366)
1992	88 (1-78, 137, 159, 176, 225, 227, 249-251, 363, 366)
1993	13 (91-97, 138, 215, 219, 254, 255, 328)
1994	7 (23, 135-139, 313)
1995	79 (120, 287-365)
1996	40 (1, 6, 7, 13, 16, 34, 40, 41, 49, 76, 85-110, 268, 309, 363, 364)

The UVB data are archived for monthly, daily, and hourly time intervals. However, hourly data are kept for only the last previous year, i.e., 1996 at the time of this analysis, because of the large size of the dataset. Hourly data are mainly useful for studying diurnal variation of UVB radiation, which is high around 4:00 pm and low after midnight.

The daily dataset includes observational data on the following quantities (defined in Table 3):

MT324, RS324, MaxACG, MaxCIE, TotACG, TotCIE, Tot295, Tot300, Tot 305, Tot310, Tot315, Tot320, Tot325

Table 3 Definitions of the daily observed UVB quantities

Quantity	Definition	Units
MT324	Mean of ratios of measured to clear-sky values of spectral irradiance at 324 nm (excluding solar elevations less than 5 degrees)	%
RS324	Relative standard deviation of above ratios (zero if only two observations)	%
MaxACG	Maximum values of ACGIH, which is a weighted integral	mW/m^2
MaxCIE	Maximum values of CIE, which is a weighted integral	mW/m^2
TotACG	Daily ACG irradiation	J/ m^2
TotCIE	Daily CIE irradiation	J/ m^2
Tot295…Tot325	Daily spectral irradiation at 295 nm…325 nm	$kJ/ m^2 \cdot nm$

A useful conversion from power (milliwatts) to energy (Joules) is

1 mW x 1 h = 3.6 J

More than 90% of the total UV radiation, i.e. TotCIE, the integrated CIE irradiation on a given day occurs during the 8-h period centered at the maximum radiation time. One half of MaxCIE times 8 times 3.6 should give an estimation of TotCIE for the day. For example, for June 19, 1994:

$$\text{TotCIE} = (150/2) \text{ x } 8 \text{ h x } 3.6 = 2160 \text{ J/m}^2$$

The actual TotCIE for this day was 2451 J/m^2. Of course, this method would yield under-estimation for very bright days and over-estimation for cloudy days.

The monthly dataset includes observational data for the following quantities (defined in Table 4):

MMACG, MMCIE, MDACG, MDCIE, AvgACG, AvgCIE, Avg295, Avg300, Avg305, Avg310, Avg315, Avg320, Avg325

Table 4 Definitions of the monthly observed UVB quantities

Quantity	Definition	Units
MMACG	Maximum value of ACGIH weighted irradiance integral	mW/m^2
MMCIE	Maximum value of CIE weighted irradiance integral	mW/m^2
MDACG	Maximum value of ACGIH weighted integral of daily irradiation	J/m^2
MDCIE	Maximum value of CIE weighted integral of daily irradiation	J/m^2
AvgACG	Average value of ACGIH weighted integral of daily irradiation	J/m^2
AvgCIE	Average value of CIE weighted integral of daily irradiation	J/m^2
Avg295…Avg325	Average monthly spectral irradiation at 295 nm…325 nm	$kJ/\ m^2 \cdot nm$

As with the daily data, half of the MMCIE value x 8 x 3.6 should yield, roughly, the magnitude of the daily AvgCIE. For example, for May 1994,

Daily AvgCIE = (184/2) x 8 x 3.6 = 2650 $J/\ m^2$

The actual AvgCIE value for this month was 2745 $J/\ m^2$. The monthly dataset was used to compute the monthly climatology covering the 4-year period from 1993 to 1996, since the available dataset ran from March 19, 1992 to December 31, 1996. For this UVB analysis, the year was divided into three seasons (winter, summer, and other), each season including four months. This division was based on the 4-year monthly means. For the data from Edmonton-Stony Plain, *summer*, in which the highest irradiation occurs, includes May, June, July, and August; *winter*, in which irradiation is the lowest, includes January, February, November, and December. The *other* season comprised the four remaining months.

The daily dataset was used for most of the trend analysis. Seasonal cycles of UVB and their variance are contained in the dataset.

2.2 Ozone Data

Ozone data used in this study were obtained from the WOUDC. The data files contain direct Brewer spectrophotometer measurements and simulation results. The simulation results are intended to correct some systematic instrumental bias. However, since these results are not yet widely accepted for analysis, only the direct measurements were used in this study. These data were available for the period from October 20, 1984 to December 30, 1996. As with the UVB dataset, there were some days during this period for which ozone data were not available. The measured data are column ozone values in DU (Dobson units; 1 DU = 2.69×10^{16} mol/cm^2 or 10^{-3} atm·cm ; 100 DU = 1 mm ozone at standard temperature and pressure).

3.0 METHOD AND RESULTS

3.1 Analysis

The most commonly used index in UVB impact studies is CIE, which is derived from a weighted integration of the spectral irradiation of Tot295…Tot325. The mathematical definition of CIE is

$$CIE = \int_{295}^{325} R(\lambda)w(\lambda)d\lambda \approx \sum_{i=1}^{7} R(\lambda_i)w(\lambda_i)\Delta\lambda_i$$

where $R(\lambda)$ is irradiation at wavelength λ, and $w(\lambda)$ is weight.

Figure 1 shows daily TotCIE for Edmonton-Stony Plain, which clearly demonstrates seasonal variations. The climatology for the year, shown in Figure 2, is based on the 4-year mean determined from the monthly data between 1993 and 1996. For example, the 4-year January mean is used as the January climatology value. The same procedure was followed for the other months. The difference between the values in Figures 1 and 2 (observed values minus climatological values) is the daily TotCIE anomaly, shown in Figure 3, which also demonstrates strong seasonal cycles. The variation in daily TotCIE anomaly suggests that the seasons should be examined separately. For this reason, the year was divided into three seasons according to the strength of the radiation, as described in the previous section on UVB data. This partition is similar to that in Kerr and McElroy (1993), but in their study, winter is from December through March. This difference can be explained in terms of geographical location (Toronto vs Edmonton).

The t-test was used for significance testing. No significant increasing trend of TotCIE at the 95% significance level was found for any of the three seasons (Figures 4-6). On the contrary, UVB radiation between 1992 and 1996 decreased in summer and the other months, but held steady in the winter. In summer, TotCIE decreased by about 560 J/m^2, a reduction of 21%.

3.2 Validation of Method and Results

Two additional analyses were performed to corroborate these findings and validate the proposed method.

3.2.1 Comparison of UVB Results from Other Studies

UVB data for Toronto were analyzed using the same method and the results were compared with those obtained by other researchers. Recalculation of results in Figure 2(B) of Kerr and McElroy (1993) gave values that were in good agreement with their published results: From 1989 to 1993, Tot300 for summer increased by 0.014 kJ/m^2·nm, an increase of 29% over the summer average (see Figure 7). This is slightly lower than the increase of 35% given by Kerr and McElroy (1993), but is within the range obtained by Michaels et al. (1994). As these authors pointed out, this rapid increase cannot be regarded as a secular increment; the large increment is due mainly to the unusually high Tot300 observed in 1993. Using three additional years of Toronto data (to

1996), the increment was found to be only 0.009 kJ/m^2·nm, or 19% (Figure 8). It is interesting that other indices show different results. TotCIE shows an increase of only 6% (180 J/m^2) for 1989 to 1993 and 5% (140 J/m^2) for 1989 to 1996 (see Figures 9-10). For the Toronto winter (December to March), TotCIE actually decreased in both the 1989-to-1993 and 1989-to-1996 periods (Figures 11-12). Tot300 increased in the period 1989 to 1993 due to unusually high values in 1993 (Figure 13), but it showed no increment in the period 1989 to 1996 (Figure 14). For the Toronto data in other months (April, September-November), there was no discernable trend in TotCIE. (Figure 15). In summary, the results for Toronto TotCIE and Tot300 were comparable to those given by Kerr and McElroy (1993) and Michaels et al. (1994).

3.2.2 Examination of Ozone Data

Ozone data were examined, since a negative correlation can be expected between ozone amount and UVB radiation. In Toronto, the increase in the summer TotCIE was accompanied by a decrease in ozone amount for the same period. For example, the sharp increase in TotCIE in 1989 to 1993 corresponds to a sharp decrease of 28 DU (or 8%) in column ozone in the same period (Figure 16).

Ozone data for Edmonton were also analyzed for comparison with trends in the UVB results. The Edmonton total ozone data are shown in Figures 17-19 for the three seasons. The climatology, which is the 4-year mean of the monthly data between 1993 and 1996, is shown in Figure 20. The differences between Figures 17-19 and Figure 20 are the daily anomalies, which are then fitted by a linear trend using the least-squares method. The total ozone increased in all three seasons, by 20 DU or over 6% during the period (Figures 21-23). The correlation coefficient between the anomalies of TotCIE and total ozone is always negative: -0.44 in summer, -0.21 in winter, and -0.32 in other months. For comparison, the correlation coefficient between the anomalies of TotCIE and total ozone in Toronto for 1989 to 1996 was also computed. It was -0.31 in summer, -0.08 in winter, and -0.17 in other months. These results appear to be consistent. Based on the above analyses, the analytical method used in the present study can be expected to provide satisfactory results.

Considering monthly variation, ozone increased in all months except July and December. Overall, the ozone level in Edmonton increased from 1992 to 1996 (Figure 24). The corresponding change of UVB radiation is illustrated in Figure 25. The only increasing trends in the UVB data occurred in winter.

Trends derived by the best-fit lines for the data points are not necessarily valid outside the period of the data. Short data periods may also give false trends, as discussed by Michaels et al., (1994). For example, the Toronto Tot300 trend derived from 1989 to 1993 cannot be applied to the period 1989 to 1996. It should also be noted that there is spatial variability in the UVB trends. The decreasing trend in UVB and corresponding increasing trend in ozone derived from the Edmonton 1992 to 1996 data were not mirrored by similar trends in Toronto; in fact opposite trends appeared.

3.3 Instrument Drift and Variance

Detection of UVB trends involves many uncertainties. These include instrument errors (accuracy and drift), physical and chemical conditions of the atmosphere, and length and continuity of the data record.

3.3.1 Instrument Drift

Instrument drift refers to systematic instrument bias towards either high or low values. It can result from improper calibration or when calibration is too infrequent. The WOUDC data are quality-controlled. As an additional check, data from individual pairings of four stations (Edmonton, Saskatoon, Winnipeg, Halifax) were compared. Since the station of primary concern is Edmonton, the period 1992 to 1996 was considered. Differences in calculated TotCIE for six station pairs (Edmonton-Saskatoon, Edmonton-Winnipeg, Edmonton-Halifax, Saskatoon-Winnipeg, Saskatoon-Halifax, and Winnipeg-Halifax) were examined. As shown by the results in Figures 26-31, no systematic bias is evident.

3.3.2 Variance of UVB Data

The physical and chemical conditions of the atmosphere cause large variations in UVB and total ozone. Standard deviations of UVB calculated for 10 long-term Canadian stations are given in Table 5. The strong background noise means that trend detection is difficult. Standard deviation of UVB is around 30% of the UVB 4-year mean. In all three seasons, the standard deviation of UVB for Edmonton-Stony Plain is intermediate among values for the 10 stations.

Table 5 Standard Deviations of the UVB Data in Canada

City	Date	Season	MaxACG	TotACG	MaxCIE	TotCIE	Tot295	Tot300	Tot305	Tot310	Tot315	Tot320	Tot325
Churchill	92-96	Summer	5.631	119.141	27.687	721.197	0.000	0.020	0.163	0.362	1.124	1.655	1.983
Edmonton	92-96	Summer	7.706	164.742	37.233	911.842	0.001	0.020	0.236	0.458	1.284	1.801	2.066
Halifax	92-96	Summer	9.846	203.406	48.550	1125.838	0.001	0.024	0.291	0.568	1.585	2.232	2.525
Montreal	93-96	Summer	8.741	180.455	42.857	997.118	0.001	0.022	0.256	0.507	1.411	1.952	2.253
Regina	94-96	Summer	6.516	158.354	30.838	856.718	0.001	0.020	0.229	0.434	1.191	1.660	1.854
Resolute	91-96	Summer	2.218	67.358	14.204	512.206	0.000	0.003	0.083	0.248	0.896	1.392	1.750
Saskatoon	89-95	Summer	7.364	157.925	36.325	876.417	0.001	0.019	0.226	0.438	1.241	1.754	2.039
Saturna	90-96	Summer	7.824	181.761	36.387	966.572	0.001	0.024	0.261	0.479	1.321	1.845	2.068
Toronto	89-96	Summer	8.925	192.452	42.322	1034.469	0.001	0.025	0.278	0.506	1.427	1.967	2.229
Winnipeg	92-96	Summer	7.410	167.316	35.825	916.861	0.001	0.021	0.238	0.464	1.274	1.797	2.074
Churchill	92-96	Winter	0.589	5.379	4.801	57.396	0.000	0.000	0.004	0.023	0.112	0.197	0.259
Edmonton	92-96	Winter	1.253	10.888	8.437	94.263	0.000	0.000	0.012	0.045	0.179	0.289	0.370
Halifax	92-96	Winter	1.804	22.066	11.530	176.924	0.000	0.001	0.027	0.087	0.320	0.513	0.650
Montreal	93-96	Winter	1.667	18.866	10.967	163.711	0.000	0.001	0.022	0.076	0.306	0.495	0.652
Regina	94-96	Winter	1.090	12.616	7.634	112.861	0.000	0.000	0.014	0.054	0.215	0.355	0.453
Resolute	91-96	Winter	0.056	0.973	0.979	17.876	0.000	0.000	0.001	0.003	0.023	0.055	0.104
Saskatoon	89-95	Winter	1.371	14.743	9.345	123.422	0.000	0.000	0.016	0.061	0.233	0.367	0.465
Saturna	90-96	Winter	1.612	17.806	10.782	152.076	0.000	0.001	0.020	0.072	0.272	0.451	0.590
Toronto	89-96	Winter	2.098	26.363	13.637	212.569	0.000	0.001	0.032	0.101	0.381	0.611	0.782
Winnipeg	92-96	Winter	1.197	13.878	7.885	116.429	0.000	0.000	0.016	0.058	0.218	0.353	0.446
Churchill	92-96	Others	2.893	50.916	16.410	345.638	0.000	0.003	0.068	0.185	0.588	0.876	1.071
Edmonton	92-96	Others	4.204	73.598	21.426	442.604	0.000	0.007	0.105	0.230	0.679	0.981	1.170
Halifax	92-96	Others	6.540	111.398	33.911	672.216	0.000	0.011	0.157	0.347	1.032	1.491	1.721
Montreal	93-96	Others	5.837	105.372	31.180	646.317	0.000	0.010	0.148	0.336	1.011	1.440	1.692
Regina	94-96	Others	4.929	86.648	26.026	547.305	0.000	0.007	0.122	0.284	0.876	1.290	1.493
Resolute	91-96	Others	0.972	18.416	6.830	175.045	0.000	0.000	0.017	0.078	0.340	0.557	0.727
Saskatoon	89-95	Others	3.884	71.642	21.236	445.197	0.000	0.006	0.101	0.229	0.702	1.022	1.236
Saturna	90-96	Others	5.115	94.694	26.306	566.197	0.000	0.010	0.133	0.292	0.872	1.264	1.476
Toronto	89-96	Others	6.440	109.874	32.717	656.729	0.000	0.011	0.156	0.332	1.007	1.440	1.679
Winnipeg	92-96	Others	4.269	79.915	22.889	497.154	0.000	0.007	0.113	0.259	0.780	1.157	1.397

3.3.3 Variance of Ozone Data

Standard deviations of ozone data were also computed, but only for Edmonton. The results are given in Table 6. The standard deviation for ozone is about 10% of the ozone 4-year mean. Background noise is lower in the ozone data than in the UVB data.

Table 6 Standard Deviations of Edmonton Ozone Data

Season	Standard Deviation (DU)
Summer (May, Jun, Jul, Aug)	23.425
Winter (Jan, Feb, Nov, Dec)	38.699
Other months (Mar, Apr, Sep, Oct)	30.791

4.0 CONCLUSIONS

The UVB data from March 19, 1992 to December 31, 1996 from the Edmonton-Stony Plain station were analyzed for possible trends. Trends in UVB were compared with changes in total column ozone.

Edmonton TotCIE decreased 21% in summer (May, June, July, August) and 11% in other months (March, April, September, October); it increased by 4% in winter (January, February, November, December).

Edmonton UVB radiation at different wavelengths decreased except for Tot315, Tot320, and Tot325 in winter. The increases of 12% in Tot325 and 8% in Tot320 in winter contributed to an increase of 4% in TotCIE.

Total ozone at Edmonton increased in all months except July (1% decrease) and December (6% decrease).

The standard deviation of UVB is about 30% of the 4-year mean, while the standard deviation of total ozone is about 10% of the 4-year mean.

