Sensitivities of the Bays Eutrophication Model (BEM) to Changes in Algal Model Coefficients

Massachusetts Water Resources Authority
Environmental Quality Department
Report ENQUAD 2002-16

HydroQual. 2002. Sensitivity of the Bays Eutrophication Model (BEM) to changes in algal model coefficients. Massachusetts Water Resources Authority Report 2002-16. 236 p.

Massachusetts Water Resources Authority
Boston, Massachusetts

Sensitivity of the Bays Eutrophication Model (Bem) to Changes in Algal Model Coefficients

HydroQual, Inc.
One Lethbridge Plaza
Mahwah, NJ 07430
201-529-5151

February 2003
BATL0090
Task 2

TABLE OF CONTENTS

SECTION **PAGE**

1 INTRODUCTION 1-1

1.1 BACKGROUND 1-1

1.2 LAWS AND CHALUP MODEL COEFFICIENTS 1-2

1.3 RESULTS OF SENSITIVITY ANALYSIS 1-5
1.3.1 Sensitivity Run Number 1 1-6
1.3.2 Sensitivity Run Number 2 1-12
1.3.3 Sensitivity Run Number 3.....1-13

1.4 SUMMARY 1-15

1.5 RECOMMENDATION 1-16

2 REFERENCES 2-1

APPENDIX A -Results from Calibration and Sensitivity Analysis

LIST OF TABLES

1.1 Model coefficients and parameter values for *Pavlova lutheri*. 1-3
1.2 Model coefficients and parameter values for *Pavlova lutheri* vs. BEM. 1-5

LIST OF FIGURES

1-1. Chl-a:C Ratios as a Function of Normalized Growth Rate for F=0.22 1-17
1-2. Chl-a:C Ratios as a Function of Light Intensity for F=0.22 1-17
1-3. C:N Ratio as a Function of Normalized Growth Rate for F=0.22 1-18
1-4. Phytoplankton Growth Rates as a Function of Nutrient Concentration for Different Nutrient Saturated Growth Rates and Michaelis Constants 1-18
1-5. Chl-a:C Ratios as a Function of Normalized Growth Rate for F-0.85 1-19
1-6. Chl-a:C Ratios Versus Light Intensity for F=0.85 1-19
1-7. Chlorophyll to Carbon Ratios Versus Normalized Growth Rate for F=0.35 1-20
1-8. Carbon to Nitrogen Ratios Versus Normalized Growth Rate for F=0.35 1-20
1-9. 1992 Calibration Results for Model Segment (11,18) - Time-series Comparisons 1-21
1-10. 1992 Sensitivity Results for Model Segment (11,18) Using Full Laws & Chalup Coefficient Set - Time-series Comparisons 1-22
1-11. 1993 Calibration Results for Model Segment (11,18) - Time-series Comparisons 1-23
1-12. 1993 Sensitivity Results for Model Segment (11,18) Using Full Laws & Chalup Coefficient Set - Time-series Comparisons 1-24
1-13. 1992 Calibration Results for Model Segment (13,4) - Time-series Comparisons 1-25
1-14. 1992 Sensitivity Results for Model Segment (13,4) Using Full Laws & Chalup Coefficient Set - Time-series Comparisons 1-26
1-15. 1992 Calibration Results for Surface C:N Ratios - Probability Distribution Comparisons 1-27
1-16. 1992 Sensitivity Results for Surface C:N Ratios Using Full Laws & Chalup Coefficient Set - Probability Distribution Comparisons 1-28
1-17. 1992 Calibration Results for Surface POC Concentrations - Probability Distribution Comparisons 1-29
1-18. 1992 Sensitivity Results for Surface POC Concentrations Using Full Laws & Chalup Coefficient Set - Probability Distribution Comparisons 1-30
1-19. 1992 Calibration Results for Surface Chlorophyll-a Concentrations - Probability Distribution Comparisons 1-31
1-20. 1992 Sensitivity Results for Surface Chlorophyll-a Concentrations Using Full Laws & Chalup Coefficient Set - Probability Distribution Comparisons 1-32
1-21. 1992 Calibration Results for Mid-depth (12.5-17.5 M) Chlorophyll-a Concentrations - Probability Distribution Comparisons 1-33
1-22. 1992 Sensitivity Results for Mid-depth (12.5-17.5 M) Chlorophyll-a Concentrations Using Full Laws & Chalup Coefficient Set - Probability Distribution Comparisons 1-34
1-23. 1992 Calibration Results for Surface C:Chl-a Ratios - Probability Distribution Comparisons 1-35
1-24. 1992 Sensitivity Results for Surface C:Chl-a Ratios Using Full Laws & Chalup Coefficient Set - Probability Distribution Comparisons 1-36

LIST OF FIGURES - continued

1-25. 1992 Calibration Results for Mid-depth (12.5-17.5 M) C:Chl-a Ratios - Probability Distribution Comparisons 1-37
1-26. 1992 Sensitivity Results for Mid-depth (12.5-17.5 M) C:Chl-a Ratios Using Full Laws & Chalup Coefficient Set - Probability Distribution Comparisons 1-38
1-27. 1992 Calibration Results for Surface DIN Concentrations - Probability Distribution Comparisons 1-39
1-28. 1992 Sensitivity Results for Surface Din Concentrations Using Full Laws& Chalup Coefficient Set - Probability Distribution Comparisons 1-40
1-29. 1992 Calibration Results for Surface PO_4 Concentrations - Probability Distribution Comparisons 1-41
1-30. 1992 Sensitivity Results for Surface PO_4 Concentrations Using Full Laws & Chalup Coefficient Set - Probability Distribution Comparisons 1-42
1-31. 1992 Sensitivity Results for Model Segment (11,18) Using F=0.22 Coefficient Set - Time-series Comparisons 1-43
1-32. 1992 Sensitivity Results for Model Segment (13,4) Using F=0.22 Coefficient Set - Time-series Comparisons 1-44
1-33. 1992 Sensitivity Results for Surface C:N Ratios Using F=0.22 Coefficient Set - Probability Distribution Comparisons 1-45
1-34 1992 Sensitivity Results for Surface POC Concentrations Using F=0.22 Coefficient Set - Probability Distribution Comparisons 1-46
1-35. 1992 Sensitivity Results for Surface Chlorophyll-a Concentrations Using F=0.22 Coefficient Set - Probability Distribution Comparisons 1-47
1-36. 1992 Sensitivity Results for Mid-depth (12.5-17.5 M) Chlorophyll-a Concentrations Using F=0.22 Coefficient Set - Probability Distribution Comparisons .. 1-48
1-37. 1992 Sensitivity Results for Surface DIN Concentrations Using F=0.22 Coefficient Set - Probability Distribution Comparisons 1-49
1-38. 1992 Sensitivity Results for Surface PO_4 Concentrations Using F=0.22 Coefficient Set - Probability Distribution Comparisons 1-50
1-39. 1992 Sensitivity Results for Model Segment (11,18) Using F=0.35 Coefficient Set - Time-series Comparisons 1-51
1-40. 1992 Sensitivity Results for Model Segment (13,4) Using F=0.35 Coefficient Set - Time-series Comparisons 1-52
1-41. 1992 Sensitivity Results for Surface C:N Ratios Using F=0.35 Coefficient Set - Probability Distribution Comparisons 1-53
1-42. 1992 Sensitivity Results for Surface POC Concentrations Using F=0.35 Coefficient Set - Probability Distribution Comparisons 1-54
1-43. 1992 Sensitivity Results for Surface Chlorophyll-a Concentrations Using F=0.22 Coefficient Set - Probability Distribution Comparisons 1-55
1-44. 1992 Sensitivity Results for Mid-depth (12.5-17.5 M) Chlorophyll-a Concentrations Using F=0.22 Coefficient Set - Probability Distribution Comparisons .. 1-56
1-45. 1992 Sensitivity Results for Surface DIN Concentrations Using F=0.22 Coefficient Set - Probability Distribution Comparisons 1-57
1-46. 1992 Sensitivity Results for Surface PO_4 Concentrations Using F=0.22 Coefficient Set - Probability Distribution Comparisons 1-58

SECTION 1

INTRODUCTION

1.1 BACKGROUND

In 1991, the Massachusetts Water Resources Authority (MWRA) funded the development of a coupled hydrodynamic/water quality model of Massachusetts and Cape Cod Bays as part of its Harbor and Outfall Monitoring Program (HOM). This model, the Bays Eutrophication Model (BEM), was developed to assess the potential impacts of relocating secondary treated effluent discharged by the Nut and Deer Island wastewater treatment plants from Boston Harbor into Massachusetts Bay. During the development of the BEM, a peer review committee, known as the Model Evaluation Group or MEG, was convened by MWRA to provide technical oversight and review of the model and to help assure the regulatory community that the final model was scientifically-credible and that it could be used to assess the impacts of outfall relocation. A limitation of the initial modeling framework was identified early in the model calibration process by the MEG and called to HydroQual's attention. The limitation concerned the inability of the BEM to reproduce the observed vertical structure in profiles of chlorophyll-a, a surrogate for algal biomass. A significant number of vertical chlorophyll-a profiles, observed in the field, showed evidence of a sub-surface chlorophyll-a maximum. These maxima were generally observed in the vicinity of 15-25m below the water surface. However, based upon further review and analysis of vertical distributions of dissolved oxygen and limited measurements of particulate organic carbon (POC), it was not evident that the sub-surface chlorophyll-a maxima were the result of higher levels of primary production occurring at these water depths (i.e., the vertical profiles of dissolved oxygen did not show maxima occurring at the same water depths).

A review of the scientific literature identified a model of algal growth and algal carbon, nutrient, and chlorophyll-a stoichiometry that offered a framework that could be used to explain the observed vertical chlorophyll data. This model, developed by Laws and Chalup (1990), posited that the ratio of carbon to chlorophyll in a phytoplankton cell was a function of both nutrients and light. In particular, under similar nutrient regimes, the model, supported by the laboratory data of Chalup and Laws (1990), computed a higher cell carbon to chlorophyll-a ratio under high light conditions versus a lower cell carbon to chlorophyll-a ratio computed under low light conditions. Stated another way, under low light levels, phytoplankton increase their production of chlorophyll per unit cell carbon, thereby decreasing the carbon to chlorophyll ratio (or increasing the chlorophyll to carbon ratio). Therefore, it is possible that the sub-surface chlorophyll-a maxima observed in Massachusetts and Cape Cod Bays may, in part, be attributed to enhanced production of chlorophyll-a under lower light levels that exist in the deeper

sub-surface waters of the bays, rather that by having maximum primary production occur in the deeper waters.

The model developed by Laws and Chalup was incorporated, with some modifications, into the BEM framework. The principal modifications to the Laws and Chalup framework, as adapted for the Bays system and BEM, were as follows:

- revision of the steady-state (or equilibrium) Laws and Chalup (1990) equations of state to a time-variable formulation (HydroQual, 1995), and
- modification of some of the model coefficients used by Laws and Chalup to validate the model against pure-cultures of *Pavlova lutheri* (Chalup and Laws, 1990).

Details of the implementation of the first modification (conversion to a time-variable equation set) have been presented previously by HydroQual (1995). The purpose of this analysis is to review the rationale for modifying the model coefficient set used by Laws and Chalup and to present the results of a sensitivity analysis of the key model coefficients modified in the application to the Massachusetts Bays system.

1.2 LAWS AND CHALUP MODEL COEFFICIENTS

The model developed by Laws and Chalup employs nine key coefficients to determine phytoplankton growth, the nitrogen to carbon ratio, and the chlorophyll-a to carbon ratio. The coefficients and their parameter values (plus 95% confidence intervals) are presented in Table 1-1. Figures 1-1 through 1-3 illustrate how the chlorophyll-a to carbon (Chl-a:C) ratio and carbon to nitrogen (C:N) ratio change as a function of nutrients and light using the coefficients developed by Laws and Chalup for *Pavlova lutheri*. Figure 1-1 presents the Chl-a:C ratio as a function of the normalized growth rate (the ratio of the actual growth rate to the nutrient-saturated rate) for various light intensities. The Chl-a:C ratio increases in a linear fashion for each light intensity as the normalized growth rate increases. The Chl-a:C ratio is the highest at the lowest light intensity, given the same normalized growth rate. Figure 1-2 presents the same information contained in Figure 1-1, but in a slightly different way. The Chl-a:C ratio is plotted as a function of light intensity for various normalized growth rates. Presented this way, the Laws and Chalup model indicates that higher Chl-a:C ratios (hence, higher chlorophyll levels) should occur in darker waters and when the phytoplankton cells have a sufficient supply of nutrients. Conversely, phytoplankton should have a lower Chl-a:C ratio (and lower chlorophyll levels) in highly illuminated waters or when they are nutrient limited. It should also be noted that changes in the Chl-a:C ratio are smaller under more limited nutrient conditions (low μ ratio) than under nutrient replete conditions (high μ ratio). The Laws and Chalup model also predicts that the C:N ratio decreases

Table 1-1. Model coefficients and parameter values for *Pavlova lutheri.*

Coefficient	Description (units)	Value (95% C.I.)
r_g	rate of change of respiration per unit change in gross photosynthetic rate per cell (gC/cell-day)	0.28 (0.03-0.43)
r_0/C	basal respiration rate (day^{-1})	0.03 (-0.11-0.16)
W_N	ratio of total cell C to nutrient in structural, light/dark reactions of (g C/g N)	6.9 (6.2-7.7)
F	quotient of nutrient-limited N/C ratios at relative growth rates of 0 and 1	0.22 (0.17-0.27)
G_{prd}	gross photosynthetic rate per unit quantity of dark reaction carbon (day^{-1})	3.6 (2.4-42)
W_{Chl}	ratio of total cell carbon to chlorophyll-a in the light reaction component of C (g C/g Chl-a)	17 (13-34)
S/C	structural carbon per total C	0.1 (-0.1-0.2)
G_{prl}	value of gross rate of photosynthesis per unit light reaction carbon per unit light intensity in the limit of zero irradiance (m^2/mol quanta)	0.28 (0.16-0.51)
I_S	half-saturation irradiance (mol quanta/m^2-day)	64 (10-122)

as nutrient enrichment increases (Figure 1-3). In the case of the coefficients developed for *Pavlova lutheri* by Laws and Chalup, the C:N ratio changes approximately threefold for a ninefold change in the normalized growth rate.

It is important to note that the coefficients developed by Laws and Chalup are for a single species cultured under monoaxenic conditions. It is also important to remember that competition for resources occurs in the natural environment. Competition or natural selection implies that the growth rate and, therefore, the dominance of different algal species depend upon the ambient conditions of temperature, light, and available nutrients at a given point in time and space. For example, one algal species or genera may be able to out compete another species or genera under conditions of high nutrients because its nutrient saturated growth rate, μ_{max}, is higher. However, the species with the lower growth rate may become dominant under low nutrient conditions if its nutrient limitation or Michaelis constant (K_{mn}) is lower than the species with the higher nutrient-saturated growth rate (Figure 1-4 for two hypothetical species). In the case of *Pavlova lutheri,* it may be possible that another phytoplankton species that is able to utilize available light and low nutrient concentrations may out compete a species such as *Pavlova lutheri* before it can completely change its internal stoichiometry (C:N ratio) to that observed under fully nutrient limited conditions. Therefore, recognition of species competition or natural selection should have some influence on the choice of model parameter values used for the Laws and Chalup coefficients as applied to the Massachusetts Bays system. Finally, it is also important to note that the BEM model

represents the multitude of phytoplankton species that are observed over an annual cycle in Massachusetts and Cape Cod Bays with two functional algal groups; a winter diatom group and a summer mixed assemblage. Therefore, the parameter values determined for *Pavlova lutheri* may not be the most appropriate to model phytoplankton in Massachusetts and Cape Cod Bays.

Given these considerations, as well as the results of previous modeling efforts, it was decided during the model calibration process to modify some of the parameter values used for the Laws and Chalup model, when applying it to the Massachusetts Bays system. Table 1-2 presents a comparison of the parameter values used by Laws and Chalup for *Pavlova lutheri* versus those used for the winter and summer groups in the BEM. The differences between the parameters values used for *Pavlova lutheri* and the BEM are:

- G_{prl}, the gross photosynthesis rate per unit quantity of dark reaction carbon. The value chosen for the BEM were the result of the initial BEM calibration effort, using data collected by various researchers between 1989 and 1991 and the 1992 HOM monitoring effort.

- F, the quotient of nutrient-limited N:C ratios at relative growth rates of 0 and 1. The value chosen for the BEM represented a best fit of the C:N data observed during the 1992 HOM field monitoring effort.

- W_N, the ratio of cell C to nutrient in structural, light/dark reactions of C. The values used in the BEM for both the winter and summer groups is 5.67 versus the value of 6.9 for *Pavlova lutheri*. The value of 5.67 was chosen for the BEM, since this represents the average value of C:N found by Redfield for nutrient saturated phytoplankton.

- W_{chl}, the ratio of cell carbon to chlorophyll-a in the light reaction of photosynthesis. The values chosen for the BEM represented a best fit of the C:Chl-a data observed during the 1992 HOM field monitoring effort.

Based on comments received from the MEG and from MWRA, the BEM was rerun for the 1992-1994 conditions, but using the parameter values reported by Laws and Chalup. The principal reason for performing this sensitivity run was the observation that the parameter value of 0.85 used in BEM for F, produced Chl-a:C ratios (as a function of the normalized growth rate), which were at variance with the data reported by Chalup and Laws (1990) for *Pavlova lutheri*. With the exception of the lowest light

Table 1-2. Model coefficients and parameter values for *Pavlova lutheri* vs. BEM

Coefficient	*Pavlova lutheri*	BEM - Winter Group	BEM - Summer Group
r_g	0.28	0.28	0.28
r_0/C	0.03	0.03	0.036
W_N	6.9	5.68	5.68
F	0.22	0.85	0.85
G_{prd}	3.6	2.5	3.0
W_{Chl}	17	40	65
S/C	0.10	0.10	0.10
G_{prl}	0.28	0.28	0.28
I_S	64	(1)	(1)

intensities, the Chl-a:C ratio decreases, rather than increases, with increasing normalized growth rate (Figure 1-5) for F equal to 0.85 (and all other parameter values as per Laws and Chalup). However, the desired behavior of the Laws and Chalup model, i.e., that the Chl-a:C ratio increase with decreasing light availability, is still reproduced even with the 0.85 parameter value. For a parameter value of 0.85 for F and for the same normalized growth rate, decreasing light intensity results in increasing the Chl-a:C ratio (Figure 1-6). As additional sensitivity runs, the BEM was also evaluated using parameter values of 0.22 and 0.35 for F, but using the remaining parameter values as per the BEM calibration (Table 1-2). The parameter value of 0.35 for F, provides for a similar response in Chl-a:C ratio (Figure 1-7) as is obtained using the value of 0.22 reported by Laws and Chalup. At the same time, it also limits the variation in the C:N ratio to approximately a twofold change in C:N for a ninefold change in the normalized growth rate (Figure 1-8), rather than the threefold increase reported by Laws and Chalup (Figure 1-3).

1.3 RESULTS OF SENSITIVITY ANALYSIS

Previous reports (HydroQual, 1995, 2000), documenting the development and calibration/validation of the BEM, presented model versus data comparisons using time-series and probability distributions. The time-series plots provided comparisons of model computations versus observed data for specific model grid cells versus HOM data collected within the model grid cell. The time-series comparisons tended to provide a more rigorous analysis of model calibration, since the model could be compared to observed data on a point-by-point basis and permitted the evaluation of model performance to be

---

[1] I_s varies as a function of the last three days of solar radiation. $I_s = \left(0.1 * I_{tot_{n-3}} + 0.2 * I_{tot_{n-2}} + 0.7 * I_{tot_{n-1}}\right) / 3$

made for a number of water quality state-variables or constituents at the same time. The probability plots compared model computations versus data, aggregating over space and time. The probability plots provided an assessment of the model's ability to reproduce seasonal means and distributions for data collected at the near field and far field HOM designated stations.

The time-series plots consist of model versus data comparisons for the calibration and for three sensitivity runs for the three years previously analyzed (1992-1994) for two model segments, one located in the middle of the near field stations and one located in Cape Cod Bay. The three sensitivities are as follows:

- the Laws and Chalup coefficient set: $G_{prl} = 3.6$, $F = 0.22$, $W_N = 6.9$, and $W_{chl} = 17$,
- $F = 0.22$, all other coefficients as per the calibration, and
- $F = 0.35$, all other coefficients as per the calibration.

1.3.1 Sensitivity Run Number 1

Figure 1-9 presents temporal comparisons of model versus data for the 1992 calibration run for a number of the key water quality variables. The results are presented for the model cell (grid location 11,18), representing the future (at the time) outfall location. The data are from three HOM stations (N16P, N17, and N21) lying within the boundaries of the model cell. Model results from the first sensitivity (the Laws and Chalup coefficient set) are presented on Figure 1-10. Comparing the model computations from these two runs, the following observations can be made:

- computed chlorophyll-a levels for the sensitivity run are markedly higher than computed for the calibration case for the summer months and the calibration appears to represent a better fit to the observed chlorophyll data,
- summer concentrations of particulate organic carbon (POC) computed by the sensitivity run are approximately a factor of two higher than those computed in the calibration case and appear high relative to the observed data; however, there are insufficient POC data available to make a full determination as to which coefficient set provides a better calibration to the observed data,
- computed concentrations of surface dissolved inorganic nitrogen (DIN), the sum of NH_4, NO_2, and NO_3, differ by a factor of two to three during the summer months between the two model runs, with the calibration computing lower concentrations there is enough variation in the observed data that one cannot conclude definitively which coefficient set provides a better comparison to the observed data,
- computed concentrations of summer surface dissolved inorganic phosphorus (DIP) are lower for the sensitivity run and appear inconsistent with the observed data; the calibration compares

more favorably to the observed DIP data,

- computed concentrations of summer surface dissolved inorganic silica (DSi) are also lower for the sensitivity run and also appear lower than the observed data; the calibration, however, appears to over estimate the surface DSi in the late summer months.

The reason that the summer concentrations of surface DIP and DSi are lower for the sensitivity run is due to the fact that the values of W_N (the ratio of cell carbon to nutrient in the structural, light and dark portions of the algal cell, = 6.9) and F (the quotient of nutrient-limited N/C ratios at relative growth rates of 0 and 1, = 0.22) chosen for the sensitivity run permit higher concentrations of algal carbon to develop (since the C:N ratio starts higher and can get even higher for low levels of DIN relative to the calibration value of F = 0.85). As higher levels of algal carbon develop in the sensitivity run, greater uptake and utilization of DIP and DSi also occurs.

Figures 1-11 and 1-12 present model versus data comparisons for 1993 for the calibration and the first sensitivity, respectively. Again the model computations from the sensitivity run (Figure 1-12) show higher concentrations of chlorophyll-a and higher concentrations of POC relative to the calibration. The sensitivity results are marginally better for chlorophyll-a than the calibration, while limited POC data make it difficult to say which coefficient set provides for a better match to the observed data. However, the calibration coefficient set appears to provide a better comparison to the observed surface profiles of DIN and DIP during the summer months. The comparisons for DSi indicate that the calibration computed high concentrations, relative to the observed data, while the sensitivity run may have computed low concentrations. It is interesting to note that neither coefficient set provided for a favorable comparison to the fall algal bloom (dominated by *Asterionellopsis glacialis*) that occurred in 1993. Similar computational results and conclusions (i.e., the sensitivity computes lower chlorophyll and DIP levels and higher POC levels compared to the calibration) can be drawn from comparing the calibration and sensitivity to observed data for 1994 (Appendix A).

A second model segment, located in southeastern Cape Cod Bay, was selected to illustrate results from the sensitivity analysis. Computations from this model segment (13,4) are compared to data observed at HOM station F02P. The model calibration and the first sensitivity (the Laws and Chalup coefficient set) are compared for 1992 in Figures 1-13 and 1-14, respectively. Results are similar to those observed for model segment (11,18), i.e., concentrations of POC and chlorophyll-a levels computed for the sensitivity are significantly higher than computed for the calibration. Based on the limited data available, the sensitivity run seems to provide a better calibration for POC from late-winter (March) through the late summer (August), before over estimating POC in the fall (early October). The sensitivity run extends the development of the winter bloom, capturing the maximum concentration of POC observed in April (and approximately matching the observed dissolved oxygen (DO) for April).

The reason for this phenomenon is again related to the higher C:N ratio that the sensitivity run permits. However, the sensitivity run once again severely under estimates surface DIP in the late winter-early spring (April) and summer months (and surface DSi in June). In addition, the sensitivity run also under estimates the bottom water DIP during the same period. Similar results are also computed for 1993 (Appendix A). Model versus data comparisons for the calibration versus the sensitivity runs for 1994 suggest that either calibration coefficient set provides a reasonable calibration to the observed data for this model segment for 1994.

From the plots presented here and in Appendix A, it appears that the calibration coefficient set provides more favorable comparisons to the observed data. While there are some cases in which the sensitivity coefficient set seems to provide a better comparison to the observed chlorophyll-a and POC data, in general, the calibration seems to provide a better calibration to the observed DIP data. However, the limited data availability for some of the key model constituents (e.g., POC) and the limited sampling conducted for the far field stations does allow for some degree of uncertainty about which coefficient set provides a better calibration if based on the time-series plots alone. Another way to examine the calibration versus sensitivity computations versus observed data is via the use of probability plots. These plots attempt to show how well the model computations reproduce the median concentrations and range observed in the data on a spatially averaged and on a seasonally-averaged and annually-averaged basis. For the probability plots, data from all of the HOM near field data stations are compared against model computations from model segments in which the near field stations lie. For the near field stations, each year has been broken into four averaging periods for both the model and data:

- winter - February and March (no data were collected in January, therefore, no January model computations are included in the winter average),
- spring - April through June,
- summer - July through September, and
- fall - October through December.

Comparisons are also presented for the near field and far field stations for the "annual" period. Figures 1-15 and 1-16 present the seasonal and annual distributions of the computed carbon to nitrogen (C:N) ratios versus the observed data for 1992 for the calibration and Laws and Chalup coefficient sets, respectively. The calibration coefficient set approximately reproduces the median C:N ratio for the winter and spring averaging periods, slightly over estimates the summer median, and significantly under estimates the fall median for the near field stations (Figure 1-15). On an annual basis, the calibration reproduces the median for the near field stations and slightly under estimates the median for the far field stations. The calibration, however, does not reproduce the range in variation in the C:N ratios observed

in the near field or far field stations. The observed C:N ratios for the fall averaging period are reproduced by the model using the Laws and Chalup coefficient set. However, the Laws and Chalup coefficient set results in the median C:N ratios being over estimated for the winter, spring, and summer averaging periods. On an annual basis, the sensitivity run significantly over estimates the median C:N ratio (as well as the overall distribution of C:N ratios) for the near field stations. The sensitivity run also significantly over estimates the far field C:N ratios. One improvement that the sensitivity coefficient set provides, however, is that the variation (minimum to maximum) in the observed C:N ratios are somewhat better captured in both the near field and far field data. Similar results were computed and observed for the years 1993 and 1994 (Appendix A).

The calibration and Laws and Chalup coefficient sets appear to produce similar computational results for POC when the water column is not strongly nutrient limited. Model computations of POC for the near field segments for the winter averaging period (little nutrient limitation) are quite similar (Figures 1-17 and 1-18). However, as nutrient limitation becomes a factor during the spring, summer, and fall averaging periods, the sensitivity run computes higher POC concentrations than does the calibration run. On an annual basis, the calibration appears to provide a slightly better fit to the observed near field data than does the sensitivity run. However, the sensitivity run seems to fit the far field data better than the calibration. Overall for 1992, on the basis of POC, it would be difficult to say which coefficient set provides the better calibration. However, the calibration appears to perform better on an annual basis for 1993 and 1994 (Appendix A).

Figures 1-19 and 1-20 present model versus data comparisons of surface chlorophyll-a for the calibration and Laws and Chalup coefficient sets, respectively. The use of either coefficient set results in the model over estimating the spring chlorophyll-a. For the summer months the calibration coefficient set provides a more favorable comparison to the observed surface chlorophyll data. However, in the fall the Laws and Chalup coefficient set provides for a more favorable calibration. On a yearly-averaged basis the calibration coefficient set provides a better overall comparison to the near-field and far-field data, although the Laws and Chalup coefficients reproduce the maximum chlorophyll-a concentrations better. A comparison of the calibration and sensitivity results versus observed data for 1993 and 1994 (Appendix A) clearly indicates that the calibration coefficient set compares more favorably to the data than the Laws and Chalup coefficient set across almost all averaging periods.

One of the reasons for implementing the Laws and Chalup algal growth model was to attempt to reproduce the observed sub-surface chlorophyll-a maxima observed at depth. Figures 1-21 and 1-22 present approximately mid-depth (12.5-17.5 m) model computations versus observed chlorophyll-a data for 1992. Clearly the Laws and Chalup coefficient set over estimates mid-depth chlorophyll-a on an annual basis for both the near field and far field stations (Figure 1-22) as compared to the calibration

coefficient set (Figure 1-21). The Laws and Chalup coefficient set also over estimates summer mid-depth chlorophyll-a by a factor of three to four as compared to the coefficient set used for model calibration, which compares well to the observed data. The only averaging period where the Laws and Chalup coefficient set performs well is for the winter period. On an annual basis the calibration run seems to provide better comparisons to the surface and mid-depth data for both the near field and far field data. Similar results and conclusions were observed for the 1993 and 1994 calibration years (Appendix A).

One of the issues that drove this sensitivity analysis was the differences in C:Chl-a ratios that might be expected for a value of F = 0.85, used in the calibration, versus F = 0.22 used by Laws and Chalup. Figures 1-23 through 1-26 present the C:Chl-a ratios computed by the model versus the observed data for the surface and mid-depth (12.5-17.5 m) for 1992. Comparing model versus surface C:Chl-a data (Figures 1-23 and 1-24) on a seasonal basis, a case cannot be made for which coefficient set performs better. On an annual basis, the sensitivity run compares more favorably to the near field data (the calibration approximately reproduces the observed probability distribution or variance but under estimates the data by 40-90 percent), while the calibration run compares more favorably to the far field data (the sensitivity approximately reproduces the observed probability distribution or variance but under estimates the data by 40-90 percent). It should also be noted that the sensitivity run computes a slightly greater range in the maximum to minium C:Chl-a ratios than does the calibration run. For the mid-depth comparisons, both coefficient sets appear to produce similar results. Both the calibration (Figure 1-25) and the sensitivity run (Figure 1-26) under estimate the near field data and over estimate the far field data on an annual basis. However, it should be noted that there are few data with which to make a comprehensive comparison. The sensitivity run also appears to perform slightly better on an annual basis for the surface model versus data comparisons for the near field data for 1993 and 1994 (Appendix A) considering both the observed median and variance. Considering the far field data for 1993 and 1994, the calibration compares more favorably to the observed median, while the sensitivity compares more favorably to the observed variance.

To this point in making model versus data comparisons for the calibration and sensitivity runs, it is not possible to say definitively which model coefficient set provides a better calibration to the observed data, although one might lean in the direction of the calibration coefficient set. Comparisons to the observed nutrient data also suggest this to be the case. Model computations of average (averaging period of two and a half days), minimum, and maximum DIN are compared to observed surface DIN for the calibration and sensitivity runs in Figures 1-27 and 1-28, respectively. There are no significant differences between computed concentrations of DIN for the winter period (a period wherein N-limitation generally does not occur) using the two coefficient sets. However, differences for the spring, summer, and fall periods are more evident. In general, the calibration results compare more favorably

to the observed DIN data than do the results computed by the Laws and Chalup coefficient set. On an annual basis, the calibration coefficient set also provides a more favorable comparison to the observed DIN data. The Laws and Chalup coefficient set compares more favorably to the median of far field DIN data, but over estimates the observed minima.

Results are somewhat similar for 1993 and 1994 (Appendix A). The calibration and sensitivity runs compute similar concentrations of DIN for the winter averaging period. Median spring concentrations (minima, maxima, and two and a half day averages) computed by both coefficient sets are approximately the same for each year. However, the minimum two and a half day averaged values computed by the calibration coefficient set are more consistent with the observed data. For the summer averaging period the calibration provides a better comparison for 1993, while the Laws and Chalup coefficient set compares more favorably for 1994. On an annual basis both coefficient sets compute similar medians and, therefore, compare approximately the same to the observed medians for both the near field and far field data. However, the calibration compares more favorably to the observed minima.

Comparisons of computed means, minima, and maxima (for two and a half day averaging periods) versus observed surface dissolved inorganic phosphate (PO_4) are presented for 1992 for the calibration and Laws and Chalup coefficient sets in Figures 1-29 and 1-30, respectively. Overall, the coefficient set used for the calibration compares more favorably to the observed surface PO_4 data than does the Laws and Chalup coefficient set. This is particularly noticeable for the summer averaging period, where the two and a half day means computed by the Laws and Chalup coefficient set under estimates the observed PO_4 data by almost an order of magnitude. On an annual basis, the minima and maxima PO_4 computed by the model envelop approximately 90 percent of the observed PO_4 data versus only 60 percent for the Laws and Chalup coefficient set. The calibration also provides for a better fit to the observed far field PO_4 data. Similar results and conclusions were observed for 1993 and 1994 (Appendix A).

Interestingly the choice of the coefficient data set does not seem to have a significant effect on the dissolved oxygen calibration results. Considering the surface layer of the model, the Laws and Chalup coefficient set does compare better to the observed near field data for the summer averaging period and on an annual basis for the far field data (Appendix A). The Laws and Chalup coefficient set also performs slightly better against the observed mid-depth dissolved oxygen data, but the differences between the two computations are generally small (on the order of a few tenths of a mg/L). With the exception of the absolute minima (frequency of occurrence of less than one percent of the computed values) the bottom water concentrations of dissolved oxygen are virtually the same for both coefficient sets.

1.3.2 Sensitivity Run Number 2

As described earlier, the values selected for G_{prd}, W_N, and W_{chl} for the calibration were based on attempting to reproduce the observed medians for key data (chlorophyll-a, POC, DIN, PO_4, and DO) collected during the 1992-1994 HOM surveys. Particular attention was paid to reproducing the summer and annual medians. However, the choice for the value of (F = 0.85) was made on the belief that the Laws and Chalup value (F = 0.22), while appropriate for *Pavlova lutheri*, might not be appropriate in modeling the Massachusetts and Cape Cod Bays system, where species competition and species succession occur. Therefore, another model sensitivity run was made, wherein the values for G_{prd}, W_N, and W_{chl} are as per the calibration and the value of F is as per Laws and Chalup. Temporal comparisons of model versus data are presented for 1992 for the second sensitivity run (F = 0.22) for segments (11,18), the outfall site, and (13,04), eastern Cape Cod Bay, in Figures 1-31 and 1-32, respectively. Compared to the previous sensitivity run (Figures 1-10 and 1-14), the new sensitivity run does not over estimate the chlorophyll-a and compares quite well to the observed data. In fact, the new run appears to compare more favorably than does the calibration (Figures 1-9 and 1-13). A paucity of POC data still makes it difficult to fully evaluate the degree of successful calibration, but the second sensitivity appears to be slightly better than the calibration. However, the second sensitivity run still under estimates the surface DIP during the summer months. These general observations are consistent across the three calibration years (Appendix A).

The second sensitivity run also resulted in model versus data improvements for the C:N ratios (Figure 1-33) relative to the first sensitivity (Figure 1-16), but the calibration (Figure 1-15) still appears to perform better when compared to the observed C:N data. (Similar results are presented in Appendix A for 1993 and 1994.) The second sensitivity run (Figure 1-34) also compares more favorably to observed 1992 surface POC than does the Laws and Chalup coefficient sensitivity (Figure 1-18). It is still unclear, however, whether the second coefficient set performs better than the calibration coefficient set for surface POC. The calibration (Figure 1-17) compares more favorably to the near field data on an annual basis, while the second sensitivity (F = 0.22) compares more favorably to the far field data for 1992. Results are similar for 1993, but for the 1994 HOM POC data, the calibration data set appears to provide a better overall calibration to the observed data (Appendix A).

The second sensitivity coefficient set results in a significant improvement in reproducing the 1992 surface (Figure 1-35) and mid-depth chlorophyll-a data (Figure 1-36) as compared to the Laws and Chalup coefficient set (Figures 1-20 and 1-22). This is the result of picking values for W_{chl} that may be more appropriate for Massachusetts and Cape Cod Bays. While results from the second sensitivity run are an improvement relative to the Laws and Chalup sensitivity run, the original calibration set (Figures 1-19 and 1-21) still provides a more favorable comparison to the observed field data for 1992. The

original calibration coefficient set also seems to provide a better calibration for the 1994 data, while the second sensitivity appears to perform slightly better for the 1993 calibration year (Appendix A).

The second sensitivity run also results in some improvements to reproducing the observed surface concentrations of DIN (Figure 1-37) and PO_4 (Figure 1-38) as compared to the Laws and Chalup coefficient set (Figures 1-28 and 1-30), but the original calibration still is better for the near field DIN (Figure 1-28 and Appendix A for 1993 and 1994) and for both the near field and far field PO_4 (Figure 1-30 and Appendix A for 1993 and 1994).

1.3.3 Sensitivity Run Number 3

The final sensitivity run performed represented a compromise between the calibration value for F of 0.85 and the Laws and Chalup reported value of 0.22. The value chosen, 0.35, still permits the chlorophyll to carbon ratio to increase as a function of normalized growth rate (Figure 1-7) as reported by Laws and Chalup for *Pavlova lutheri.* The remaining model coefficients, G_{pre}, W_N, and W_{chl}, were as per the calibration run.

Time-series plots for the third sensitivity run present model versus data comparisons for 1992 for model segment (11,18) (Figure 1-39) and (13,04) (Figure 1-40). Compared to the original calibration results (Figures 1-9 and 1-13), the third sensitivity run appears to provide roughly equivalent calibration to the observed chlorophyll-a data for both model segments. The sensitivity run also seems to compare more favorably to the observed POC for the Cape Cod segment (13,04). The lack of POC data, however, make it difficult to make a definitive statement as to which of the values chosen for F provides the better model calibration. With respect to the C:N ratios, the calibration (Figure 1-15) still compares more favorably to the observed spring and summer ratios, as compared to the third sensitivity (Figure 1-41). The calibration also reproduces the observed median C:N ratio on an annual basis. However, the sensitivity run appears to better represent the observed distribution of the near field C:N data, although it generally over estimates the actual ratios. Neither value of F can be said to provide the better calibration to the observed annual distribution of the far field C:N data. In general, similar results were also obtained for 1993 and 1994 (Appendix A), although the calibration coefficient set appears to provide a better overall calibration to the 1994 C:N ratio data.

The calibration run also seems to provide for a slightly better comparison to the observed near field POC data for the spring, summer, and annual averaging periods (Figure 1-17) than does the third sensitivity run (Figure 1-42), but the differences are not all that significant. Considering the far field data, the sensitivity run appears to compare more favorably to the observed annual distribution for 1992 than does the calibration. The calibration value chosen for F appears to provide a better calibration to

the 1992 surface chlorophyll-a data for the near field winter period and on an annual basis for the near field and far field data (Figure 1-19), while the value chosen for the third sensitivity run (F = 0.35) compares more favorably during the summer period (Figure 1-43). On an annual basis, the calibration coefficient set compares slightly more favorably to the observed 1993 near field POC data, while the F=0.35 coefficient set compares slightly more favorably to the far field data (Appendix A). However, for 1994 the calibration coefficient set provides a better comparison to the near field and far field surface POC data (Appendix A).

On a whole, the sensitivity run is biased slightly low with respect to the annual distributions of surface chlorophyll-a relative to the calibration (Figure 1-20). For the summer averaging period, model computations from the third sensitivity run compare favorably to the observed medians, while the calibration coefficient set compares favorably to the observed maxima (Appendix A). This is also observed when comparing model versus data on an annual basis. Both values of F provide a reasonable calibration to the observed mid-depth chlorophyll-a data (Figure 1-21 versus Figure 1-44 and Appendix A). Differences between the computed C:Chl-a ratios for two model values for F are relatively small, although the third sensitivity run value (F=0.35) does better in capturing the range in C:Chl-a ratios observed in the data (Appendix A). Both appear to compare reasonably well to the observed data (Appendix A).

Evaluating model performance for DIN suggests that the third sensitivity run compares slightly better to the observed summer 1992 surface DIN data (Figure 1-45) than does the calibration run (Figure 1-27). On an annual basis, however, the calibration run compares slightly more favorably to the observed near field DIN, particularly at low concentrations of DIN. There are no significant differences between the two runs on an annual basis for the far-field data. The calibration coefficient set also far field data The calibration coefficient set also provides a more favorable calibration to the observed data for 1993, but the third sensitivity run appears to be slightly better for 1994 (Appendix A). Again the biggest difference between model computations for the two model coefficients can be observed for PO_4. In general, the calibration (Figure 1-29) compares more positively to the observed surface PO_4 than does the sensitivity run (Figure 1-46). This is particularly true for the summer averaging period, wherein the sensitivity run predicts that PO_4 concentrations are approaching nutrient limiting conditions for algal growth (PO_4 concentrations less than 0.004 mg P/L) almost all of the time, which is not indicated by the observed data. The calibration predicts potentially limiting concentrations of PO_4 approximately 5-6 percent of the time, which is consistent with the observed data. Similar results were also computed and observed for 1993 and 1994 (Appendix A). In general, the calibration coefficient set is much better when comparing against summer surface PO_4 data, which show little (1993) or no (1994) limiting levels of PO_4. However, the third sensitivity run performs better in the spring when some limiting concentrations of PO_4 are observed.

The sensitivity run compares more favorably to the surface dissolved oxygen data for the summer averaging period than does the calibration (Appendix A). This is particularly evident in 1993 as compared to 1994. Differences in mid-depth dissolved oxygen computed by the two runs are not that significant on an annual basis, but the third sensitivity run does compare more favorably for the summer averaging period (Appendix A). There are virtually no differences between the bottom water dissolved oxygen concentrations computed by the two model runs (Appendix A).

1.4 SUMMARY

Calibration of complex water quality models, and in particular models of eutrophication, is a challenging task. In part, this is a function of (1) a lack of detailed scientific knowledge (2) concerning algal physiology for specific algal species, and modeling limitations, which require the parameterization of a multitude of phytoplankton species (each with different temperature, light, and nutrient requirements and desirability as food for prey) into a few functional groups, and (3) the parameterization of complex zooplankton grazing dynamics and bacterial-driven nutrient recycle kinetics into simpler first-order kinetics. Further complicating the calibration process is the limited availability of spatially and temporally complete water quality data sets and the fact that field measurements do not always directly measure key model constituents and that the field data themselves often have associated measurement error. In the case of the BEM modeling studies, the HOM data sets are among the most complete that may be found in marine environments (perhaps only rivaled by those found in Chesapeake Bay). However, even these data sets have some limitations. Perhaps the most important of these are the limited number of measurements of paired POC, PON, and chlorophyll-a. This is an important limitation when attempting to chose model coefficients which properly describe changes in C:Chl-a and C:N ratios as a function of nutrients and light. In addition, information from the literature that could be used to infer the underlying processes affecting algal growth and nutrient recycle and associated process rates are often performed for specific algal species, under monoaxenic conditions and species in a controlled laboratory setting. It is also important to note that many of these algal species are laboratory workhorses and may not be present in the waterbody under investigation and that the experimental conditions chosen may not be representative of the natural system.

The philosophy followed in developing and calibrating the BEM in the early 1990s was:

- to use a consistent set of model coefficients across all calibration years, rather than to vary them in space or time,
- to attempt to minimize model versus data differences equally between all state-variables or water quality constituents, and
- to utilize experience learned from previous estuarine modeling studies in guiding the choice of model coefficients used in the calibration effort.

The BEM that was developed in the early to mid-1990s followed this philosophy and appeared to be able to reproduce the major processes affecting nutrients, primary production, and dissolved oxygen within the Massachusetts Bays system. It is possible, however, that alternative model coefficients might be able to produce reasonably similar calibration results given the available data. This analysis investigated the sensitivity of the BEM to changes in four of the model coefficients affecting primary production and nutrient utilization. The largest model response was to the sensitivity run involving the use of the Laws and Chalup coefficient set. It could be concluded, based on model versus data comparisons for C:N ratios, POC, chlorophyll-a, and PO_4, that the Laws and Chalup coefficient set is not appropriate for the Massachusetts Bays system. However, considering the sensitivity run which involved only changes to F, the quotient of nutrient-limited N:C ratios at relative growth rates of 0 and 1, it is possible that the value proposed by Laws and Chalup (or some intermediate value), together with changes to some other model coefficients, may provide some improvements to model performance relative to the original calibration. The major problem with the use of the Laws and Chalup value (and the intermediate value) is that it under estimates concentrations of surface PO_4 during the summer months. It might be possible to compensate for this model limitation by changing other model coefficients, ex., the mineralization rates for organic phosphorus or the carbon to phosphorus ratio of algal uptake.

1.5 RECOMMENDATIONS

Based on the results of this sensitivity analysis and considering the work that has been performed to date, it is recommended that the original calibration coefficient set continue to be used in applying BEM to additional HOM monitoring data (1998-2002). However, it is also recommended that additional sensitivity analysis be conducted (1) using additional HOM data and (2) modifying other model coefficients (ex., the mineralization rates for organic phosphorus and/or the carbon to phosphorus and carbon to silica ratios for phytoplankton stoichiometry) together with the value chosen for F. This work should be performed as part of the research being conducted by the University of Massachusetts Boston.

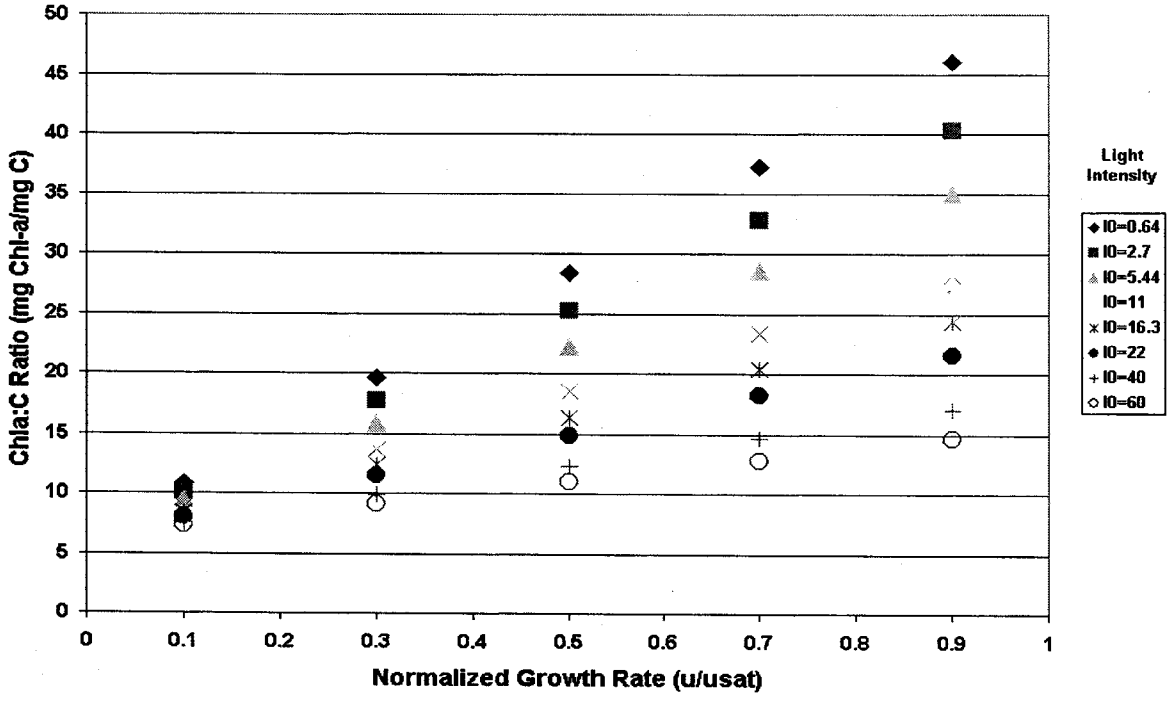


Figure 1-1. Chl-a:C Ratios as a Function of Normalized Growth Rate for F=0.22

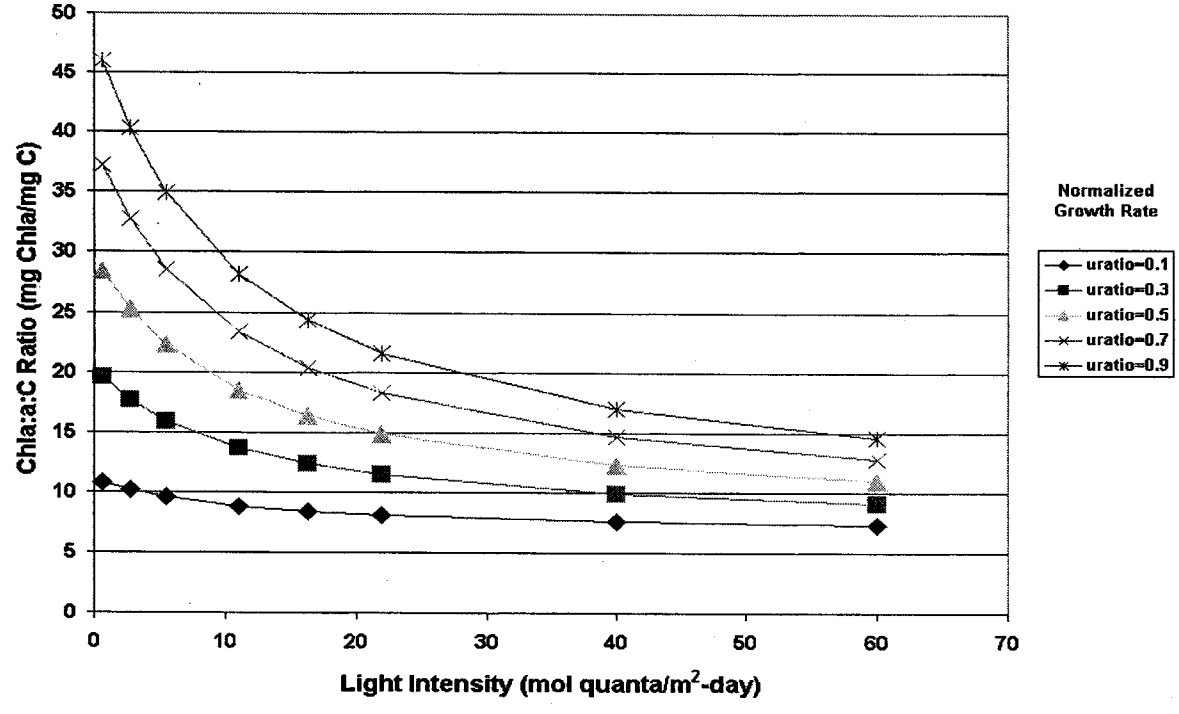


Figure 1-2. Chl-a:C Ratios as a Function of Light Intensity for F=0.22

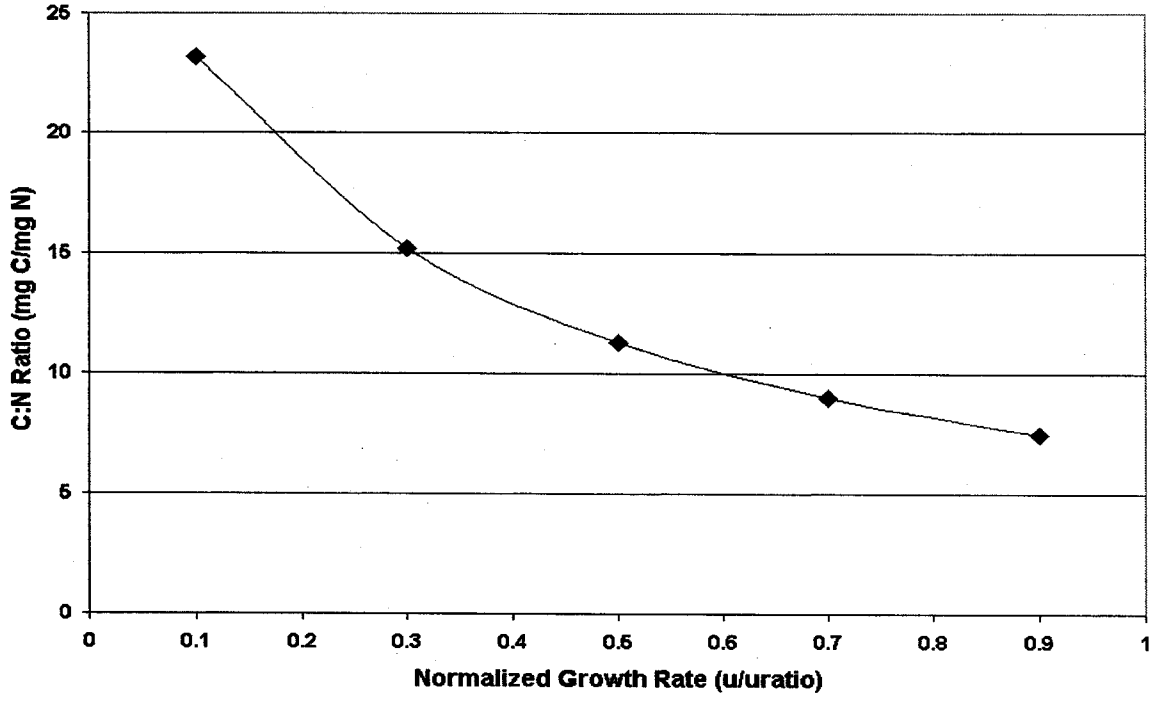


Figure 1-3. C:N Ratio as a Function of Normalized Growth Rate for F=0.22

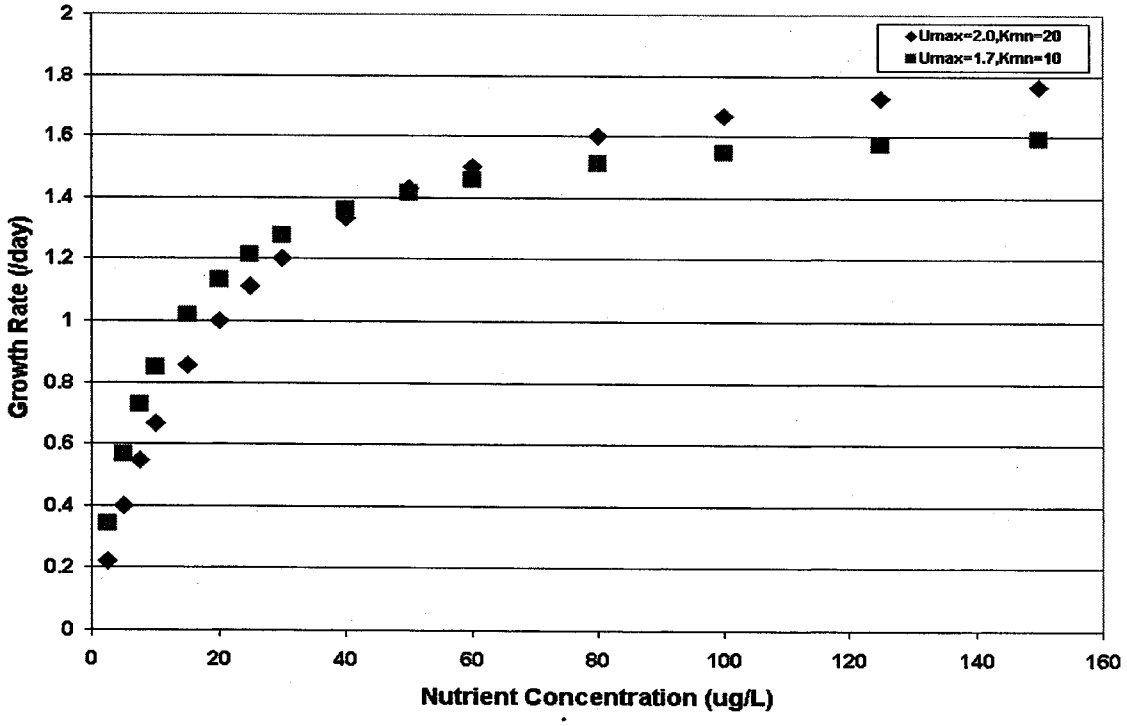


Figure 1-4. Phytoplankton Growth Rates as a Function of Nutrient Concentration for Different Nutrient Saturated Growth Rates and Michaelis Constants

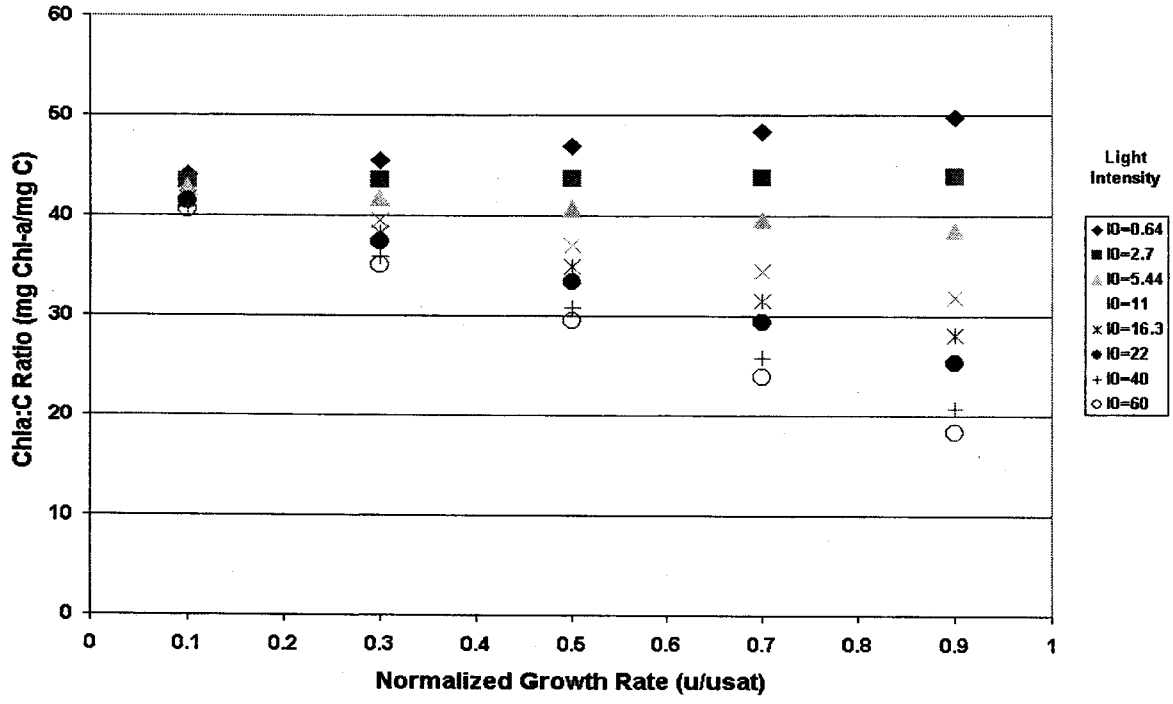


Figure 1-5. Chl-a:C Ratios as a Function of Normalized Growth Rate for F=0.85

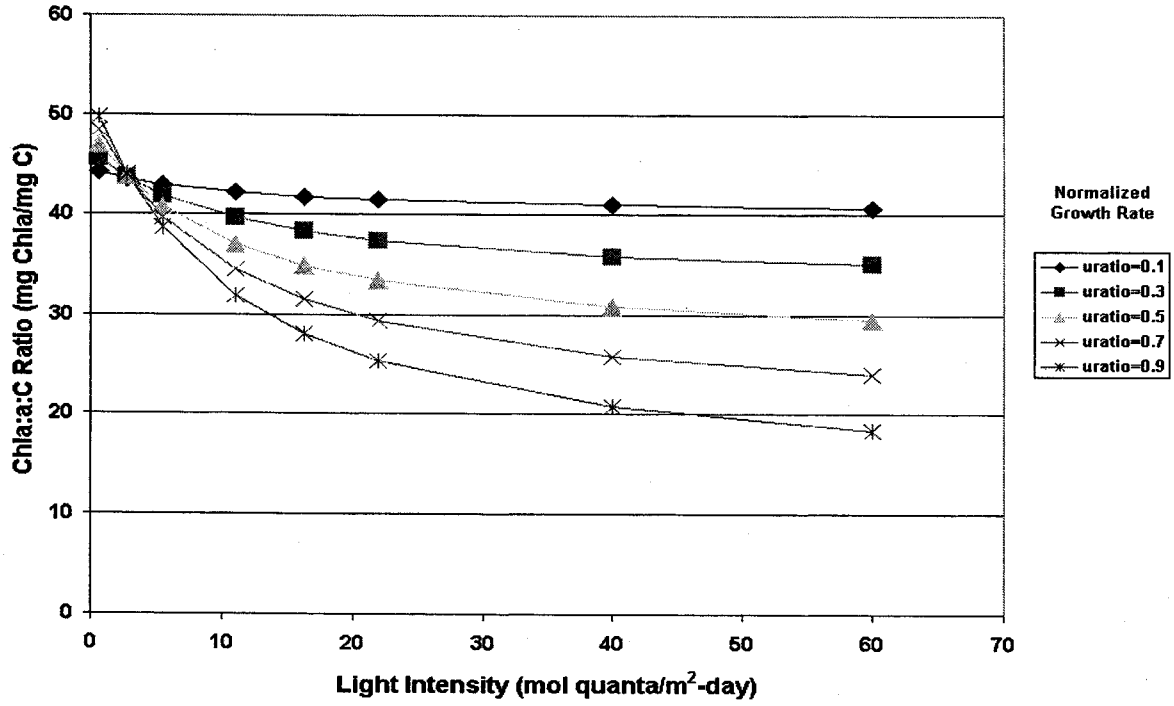


Figure 1-6. Chl-a:C Ratios Versus Light Intensity for F=0.85

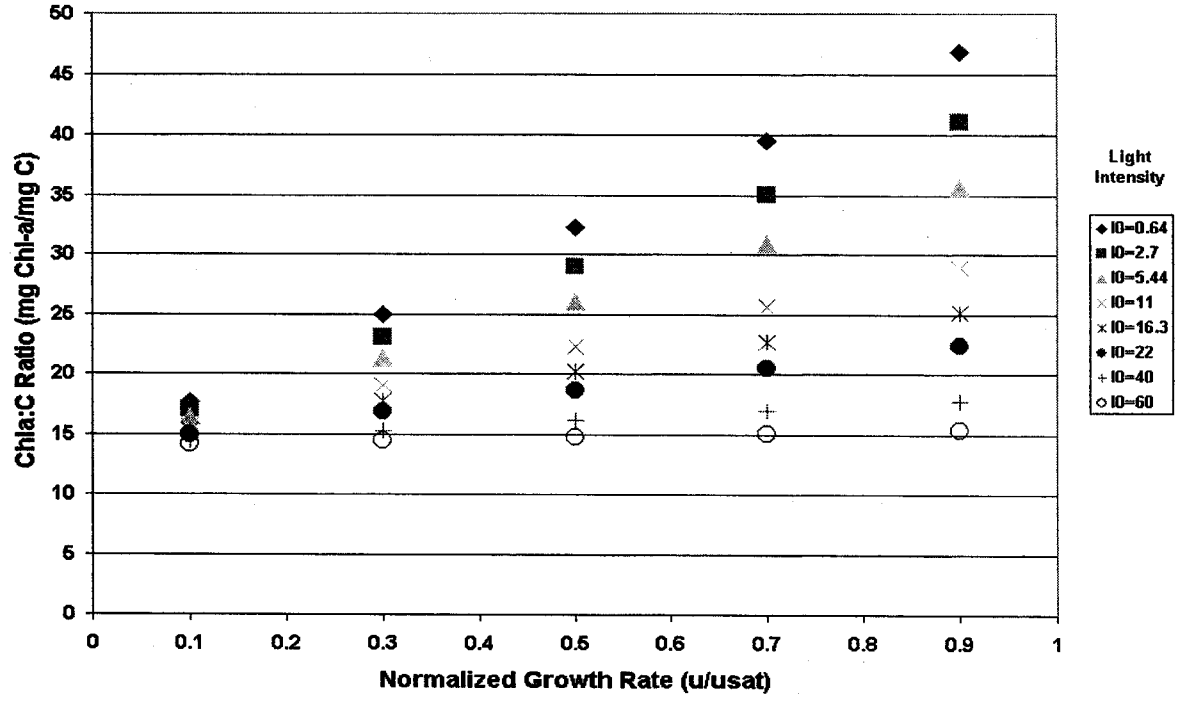


Figure 1-7. Chlorophyll to Carbon Ratios Versus Normalized Growth Rate for F=0.35

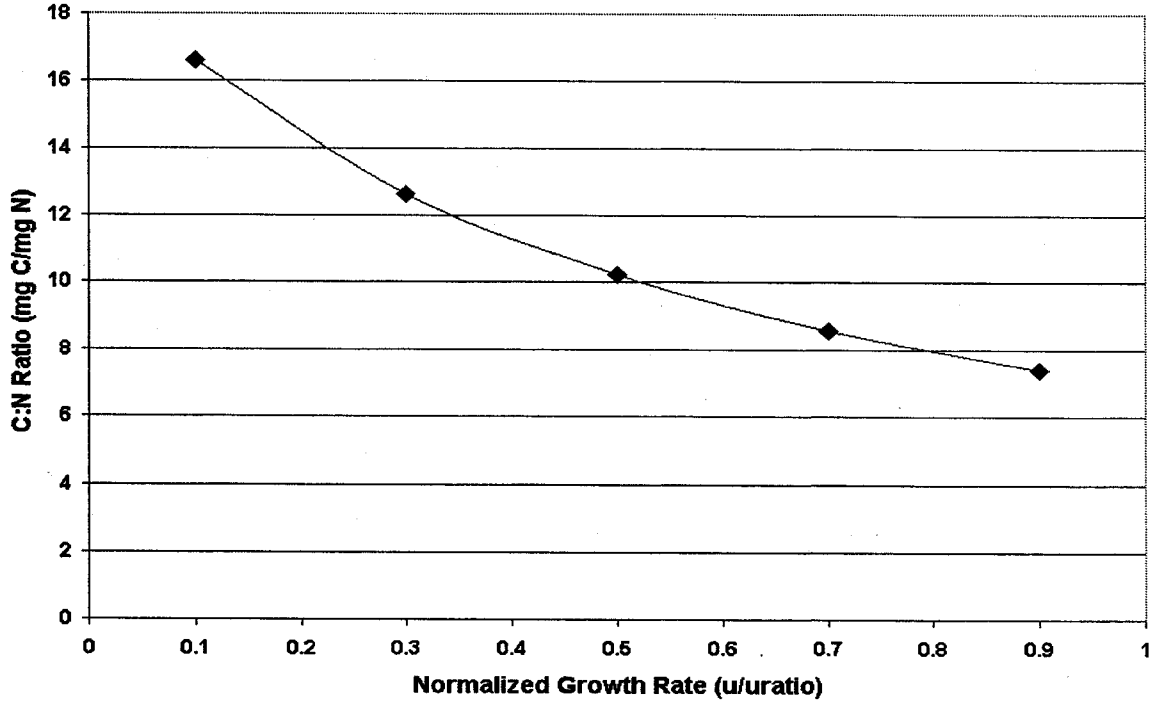


Figure 1-8. Carbon to Nitrogen Ratios Versus Normalized Growth Rate for F=0.35

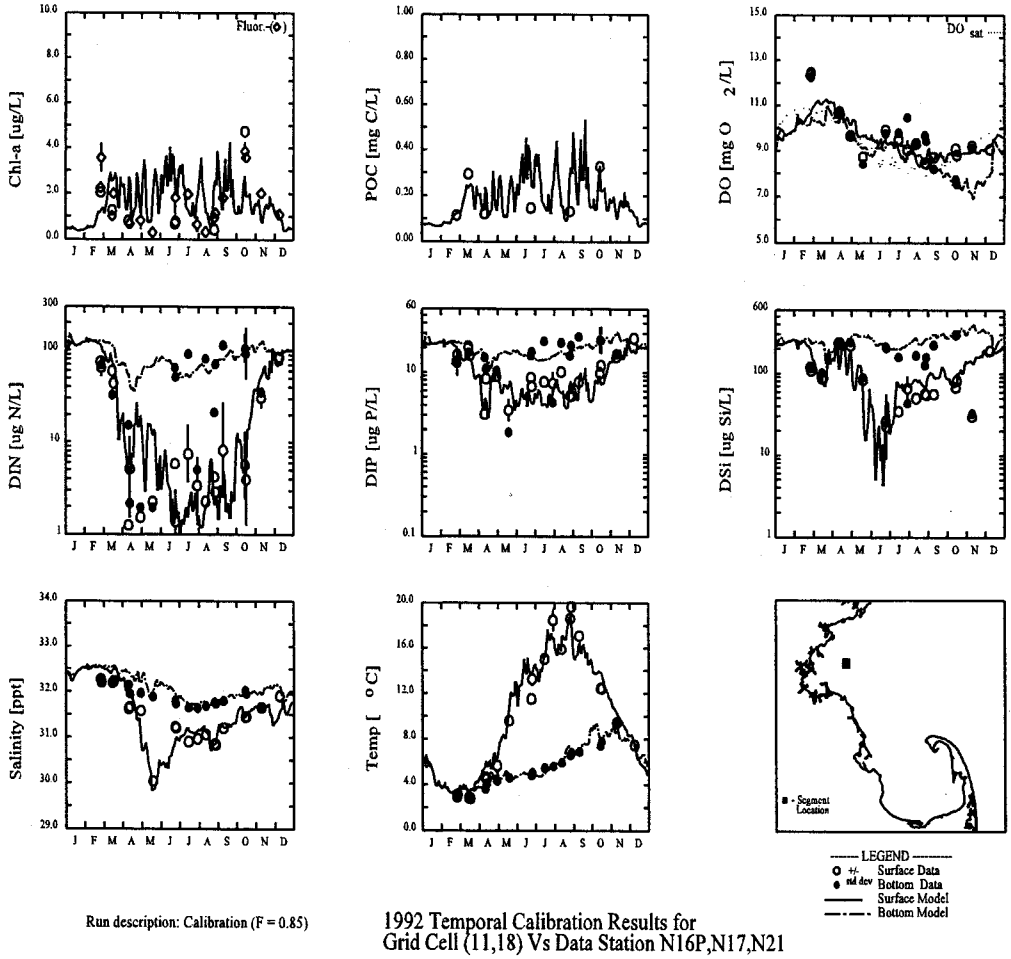


Figure 1-9. 1992 Calibration Results for Model Segment (11, 18) - Time-series Comparisons

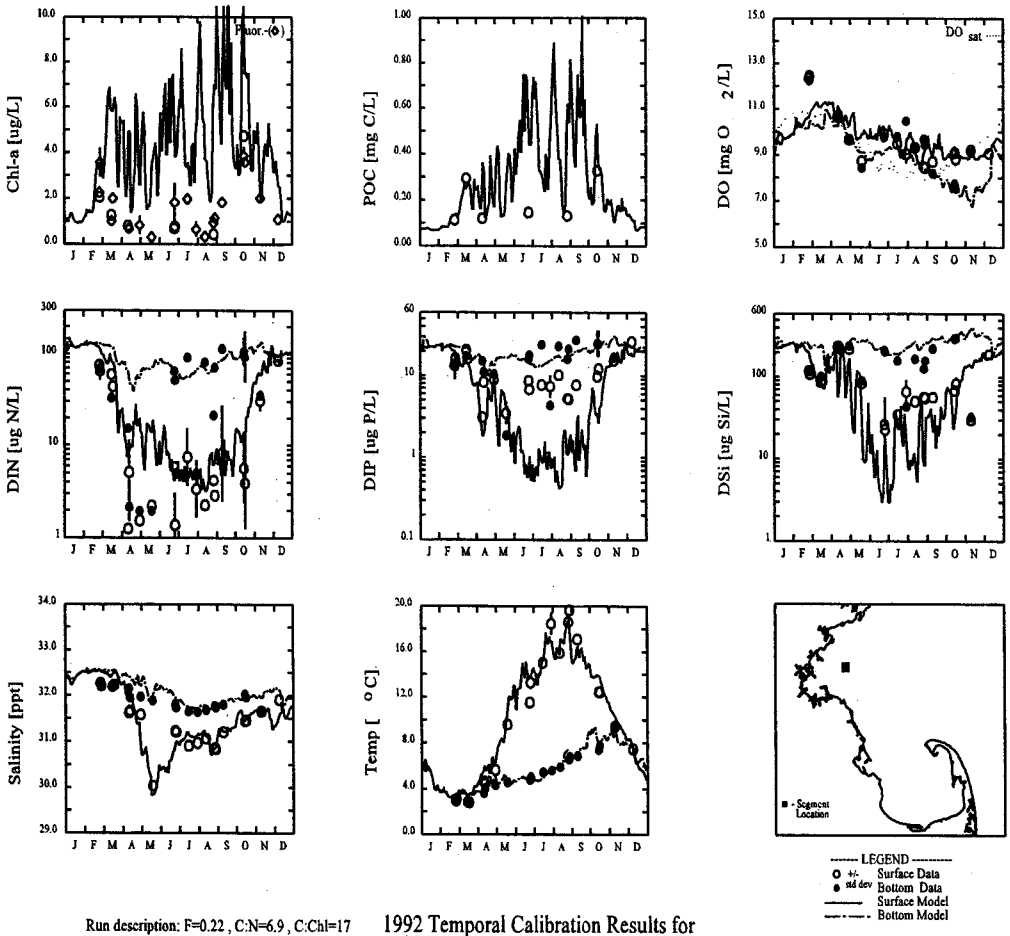


Figure 1-10. 1992 Sensitivity Results for Model Segment (11, 18) Using Full Laws & Chalup Coefficient Set - Time-series Comparisons

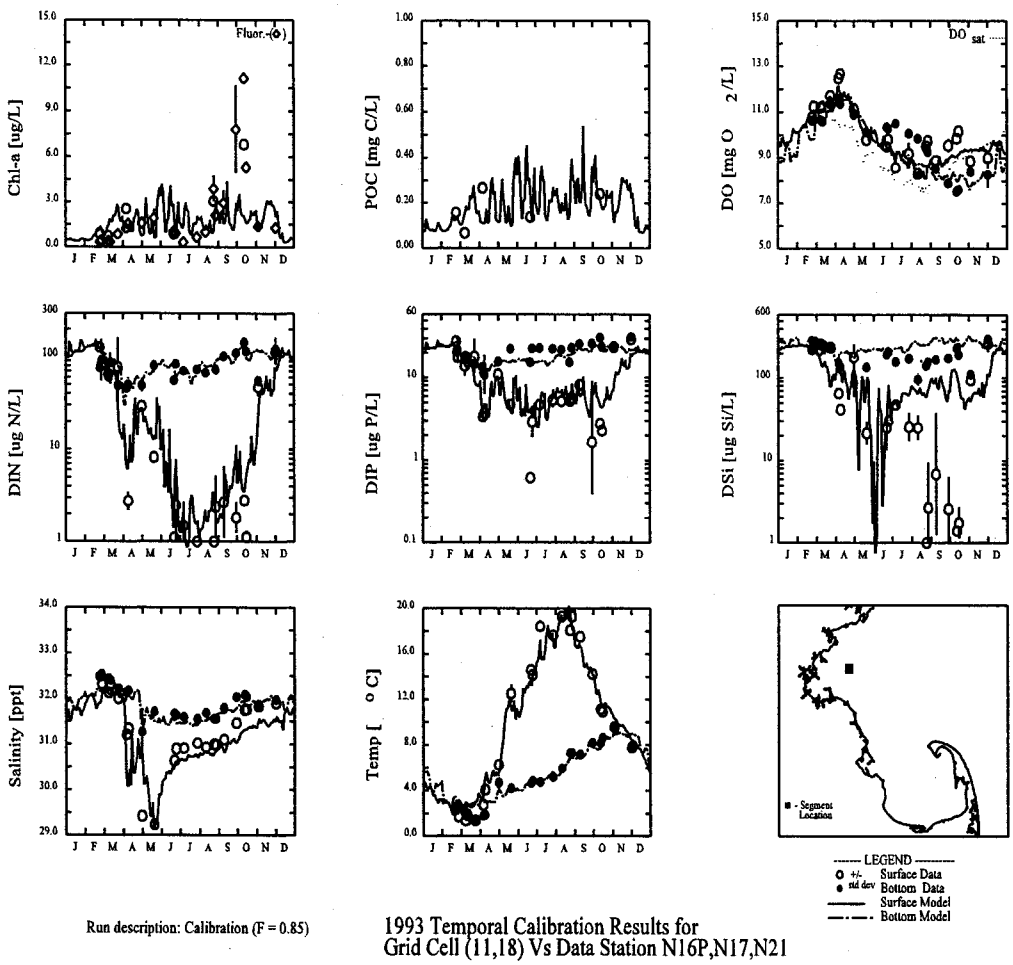


Figure 1-11. 1993 Calibration Results for Model Segment (11, 18) - Time-series Comparisons

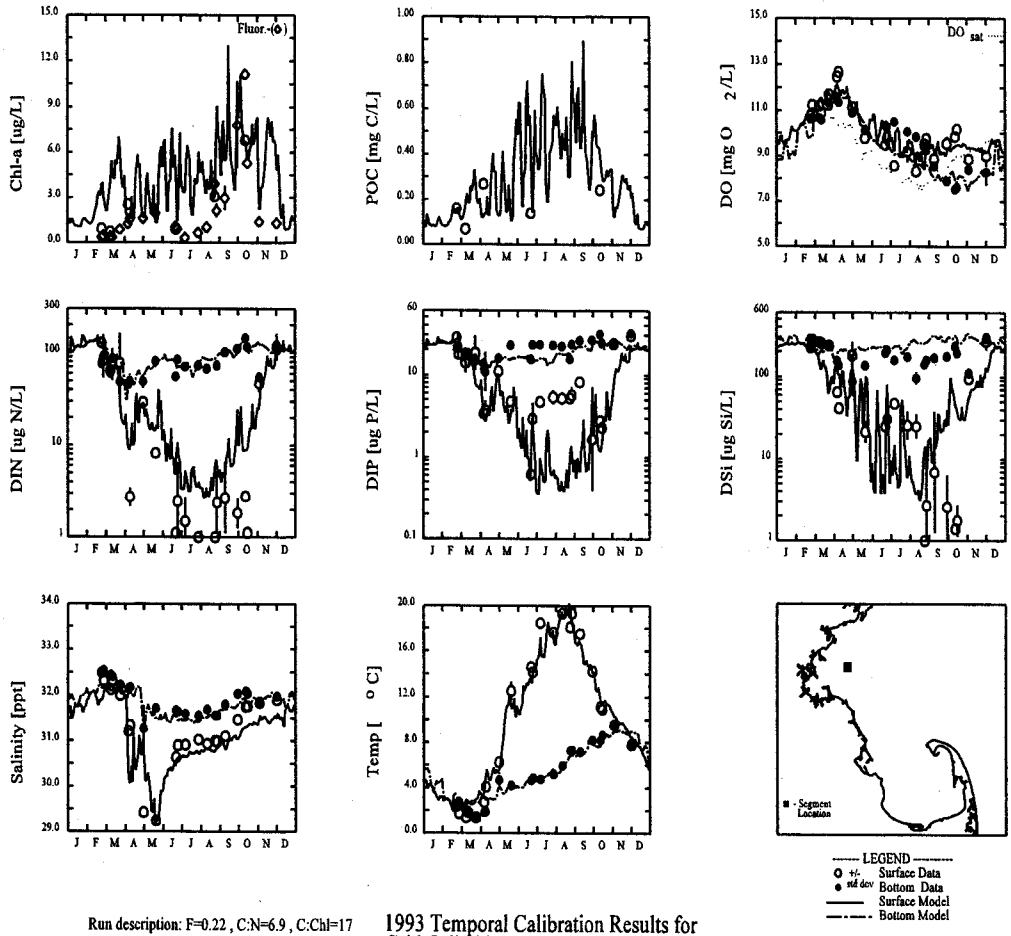


Figure 1-12. 1993 Sensitivity Results for Model Segment (11, 18) Using Full Laws & Chalup Coefficient Set - Time-series Comparisons

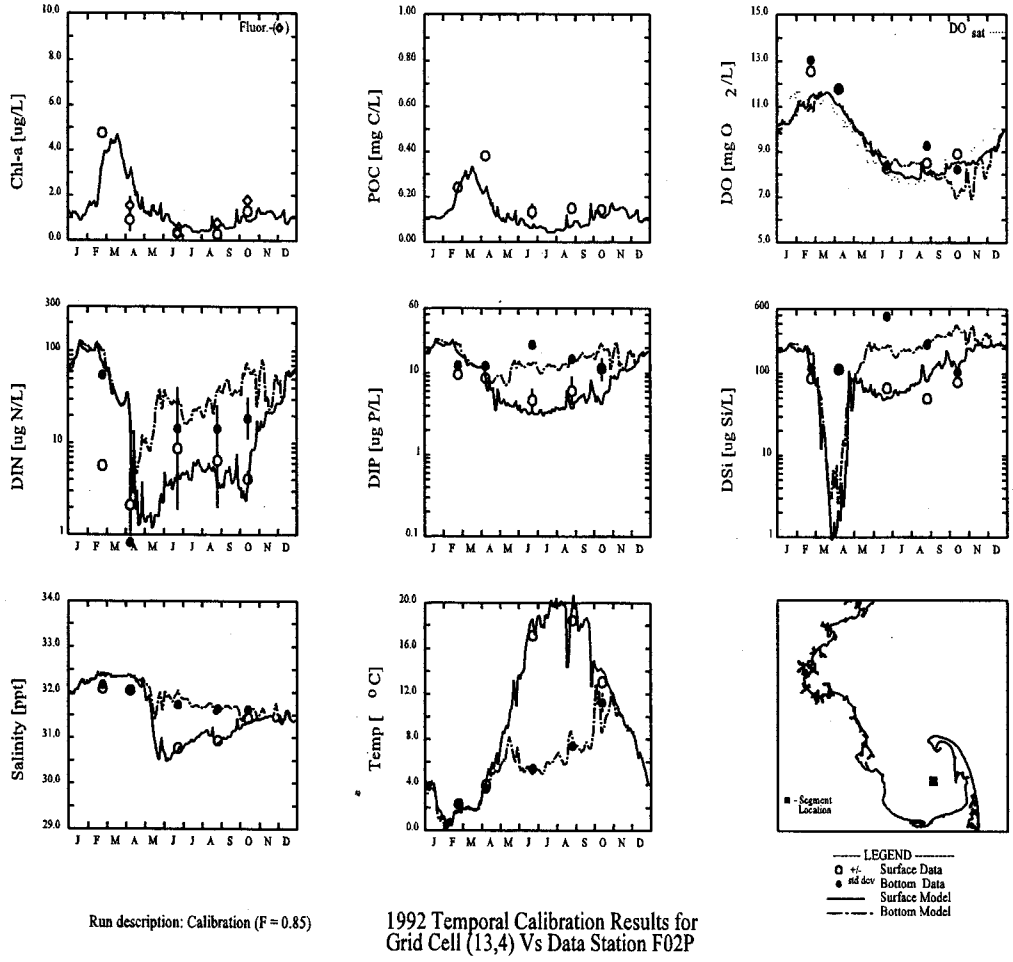


Figure 1-13. 1992 Calibration Results for Model Segment (13, 4) - Time-series Comparisons