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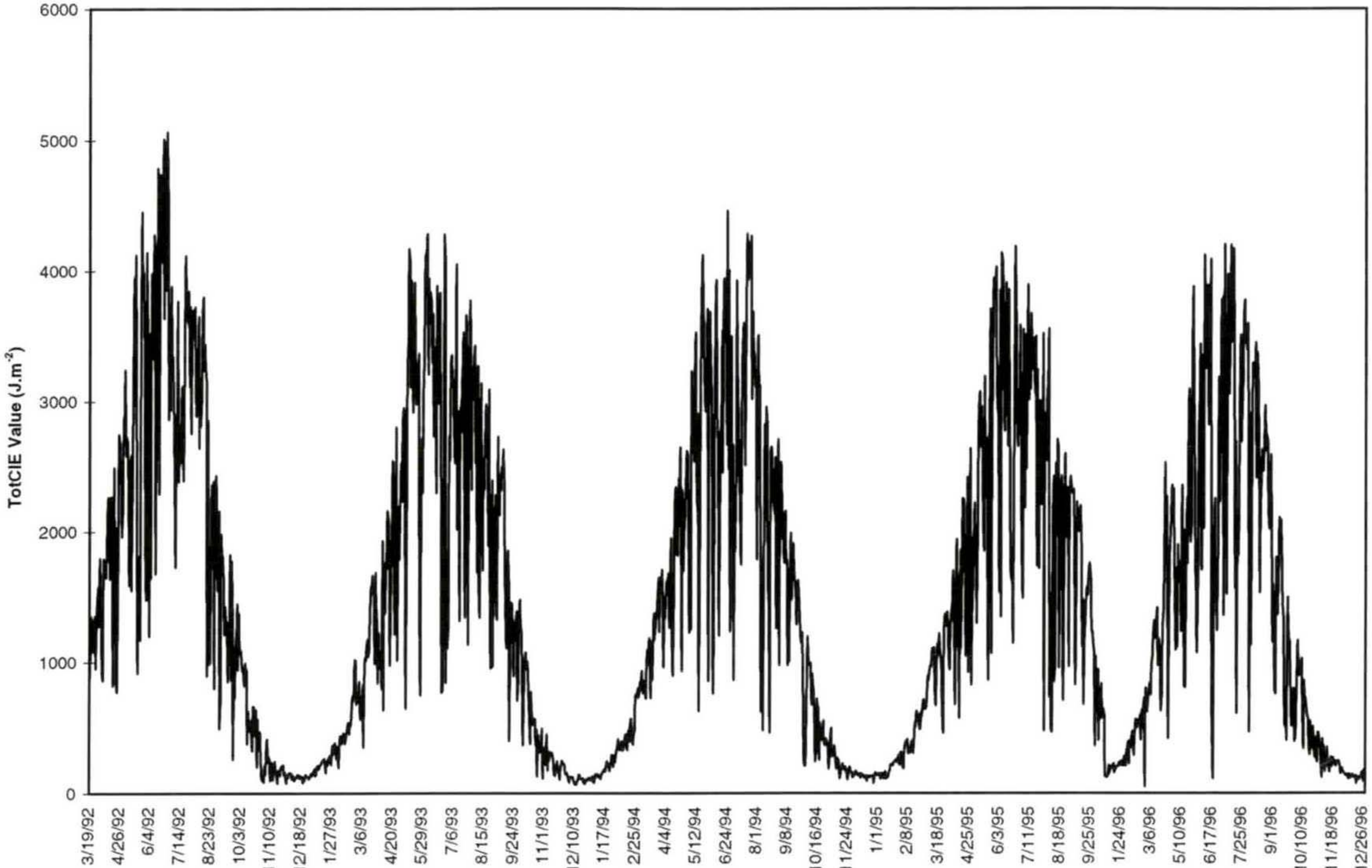

Figure 1. Edmonton daily TotCIE data

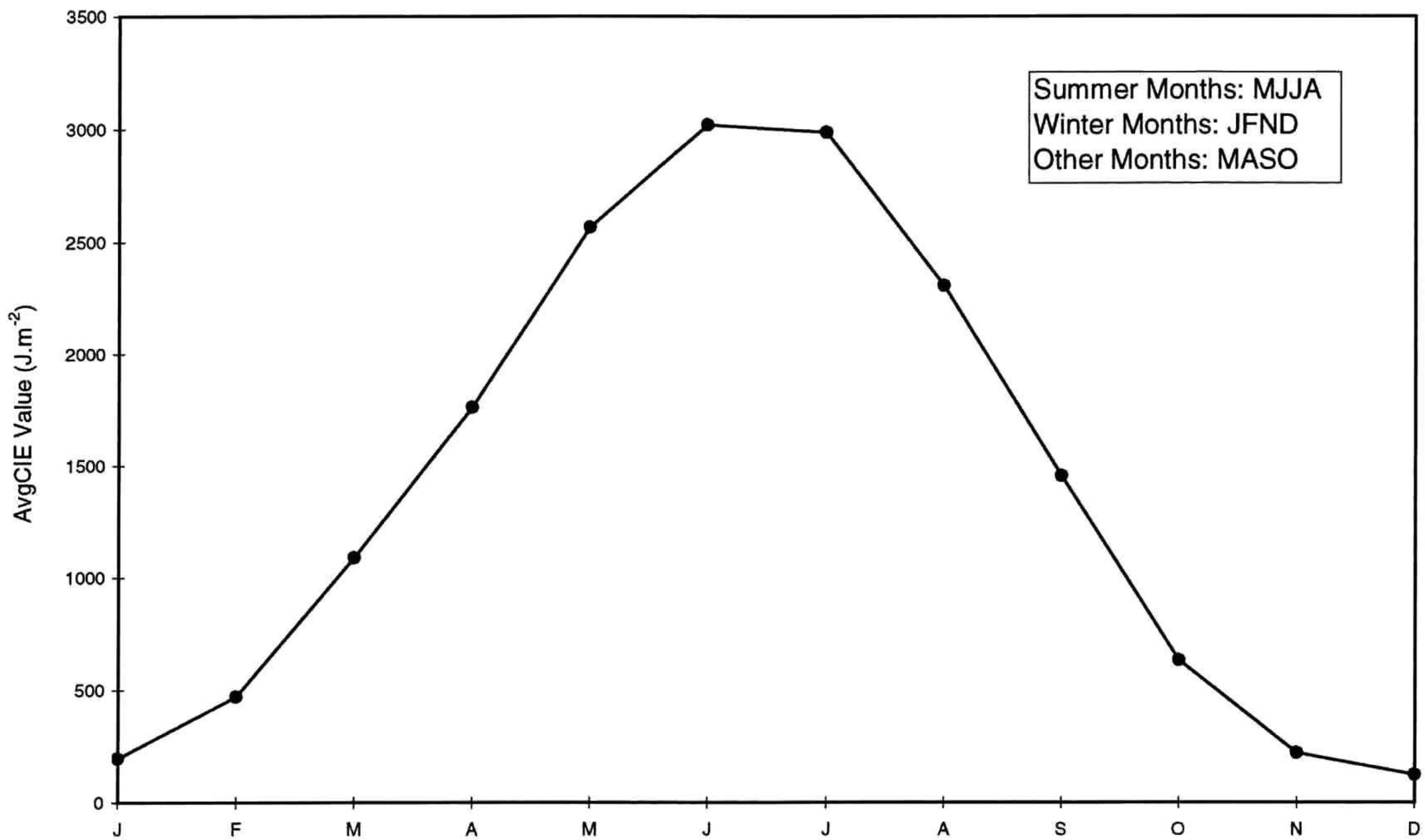

Figure 2. Edmonton AvgCIE climatology

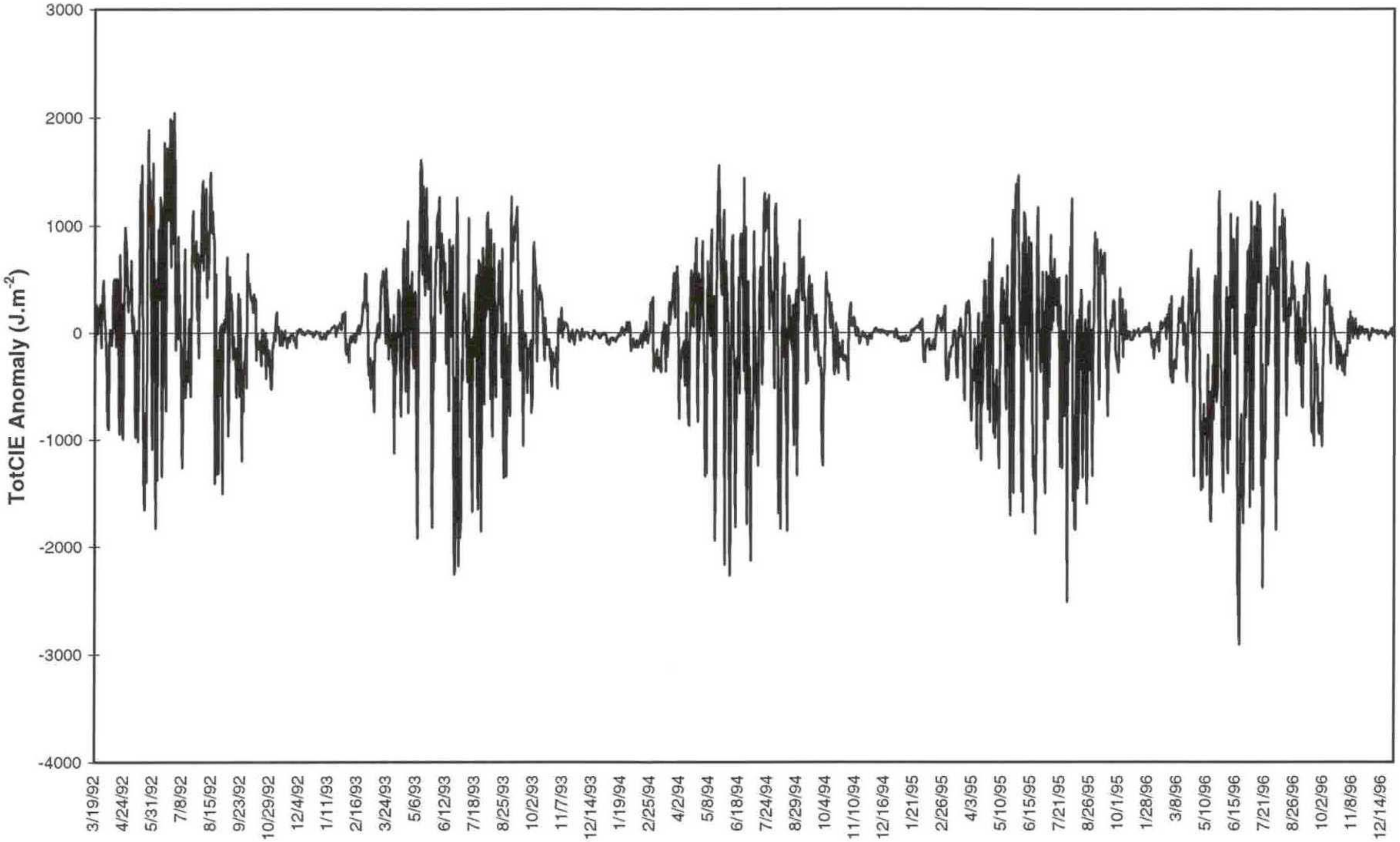

Figure 3. Edmonton daily TotCIE anomaly, 1992-1996

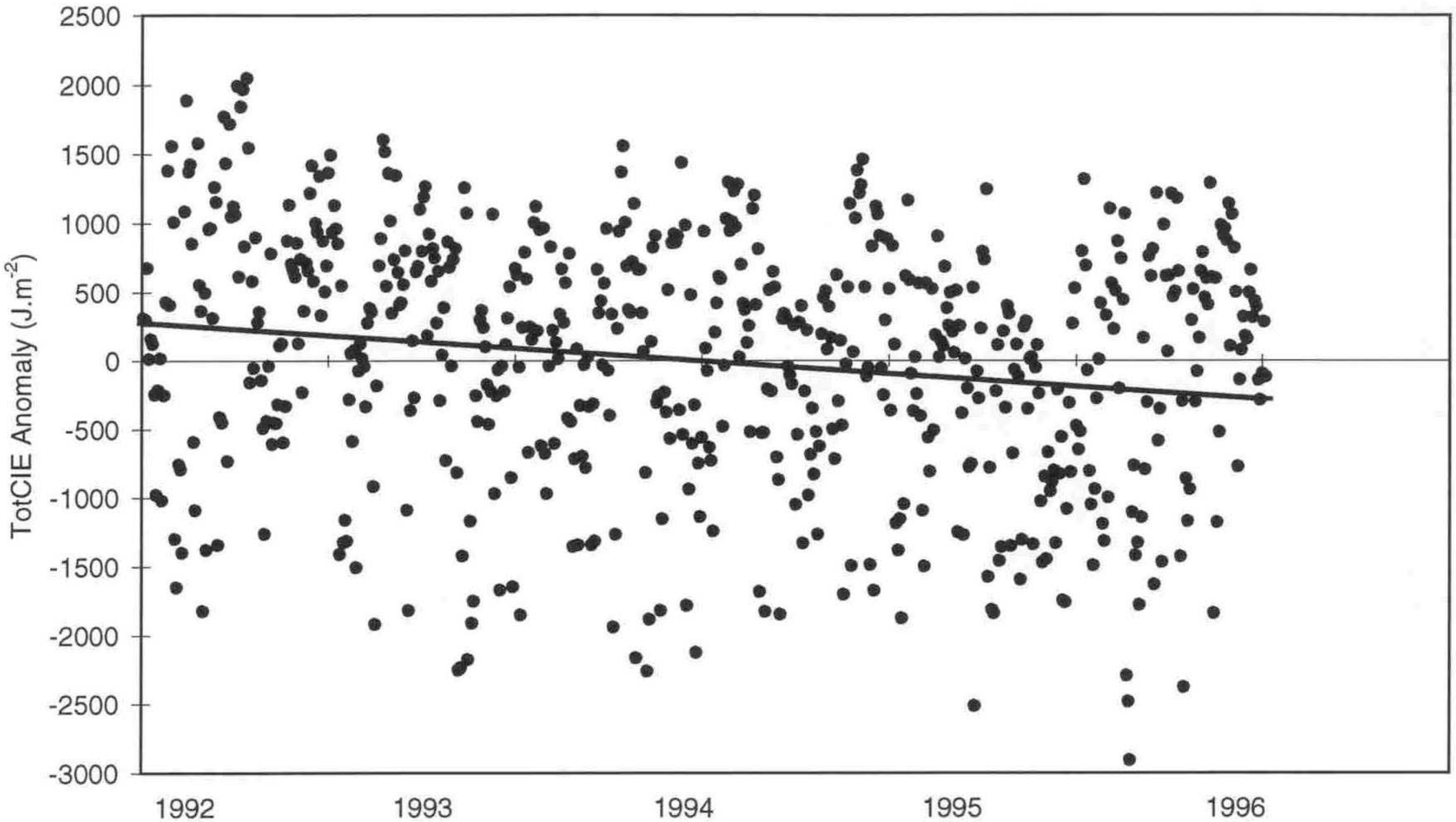

Figure 4. Regression plot of Edmonton summer TotCIE daily anomaly, 1992-1996

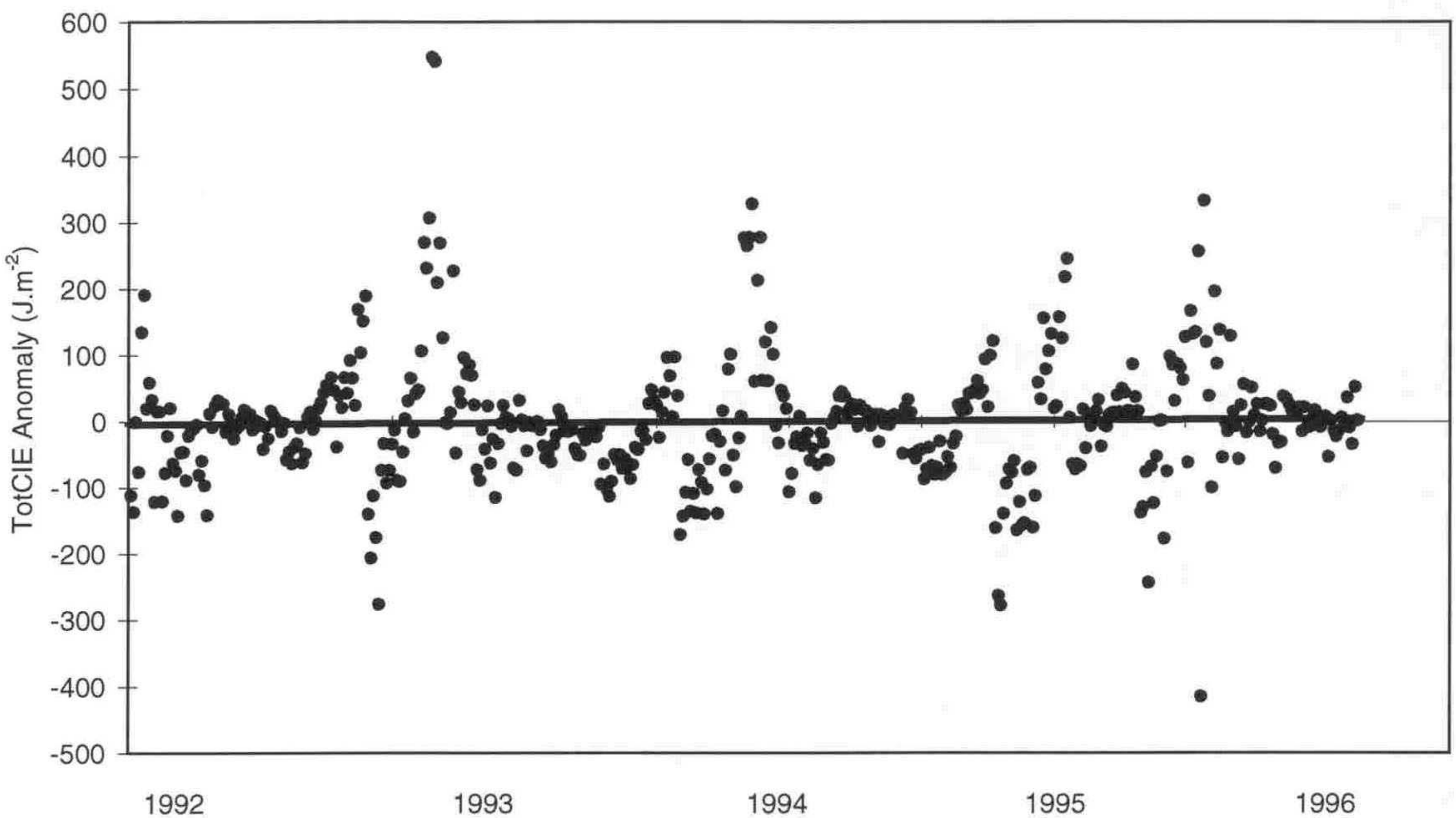

Figure 5. Regression plot of Edmonton winterTotCIE daily anomaly, 1992-1996

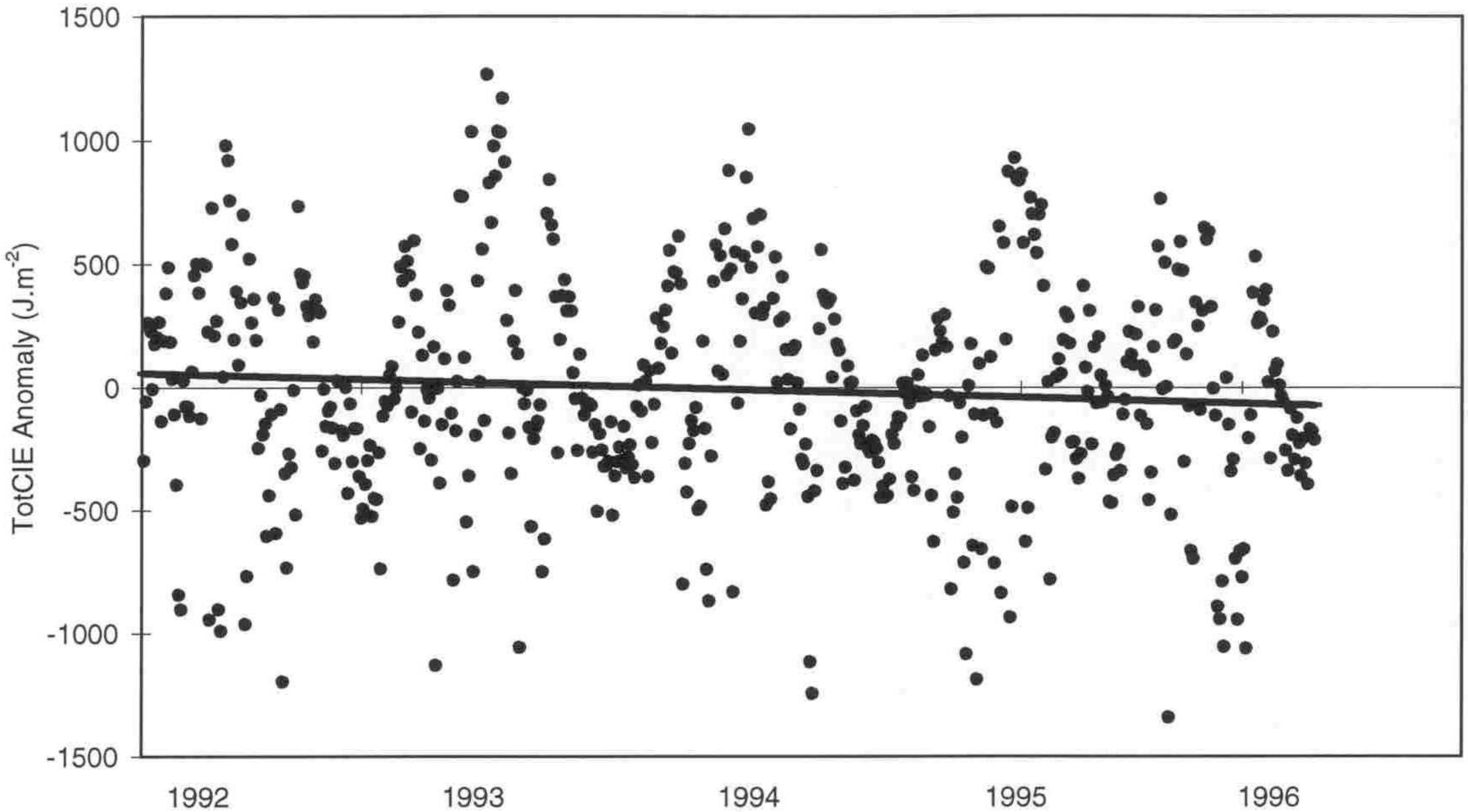

Figure 6. Regression plot of Edmonton TotCIE daily anomaly in other months, 1992-1996