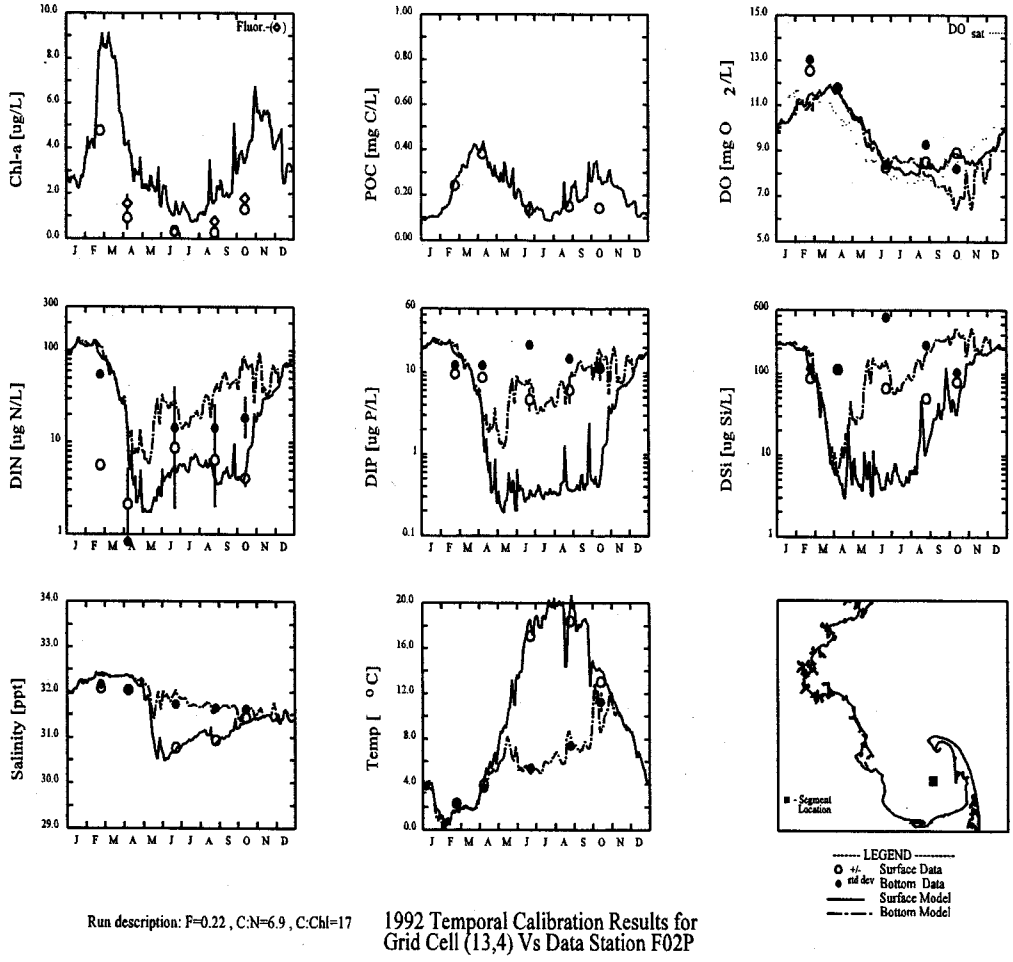


Figure 1-14. 1992 Sensitivity Results for Model Segment (13, 4) Using Full Laws & Chalup Coefficient Set - Time-series Comparisons

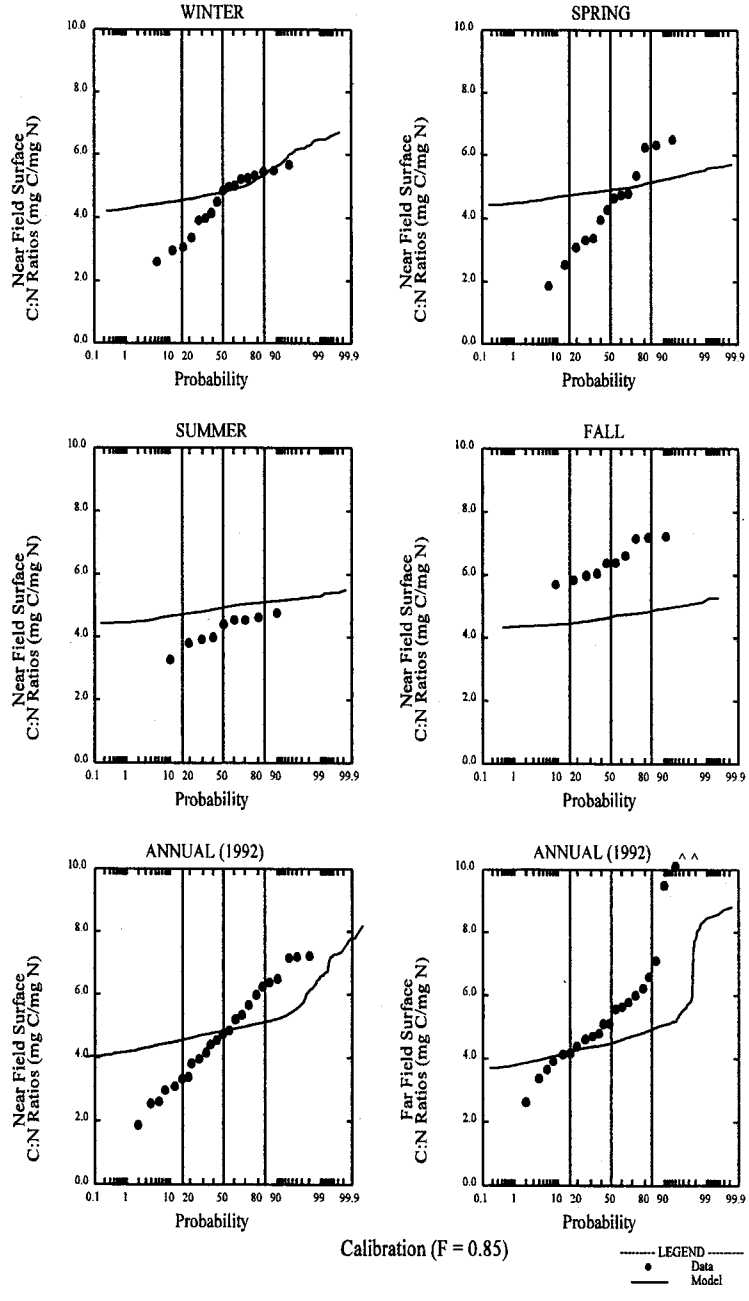


Figure 1-15. 1992 Calibration Results for surface C:N Ratios - Probability Distribution Comparisons

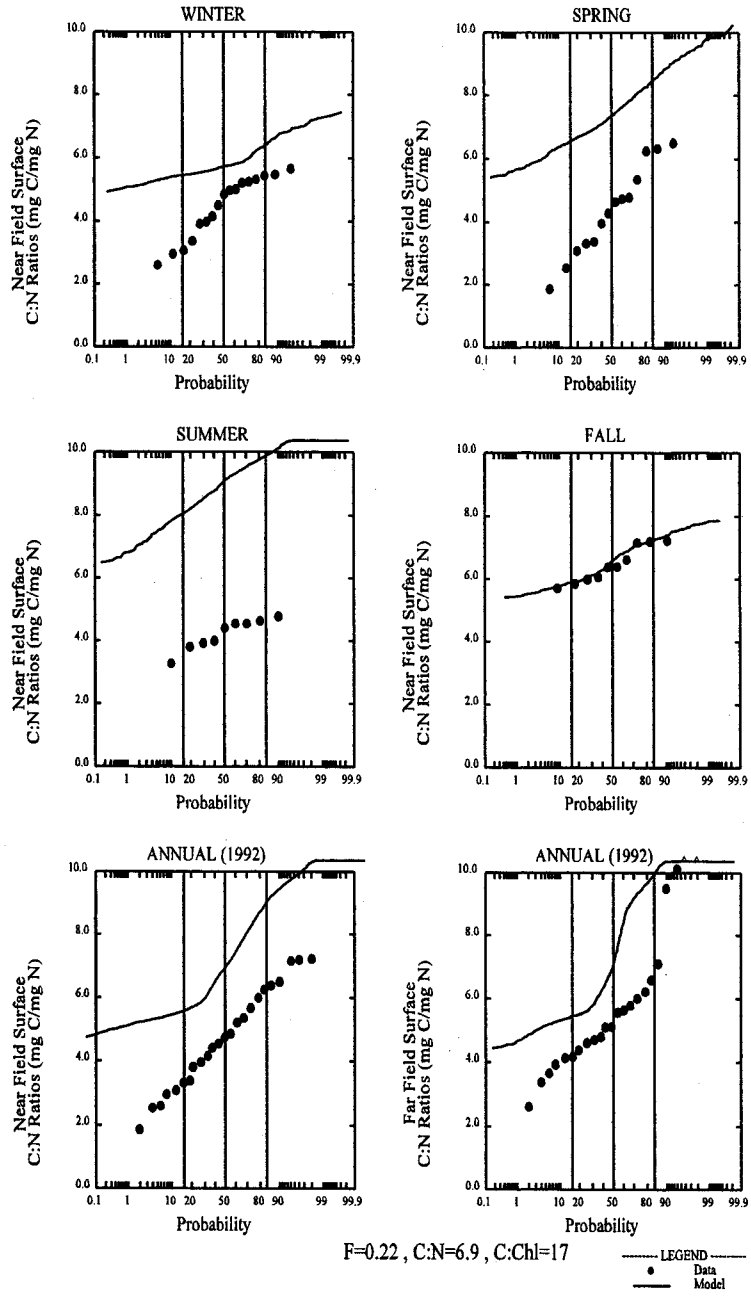


Figure 1-16. 1992 Sensitivity Results for Surface C:N Ratios Using Full Laws & Chalup Coefficient Set - Probability Distribution Comparisons

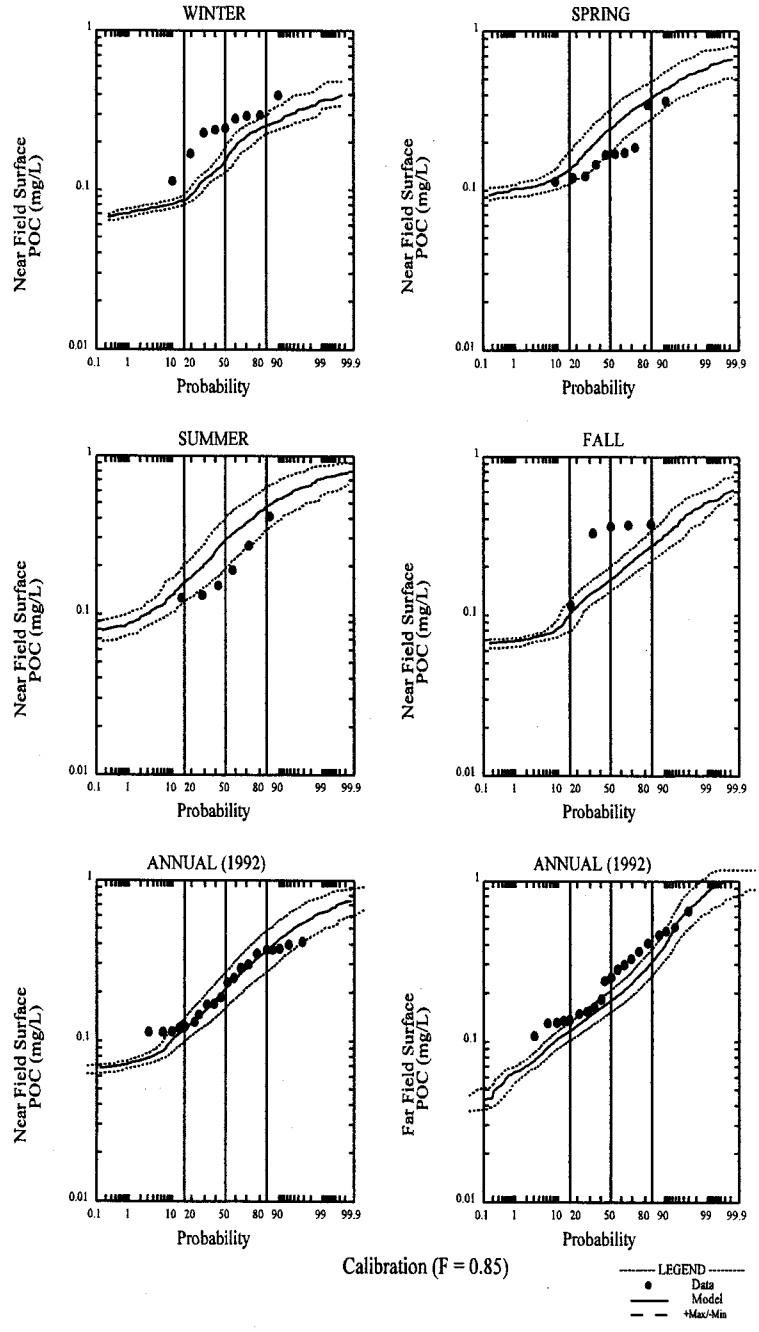


Figure 1-17. 1992 Calibration Results for Surface POC Concentrations - Probability Distribution Comparisons

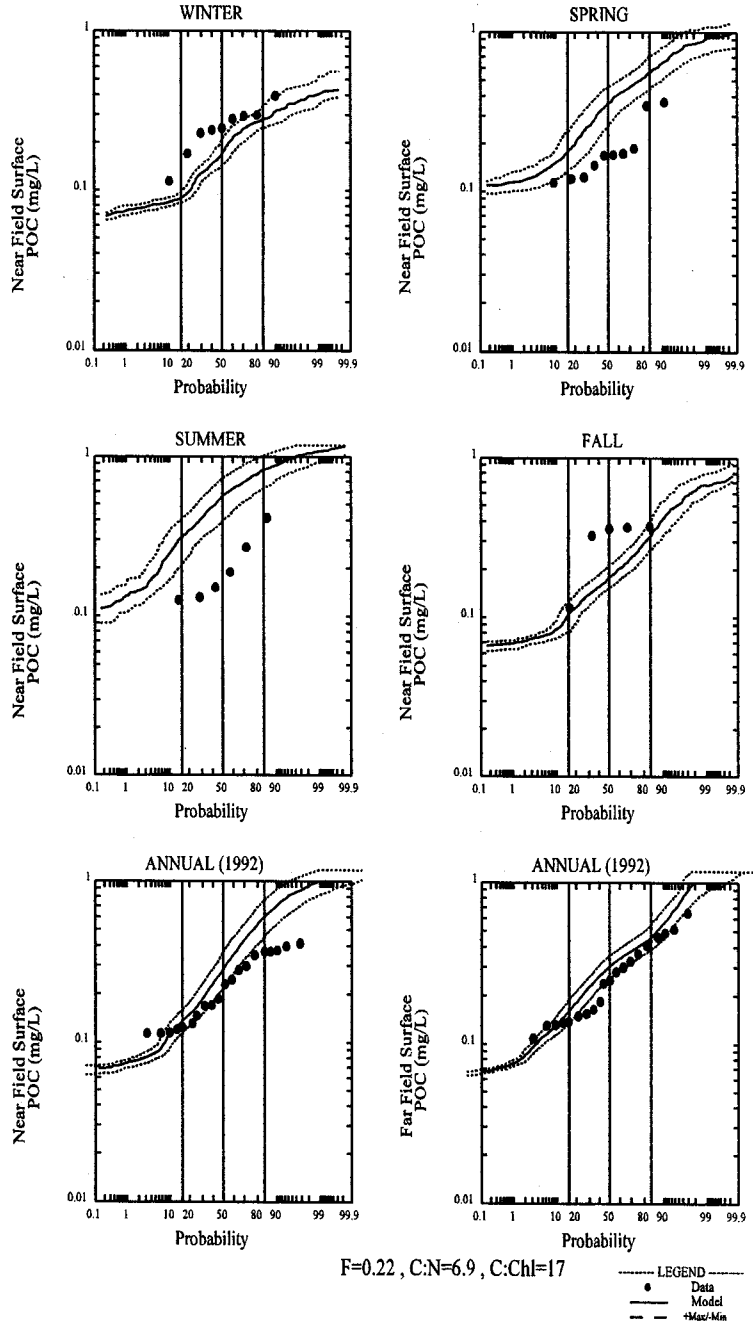


Figure 1-18. 1992 Sensitivity Results for Surface POC Concentrations Using Full Laws & Chalup Coefficient Set - Probability Distribution Comparisons

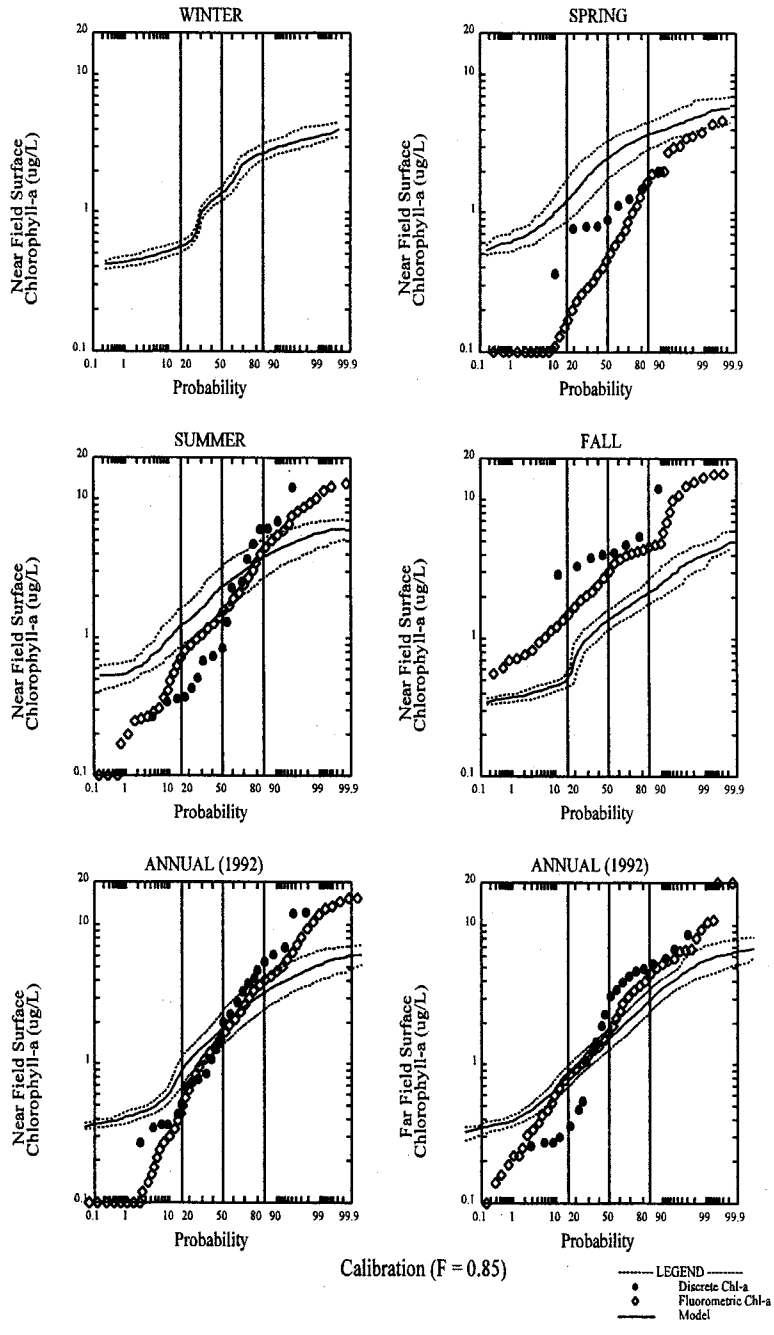


Figure 1-19. 1992 Calibration Results for Surface Chlorophyll-a Concentrations - Probability Distribution Comparisons

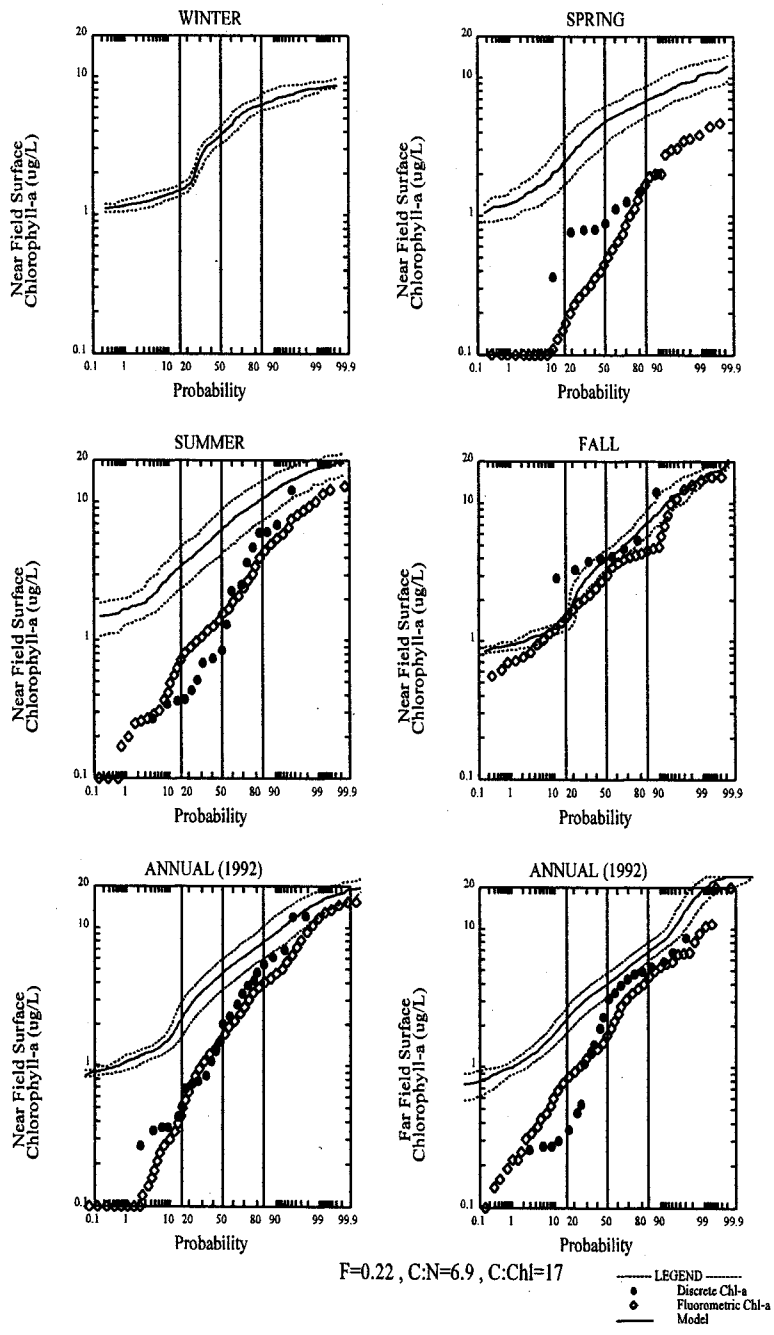


Figure 1-20. 1992 Sensitivity Results for Surface Chlorophyll-a Concentrations Using Full Laws & Chalup Coefficient Set - Probability Distribution Comparisons

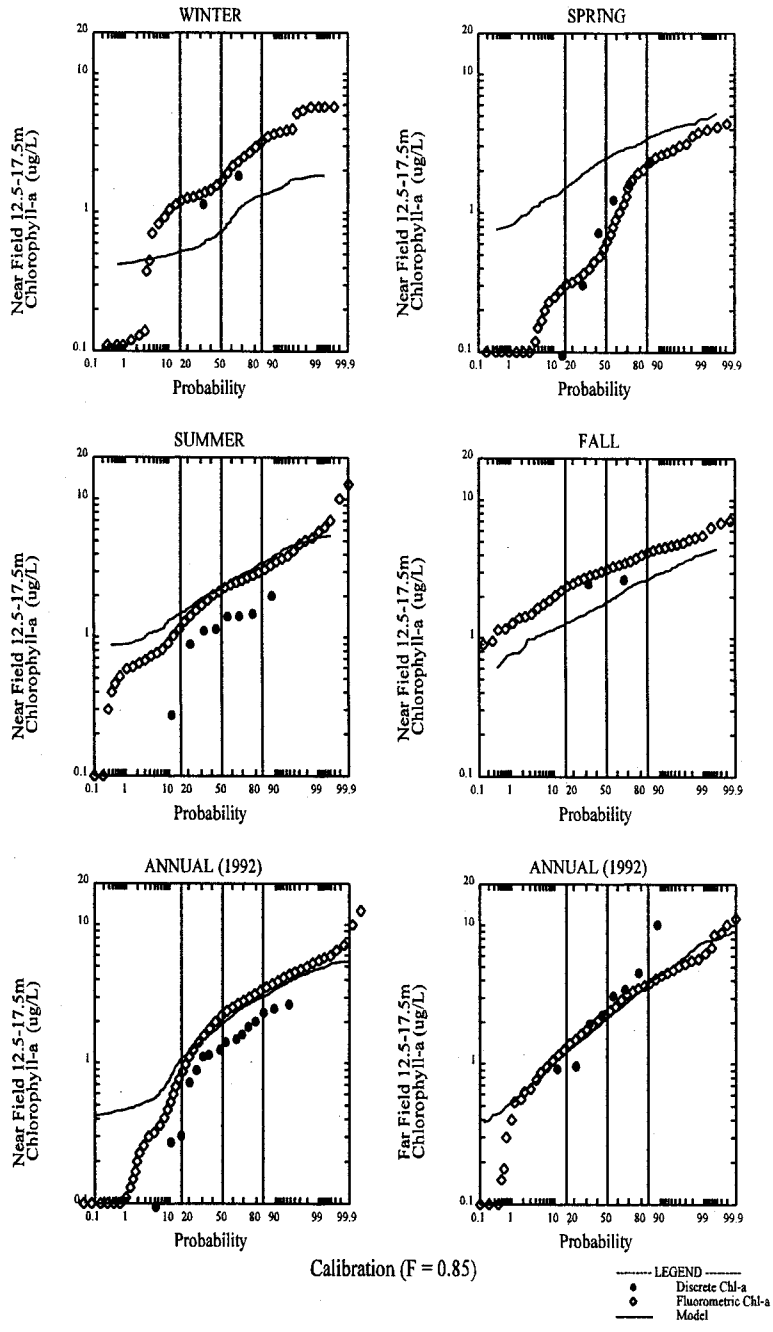


Figure 1-21. 1992 Calibration Results for Mid-depth (12.5-17.5 M) Chlorophyll-a Concentrations - Probability Distribution Comparisons

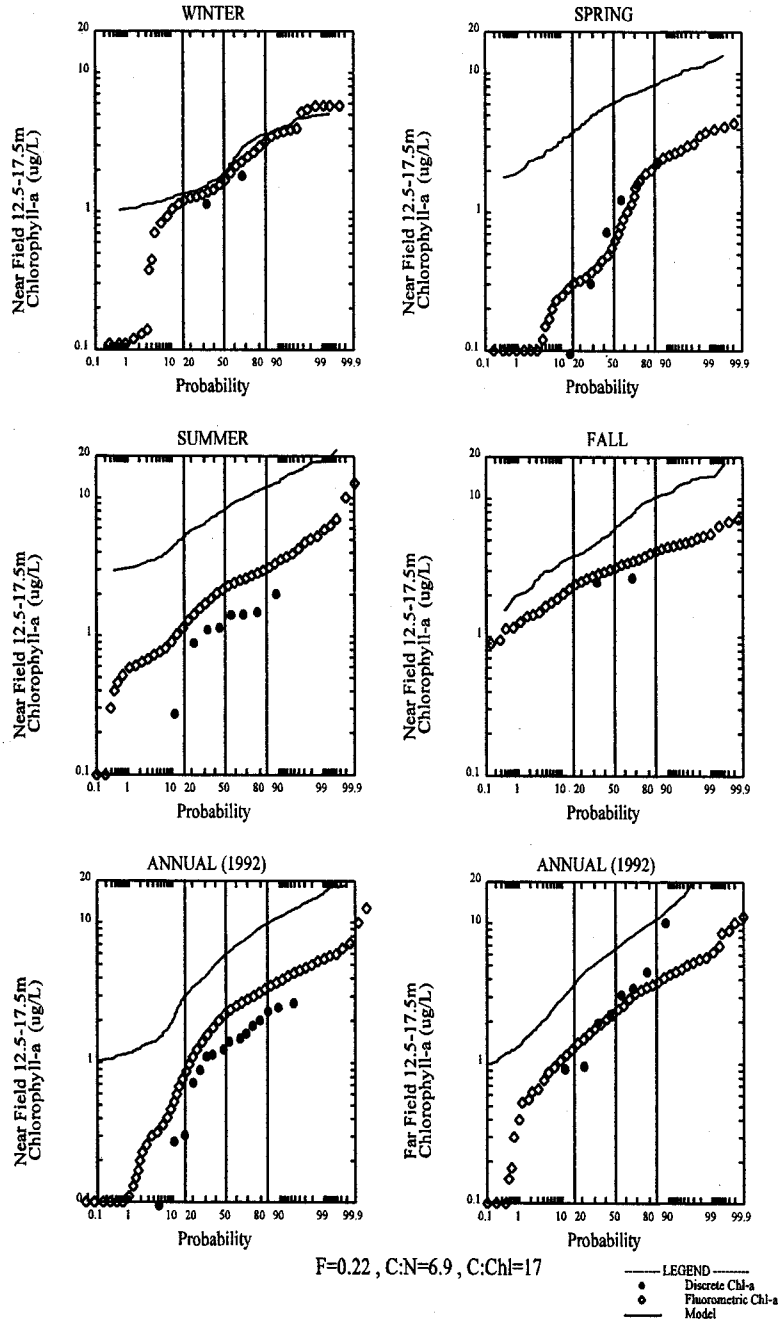


Figure 1-22. 1992 Sensitivity Results for Mid-depth (12.5-17.5 M) Chlorophyll-a Concentrations Using Full Laws & Chalup Coefficient Set - Probability Distribution Comparisons

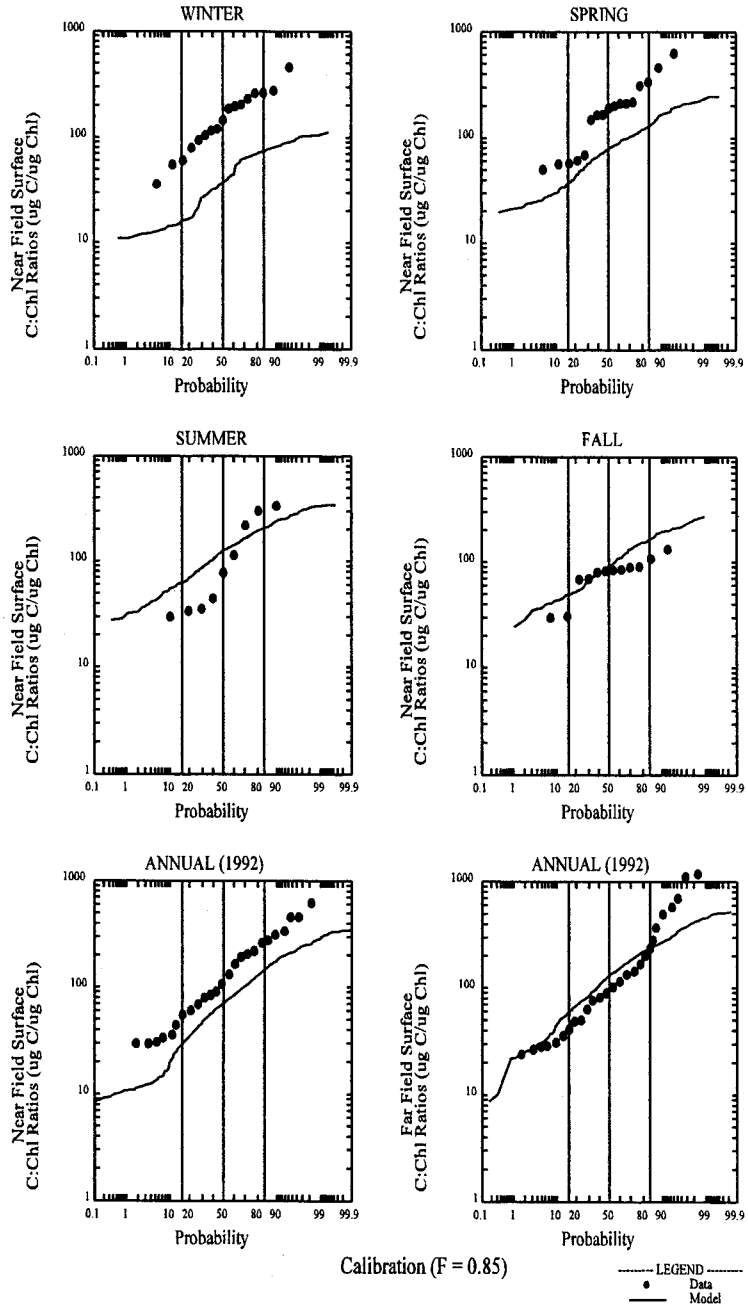


Figure 1-23. 1992 Calibration Results for Surface C:Chl-a Ratios - Probability Distribution Comparisons

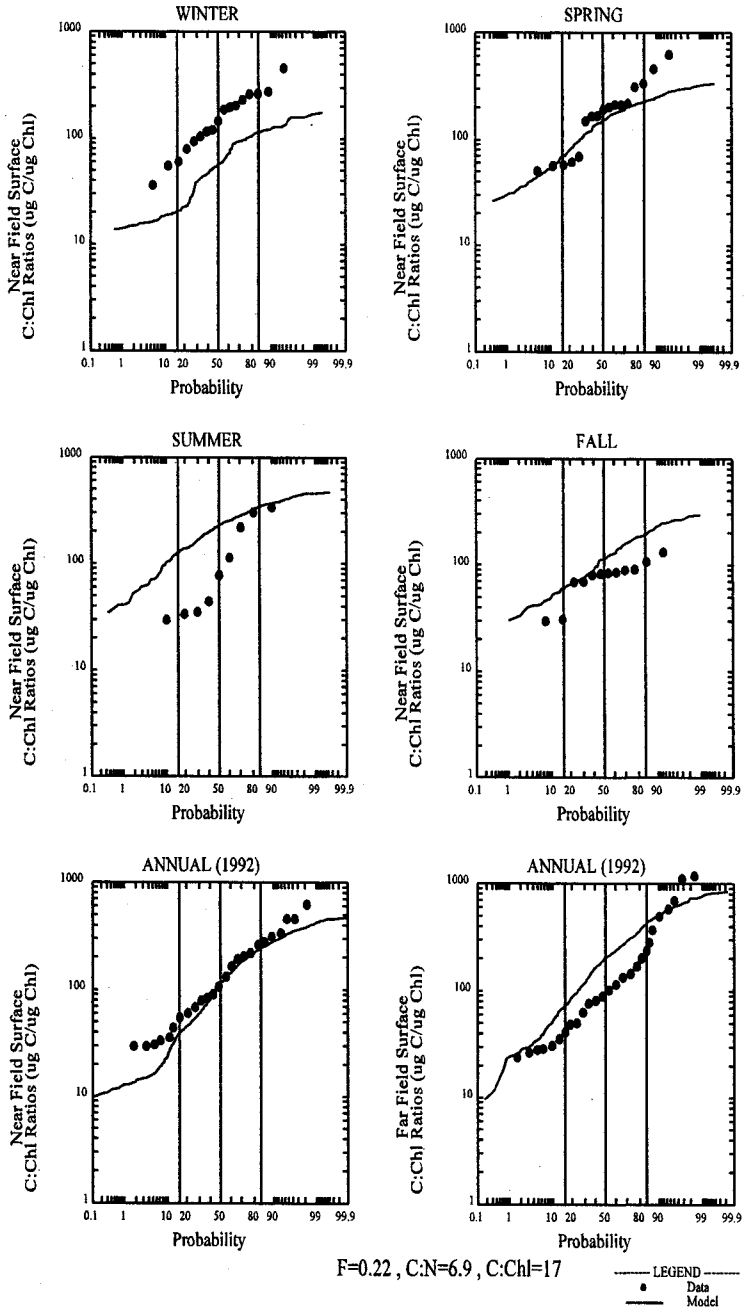


Figure 1-24. 1992 Sensitivity Results for Surface C:Chl-a Ratios Using Full Laws & Chalup Coefficient Set - Probability Distribution Comparisons

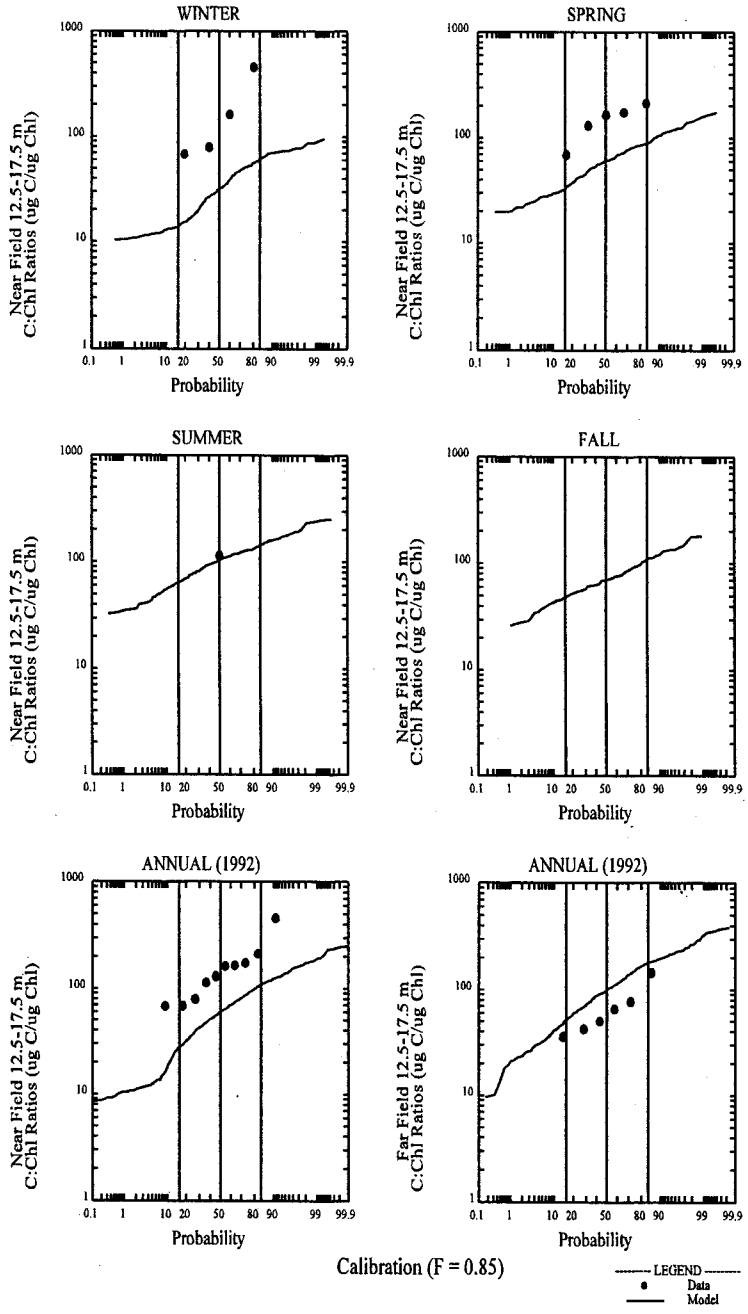


Figure 1-25. 1992 Calibration Results for Mid-depth (12.5-17.5 M) C:Chl-a Ratios - Probability Distribution Comparisons

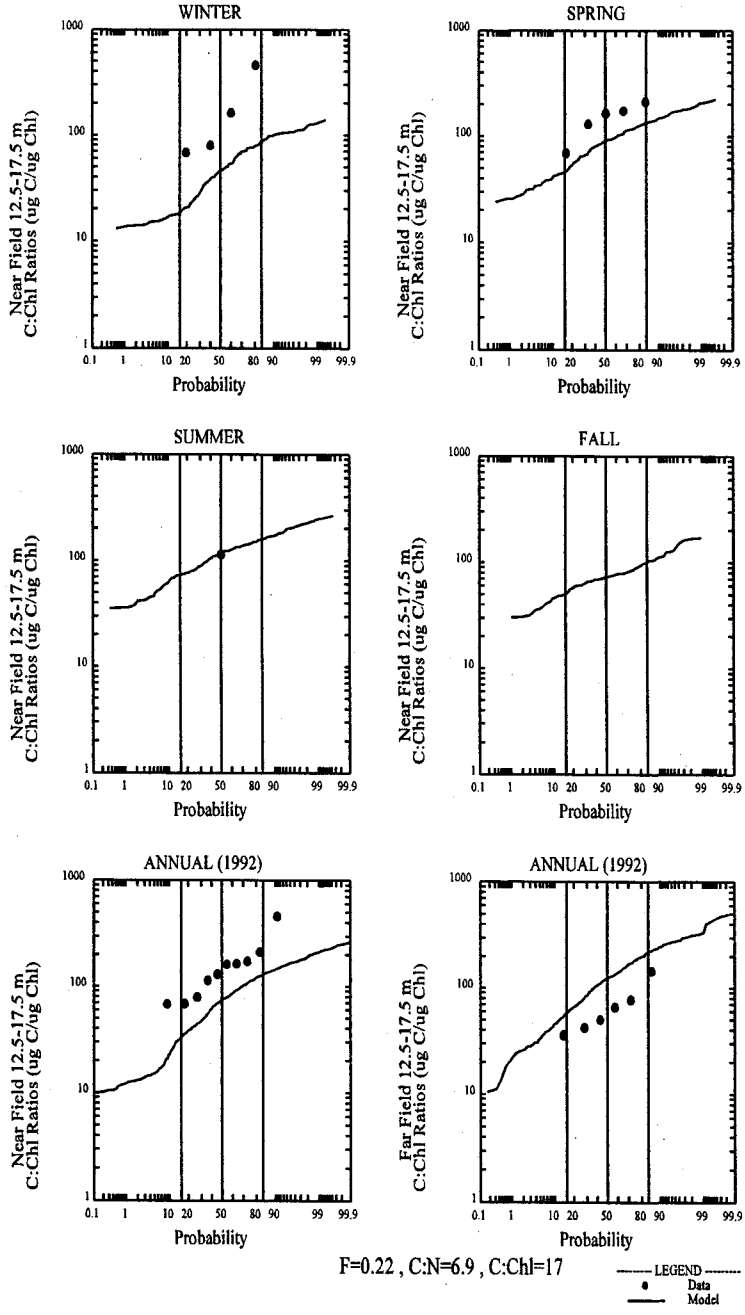


Figure 1-26. 1992 Sensitivity Results for Mid-depth (12.5-17.5 M) C:Chl-a Ratios Using Full Laws & Chalup Coefficient Set - Probability Distribution Comparisons

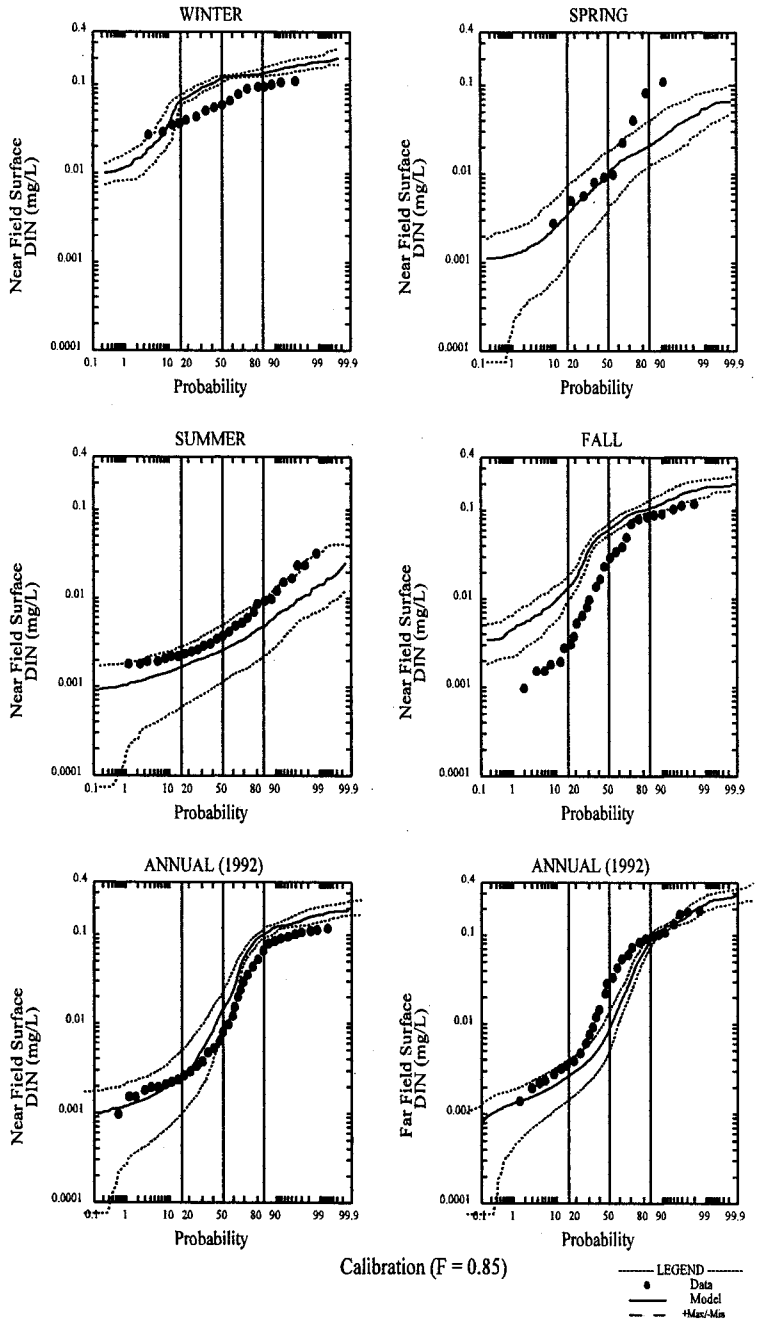


Figure 1-27. 1992 Calibration Results for Surface DIN Concentrations - Probability Distribution Comparisons

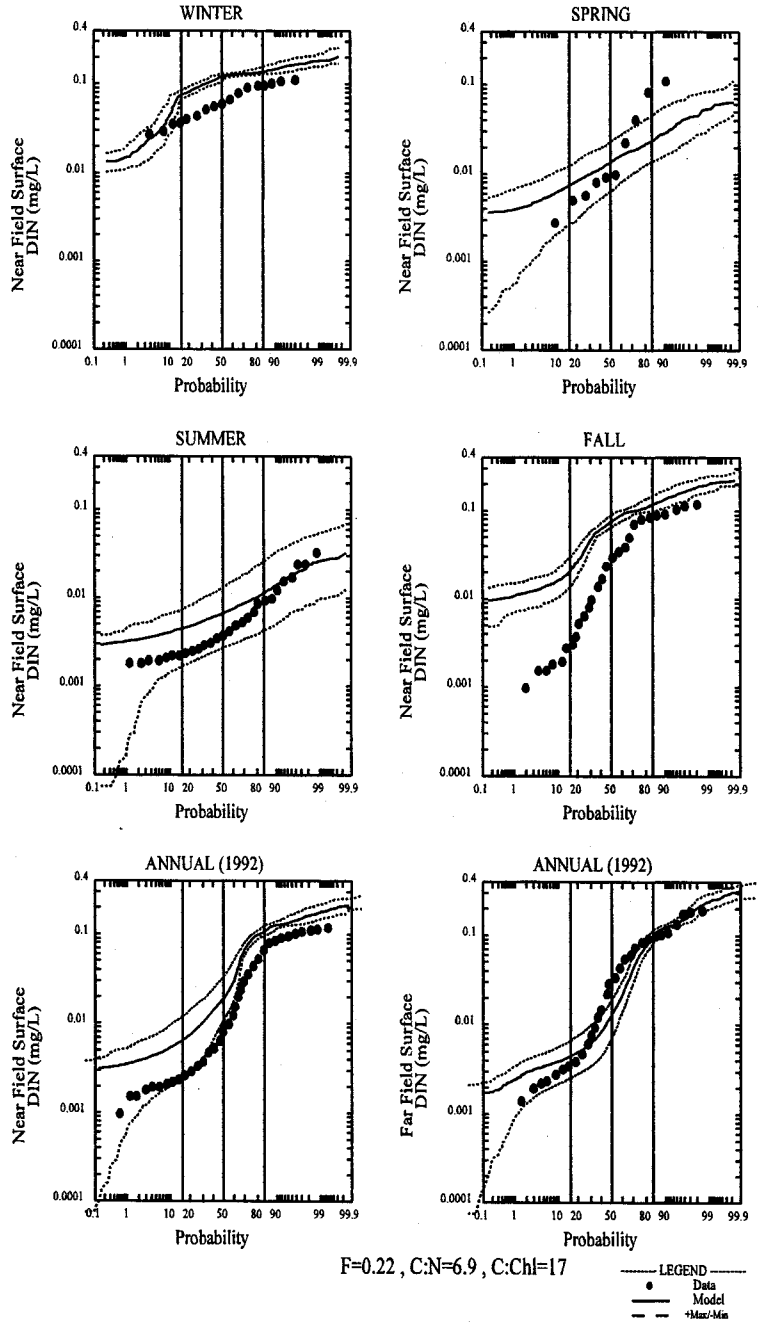


Figure 1-28. 1992 Sensitivity Results for Surface DIN Concentrations Using Full Laws & Chalup Coefficient Set - Probability Distribution Comparisons

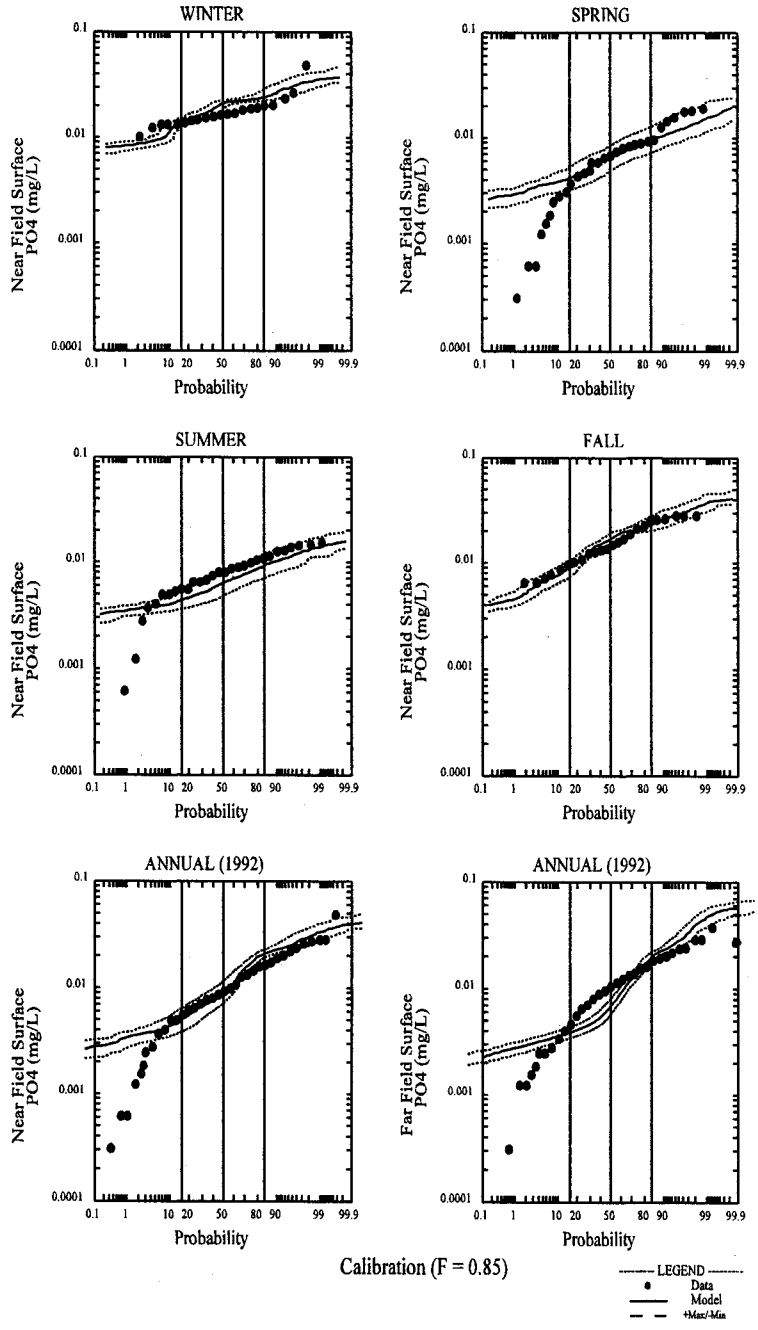


Figure 1-29. 1992 Calibration Results for Surface PO_4 Concentrations - Probability Distribution Comparisons

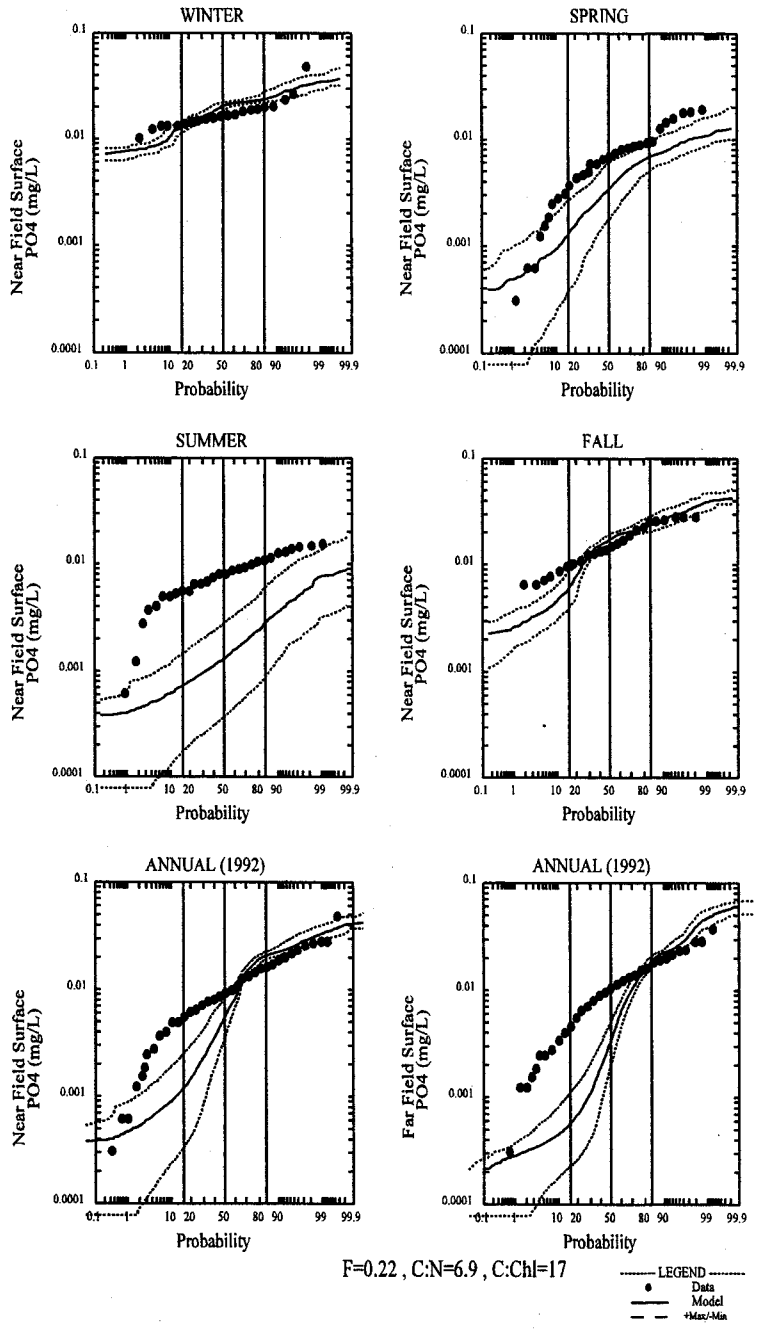


Figure 1-30. 1992 Sensitivity Results for Surface PO_4 Concentrations Using Full Laws & Chalup Coefficient Set - Probability Distribution Comparisons

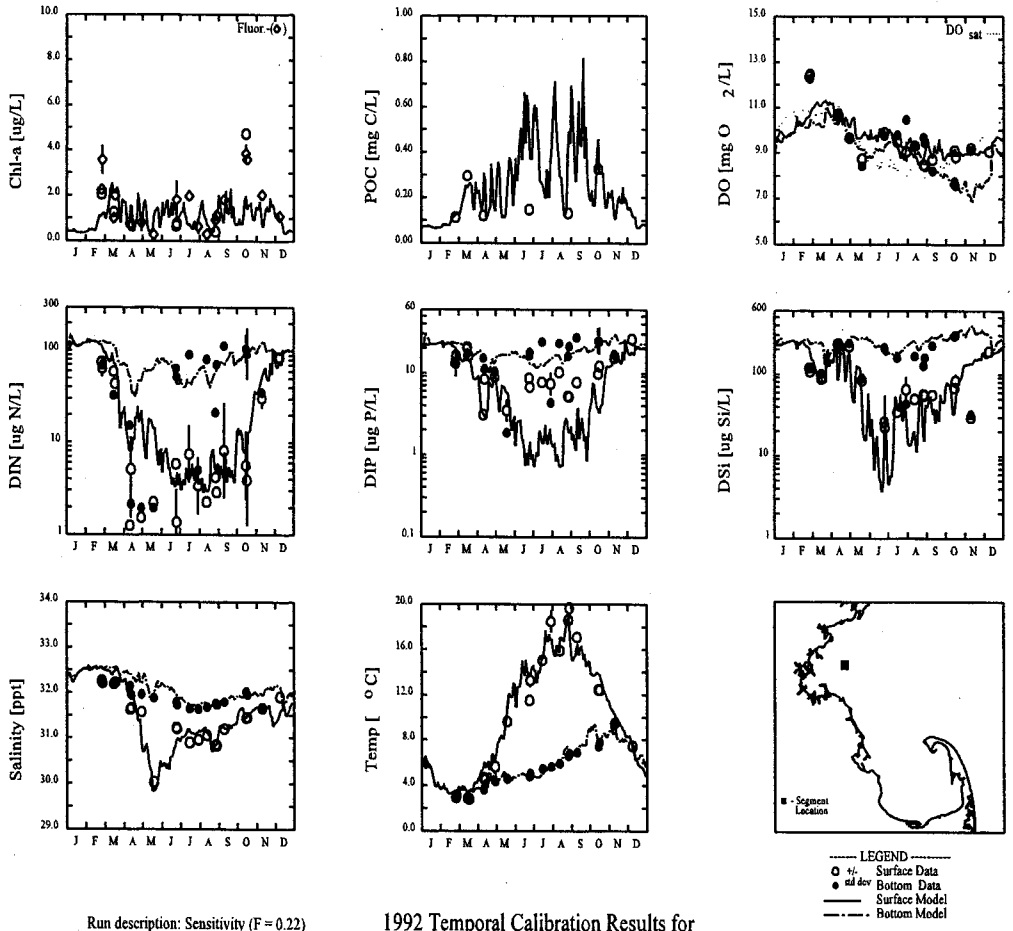


Figure 1-31. 1992 Sensitivity Results for Model Segment (11, 18) Using F=0.22 Coefficient Set - Time-series Comparisons

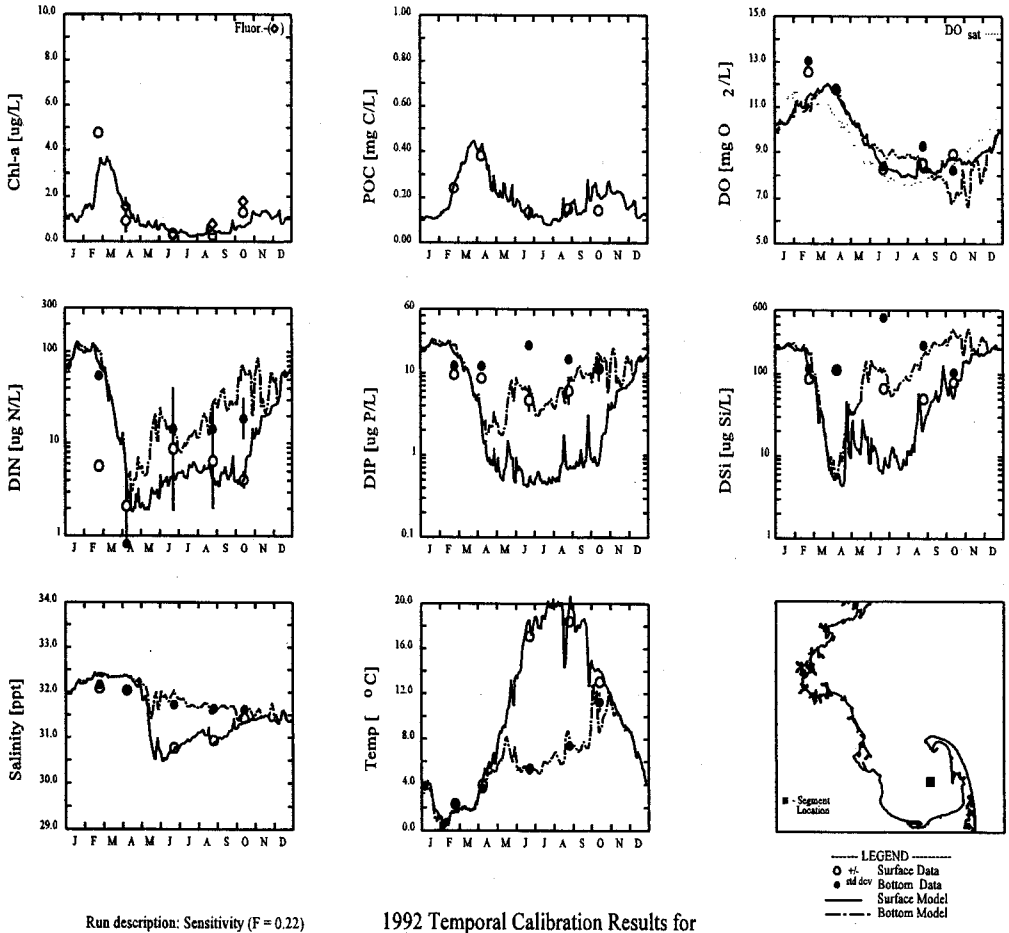


Figure 1-32. 1992 Sensitivity Results for Model Segment (13, 4) Using F=0.22 Coefficient Set - Time-series Comparisons

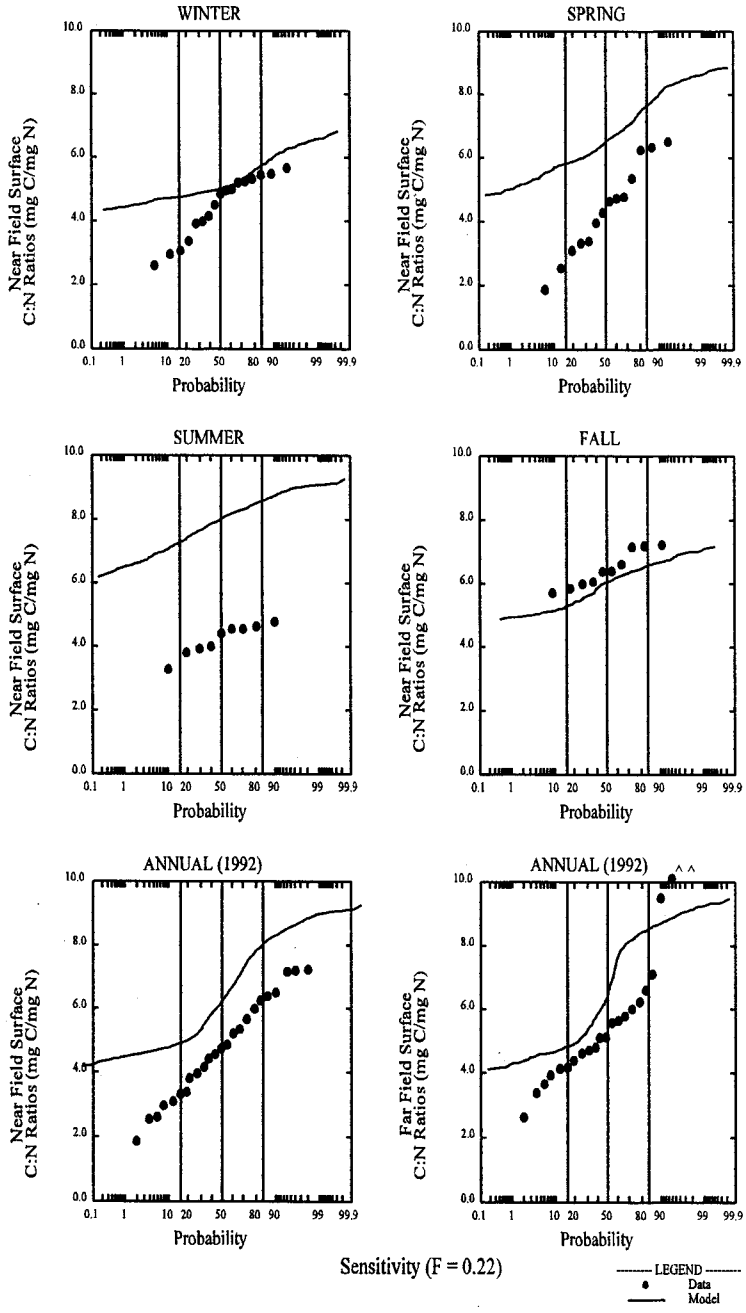


Figure 1-33. 1992 Sensitivity Results for Surface C:N Ratios Using F=0.22 Coefficient Set - Probability Distribution Comparisons

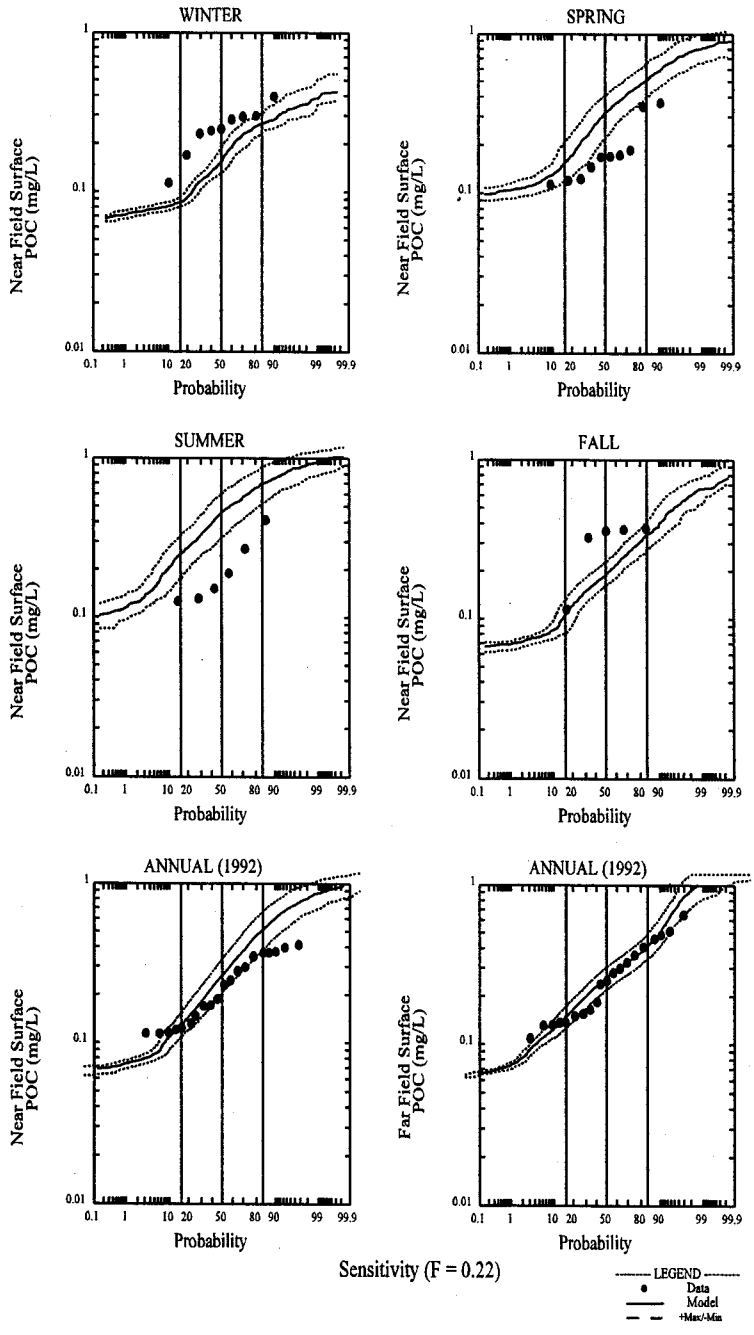


Figure 1-34. 1992 Sensitivity Results for Surface POC Concentrations Using F=0.22 Coefficient Set - Probability Distribution Comparisons

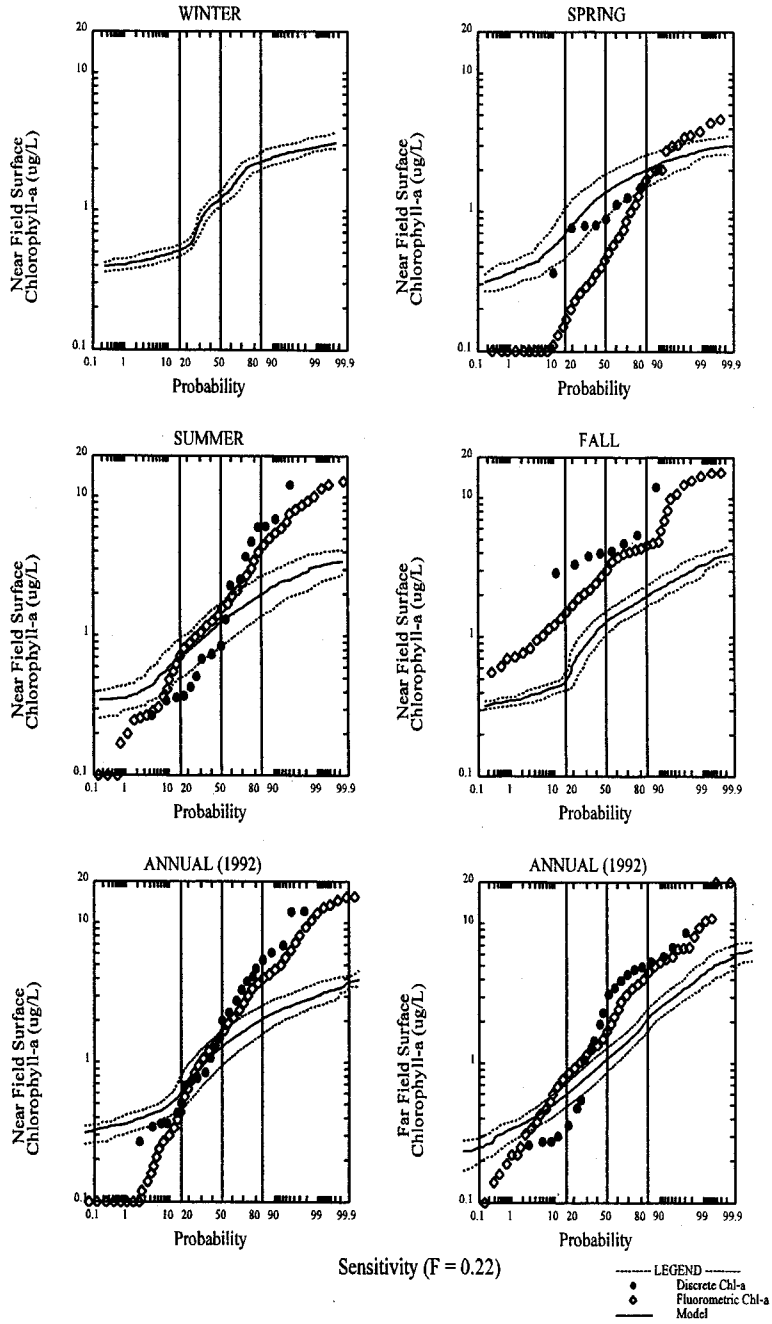


Figure 1-35. 1992 Sensitivity Results for Surface Chlorophyll-a Concentrations Using F=0.22 Coefficient Set - Probability Distribution Comparisons

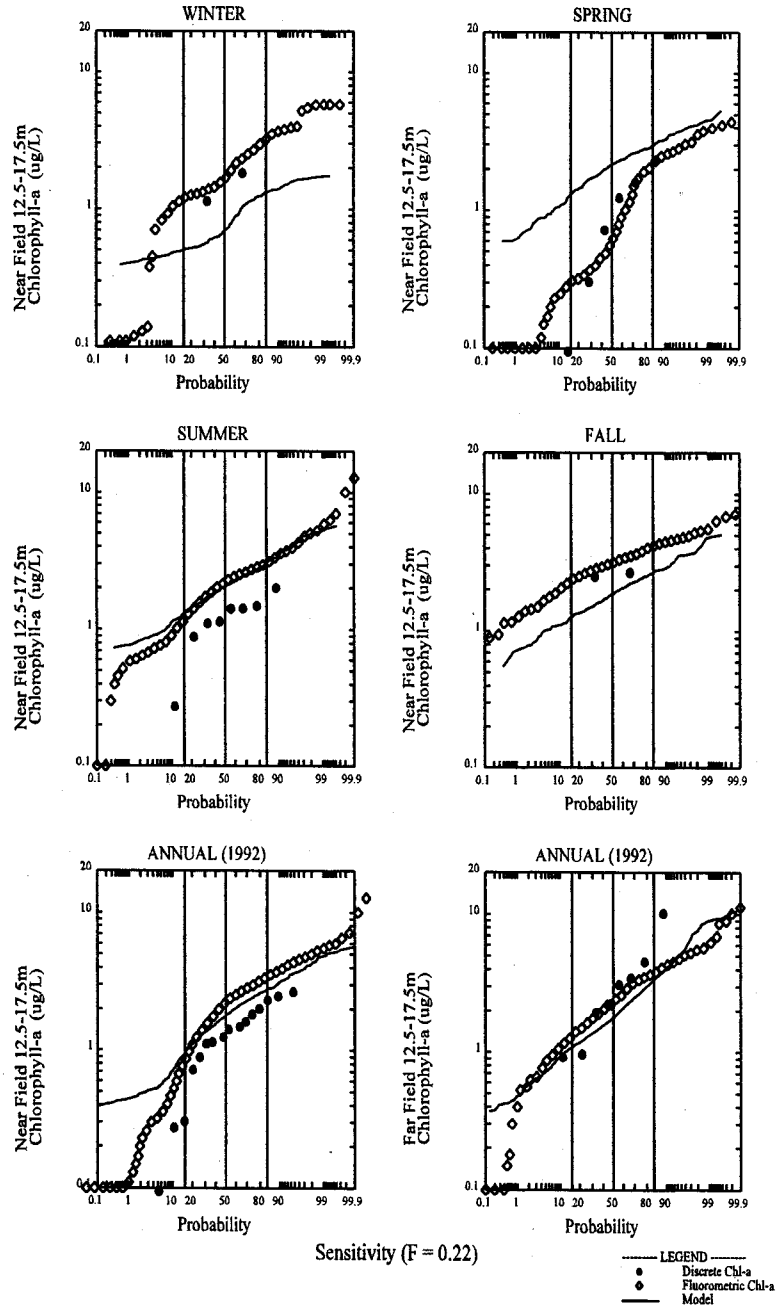


Figure 1-36. 1992 Sensitivity Results for Mid-depth (12.5-17.5 M) Chlorophyll-a Concentrations Using F=0.22 Coefficient Set - Probability Distribution Comparisons

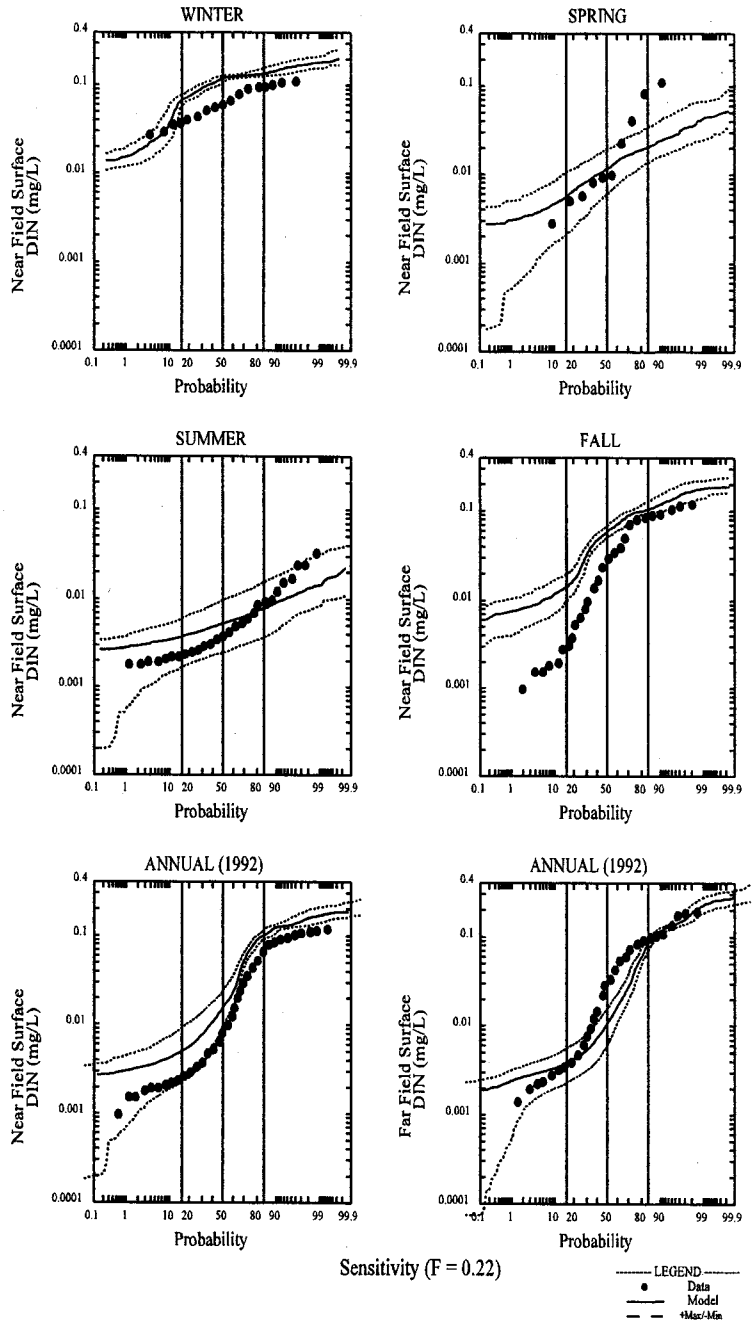


Figure 1-37. 1992 Sensitivity Results for Surface DIN Concentrations Using F=0.22 Coefficient Set - Probability Distribution Comparisons

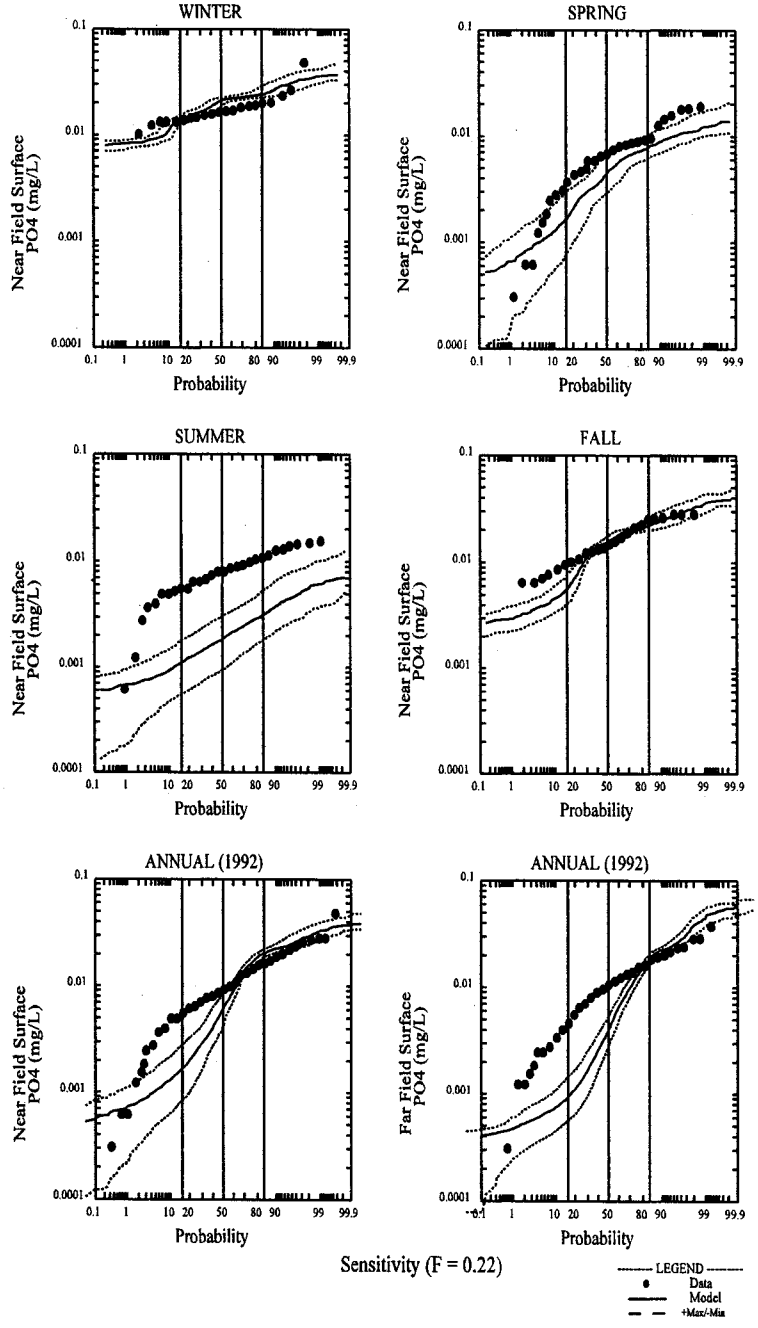


Figure 1-38. 1992 Sensitivity Results for Surface PO_4 Concentrations Using F=0.22 Coefficient Set - Probability Distribution Comparisons

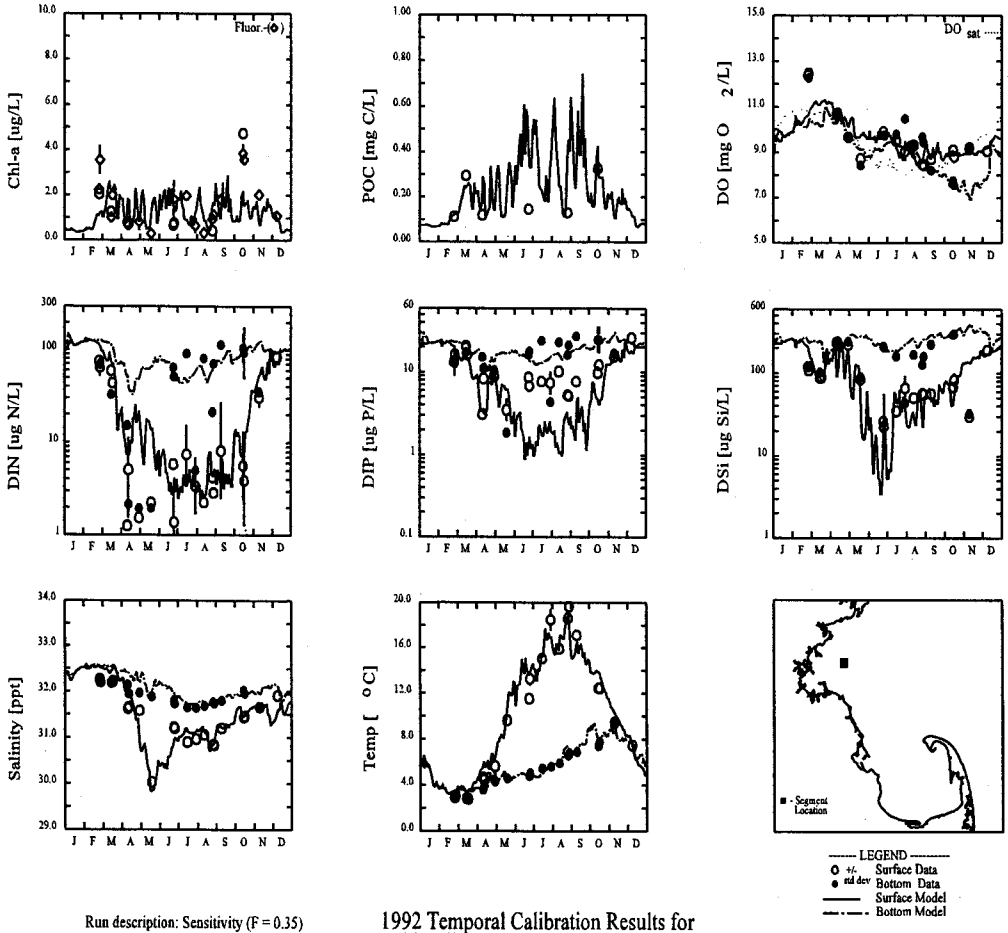


Figure 1-39. 1992 Sensitivity Results for Model Segment (11, 18) Using F=0.35 Coefficient Set - Time-series Comparisons

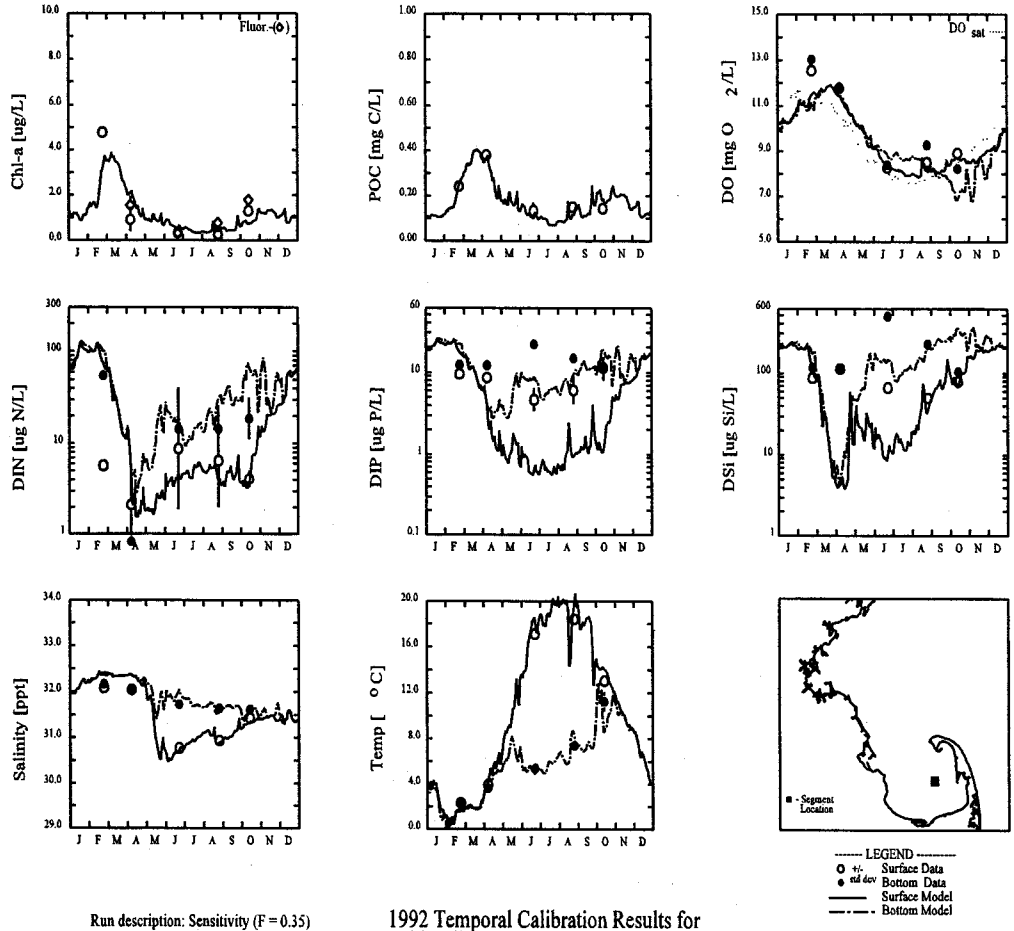


Figure 1-40. 1992 Sensitivity Results for Model Segment (13, 4) Using F=0.35 Coefficient Set - Time-series Comparisons

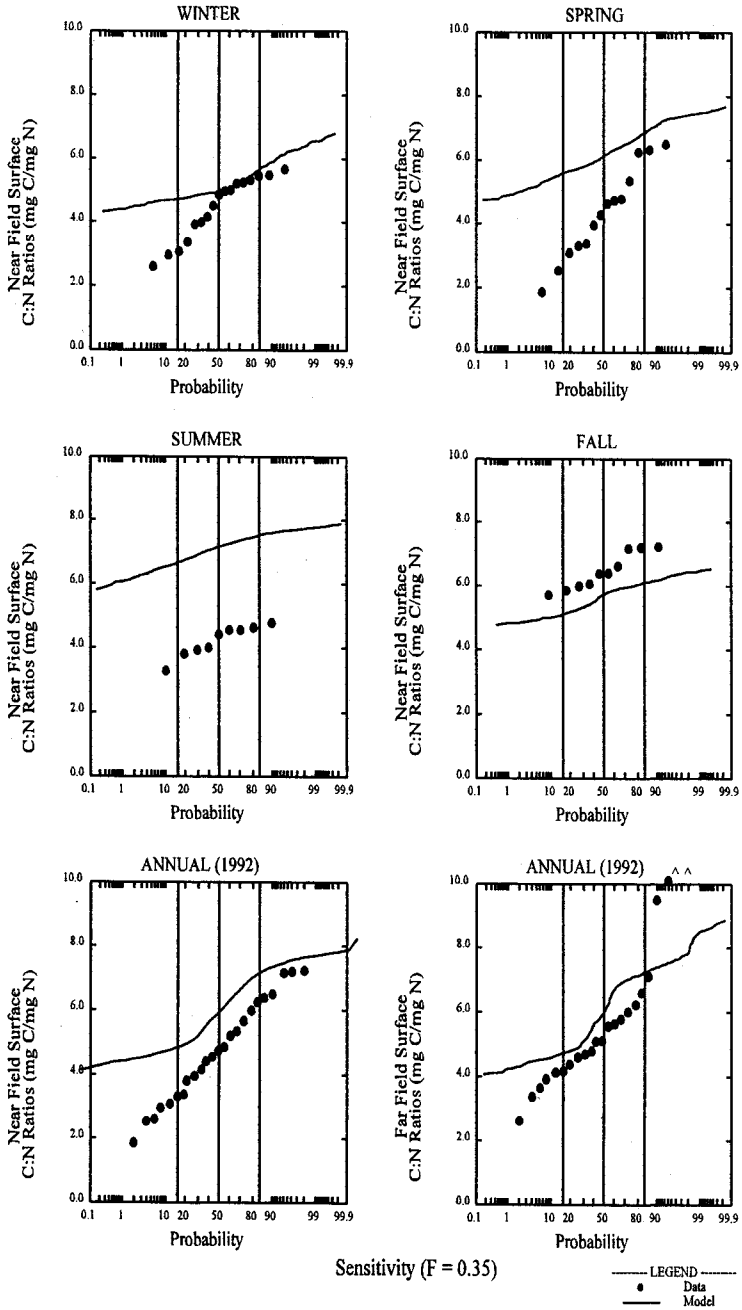


Figure 1-41. 1992 Sensitivity Results for Surface C:N Ratios Using F=0.35 Coefficient Set - Probability Distribution Comparisons

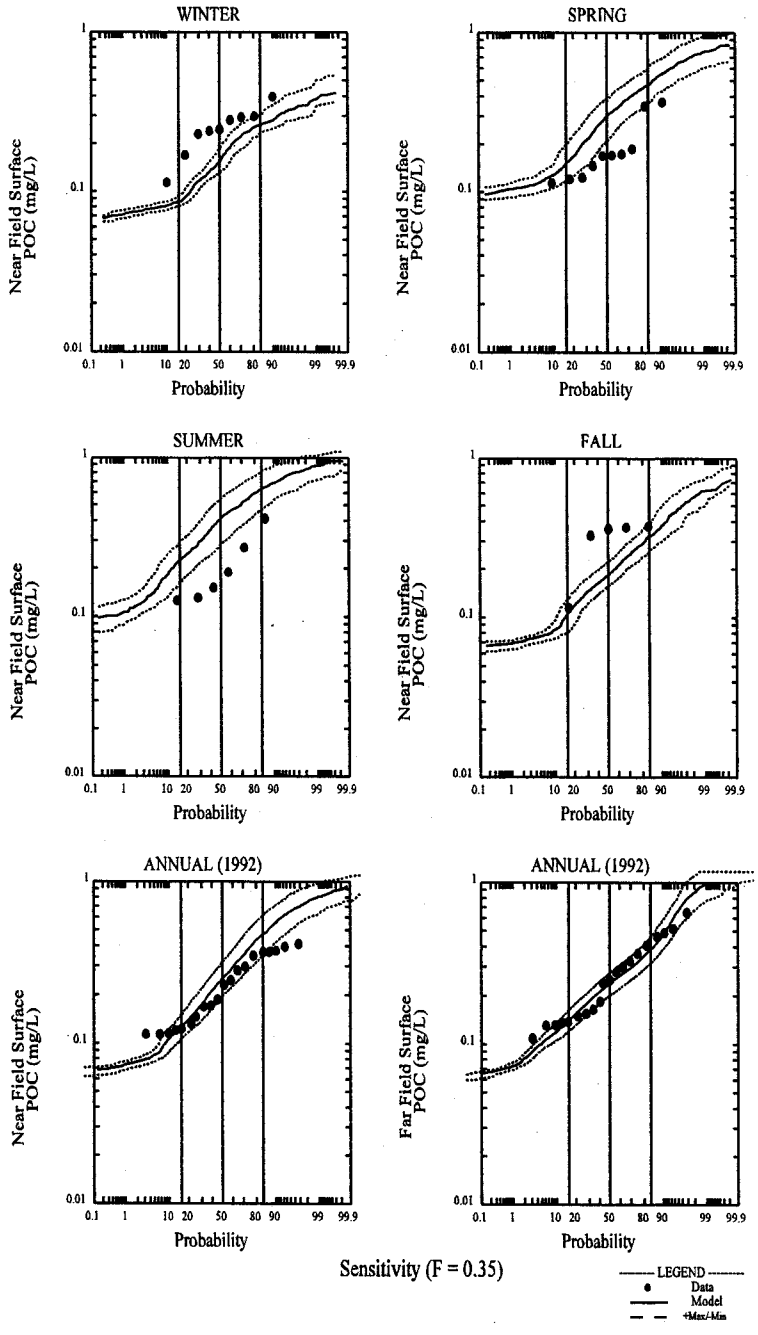


Figure 1-42. 1992 Sensitivity Results for Surface POC Concentrations Using F=0.35 Coefficient Set - Probability Distribution Comparisons

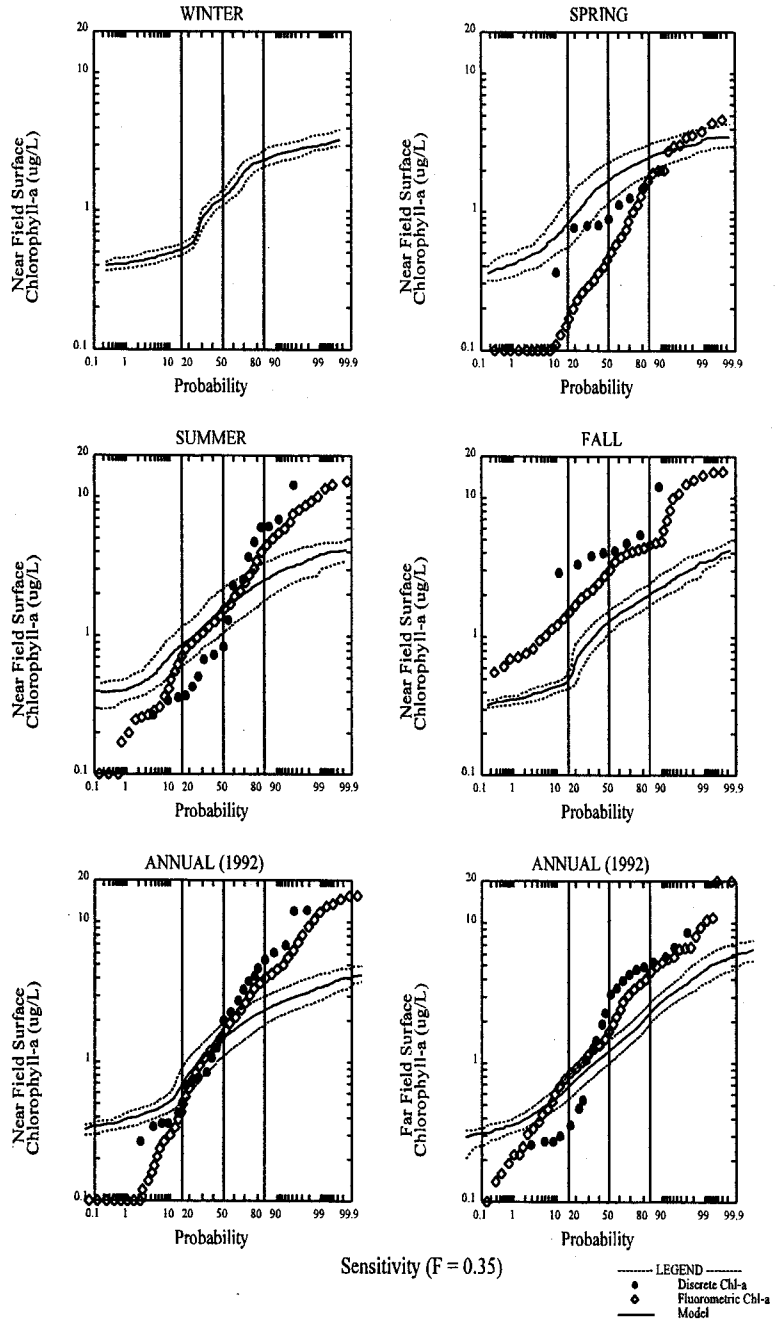


Figure 1-43. 1992 Sensitivity Results for Surface Chlorophyll-a Concentrations Using F=0.22 Coefficient Set - Probability Distribution Comparisons

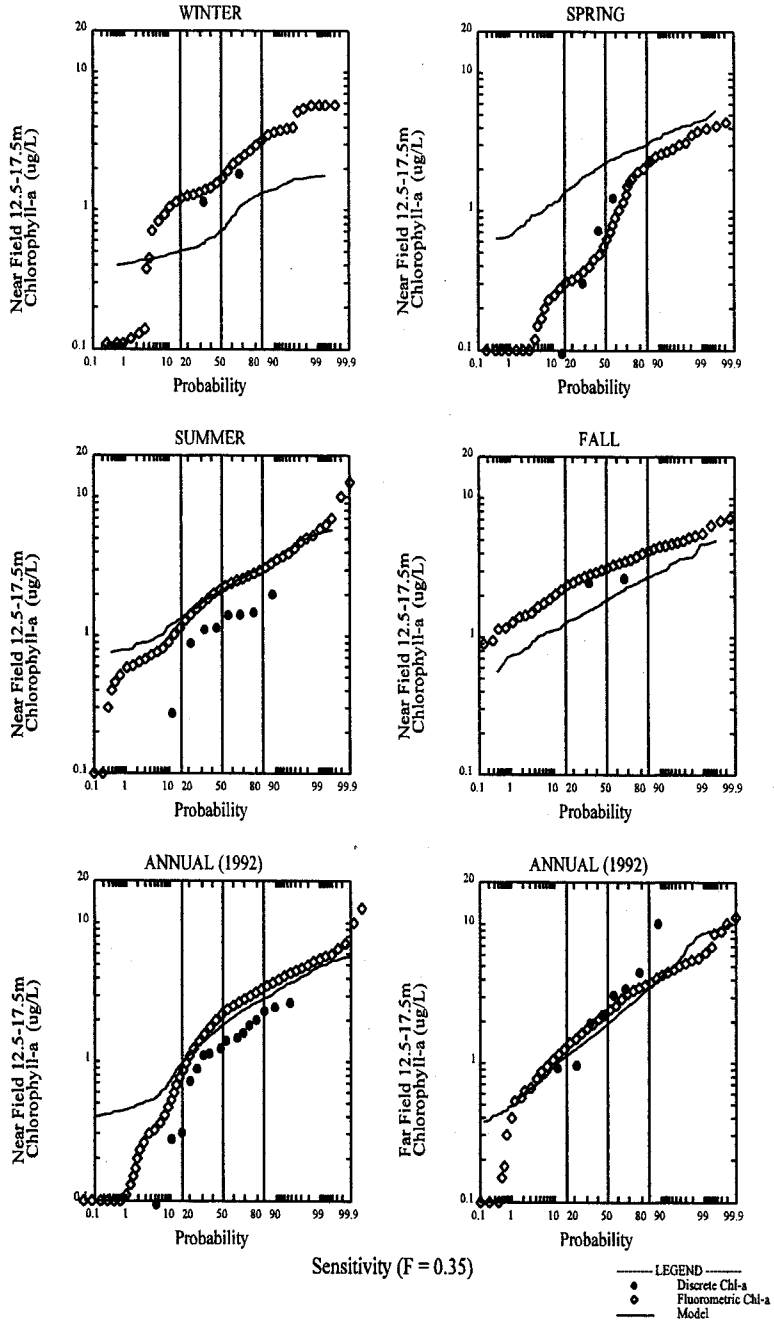


Figure 1-44. 1992 Sensitivity Results for Mid-depth (12.5-17.5 M) Chlorophyll-a Concentrations Using F=0.22 Coefficient Set - Probability Distribution Comparisons

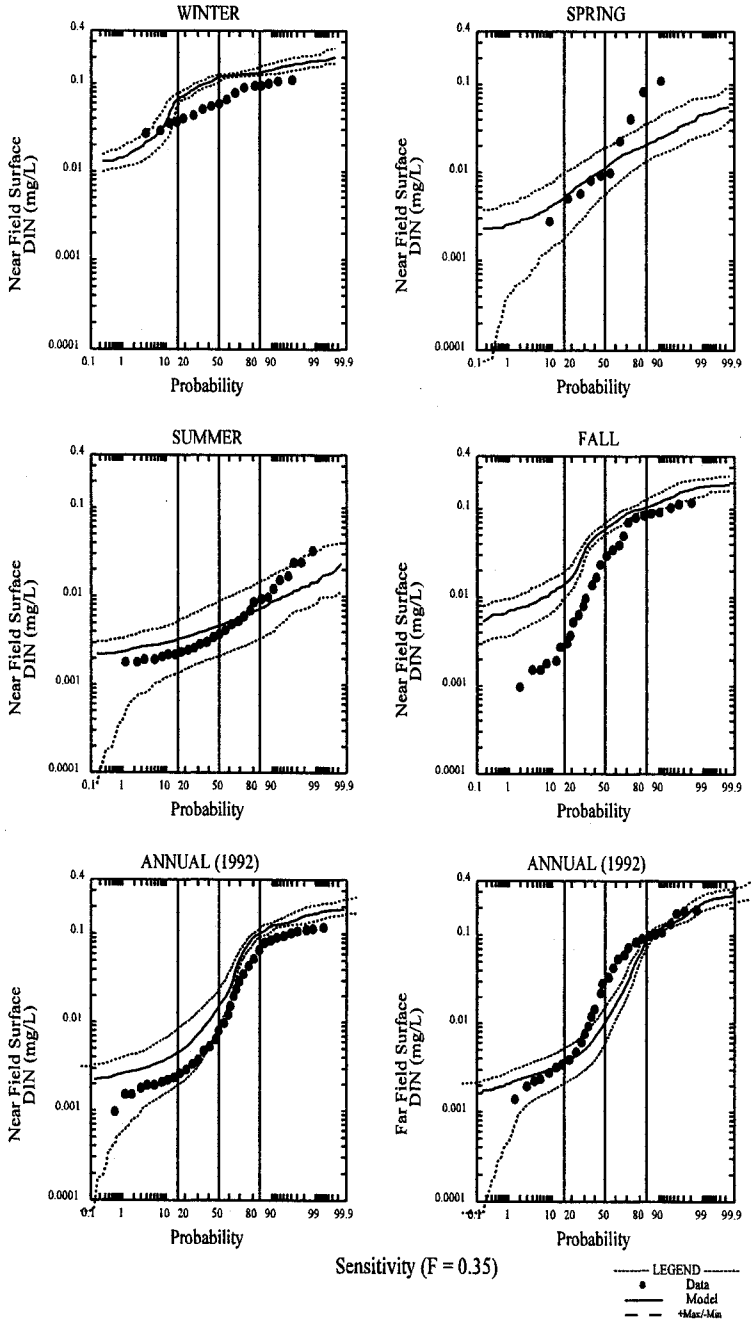


Figure 1-45. 1992 Sensitivity Results for Surface DIN Concentrations Using F=0.22 Coefficient Set - Probability Distribution Comparisons

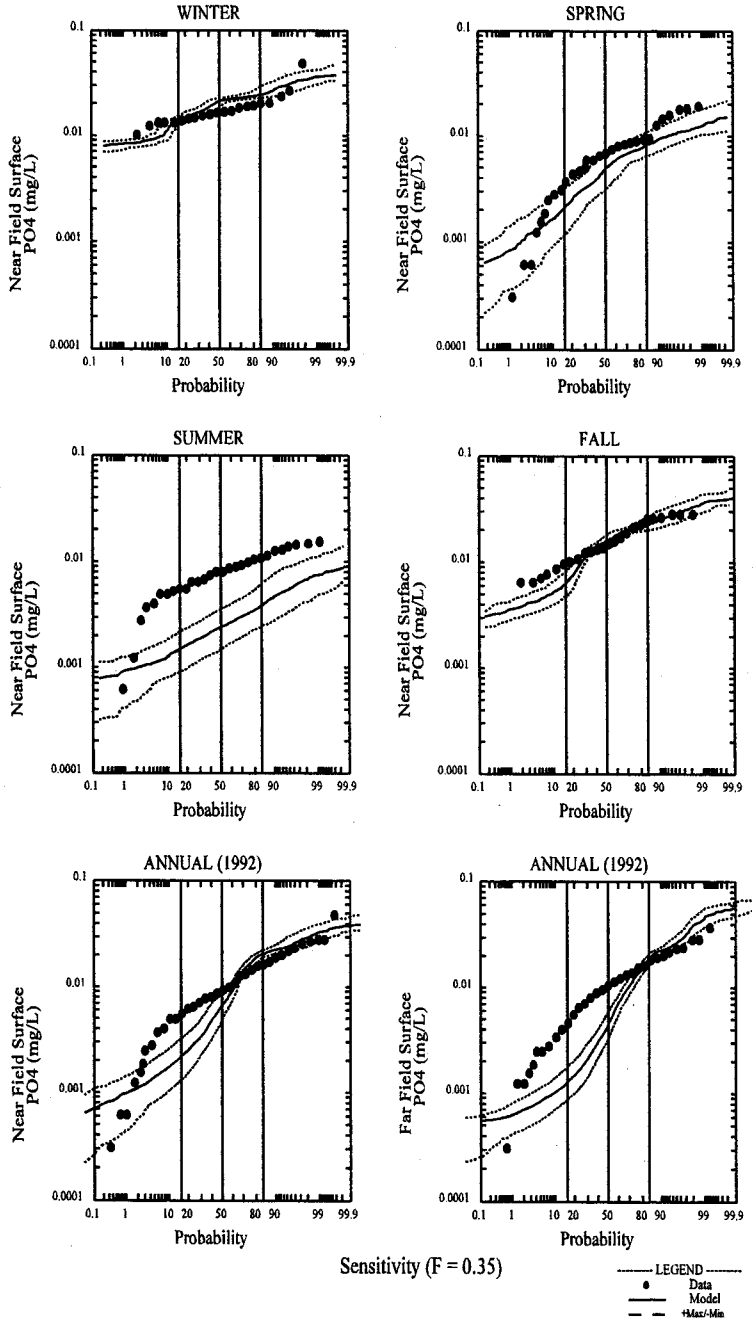


Figure 1-46. 1992 Sensitivity Results for Surface PO_4 Concentrations Using F=0.22 Coefficient Set - Probability Distribution Comparisons

SECTION 2

REFERENCES

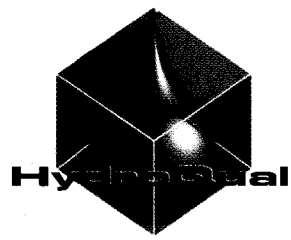
Chalup, M.S. and E.A. Laws, 1990. A test of the assumptions and predictions of recent microalgal growth models with the marine phytoplankter *Pavlova lutheri*. Limnol.Oceanogr. 35(3): 583-596.

HydroQual, Inc., 1995. A water quality model for Massachusetts and Cape Cod Bays: Calibration of the Bays Eutrophication Model (BEM). Prepared for the Massachusetts Water Resources Authority Environmental Quality Department. MWRA ENQUAD Technical Report No. 95-08. Under subcontract to Normandeau Assoc., Inc. HydroQual, Inc., Mahwah, NJ.

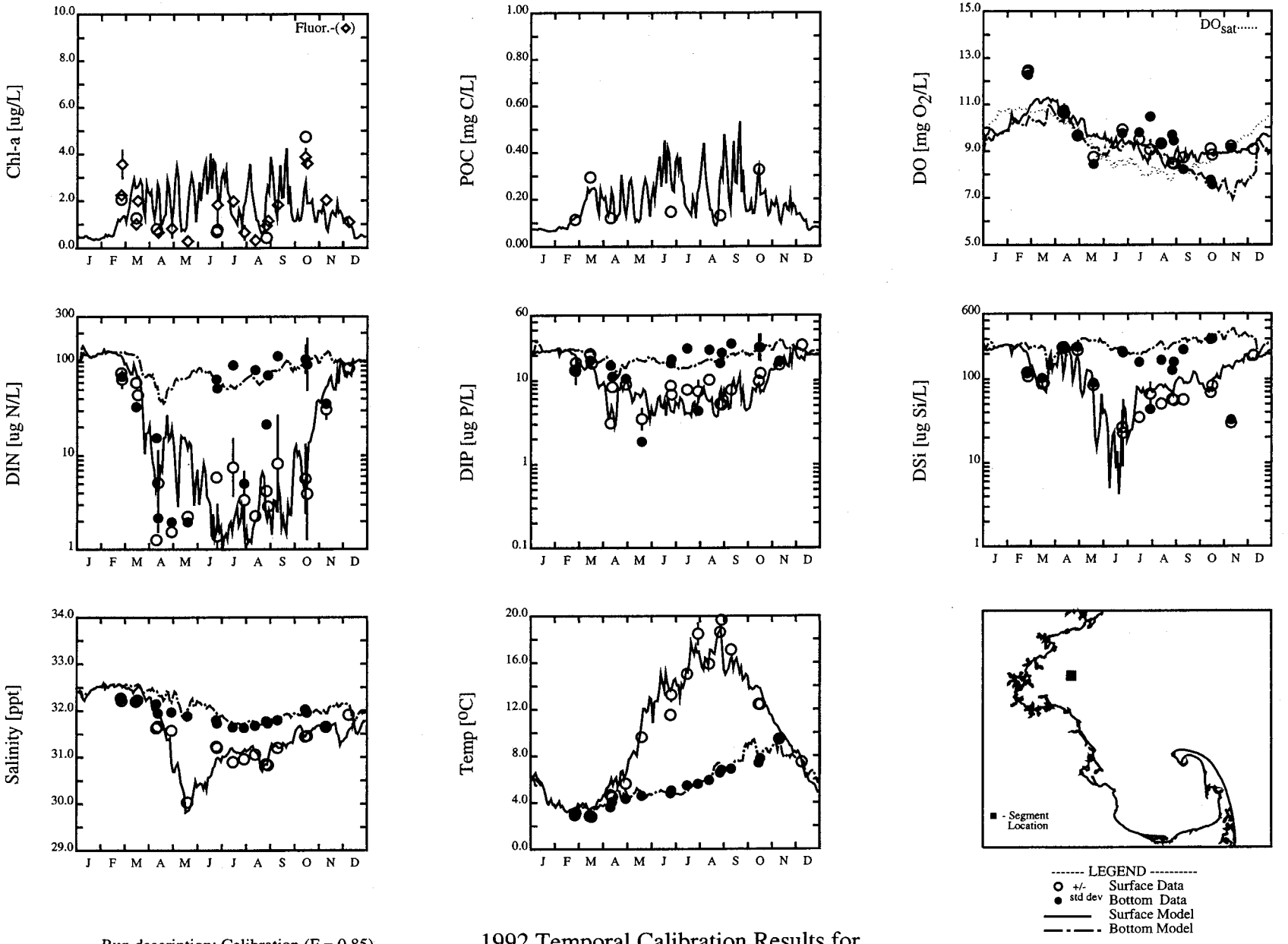
HydroQual, Inc., 2000. Bays Eutrophication Model (BEM): modeling analysis for 1992-1994. Prepared for the Massachusetts Water Resources Authority Environmental Quality Department. MWRA ENQUAD Technical Report No. 2000-02. Under subcontract to Battelle. HydroQual, Inc., Mahwah, NJ.

Laws, E.A. and M.S. Chalup, 1990. A microalgal growth model. Limnol. Oceanogr. 35(3): 597-608.

APPENDIX A
RESULTS FROM CALIBRATION AND SENSITIVITY ANALYSIS

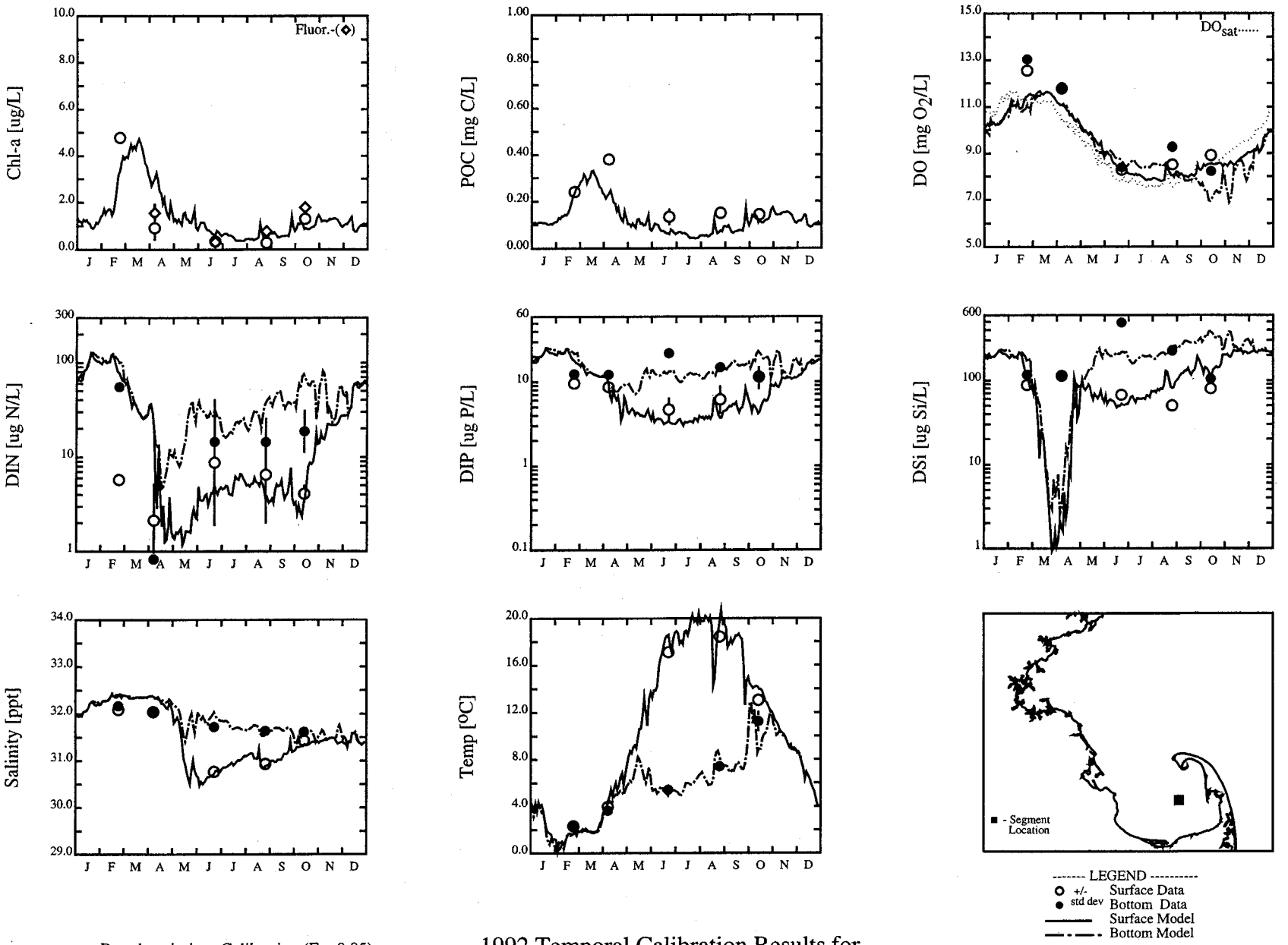


Environmental
Engineers & Scientists



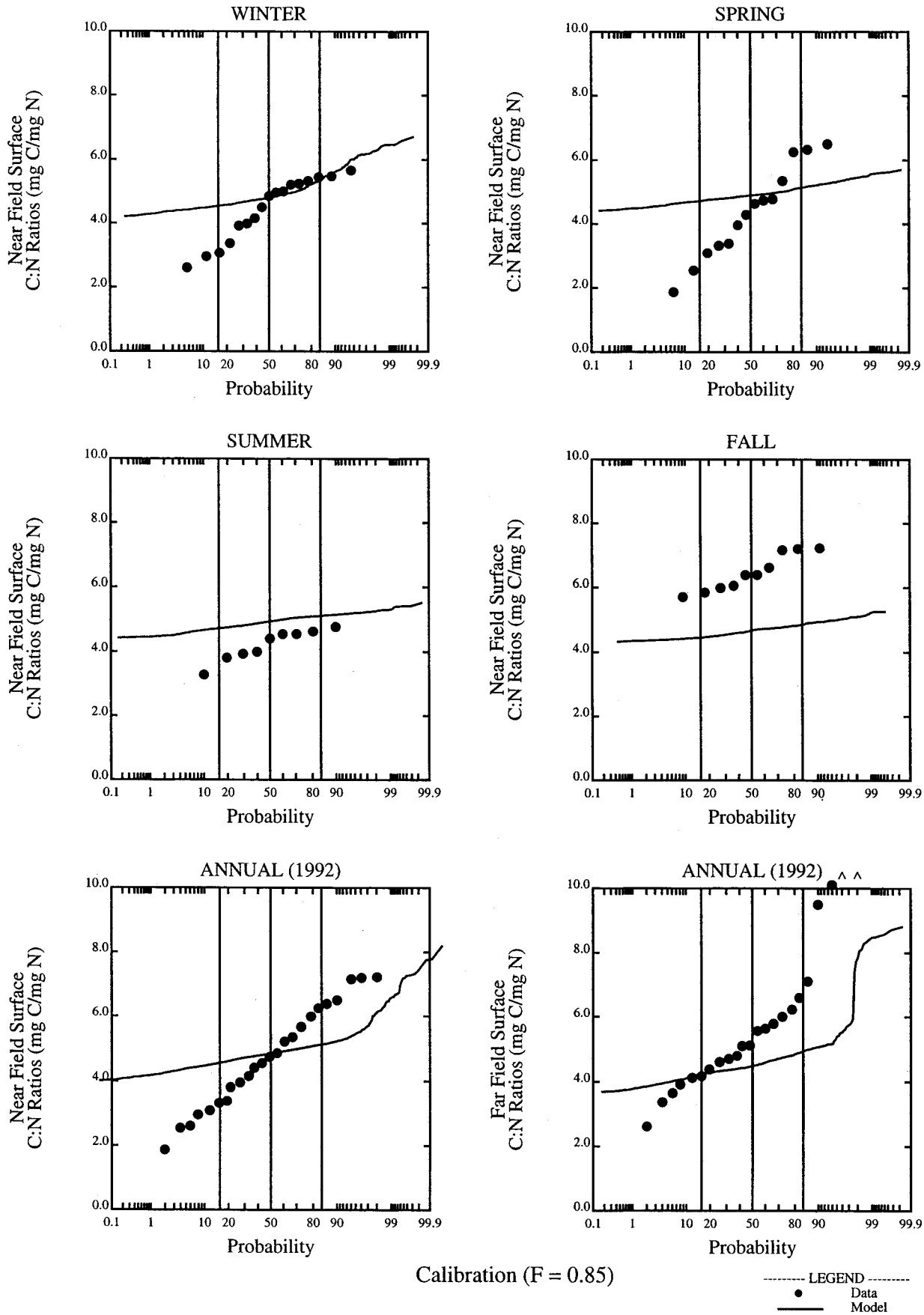
Run description: Calibration (F = 0.85)

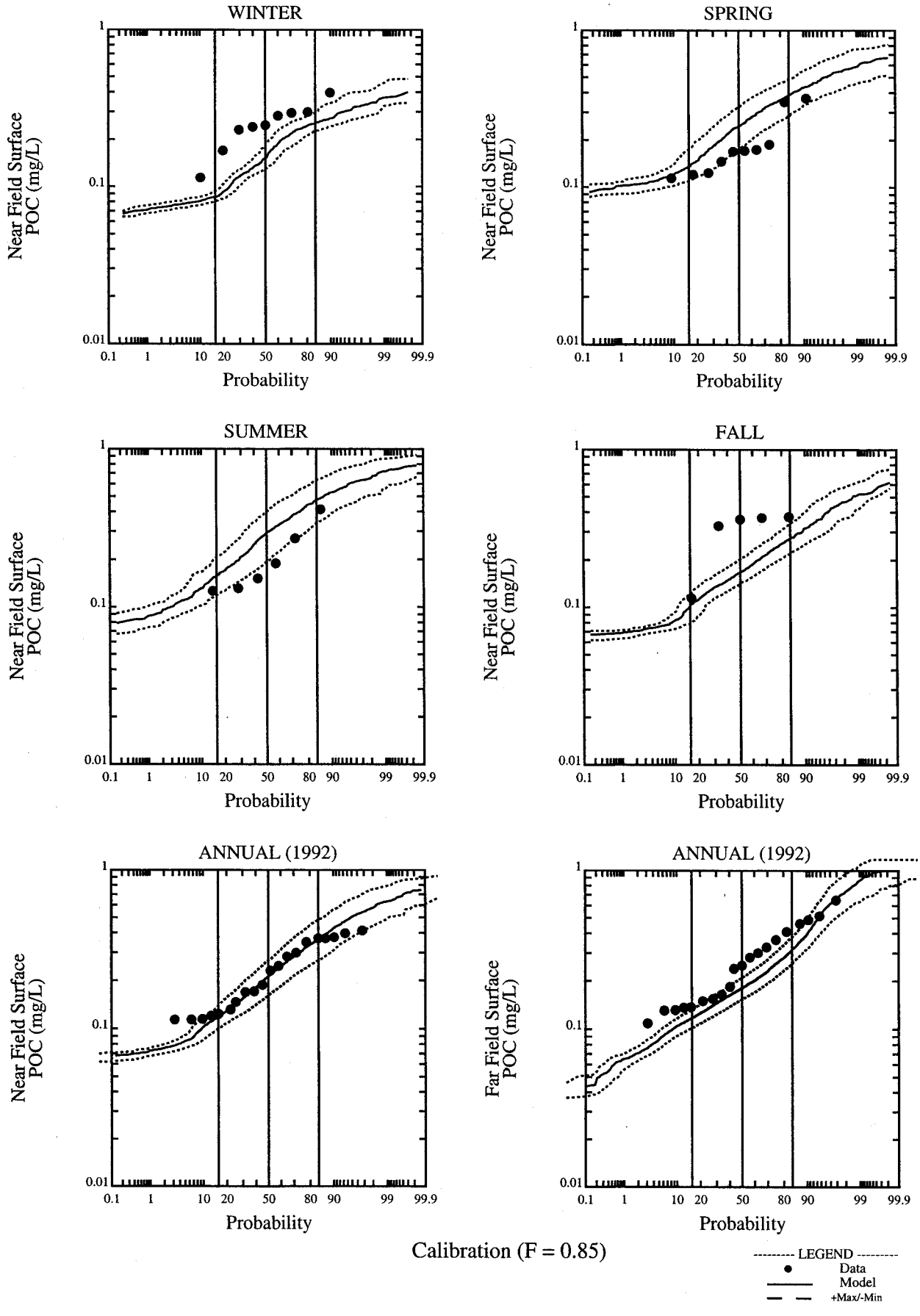
1992 Temporal Calibration Results for
Grid Cell (11,18) Vs Data Station N16P,N17,N21

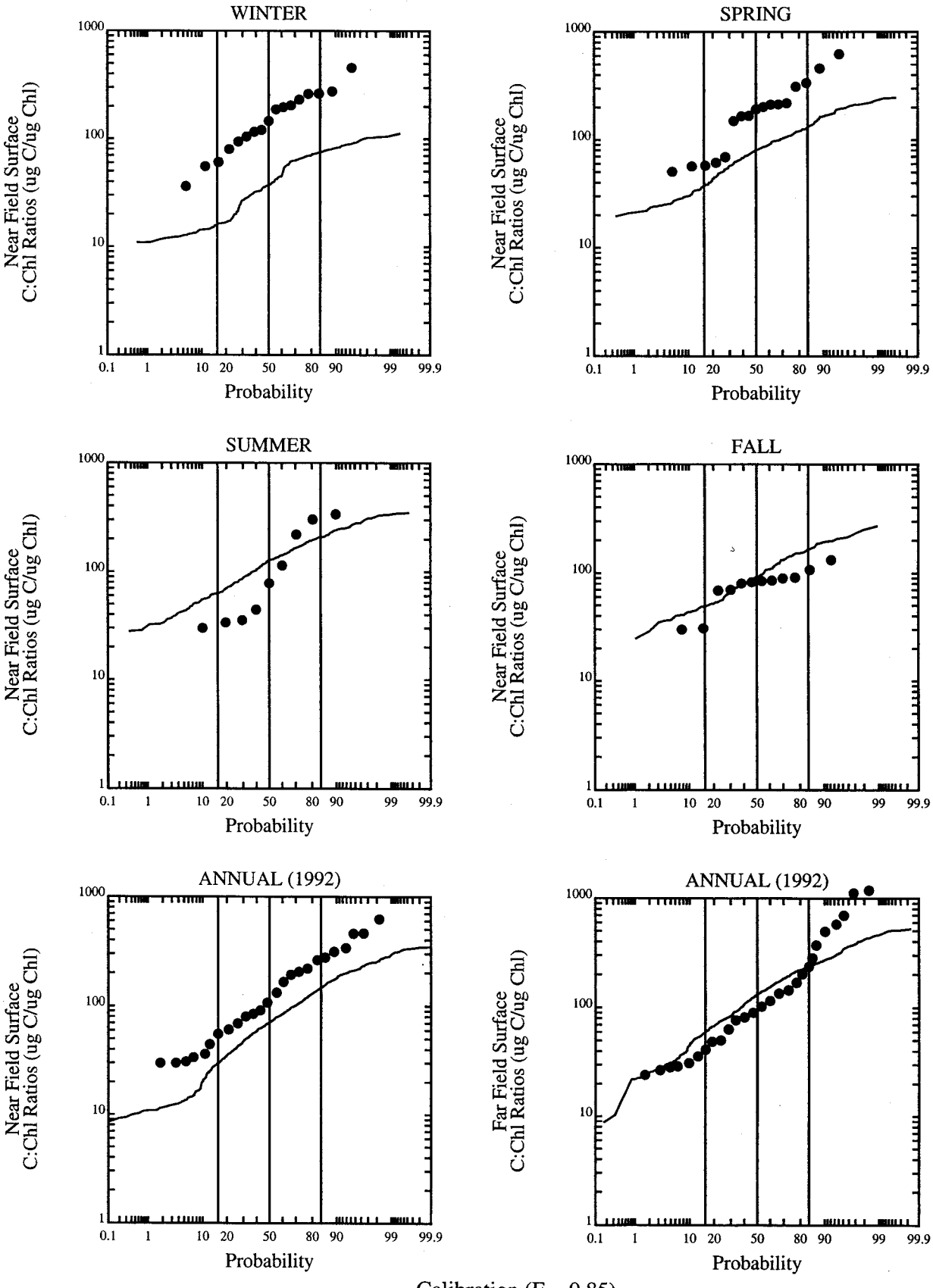


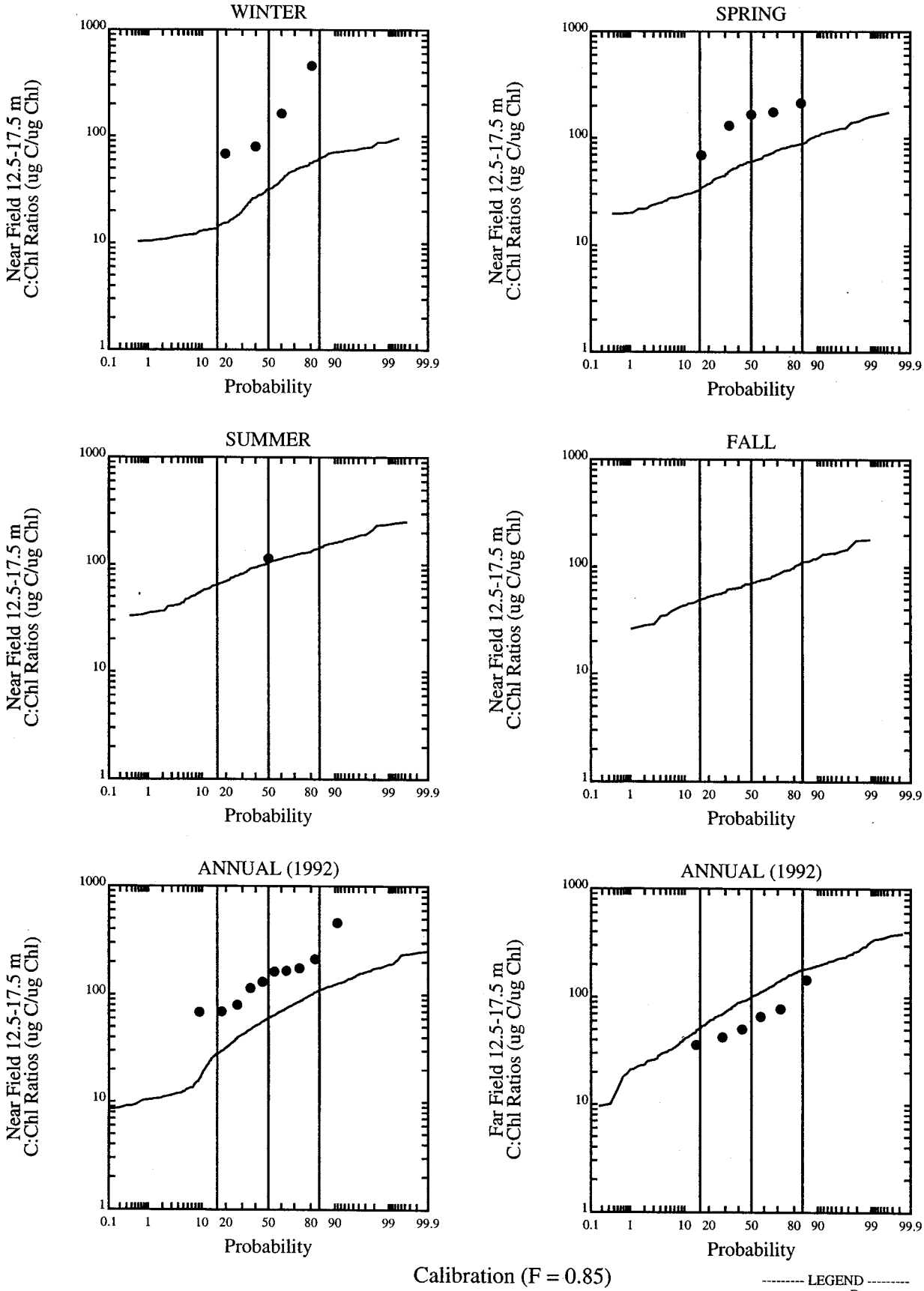
Run description: Calibration (F = 0.85)

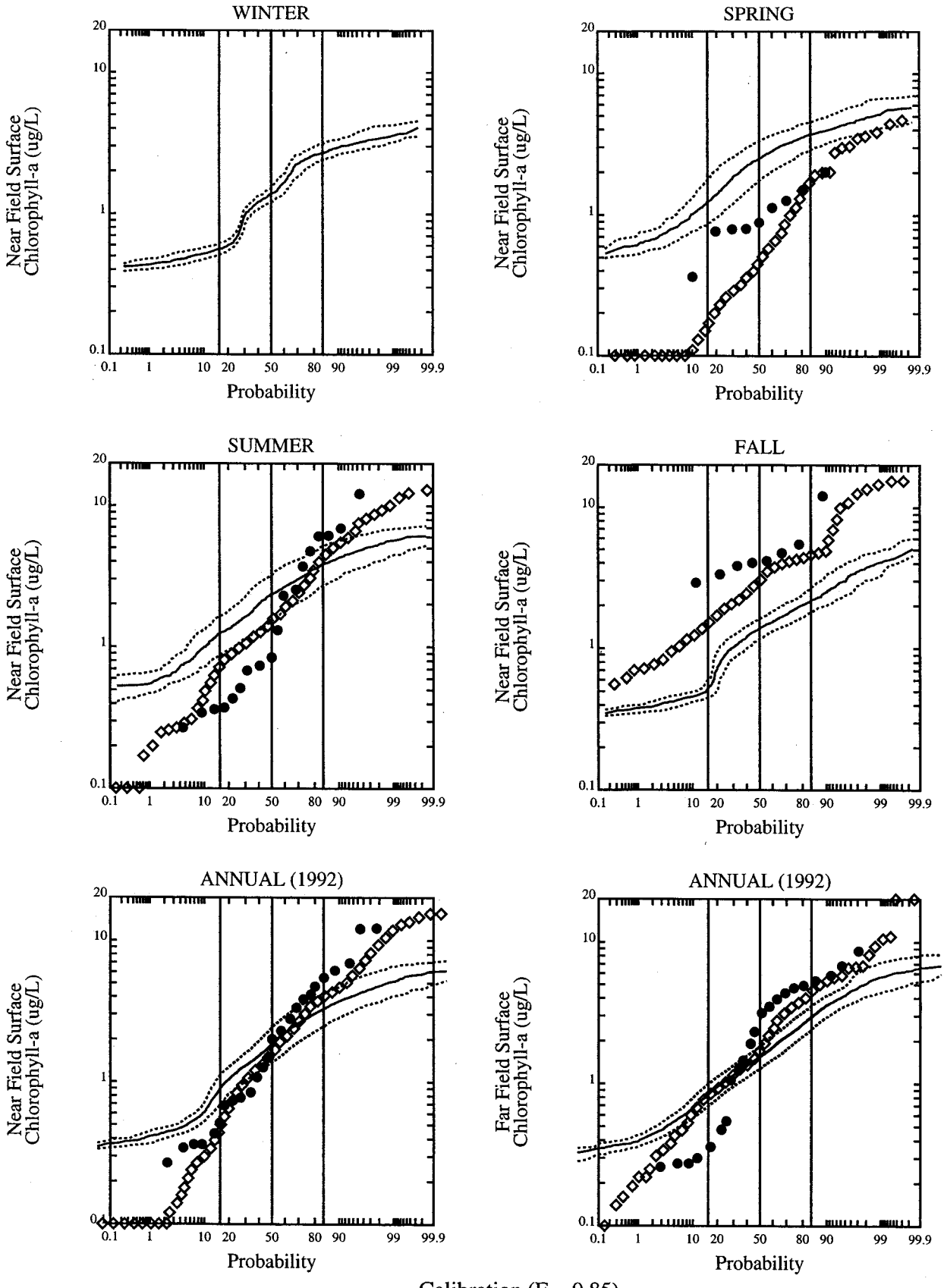
1992 Temporal Calibration Results for Grid Cell (13,4) Vs Data Station F02P

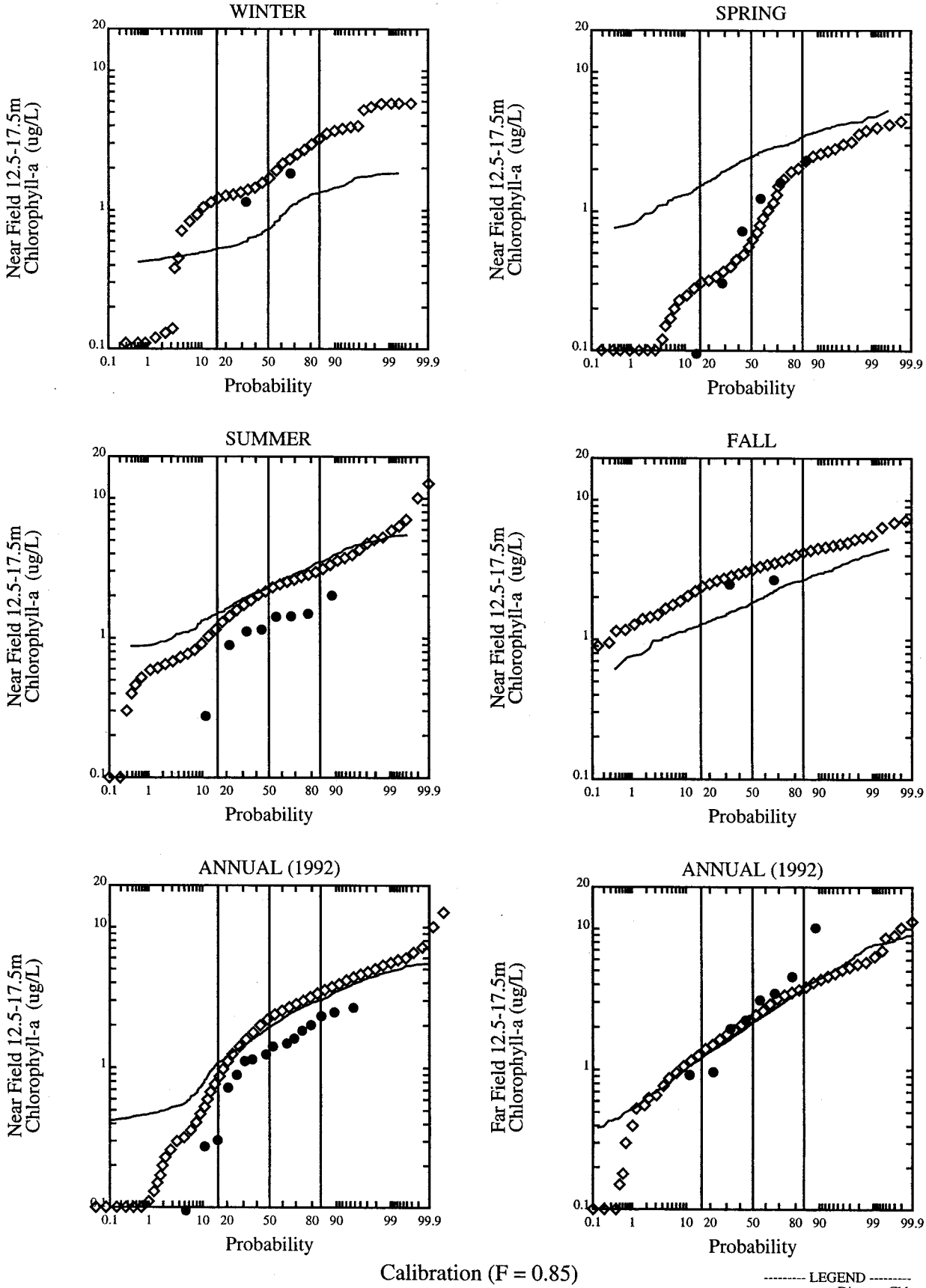

WINTER
SPRING
SUMMER
FALL
ANNUAL (1992)
ANNUAL (1992) ^ ^
Near Field Surface C:N Ratios (mg C/mg N)
Far Field Surface C:N Ratios (mg C/mg N)
10.0
8.0
6.0
4.0
2.0
0.0
0.1 1 10 20 50 80 90 99 99.9
Probability
Calibration (F = 0.85)
LEGEND
Data
Model

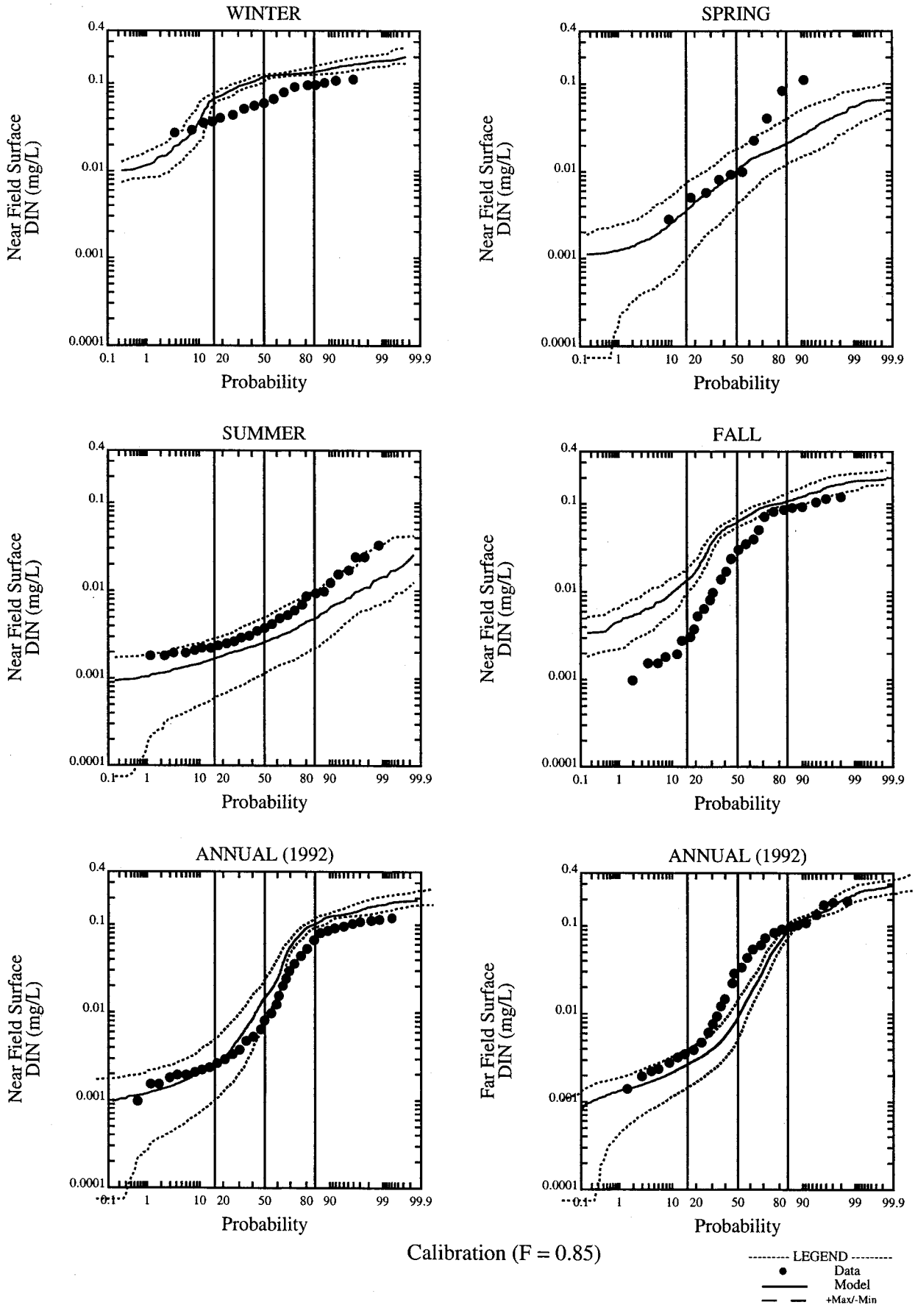

WINTER
SPRING
SUMMER
FALL
ANNUAL (1992)
ANNUAL (1992)
Near Field Surface POC (mg/L)
Far Field Surface POC (mg/L)
Probability
1
0.1
0.01
0.1 1 10 20 50 80 90 99 99.9
Calibration (F = 0.85)
LEGEND
Data
Model
+Max/-Min

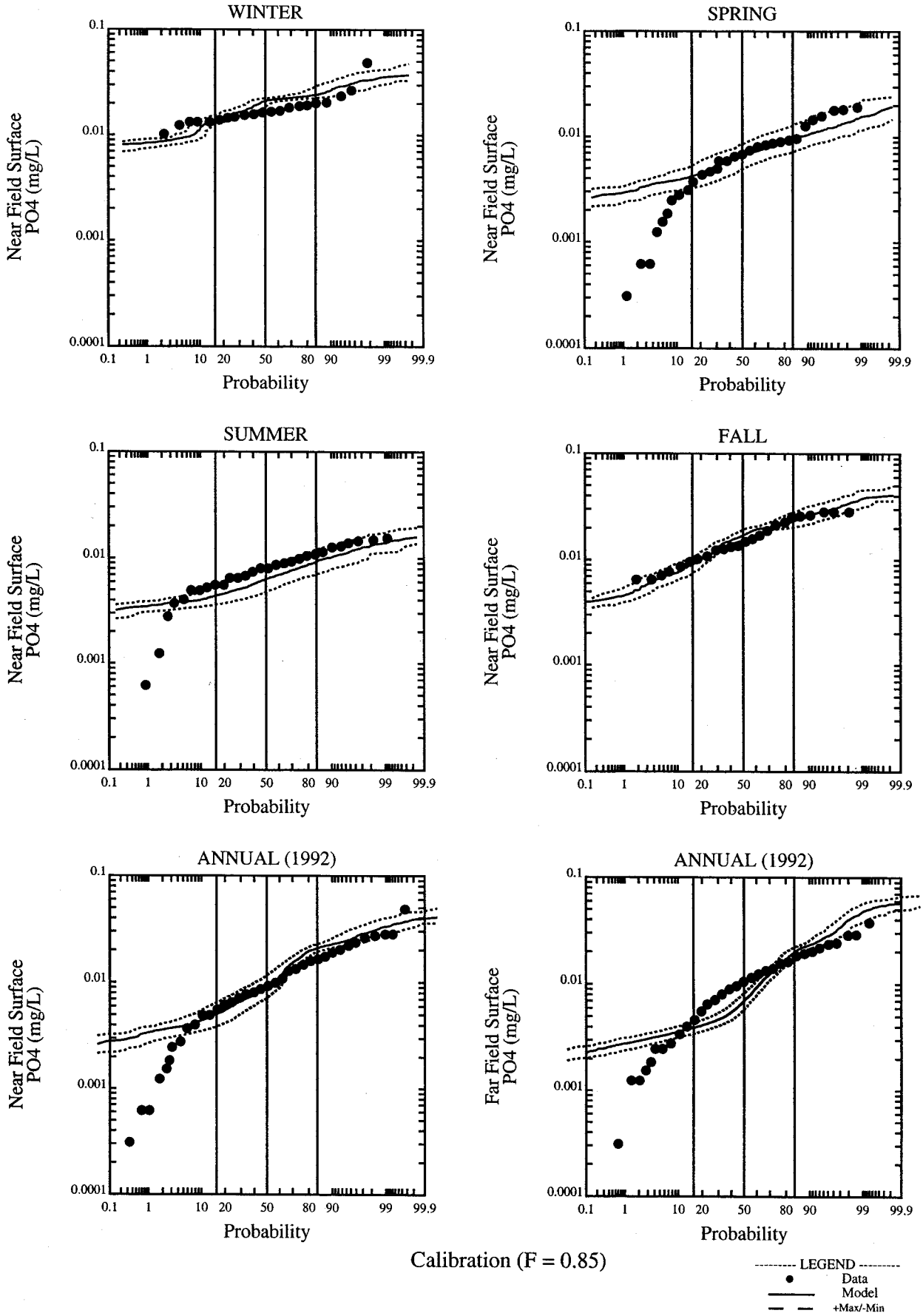

WINTER
SPRING
SUMMER
FALL
ANNUAL (1992)
ANNUAL (1992)
Near Field Surface C:Chl Ratios (ug C/ug Chl)
Far Field Surface C:Chl Ratios (ug C/ug Chl)
1000
100
10
1
0.1 1 10 20 50 80 90 99 99.9
Probability
Calibration (F = 0.85)
LEGEND
Data
Model

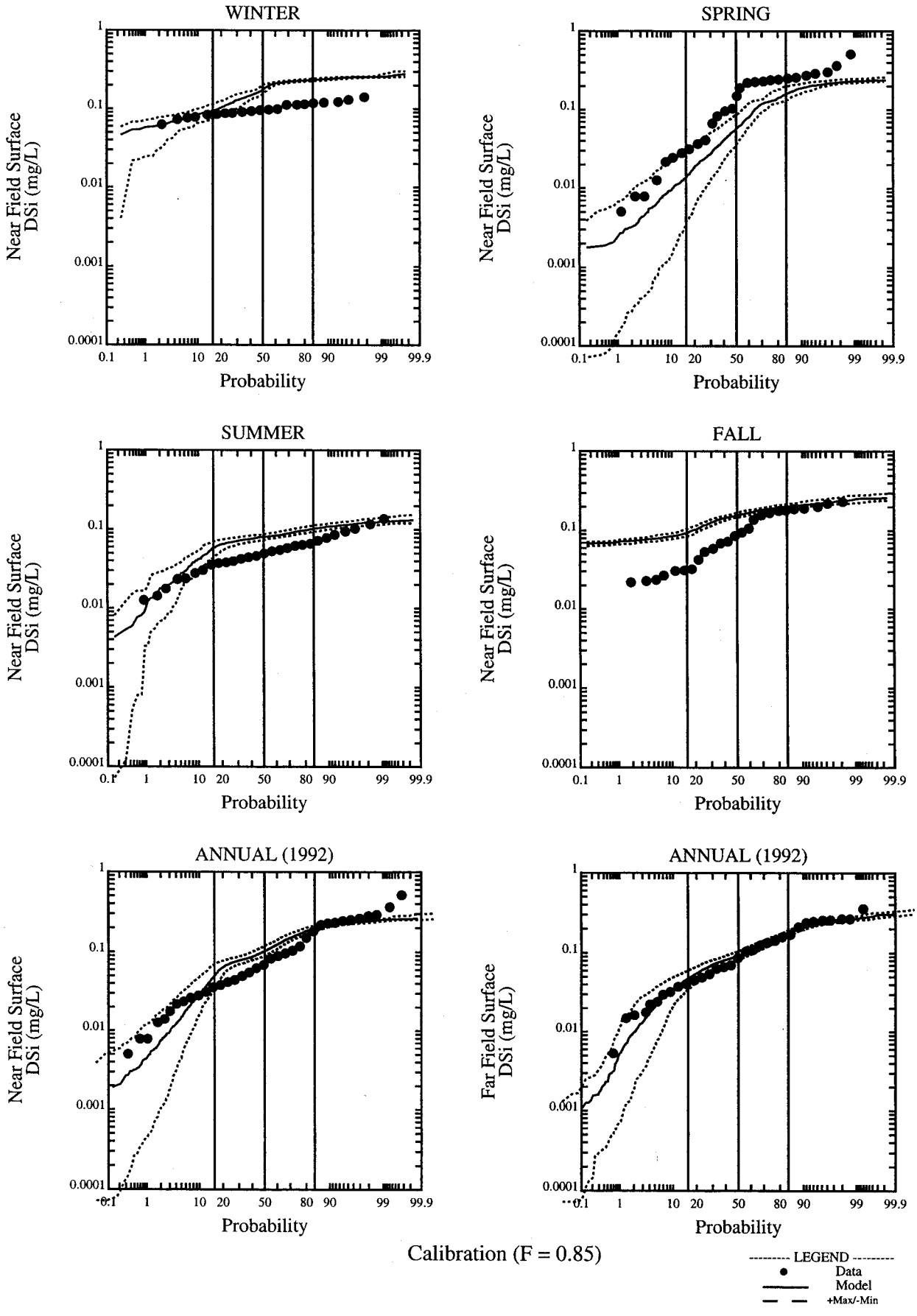

WINTER
SPRING
SUMMER
FALL
ANNUAL (1992)
ANNUAL (1992)
Near Field 12.5-17.5 m C:Chl Ratios (ug C/ug Chl)
Far Field 12.5-17.5 m C:Chl Ratios (ug C/ug Chl)
1000
100
10
1
0.1 1 10 20 50 80 90 99 99.9
Probability
Calibration (F = 0.85)
LEGEND
Data
Model

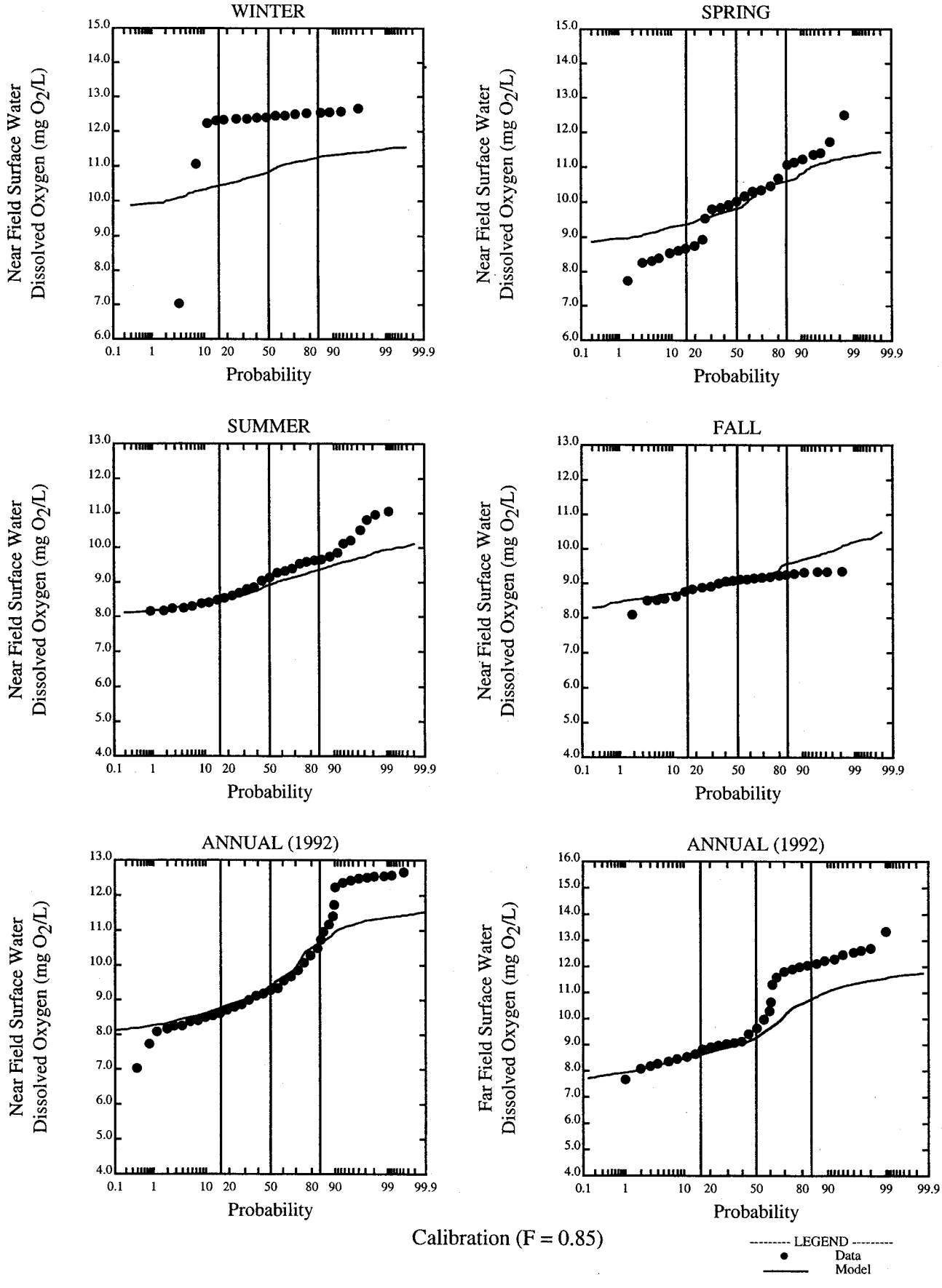

WINTER
SPRING
SUMMER
FALL
ANNUAL (1992)
ANNUAL (1992)
Near Field Surface Chlorophyll-a (ug/L)
Far Field Surface Chlorophyll-a (ug/L)
Probability
20
10
1
0.1
0.1 1 10 20 50 80 90 99 99.9
Calibration (F = 0.85)
LEGEND
Discrete Chl-a
Fluorometric Chl-a
Model

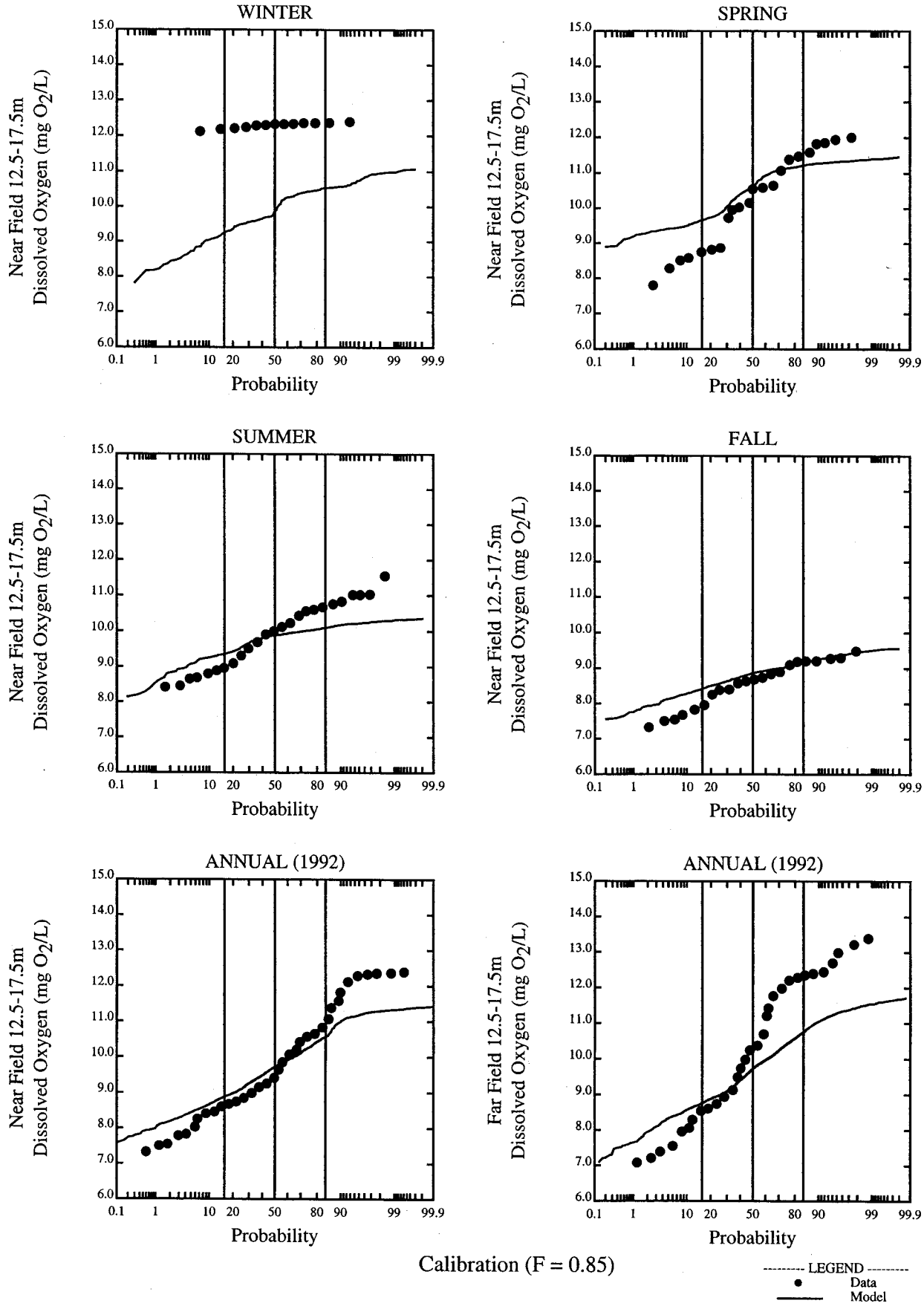

WINTER
SPRING
SUMMER
FALL
ANNUAL (1992)
ANNUAL (1992)
Near Field 12.5-17.5m Chlorophyll-a (ug/L)
Far Field 12.5-17.5m Chlorophyll-a (ug/L)
Probability
0.1 1 10 20 50 80 90 99 99.9
20 10 1 0.1
Calibration (F = 0.85)
LEGEND
Discrete Chl-a
Fluorometric Chl-a
Model

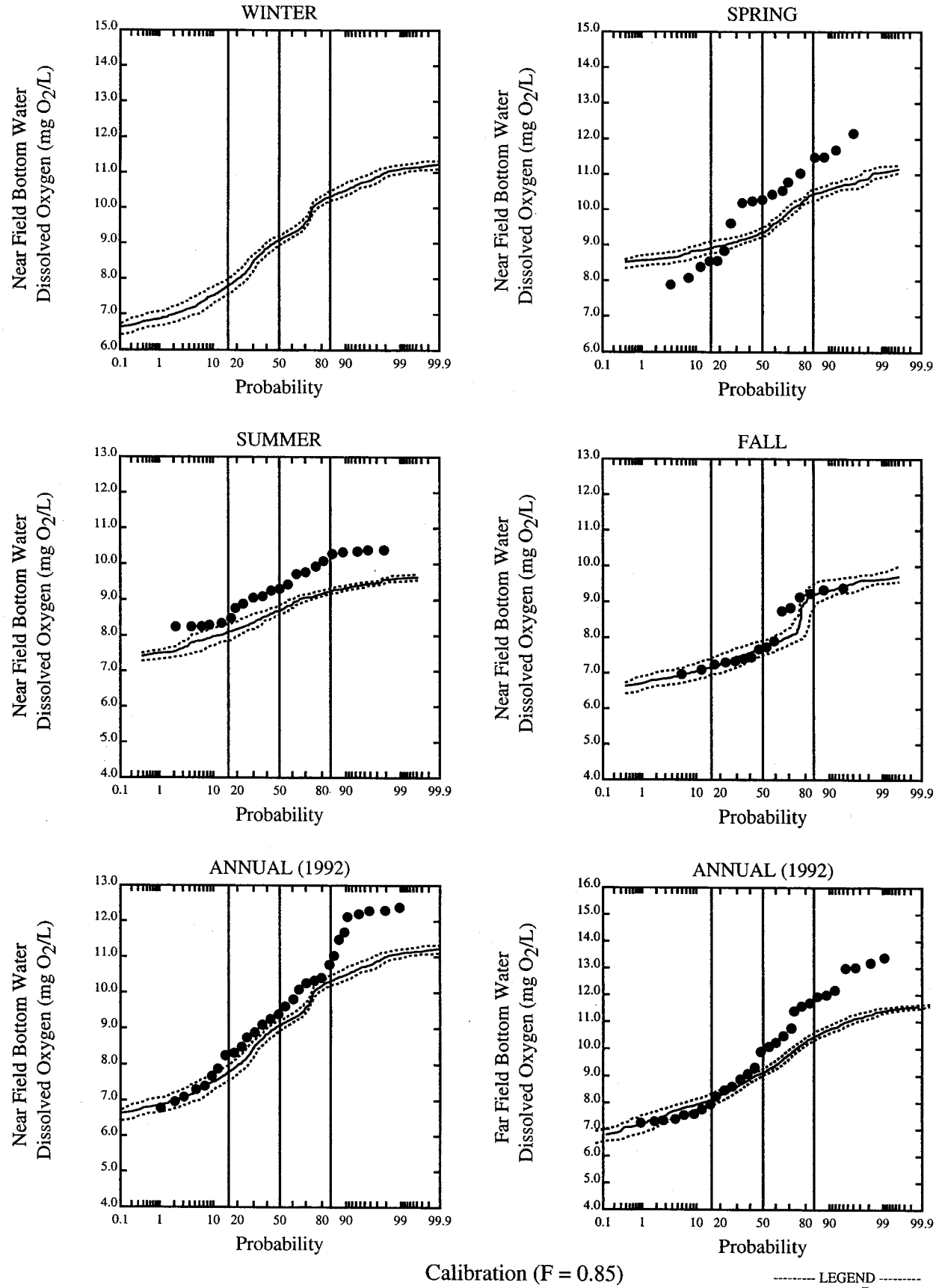

WINTER
SPRING
SUMMER
FALL
ANNUAL (1992)
ANNUAL (1992)
Near Field Surface DIN (mg/L)
Far Field Surface DIN (mg/L)
0.4
0.1
0.01
0.001
0.0001
0.1 1 10 20 50 80 90 99 99.9
Probability
Calibration (F = 0.85)
LEGEND
Data
Model
+Max/-Min

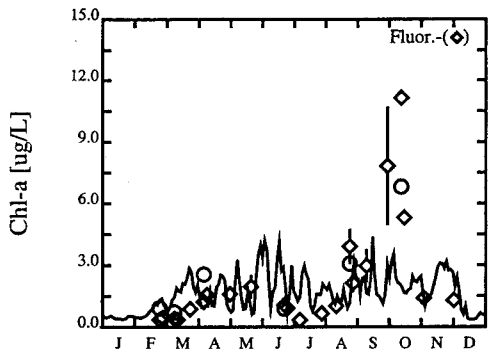

WINTER
SPRING
SUMMER
FALL
ANNUAL (1992)
ANNUAL (1992)
Near Field Surface PO4 (mg/L)
Far Field Surface PO4 (mg/L)
0.1
0.01
0.001
0.0001
0.1 1 10 20 50 80 90 99 99.9
Probability
Calibration (F = 0.85)
LEGEND
Data
Model
+Max/-Min

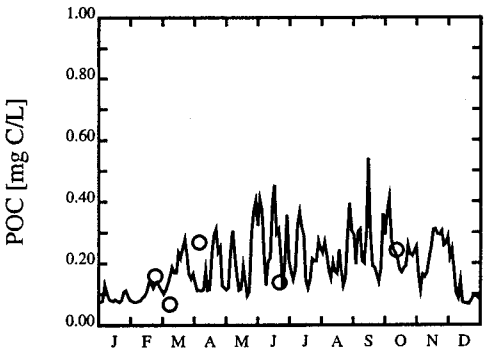

WINTER
SPRING
SUMMER
FALL
ANNUAL (1992)
ANNUAL (1992)
Near Field Surface DSi (mg/L)
Far Field Surface DSi (mg/L)
Probability
1
0.1
0.01
0.001
0.0001
0.1
1
10
20
50
80
90
99
99.9
Calibration (F = 0.85)
LEGEND
Data
Model
+Max/-Min