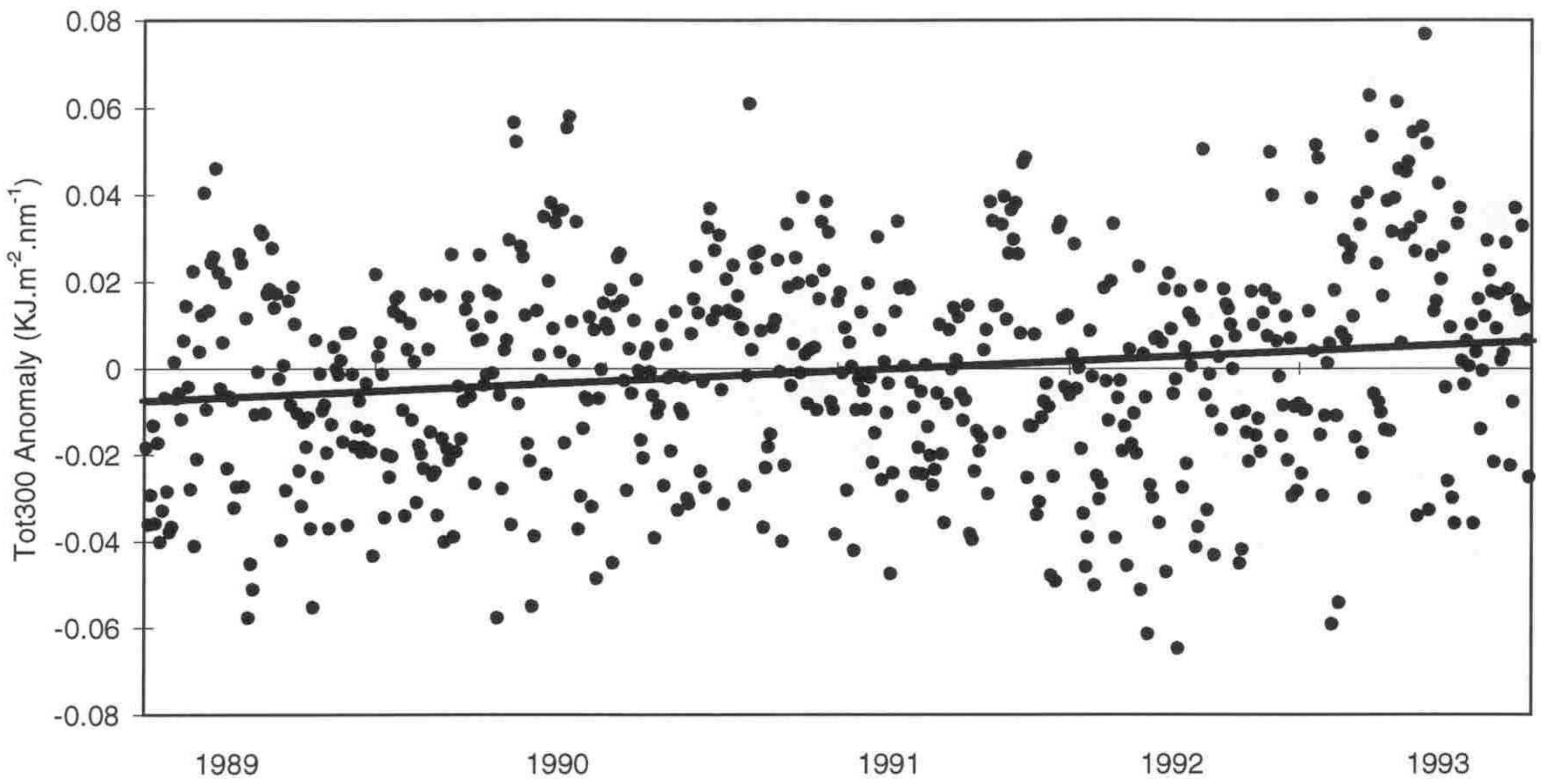

Figure 7. Regression plot of Toronto summer Tot300 daily anomaly, 1989-1993

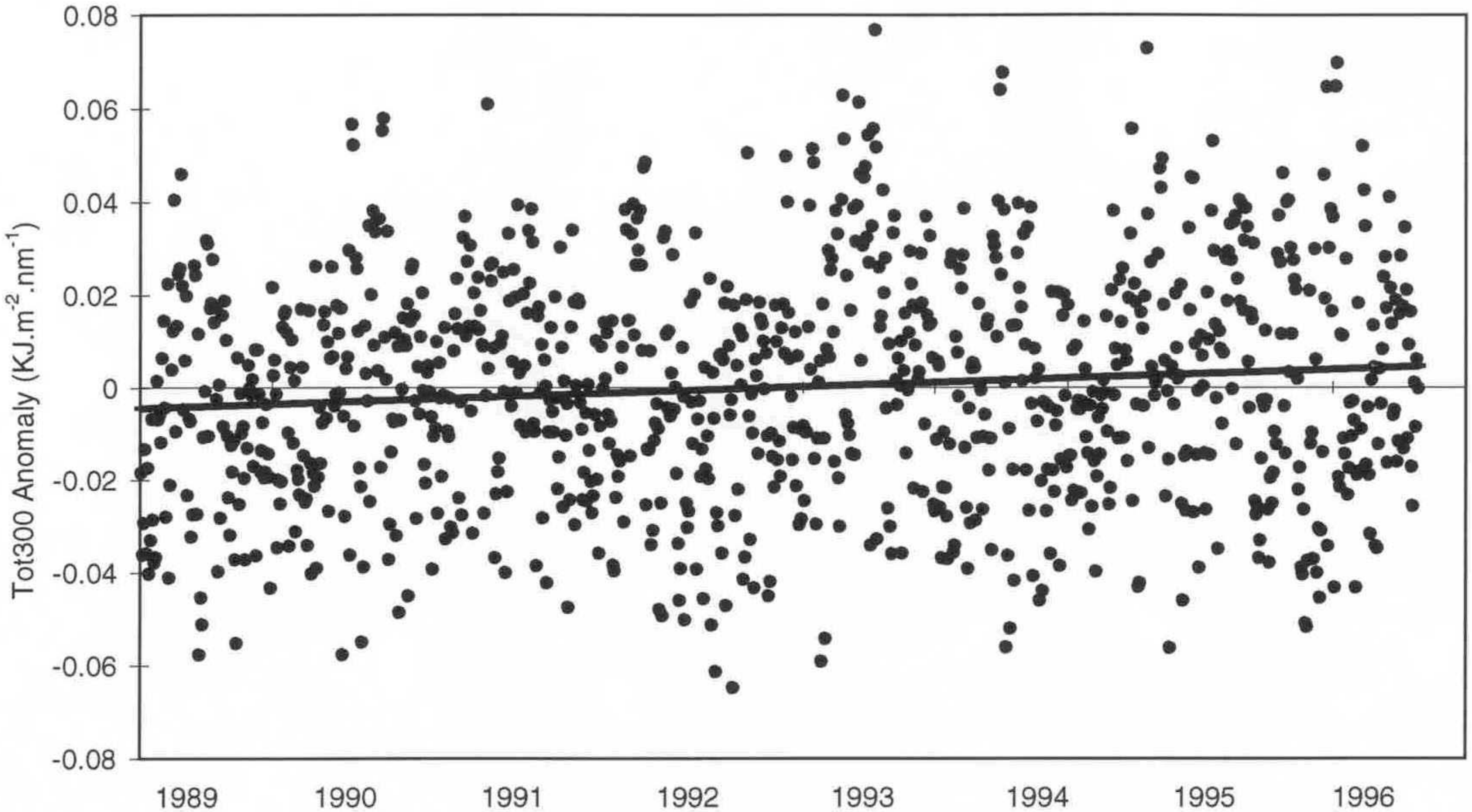

Figure 8. Regression plot of Toronto summer Tot300 daily anomaly, 1989-1996

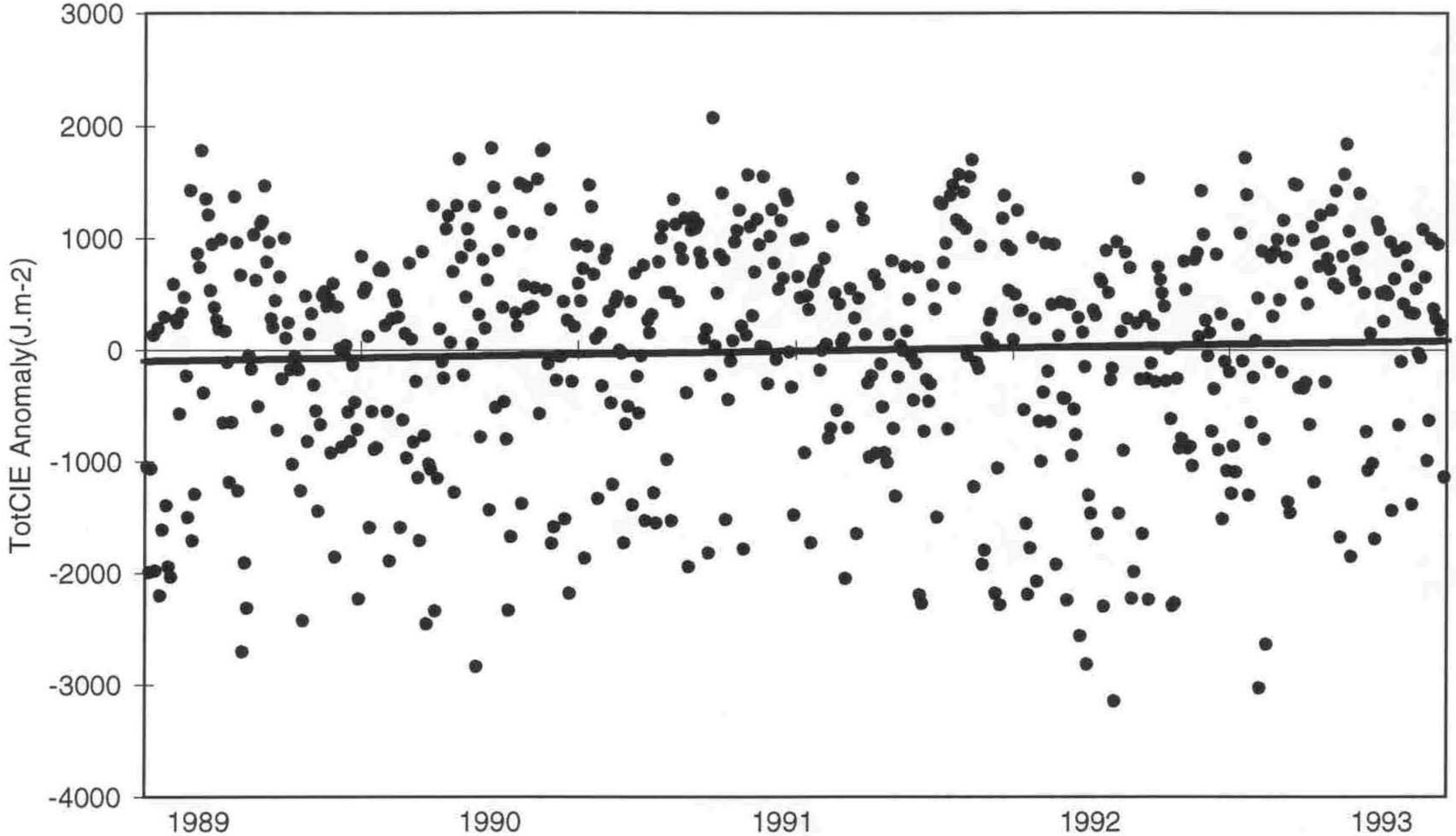

Figure 9. Regression plot of Toronto summer TotCIE daily anomaly, 1989-1993

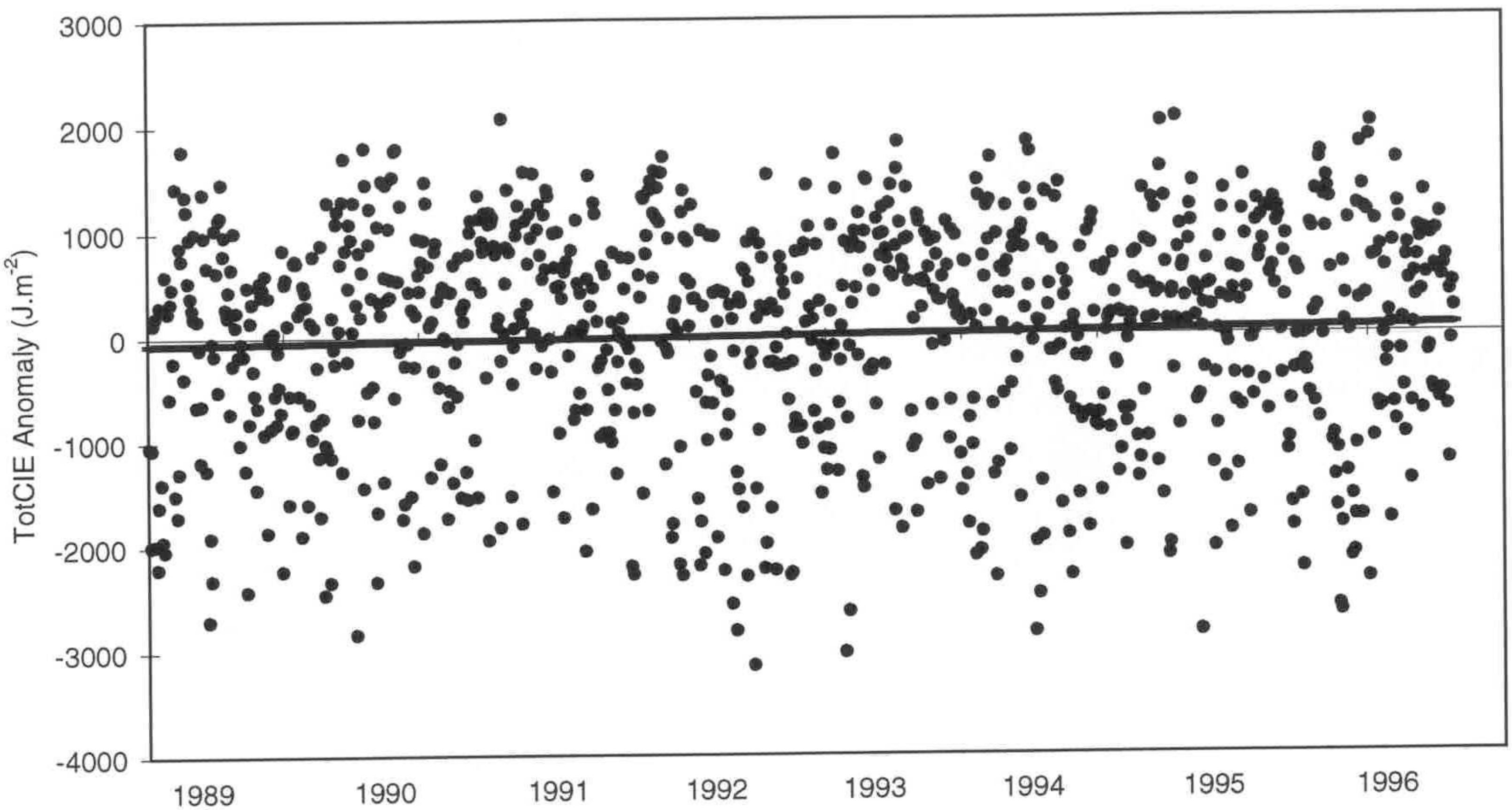

Figure 10. Regression plot of Toronto summer TotCIE daily anomaly, 1989-1996

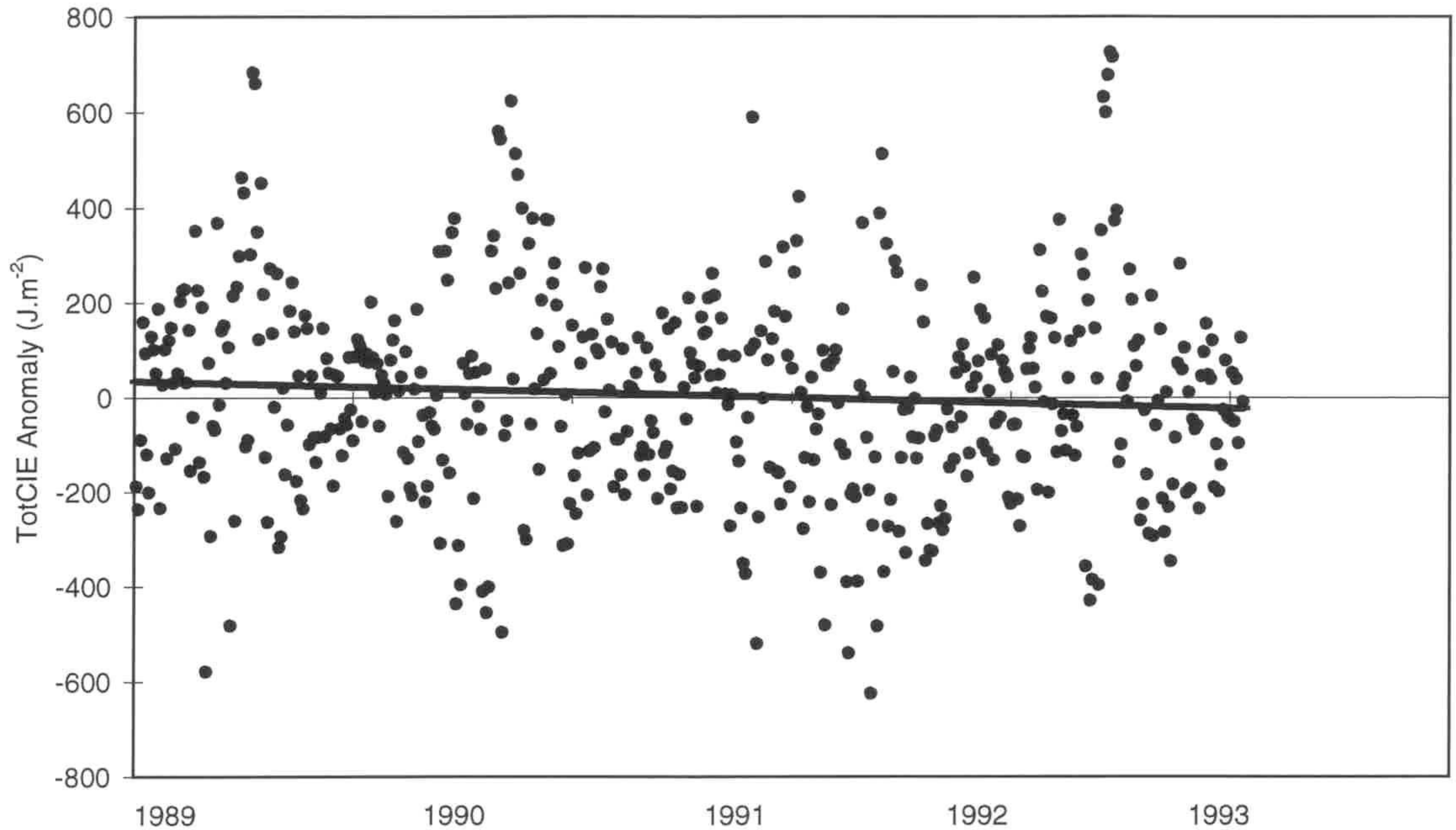

Figure 11. Regression plot of Toronto winter TotCIE daily anomaly, 1989-1993

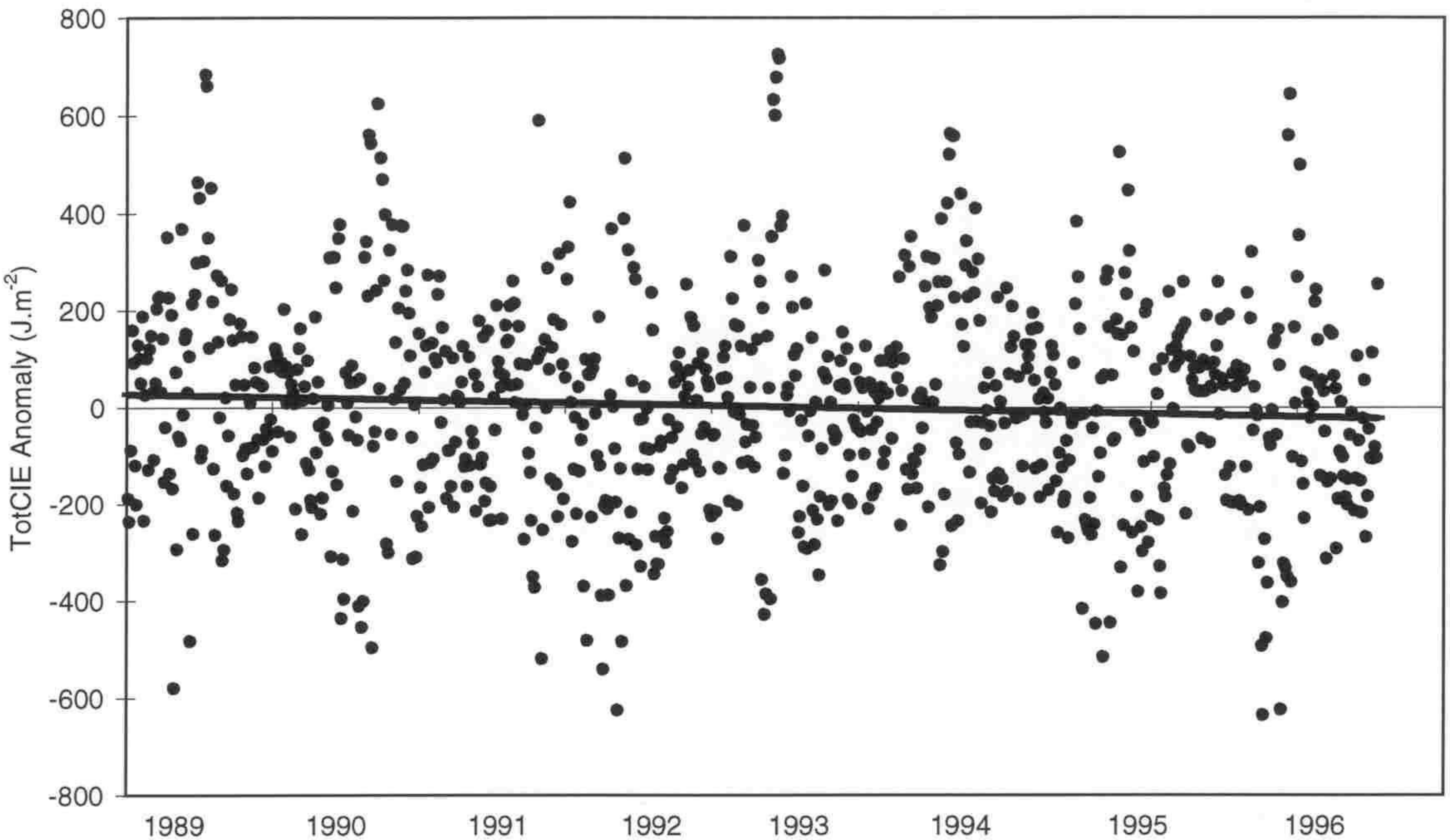

Figure 12. Regression plot of Toronto winter TotCIE daily anomaly, 1989-1996