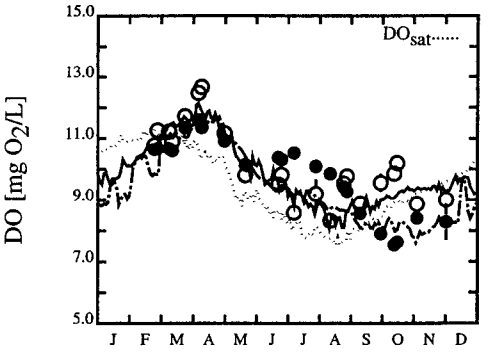

WINTER
SPRING
SUMMER
FALL
ANNUAL (1992)
ANNUAL (1992)
Near Field Surface Water Dissolved Oxygen (mg O2/L)
Far Field Surface Water Dissolved Oxygen (mg O2/L)
Probability
0.1 1 10 20 50 80 90 99 99.9
Calibration (F = 0.85)
LEGEND
Data
Model

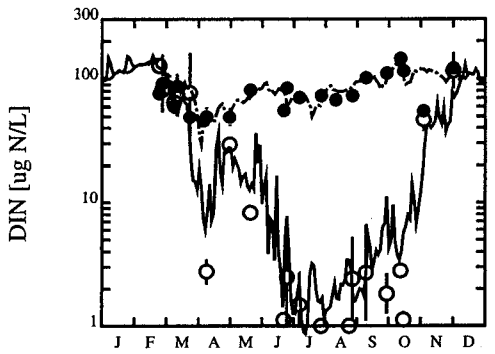

WINTER
SPRING
SUMMER
FALL
ANNUAL (1992)
ANNUAL (1992)
Near Field 12.5-17.5m Dissolved Oxygen (mg O2/L)
Far Field 12.5-17.5m Dissolved Oxygen (mg O2/L)
15.0
14.0
13.0
12.0
11.0
10.0
9.0
8.0
7.0
6.0
0.1 1 10 20 50 80 90 99 99.9
Probability
Calibration (F = 0.85)
LEGEND
Data
Model

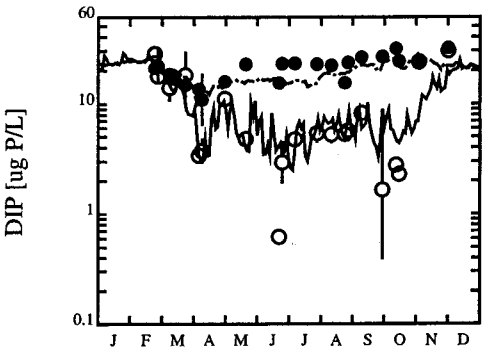

WINTER
SPRING
SUMMER
FALL
ANNUAL (1992)
ANNUAL (1992)
Near Field Bottom Water Dissolved Oxygen (mg O2/L)
Far Field Bottom Water Dissolved Oxygen (mg O2/L)
Probability
0.1 1 10 20 50 80 90 99 99.9
Calibration (F = 0.85)
LEGEND
Data
Model
+Max/-Min

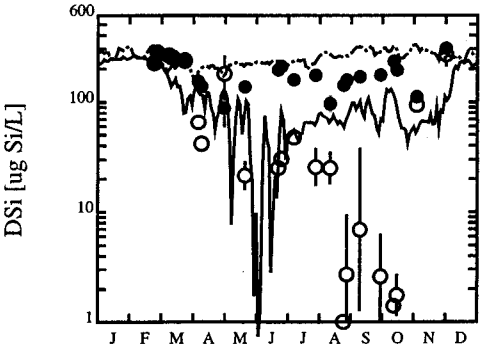


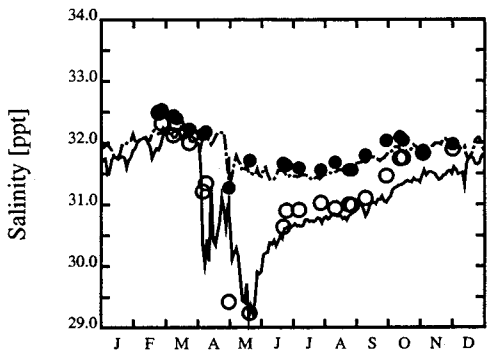


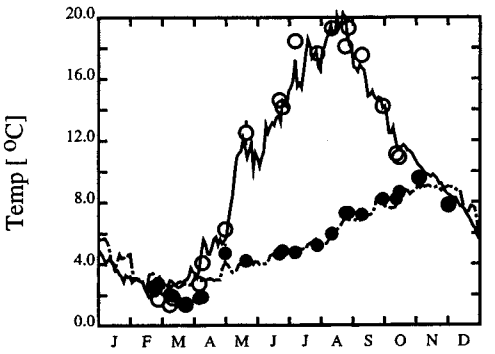


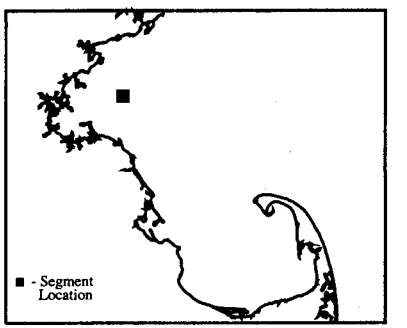


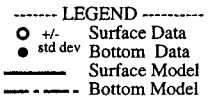






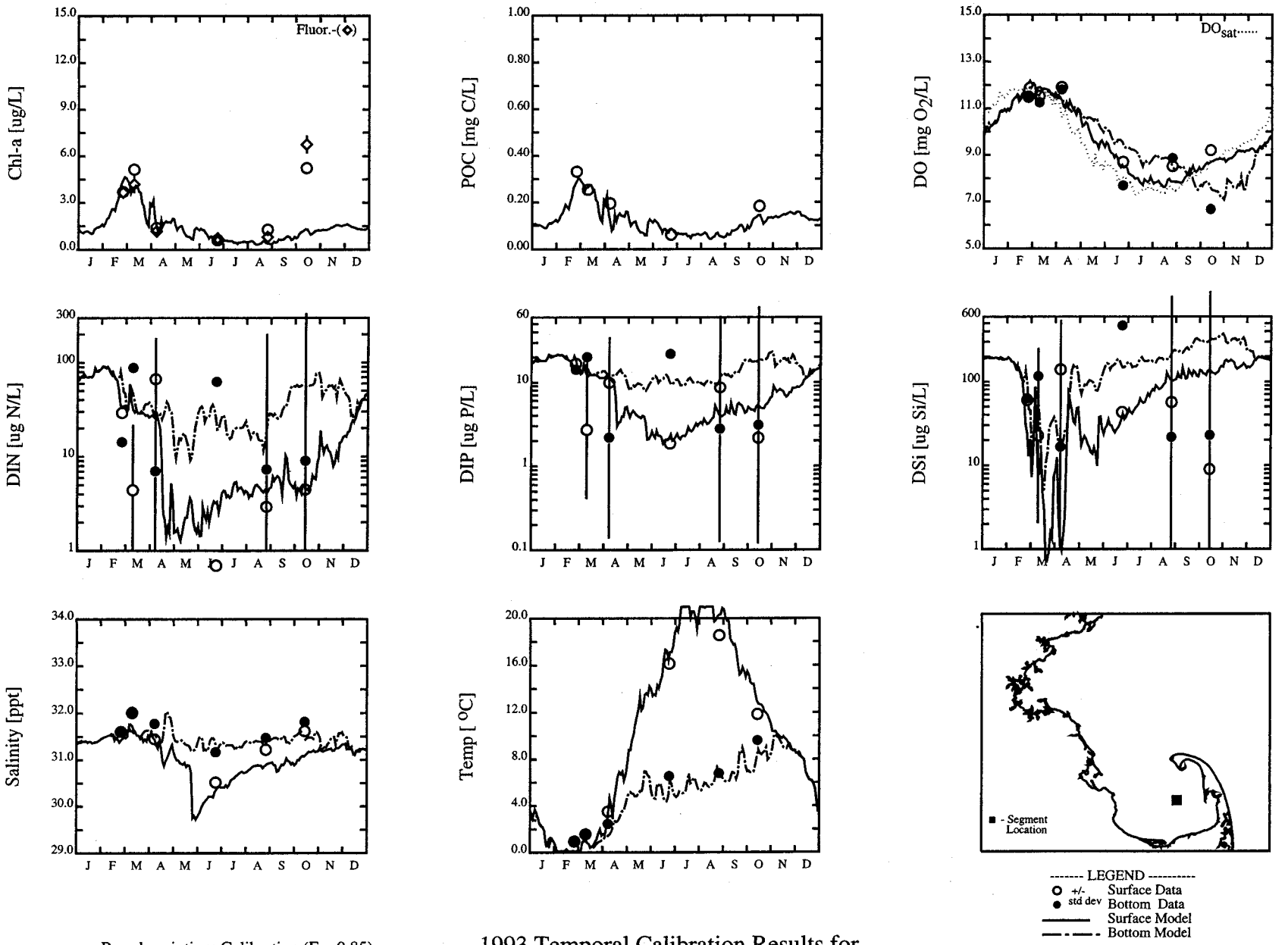






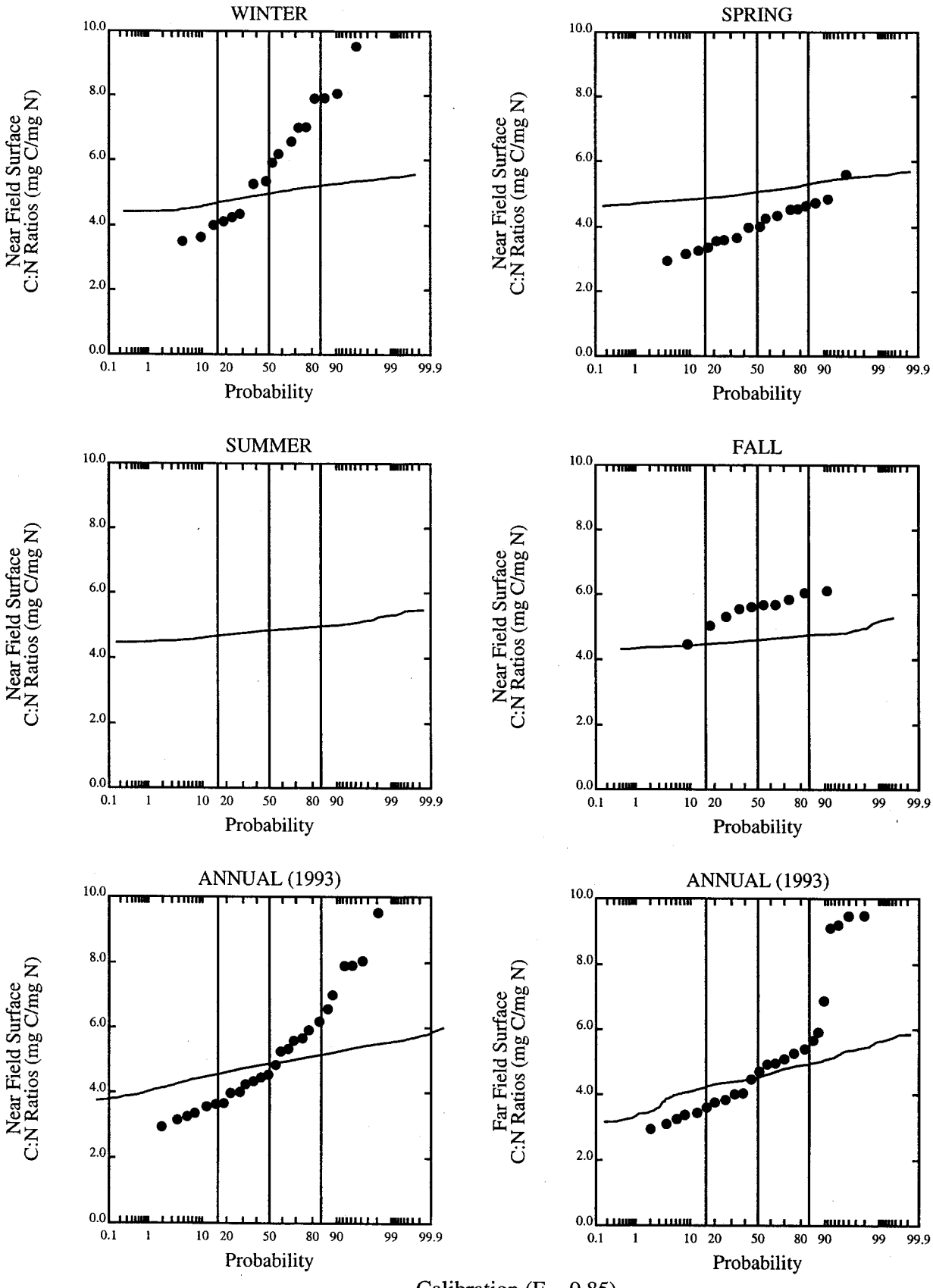
Run description: Calibration (F = 0.85)

1993 Temporal Calibration Results for
Grid Cell (11,18) Vs Data Station N16P,N17,N21

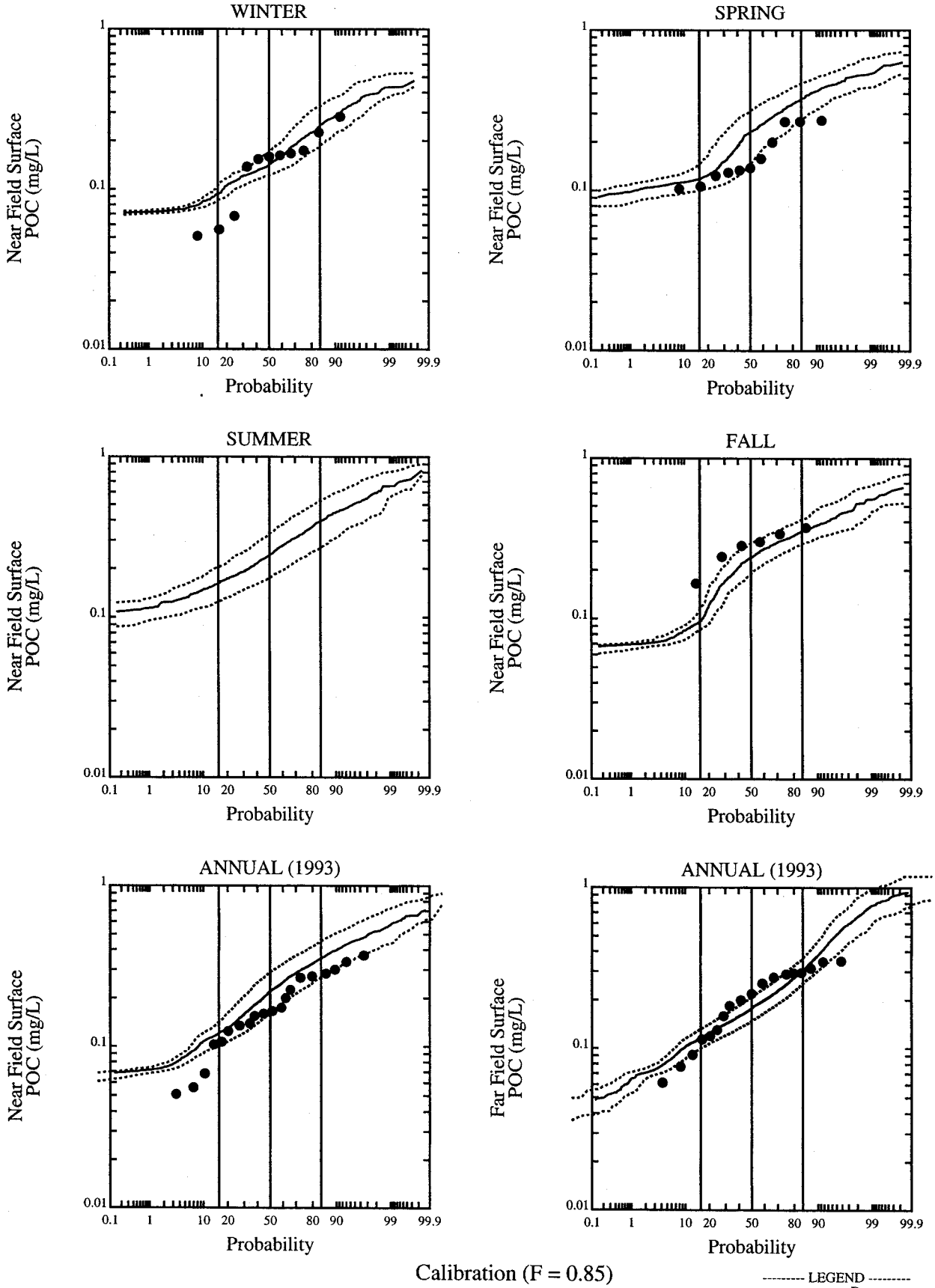


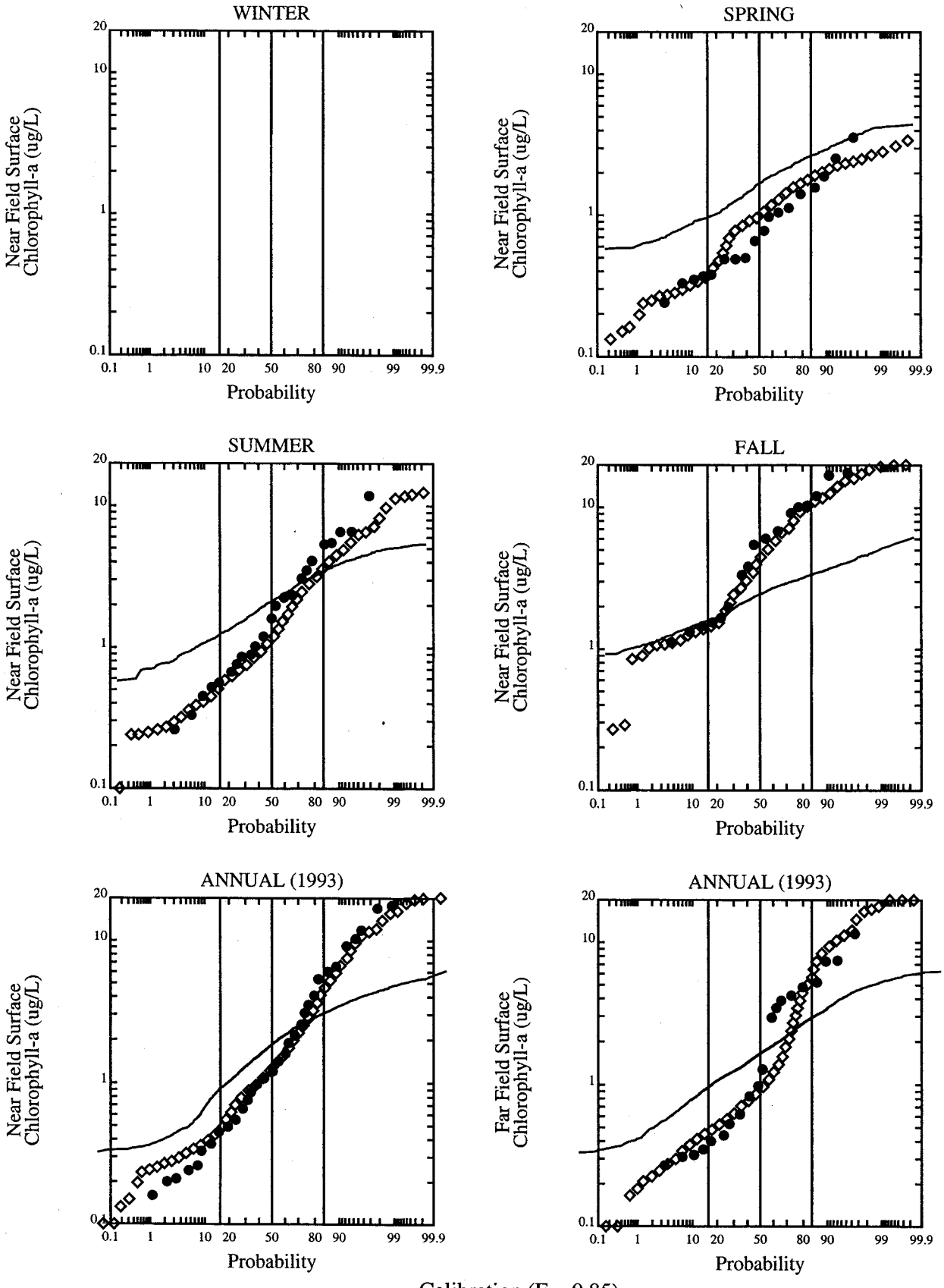
Run description: Calibration (F = 0.85)

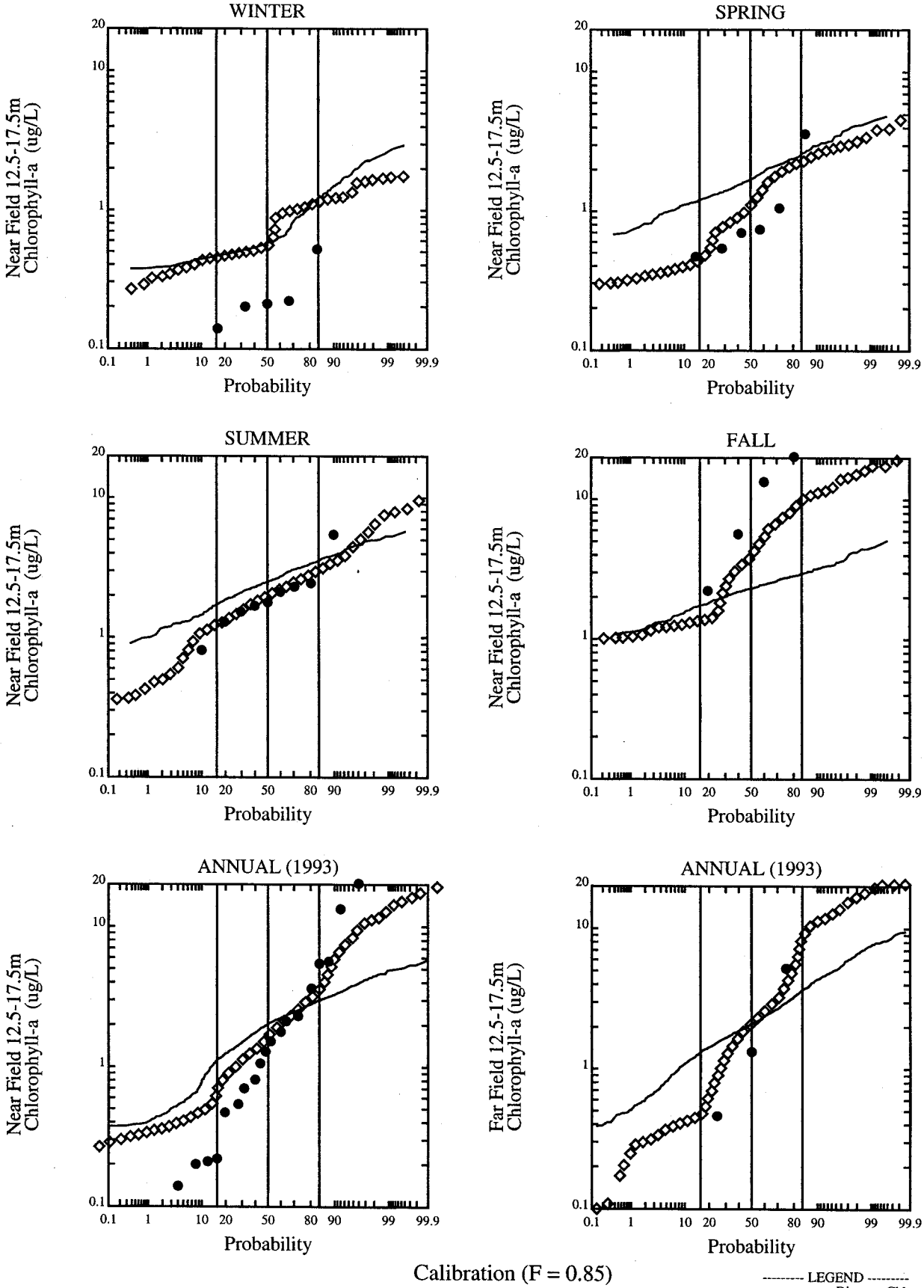
1993 Temporal Calibration Results for
Grid Cell (13,4) Vs Data Station F02P

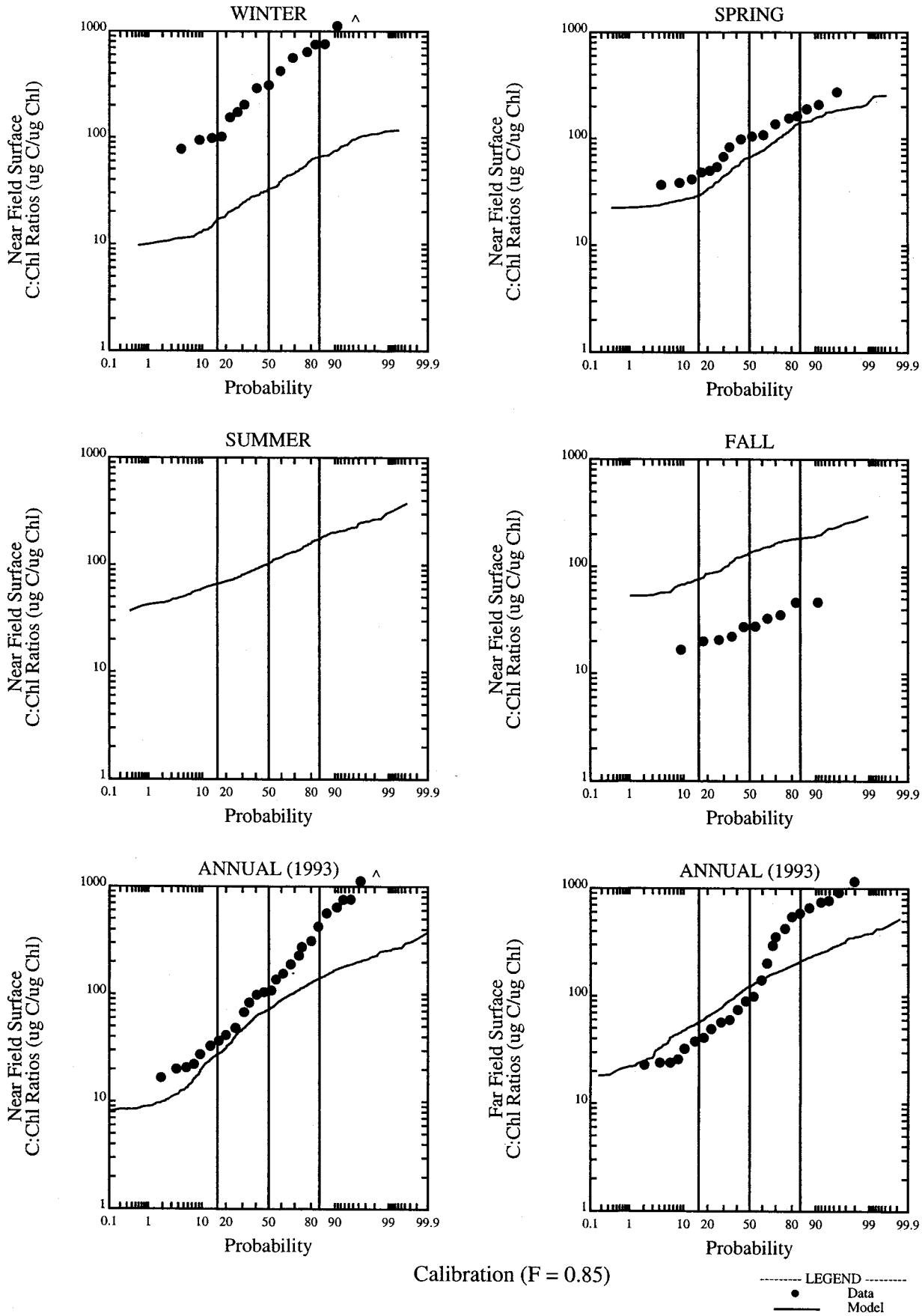


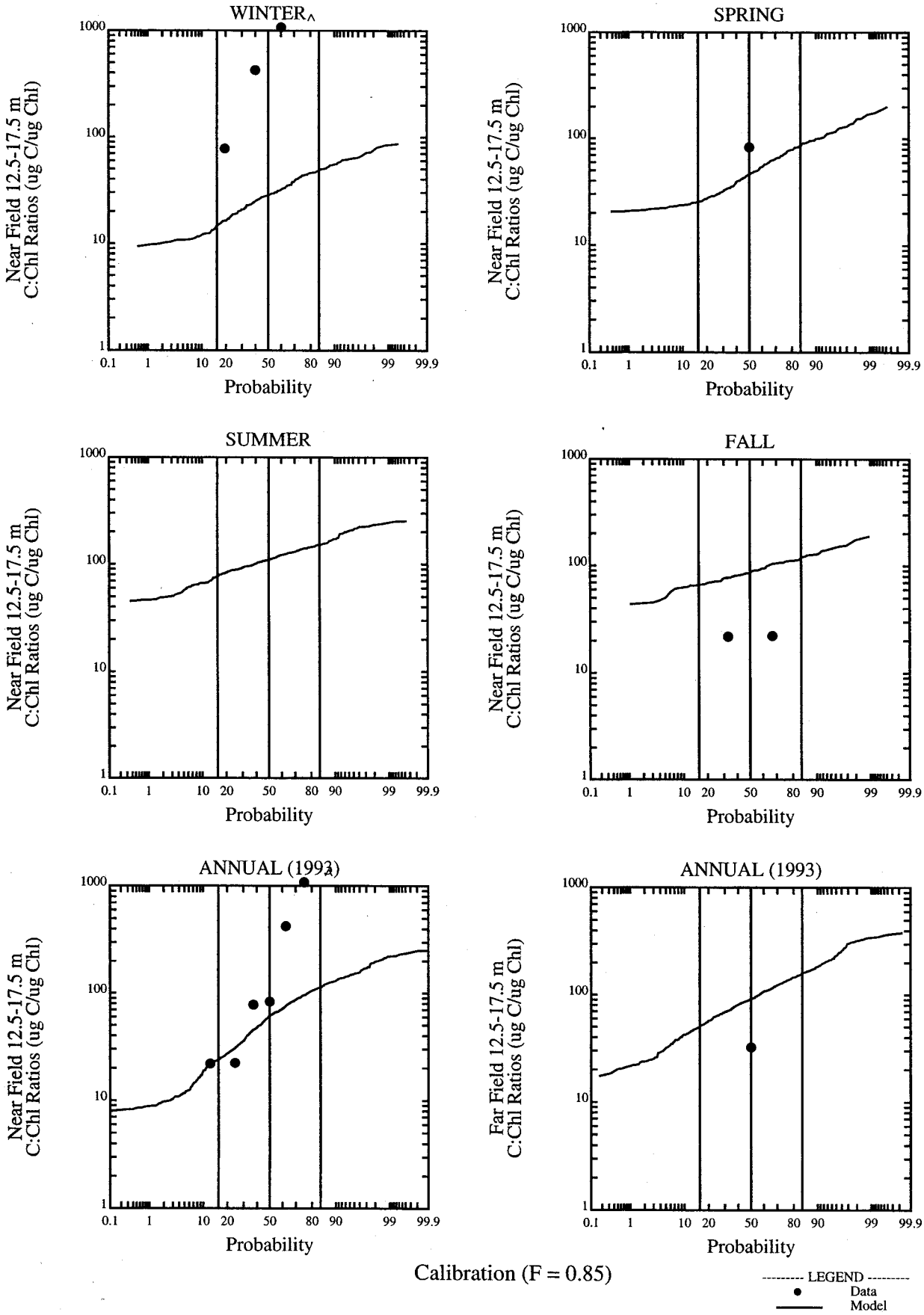
Calibration (F = 0.85)

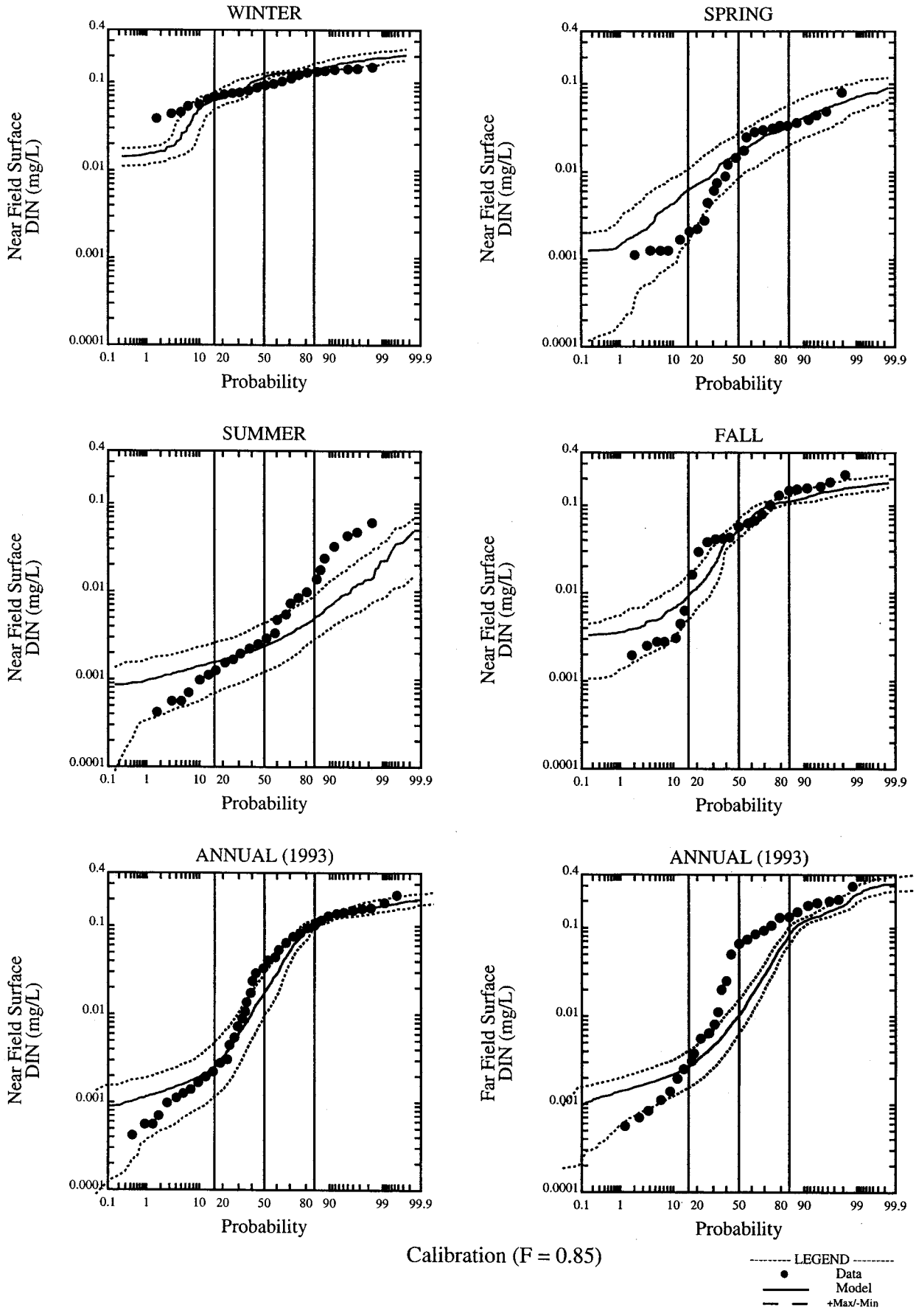

WINTER
SPRING
SUMMER
FALL
ANNUAL (1993)
ANNUAL (1993)
Near Field Surface POC (mg/L)
Far Field Surface POC (mg/L)
Probability
1
0.1
0.01
0.1 1 10 20 50 80 90 99 99.9
Calibration (F = 0.85)
LEGEND
Data
Model
+Max/-Min

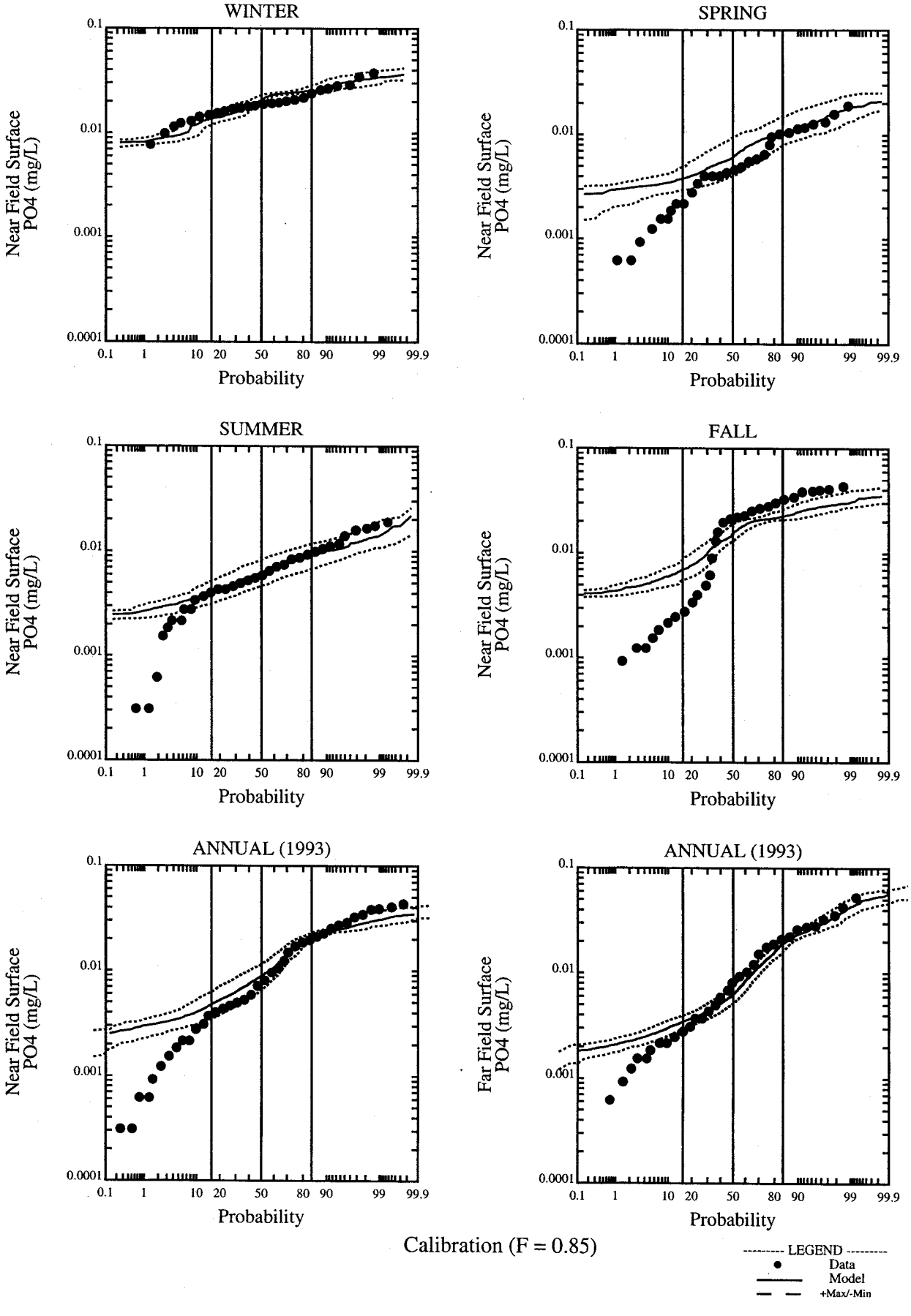

WINTER
SPRING
SUMMER
FALL
ANNUAL (1993)
ANNUAL (1993)
Near Field Surface Chlorophyll-a (ug/L)
Far Field Surface Chlorophyll-a (ug/L)
Probability
20
10
1
0.1
0.1 1 10 20 50 80 90 99 99.9
Calibration (F = 0.85)
-------- LEGEND --------
Discrete Chl-a
Fluorometric Chl-a
Model

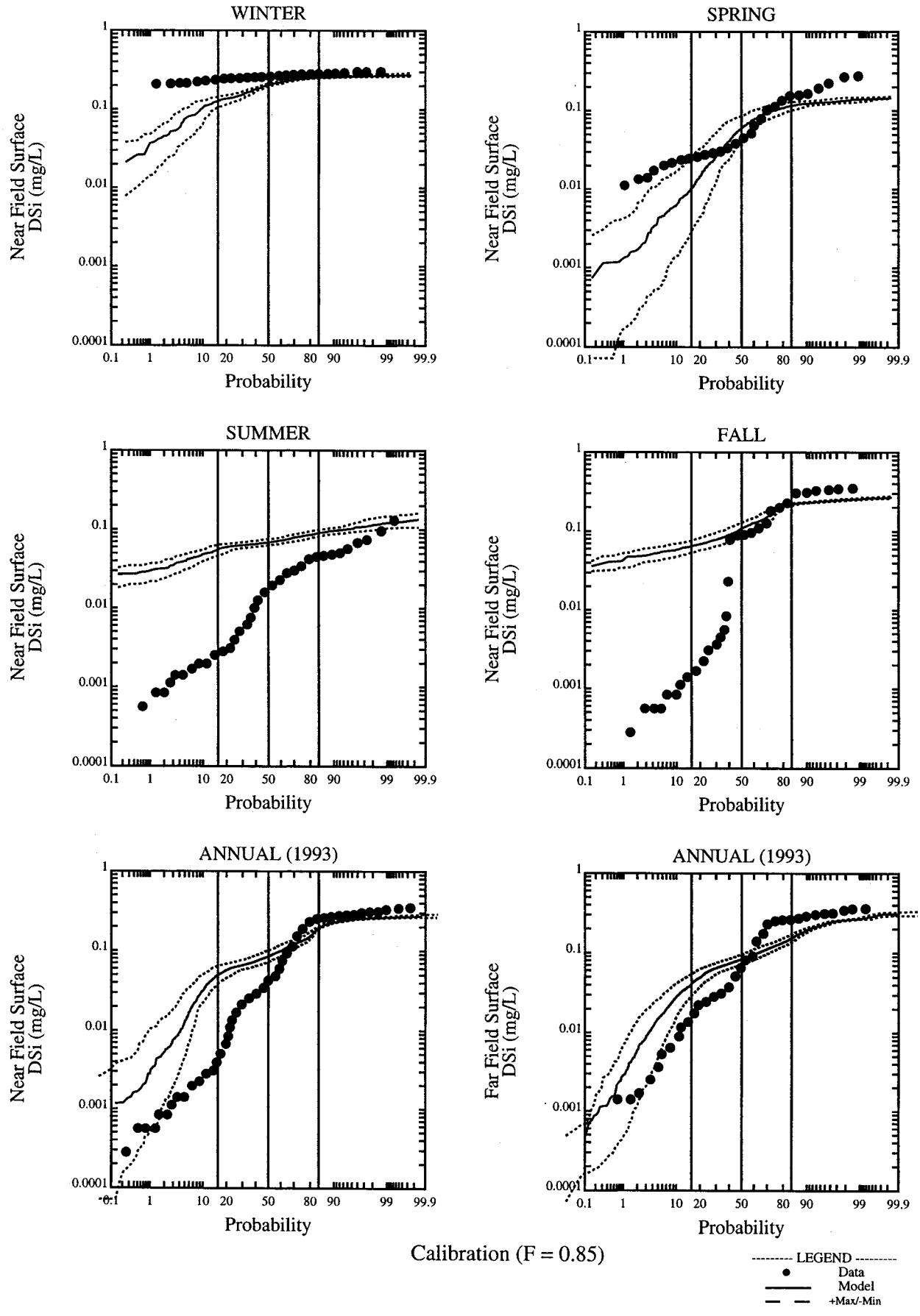

WINTER
SPRING
SUMMER
FALL
ANNUAL (1993)
ANNUAL (1993)
Near Field 12.5-17.5m Chlorophyll-a (ug/L)
Far Field 12.5-17.5m Chlorophyll-a (ug/L)
Probability
0.1
1
10
20
50
80
90
99
99.9
Calibration (F = 0.85)
LEGEND
Discrete Chl-a
Fluorometric Chl-a
Model

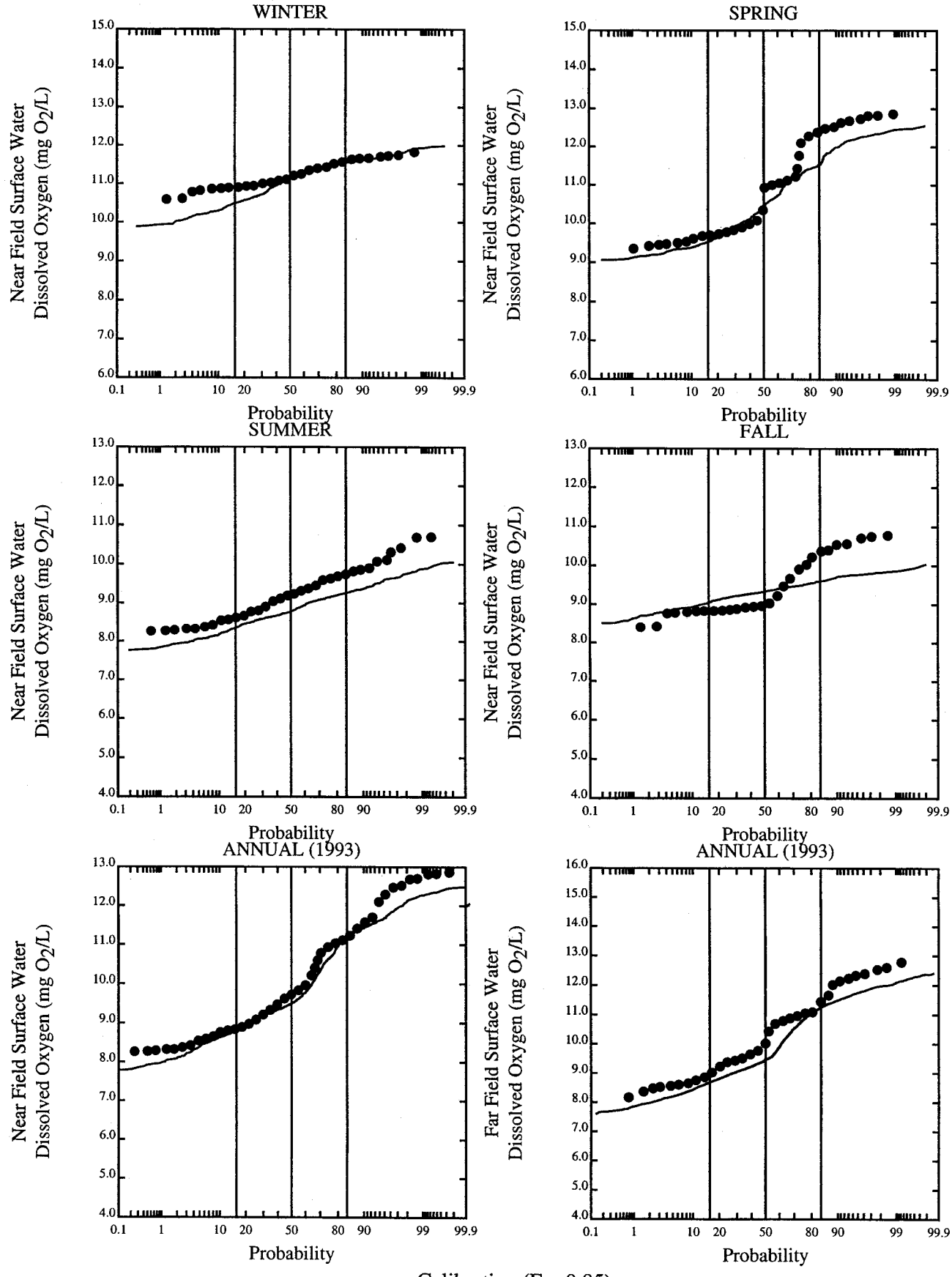

WINTER
SPRING
SUMMER
FALL
ANNUAL (1993)
ANNUAL (1993)
Near Field Surface C:Chl Ratios (ug C/ug Chl)
Far Field Surface C:Chl Ratios (ug C/ug Chl)
Probability
1000
100
10
1
0.1
1
10
20
50
80
90
99
99.9
Calibration (F = 0.85)
LEGEND
Data
Model


WINTER
SPRING
SUMMER
FALL
ANNUAL (1992)
ANNUAL (1993)
Near Field 12.5-17.5 m C:Chl Ratios (ug C/ug Chl)
Far Field 12.5-17.5 m C:Chl Ratios (ug C/ug Chl)
1000
100
10
1
0.1 1 10 20 50 80 90 99 99.9
Probability
Calibration (F = 0.85)
LEGEND
Data
Model

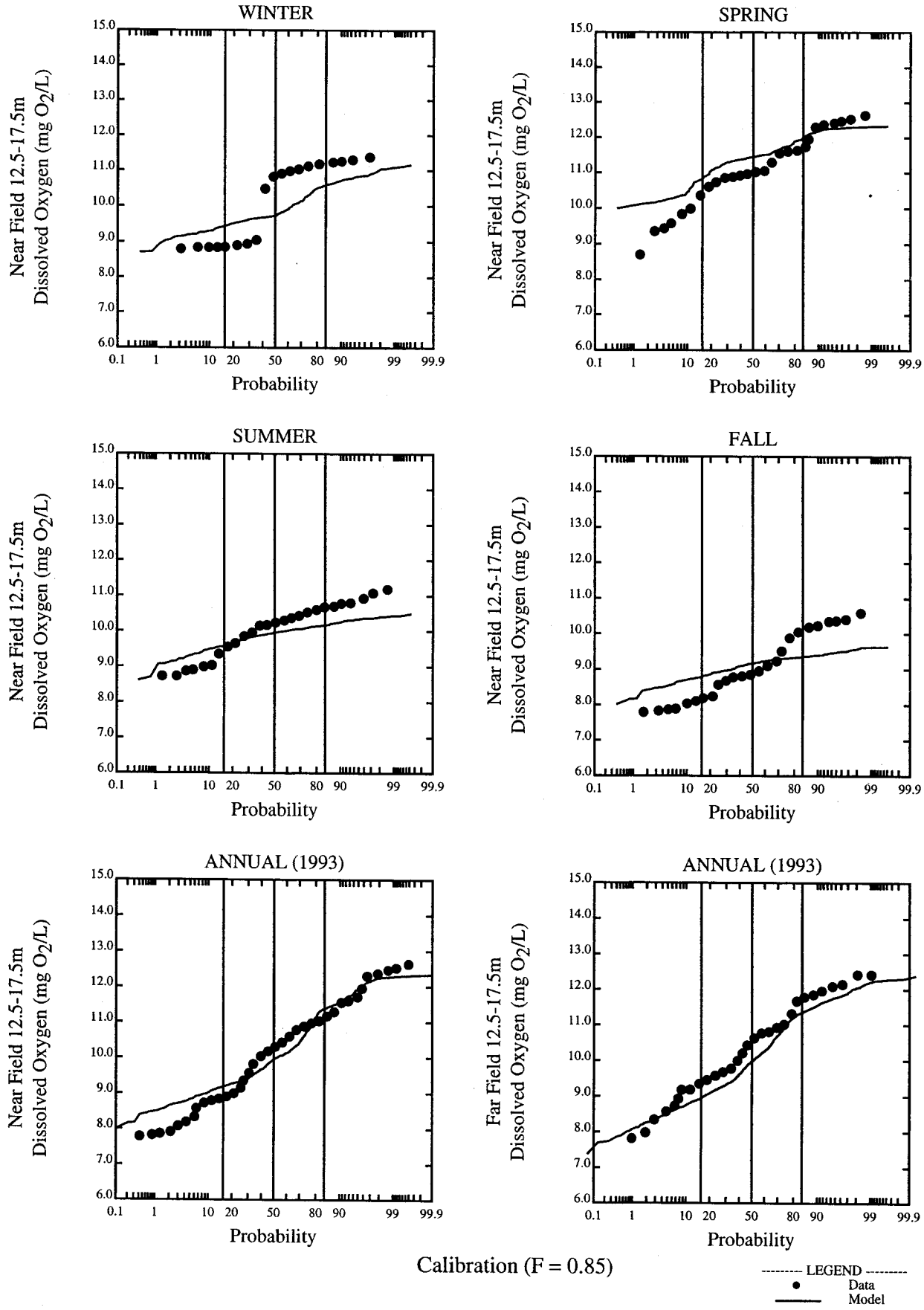

WINTER
SPRING
SUMMER
FALL
ANNUAL (1993)
ANNUAL (1993)
Near Field Surface DIN (mg/L)
Far Field Surface DIN (mg/L)
0.4
0.1
0.01
0.001
0.0001
0.1 1 10 20 50 80 90 99 99.9
Probability
Calibration (F = 0.85)
LEGEND
Data
Model
+Max/-Min

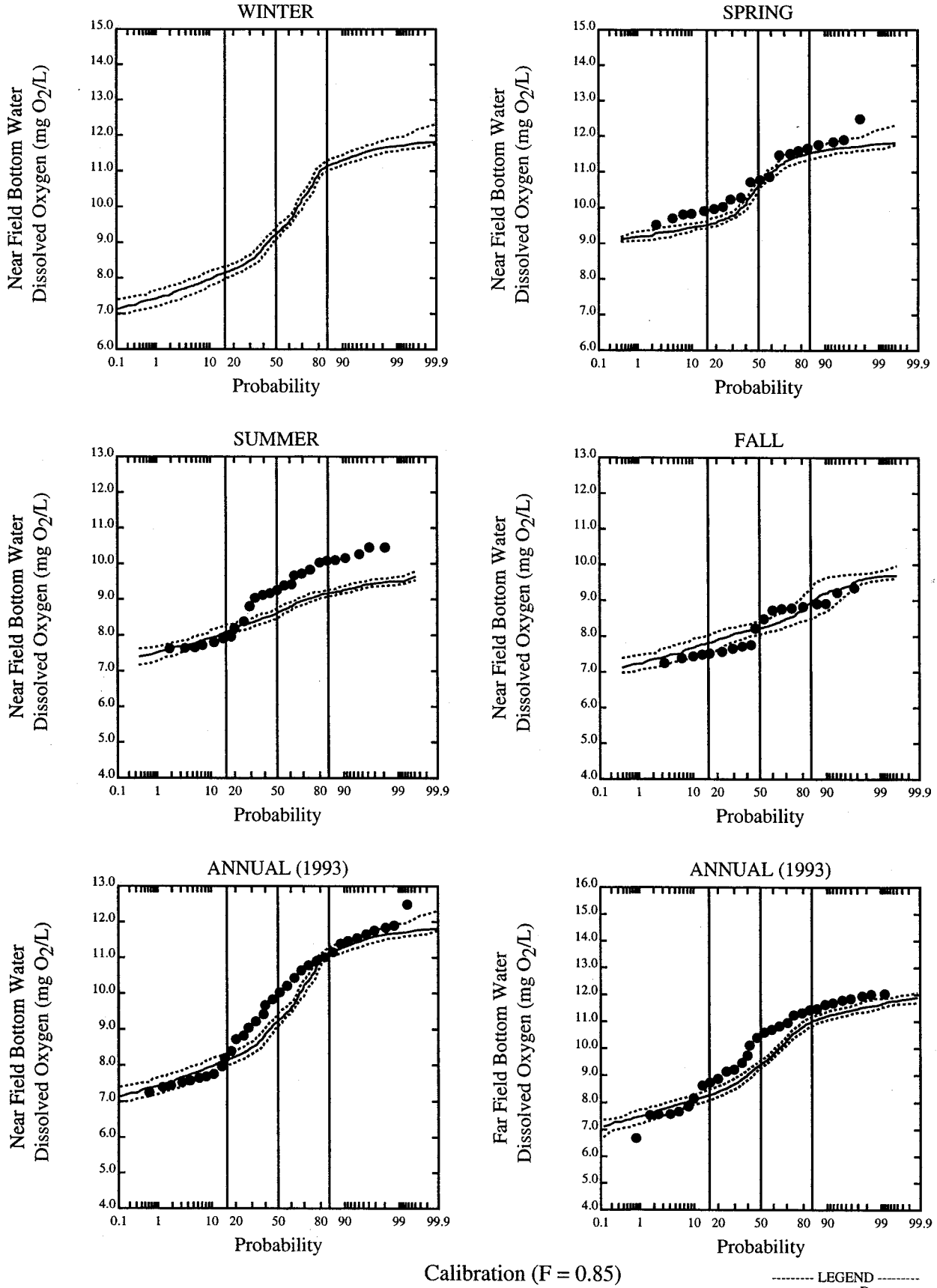

WINTER
SPRING
SUMMER
FALL
ANNUAL (1993)
ANNUAL (1993)
Near Field Surface PO4 (mg/L)
Far Field Surface PO4 (mg/L)
0.1
0.01
0.001
0.0001
0.1 1 10 20 50 80 90 99 99.9
Probability
Calibration (F = 0.85)
LEGEND
Data
Model
+Max/-Min

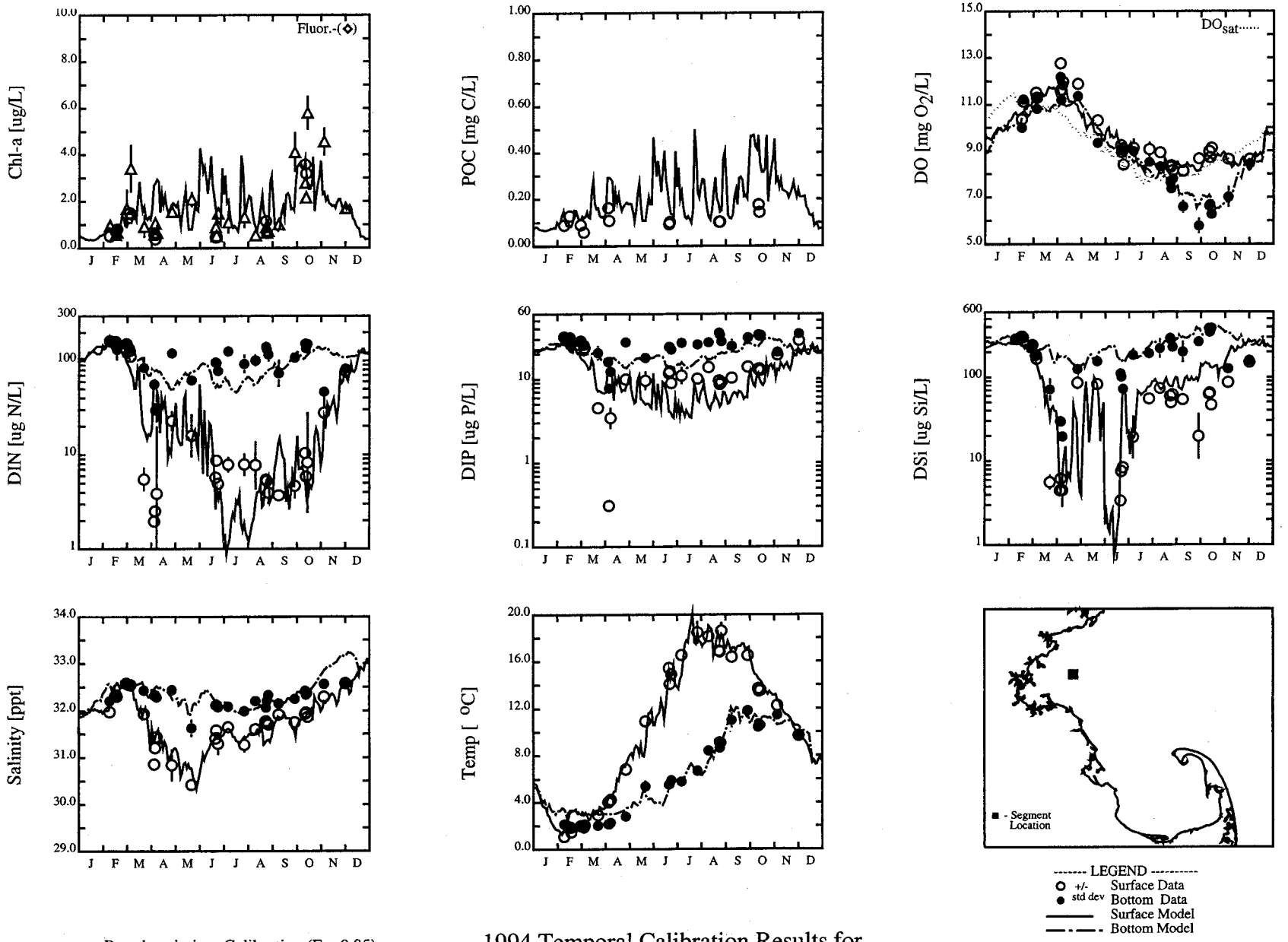

WINTER
SPRING
SUMMER
FALL
ANNUAL (1993)
ANNUAL (1993)
Near Field Surface DSi (mg/L)
Far Field Surface DSi (mg/L)
Probability
1
0.1
0.01
0.001
0.0001
0.1
1
10
20
50
80
90
99
99.9
Calibration (F = 0.85)
LEGEND
Data
Model
+Max/-Min



Calibration (F = 0.85)

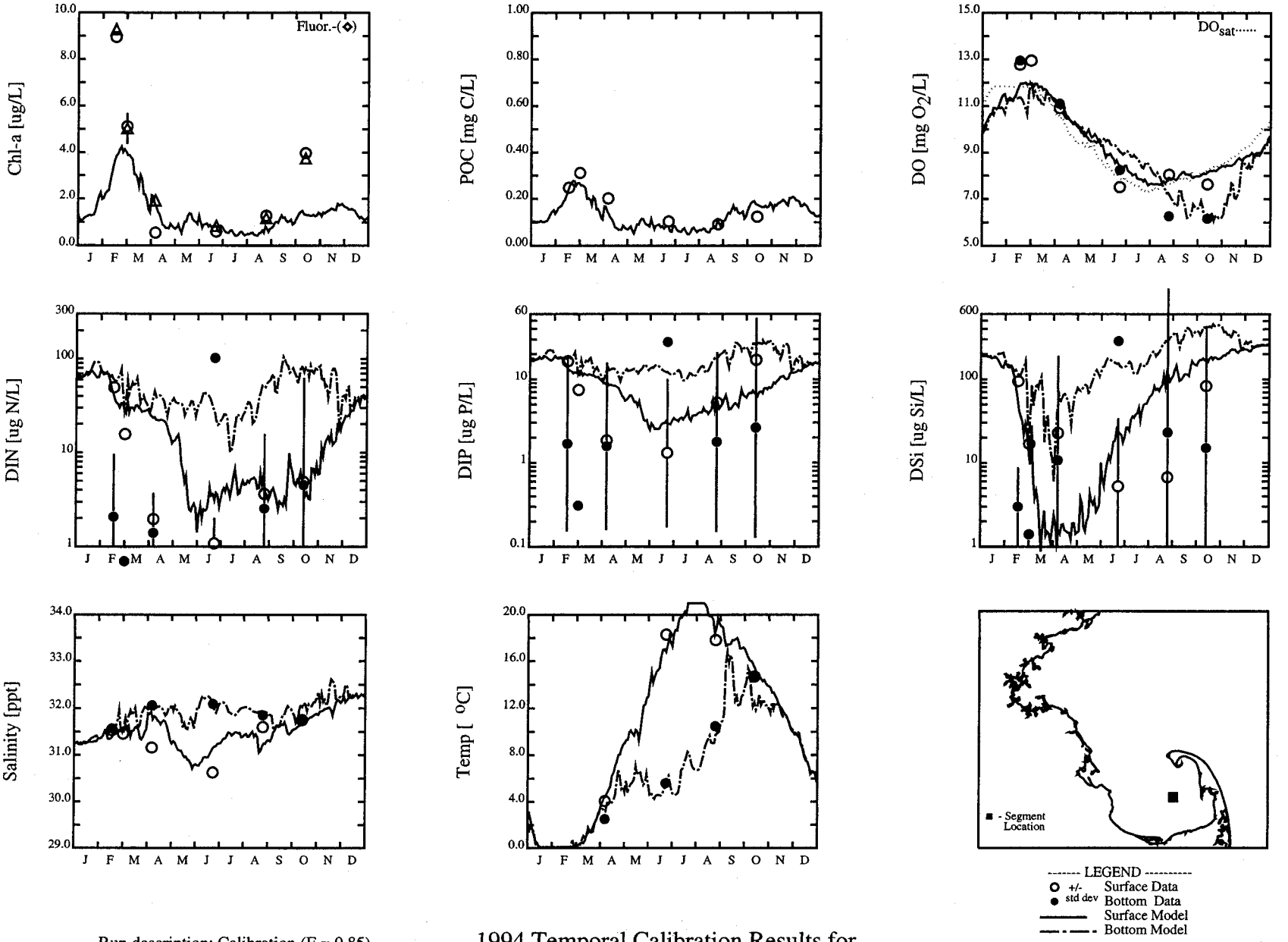

WINTER
SPRING
SUMMER
FALL
ANNUAL (1993)
ANNUAL (1993)
Near Field 12.5-17.5m Dissolved Oxygen (mg O2/L)
Far Field 12.5-17.5m Dissolved Oxygen (mg O2/L)
15.0
14.0
13.0
12.0
11.0
10.0
9.0
8.0
7.0
6.0
0.1
1
10
20
50
80
90
99
99.9
Probability
Calibration (F = 0.85)
LEGEND
Data
Model


WINTER
SPRING
SUMMER
FALL
ANNUAL (1993)
ANNUAL (1993)
Near Field Bottom Water Dissolved Oxygen (mg O2/L)
Far Field Bottom Water Dissolved Oxygen (mg O2/L)
Probability
0.1 1 10 20 50 80 90 99 99.9
Calibration (F = 0.85)
LEGEND
Data
Model
+Max/-Min



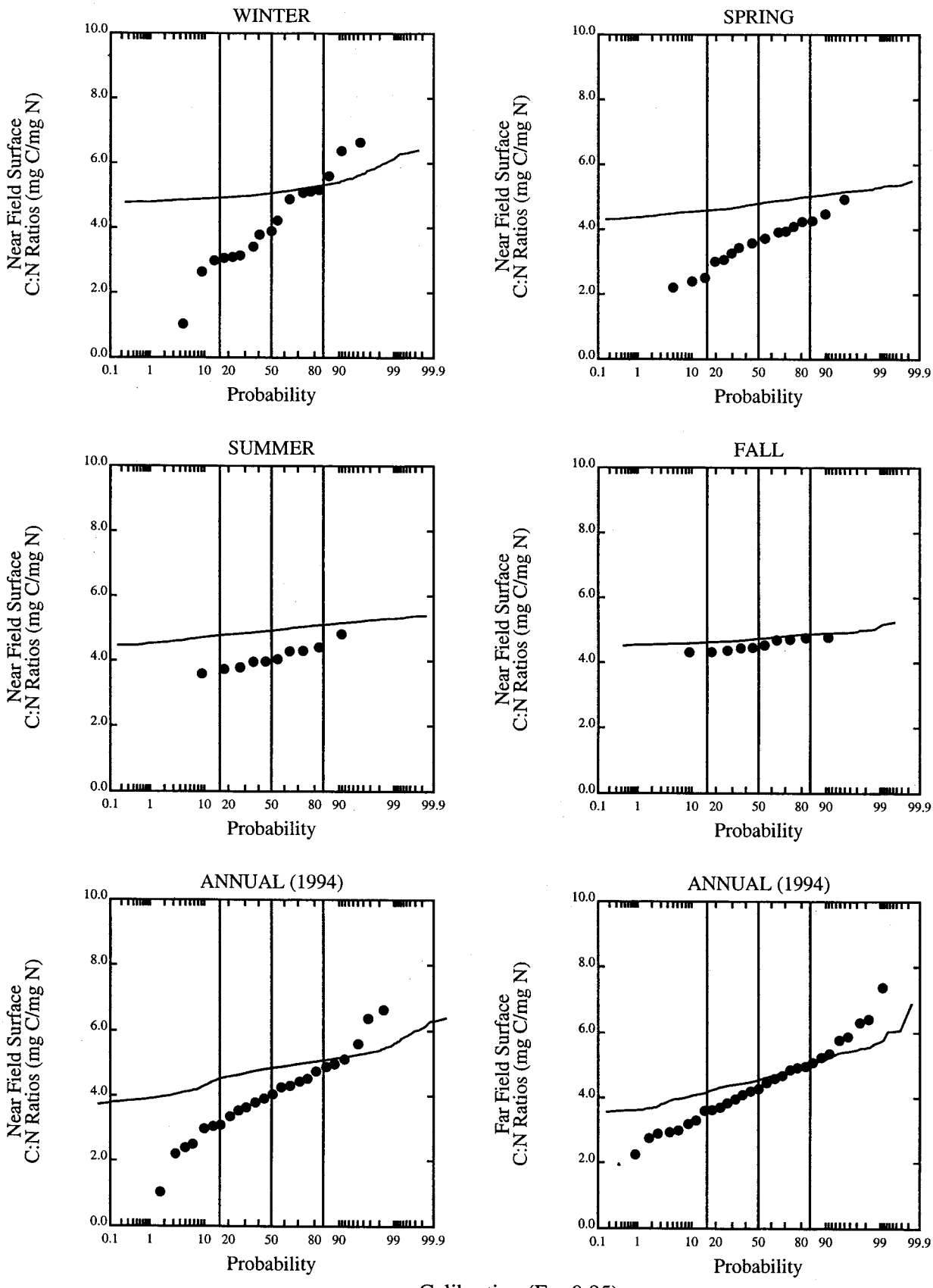
Run description: Calibration (F = 0.85)

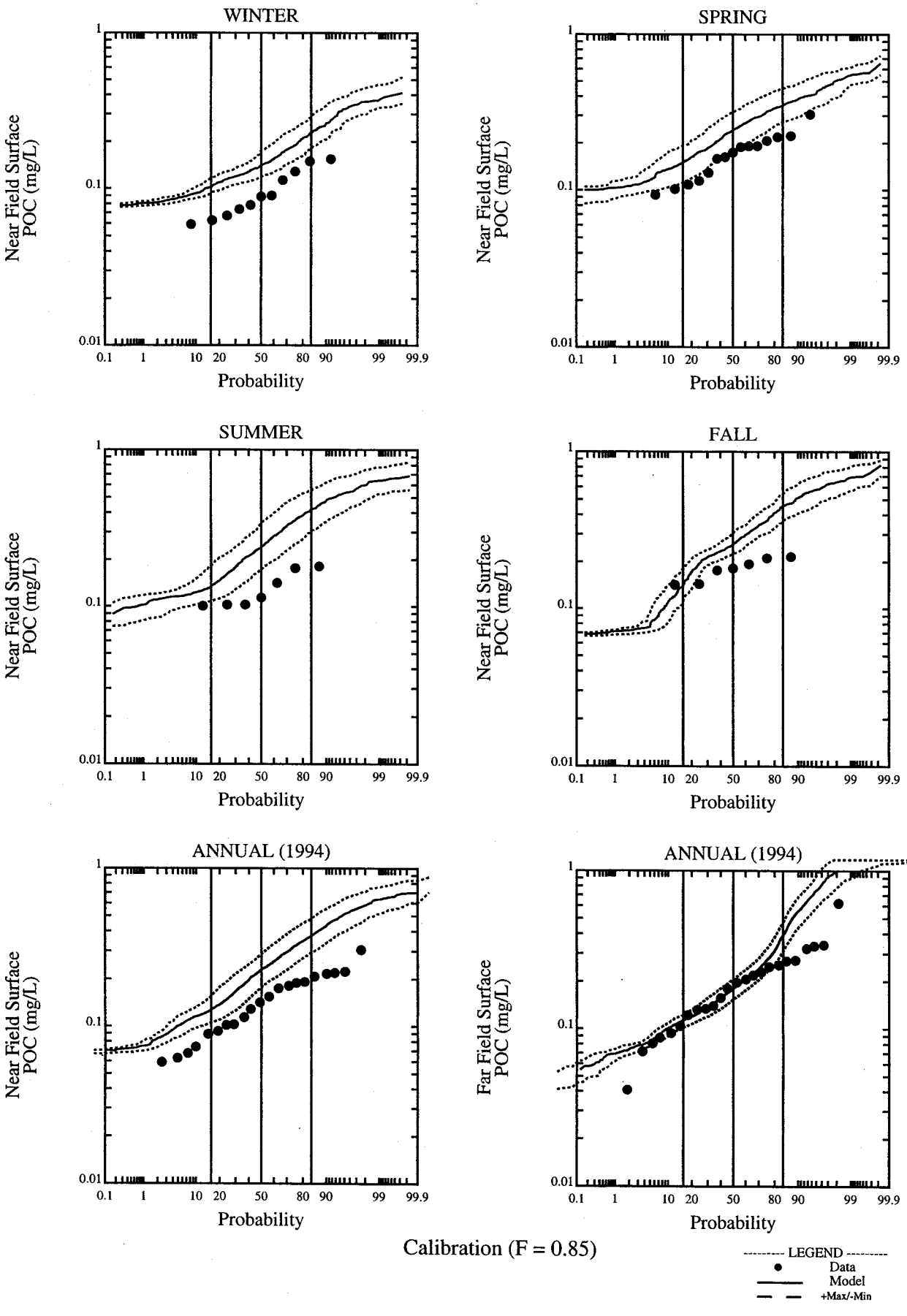
1994 Temporal Calibration Results for
Grid Cell (11,18) Vs Data Station N16P,N17,N21

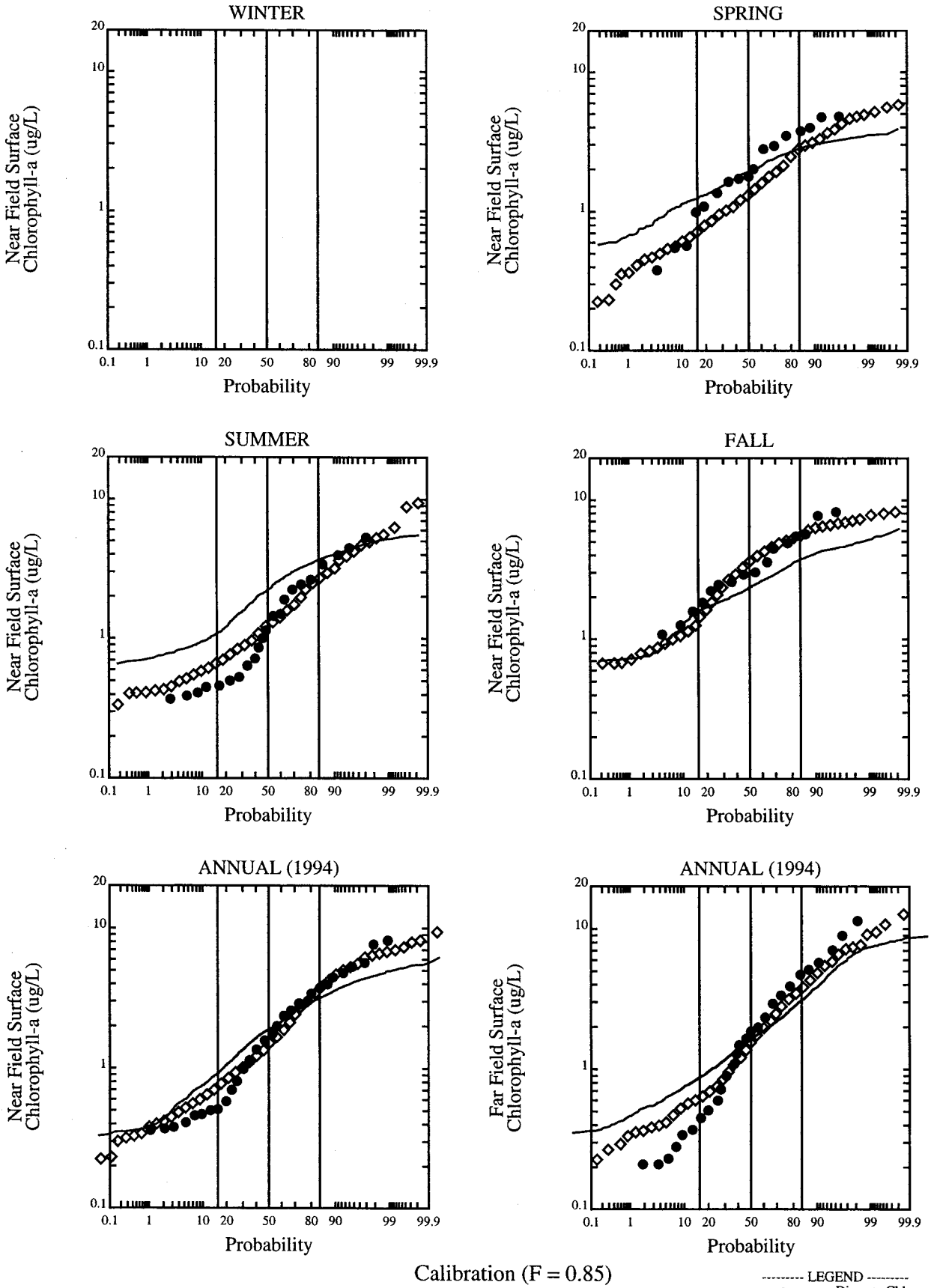


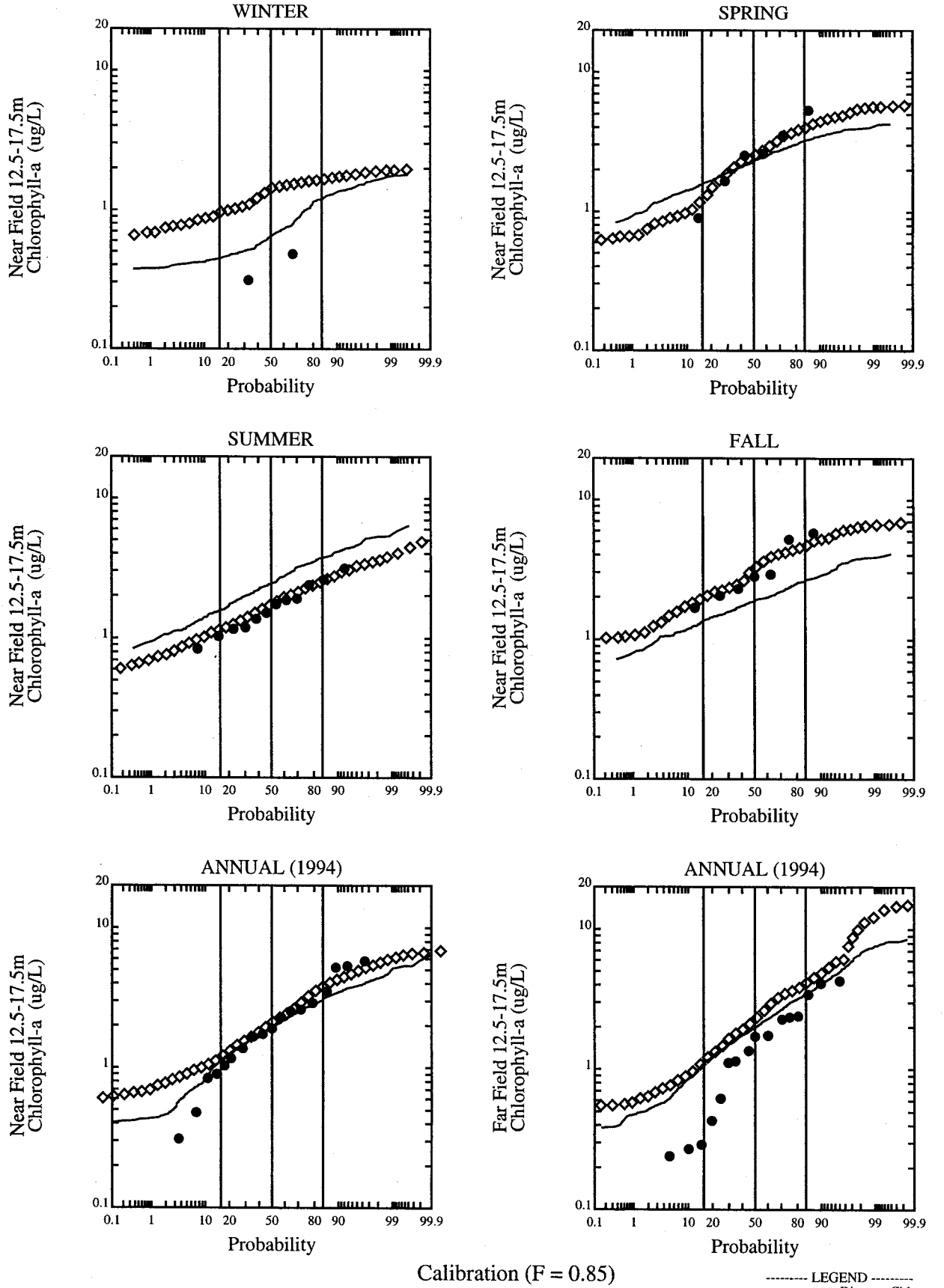
Run description: Calibration (F = 0.85)

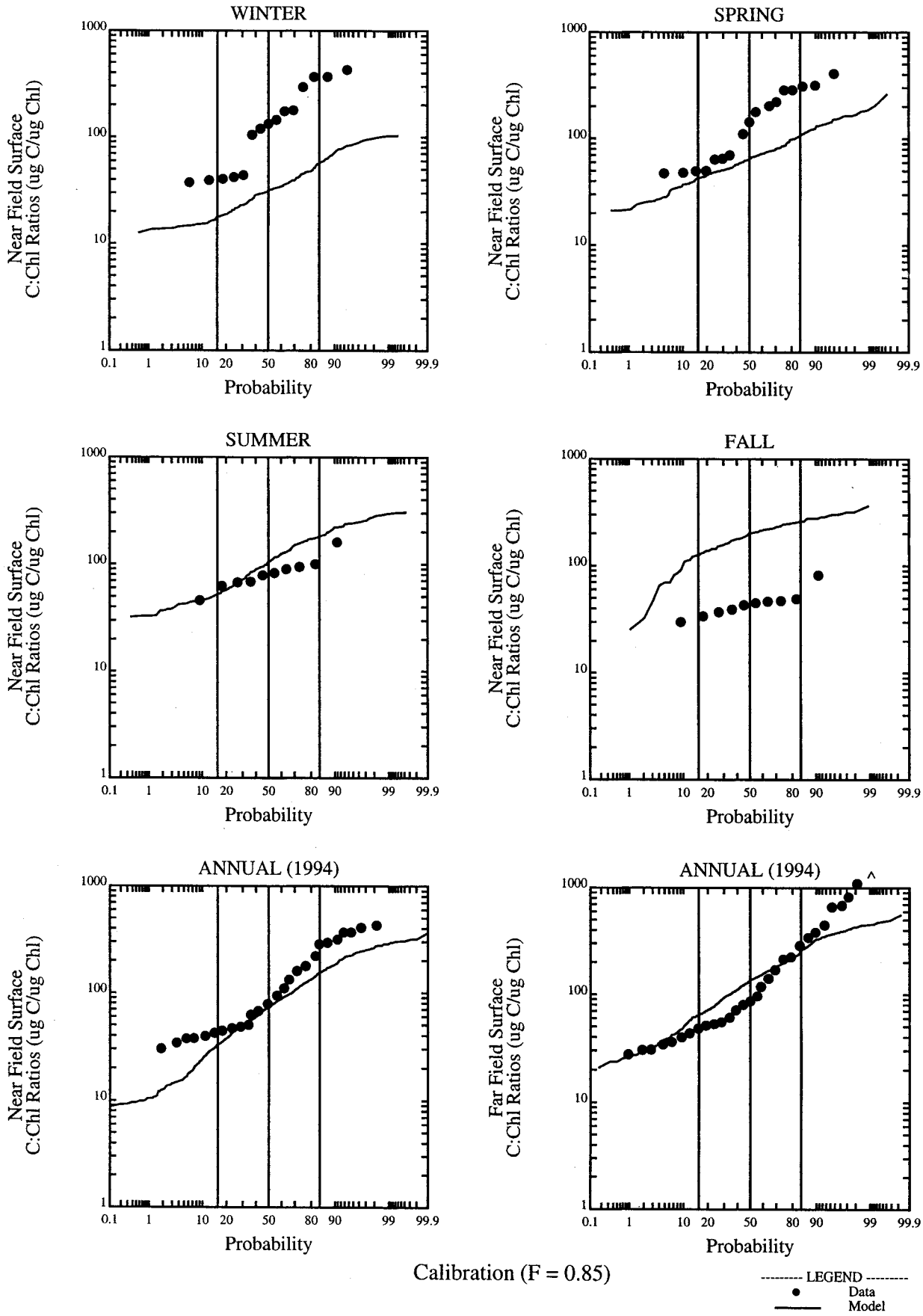
1994 Temporal Calibration Results for
Grid Cell (13,04) Vs Data Station F02P