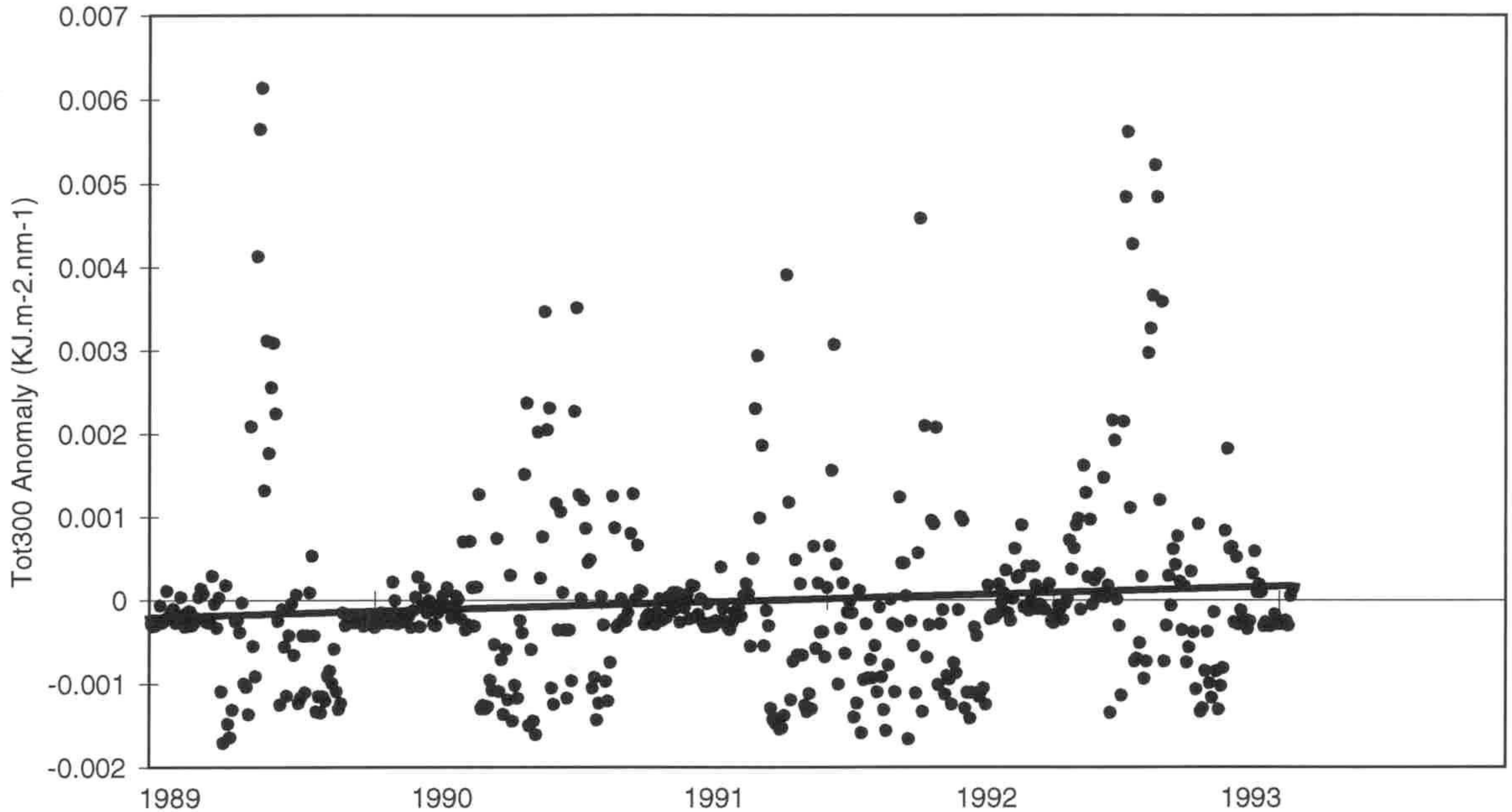

Figure 13. Regression plot of Toronto winter Tot300 daily anomaly, 1989-1993

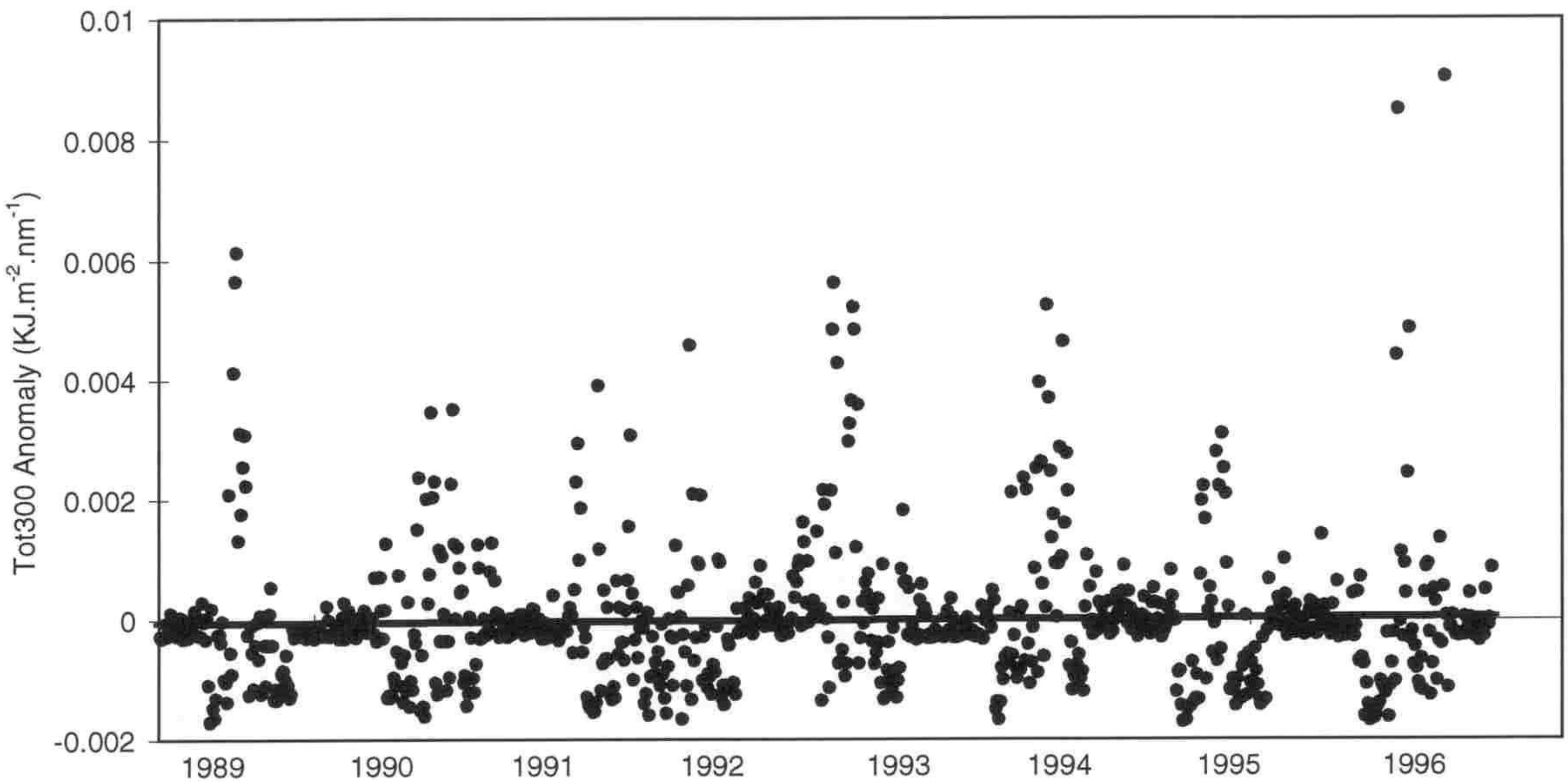

Figure 14. Regression plot of Toronto winter Tot300 daily anomaly , 1989-1996

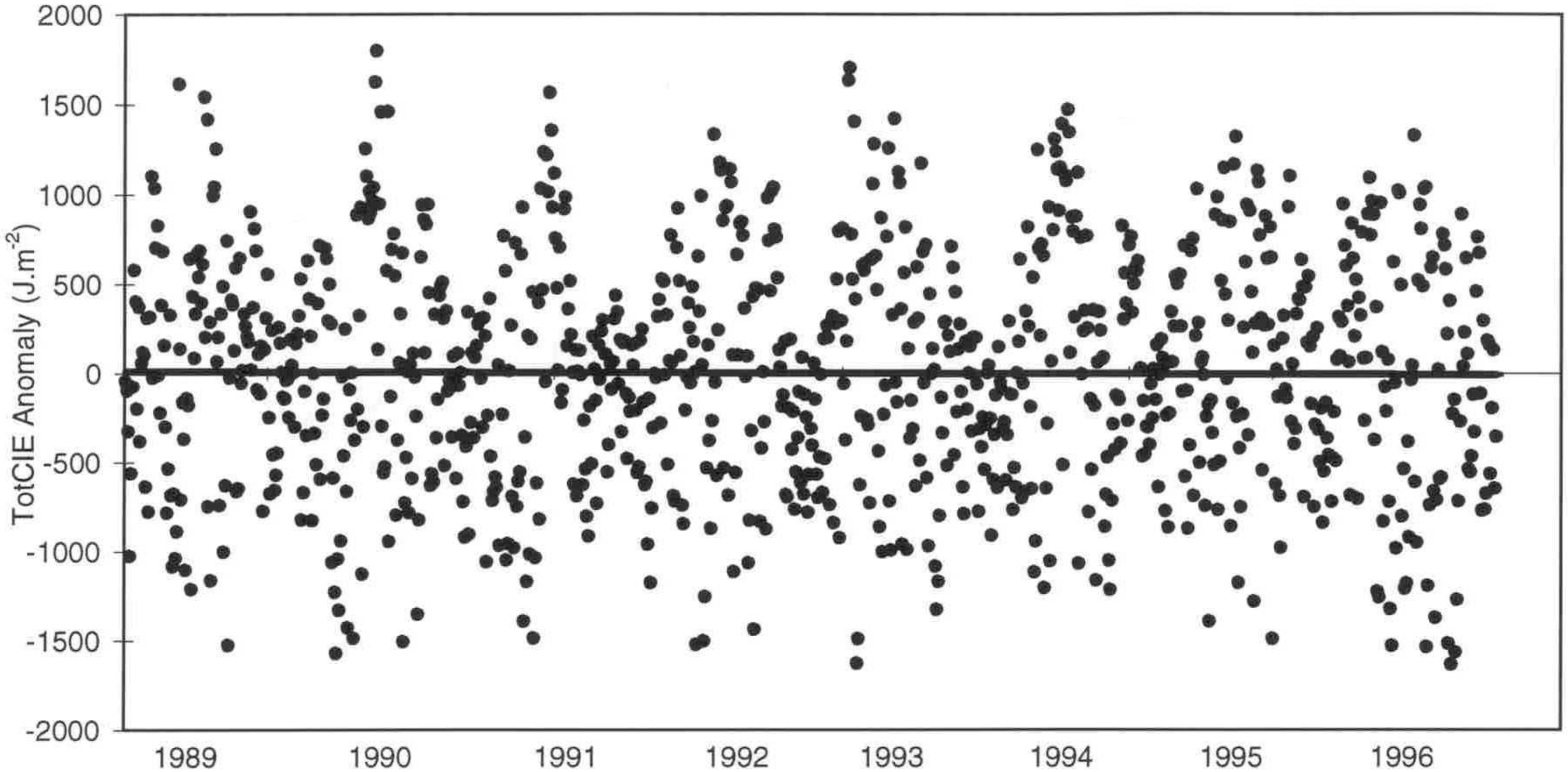

Figure 15. Regression plot of Toronto TotCIE daily anomaly in other months, 1989-1996

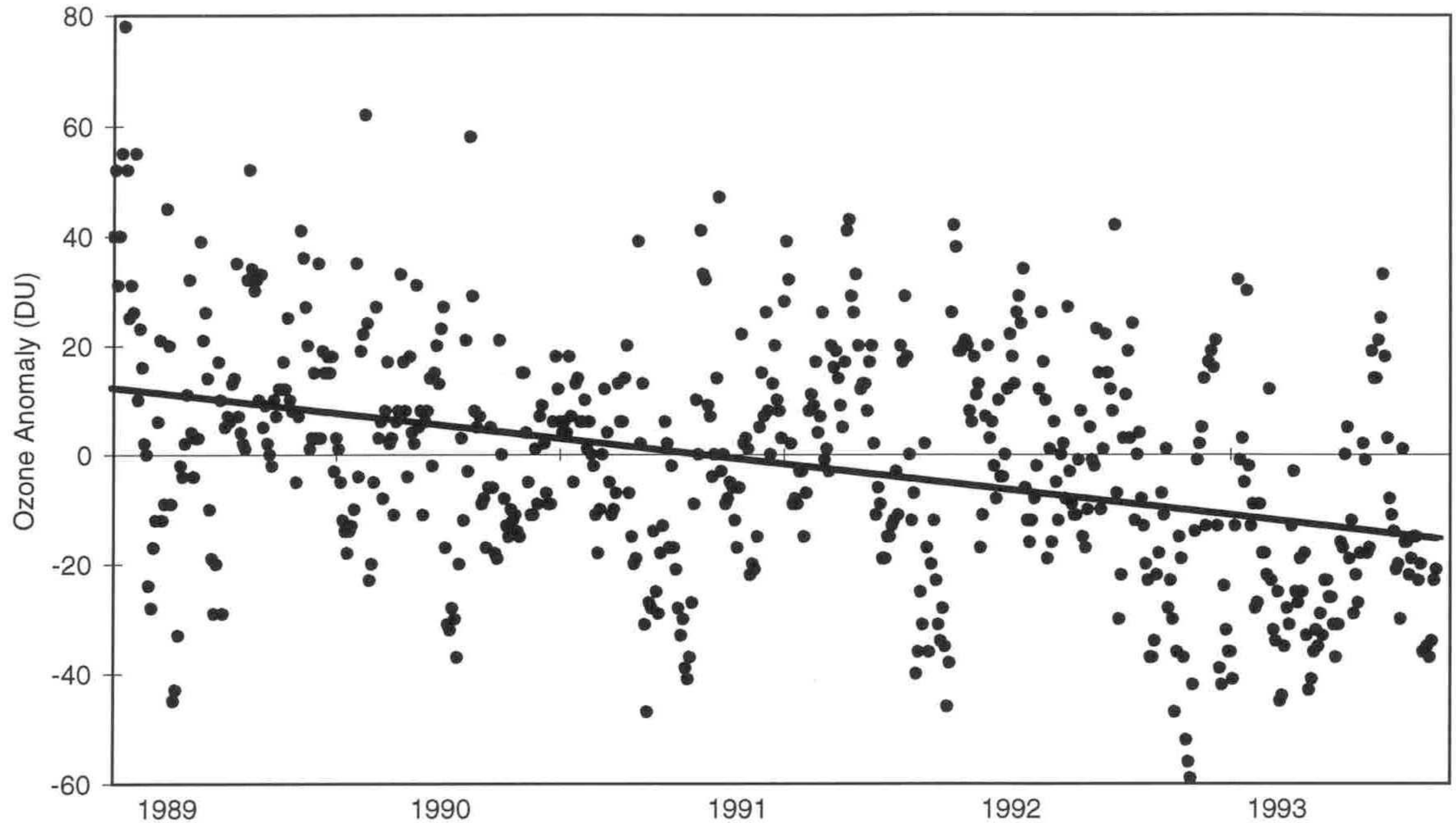

Figure 16. Regression plot of Toronto summer ozone daily anomaly, 1989-1993

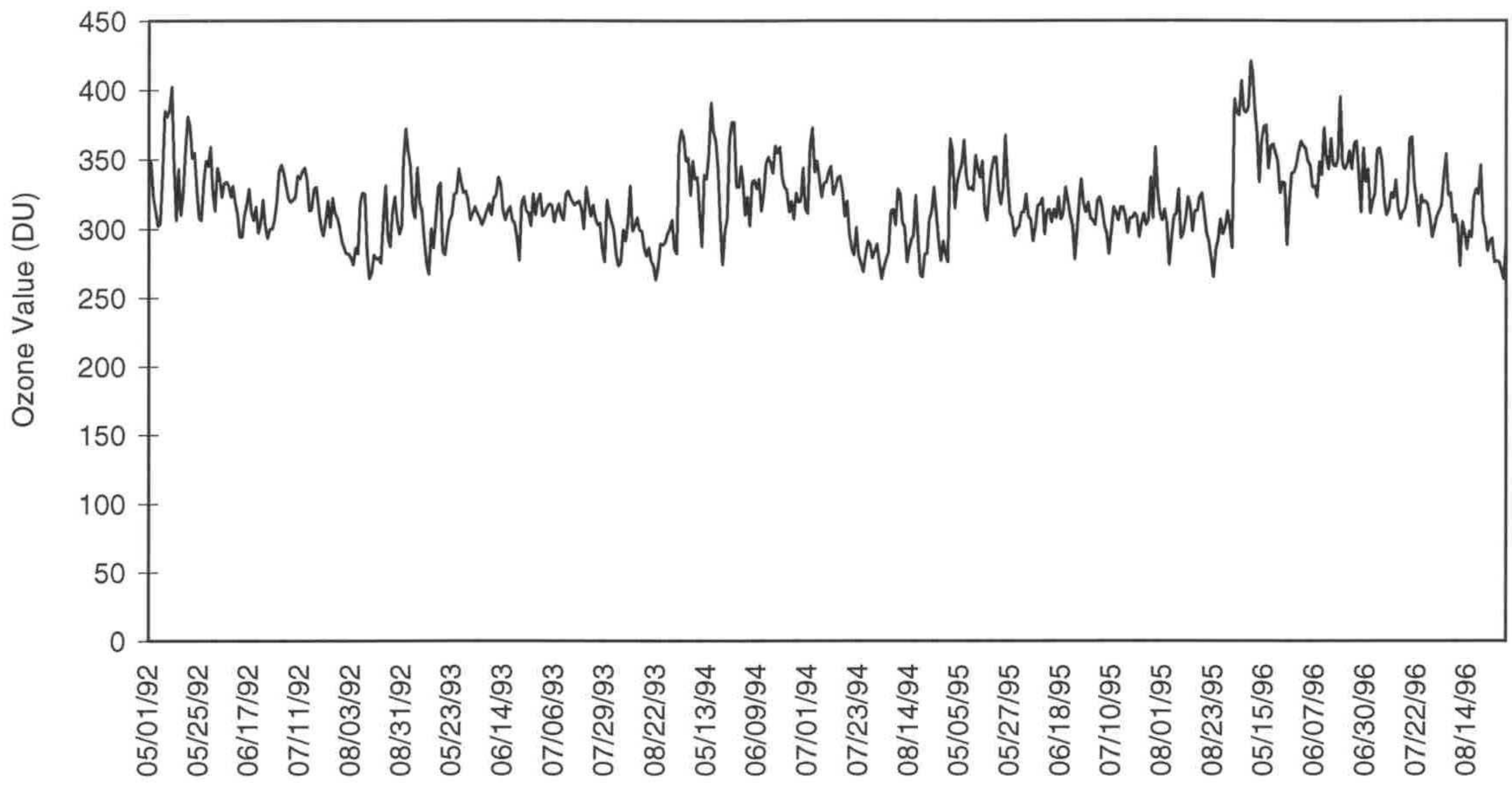

Figure 17. Edmonton summer (May, June, July, August) ozone daily data, 1992-1996

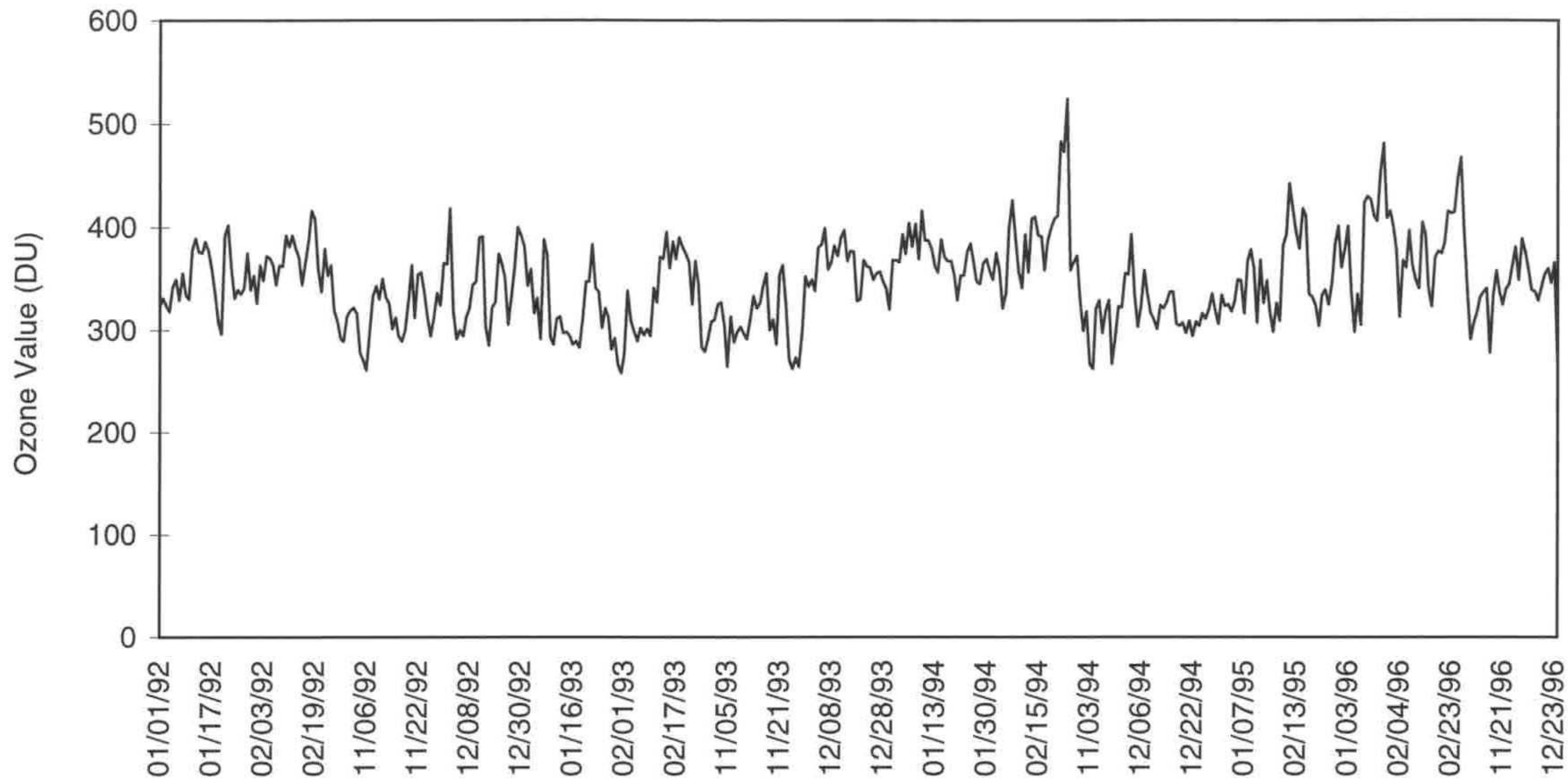

Figure 18. Edmonton winter (November, December, January, February) ozone daily data, 1992-1996