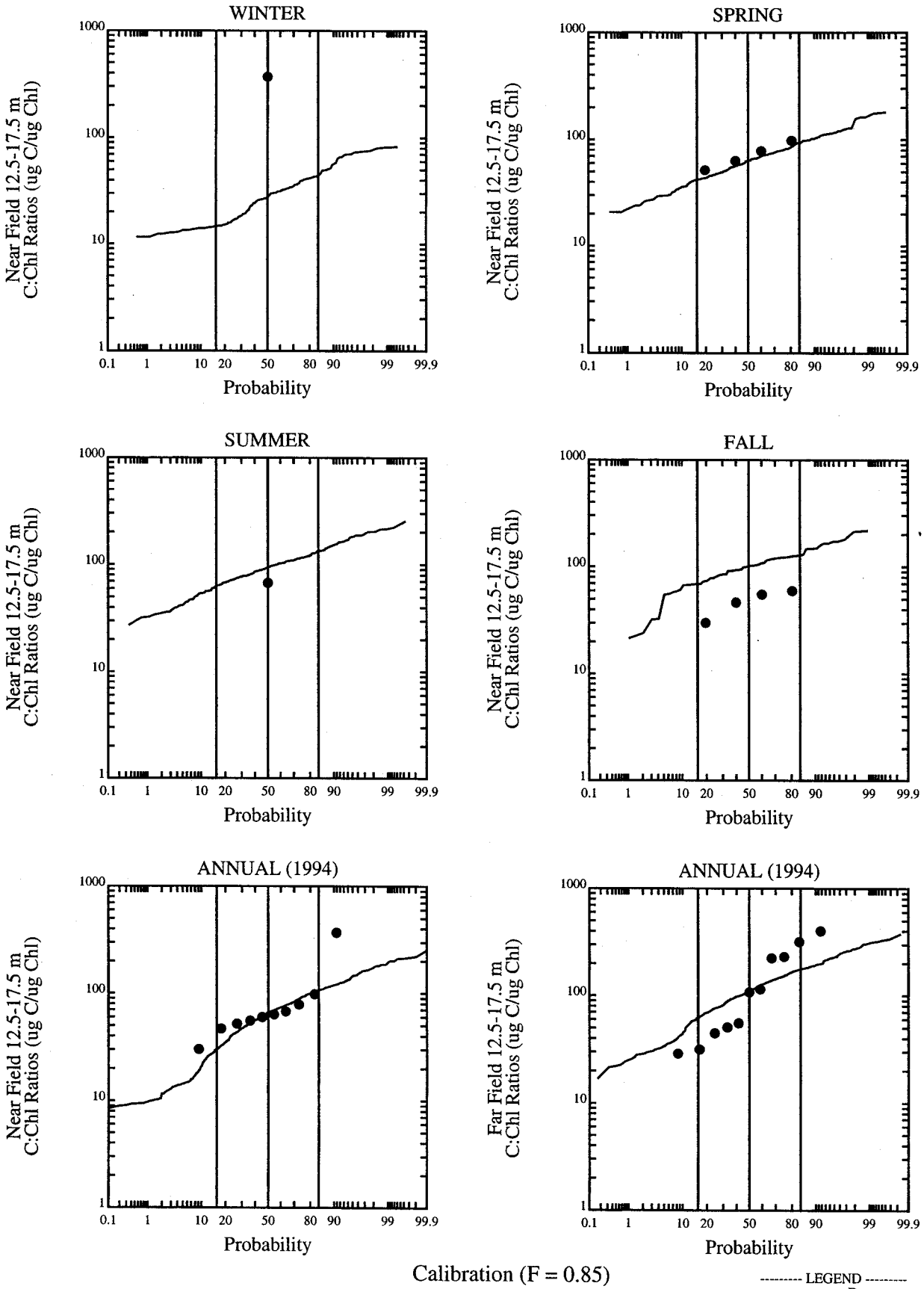

WINTER
SPRING
SUMMER
FALL
ANNUAL (1994)
ANNUAL (1994)
Near Field Surface C:N Ratios (mg C/mg N)
Far Field Surface C:N Ratios (mg C/mg N)
Probability
0.0
2.0
4.0
6.0
8.0
10.0
0.1
1
10
20
50
80
90
99
99.9
Calibration (F = 0.85)
LEGEND
Data
Model

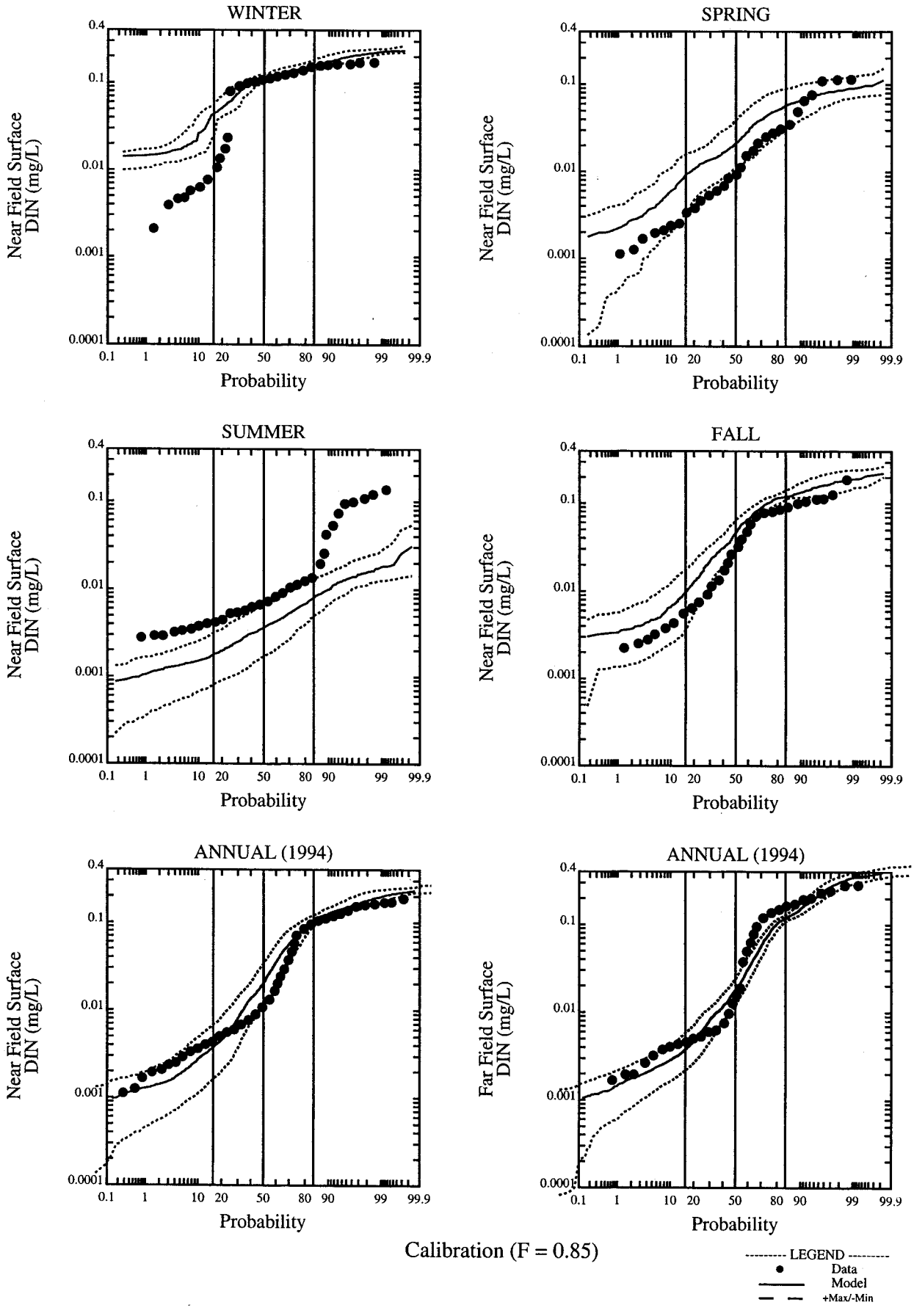

WINTER
SPRING
SUMMER
FALL
ANNUAL (1994)
ANNUAL (1994)
Near Field Surface POC (mg/L)
Far Field Surface POC (mg/L)
Probability
1
0.1
0.01
0.1 1 10 20 50 80 90 99 99.9
Calibration (F = 0.85)
LEGEND
Data
Model
+Max/-Min

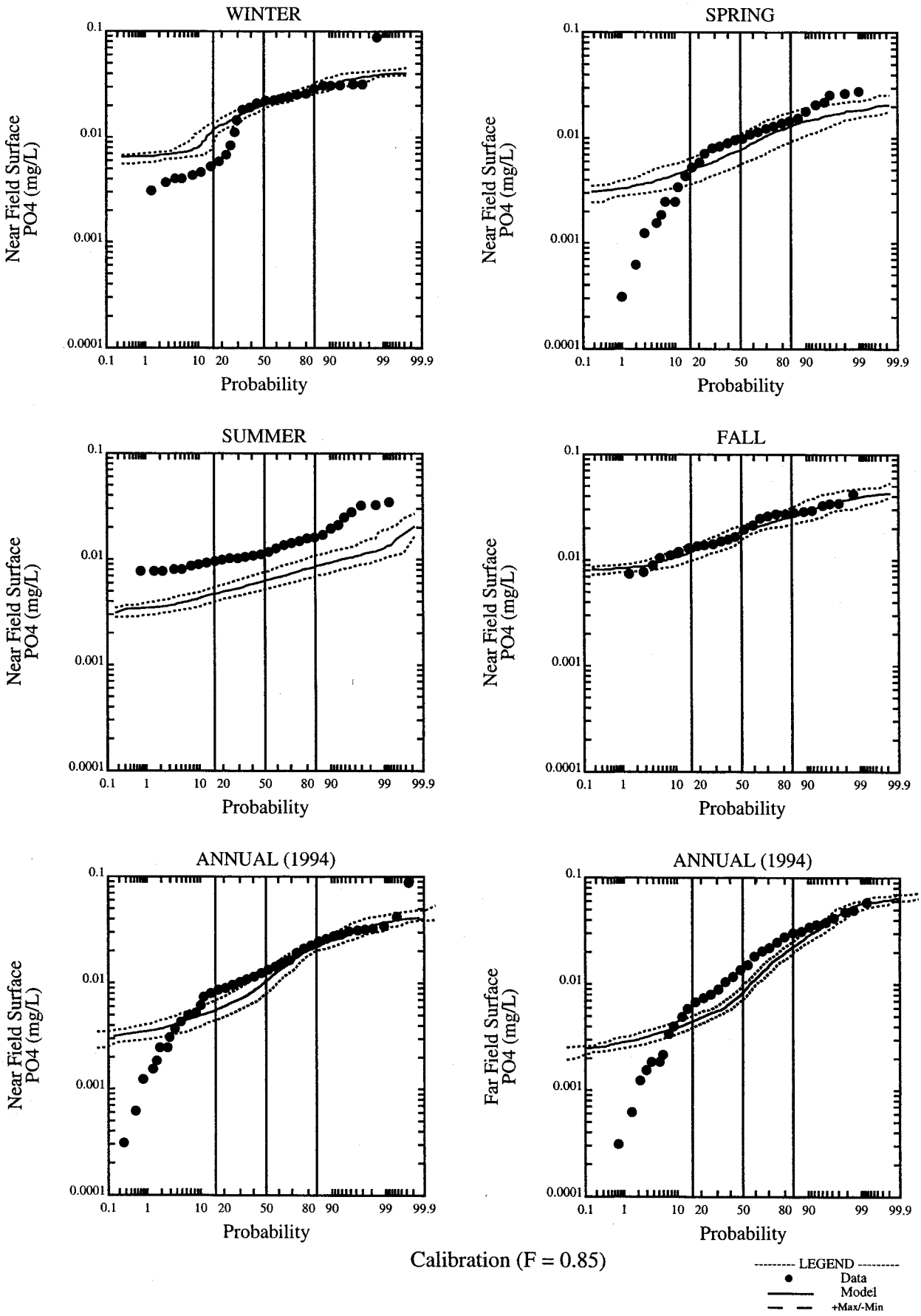

WINTER
SPRING
SUMMER
FALL
ANNUAL (1994)
ANNUAL (1994)
Near Field Surface Chlorophyll-a (ug/L)
Far Field Surface Chlorophyll-a (ug/L)
Probability
20
10
1
0.1
0.1 1 10 20 50 80 90 99 99.9
Calibration (F = 0.85)
LEGEND
Discrete Chl-a
Fluorometric Chl-a
Model

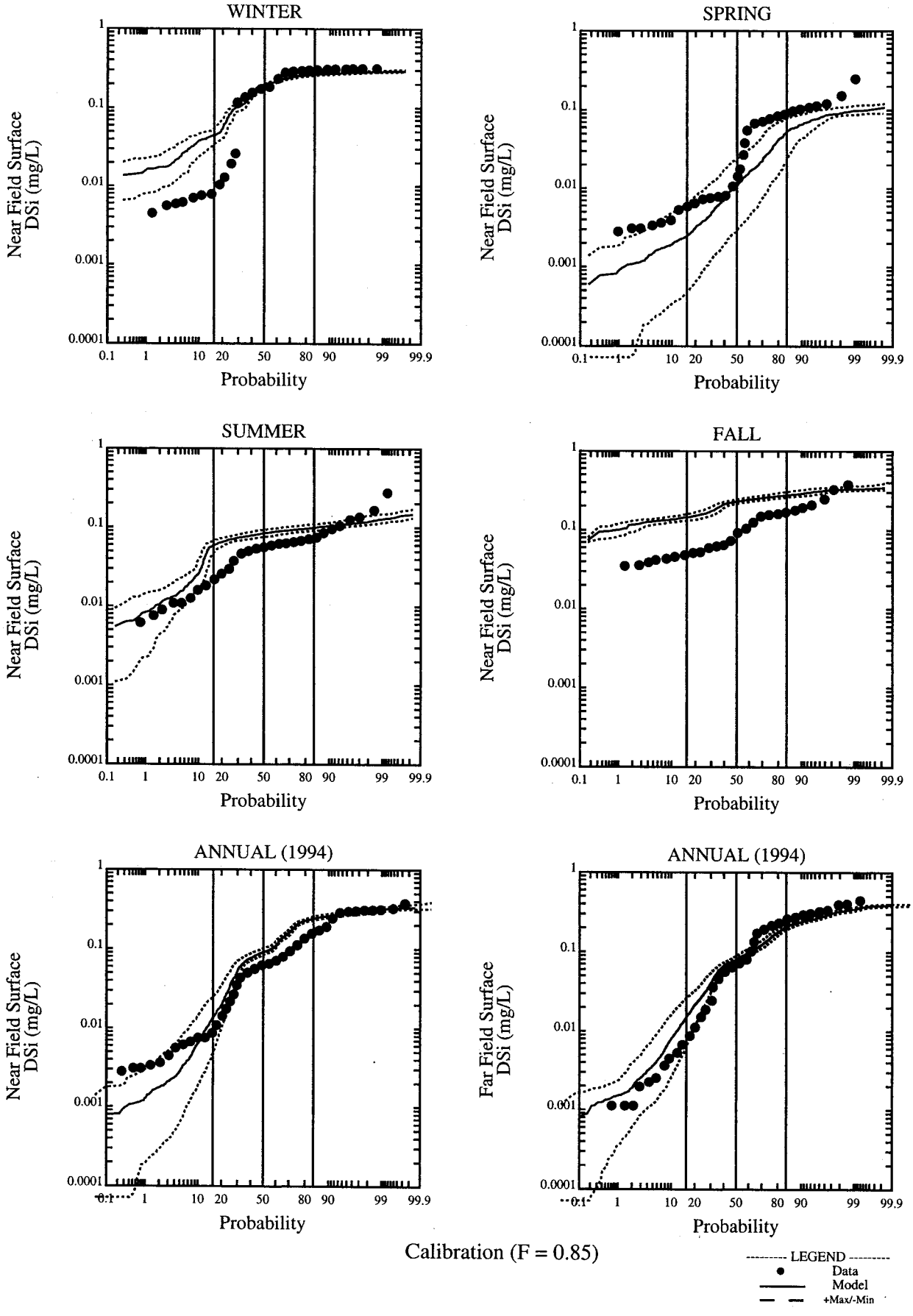

WINTER
SPRING
SUMMER
FALL
ANNUAL (1994)
ANNUAL (1994)
Near Field 12.5-17.5m Chlorophyll-a (ug/L)
Far Field 12.5-17.5m Chlorophyll-a (ug/L)
Probability
20
10
1
0.1
0.1 1 10 20 50 80 90 99 99.9
Calibration (F = 0.85)
LEGEND
Discrete Chl-a
Fluorometric Chl-a
Model

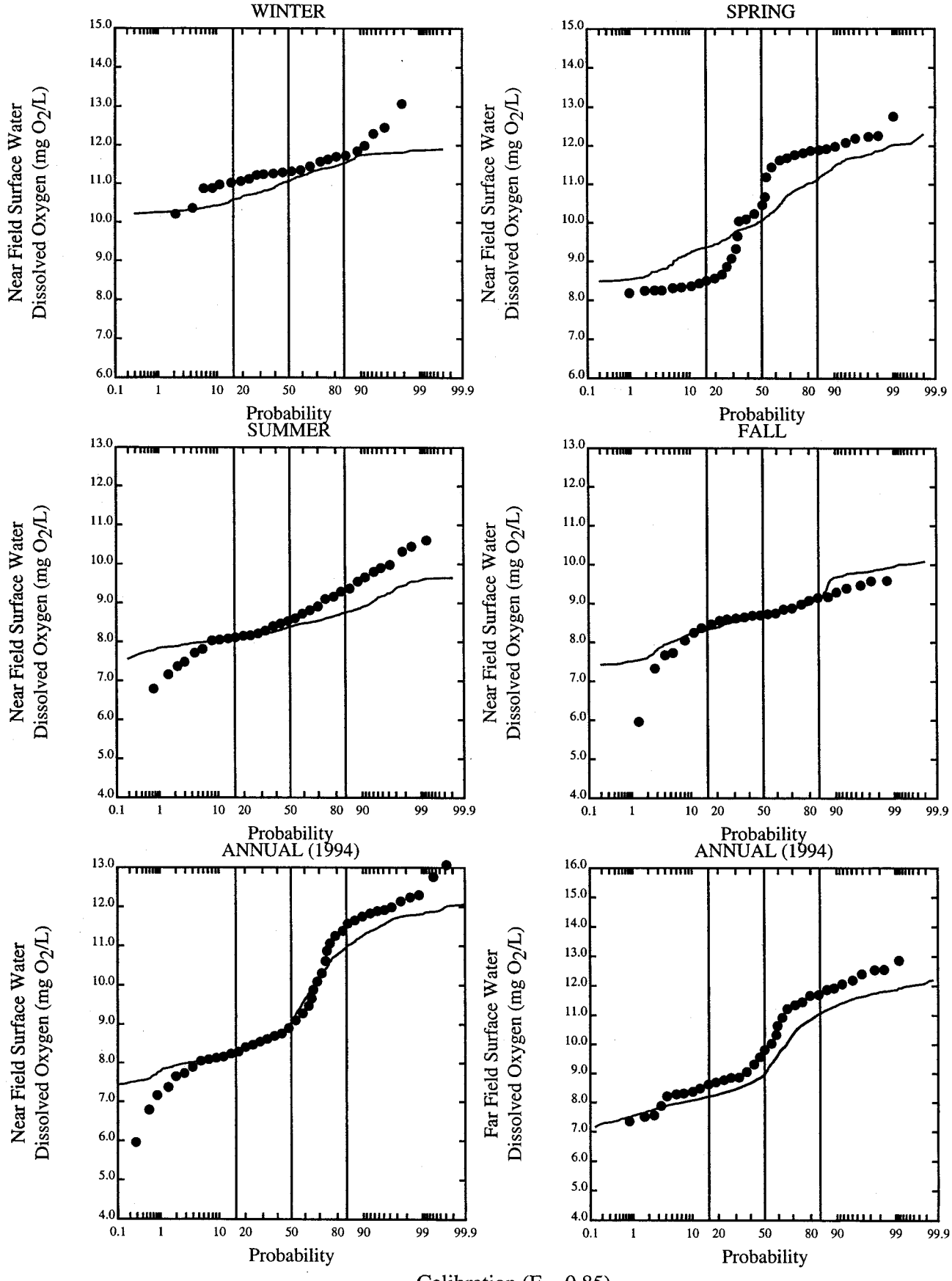

WINTER
SPRING
SUMMER
FALL
ANNUAL (1994)
ANNUAL (1994)
Near Field Surface C:Chl Ratios (ug C/ug Chl)
Far Field Surface C:Chl Ratios (ug C/ug Chl)
Probability
1000
100
10
1
0.1
1
10
20
50
80
90
99
99.9
Calibration (F = 0.85)
LEGEND
Data
Model

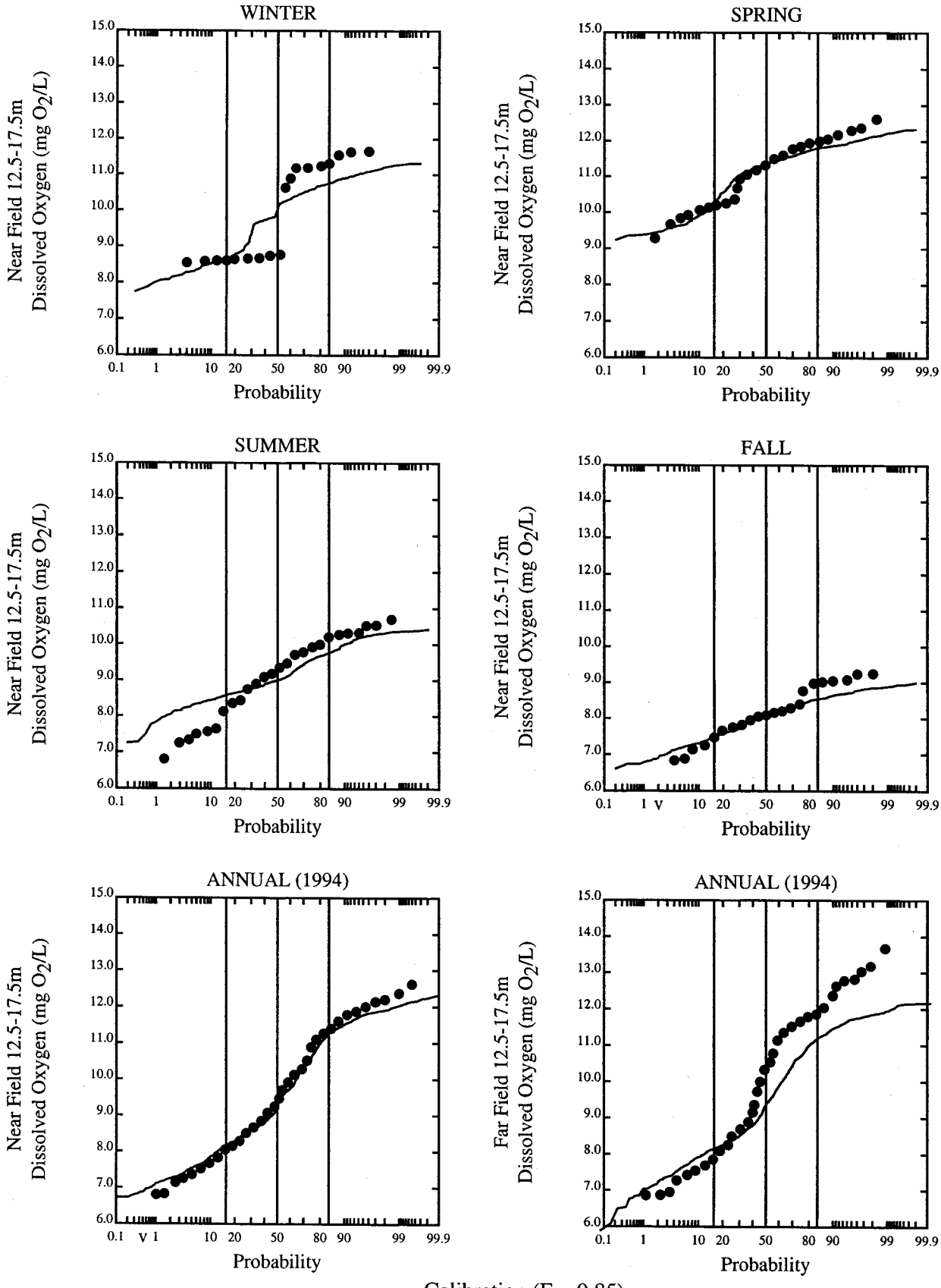

WINTER
SPRING
SUMMER
FALL
ANNUAL (1994)
ANNUAL (1994)
Near Field 12.5-17.5 m C:Chl Ratios (ug C/ug Chl)
Far Field 12.5-17.5 m C:Chl Ratios (ug C/ug Chl)
1000
100
10
1
0.1 1 10 20 50 80 90 99 99.9
Probability
Calibration (F = 0.85)
LEGEND
Data
Model

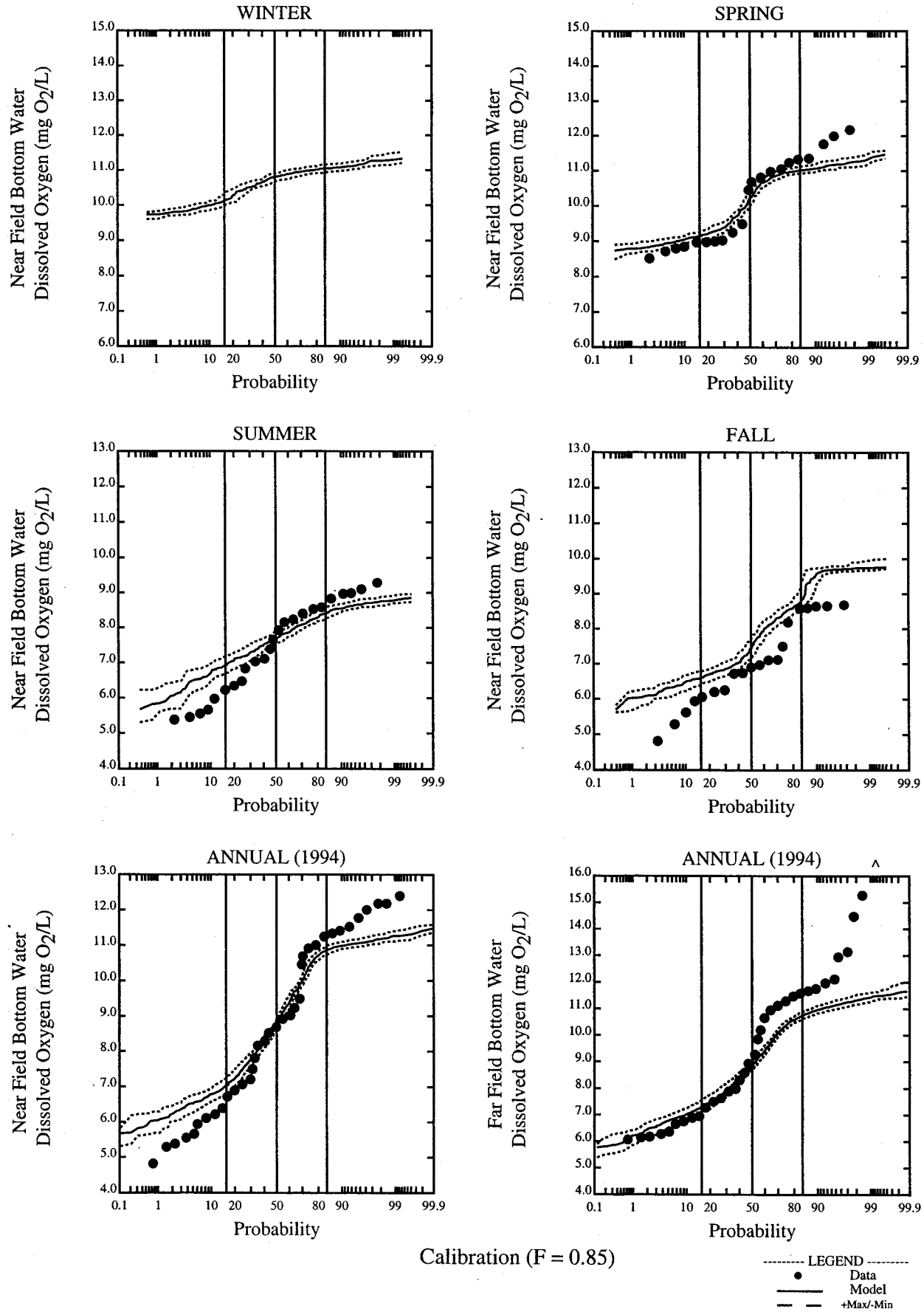

WINTER
SPRING
SUMMER
FALL
ANNUAL (1994)
ANNUAL (1994)
Near Field Surface DIN (mg/L)
Far Field Surface DIN (mg/L)
Probability
0.4
0.1
0.01
0.001
0.0001
0.1 1 10 20 50 80 90 99 99.9
Calibration (F = 0.85)
LEGEND
Data
Model
+Max/-Min


WINTER
SPRING
SUMMER
FALL
ANNUAL (1994)
ANNUAL (1994)
Near Field Surface PO4 (mg/L)
Far Field Surface PO4 (mg/L)
0.1
0.01
0.001
0.0001
0.1 1 10 20 50 80 90 99 99.9
Probability
Calibration (F = 0.85)
LEGEND
Data
Model
+Max/-Min

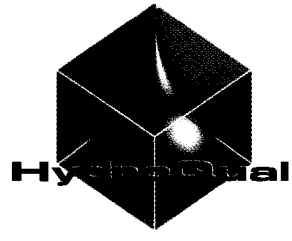

WINTER
SPRING
SUMMER
FALL
ANNUAL (1994)
ANNUAL (1994)
Near Field Surface DSi (mg/L)
Far Field Surface DSi (mg/L)
Probability
1
0.1
0.01
0.001
0.0001
0.1 1 10 20 50 80 90 99 99.9
Calibration (F = 0.85)
LEGEND
Data
Model
+Max/-Min


WINTER
SPRING
SUMMER
FALL
ANNUAL (1994)
ANNUAL (1994)
Near Field Surface Water Dissolved Oxygen (mg O2/L)
Near Field Surface Water Dissolved Oxygen (mg O2/L)
Near Field Surface Water Dissolved Oxygen (mg O2/L)
Near Field Surface Water Dissolved Oxygen (mg O2/L)
Near Field Surface Water Dissolved Oxygen (mg O2/L)
Far Field Surface Water Dissolved Oxygen (mg O2/L)
Probability
Probability
Probability
Probability
Probability
Probability
0.1 1 10 20 50 80 90 99 99.9
Calibration (F = 0.85)
LEGEND
Data
Model


WINTER
SPRING
SUMMER
FALL
ANNUAL (1994)
ANNUAL (1994)
Near Field 12.5-17.5m Dissolved Oxygen (mg O2/L)
Far Field 12.5-17.5m Dissolved Oxygen (mg O2/L)
Probability
0.1 1 10 20 50 80 90 99 99.9
6.0 7.0 8.0 9.0 10.0 11.0 12.0 13.0 14.0 15.0
Calibration (F = 0.85)
LEGEND
Data
Model

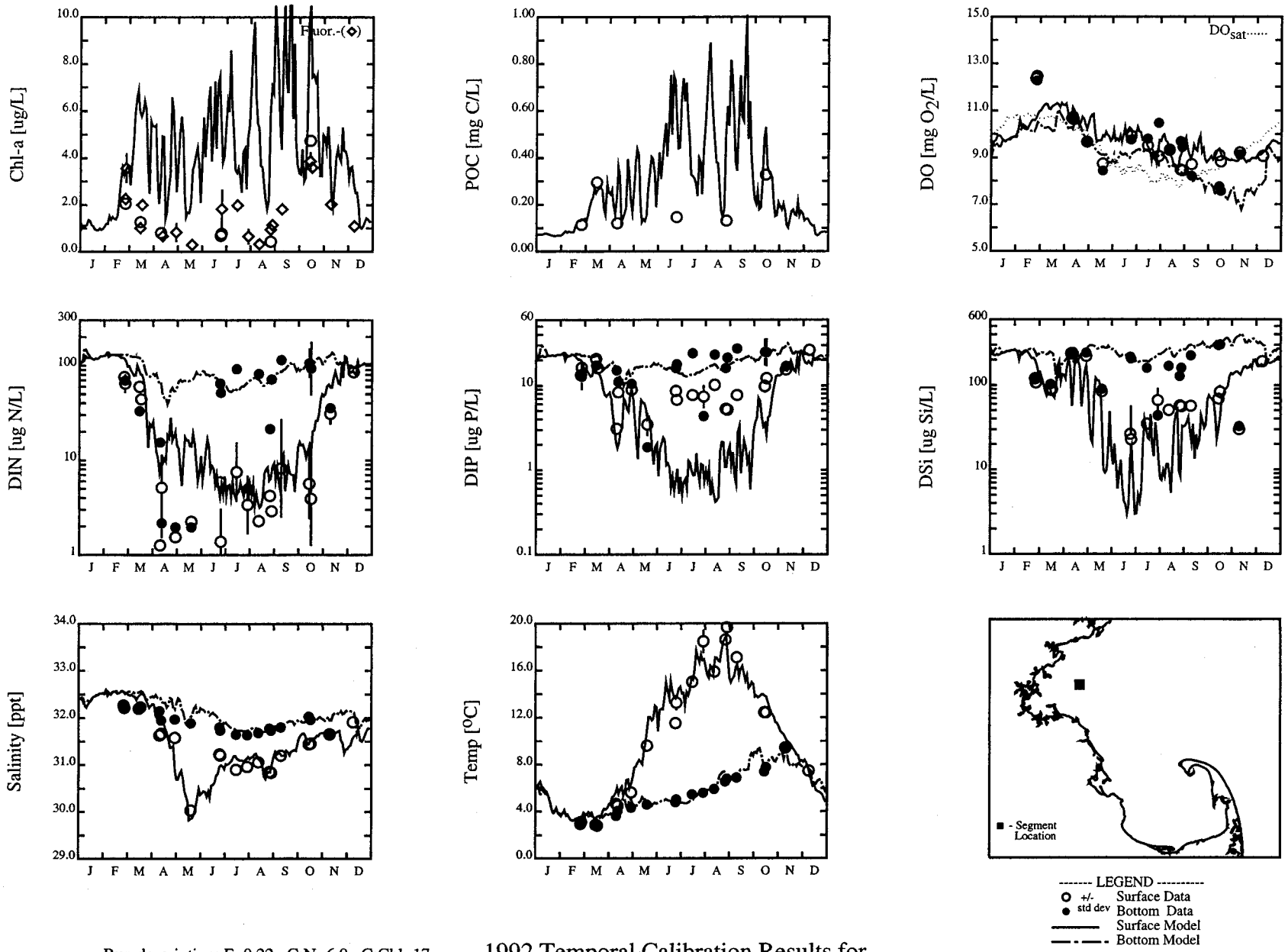

WINTER
SPRING
SUMMER
FALL
ANNUAL (1994)
ANNUAL (1994)
Near Field Bottom Water Dissolved Oxygen (mg O2/L)
Far Field Bottom Water Dissolved Oxygen (mg O2/L)
Probability
0.1 1 10 20 50 80 90 99 99.9
Calibration (F = 0.85)
LEGEND
Data
Model
+Max/-Min

APPENDIX A.2
RESULTS FROM FULL LAWS&CHALUP COEFFICIENT SET SENSITIVITY ANALYSIS



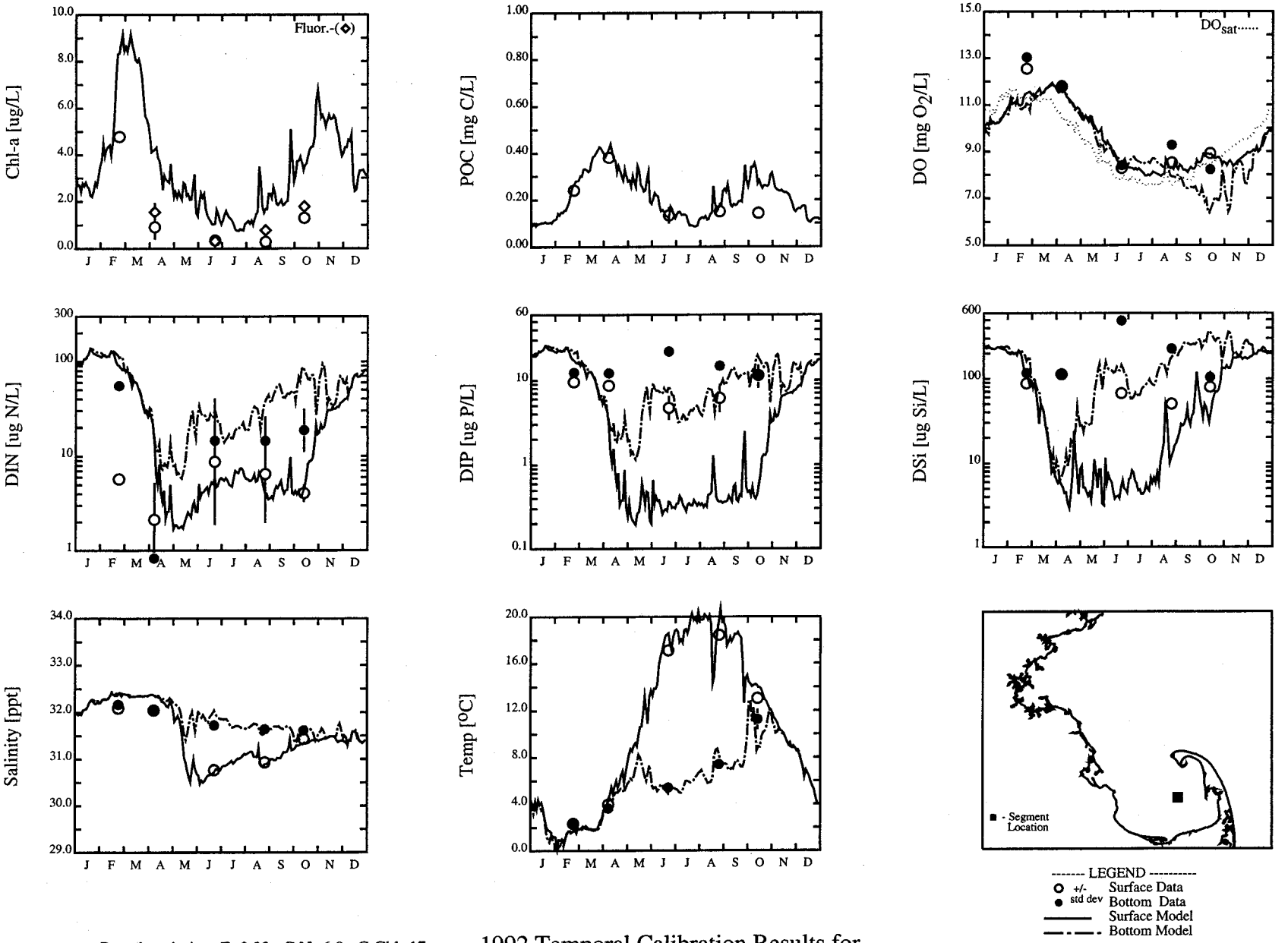
Environmental

Engineers & Scientists



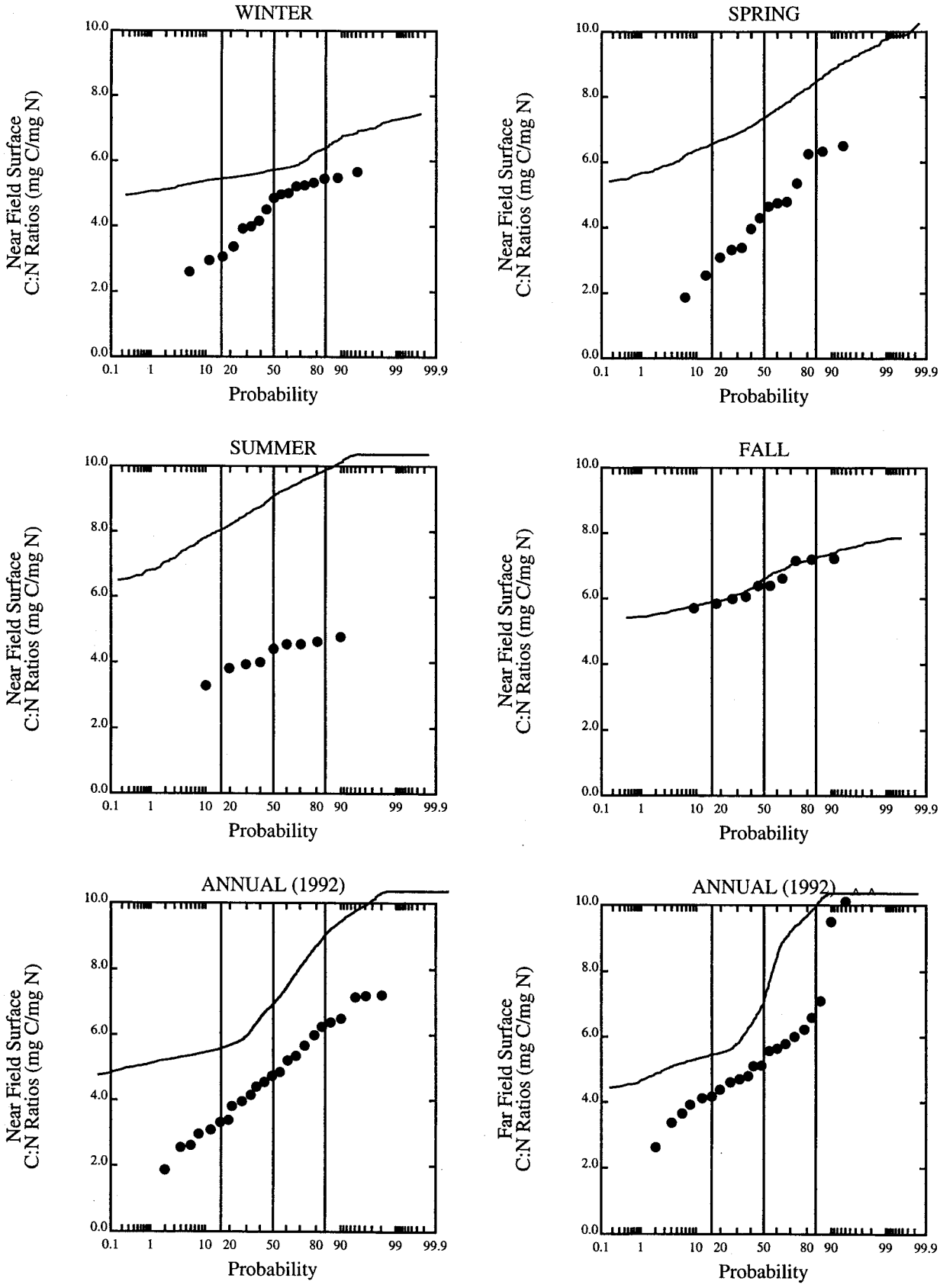
Run description: F=0.22 , C:N=6.9 , C:Chl=17

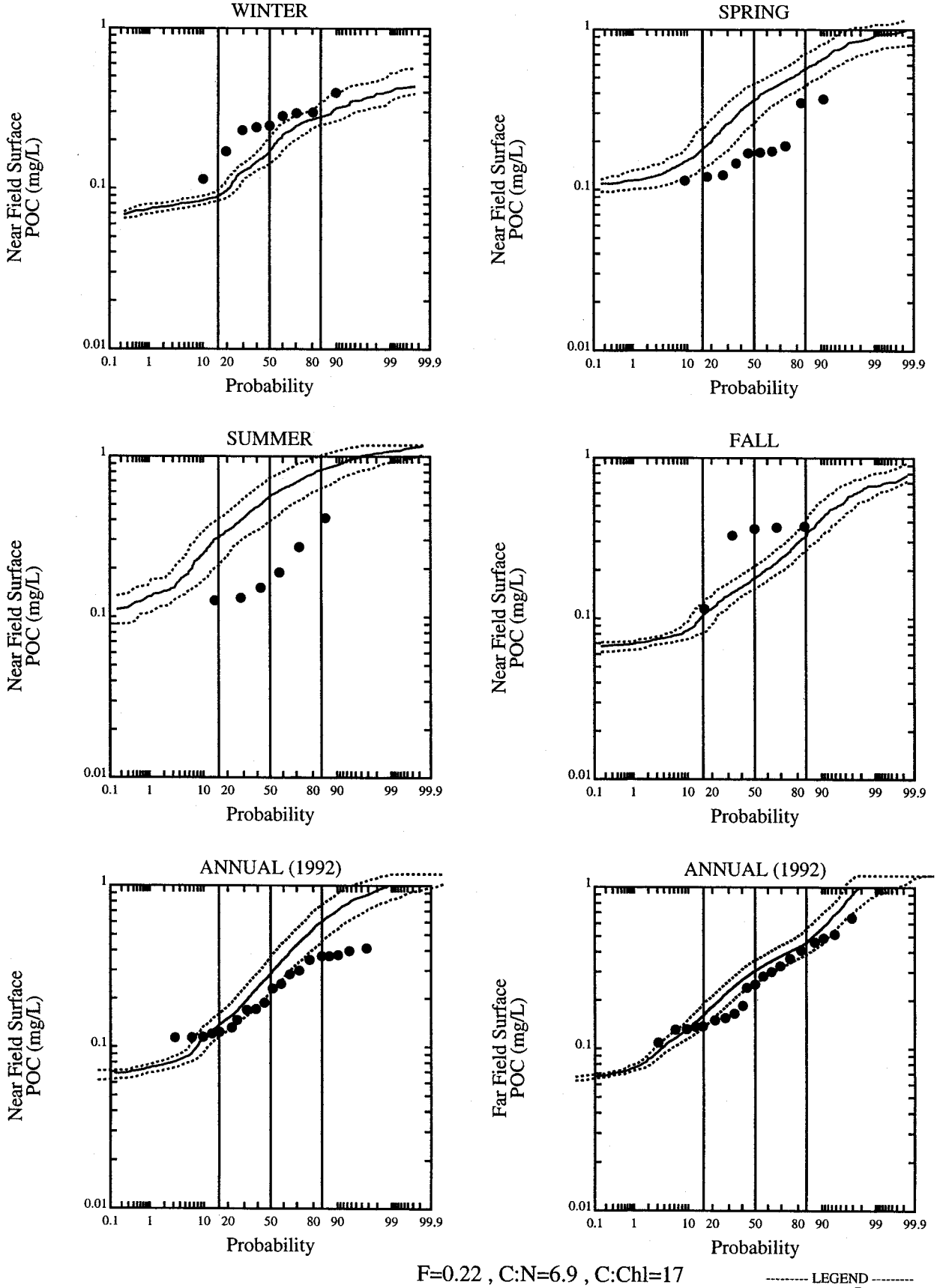
1992 Temporal Calibration Results for
Grid Cell (11,18) Vs Data Station N16P,N17,N21

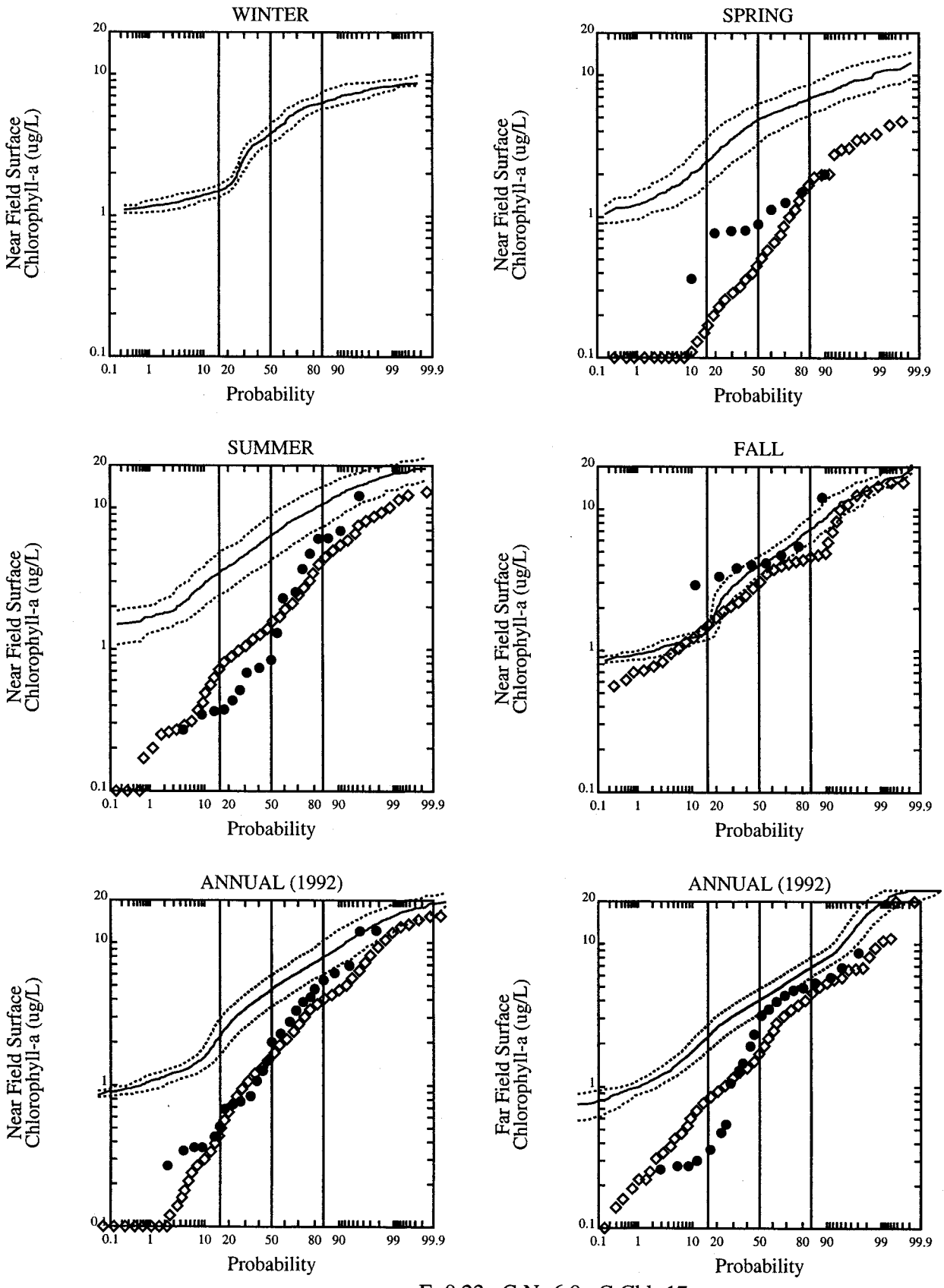


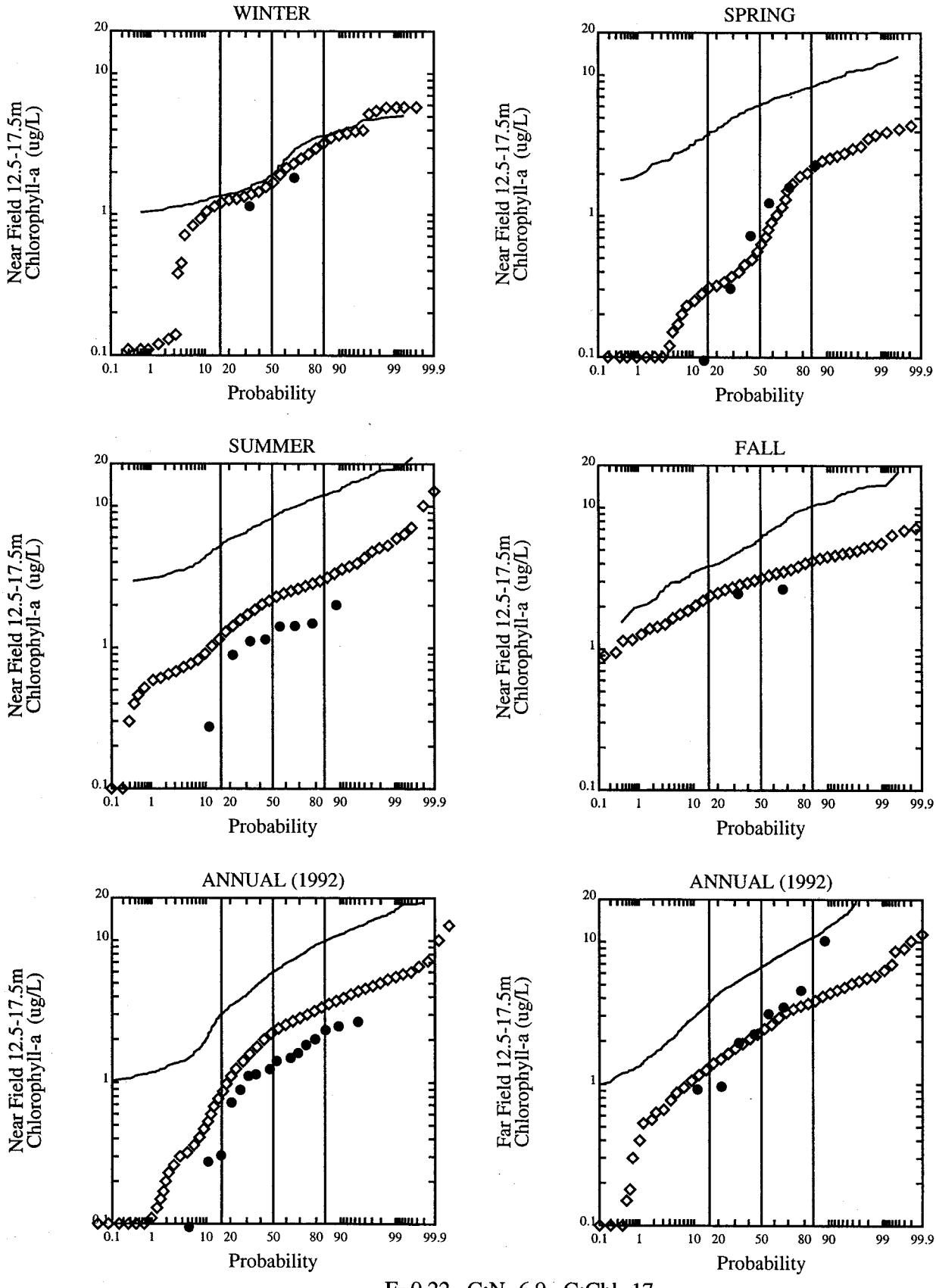
Run description: F=0.22 , C:N=6.9 , C:Chl=17

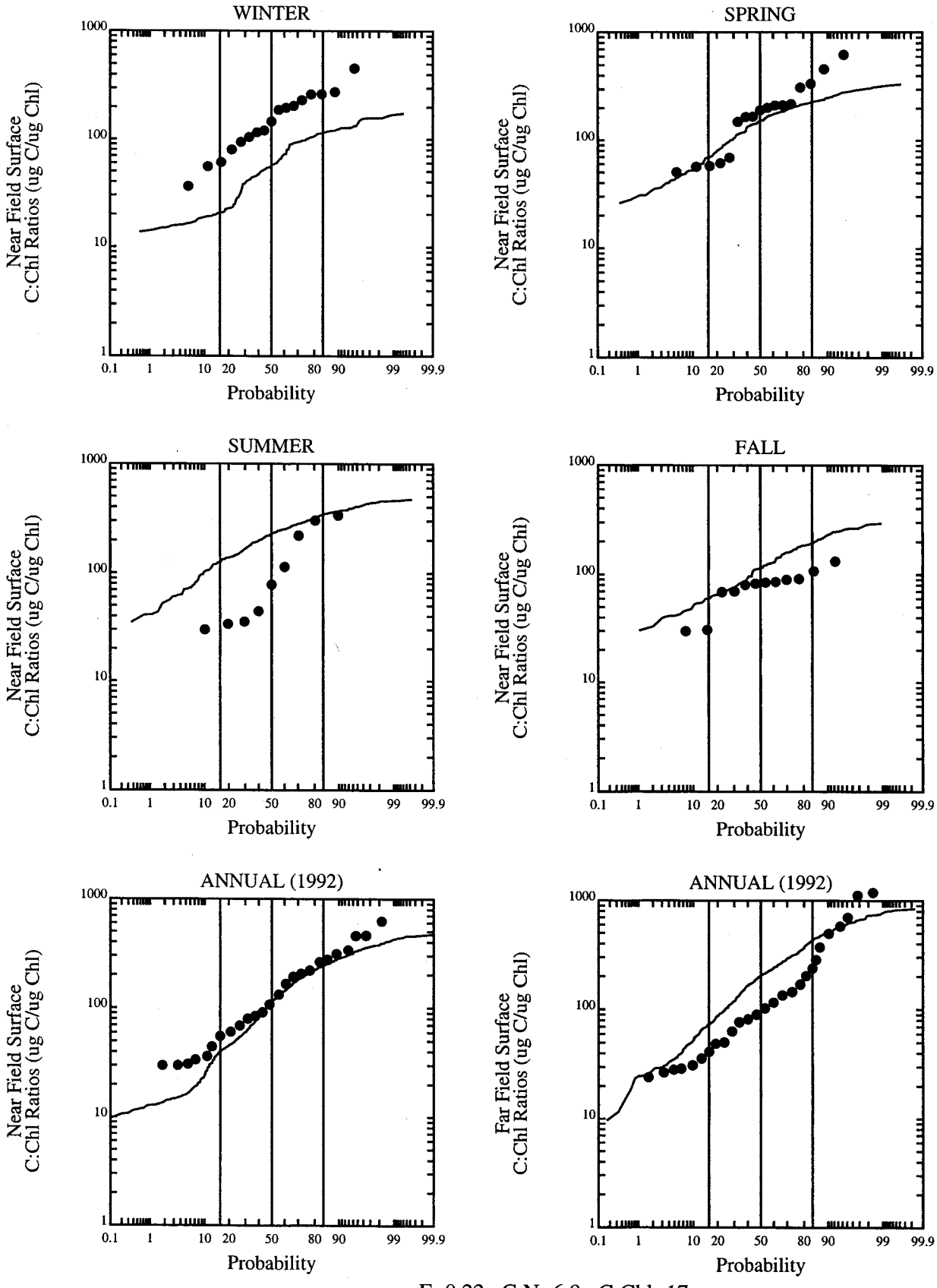
1992 Temporal Calibration Results for Grid Cell (13,4) Vs Data Station F02P

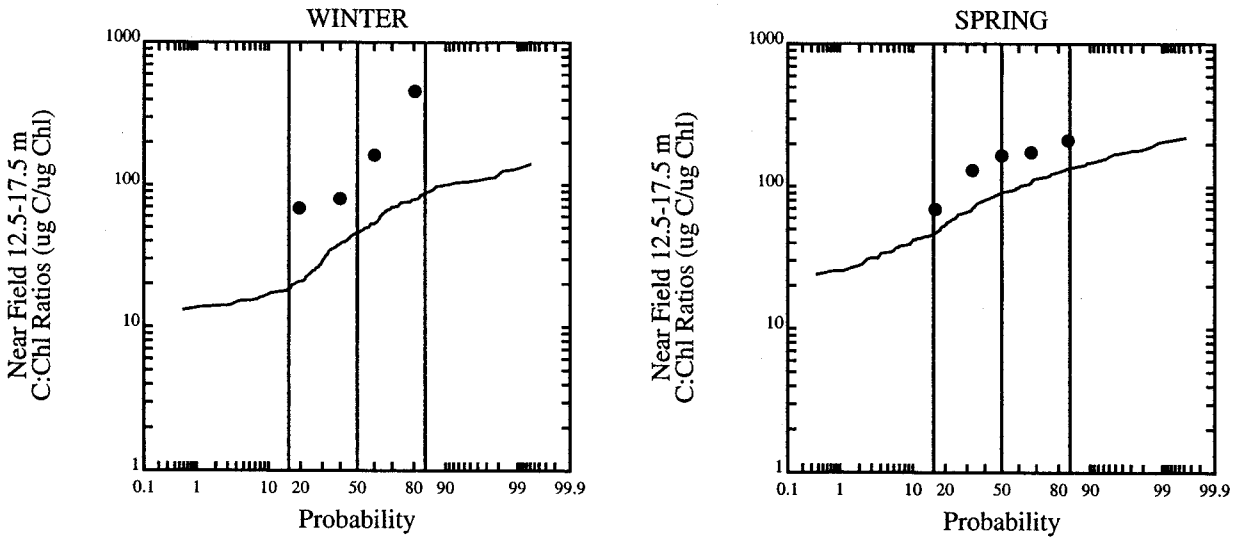

WINTER
SPRING
SUMMER
FALL
ANNUAL (1992)
ANNUAL (1992)
Near Field Surface C:N Ratios (mg C/mg N)
Far Field Surface C:N Ratios (mg C/mg N)
Probability
10.0
8.0
6.0
4.0
2.0
0.0
0.1
1
10
20
50
80
90
99
99.9
F=0.22 , C:N=6.9 , C:Chl=17
LEGEND
Data
Model

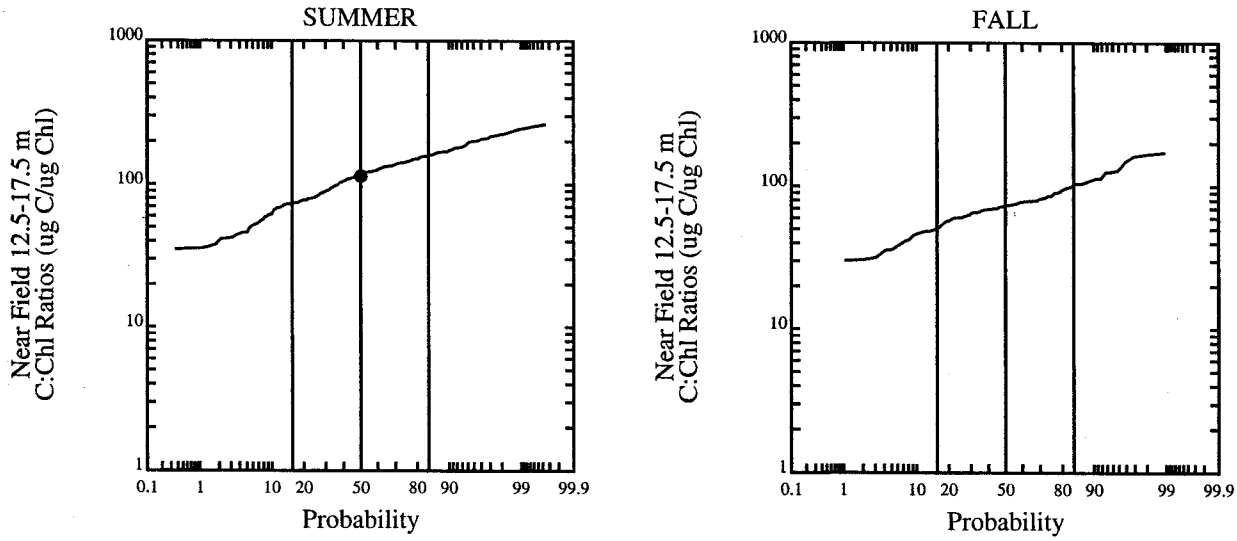

WINTER
SPRING
SUMMER
FALL
ANNUAL (1992)
ANNUAL (1992)
Near Field Surface POC (mg/L)
Far Field Surface POC (mg/L)
Probability
1
0.1
0.01
0.1 1 10 20 50 80 90 99 99.9
F=0.22 , C:N=6.9 , C:Chl=17
LEGEND
Data
Model
+Max/-Min

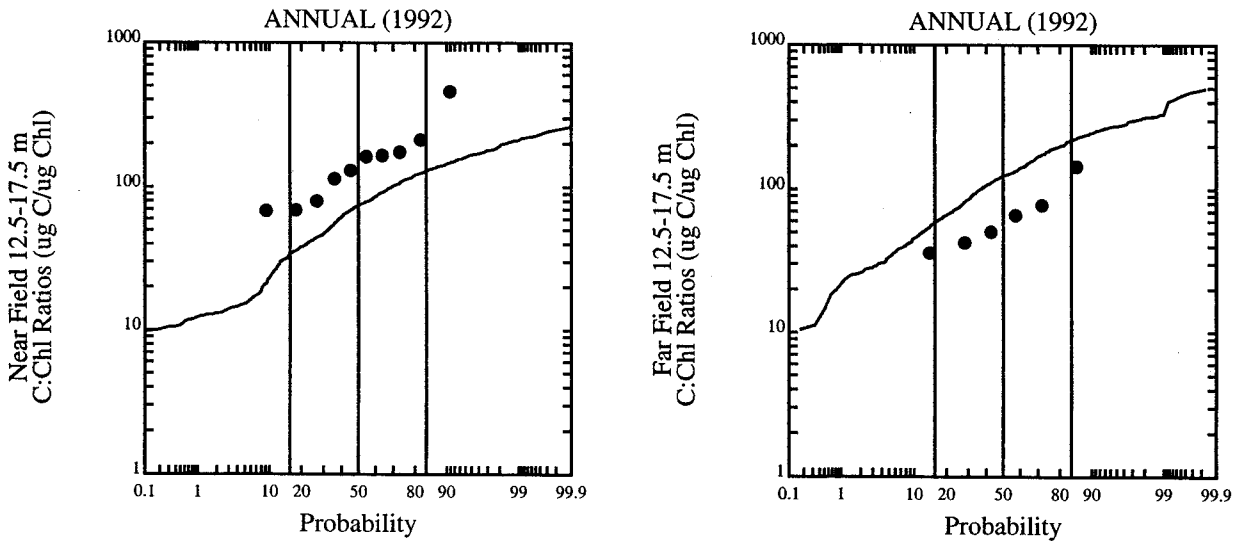

WINTER
SPRING
SUMMER
FALL
ANNUAL (1992)
ANNUAL (1992)
Near Field Surface Chlorophyll-a (ug/L)
Far Field Surface Chlorophyll-a (ug/L)
Probability
20
10
1
0.1
0.1 1 10 20 50 80 90 99 99.9
F=0.22 , C:N=6.9 , C:Chl=17
LEGEND
Discrete Chl-a
Fluorometric Chl-a
Model


WINTER
SPRING
SUMMER
FALL
ANNUAL (1992)
ANNUAL (1992)
Near Field 12.5-17.5m Chlorophyll-a (ug/L)
Far Field 12.5-17.5m Chlorophyll-a (ug/L)
Probability
20
10
1
0.1
0.1 1 10 20 50 80 90 99 99.9
F=0.22 , C:N=6.9 , C:Chl=17
LEGEND
Discrete Chl-a
Fluorometric Chl-a
Model

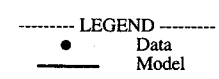

WINTER
SPRING
SUMMER
FALL
ANNUAL (1992)
ANNUAL (1992)
Near Field Surface C:Chl Ratios (ug C/ug Chl)
Far Field Surface C:Chl Ratios (ug C/ug Chl)
1000
100
10
1
0.1
1
10
20
50
80
90
99
99.9
Probability
F=0.22 , C:N=6.9 , C:Chl=17
LEGEND
Data
Model

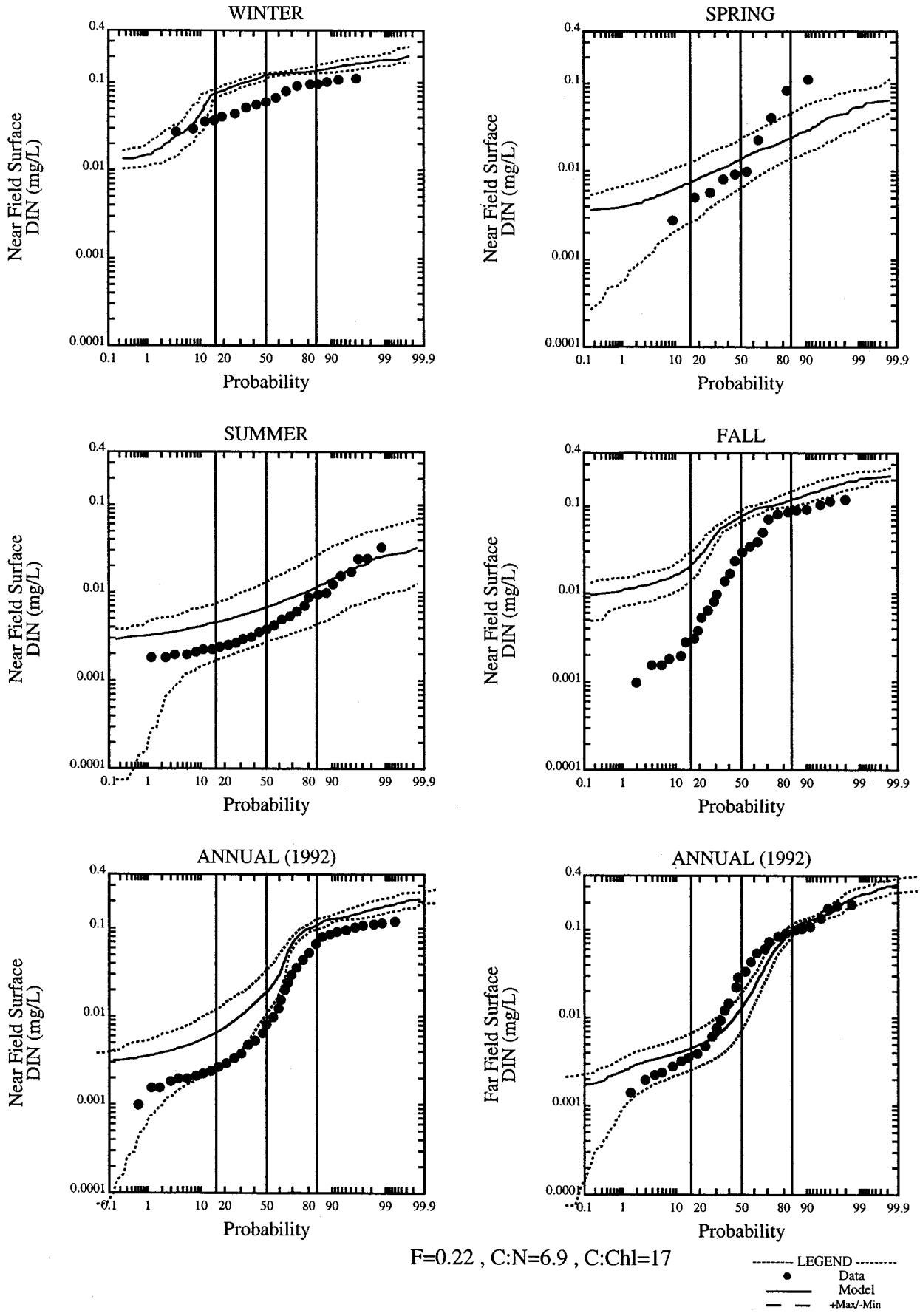


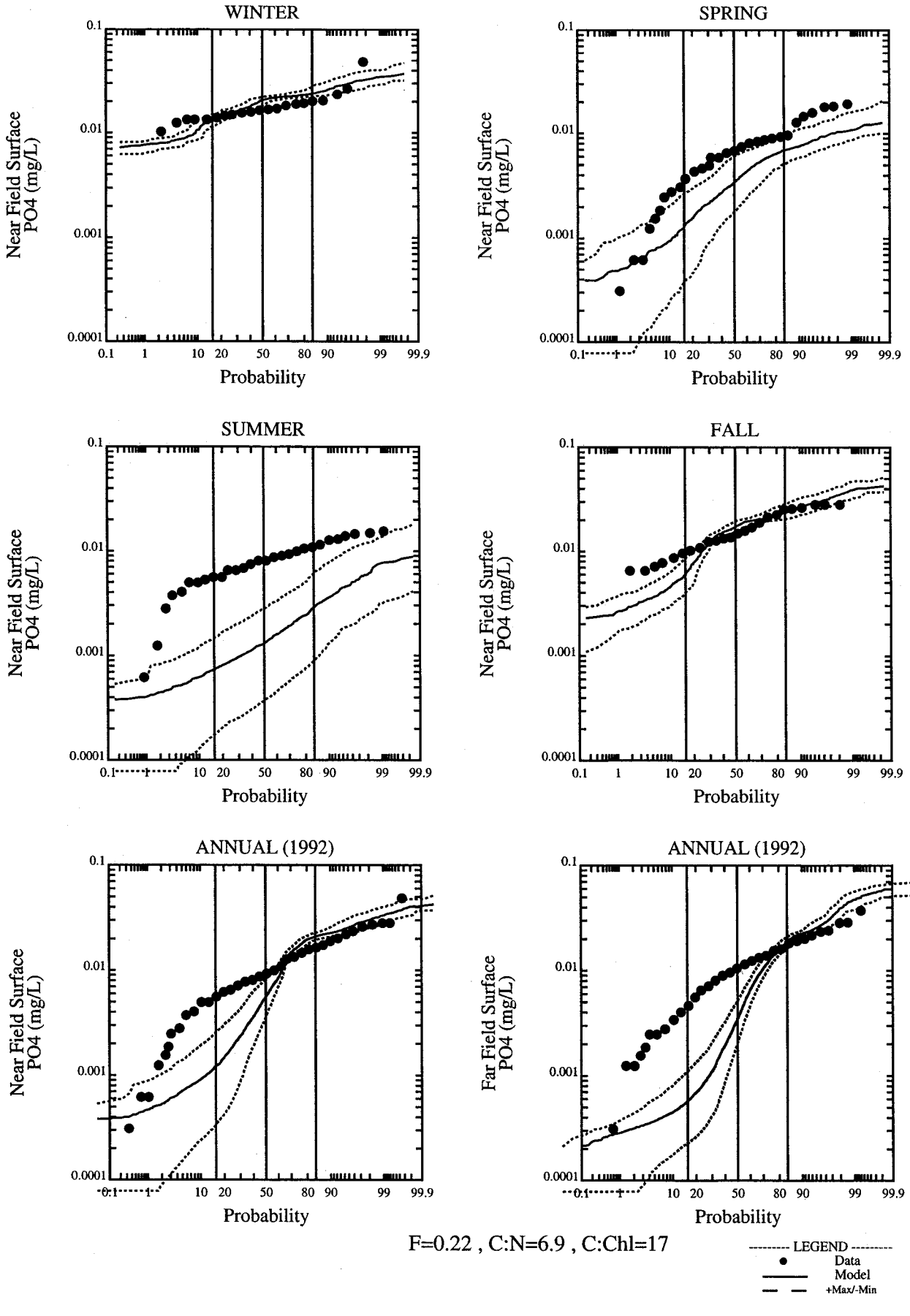


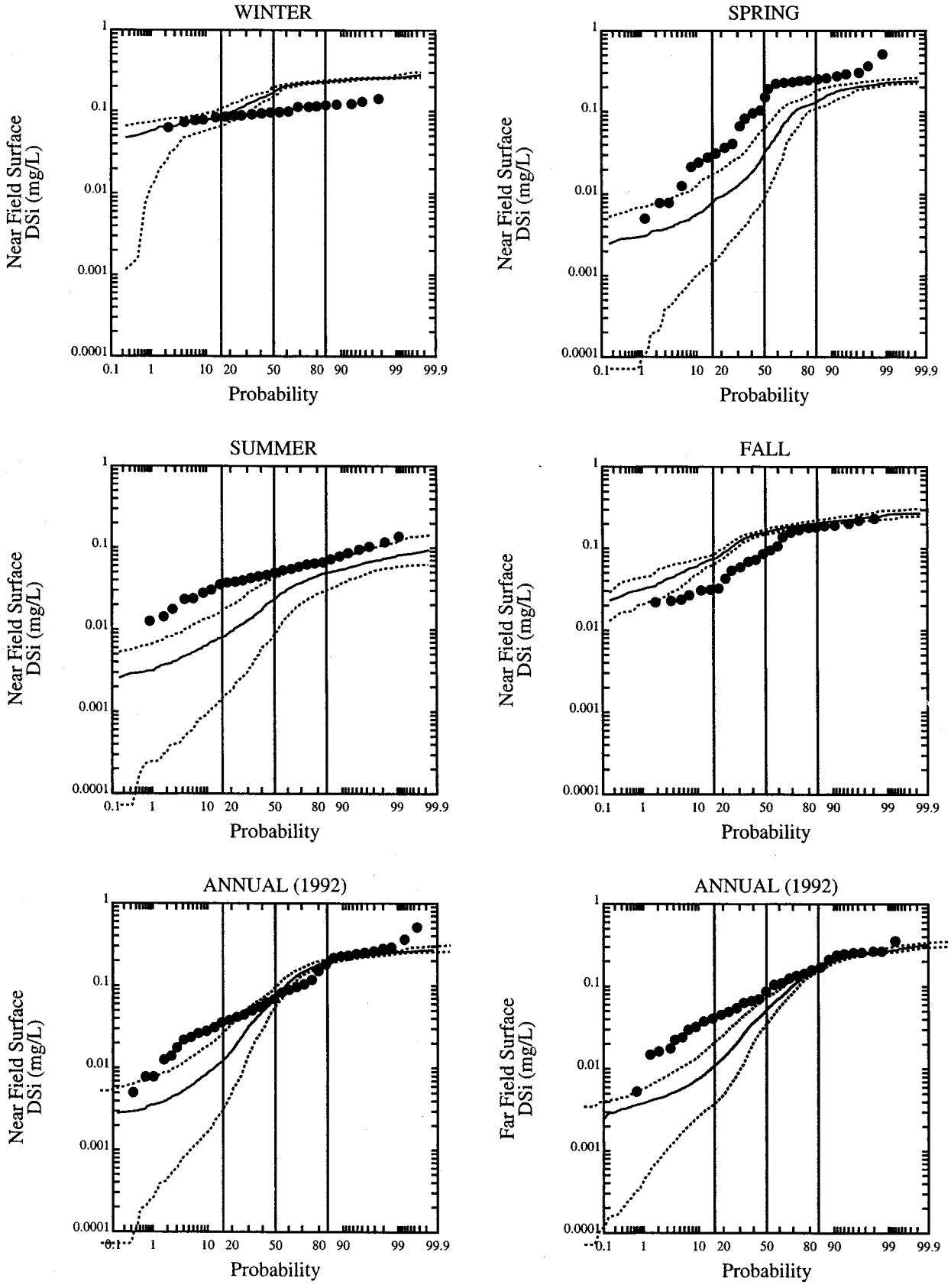


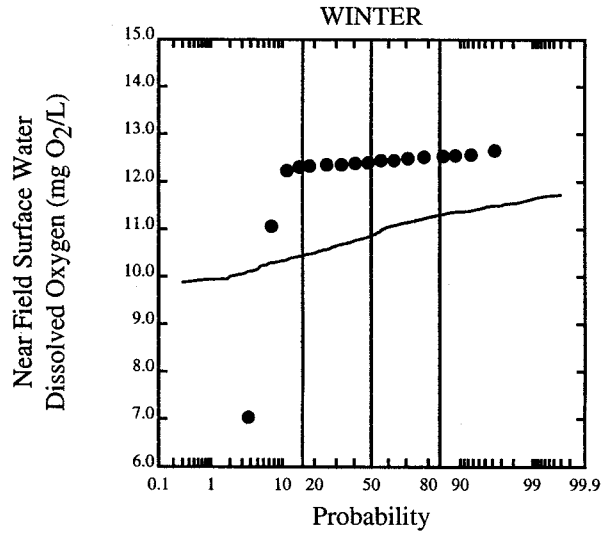
F=0.22 , C:N=6.9 , C:Chl=17

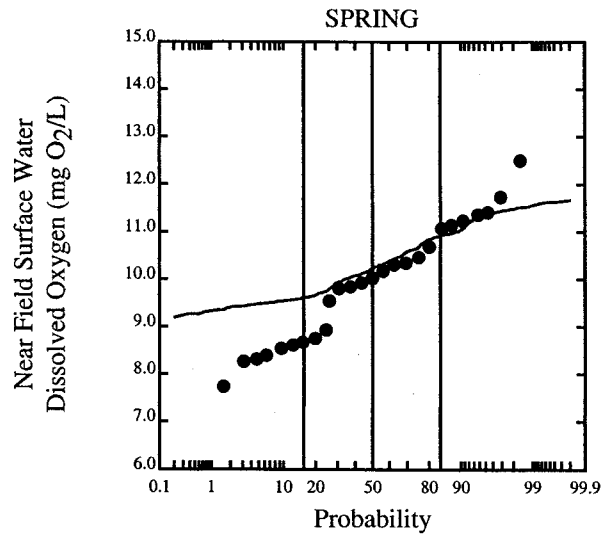


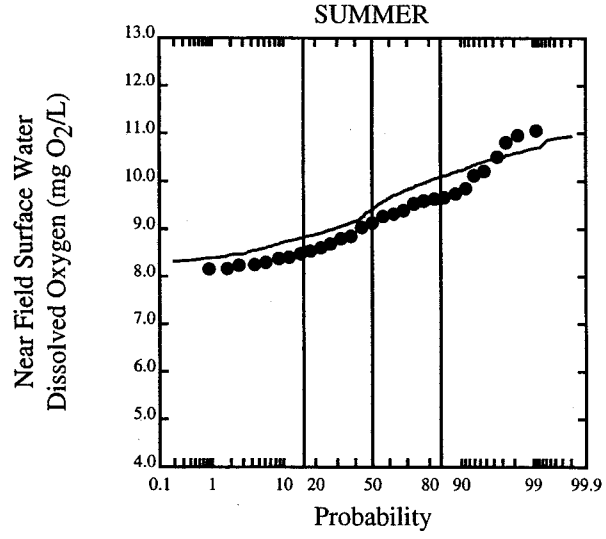

WINTER
SPRING
SUMMER
FALL
ANNUAL (1992)
ANNUAL (1992)
Near Field Surface DIN (mg/L)
Far Field Surface DIN (mg/L)
0.4
0.1
0.01
0.001
0.0001
0.1 1 10 20 50 80 90 99 99.9
Probability
F=0.22 , C:N=6.9 , C:Chl=17
LEGEND
Data
Model
+Max/-Min

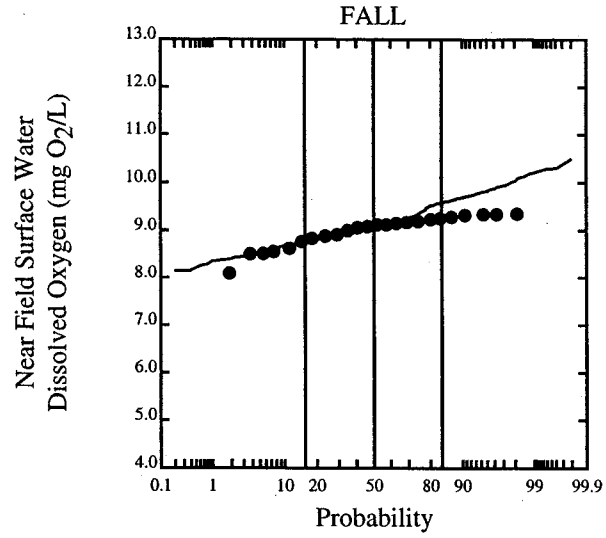

WINTER
SPRING
SUMMER
FALL
ANNUAL (1992)
ANNUAL (1992)
Near Field Surface PO4 (mg/L)
Far Field Surface PO4 (mg/L)
0.1
0.01
0.001
0.0001
0.1 1 10 20 50 80 90 99 99.9
Probability
F=0.22 , C:N=6.9 , C:Chl=17
LEGEND
Data
Model
+Max/-Min

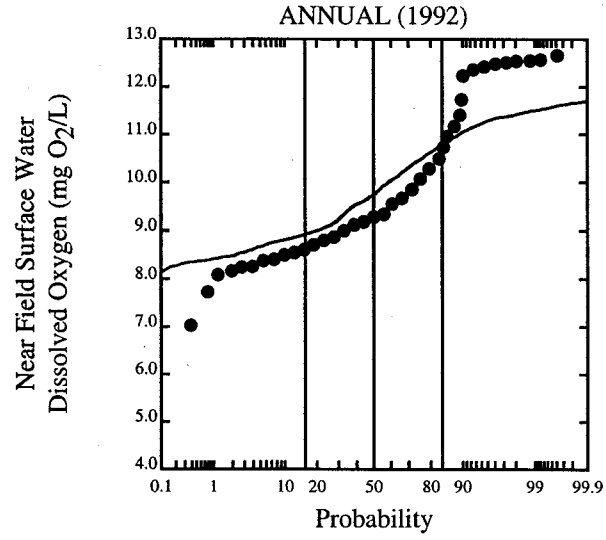

WINTER
SPRING
SUMMER
FALL
ANNUAL (1992)
ANNUAL (1992)
Near Field Surface DSi (mg/L)
Far Field Surface DSi (mg/L)
Probability
1
0.1
0.01
0.001
0.0001
0.1
1
10
20
50
80
90
99
99.9
F=0.22 , C:N=6.9 , C:Chl=17
LEGEND
Data
Model
+Max/-Min

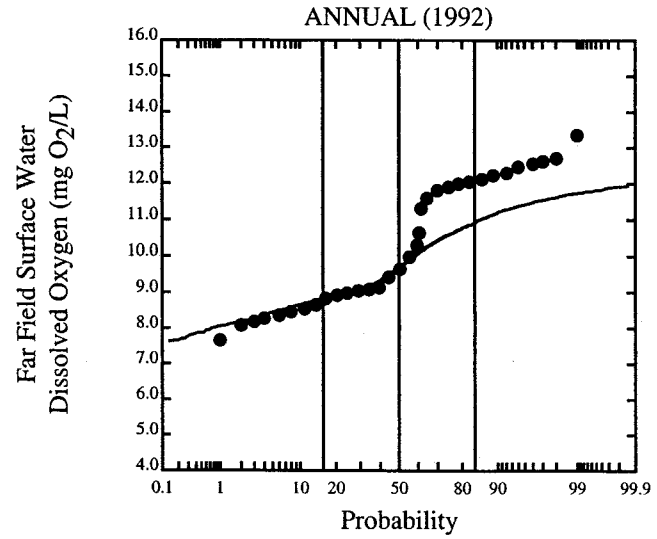




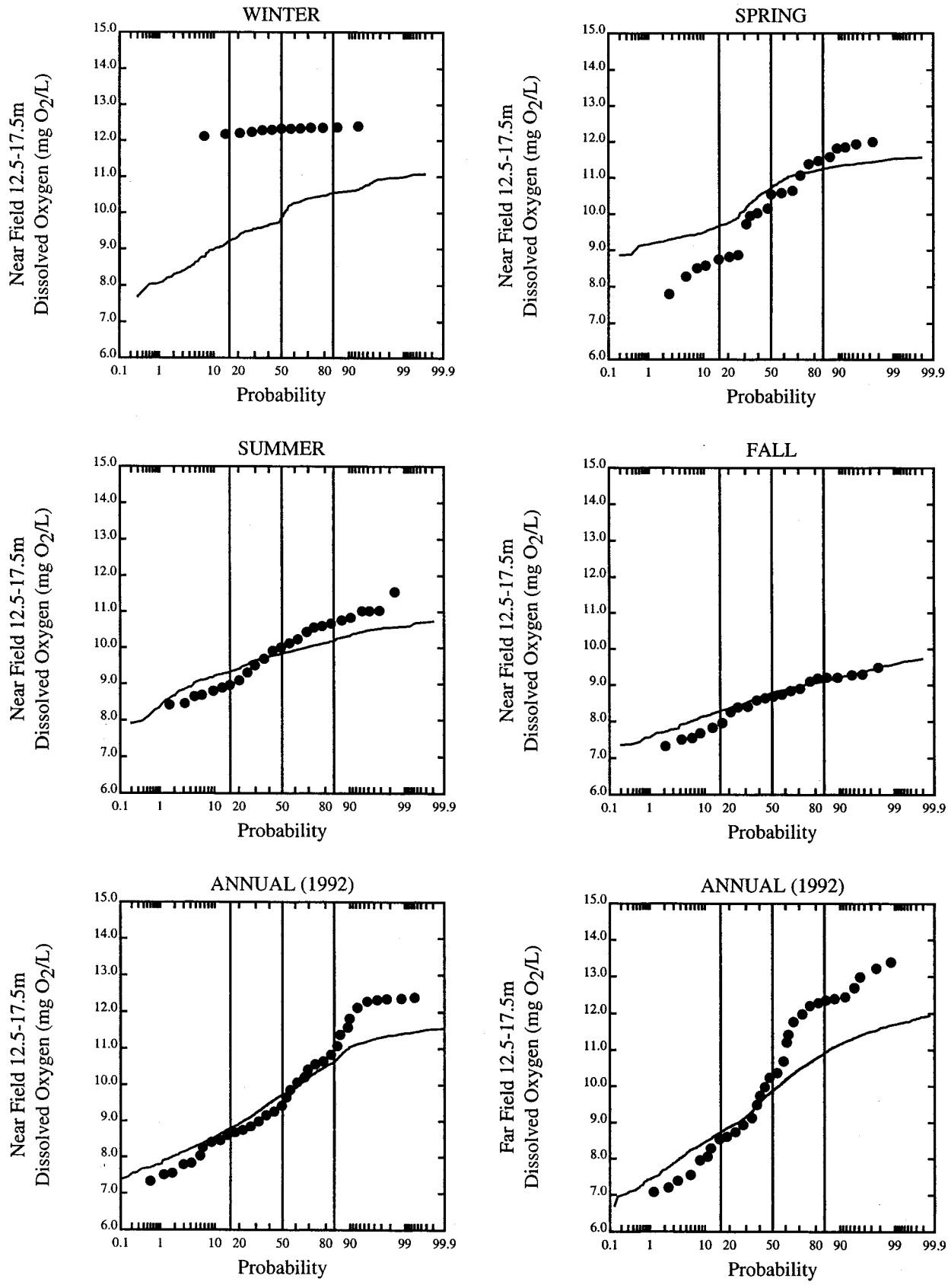


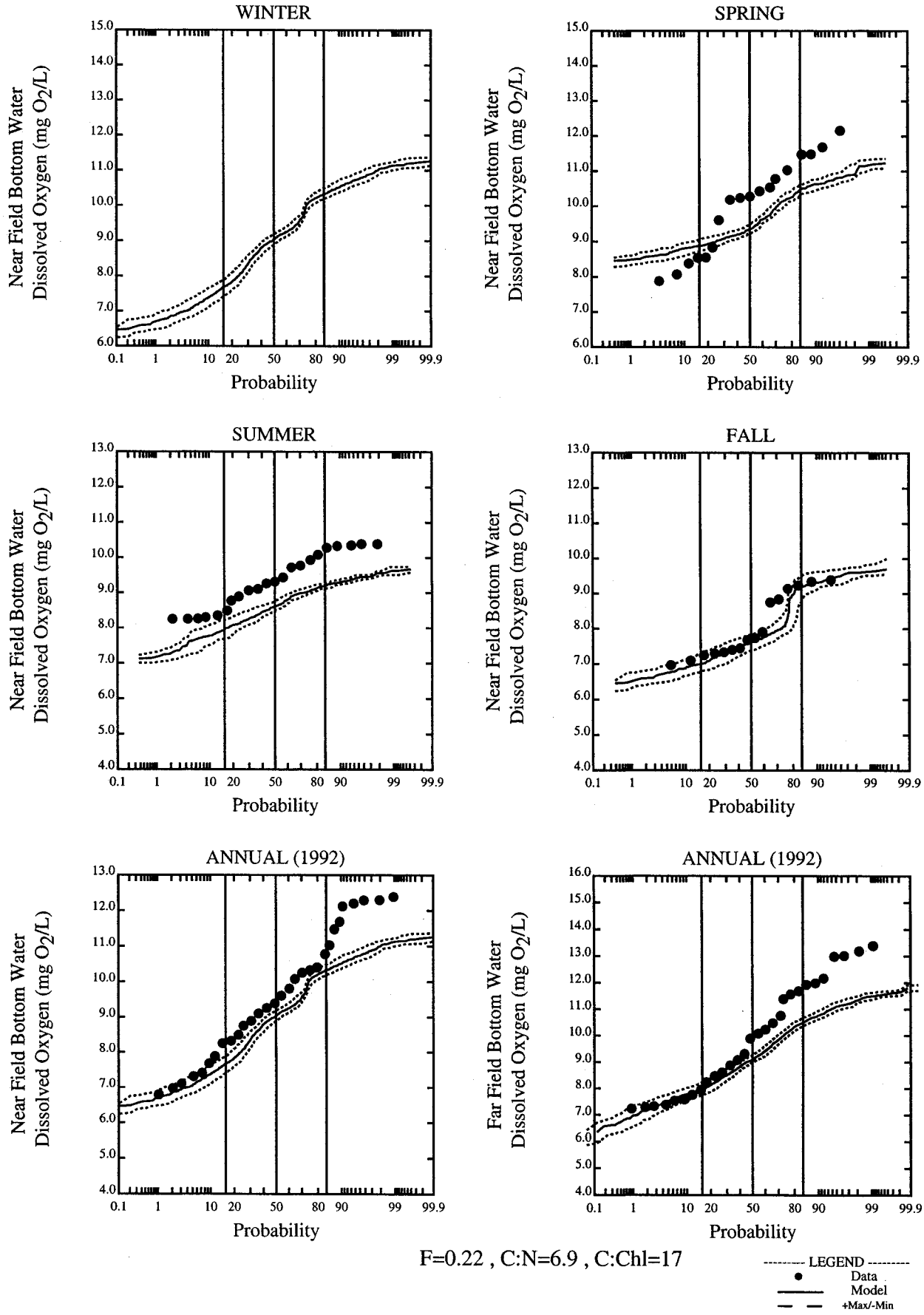


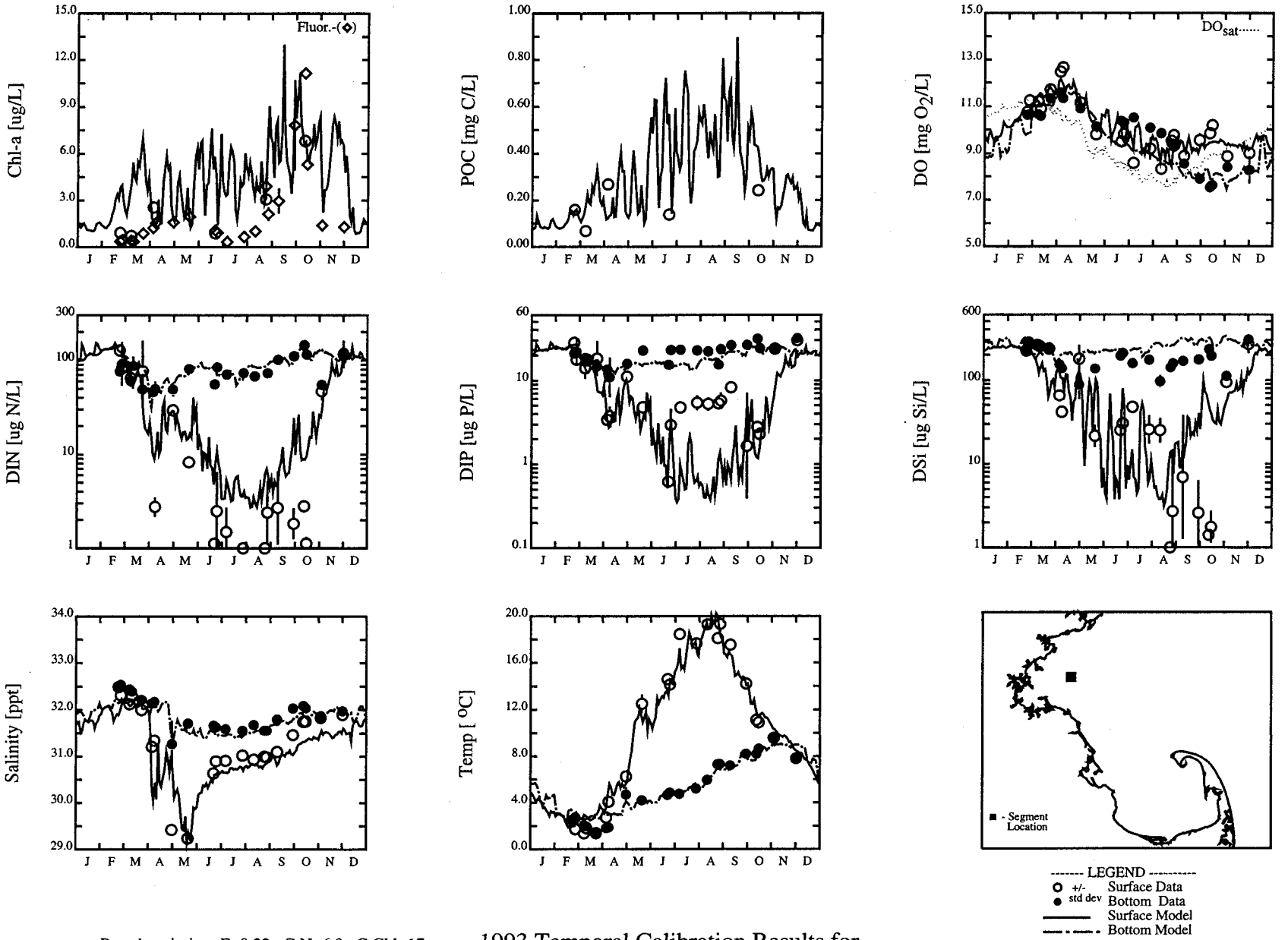




F=0.22 , C:N=6.9 , C:Chl=17

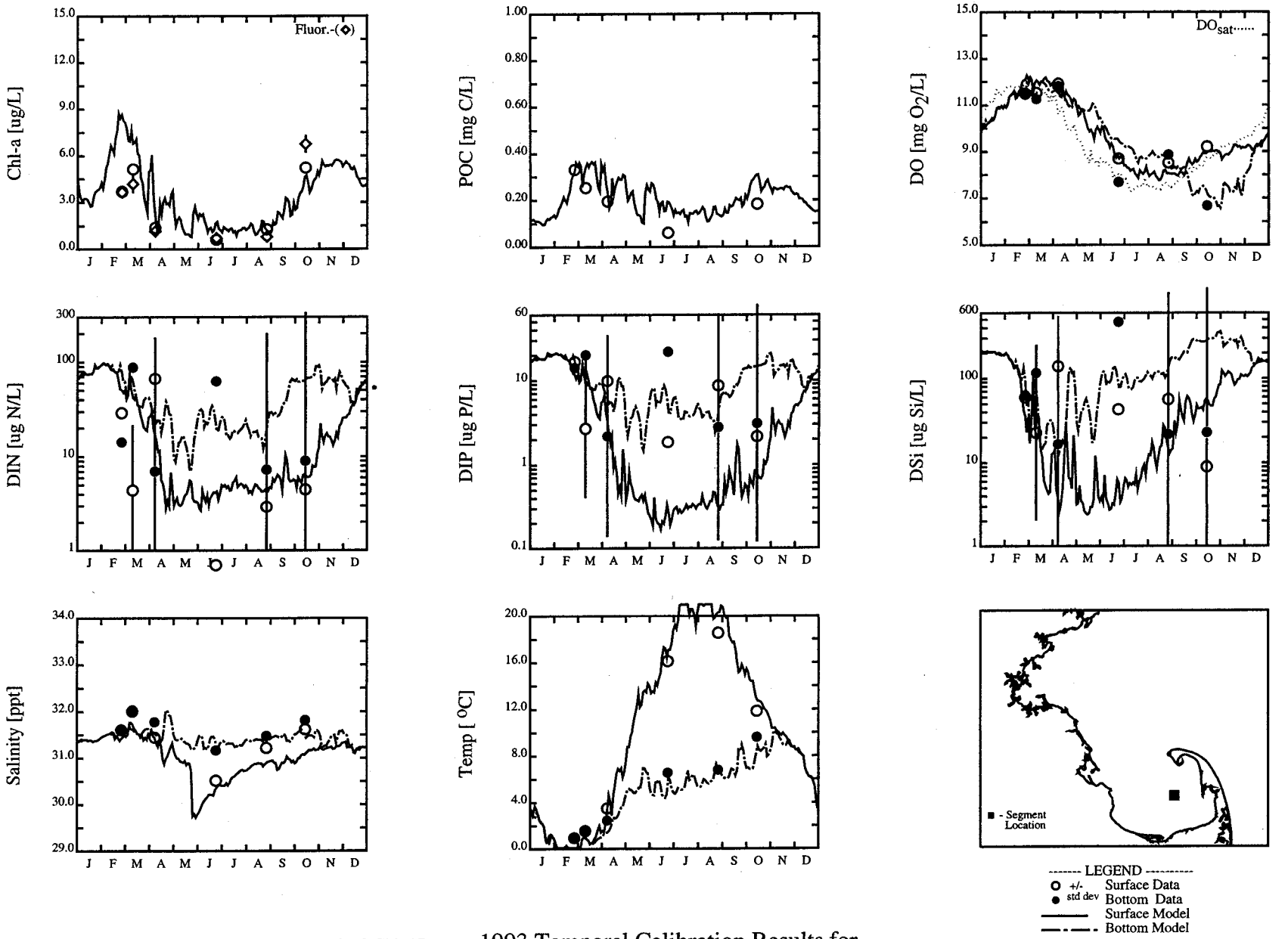

WINTER
SPRING
SUMMER
FALL
ANNUAL (1992)
ANNUAL (1992)
Near Field 12.5-17.5m Dissolved Oxygen (mg O2/L)
Far Field 12.5-17.5m Dissolved Oxygen (mg O2/L)
15.0
14.0
13.0
12.0
11.0
10.0
9.0
8.0
7.0
6.0
0.1 1 10 20 50 80 90 99 99.9
Probability
F=0.22 , C:N=6.9 , C:Chl=17
LEGEND
Data
Model


WINTER
SPRING
SUMMER
FALL
ANNUAL (1992)
ANNUAL (1992)
Near Field Bottom Water Dissolved Oxygen (mg O2/L)
Far Field Bottom Water Dissolved Oxygen (mg O2/L)
Probability
0.1 1 10 20 50 80 90 99 99.9
F=0.22 , C:N=6.9 , C:Chl=17
LEGEND
Data
Model
+Max/-Min



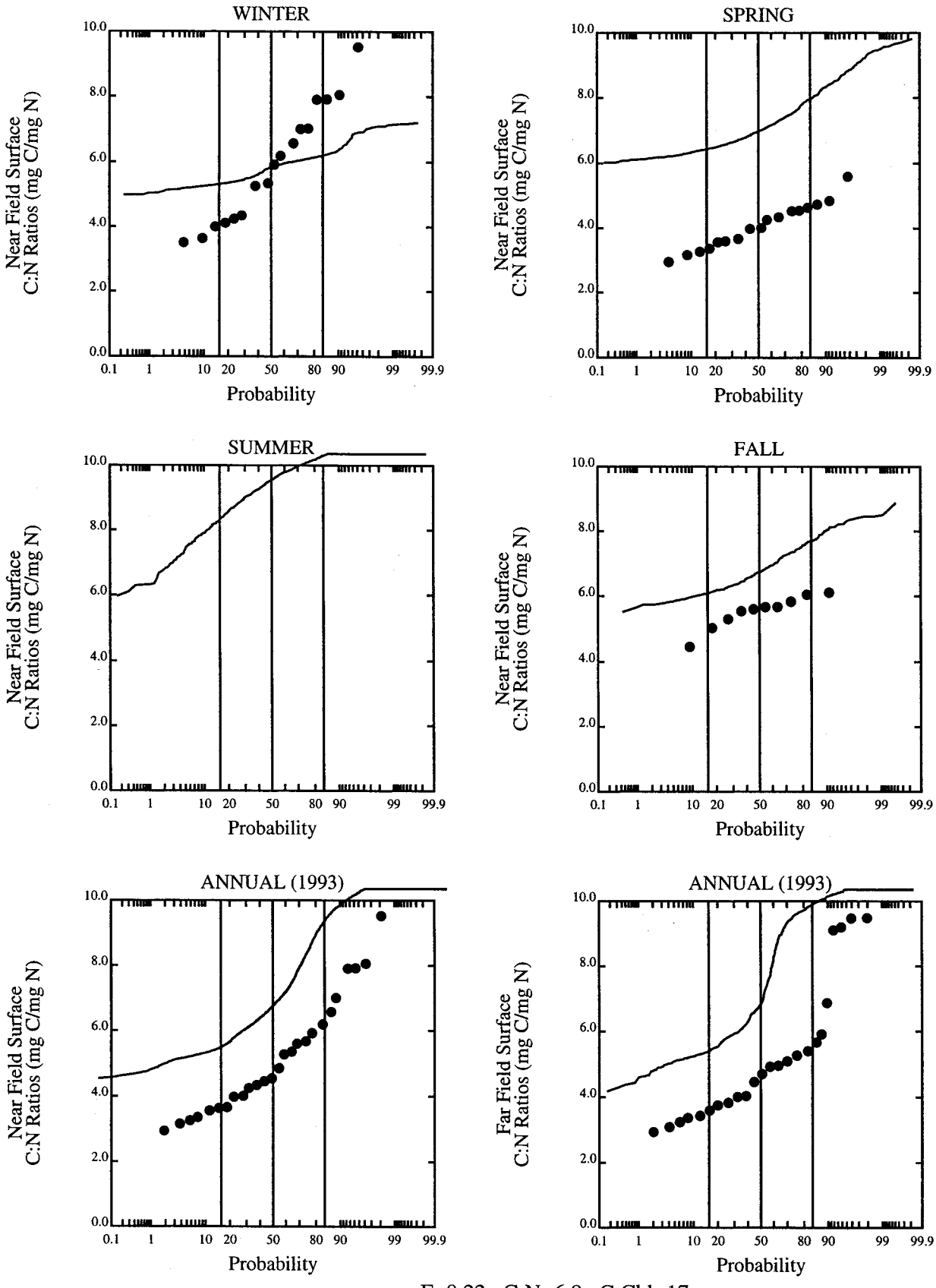
Run description: F=0.22 , C:N=6.9 , C:Chl=17

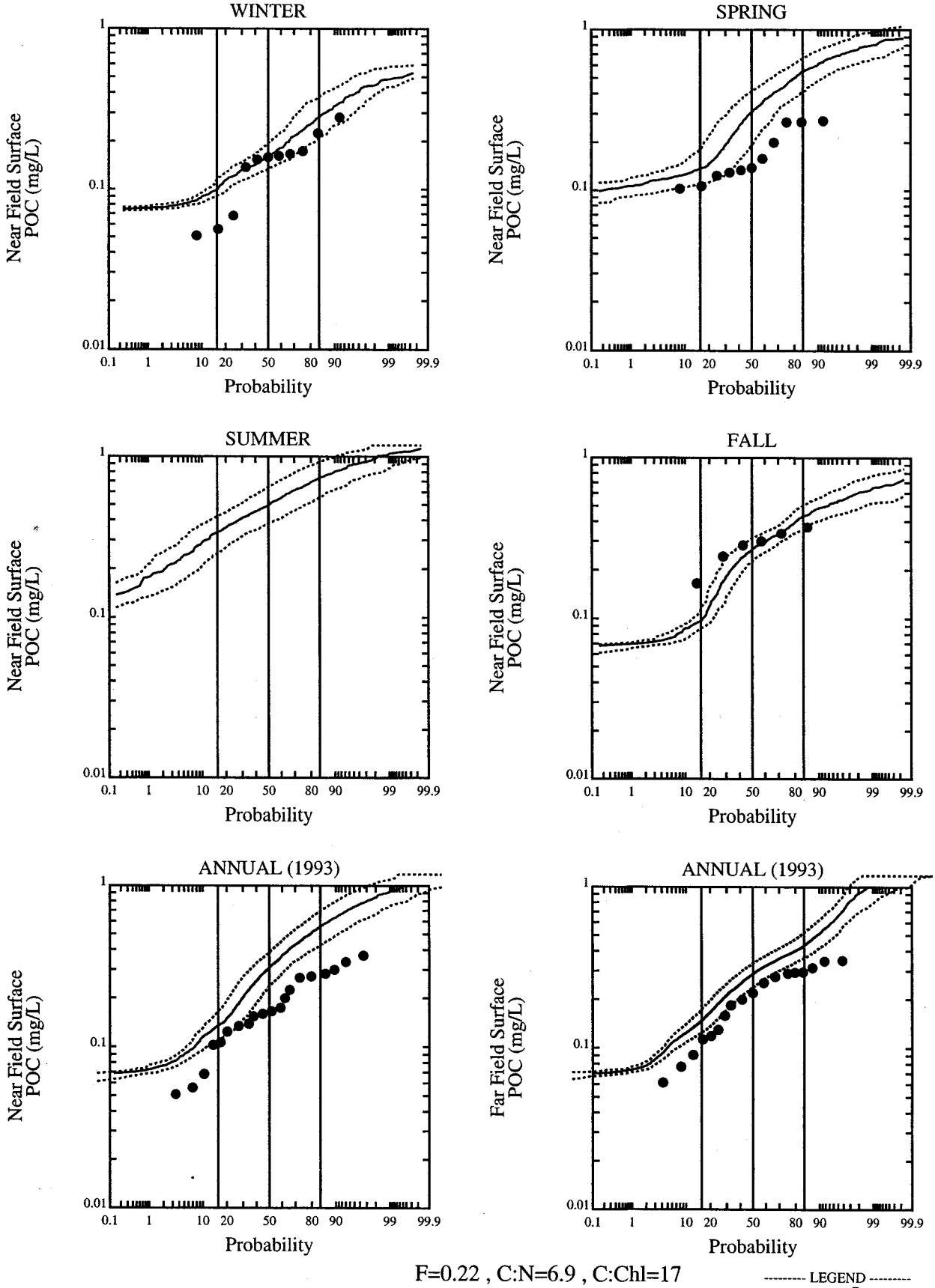
1993 Temporal Calibration Results for
Grid Cell (11,18) Vs Data Station N16P,N17,N21

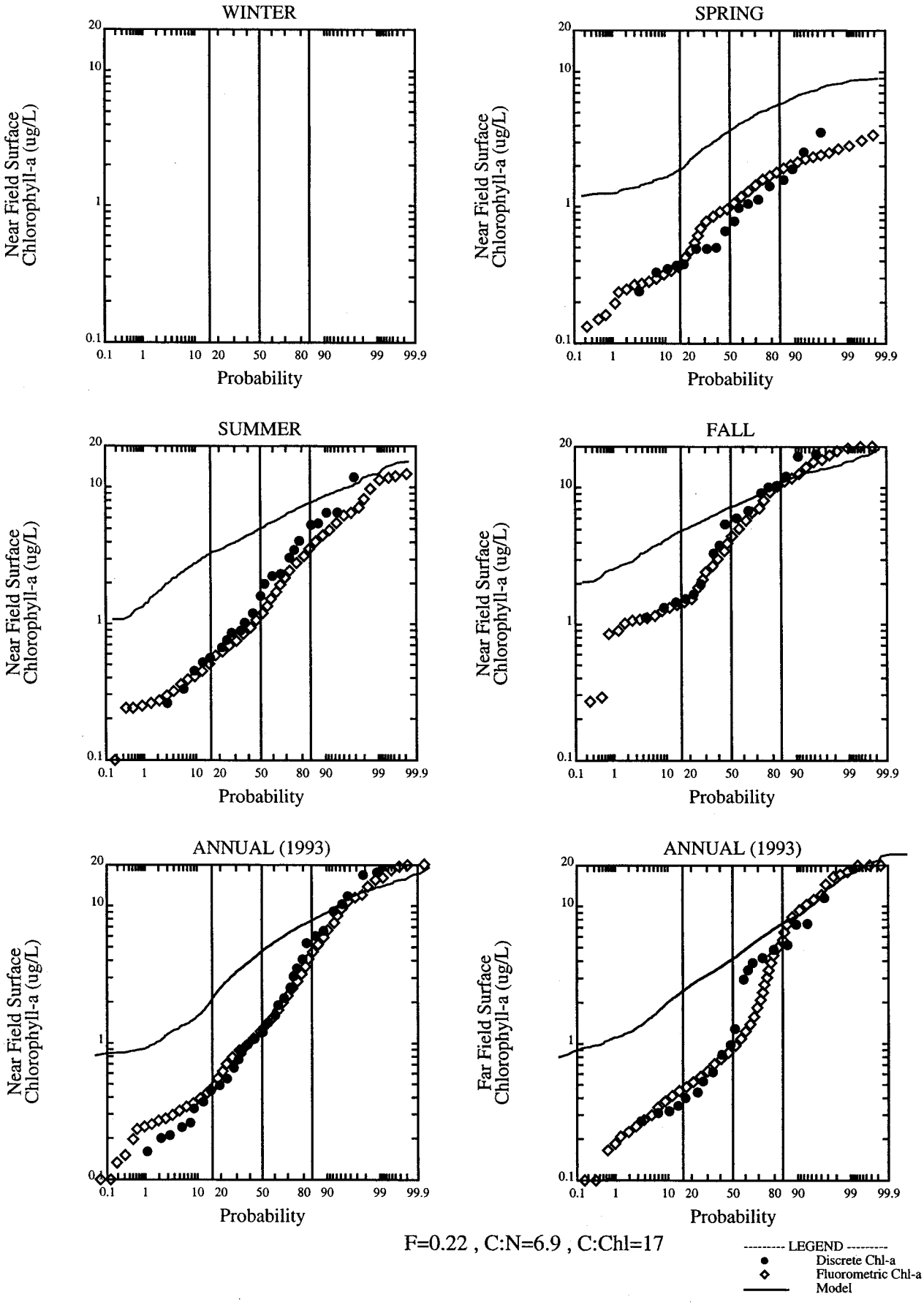


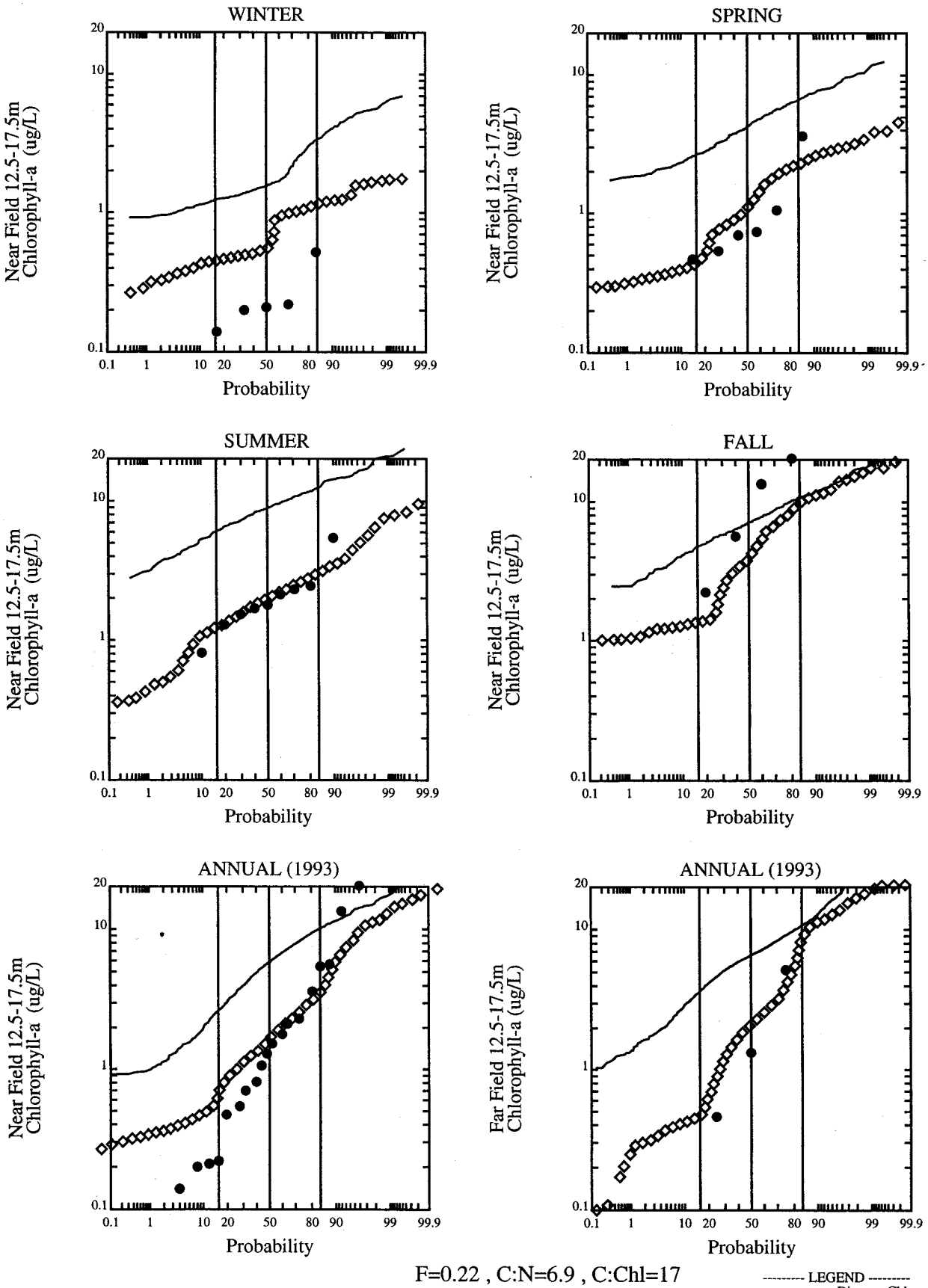
Run description: F=0.22 , C:N=6.9 , C:Chl=17

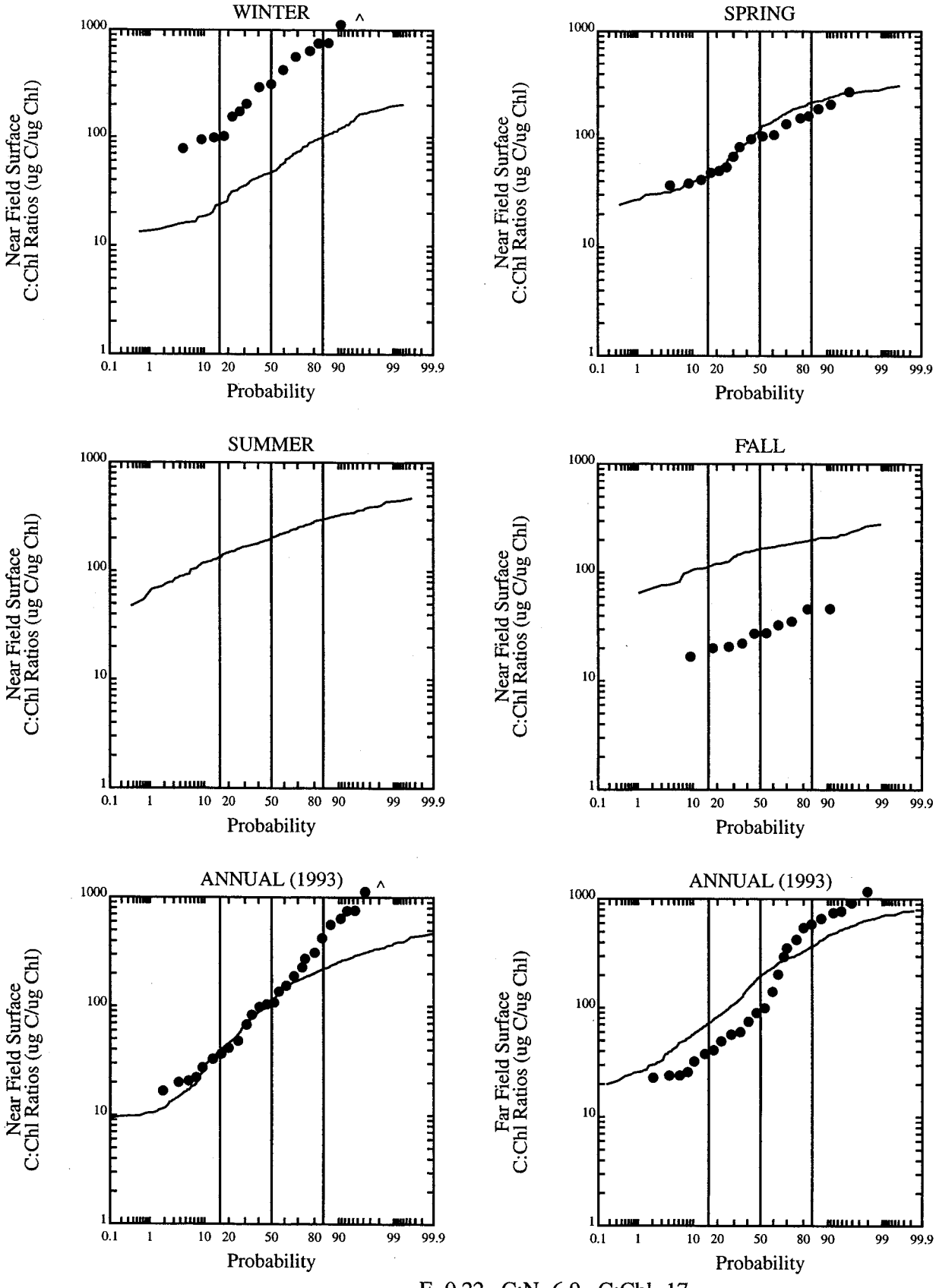
1993 Temporal Calibration Results for Grid Cell (13,4) Vs Data Station F02P

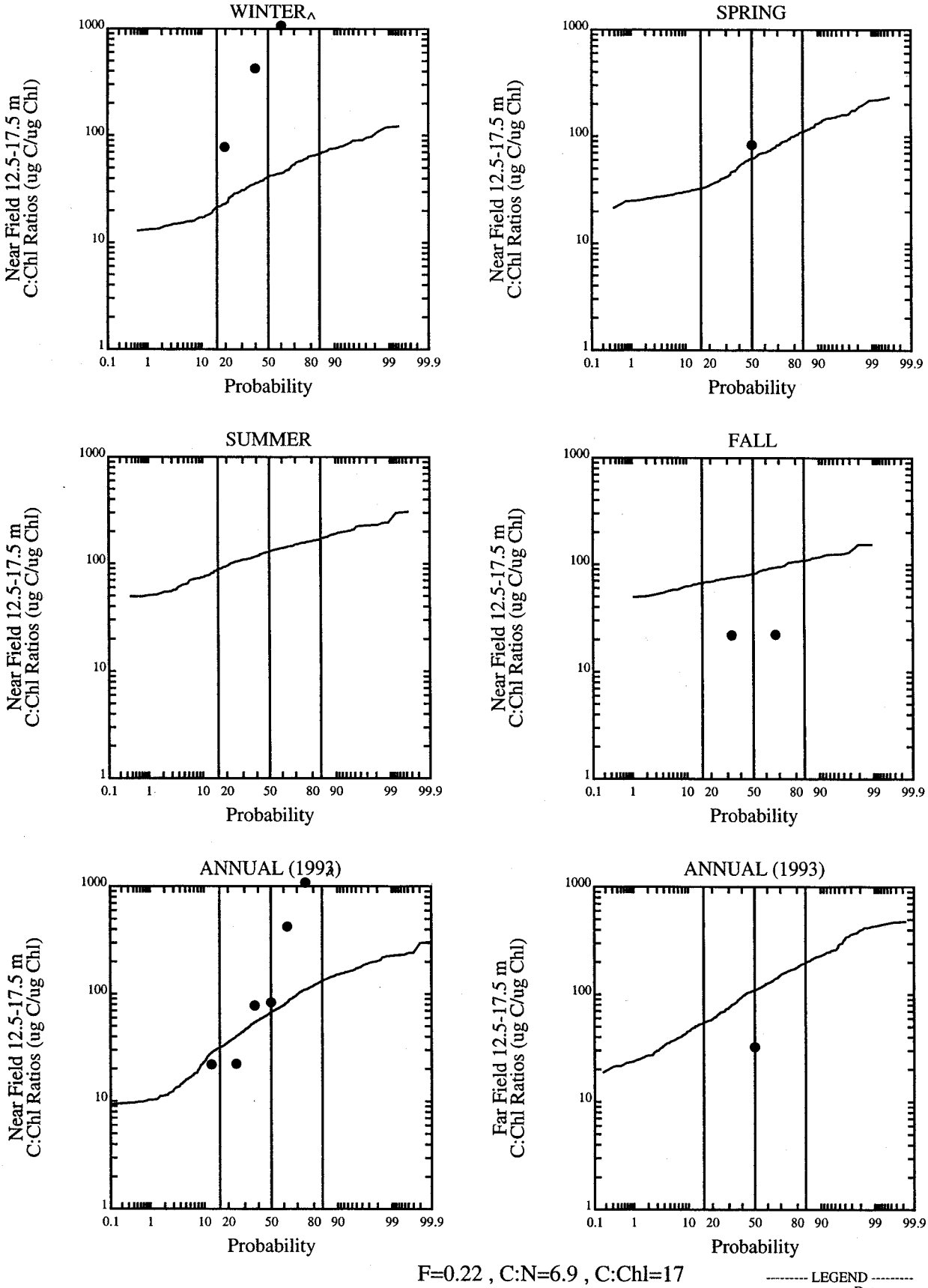

WINTER
SPRING
SUMMER
FALL
ANNUAL (1993)
ANNUAL (1993)
Near Field Surface C:N Ratios (mg C/mg N)
Far Field Surface C:N Ratios (mg C/mg N)
Probability
10.0
8.0
6.0
4.0
2.0
0.0
0.1
1
10
20
50
80
90
99
99.9
F=0.22 , C:N=6.9 , C:Chl=17
LEGEND
Data
Model

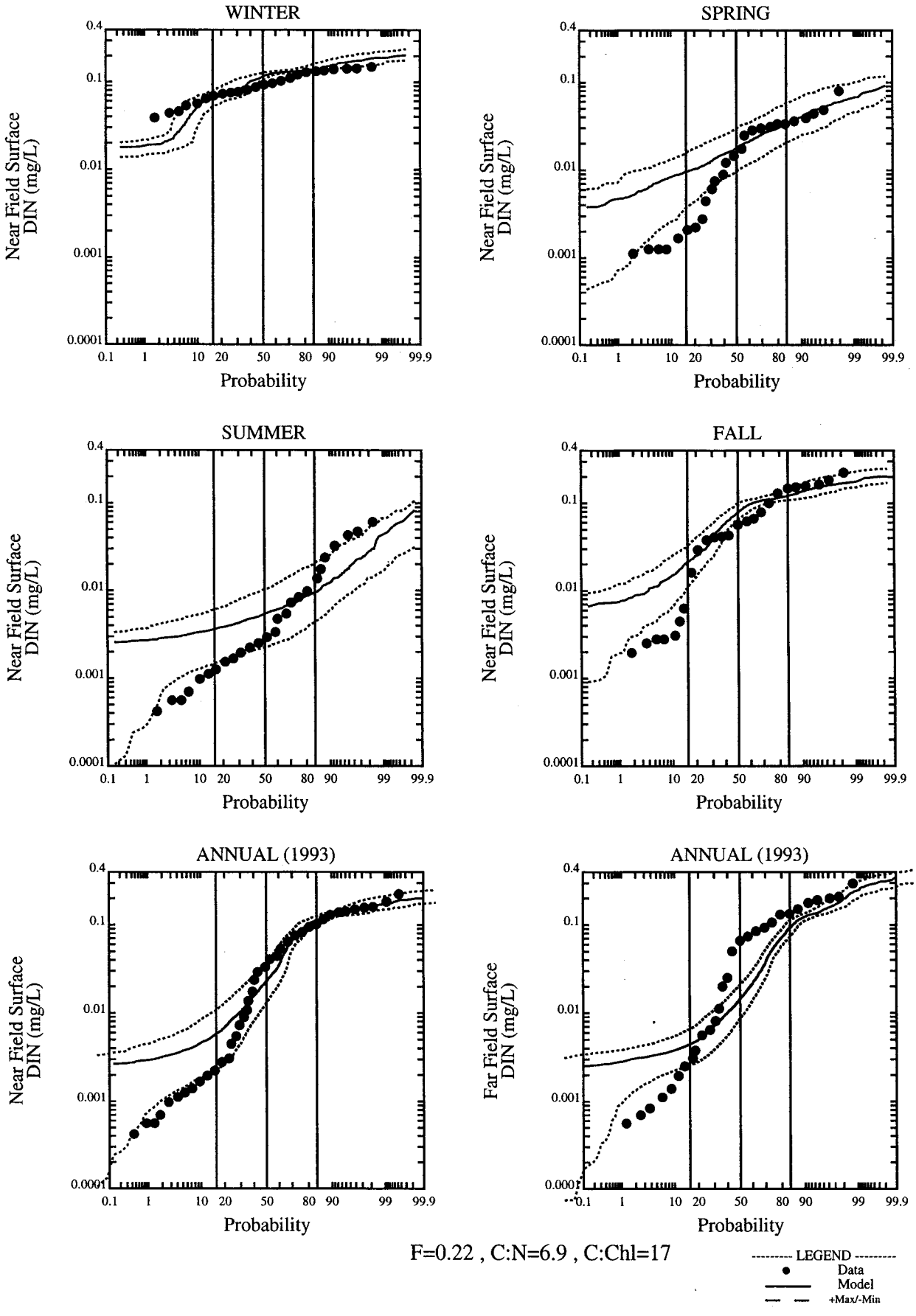

WINTER
SPRING
SUMMER
FALL
ANNUAL (1993)
ANNUAL (1993)
Near Field Surface POC (mg/L)
Far Field Surface POC (mg/L)
Probability
1
0.1
0.01
0.1 1 10 20 50 80 90 99 99.9
F=0.22 , C:N=6.9 , C:Chl=17
LEGEND
Data
Model
+Max/-Min

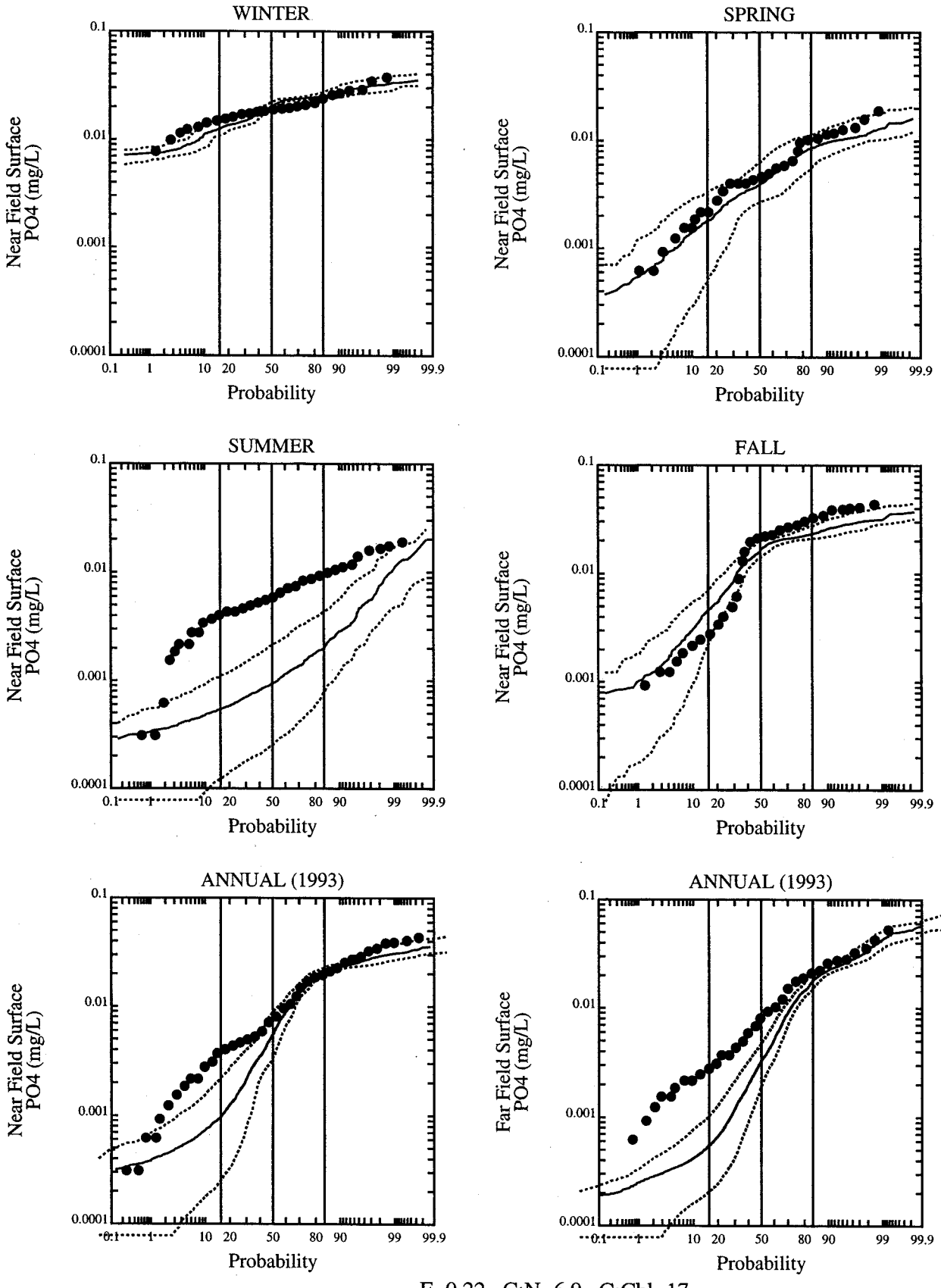

WINTER
SPRING
SUMMER
FALL
ANNUAL (1993)
ANNUAL (1993)
Near Field Surface Chlorophyll-a (ug/L)
Far Field Surface Chlorophyll-a (ug/L)
Probability
20
10
1
0.1
0.1
1
10
20
50
80
90
99
99.9
F=0.22 , C:N=6.9 , C:Chl=17
LEGEND
Discrete Chl-a
Fluorometric Chl-a
Model

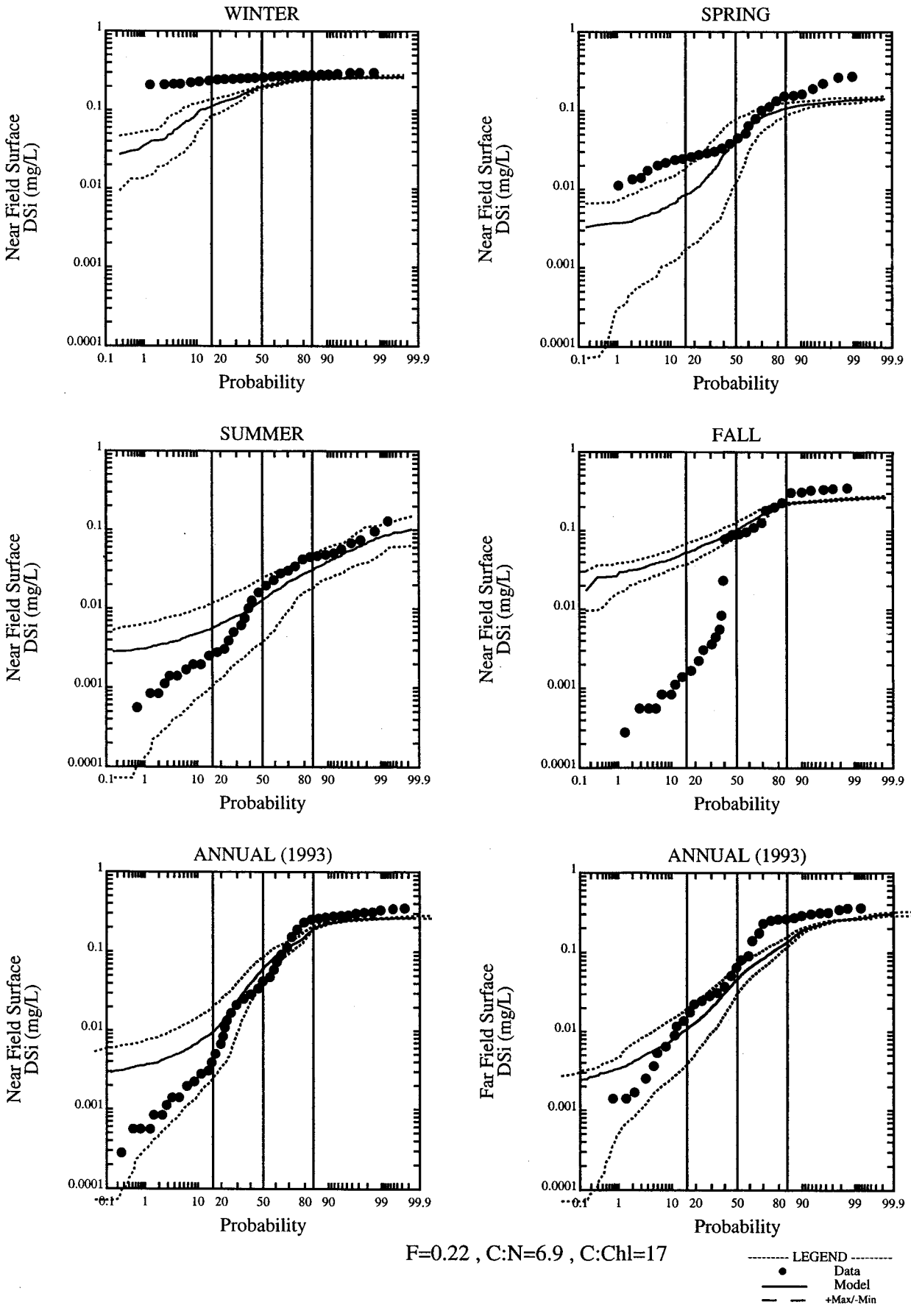

WINTER
SPRING
SUMMER
FALL
ANNUAL (1993)
ANNUAL (1993)
Near Field 12.5-17.5m Chlorophyll-a (ug/L)
Far Field 12.5-17.5m Chlorophyll-a (ug/L)
Probability
20
10
1
0.1
0.1 1 10 20 50 80 90 99 99.9
F=0.22 , C:N=6.9 , C:Chl=17
LEGEND
Discrete Chl-a
Fluorometric Chl-a
Model

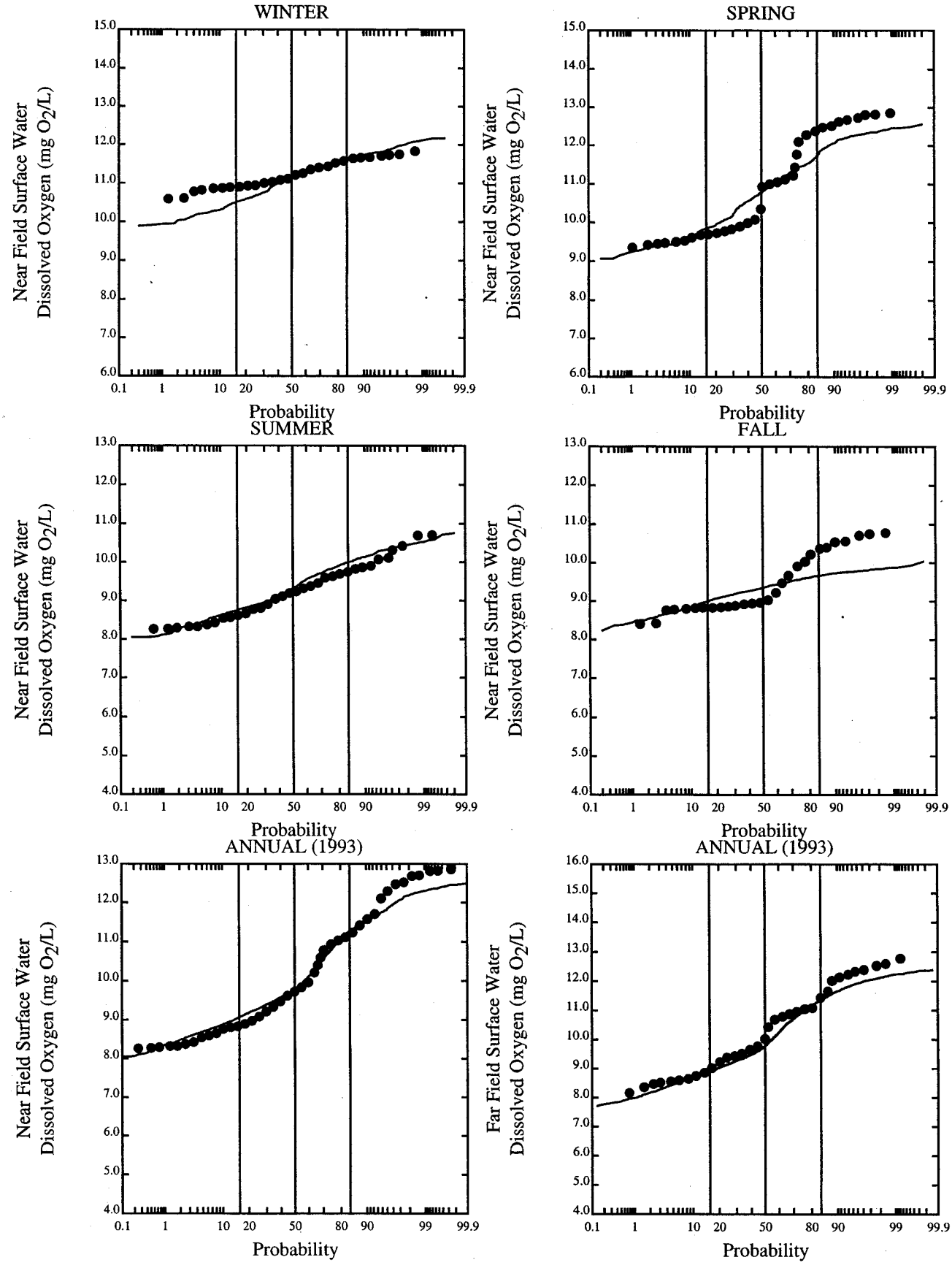

WINTER
SPRING
SUMMER
FALL
ANNUAL (1993)
ANNUAL (1993)
Near Field Surface C:Chl Ratios (ug C/ug Chl)
Far Field Surface C:Chl Ratios (ug C/ug Chl)
Probability
1000
100
10
1
0.1
1
10
20
50
80
90
99
99.9
F=0.22 , C:N=6.9 , C:Chl=17
LEGEND
Data
Model

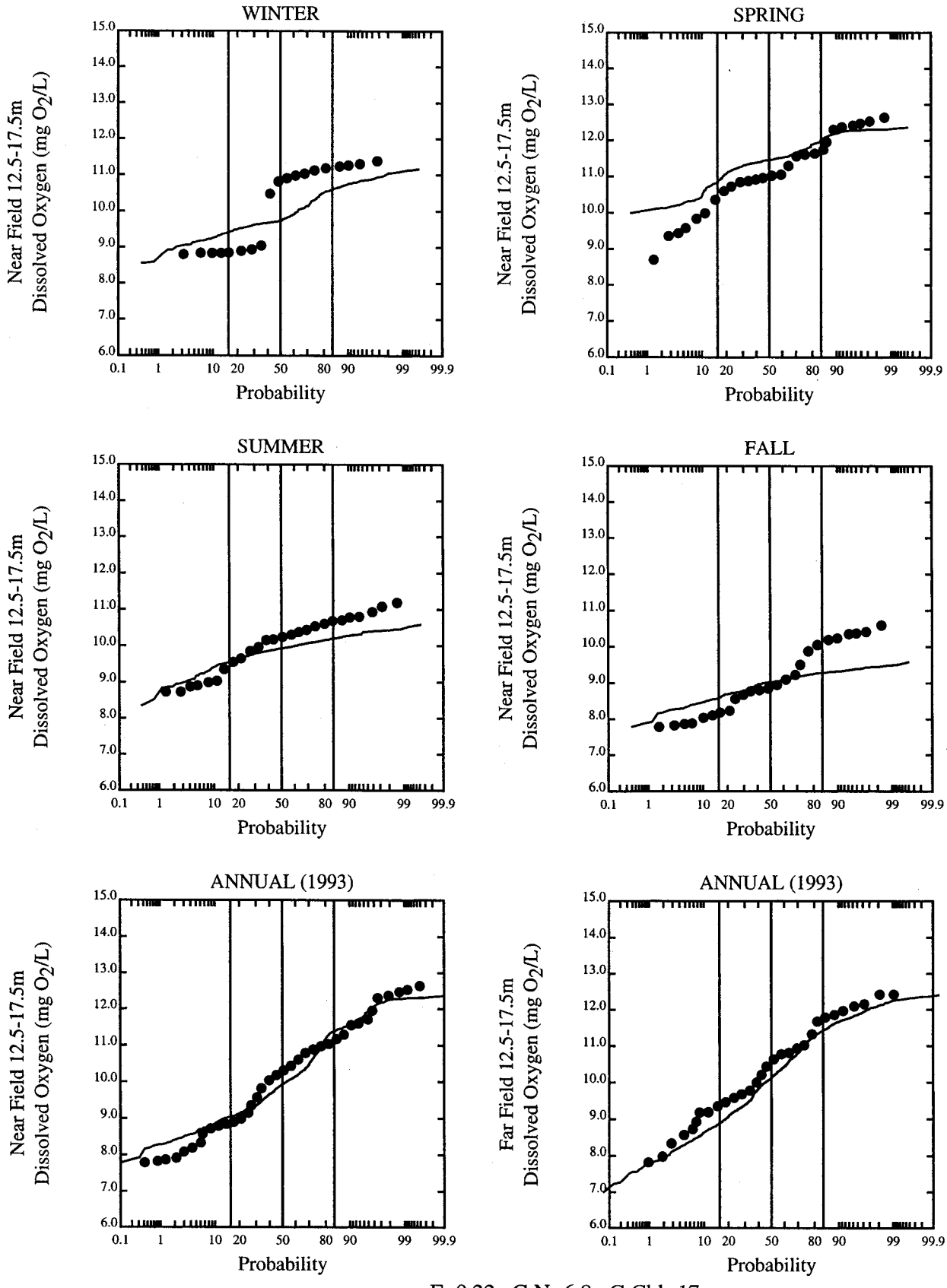

WINTER
SPRING
SUMMER
FALL
ANNUAL (1992)
ANNUAL (1993)
Near Field 12.5-17.5 m C:Chl Ratios (ug C/ug Chl)
Far Field 12.5-17.5 m C:Chl Ratios (ug C/ug Chl)
Probability
1000
100
10
1
0.1
1
10
20
50
80
90
99
99.9
F=0.22 , C:N=6.9 , C:Chl=17
LEGEND
Data
Model

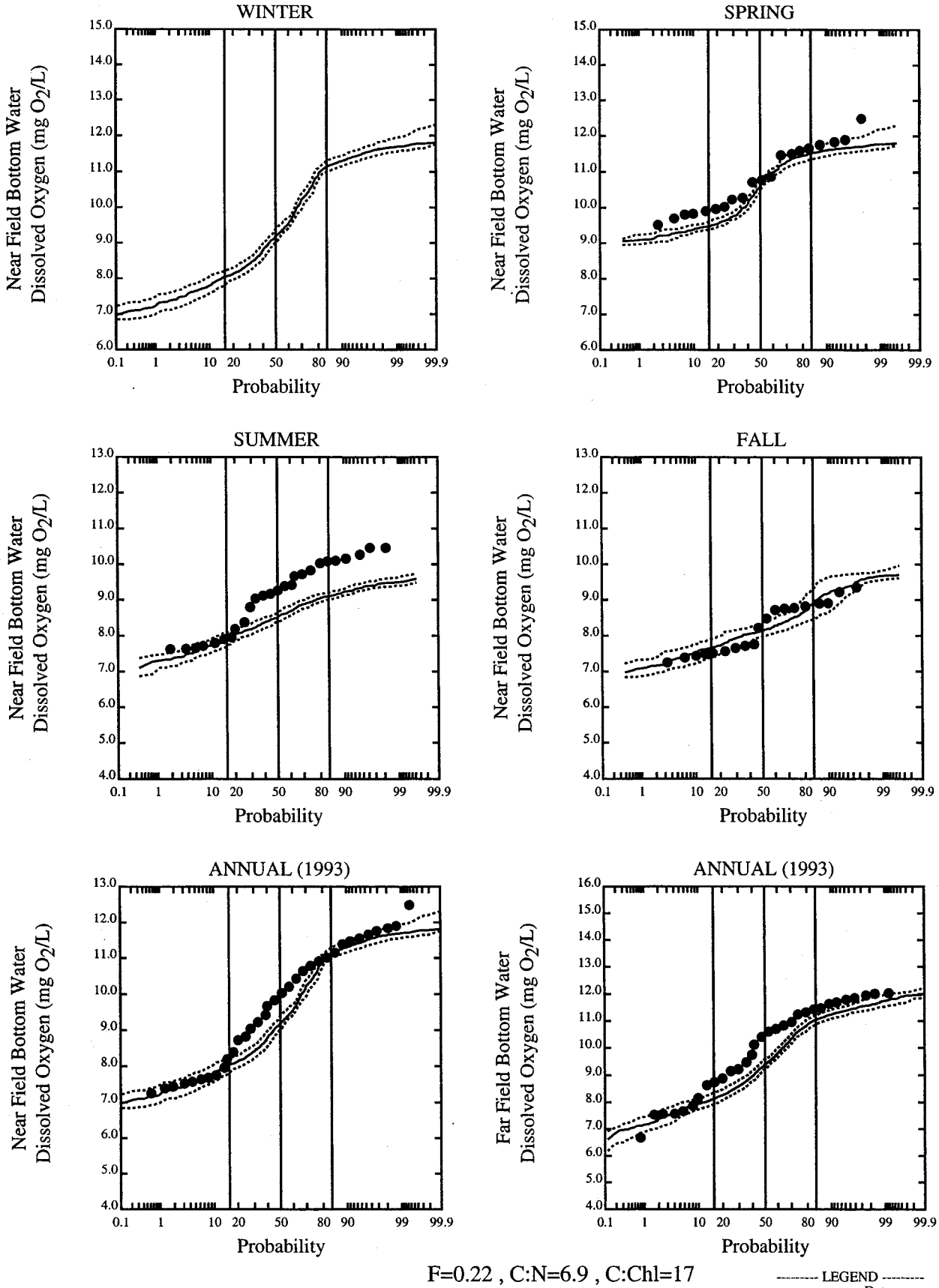

WINTER
SPRING
SUMMER
FALL
ANNUAL (1993)
ANNUAL (1993)
Near Field Surface DIN (mg/L)
Far Field Surface DIN (mg/L)
0.4
0.1
0.01
0.001
0.0001
0.1 1 10 20 50 80 90 99 99.9
Probability
F=0.22 , C:N=6.9 , C:Chl=17
-------- LEGEND --------
Data
Model
+Max/-Min

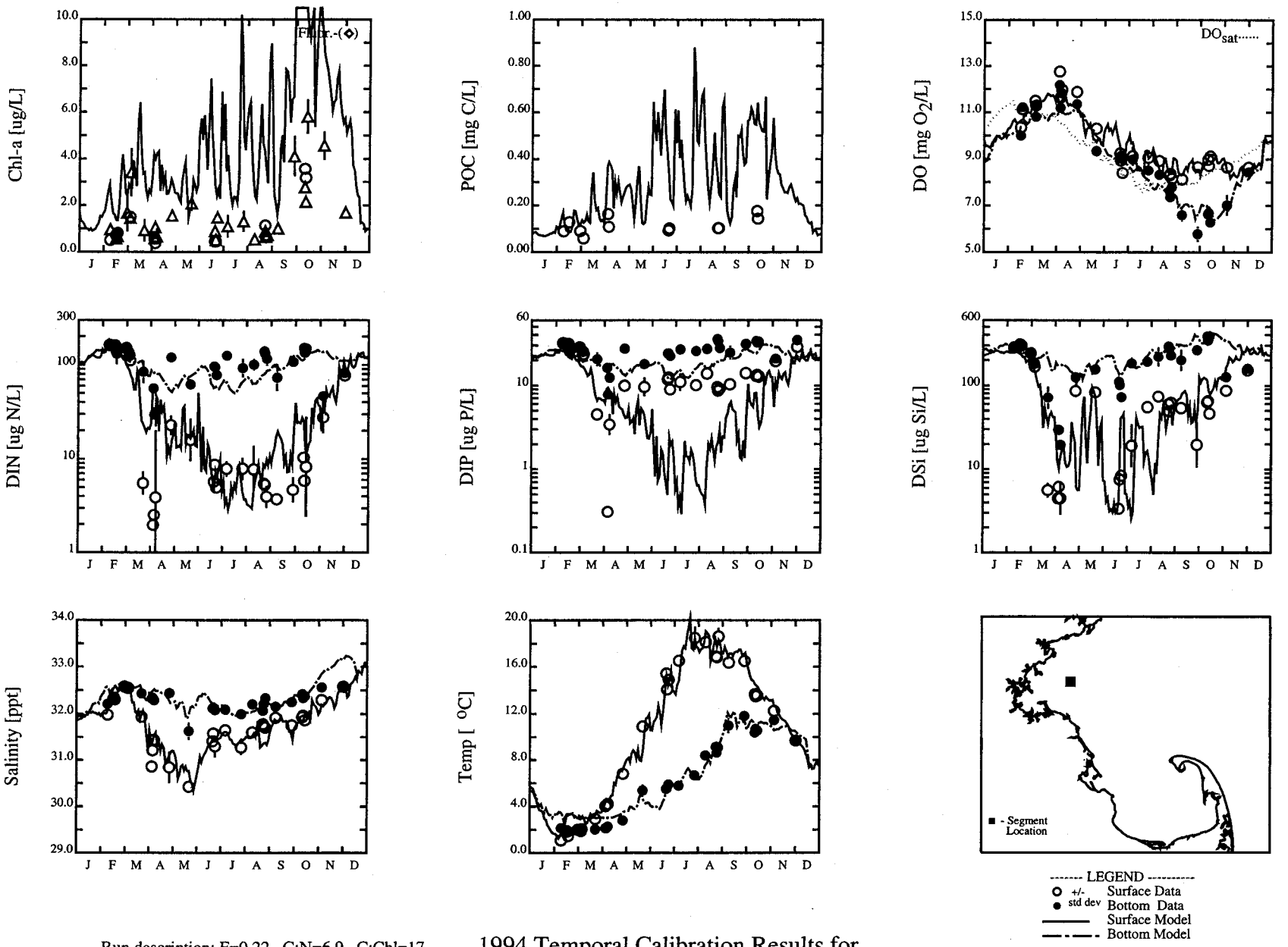

WINTER
SPRING
SUMMER
FALL
ANNUAL (1993)
ANNUAL (1993)
Near Field Surface PO4 (mg/L)
Far Field Surface PO4 (mg/L)
0.1
0.01
0.001
0.0001
0.1 1 10 20 50 80 90 99 99.9
Probability
F=0.22 , C:N=6.9 , C:Chl=17
LEGEND
Data
Model
+Max/-Min


WINTER
SPRING
SUMMER
FALL
ANNUAL (1993)
ANNUAL (1993)
Near Field Surface DSi (mg/L)
Far Field Surface DSi (mg/L)
Probability
1
0.1
0.01
0.001
0.0001
0.1
1
10
20
50
80
90
99
99.9
F=0.22 , C:N=6.9 , C:Chl=17
LEGEND
Data
Model
+Max/-Min


WINTER
SPRING
SUMMER
FALL
ANNUAL (1993)
ANNUAL (1993)
Near Field Surface Water Dissolved Oxygen (mg O2/L)
Far Field Surface Water Dissolved Oxygen (mg O2/L)
Probability
F=0.22 , C:N=6.9 , C:Chl=17
LEGEND
Data
Model

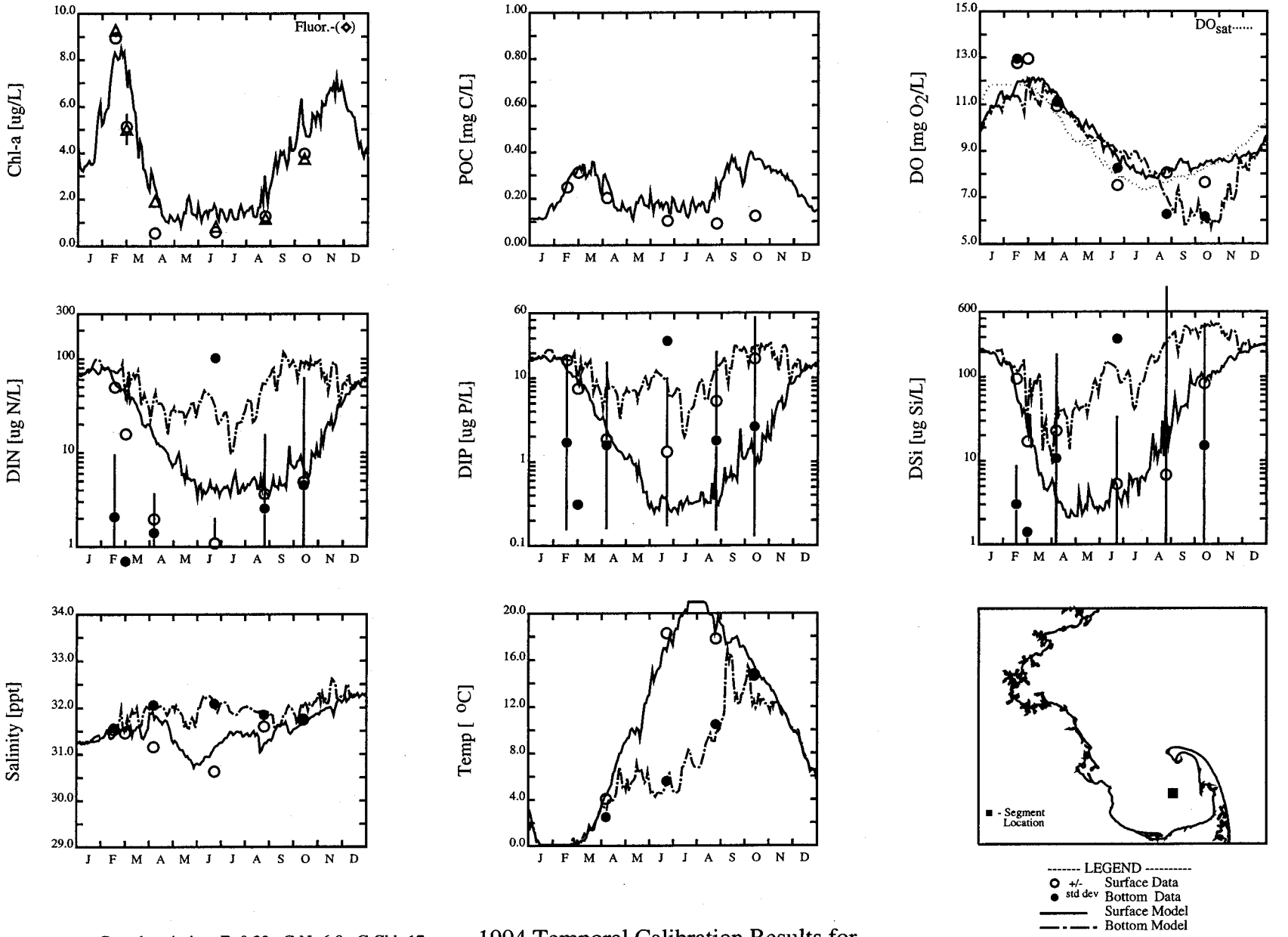

WINTER
SPRING
SUMMER
FALL
ANNUAL (1993)
ANNUAL (1993)
Near Field 12.5-17.5m Dissolved Oxygen (mg O2/L)
Far Field 12.5-17.5m Dissolved Oxygen (mg O2/L)
15.0
14.0
13.0
12.0
11.0
10.0
9.0
8.0
7.0
6.0
0.1 1 10 20 50 80 90 99 99.9
Probability
F=0.22 , C:N=6.9 , C:Chl=17
LEGEND
Data
Model


WINTER
SPRING
SUMMER
FALL
ANNUAL (1993)
ANNUAL (1993)
Near Field Bottom Water Dissolved Oxygen (mg O2/L)
Far Field Bottom Water Dissolved Oxygen (mg O2/L)
Probability
0.1 1 10 20 50 80 90 99 99.9
F=0.22 , C:N=6.9 , C:Chl=17
LEGEND
Data
Model
+Max/-Min



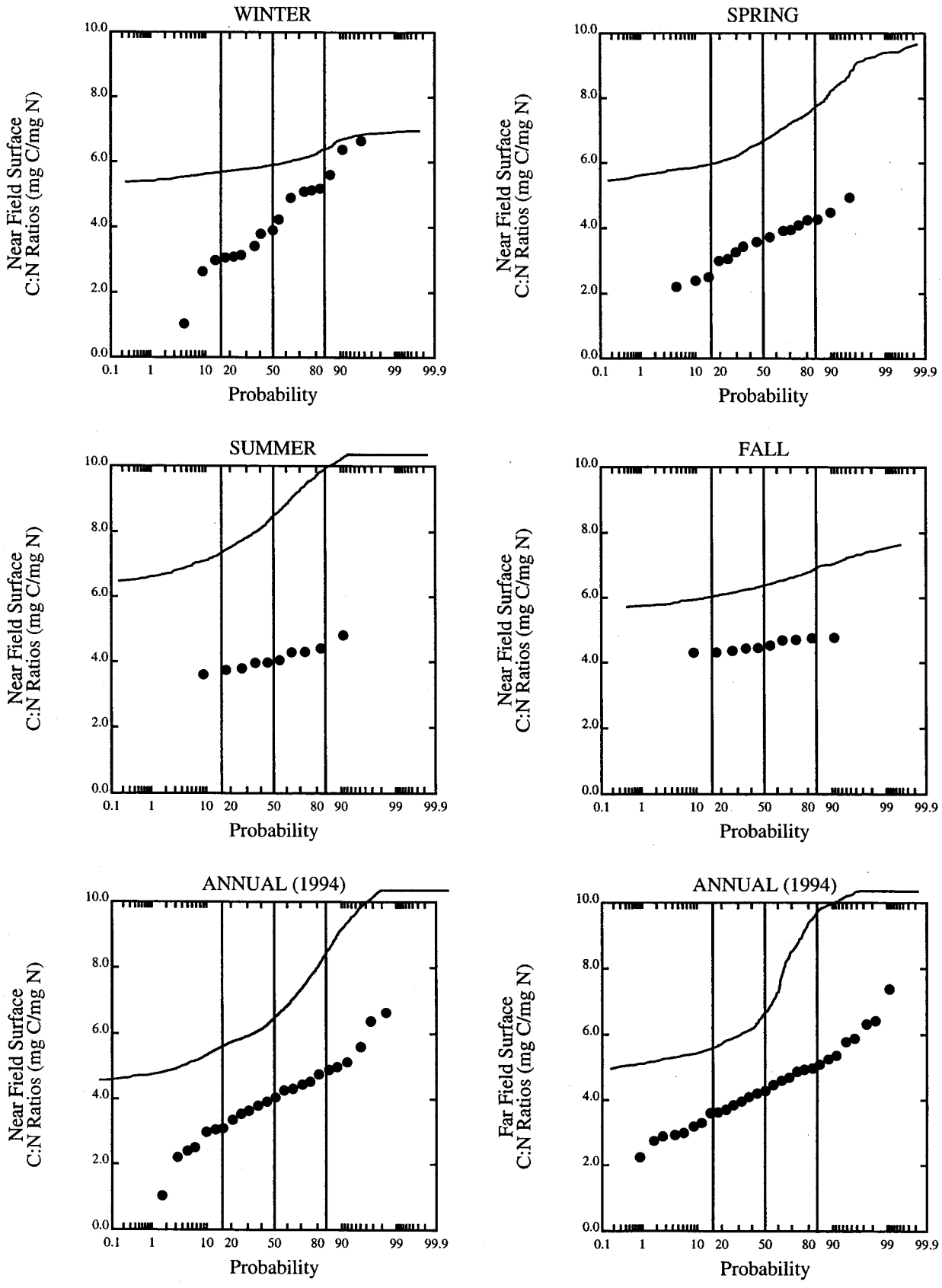
Run description: F=0.22 , C:N=6.9 , C:Chl=17

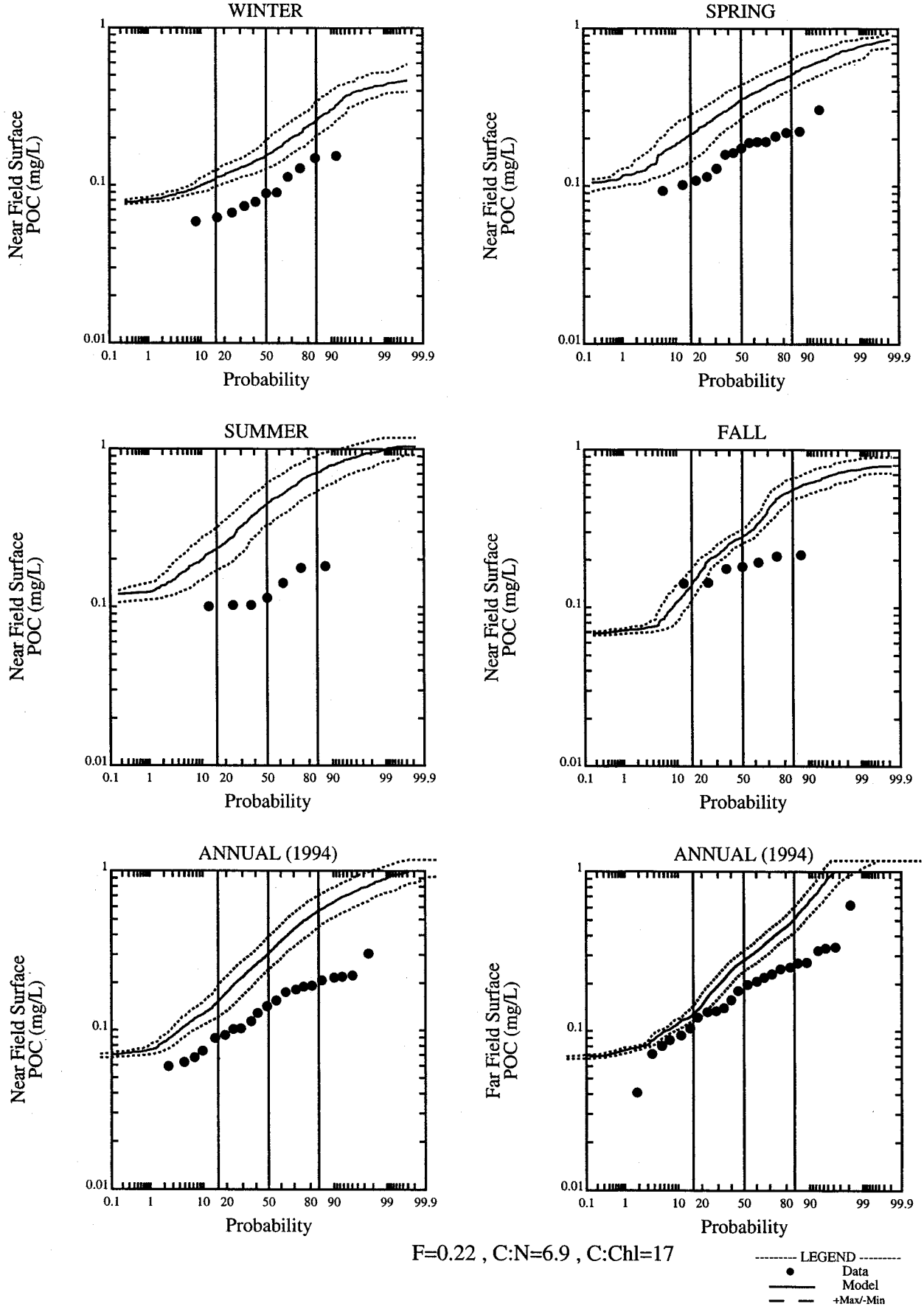
1994 Temporal Calibration Results for
Grid Cell (11,18) Vs Data Station N16P,N17,N21