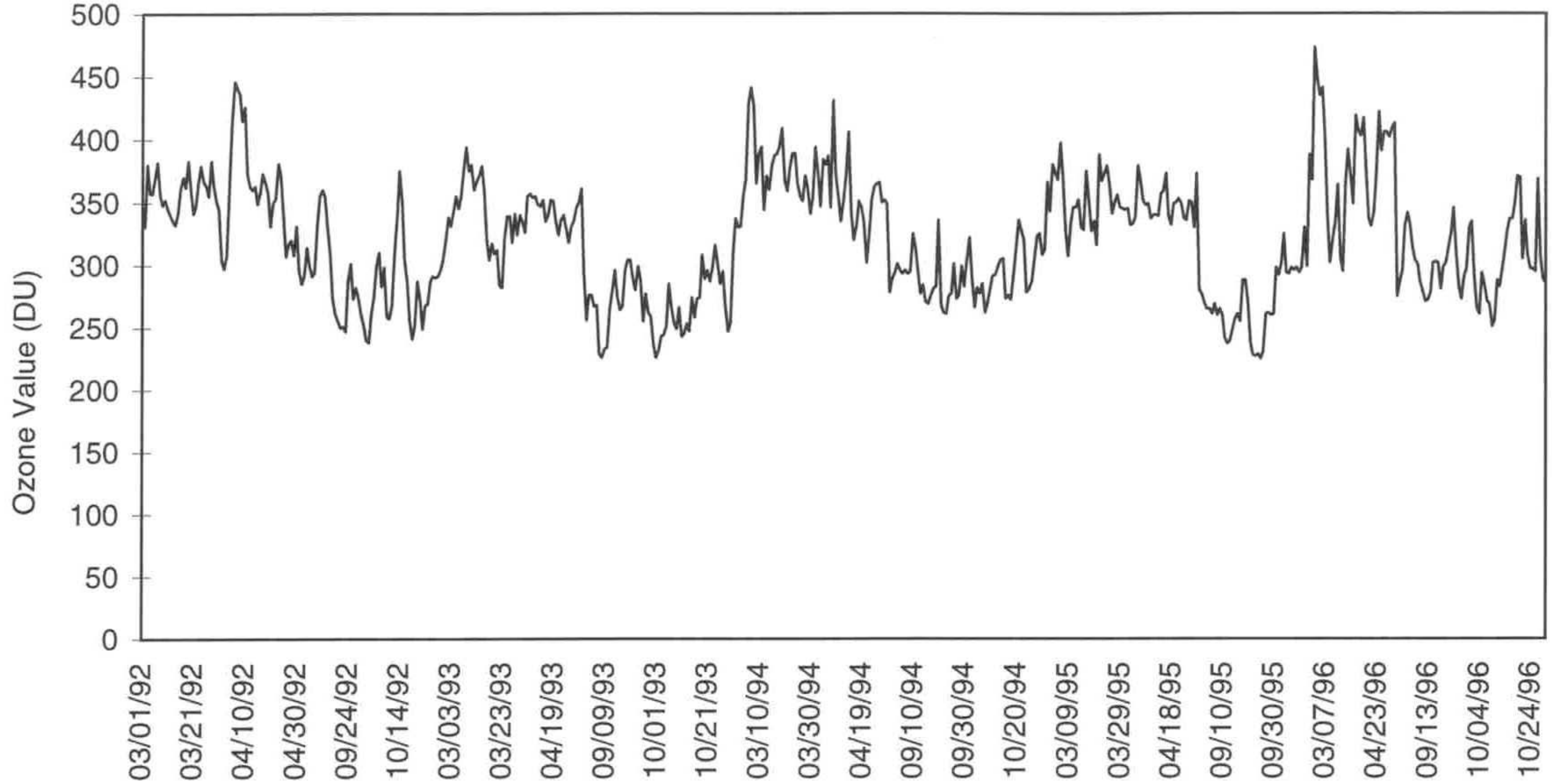

Figure 19. Edmonton other months (March, April, September, October) ozone daily data, 1992-1996