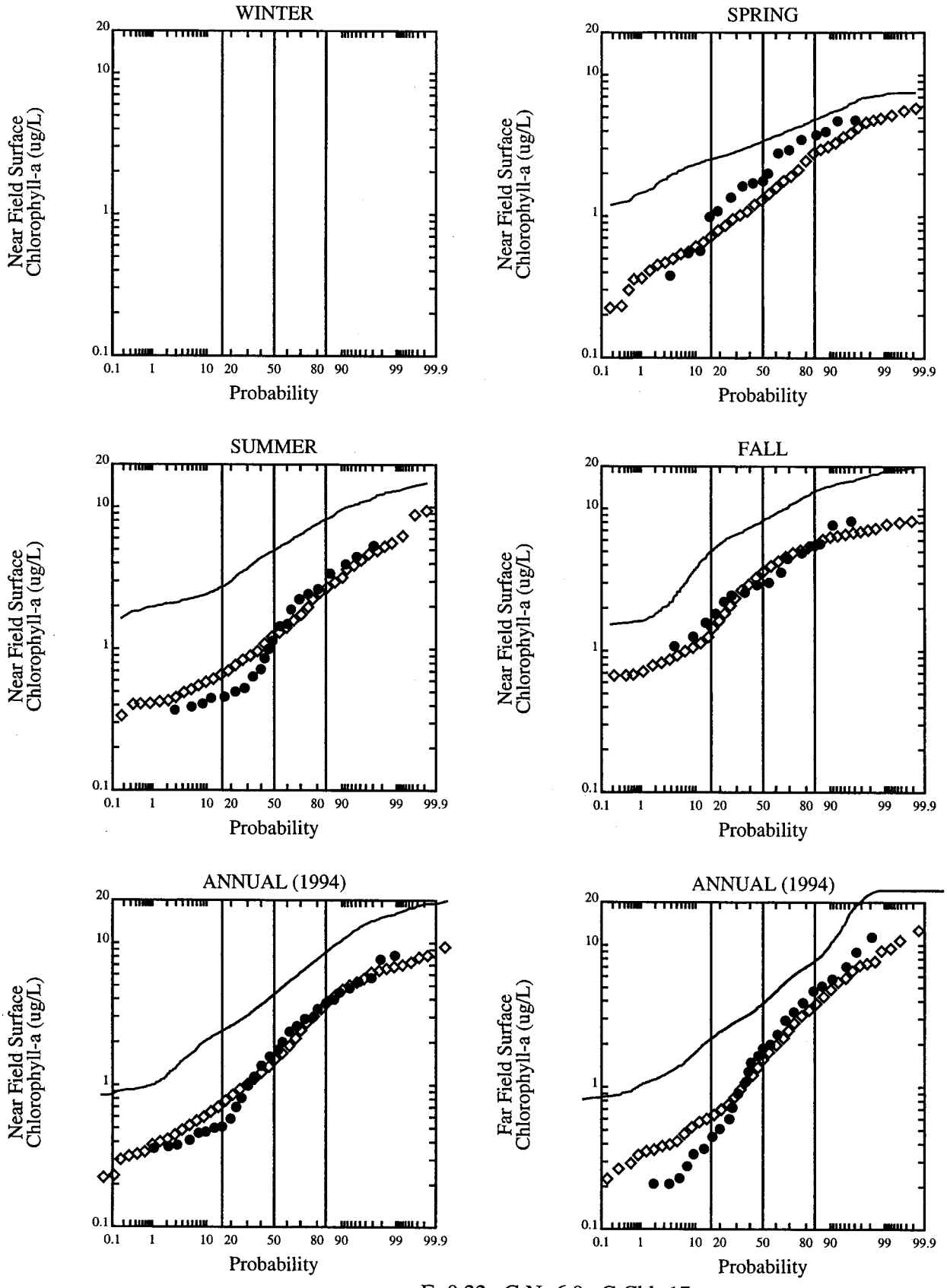


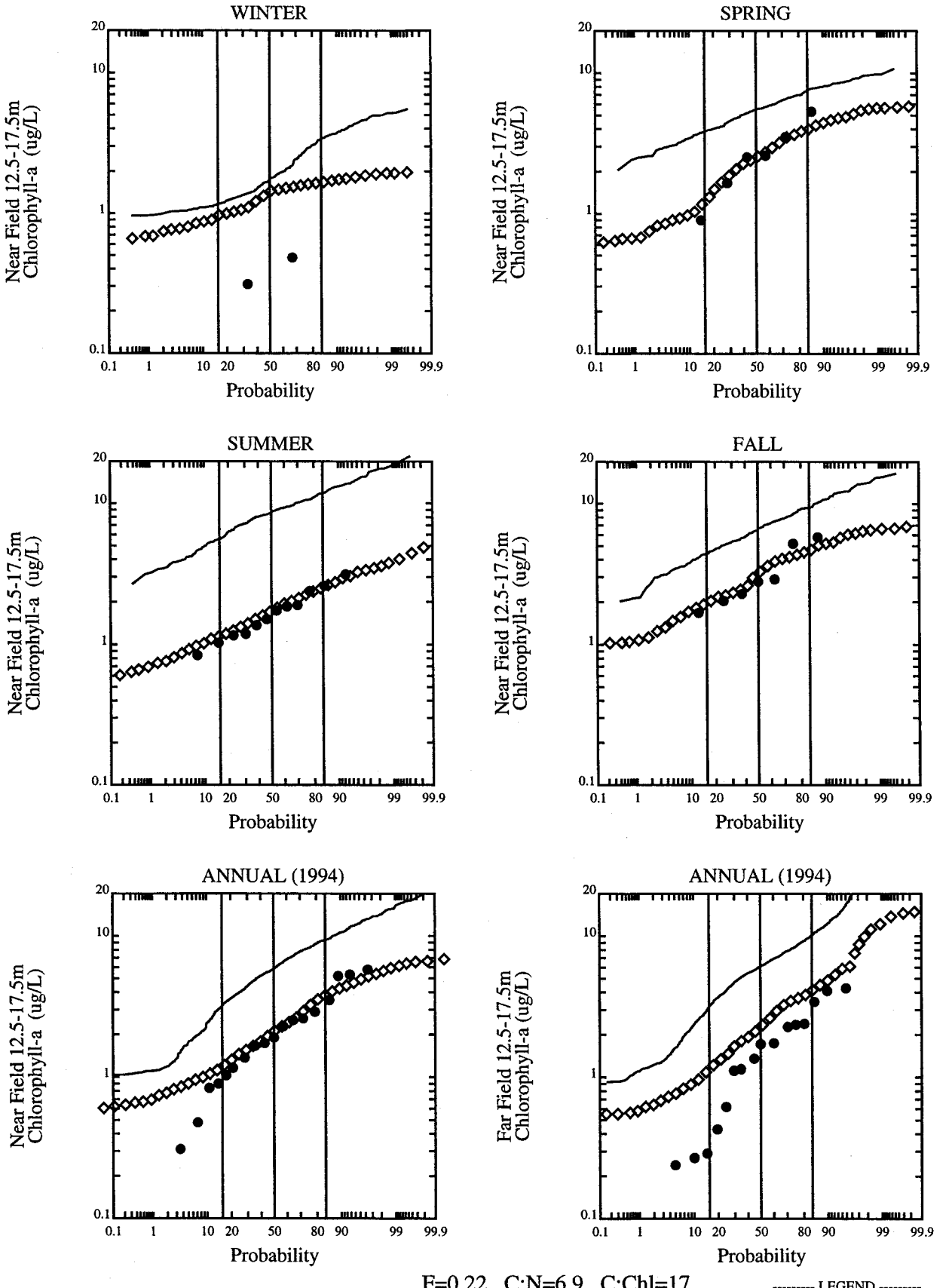
Run description: F=0.22 , C:N=6.9 , C:Chl=17

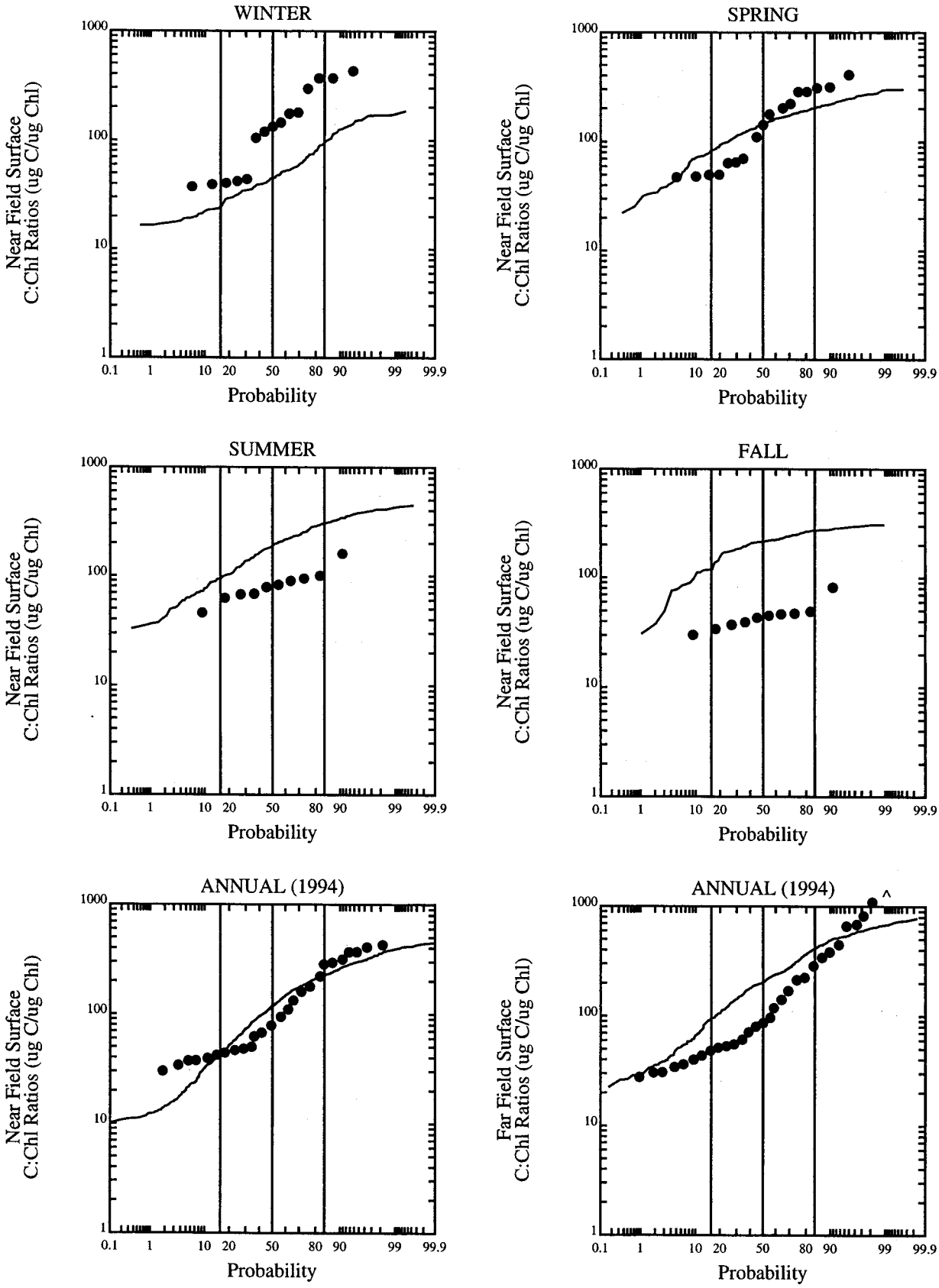
1994 Temporal Calibration Results for
Grid Cell (13,04) Vs Data Station F02P

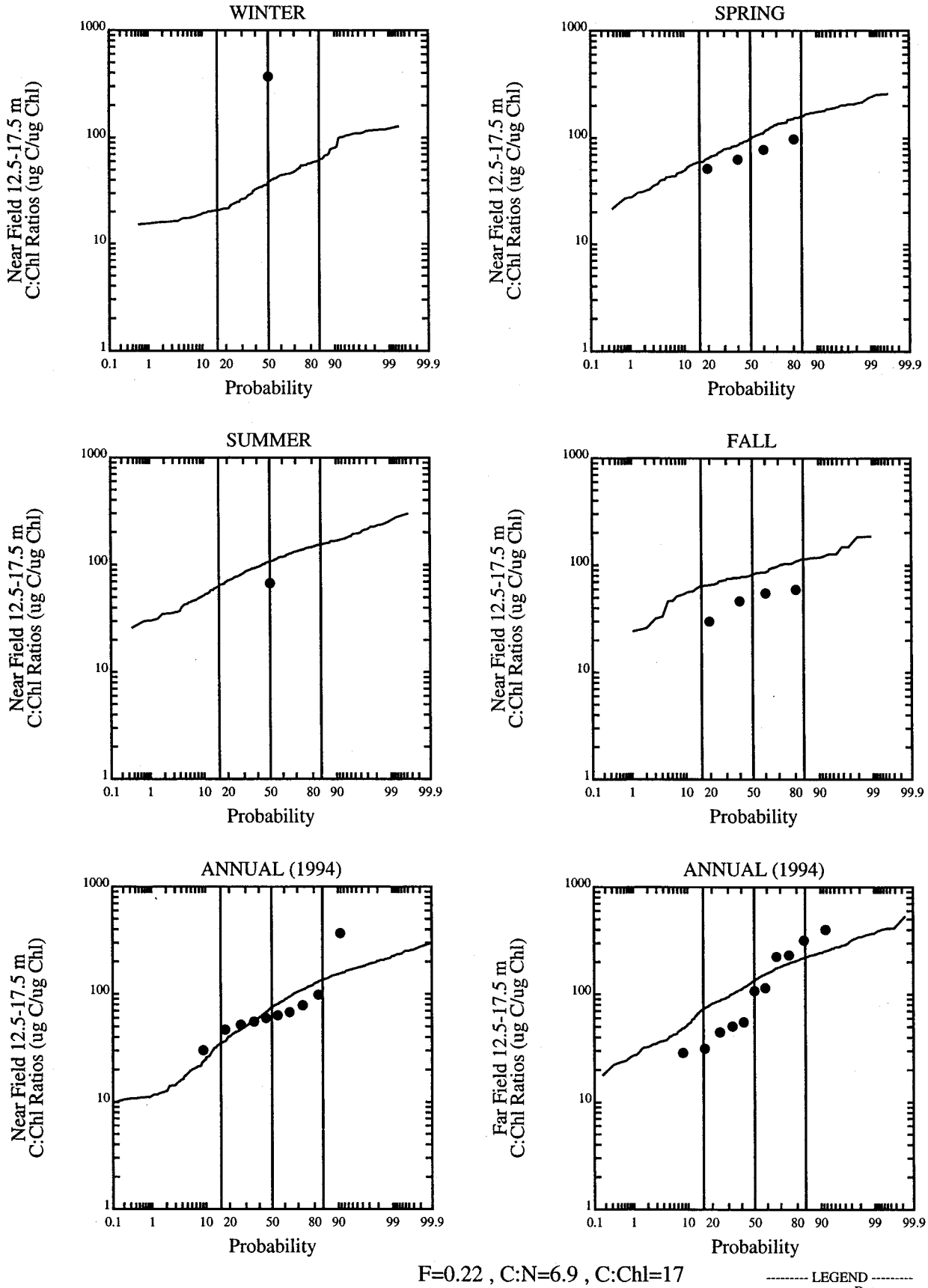

WINTER
SPRING
SUMMER
FALL
ANNUAL (1994)
ANNUAL (1994)
Near Field Surface C:N Ratios (mg C/mg N)
Far Field Surface C:N Ratios (mg C/mg N)
Probability
0.1 1 10 20 50 80 90 99 99.9
0.0 2.0 4.0 6.0 8.0 10.0
F=0.22 , C:N=6.9 , C:Chl=17
LEGEND
Data
Model

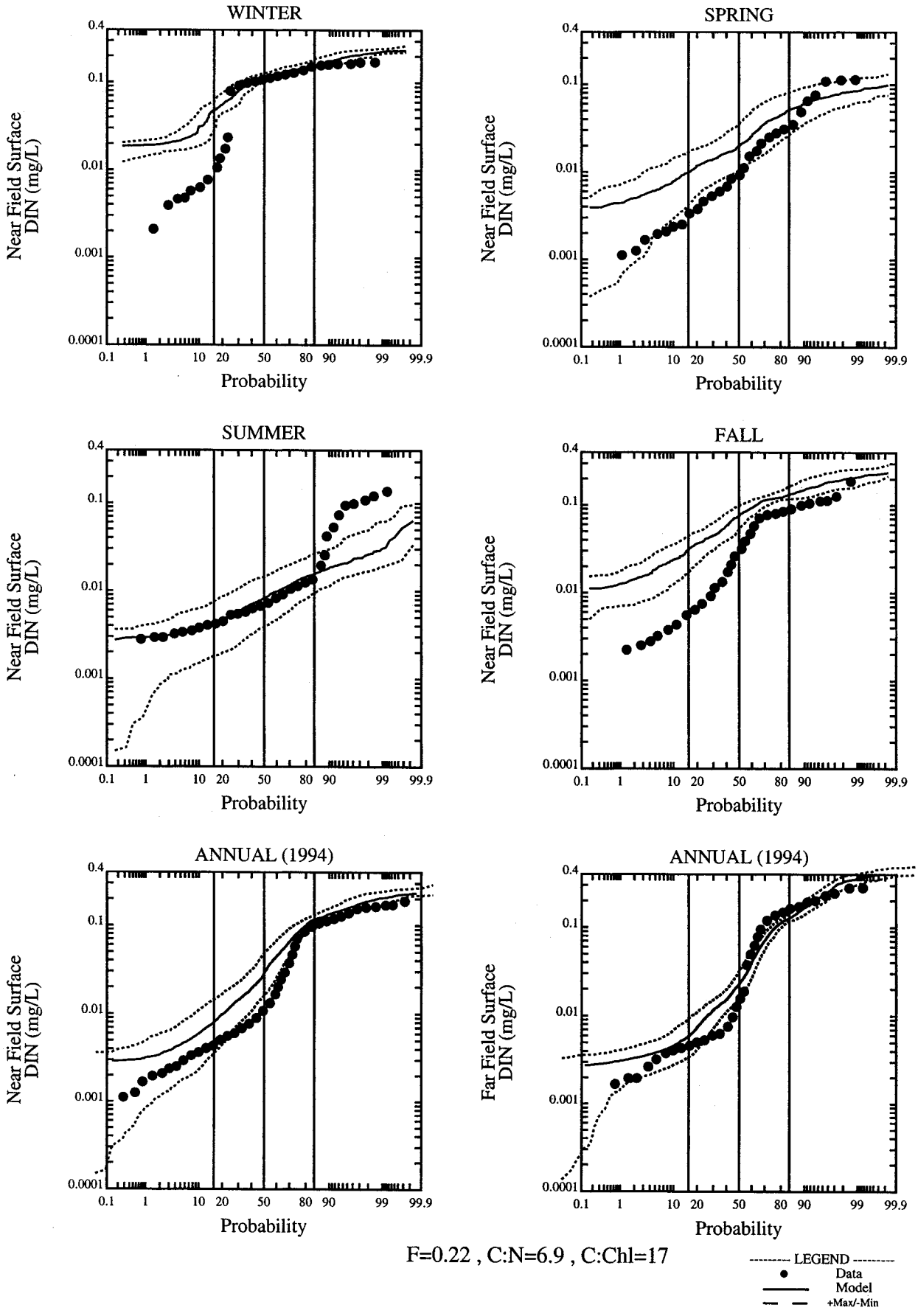

WINTER
SPRING
SUMMER
FALL
ANNUAL (1994)
ANNUAL (1994)
Near Field Surface POC (mg/L)
Far Field Surface POC (mg/L)
Probability
1
0.1
0.01
0.1 1 10 20 50 80 90 99 99.9
F=0.22 , C:N=6.9 , C:Chl=17
LEGEND
Data
Model
+Max/-Min

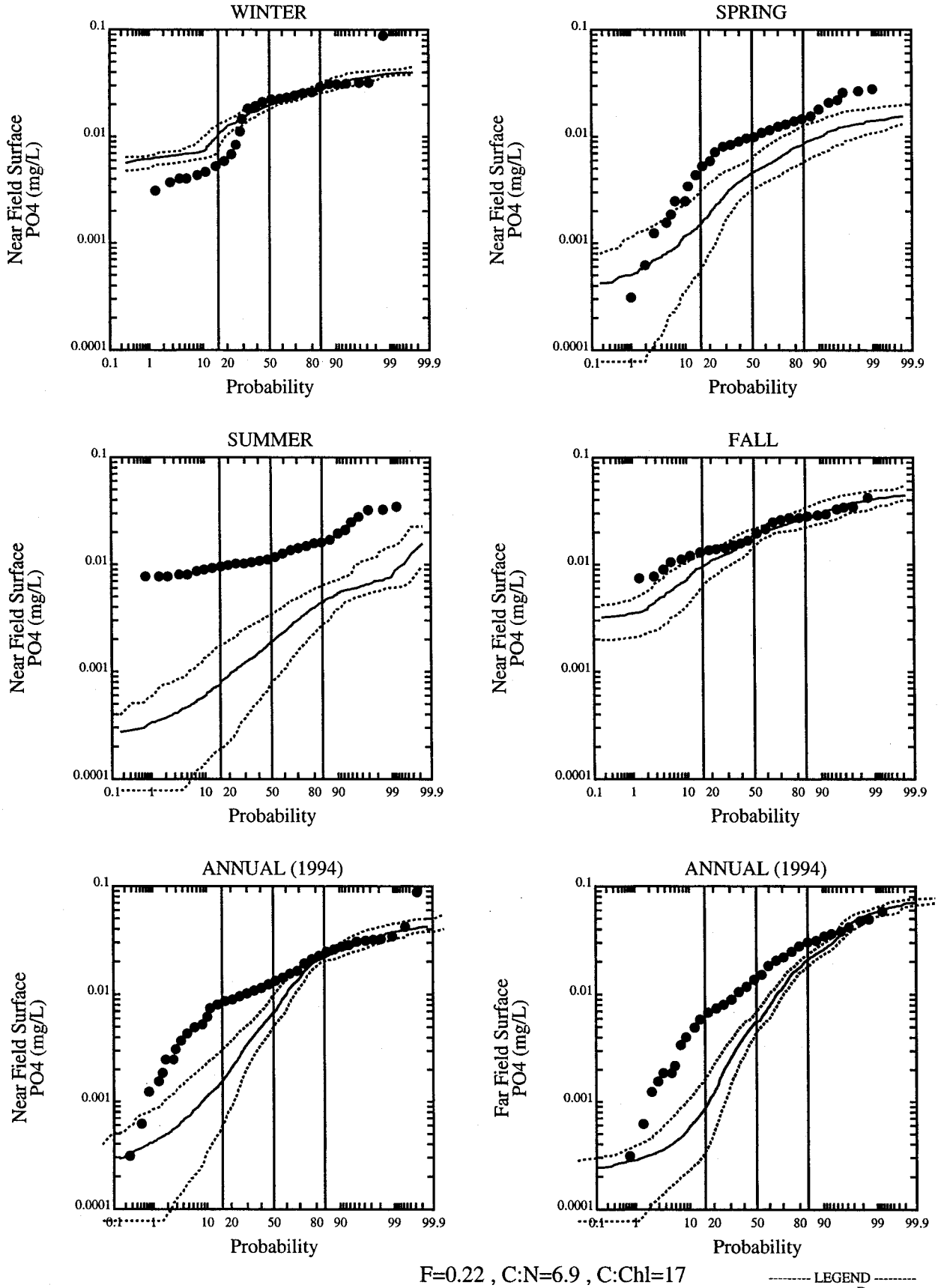

WINTER
SPRING
SUMMER
FALL
ANNUAL (1994)
ANNUAL (1994)
Near Field Surface Chlorophyll-a (ug/L)
Far Field Surface Chlorophyll-a (ug/L)
Probability
20
10
1
0.1
0.1 1 10 20 50 80 90 99 99.9
F=0.22 , C:N=6.9 , C:Chl=17
--------- LEGEND ---------
Discrete Chl-a
Fluorometric Chl-a
Model

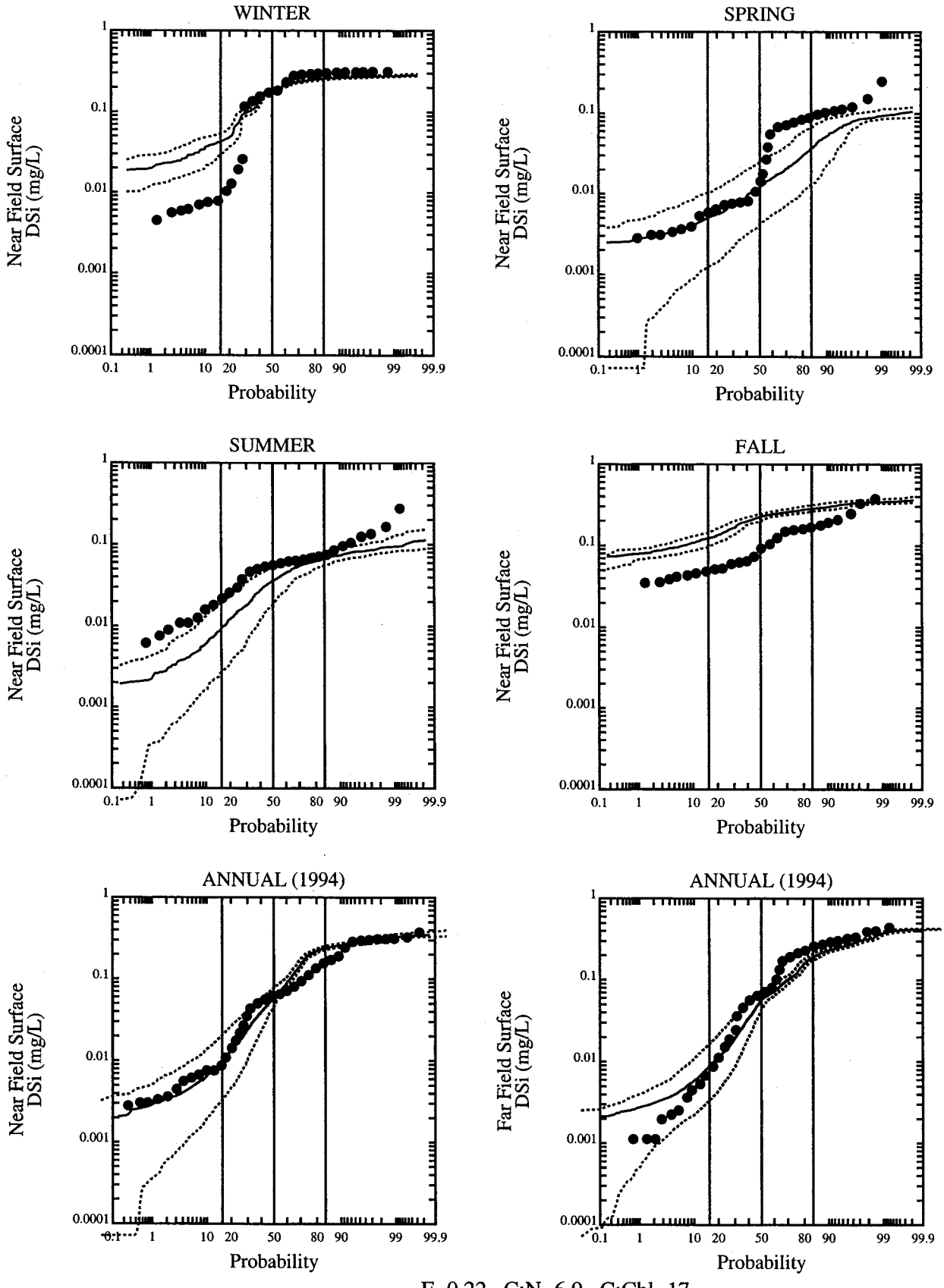

WINTER
SPRING
SUMMER
FALL
ANNUAL (1994)
ANNUAL (1994)
Near Field 12.5-17.5m Chlorophyll-a (ug/L)
Far Field 12.5-17.5m Chlorophyll-a (ug/L)
Probability
20
10
1
0.1
0.1 1 10 20 50 80 90 99 99.9
F=0.22 , C:N=6.9 , C:Chl=17
LEGEND
Discrete Chl-a
Fluorometric Chl-a
Model

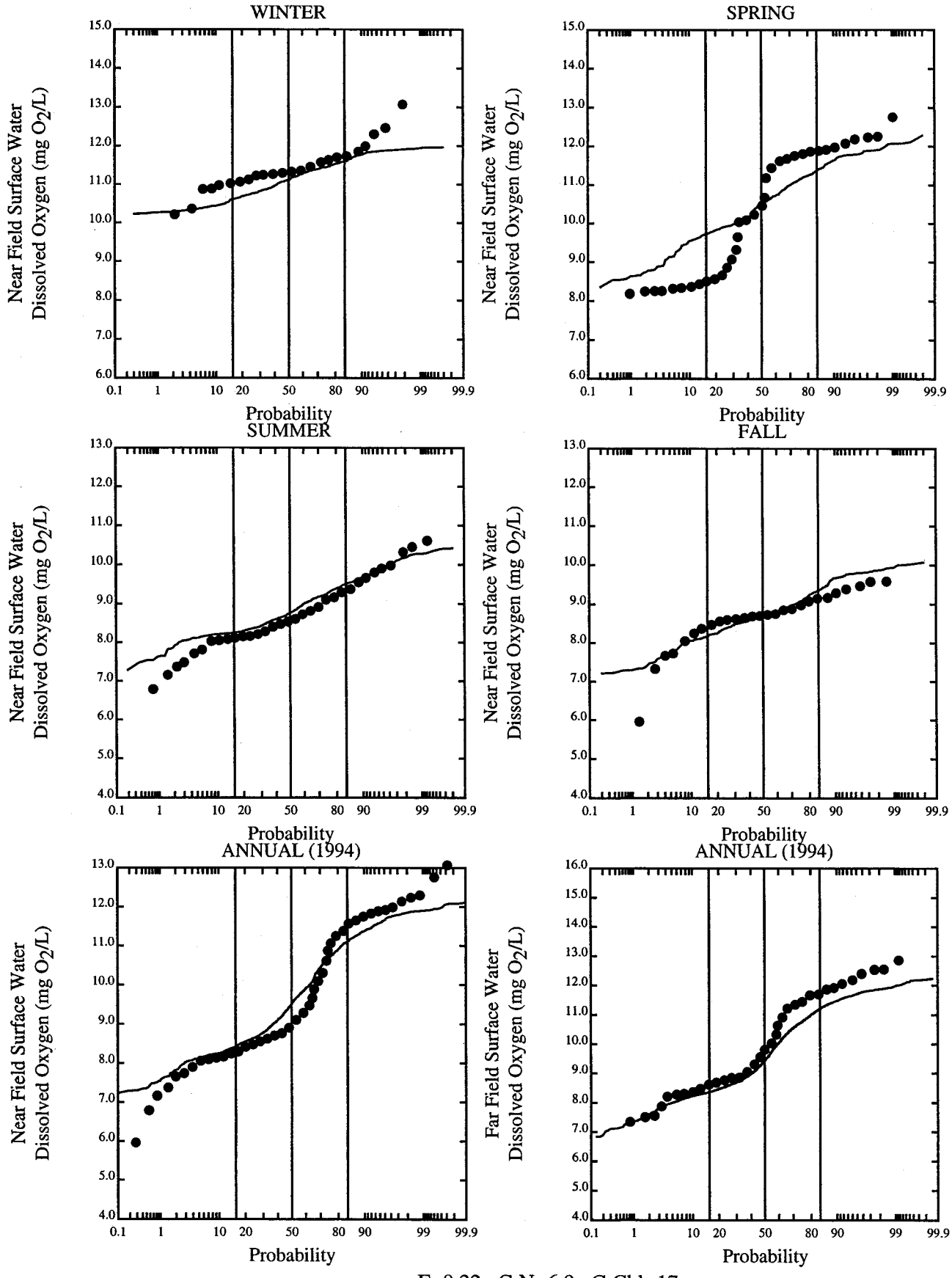

WINTER
SPRING
SUMMER
FALL
ANNUAL (1994)
ANNUAL (1994)
Near Field Surface C:Chl Ratios (ug C/ug Chl)
Far Field Surface C:Chl Ratios (ug C/ug Chl)
Probability
1000
100
10
1
0.1
1
10
20
50
80
90
99
99.9
F=0.22 , C:N=6.9 , C:Chl=17
LEGEND
Data
Model

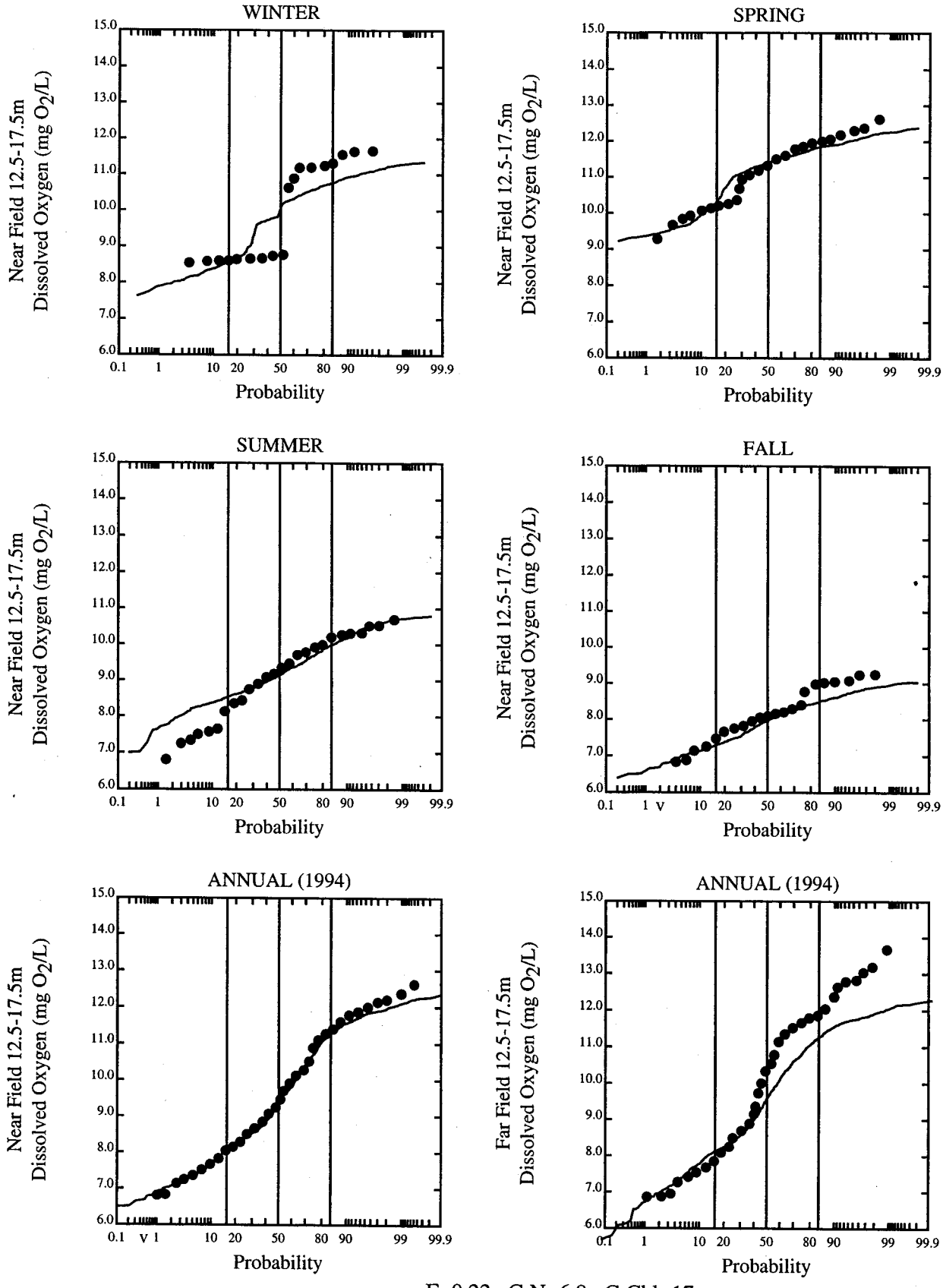

WINTER
SPRING
SUMMER
FALL
ANNUAL (1994)
ANNUAL (1994)
Near Field 12.5-17.5 m C:Chl Ratios (ug C/ug Chl)
Far Field 12.5-17.5 m C:Chl Ratios (ug C/ug Chl)
1000
100
10
1
0.1 1 10 20 50 80 90 99 99.9
Probability
F=0.22 , C:N=6.9 , C:Chl=17
LEGEND
Data
Model

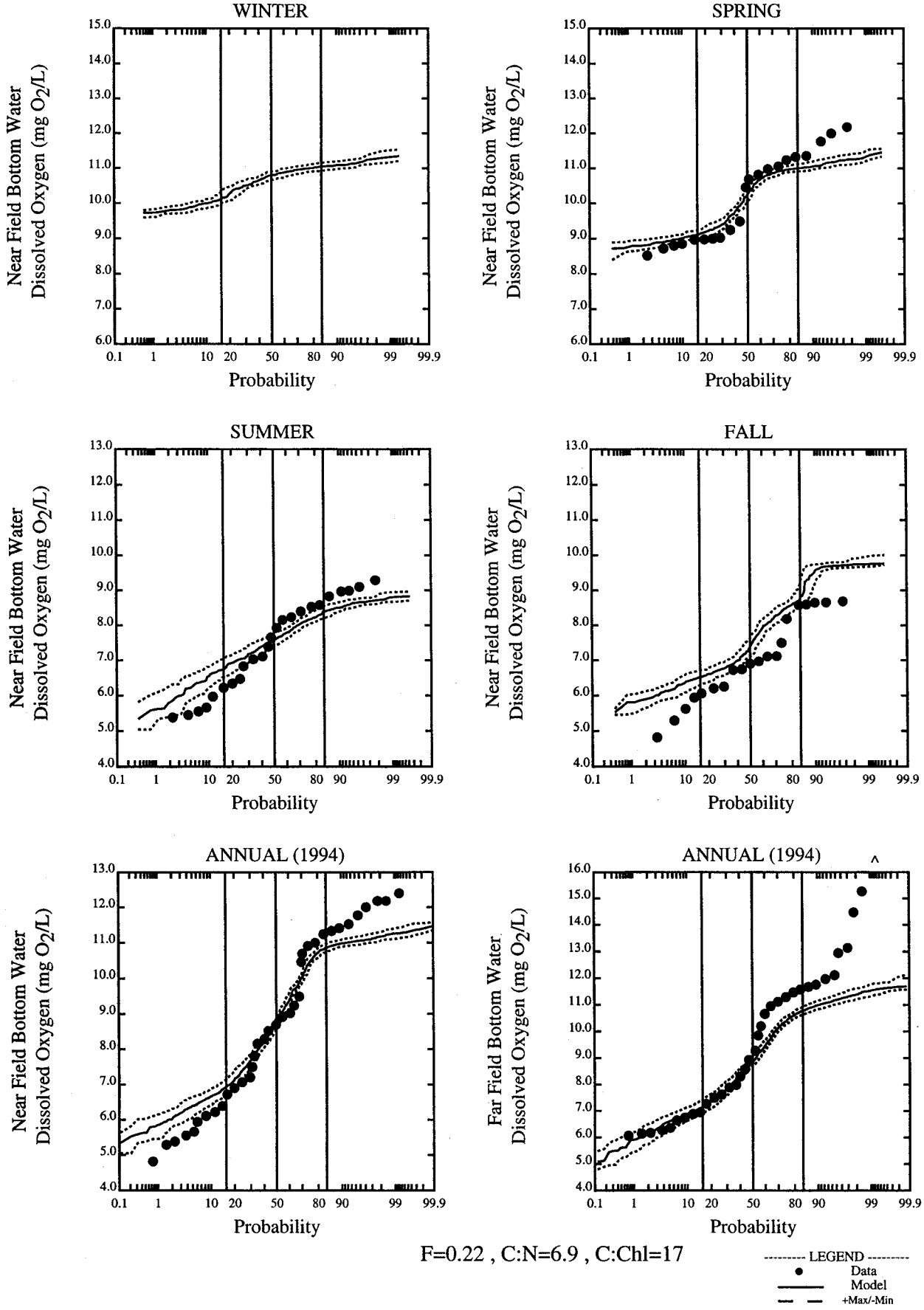

WINTER
SPRING
SUMMER
FALL
ANNUAL (1994)
ANNUAL (1994)
Near Field Surface DIN (mg/L)
Far Field Surface DIN (mg/L)
0.4
0.1
0.01
0.001
0.0001
0.1 1 10 20 50 80 90 99 99.9
Probability
F=0.22 , C:N=6.9 , C:Chl=17
LEGEND
Data
Model
+Max/-Min


WINTER
SPRING
SUMMER
FALL
ANNUAL (1994)
ANNUAL (1994)
Near Field Surface PO4 (mg/L)
Far Field Surface PO4 (mg/L)
0.1
0.01
0.001
0.0001
0.1 1 10 20 50 80 90 99 99.9
Probability
F=0.22 , C:N=6.9 , C:Chl=17
LEGEND
Data
Model
+Max/-Min

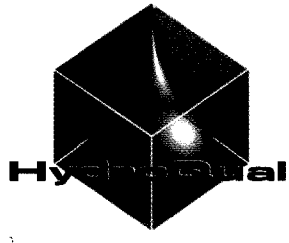

WINTER
SPRING
SUMMER
FALL
ANNUAL (1994)
ANNUAL (1994)
Near Field Surface DSi (mg/L)
Far Field Surface DSi (mg/L)
Probability
1
0.1
0.01
0.001
0.0001
0.1
1
10
20
50
80
90
99
99.9
F=0.22 , C:N=6.9 , C:Chl=17
LEGEND
Data
Model
+Max/-Min


WINTER
SPRING
SUMMER
FALL
ANNUAL (1994)
ANNUAL (1994)
Near Field Surface Water Dissolved Oxygen (mg O2/L)
Far Field Surface Water Dissolved Oxygen (mg O2/L)
Probability
0.1 1 10 20 50 80 90 99 99.9
F=0.22 , C:N=6.9 , C:Chl=17
LEGEND
Data
Model

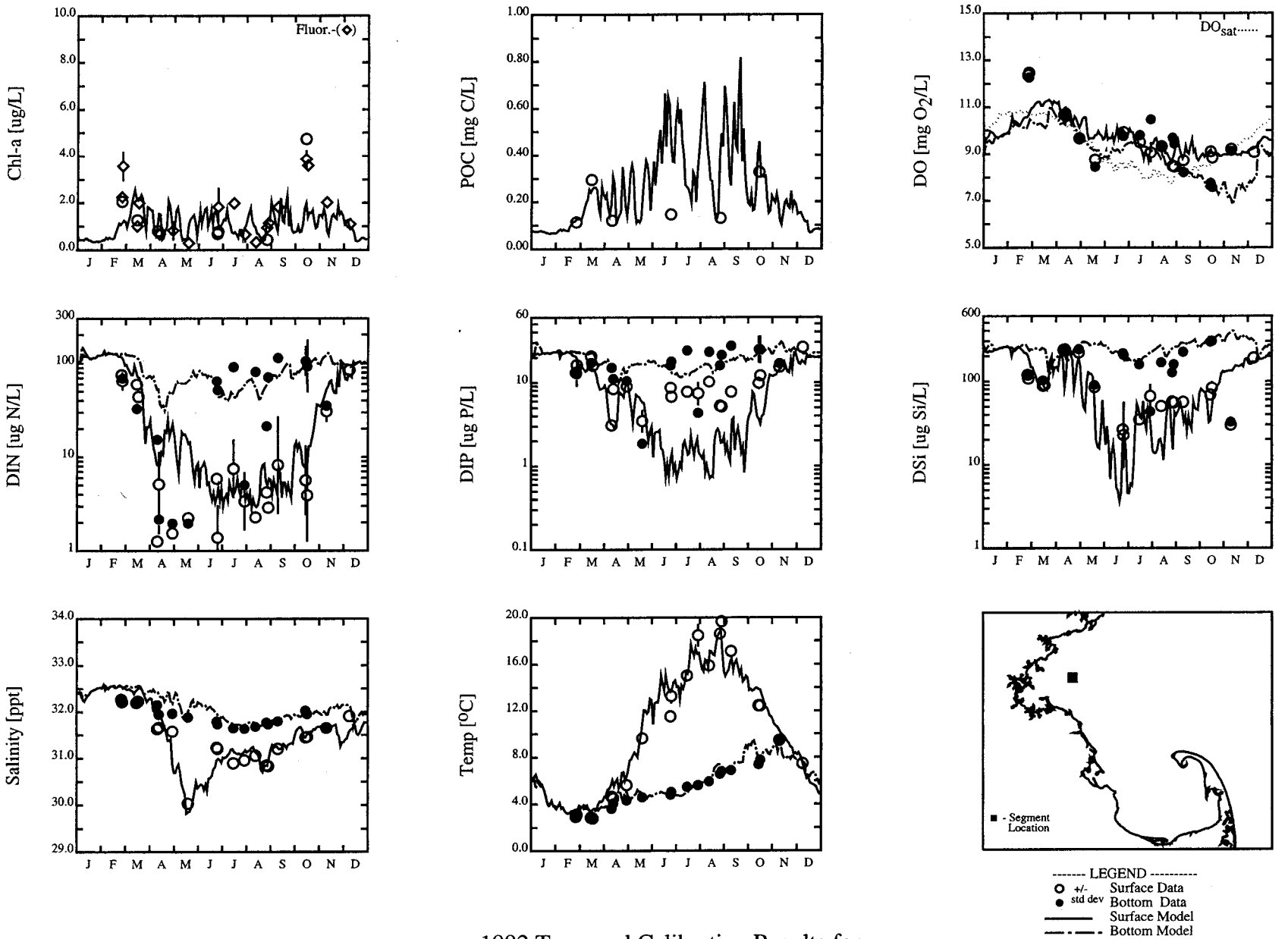

WINTER
SPRING
SUMMER
FALL
ANNUAL (1994)
ANNUAL (1994)
Near Field 12.5-17.5m Dissolved Oxygen (mg O2/L)
Far Field 12.5-17.5m Dissolved Oxygen (mg O2/L)
Probability
15.0
14.0
13.0
12.0
11.0
10.0
9.0
8.0
7.0
6.0
0.1
1
10
20
50
80
90
99
99.9
F=0.22 , C:N=6.9 , C:Chl=17
LEGEND
Data
Model


WINTER
SPRING
SUMMER
FALL
ANNUAL (1994)
ANNUAL (1994)
Near Field Bottom Water Dissolved Oxygen (mg O2/L)
Far Field Bottom Water Dissolved Oxygen (mg O2/L)
Probability
0.1 1 10 20 50 80 90 99 99.9
F=0.22 , C:N=6.9 , C:Chl=17
LEGEND
Data
Model
+Max/-Min

APPENDIX A.3
F = 0.22 SENSITIVITY ANALYSIS

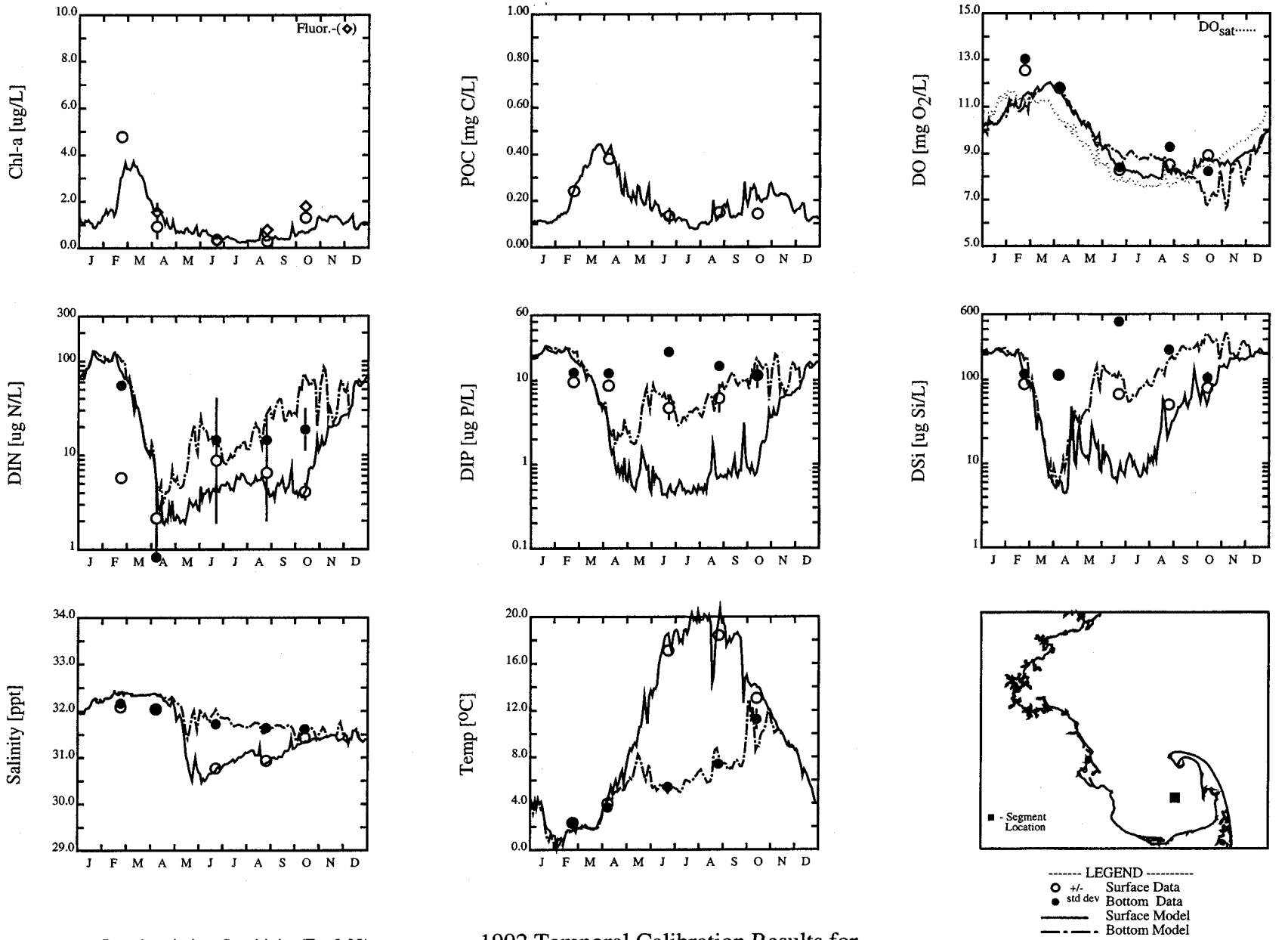


Environmental
Engineers & Scientists



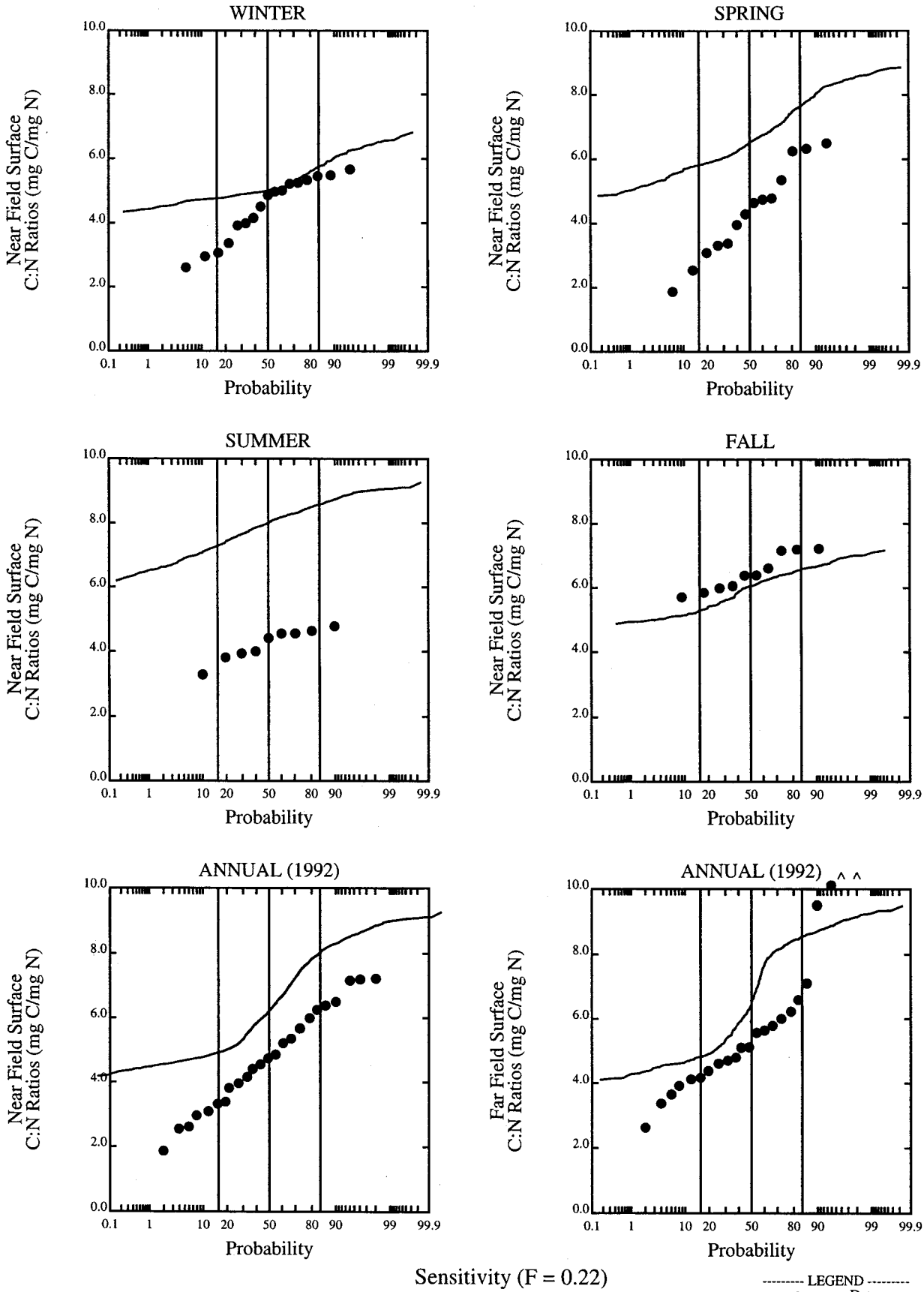
Run description: Sensitivity (F = 0.22)

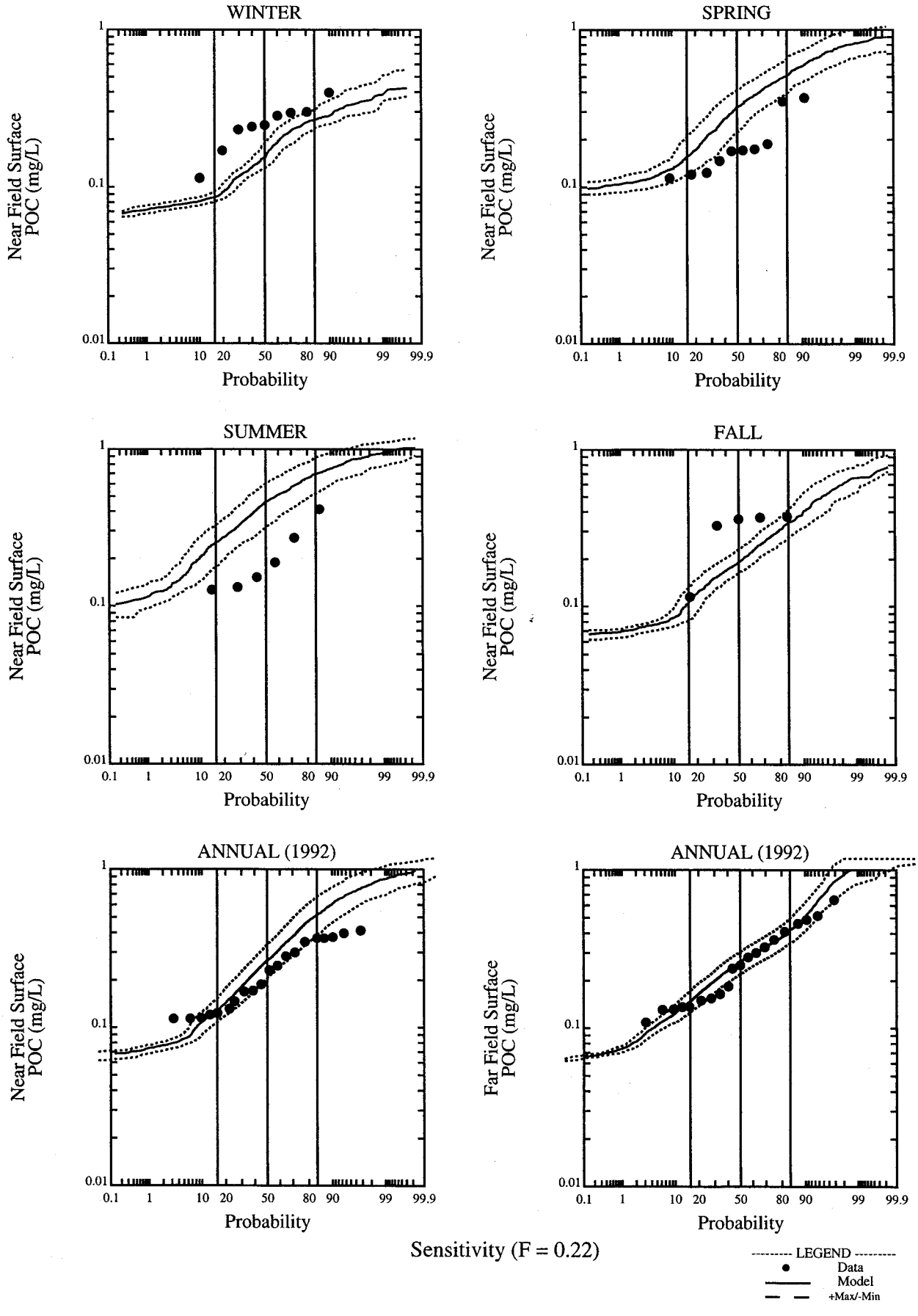
1992 Temporal Calibration Results for
Grid Cell (11,18) Vs Data Station N16P,N17,N21

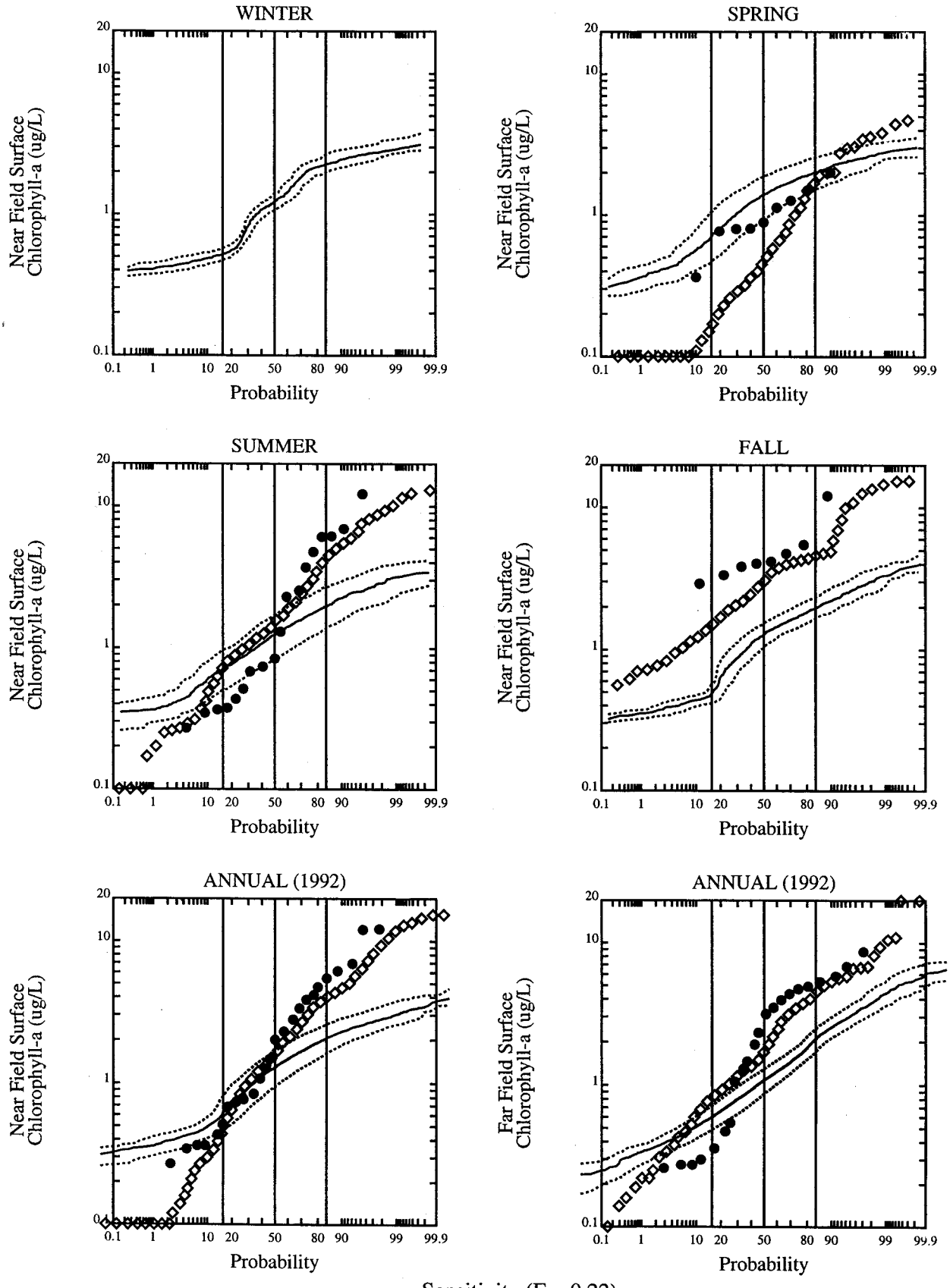


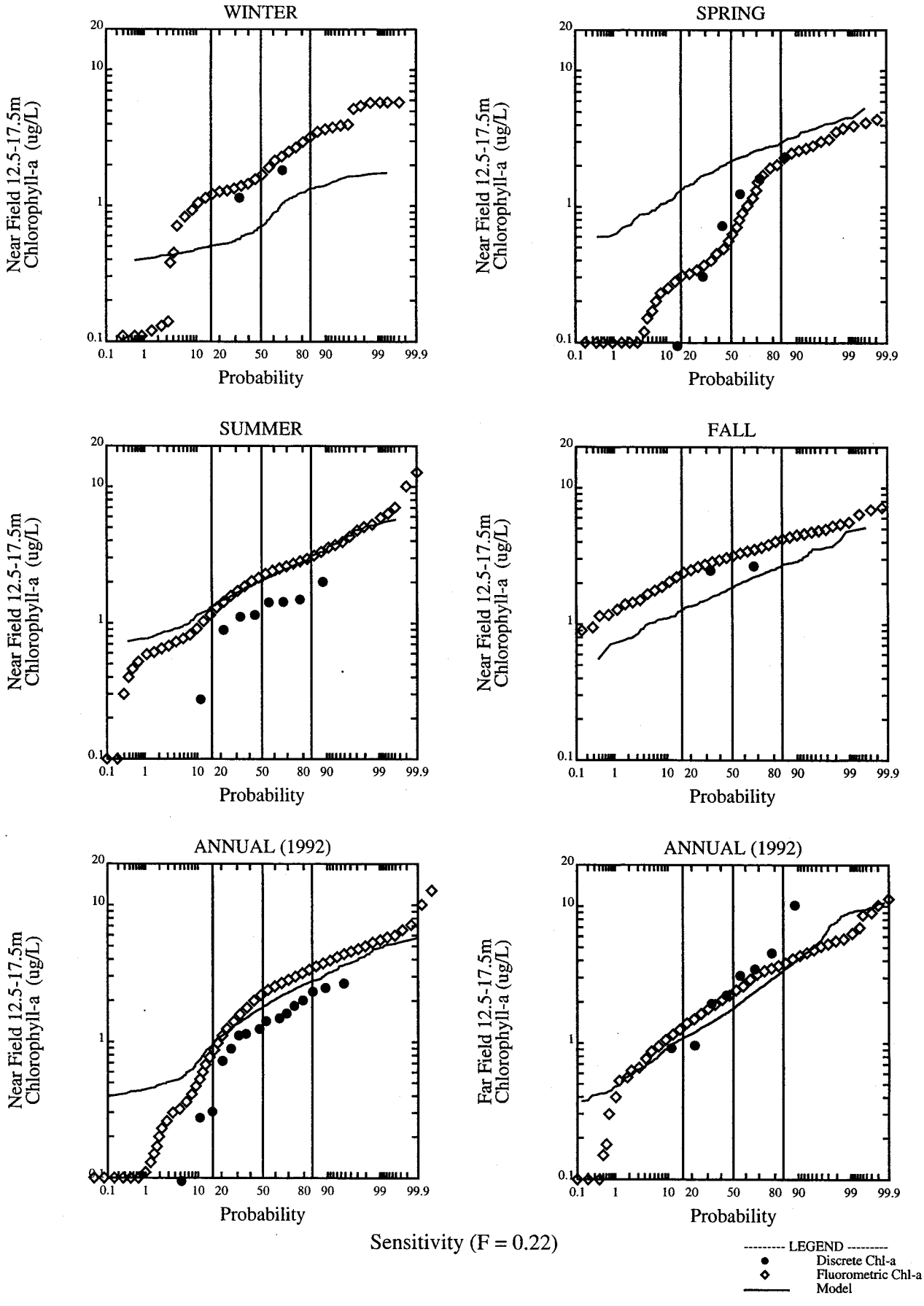
Run description: Sensitivity (F = 0.22)

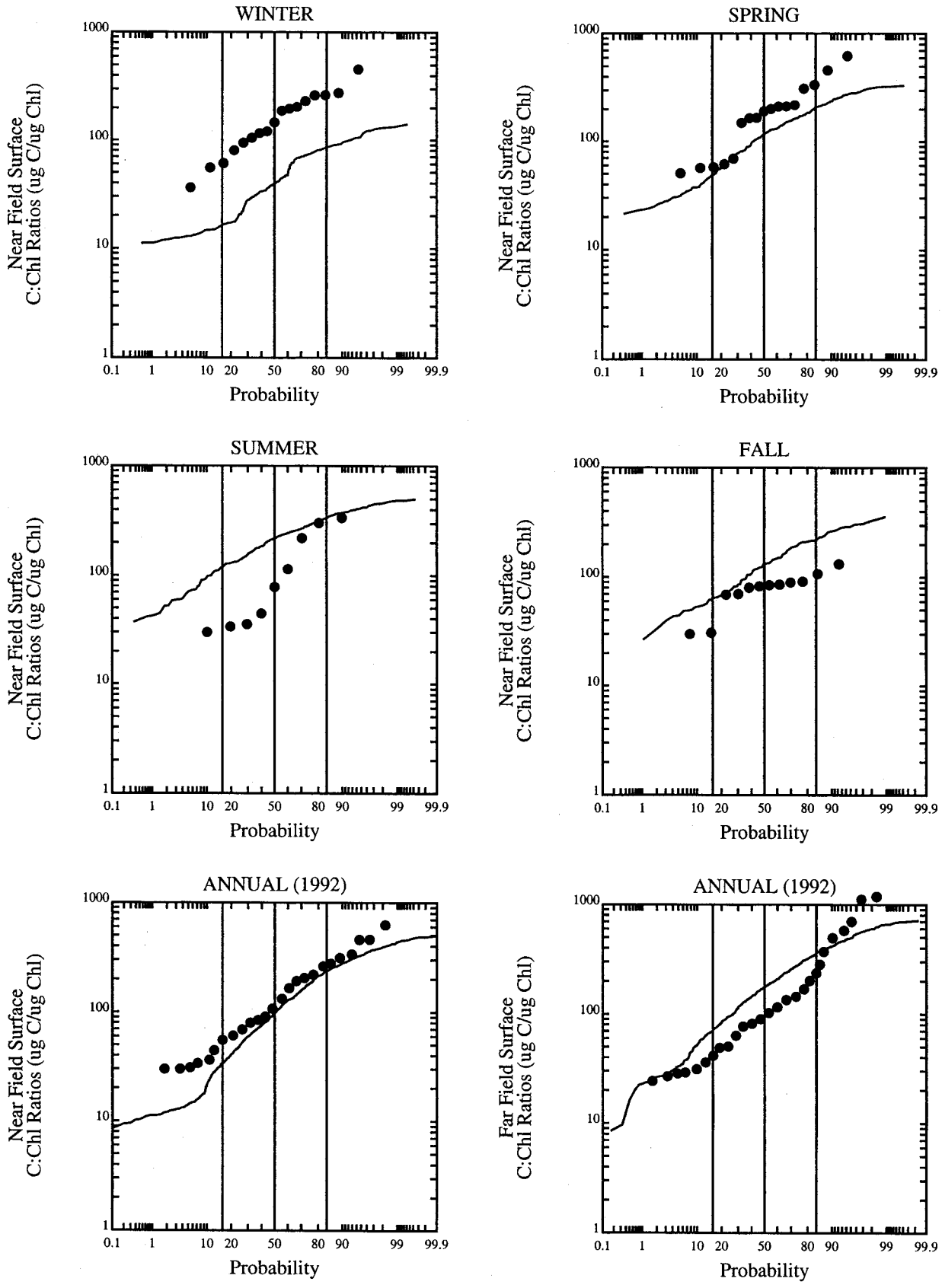
1992 Temporal Calibration Results for
Grid Cell (13,4) Vs Data Station F02P

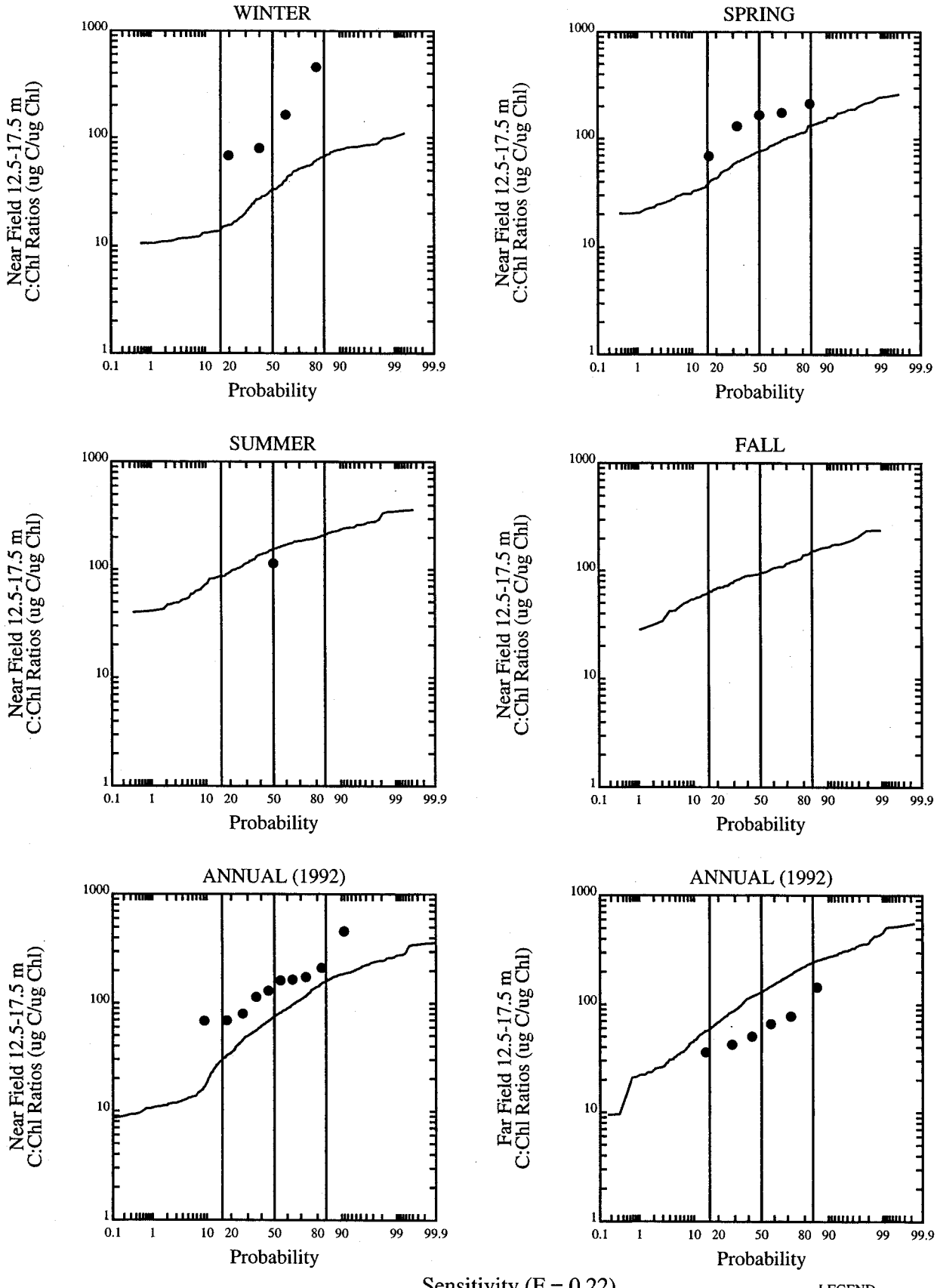

WINTER
SPRING
SUMMER
FALL
ANNUAL (1992)
ANNUAL (1992) ^ ^
Near Field Surface C:N Ratios (mg C/mg N)
Far Field Surface C:N Ratios (mg C/mg N)
10.0
8.0
6.0
4.0
2.0
0.0
0.1 1 10 20 50 80 90 99 99.9
Probability
Sensitivity (F = 0.22)
LEGEND
Data
Model

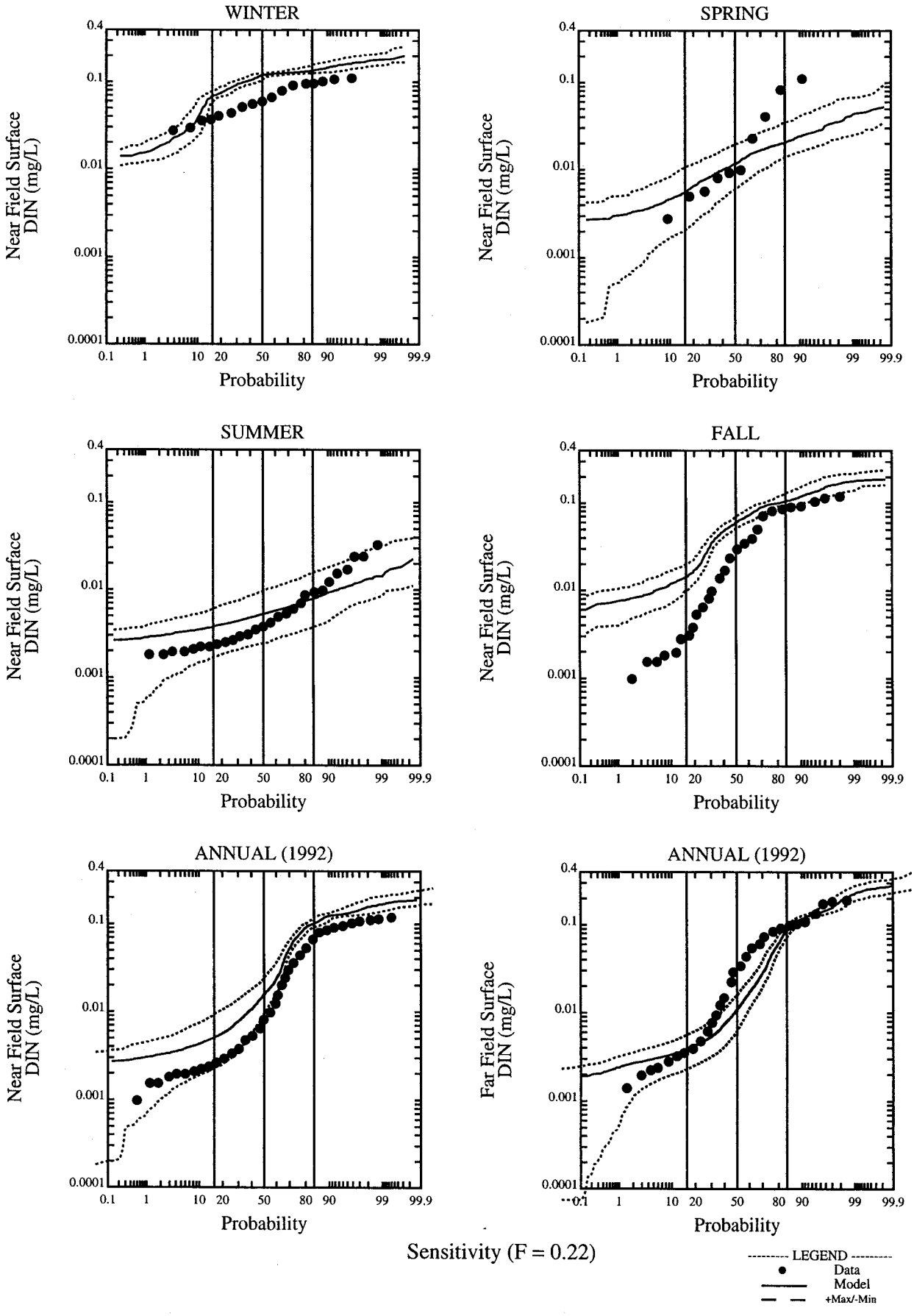

WINTER
SPRING
SUMMER
FALL
ANNUAL (1992)
ANNUAL (1992)
Near Field Surface POC (mg/L)
Far Field Surface POC (mg/L)
Probability
1
0.1
0.01
0.1 1 10 20 50 80 90 99 99.9
Sensitivity (F = 0.22)
LEGEND
Data
Model
+Max/-Min

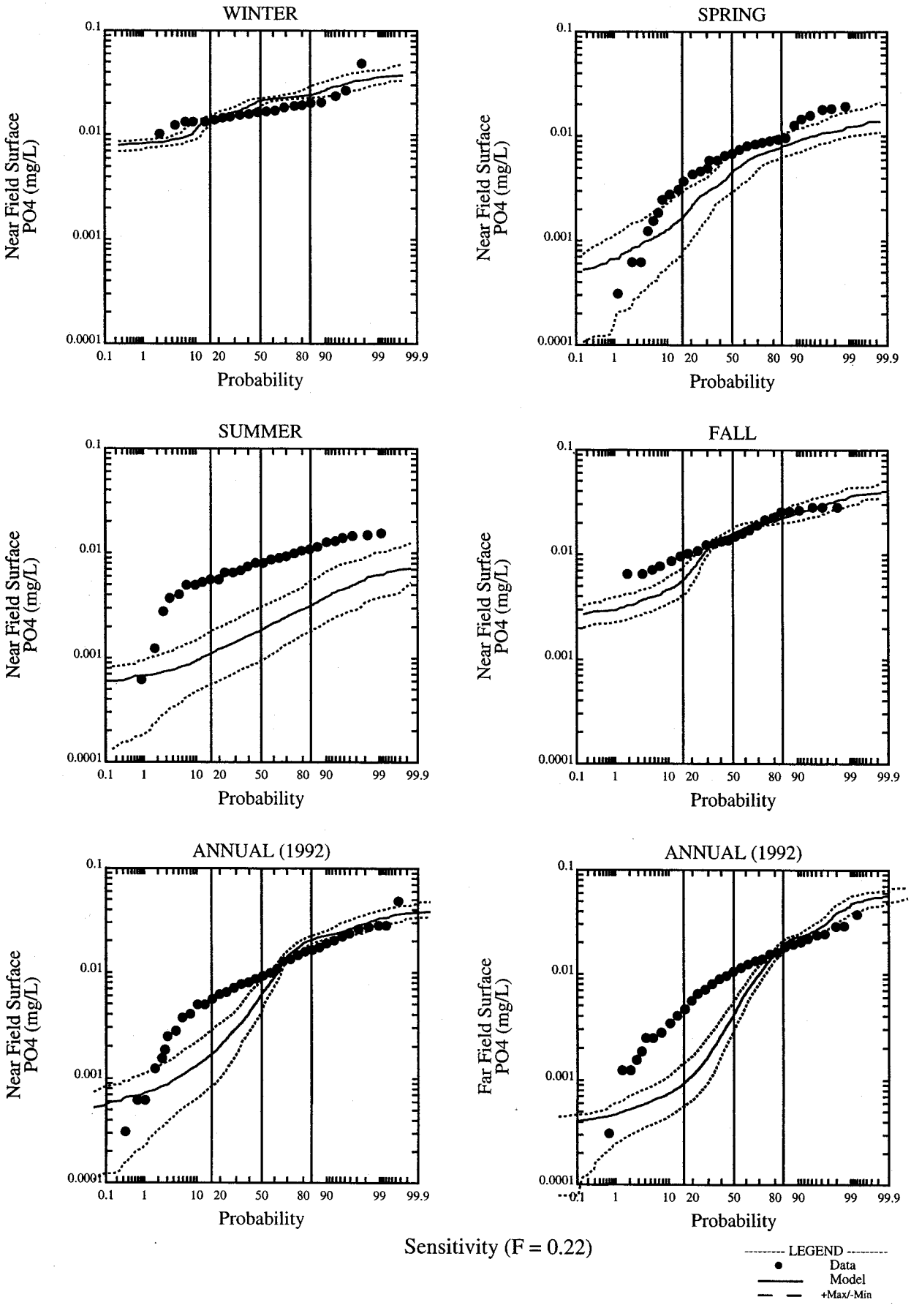

WINTER
SPRING
SUMMER
FALL
ANNUAL (1992)
ANNUAL (1992)
Near Field Surface Chlorophyll-a (ug/L)
Far Field Surface Chlorophyll-a (ug/L)
Probability
20
10
1
0.1
0.1
1
10
20
50
80
90
99
99.9
Sensitivity (F = 0.22)
LEGEND
Discrete Chl-a
Fluorometric Chl-a
Model