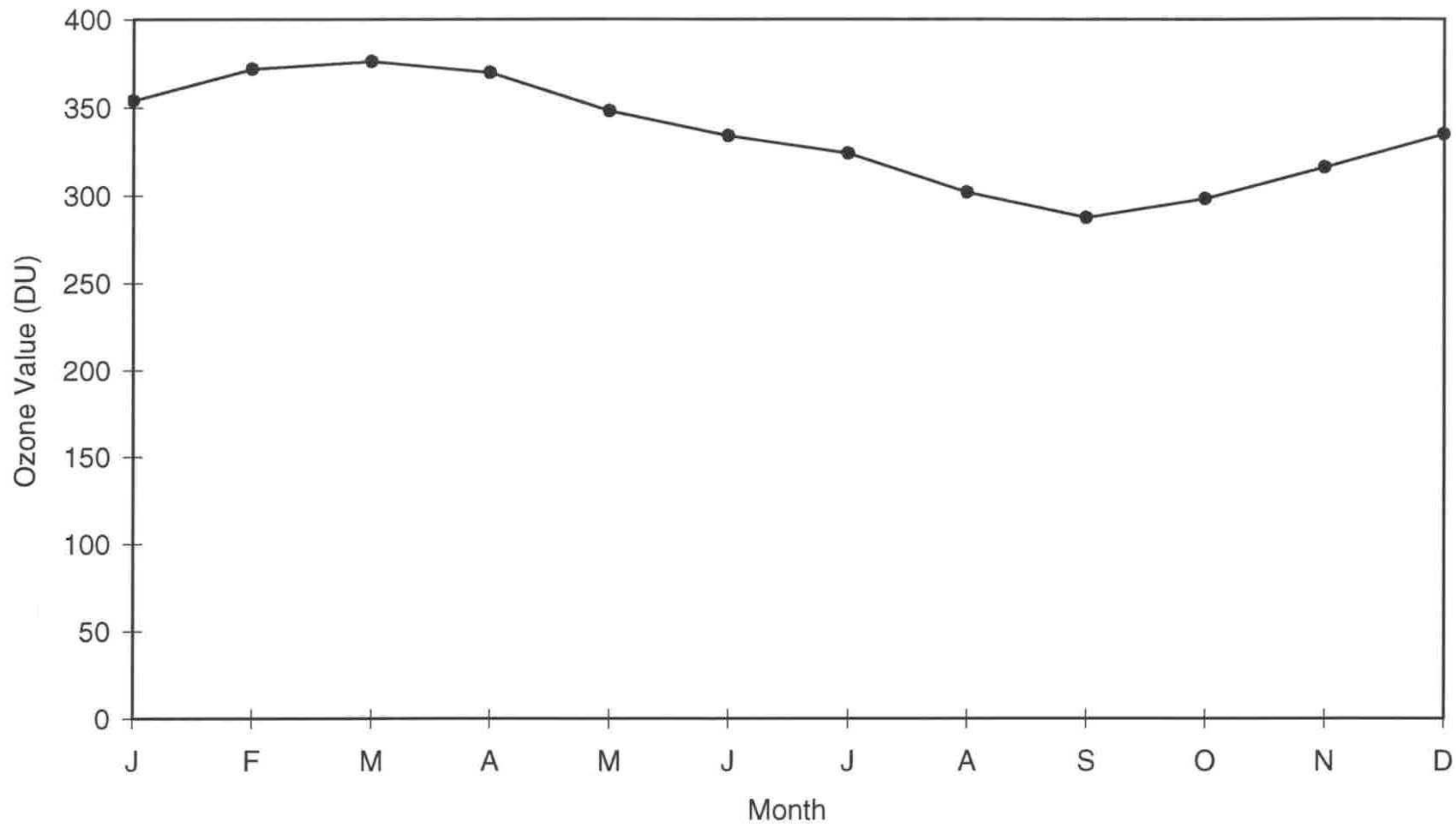

Figure 20. Edmonton monthly ozone climatology

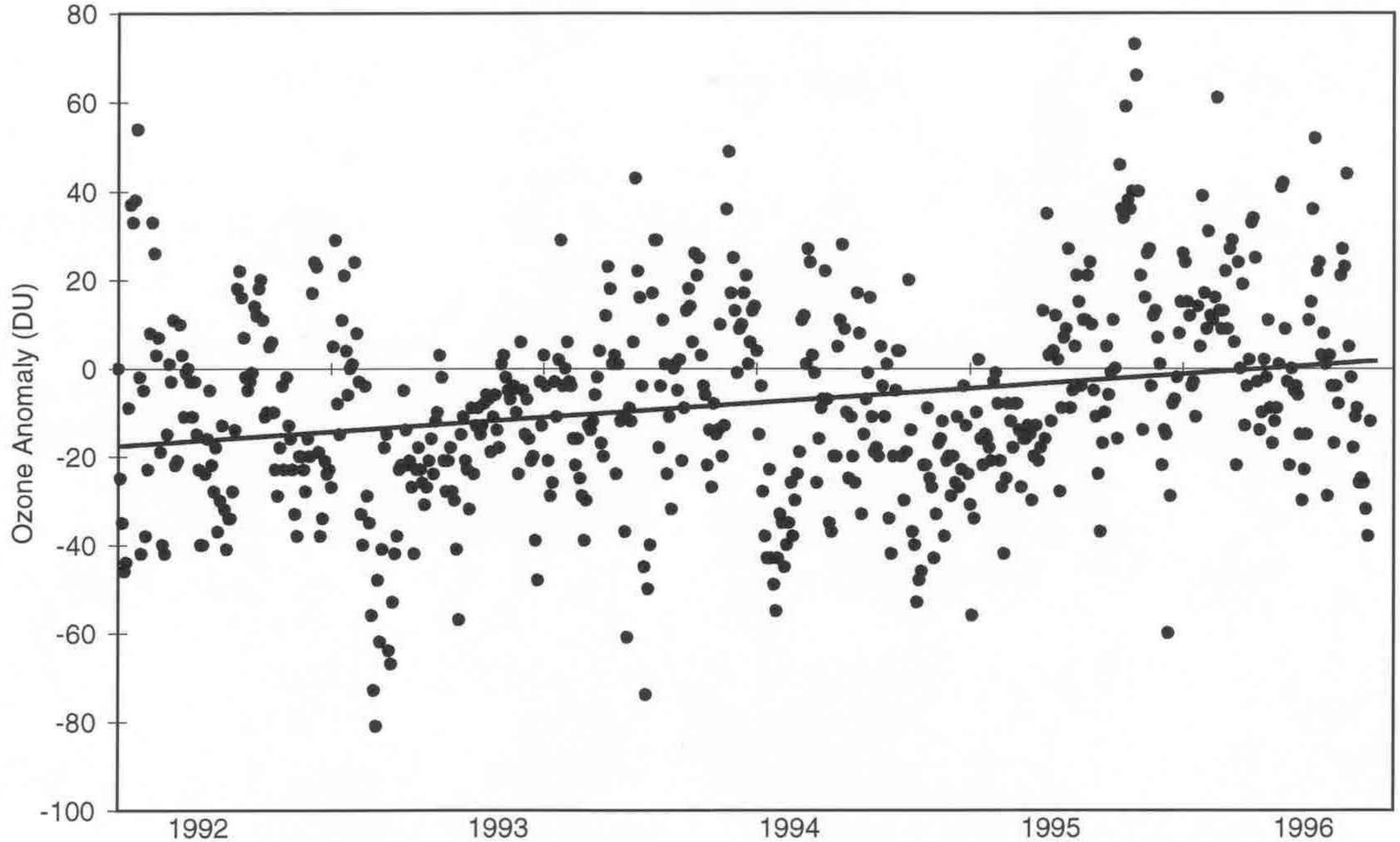

Figure 21. Regression plot of Edmonton summer ozone daily anomaly, 1992-1996

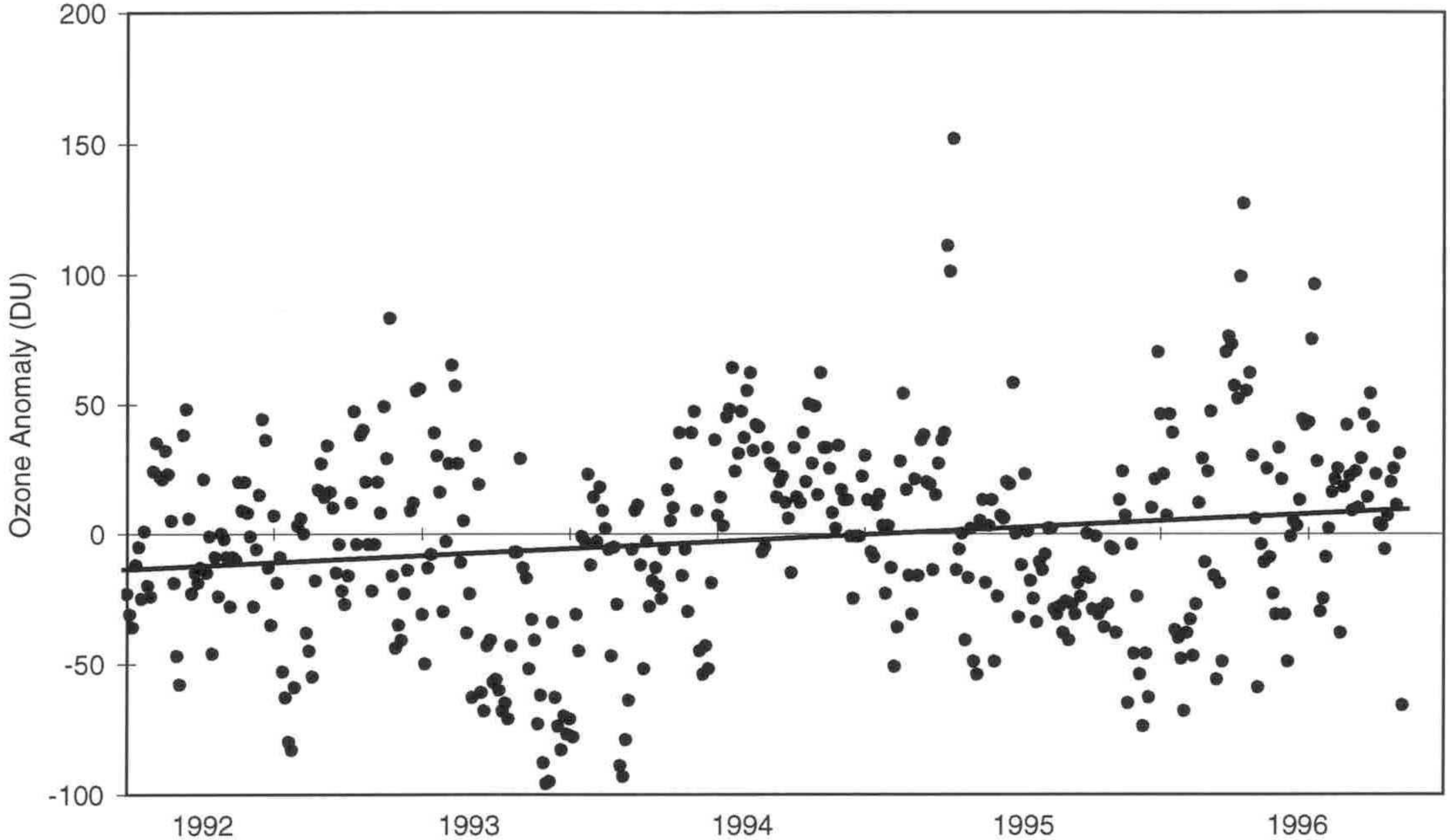

Figure 22. Regression plot of Edmonton winter ozone daily anomaly, 1992-1996

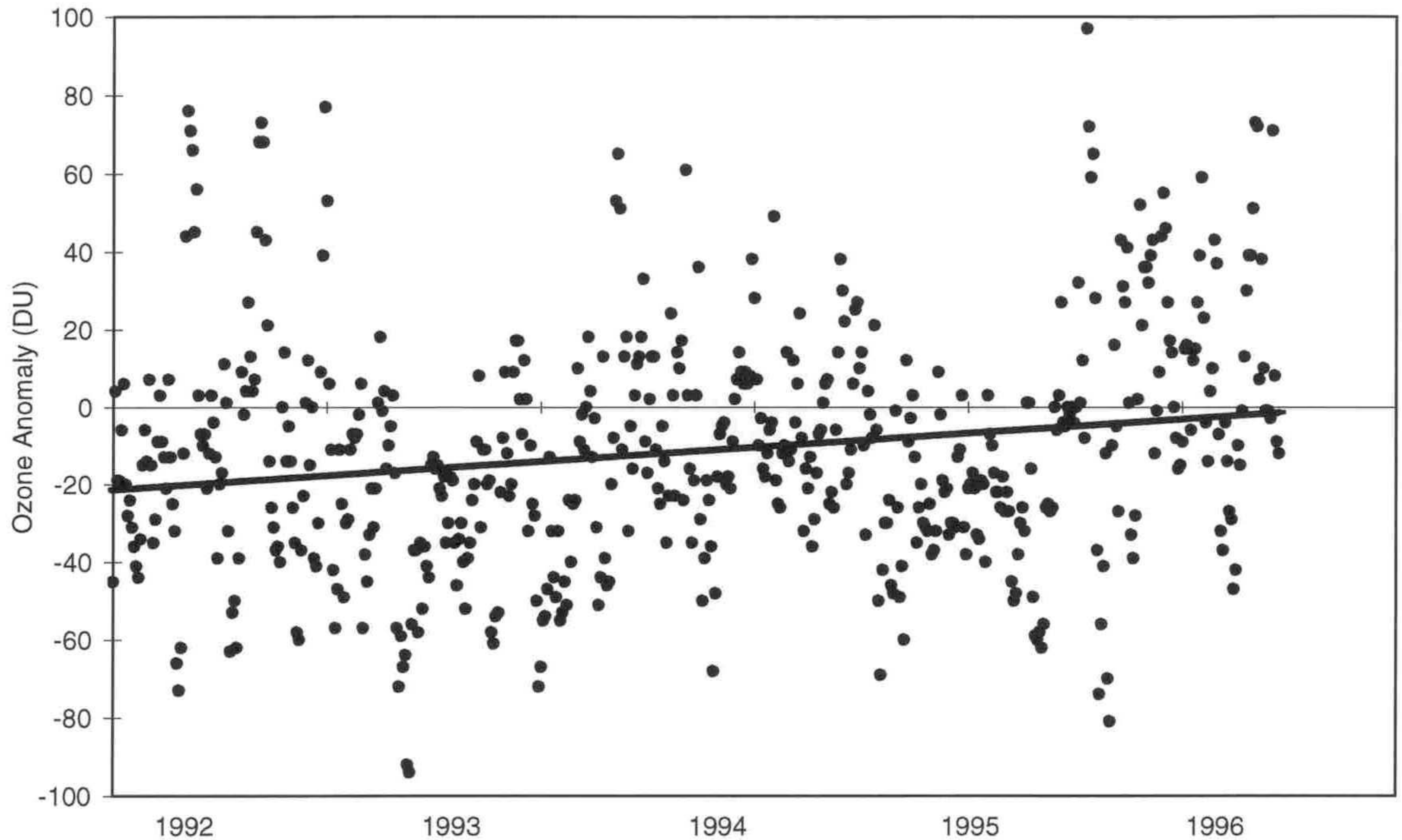

Figure 23. Regression plot of Edmonton ozone daily anomaly in other months, 1992-1996

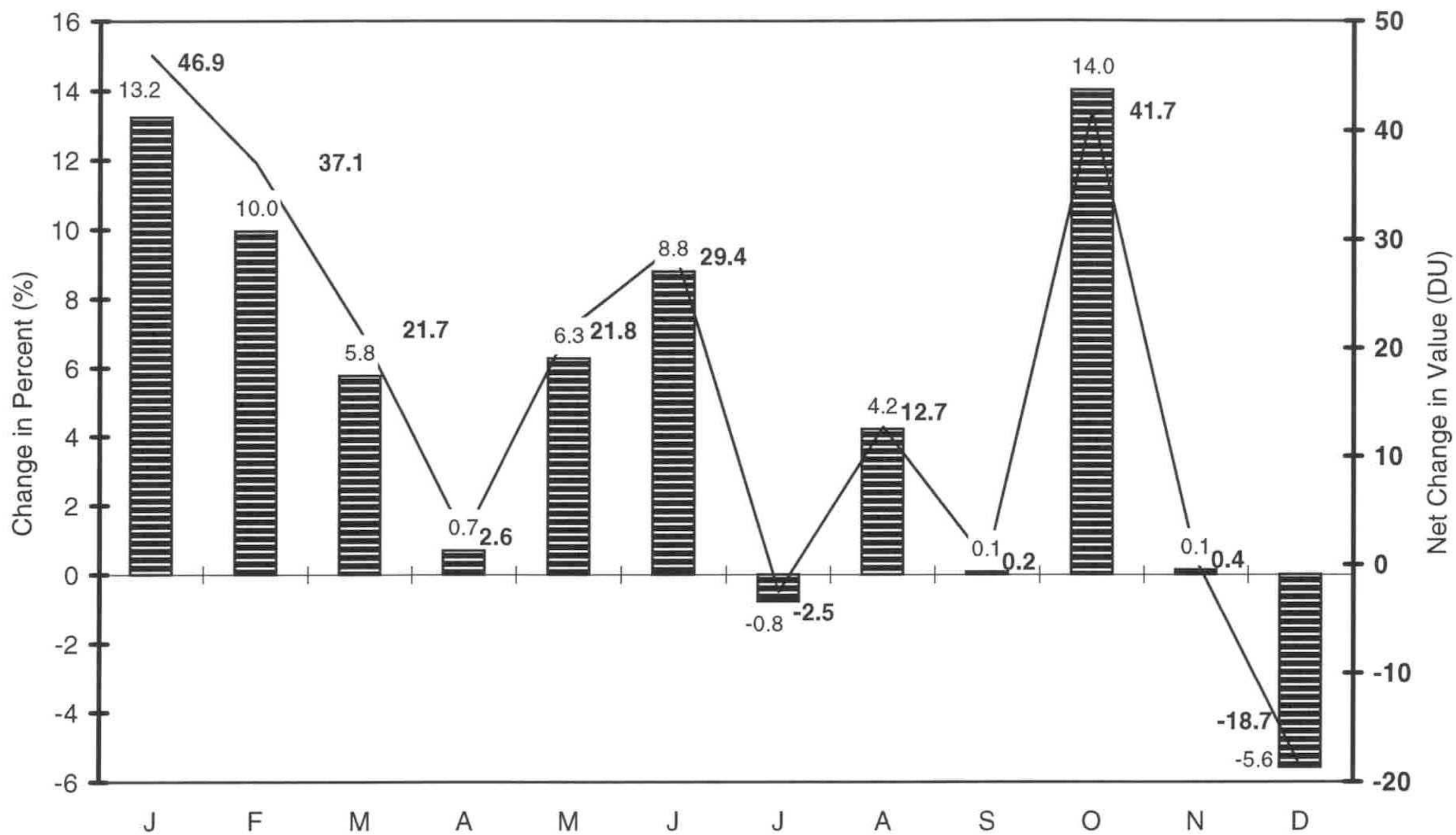

Figure 24. Edmonton ozone value changes stratified by month
(from daily data, 1992-1996)

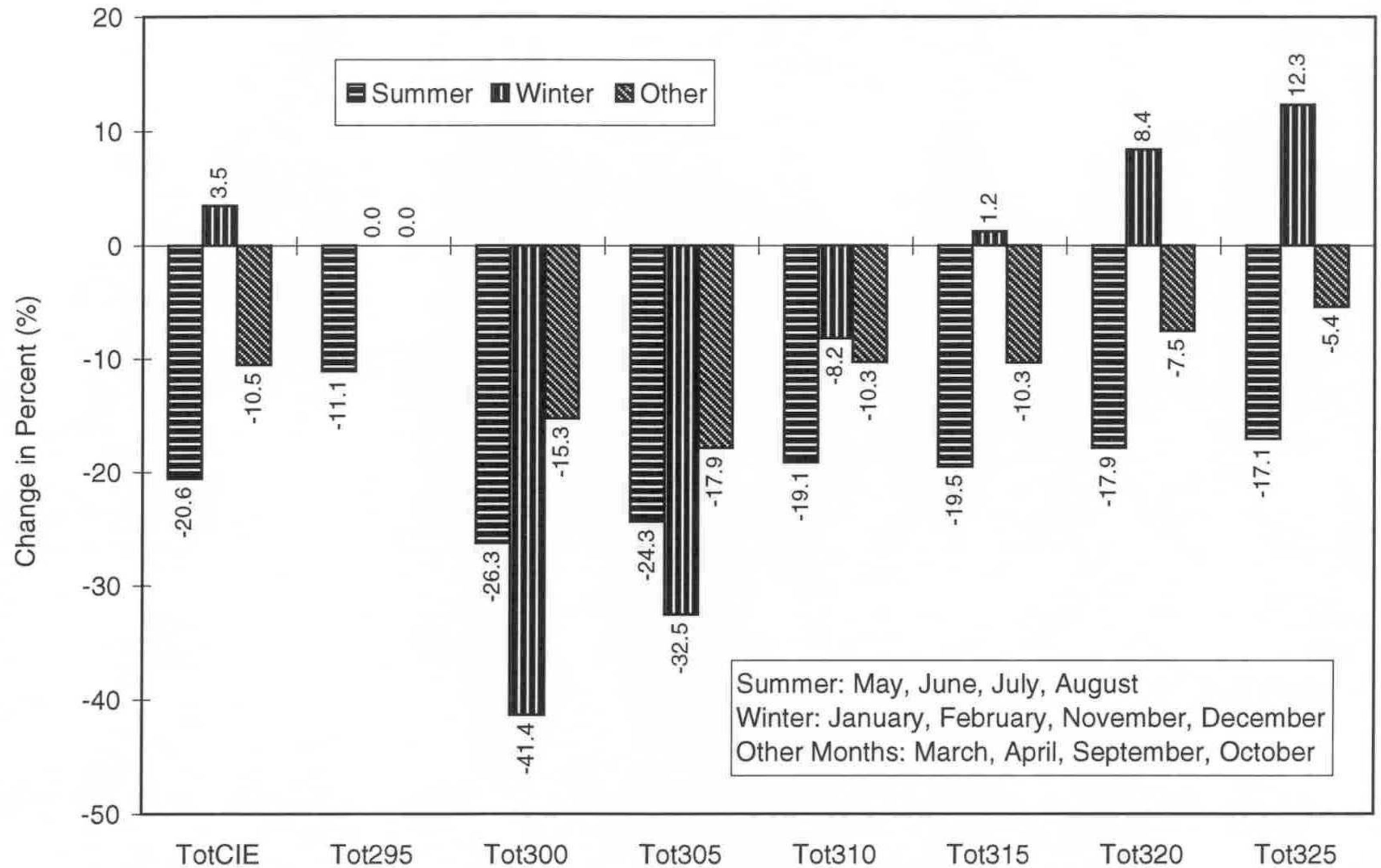

Figure 25. Edmonton UVB value changes stratified by seasons (from daily data, 1992-1996)

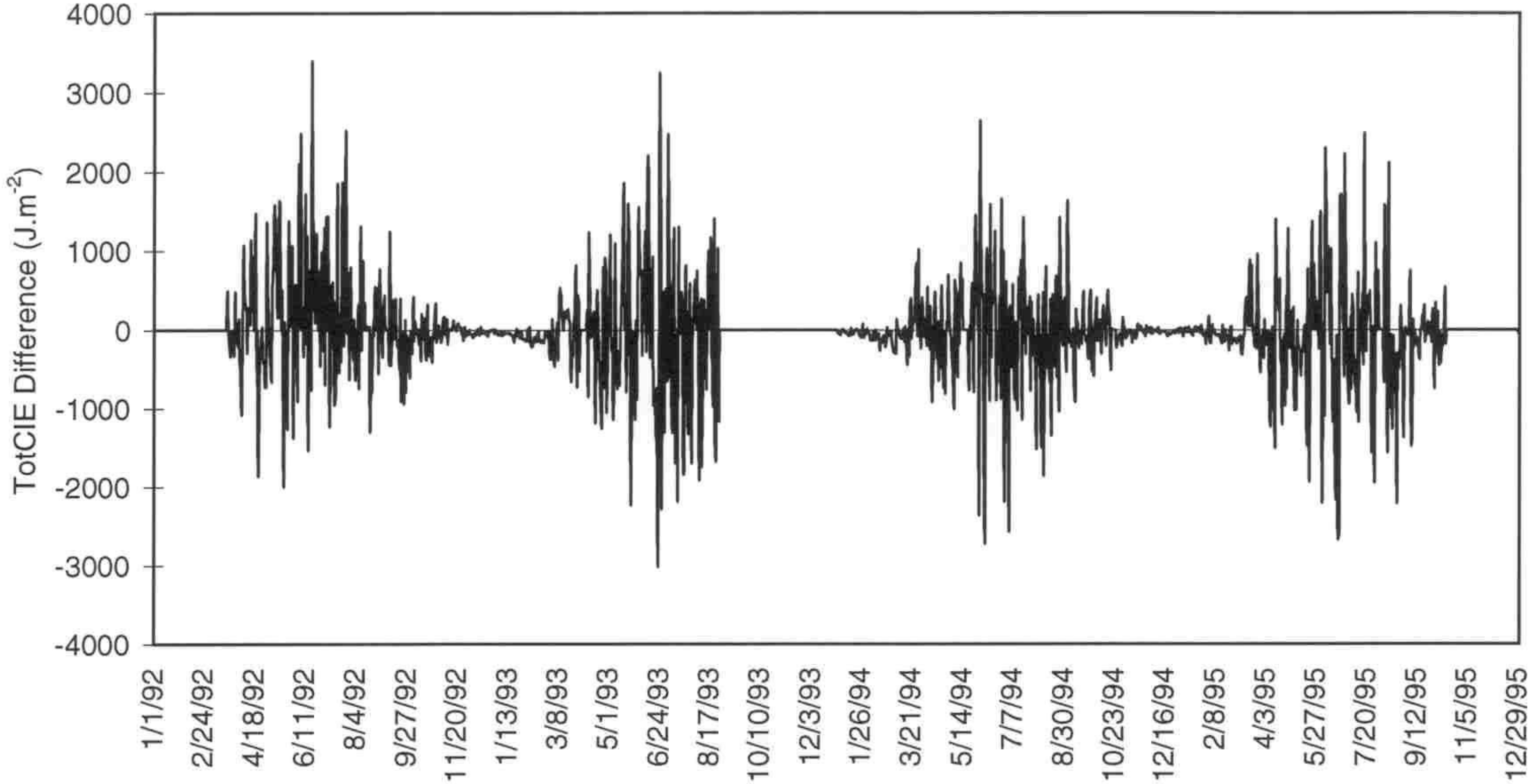

Figure 26. The daily difference of TotCIE between Edmonton and Saskatoon, 1992-1995

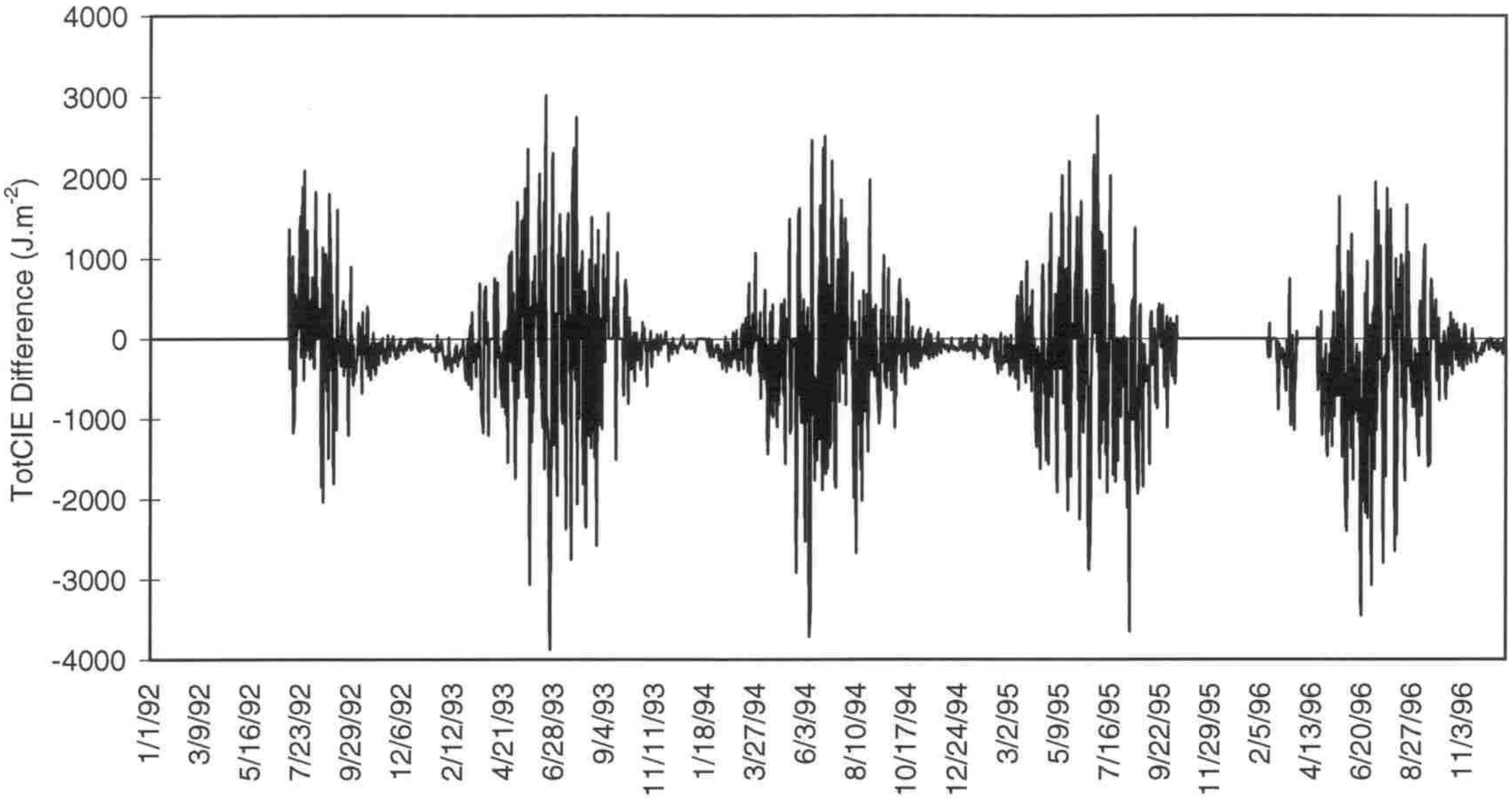

Figure 27. The daily difference of TotCIE between Edmonton and Winnipeg, 1992-1996

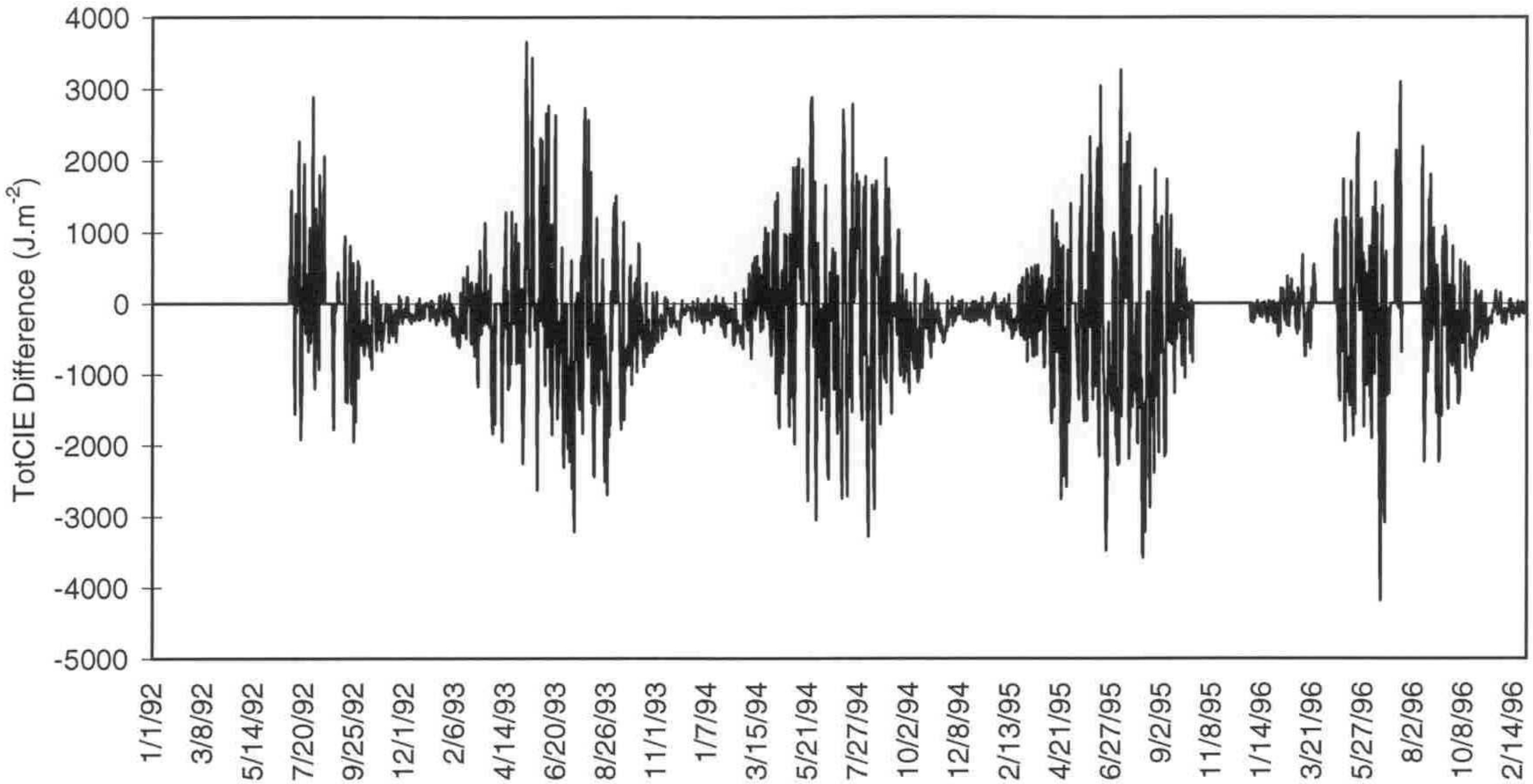

Figure 28. The daily difference of TotCIE between Edmonton and Halifax, 1992-1996

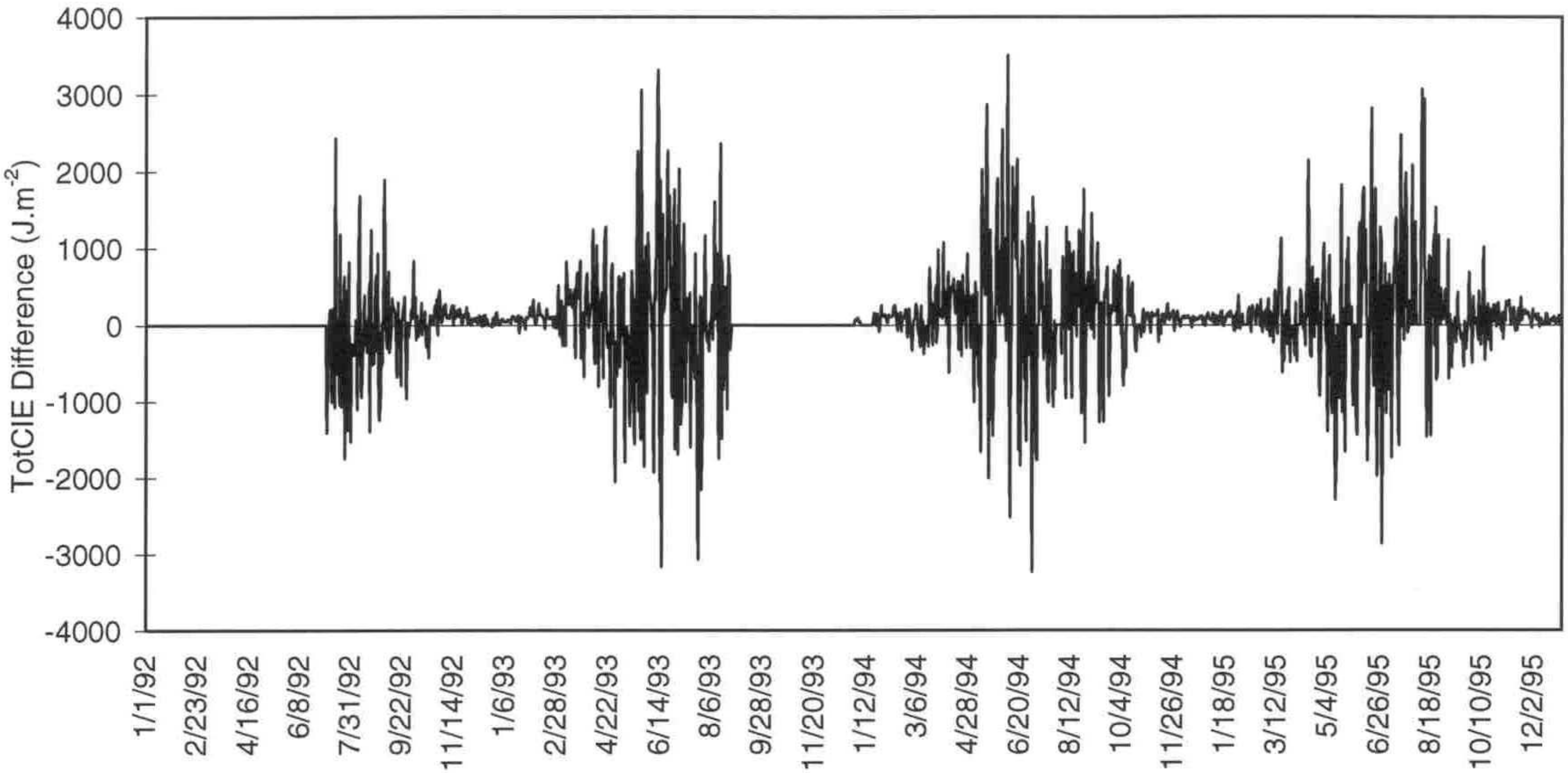

Figure 29. The daily difference of TotCIE between Saskatoon and Winnipeg, 1992-1995

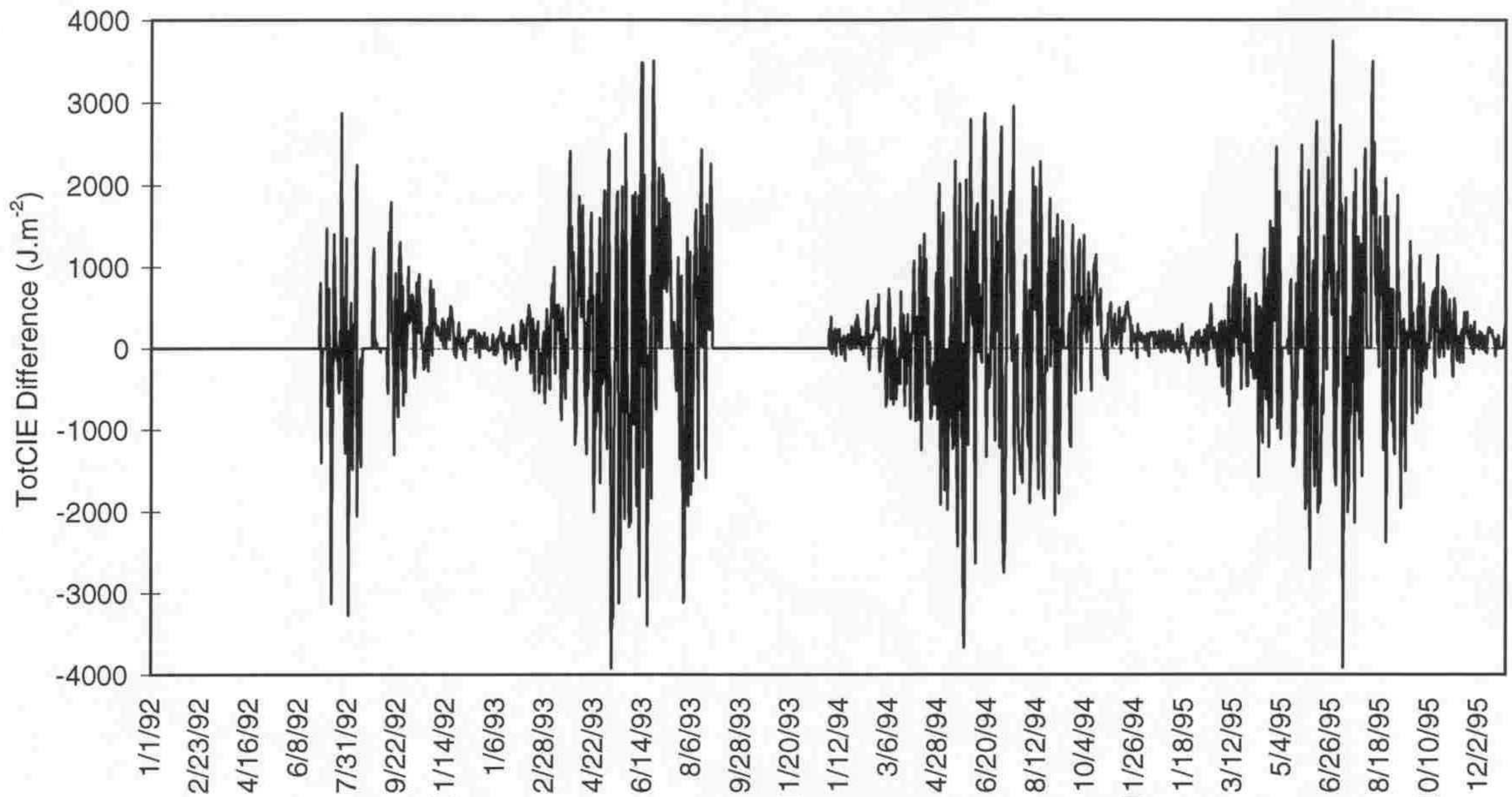

Figure 30. The daily difference of TotCIE between Saskatoon and Halifax, 1992-1995

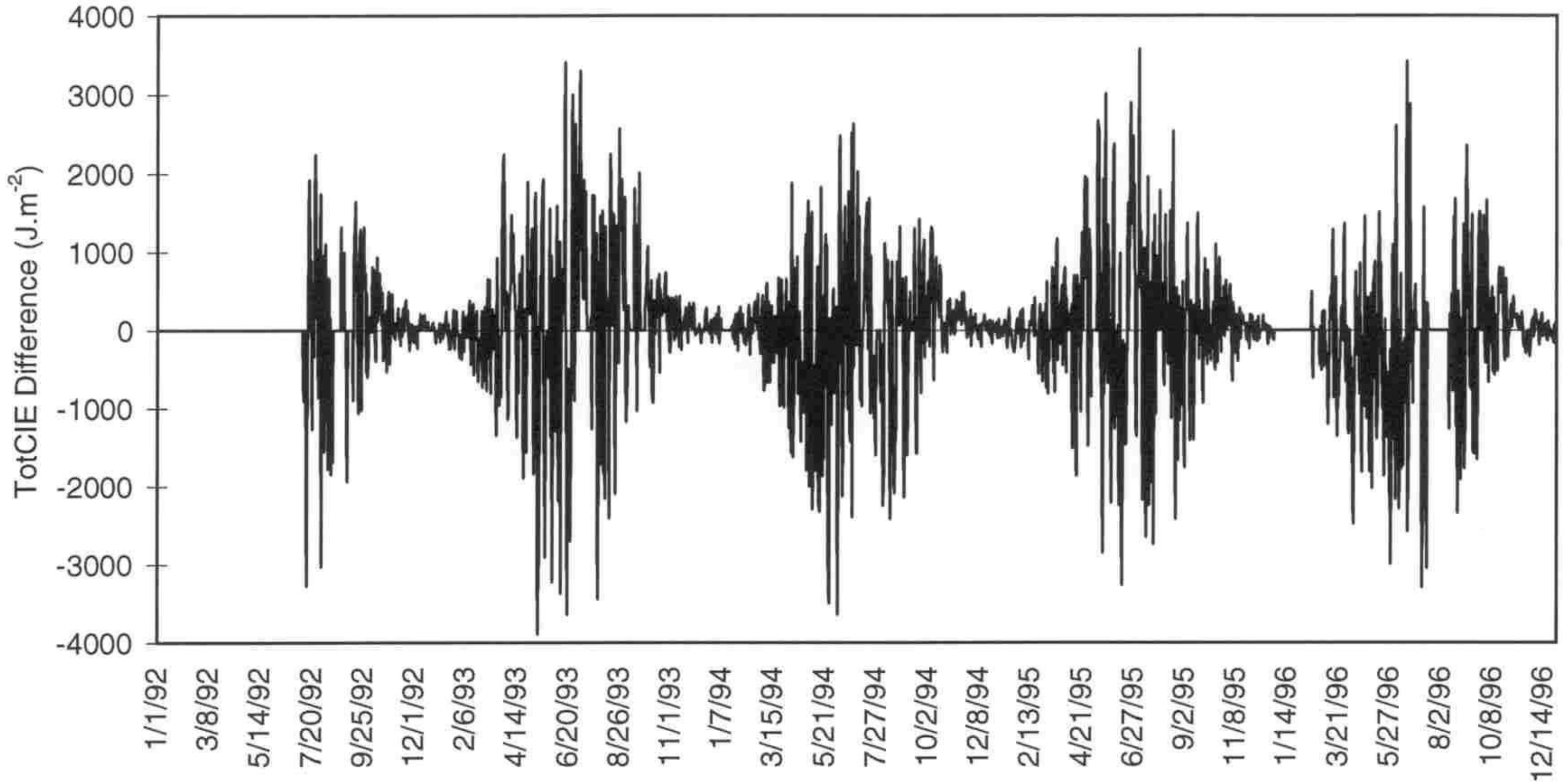

Figure 31. The daily difference of TotCIE between Winnipeg and Halifax, 1992-1996