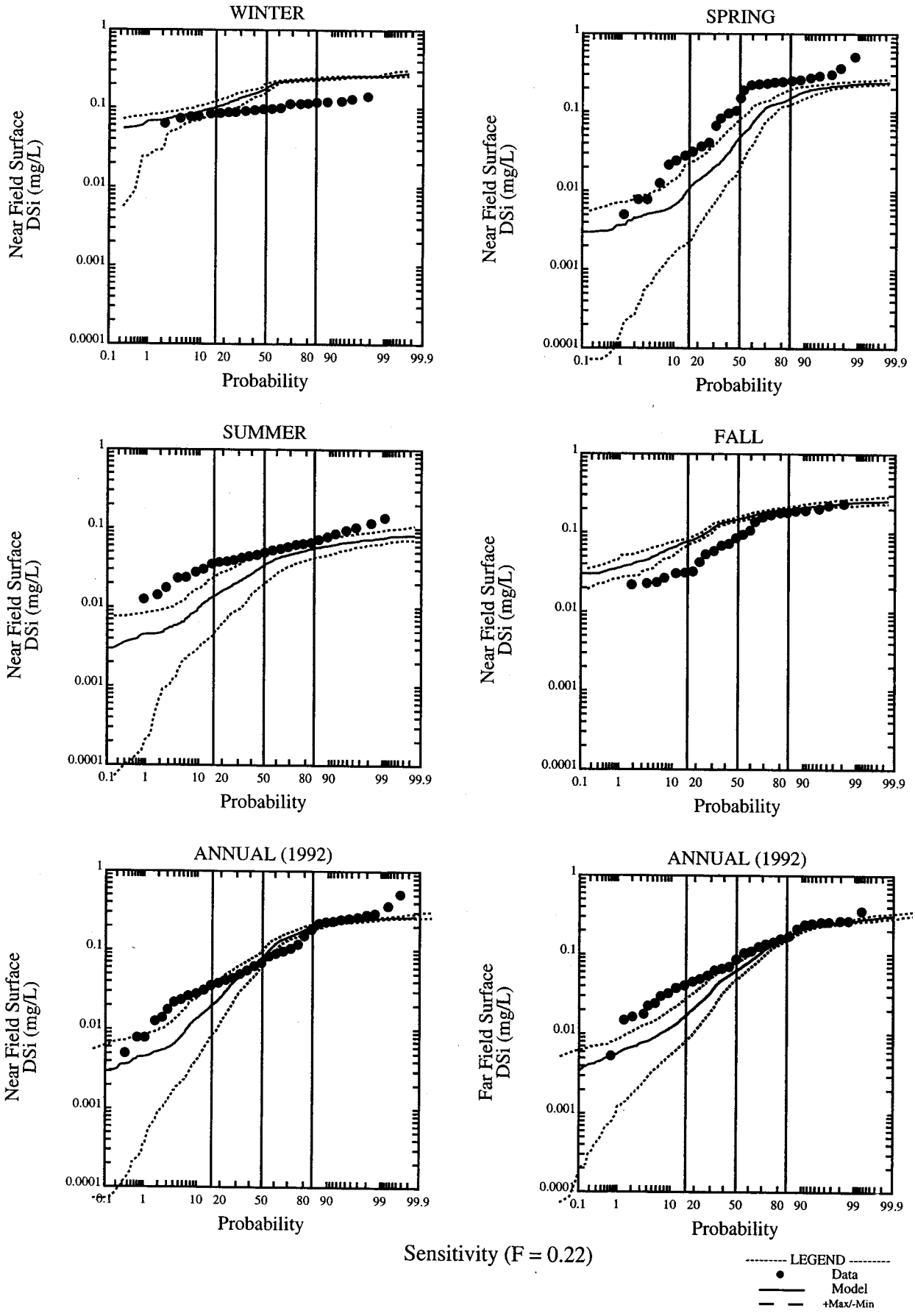

WINTER
SPRING
SUMMER
FALL
ANNUAL (1992)
ANNUAL (1992)
Near Field 12.5-17.5m Chlorophyll-a (ug/L)
Far Field 12.5-17.5m Chlorophyll-a (ug/L)
Probability
0.1 1 10 20 50 80 90 99 99.9
20 10 1 0.1
Sensitivity (F = 0.22)
LEGEND
Discrete Chl-a
Fluorometric Chl-a
Model

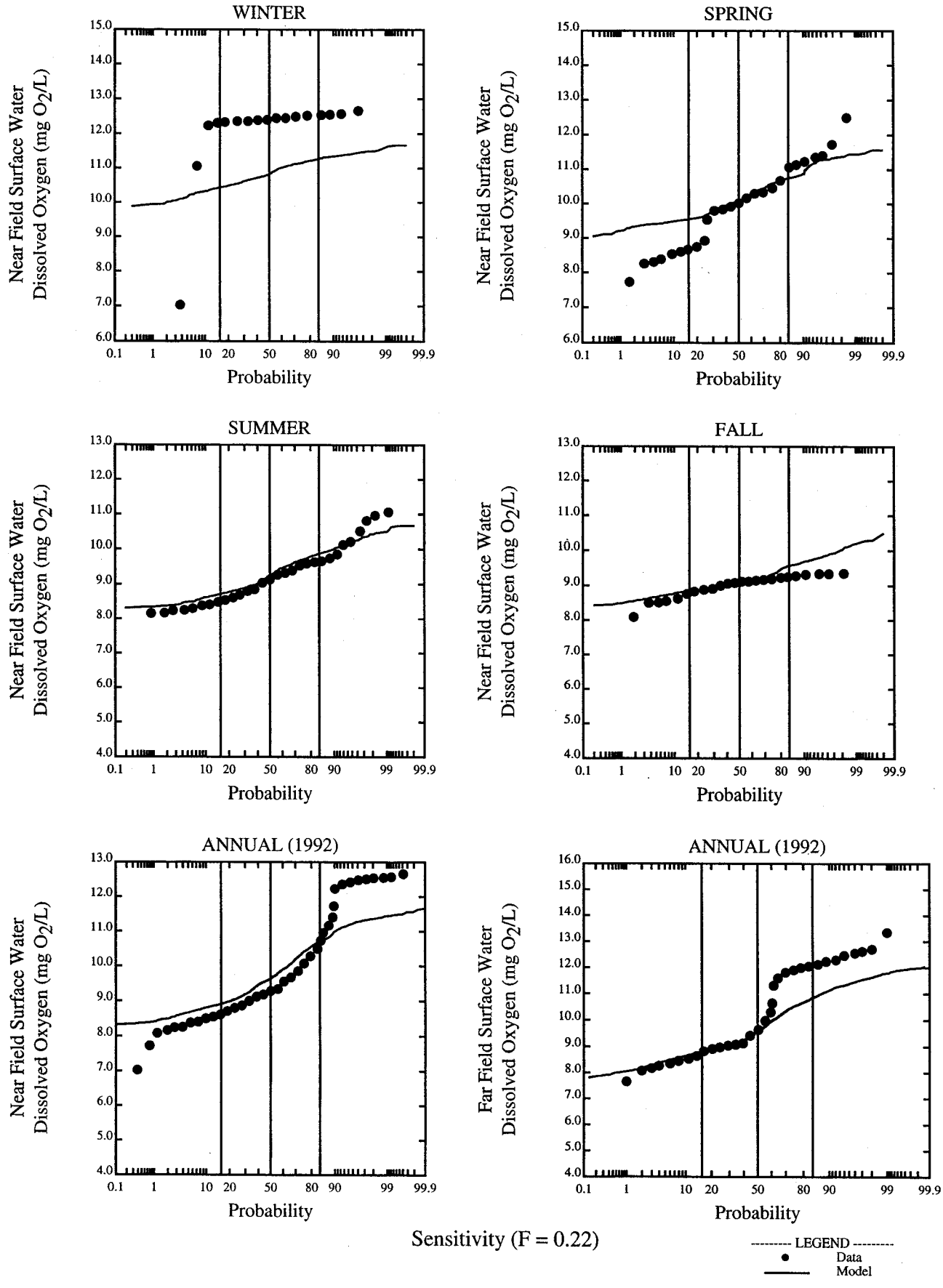

WINTER
SPRING
SUMMER
FALL
ANNUAL (1992)
ANNUAL (1992)
Near Field Surface C:Chl Ratios (ug C/ug Chl)
Far Field Surface C:Chl Ratios (ug C/ug Chl)
1000
100
10
1
0.1
1
10
20
50
80
90
99
99.9
Probability
Sensitivity (F = 0.22)
LEGEND
Data
Model

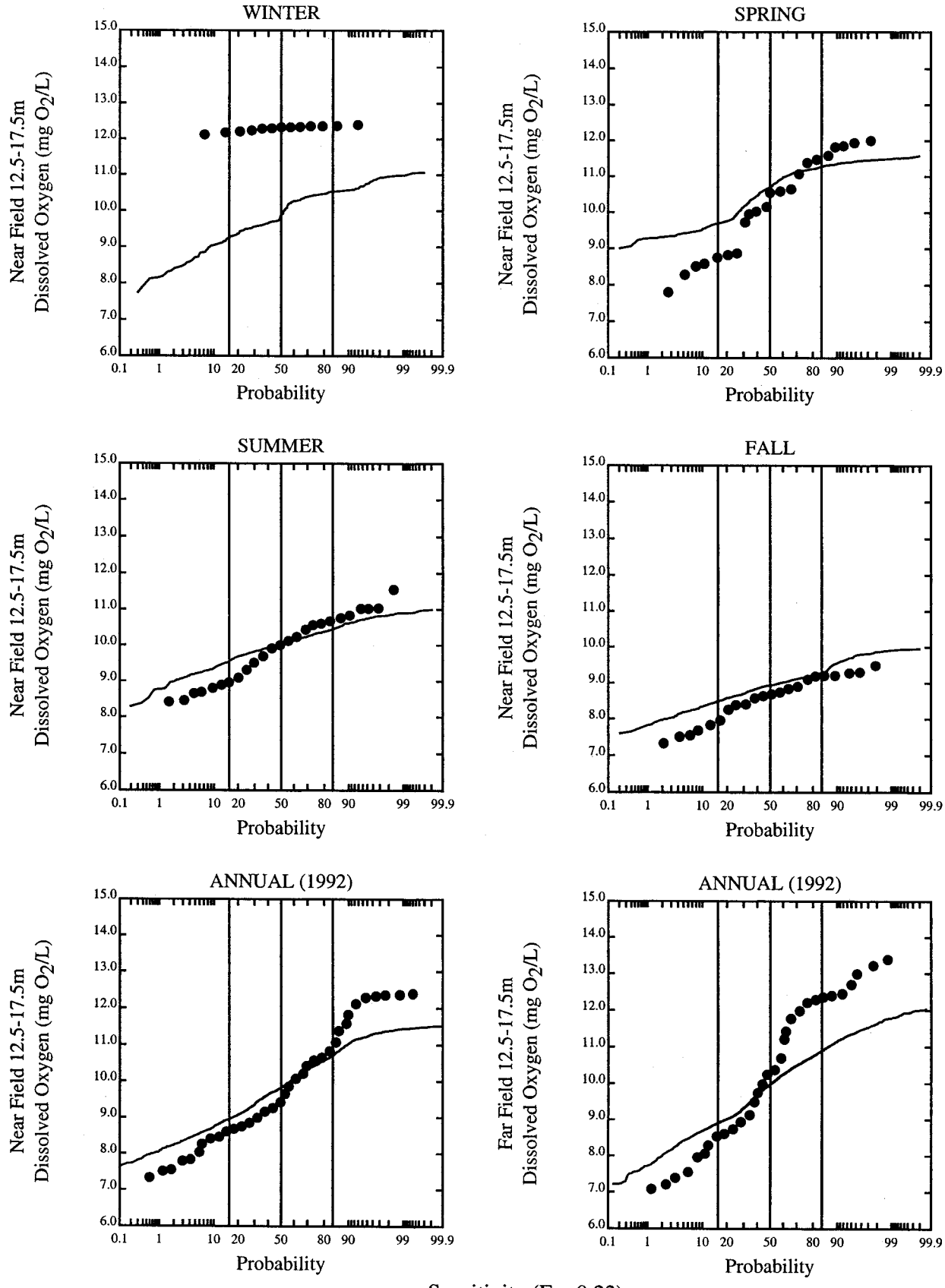

WINTER
SPRING
SUMMER
FALL
ANNUAL (1992)
ANNUAL (1992)
Near Field 12.5-17.5 m C:Chl Ratios (ug C/ug Chl)
Far Field 12.5-17.5 m C:Chl Ratios (ug C/ug Chl)
1000
100
10
1
0.1 1 10 20 50 80 90 99 99.9
Probability
Sensitivity (F = 0.22)
LEGEND
Data
Model

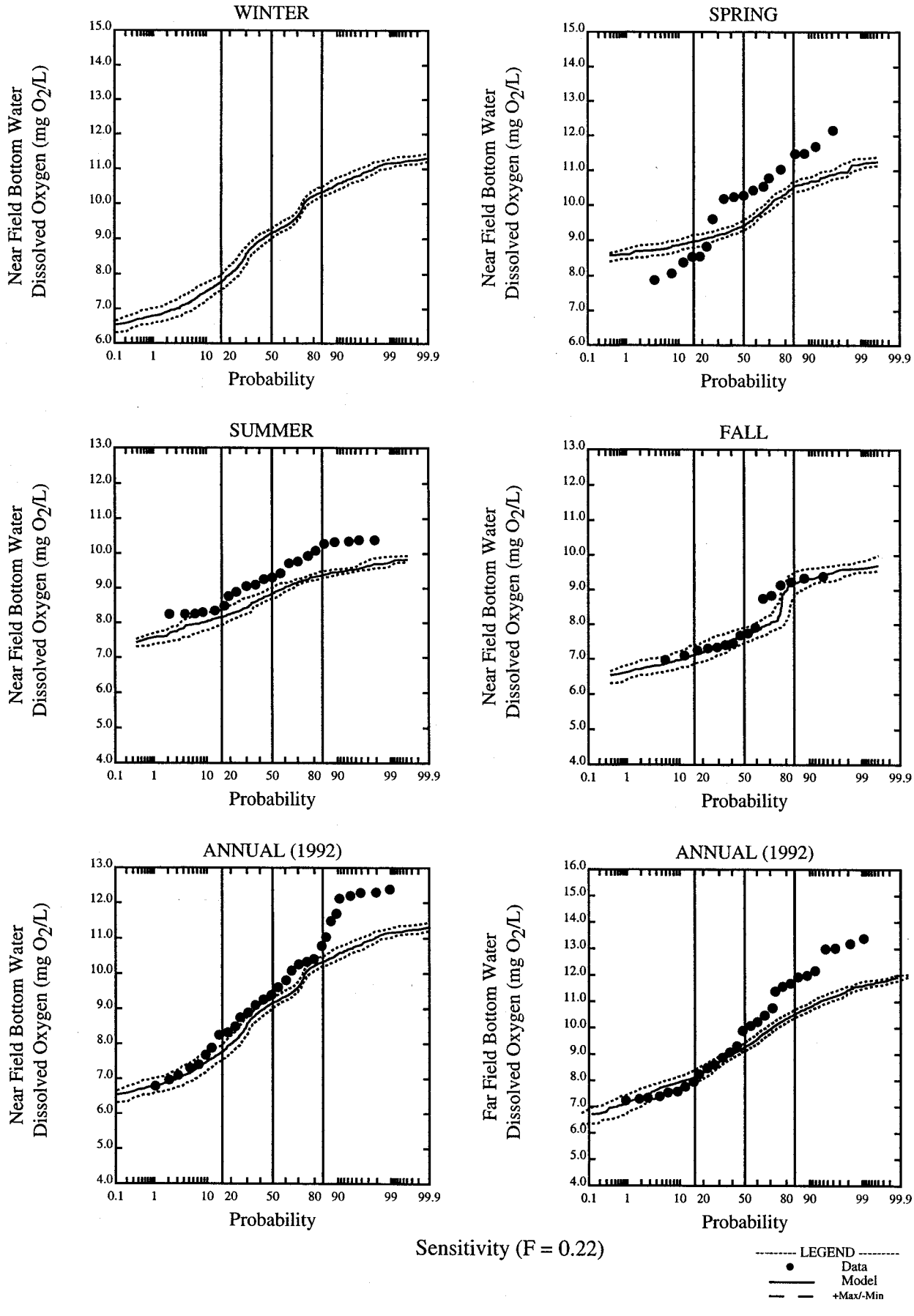

WINTER
SPRING
SUMMER
FALL
ANNUAL (1992)
ANNUAL (1992)
Near Field Surface DIN (mg/L)
Far Field Surface DIN (mg/L)
0.4
0.1
0.01
0.001
0.0001
0.1 1 10 20 50 80 90 99 99.9
Probability
Sensitivity (F = 0.22)
LEGEND
Data
Model
+Max/-Min

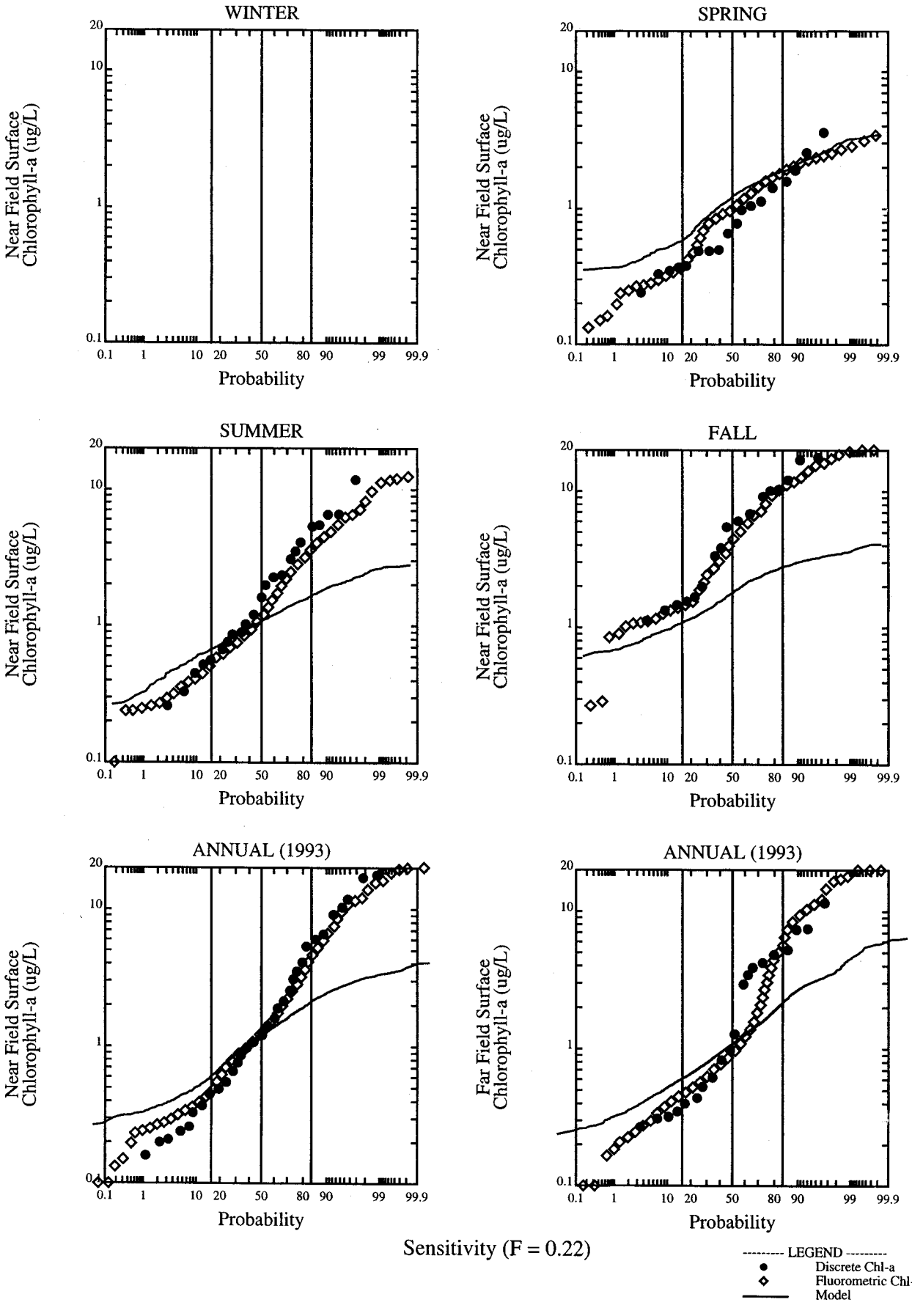

WINTER
SPRING
SUMMER
FALL
ANNUAL (1992)
ANNUAL (1992)
Near Field Surface PO4 (mg/L)
Far Field Surface PO4 (mg/L)
0.1
0.01
0.001
0.0001
0.1 1 10 20 50 80 90 99 99.9
Probability
Sensitivity (F = 0.22)
LEGEND
Data
Model
+Max/-Min

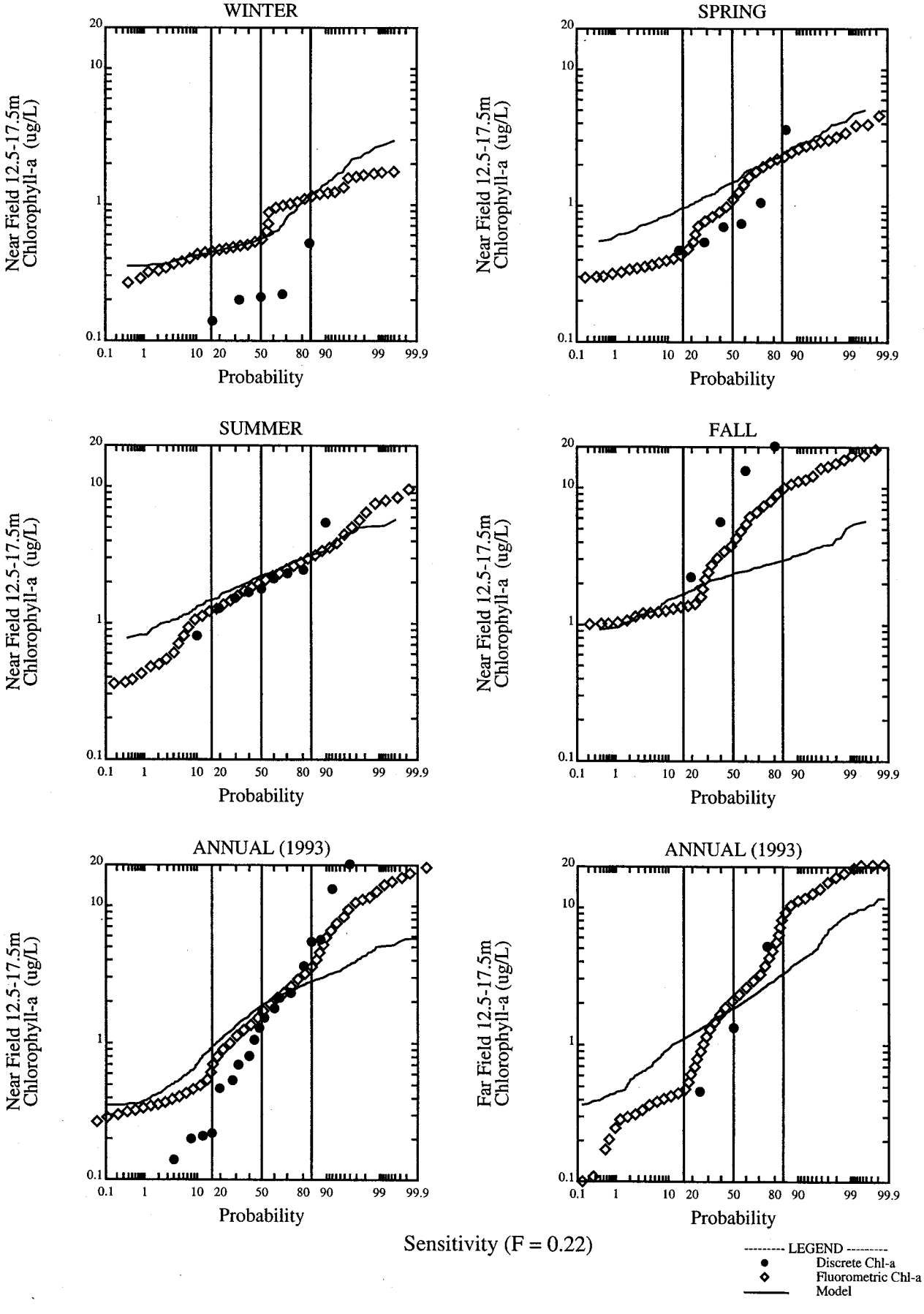

WINTER
SPRING
SUMMER
FALL
ANNUAL (1992)
ANNUAL (1992)
Near Field Surface DSi (mg/L)
Far Field Surface DSi (mg/L)
Probability
1
0.1
0.01
0.001
0.0001
0.1 1 10 20 50 80 90 99 99.9
Sensitivity (F = 0.22)
LEGEND
Data
Model
+Max/-Min

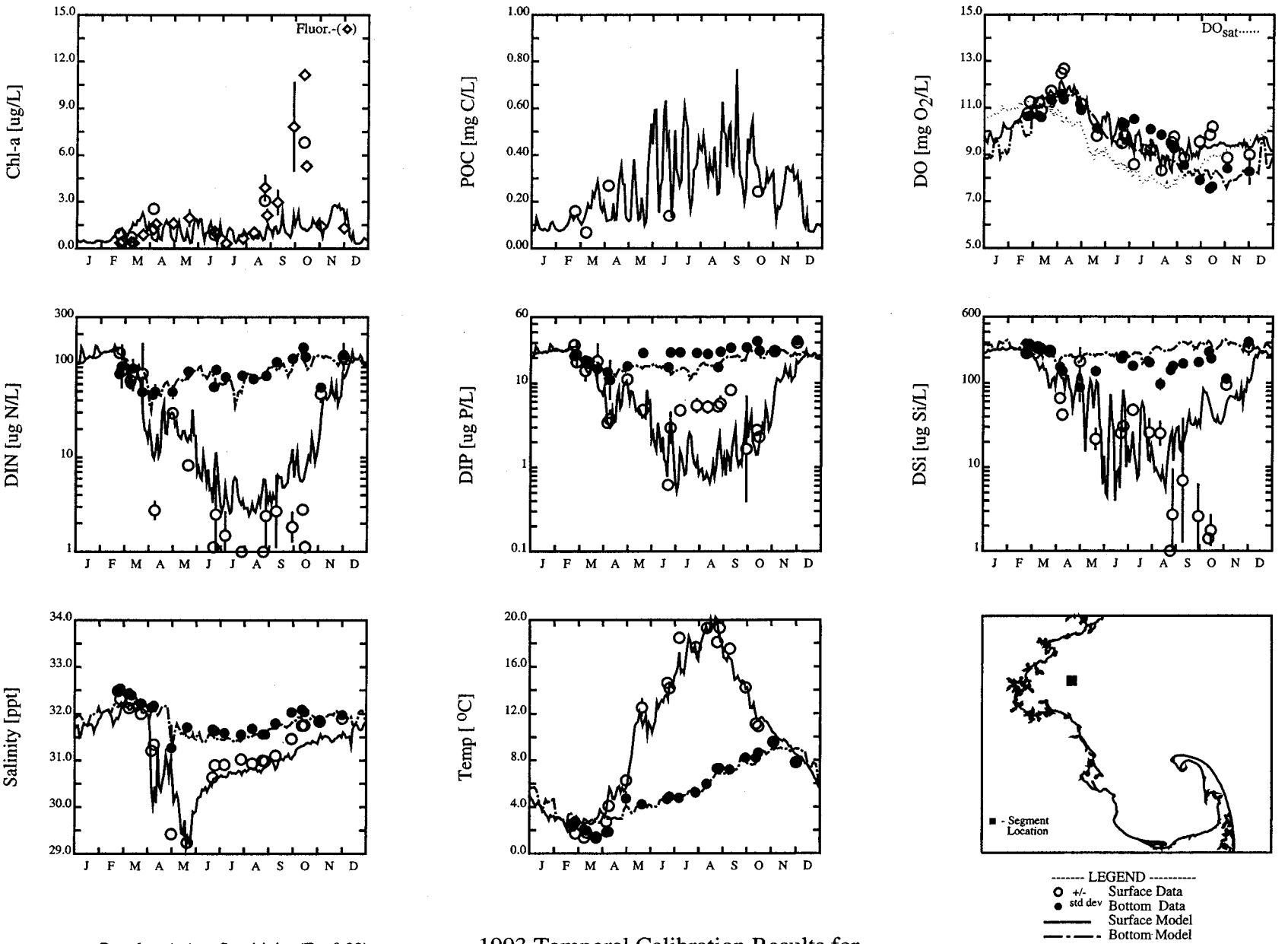

WINTER
SPRING
SUMMER
FALL
ANNUAL (1992)
ANNUAL (1992)
Near Field Surface Water Dissolved Oxygen (mg O2/L)
Far Field Surface Water Dissolved Oxygen (mg O2/L)
Probability
0.1 1 10 20 50 80 90 99 99.9
Sensitivity (F = 0.22)
LEGEND
Data
Model


WINTER
SPRING
SUMMER
FALL
ANNUAL (1992)
ANNUAL (1992)
Near Field 12.5-17.5m Dissolved Oxygen (mg O2/L)
Far Field 12.5-17.5m Dissolved Oxygen (mg O2/L)
15.0
14.0
13.0
12.0
11.0
10.0
9.0
8.0
7.0
6.0
0.1
1
10
20
50
80
90
99
99.9
Probability
Sensitivity (F = 0.22)
LEGEND
Data
Model


WINTER
SPRING
SUMMER
FALL
ANNUAL (1992)
ANNUAL (1992)
Near Field Bottom Water Dissolved Oxygen (mg O2/L)
Far Field Bottom Water Dissolved Oxygen (mg O2/L)
Probability
0.1 1 10 20 50 80 90 99 99.9
Sensitivity (F = 0.22)
LEGEND
Data
Model
+Max/-Min

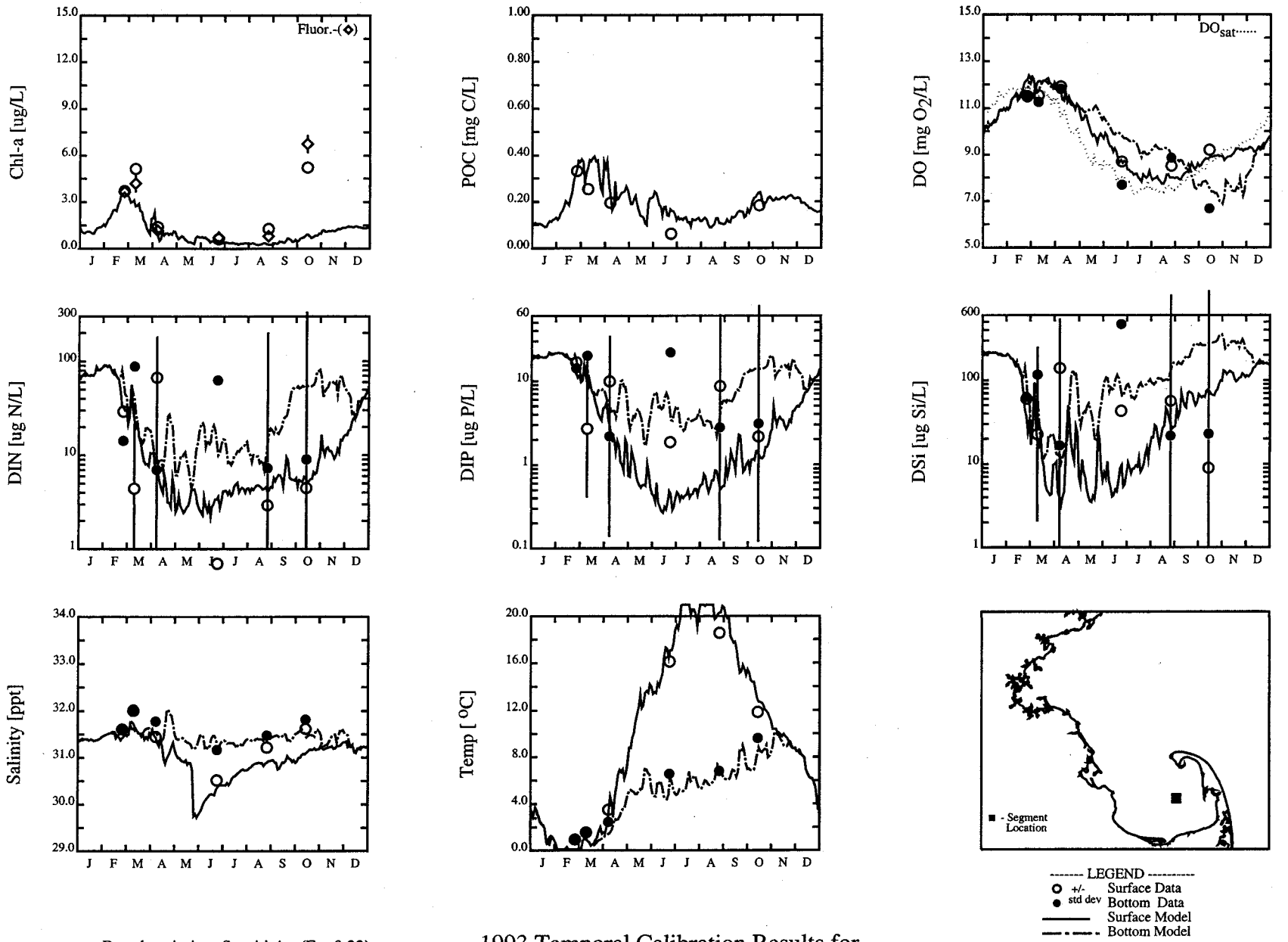

WINTER
SPRING
SUMMER
FALL
ANNUAL (1993)
ANNUAL (1993)
Near Field Surface Chlorophyll-a (ug/L)
Far Field Surface Chlorophyll-a (ug/L)
Probability
20
10
1
0.1
0.1 1 10 20 50 80 90 99 99.9
Sensitivity (F = 0.22)
LEGEND
Discrete Chl-a
Fluorometric Chl-a
Model


WINTER
SPRING
SUMMER
FALL
ANNUAL (1993)
ANNUAL (1993)
Near Field 12.5-17.5m Chlorophyll-a (ug/L)
Far Field 12.5-17.5m Chlorophyll-a (ug/L)
Probability
0.1 1 10 20 50 80 90 99 99.9
20 10 1 0.1
Sensitivity (F = 0.22)
LEGEND
Discrete Chl-a
Fluorometric Chl-a
Model



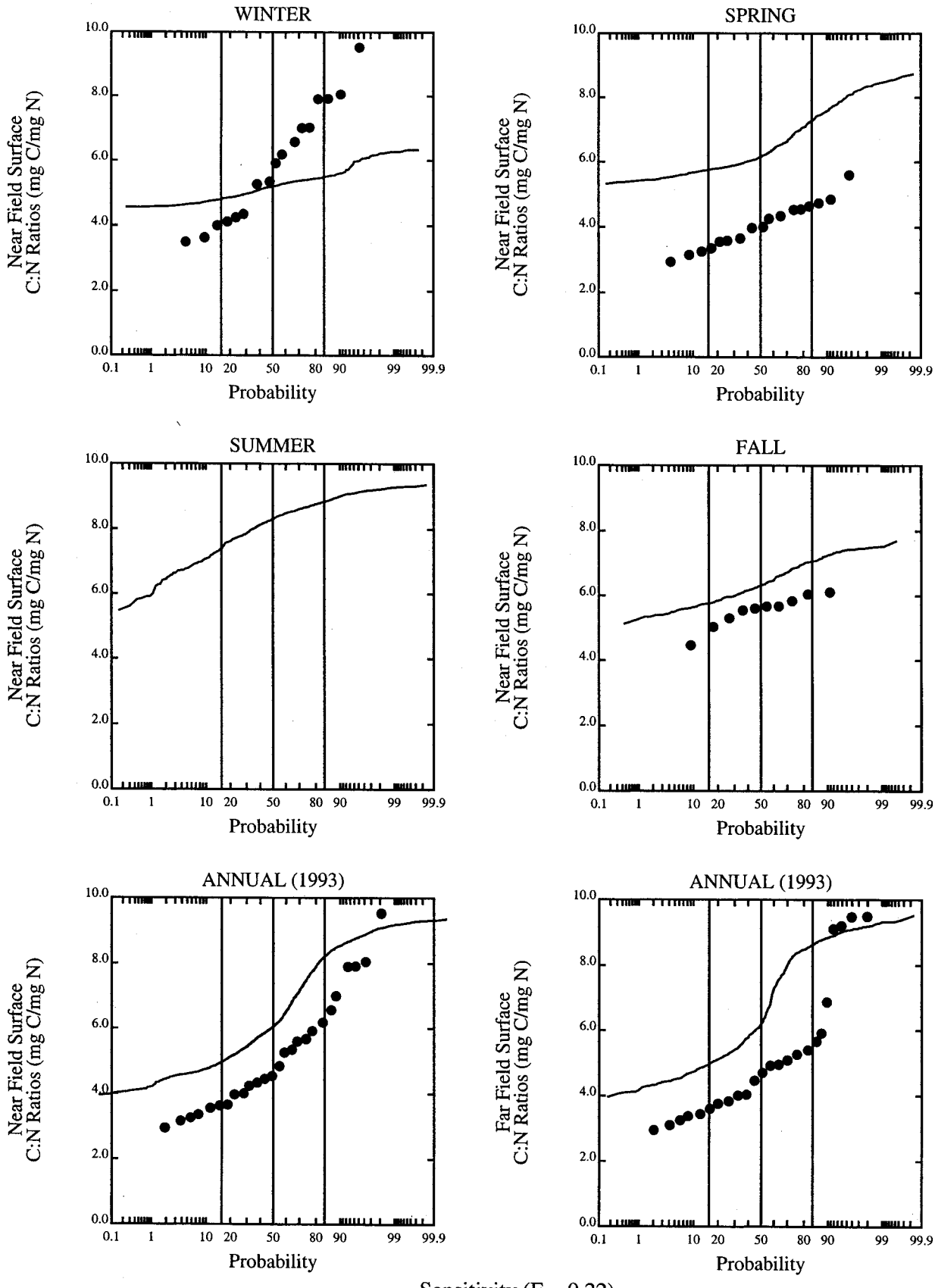
Run description: Sensitivity (F = 0.22)

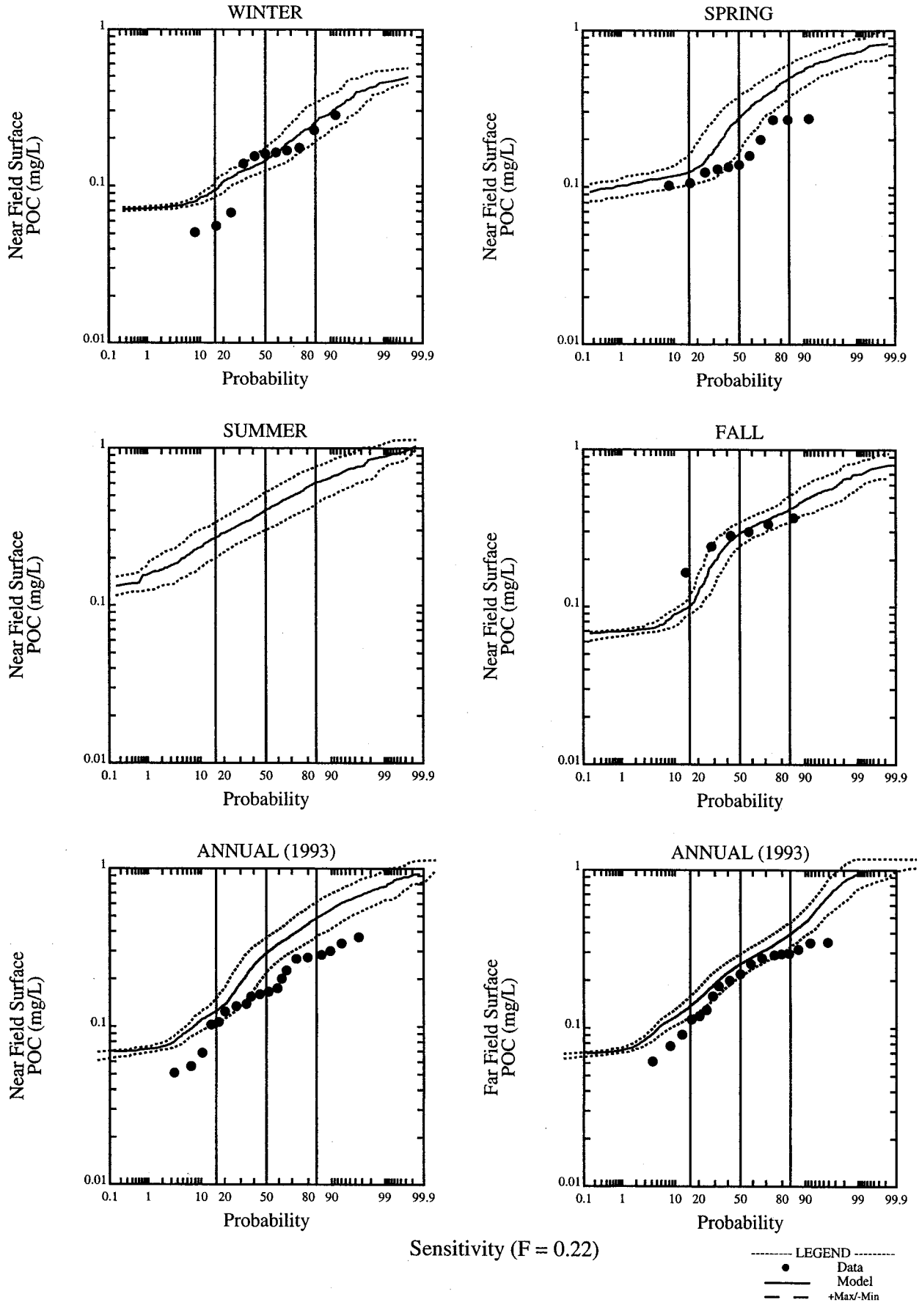
1993 Temporal Calibration Results for
Grid Cell (11,18) Vs Data Station N16P,N17,N21

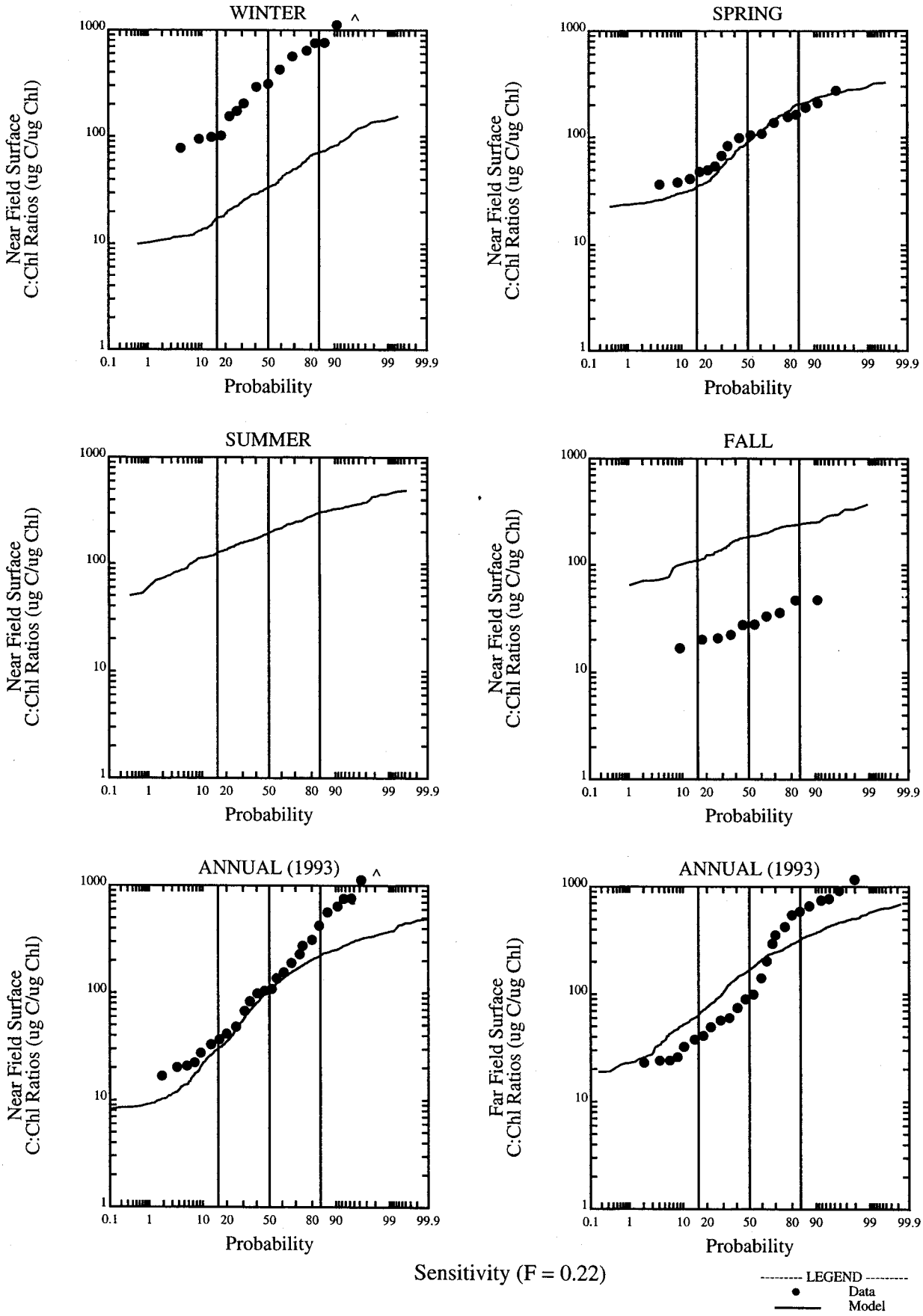


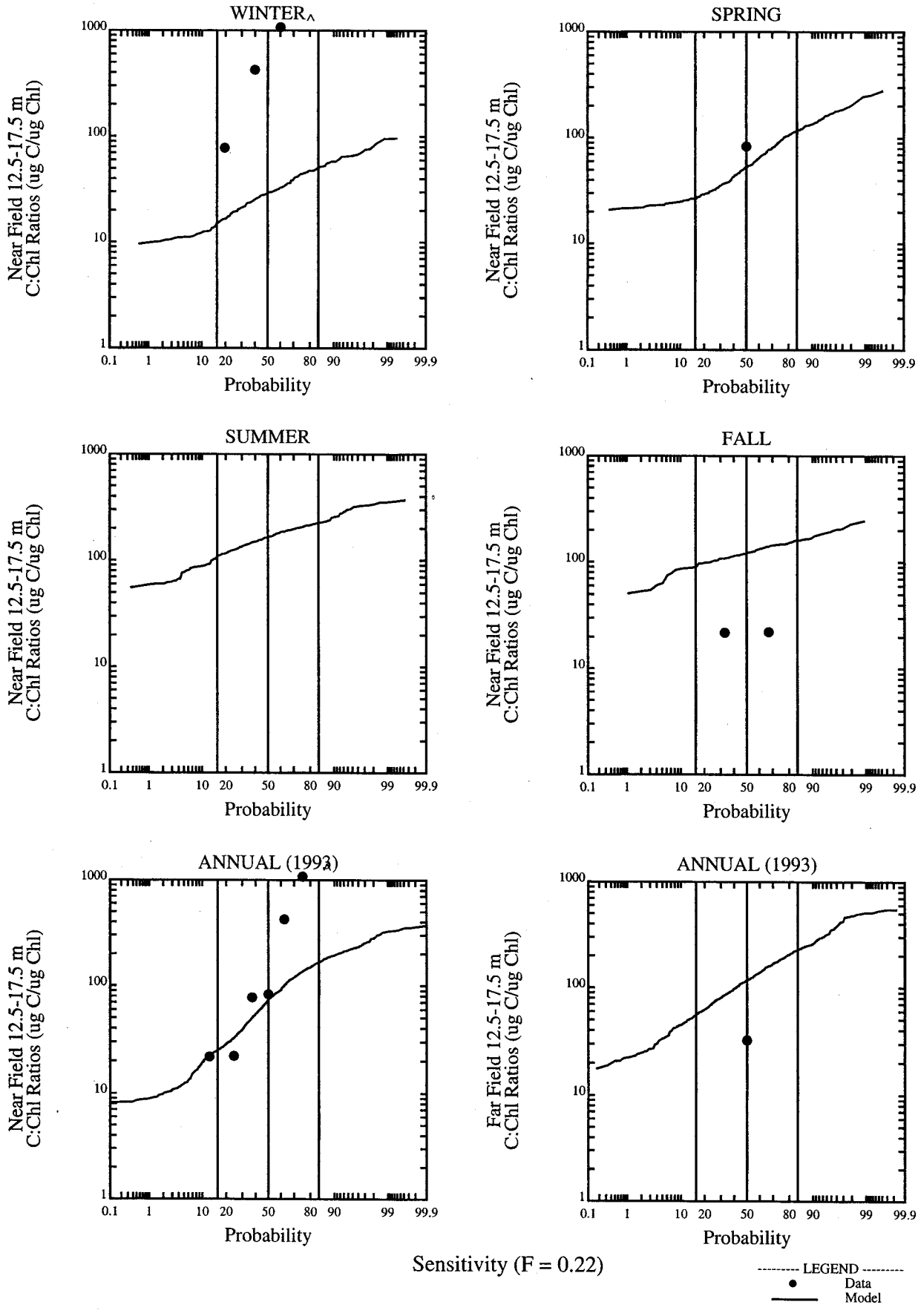
Run description: Sensitivity (F = 0.22)

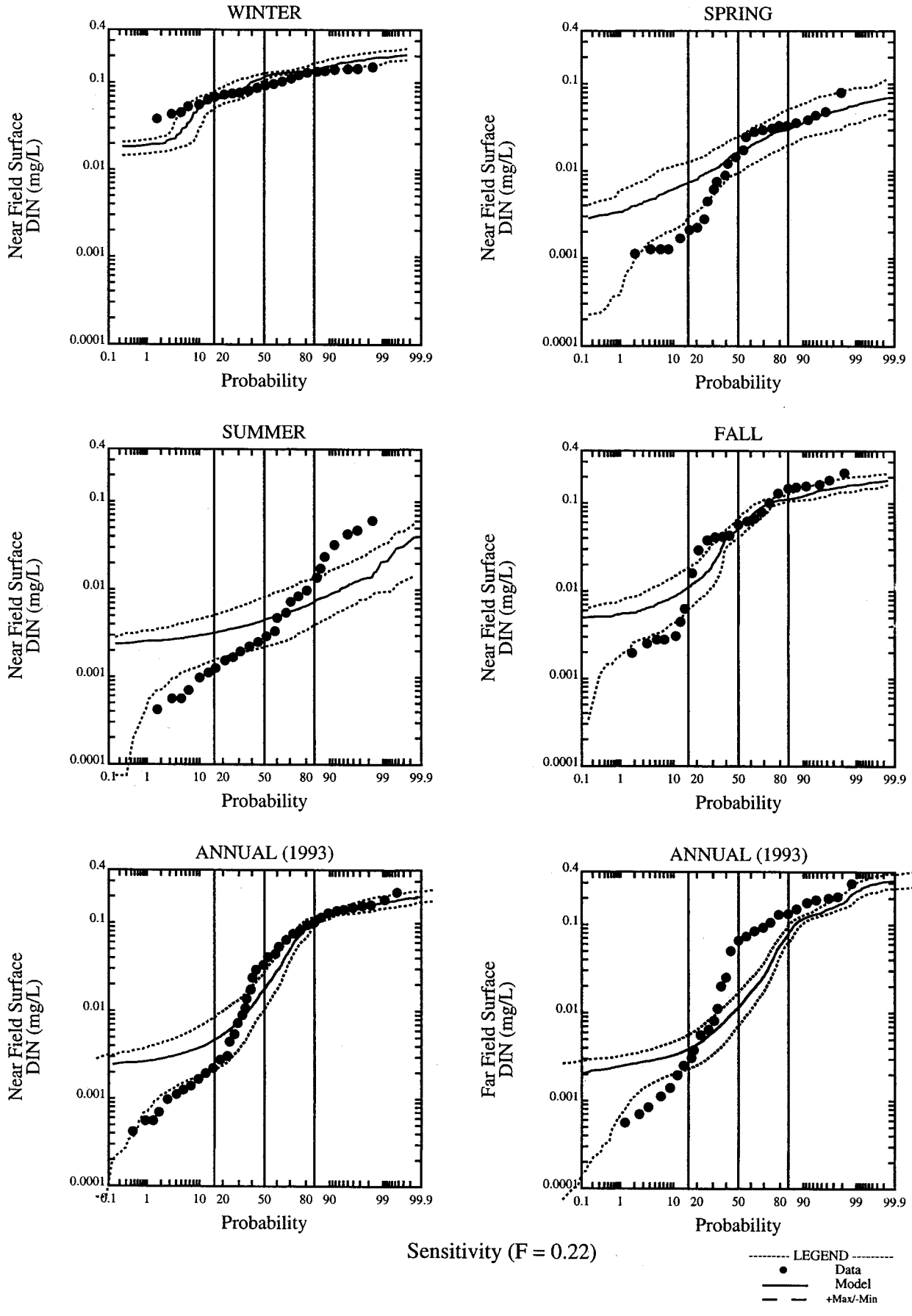
1993 Temporal Calibration Results for
Grid Cell (13,4) Vs Data Station F02P

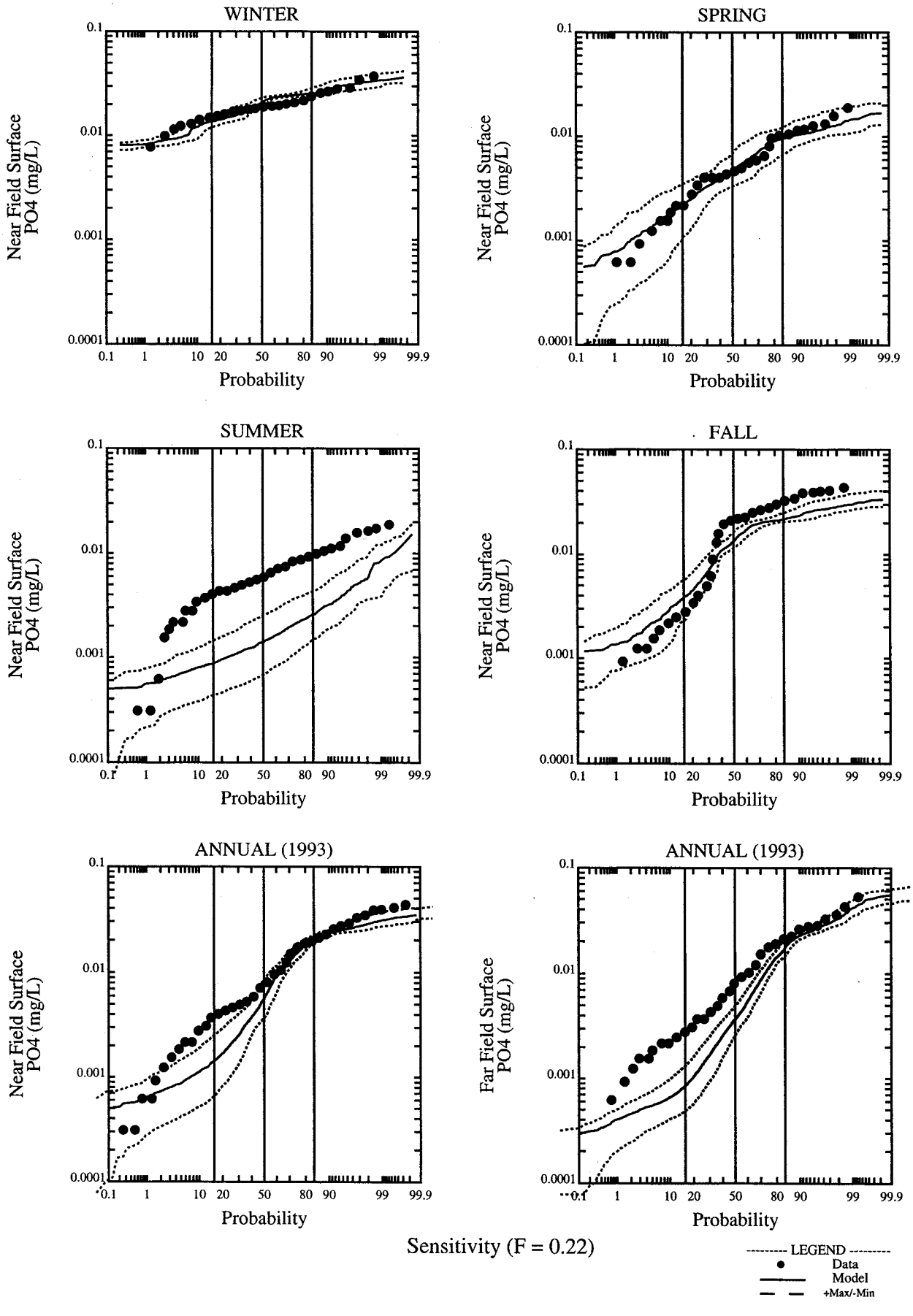

WINTER
SPRING
SUMMER
FALL
ANNUAL (1993)
ANNUAL (1993)
Near Field Surface C:N Ratios (mg C/mg N)
Far Field Surface C:N Ratios (mg C/mg N)
Probability
0.0
2.0
4.0
6.0
8.0
10.0
0.1
1
10
20
50
80
90
99
99.9
Sensitivity (F = 0.22)
LEGEND
Data
Model

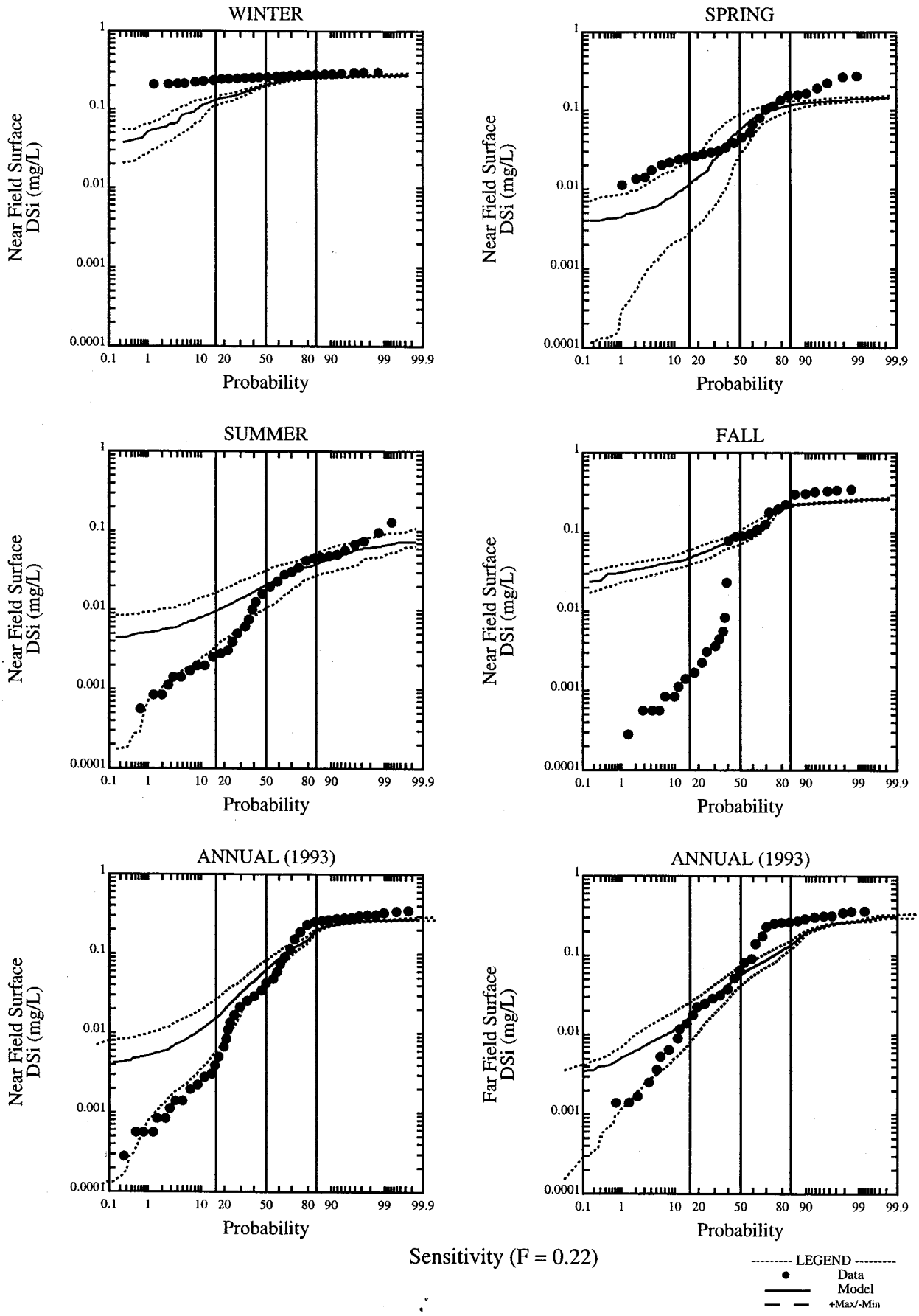

WINTER
SPRING
SUMMER
FALL
ANNUAL (1993)
ANNUAL (1993)
Near Field Surface POC (mg/L)
Far Field Surface POC (mg/L)
Probability
1
0.1
0.01
0.1 1 10 20 50 80 90 99 99.9
Sensitivity (F = 0.22)
LEGEND
Data
Model
+Max/-Min

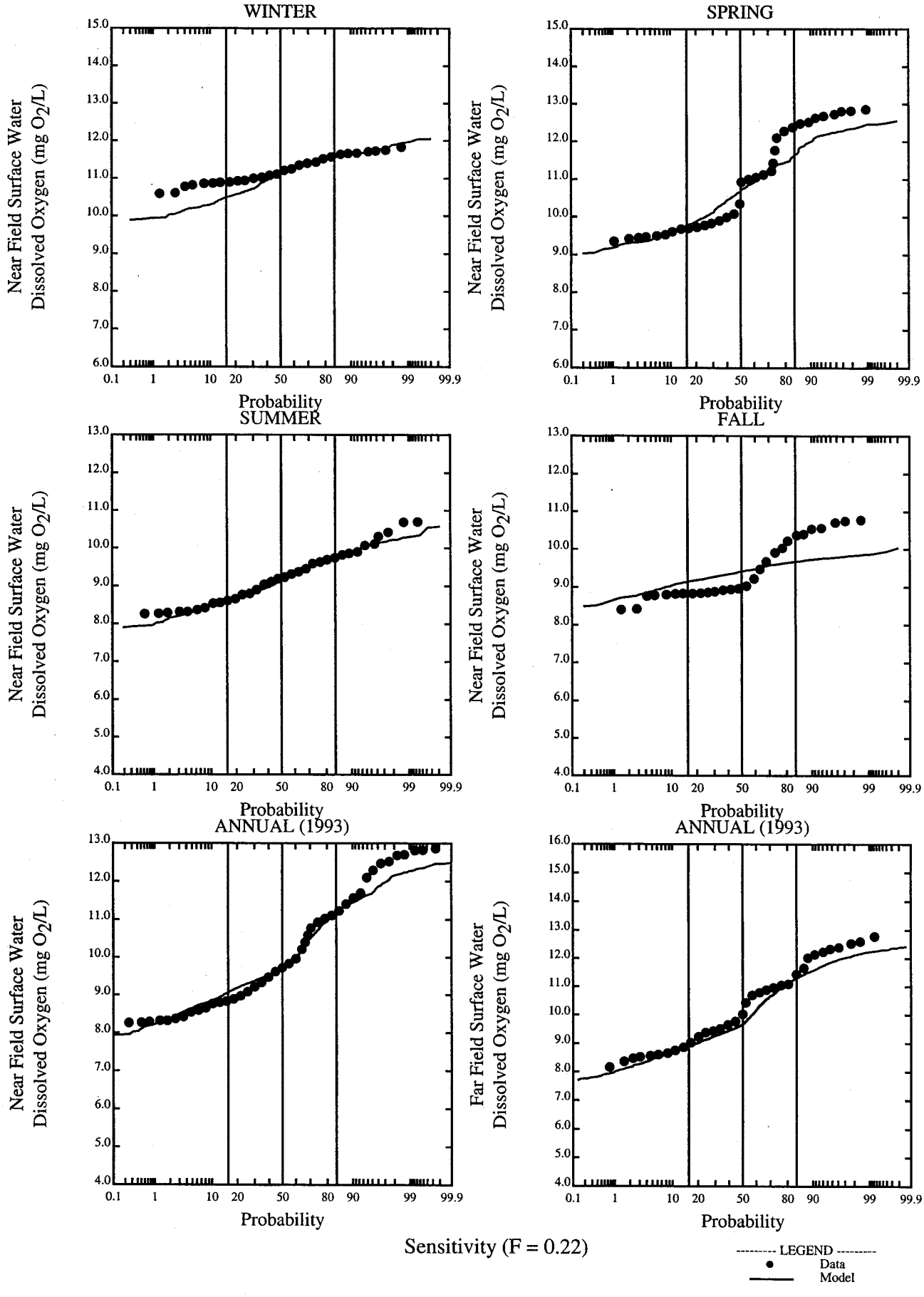

WINTER
SPRING
SUMMER
FALL
ANNUAL (1993)
ANNUAL (1993)
Near Field Surface C:Chl Ratios (ug C/ug Chl)
Far Field Surface C:Chl Ratios (ug C/ug Chl)
Probability
1000
100
10
1
0.1
1
10
20
50
80
90
99
99.9
Sensitivity (F = 0.22)
LEGEND
Data
Model

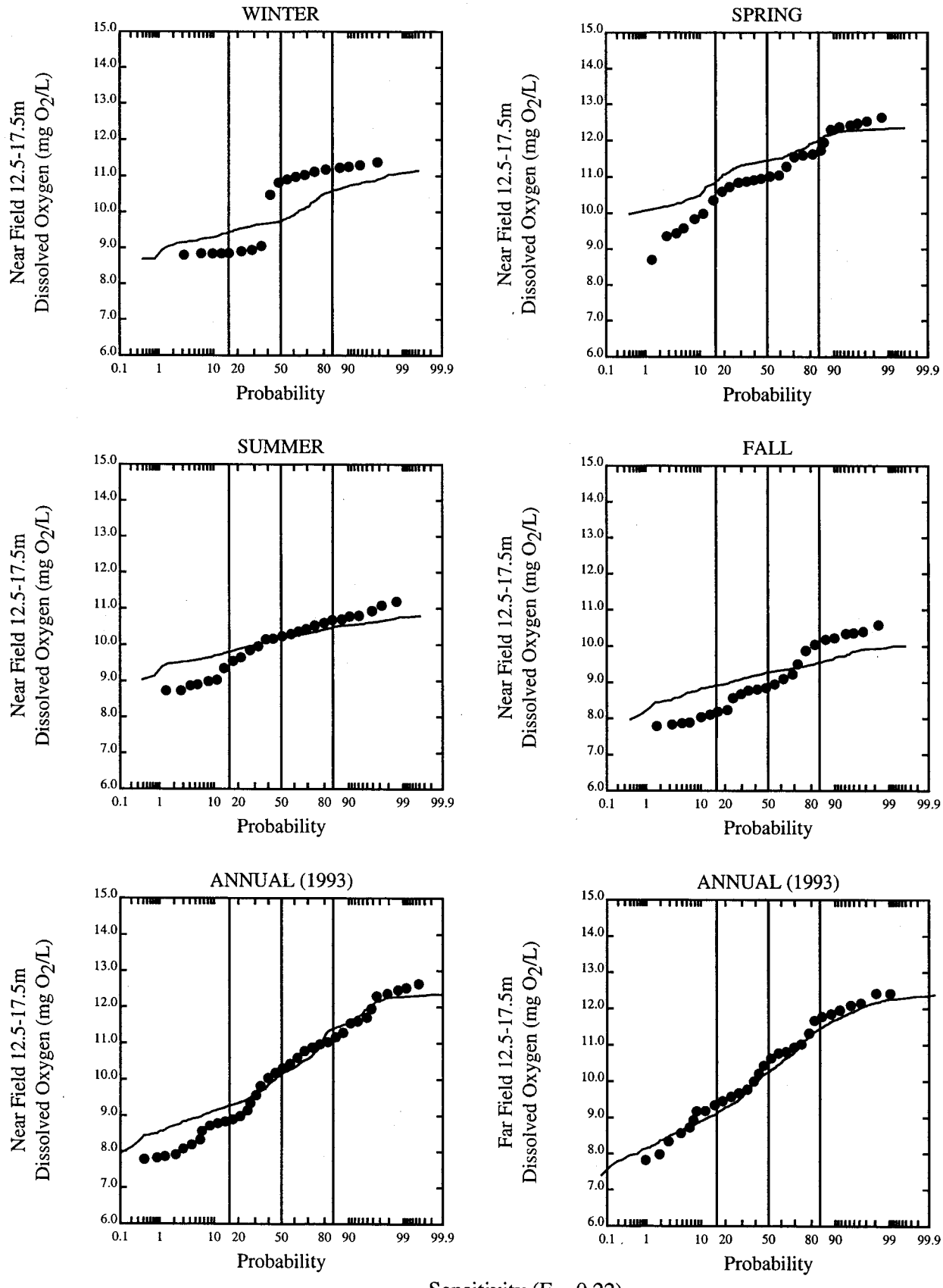

WINTER
SPRING
SUMMER
FALL
ANNUAL (1993)
ANNUAL (1993)
Near Field 12.5-17.5 m C:Chl Ratios (ug C/ug Chl)
Far Field 12.5-17.5 m C:Chl Ratios (ug C/ug Chl)
1000
100
10
1
0.1
1
10
20
50
80
90
99
99.9
Probability
Sensitivity (F = 0.22)
LEGEND
Data
Model

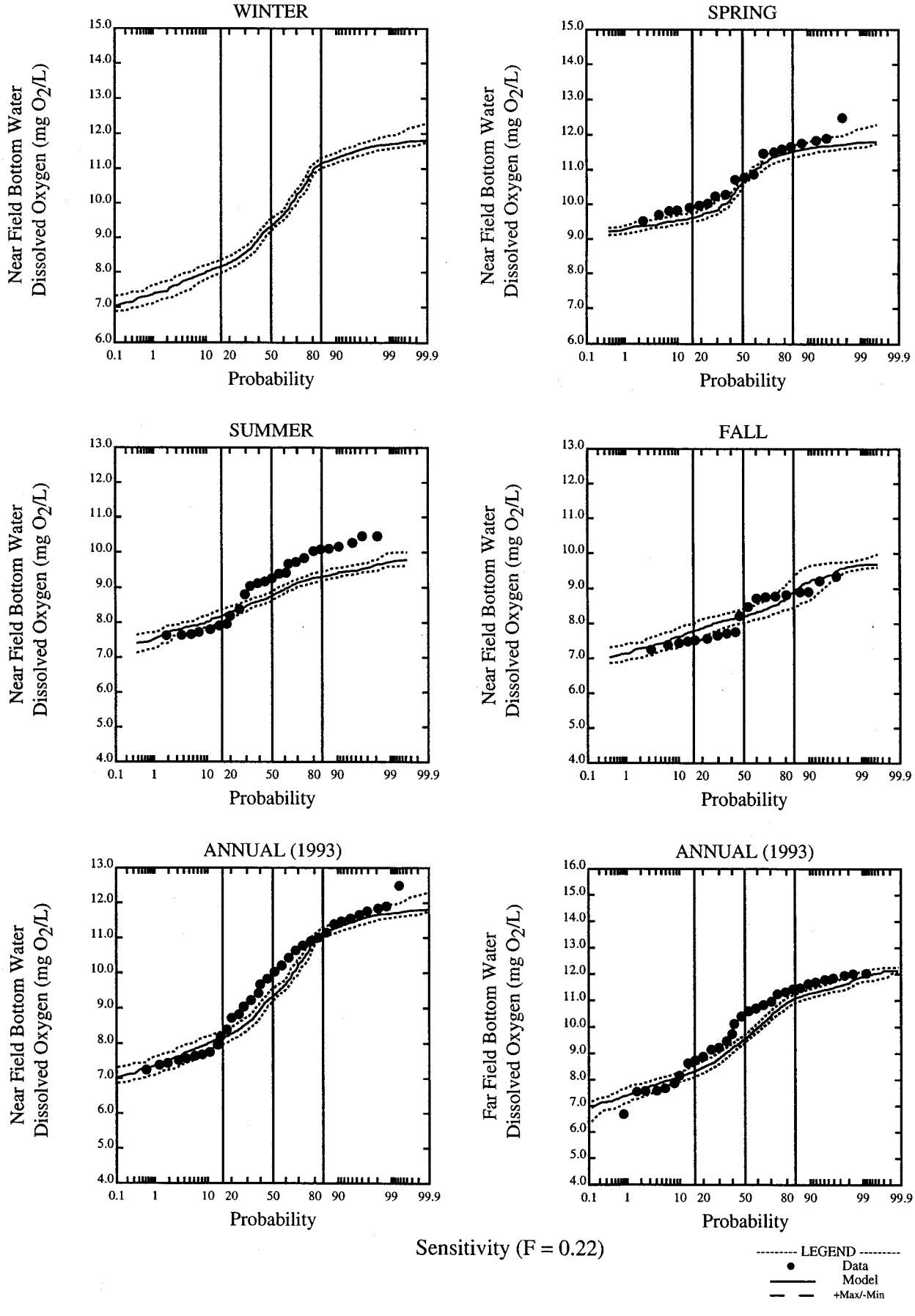

WINTER
SPRING
SUMMER
FALL
ANNUAL (1993)
ANNUAL (1993)
Near Field Surface DIN (mg/L)
Far Field Surface DIN (mg/L)
0.4
0.1
0.01
0.001
0.0001
0.1 1 10 20 50 80 90 99 99.9
Probability
Sensitivity (F = 0.22)
LEGEND
Data
Model
+Max/-Min

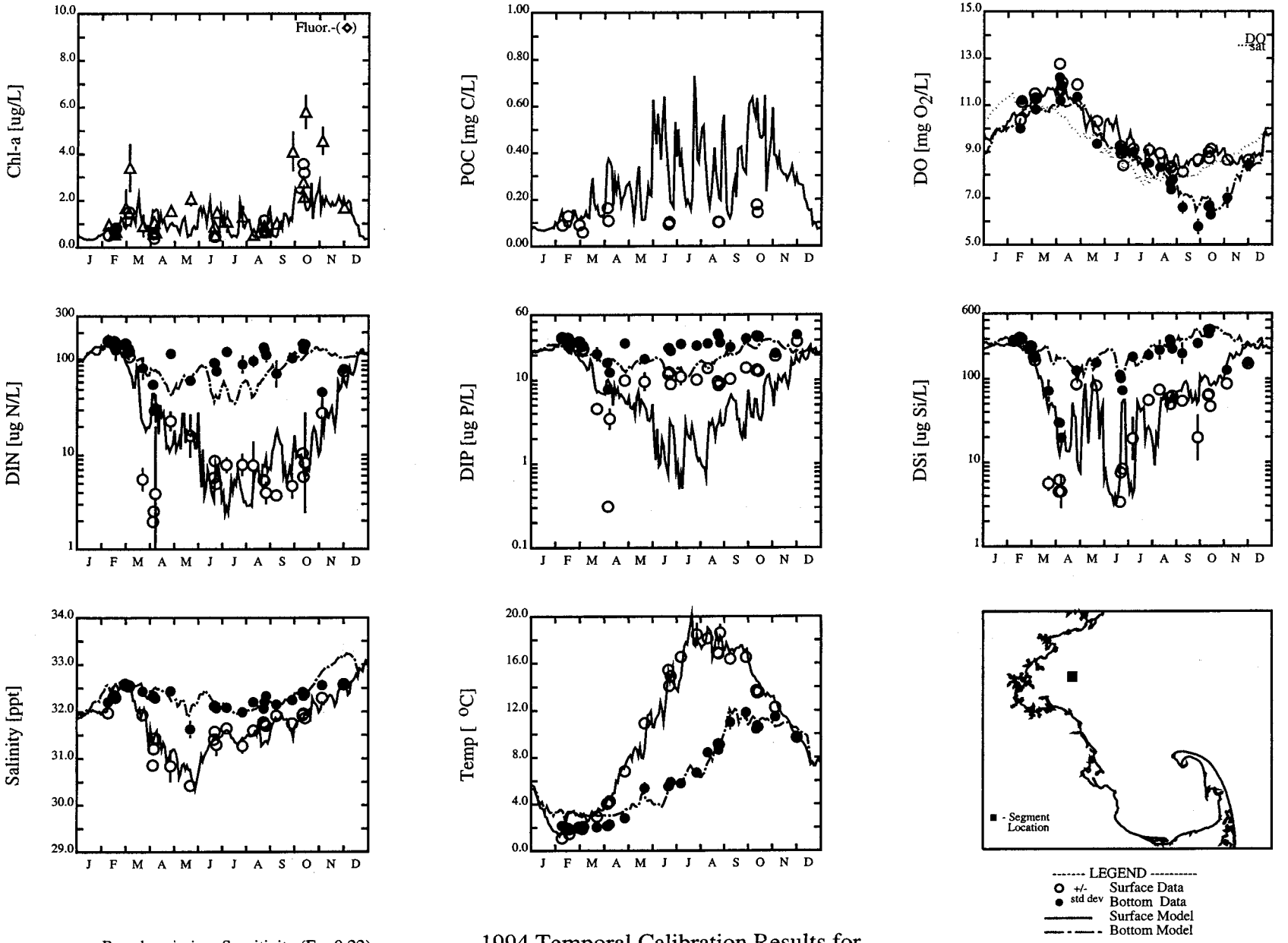

WINTER
SPRING
SUMMER
FALL
ANNUAL (1993)
ANNUAL (1993)
Near Field Surface PO4 (mg/L)
Far Field Surface PO4 (mg/L)
0.1
0.01
0.001
0.0001
0.1 1 10 20 50 80 90 99 99.9
Probability
Sensitivity (F = 0.22)
LEGEND
Data
Model
+Max/-Min


WINTER
SPRING
SUMMER
FALL
ANNUAL (1993)
ANNUAL (1993)
Near Field Surface DSi (mg/L)
Far Field Surface DSi (mg/L)
Probability
1
0.1
0.01
0.001
0.0001
0.1
1
10
20
50
80
90
99
99.9
Sensitivity (F = 0.22)
LEGEND
Data
Model
+Max/-Min


WINTER
SPRING
SUMMER
FALL
ANNUAL (1993)
ANNUAL (1993)
Near Field Surface Water Dissolved Oxygen (mg O2/L)
Far Field Surface Water Dissolved Oxygen (mg O2/L)
Probability
0.1 1 10 20 50 80 90 99 99.9
Sensitivity (F = 0.22)
LEGEND
Data
Model

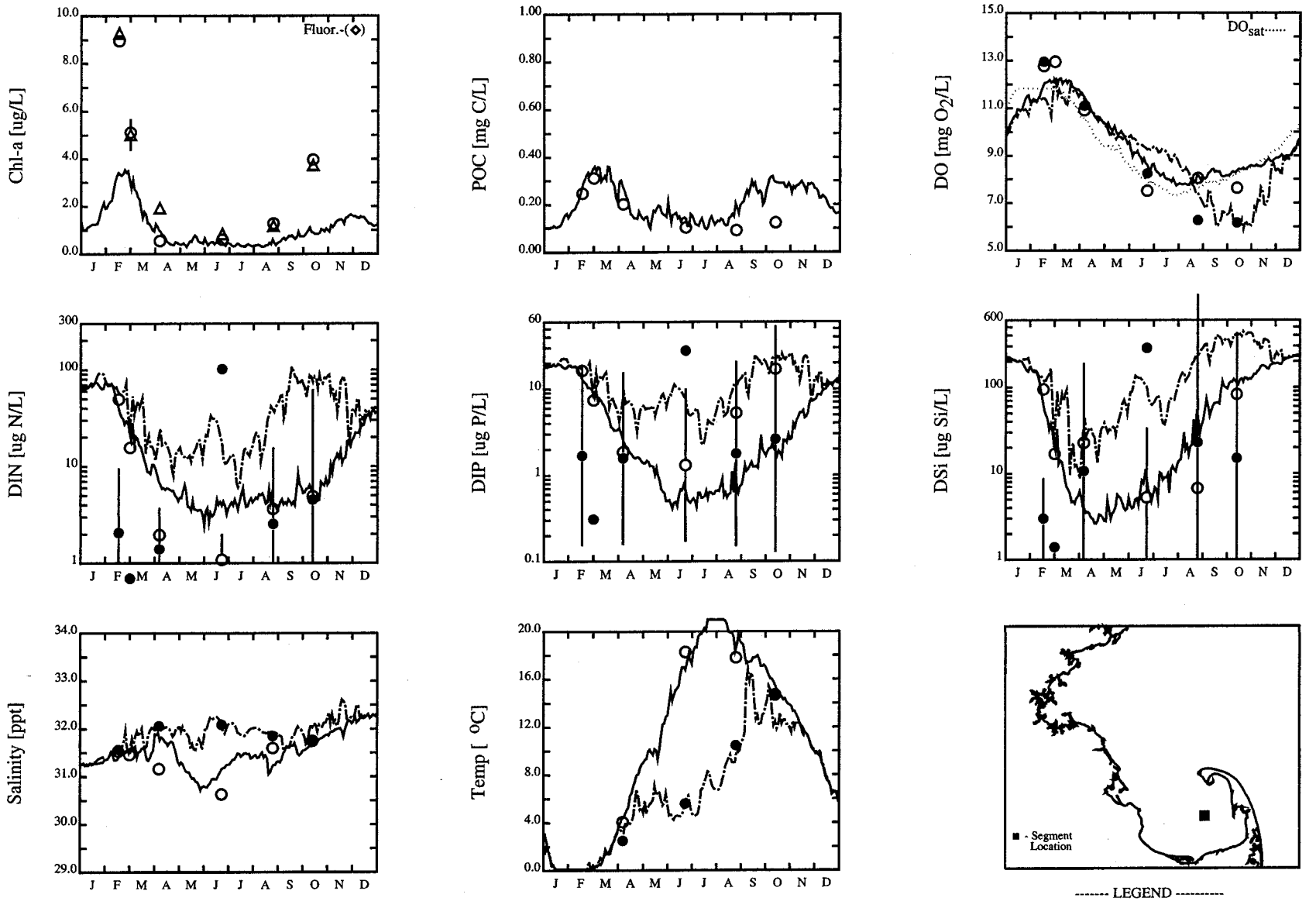

WINTER
SPRING
SUMMER
FALL
ANNUAL (1993)
ANNUAL (1993)
Near Field 12.5-17.5m Dissolved Oxygen (mg O2/L)
Far Field 12.5-17.5m Dissolved Oxygen (mg O2/L)
15.0
14.0
13.0
12.0
11.0
10.0
9.0
8.0
7.0
6.0
0.1
1
10
20
50
80
90
99
99.9
Probability
Sensitivity (F = 0.22)
LEGEND
Data
Model


WINTER
SPRING
SUMMER
FALL
ANNUAL (1993)
ANNUAL (1993)
Near Field Bottom Water Dissolved Oxygen (mg O2/L)
Far Field Bottom Water Dissolved Oxygen (mg O2/L)
Probability
0.1 1 10 20 50 80 90 99 99.9
Sensitivity (F = 0.22)
LEGEND
Data
Model
+Max/-Min



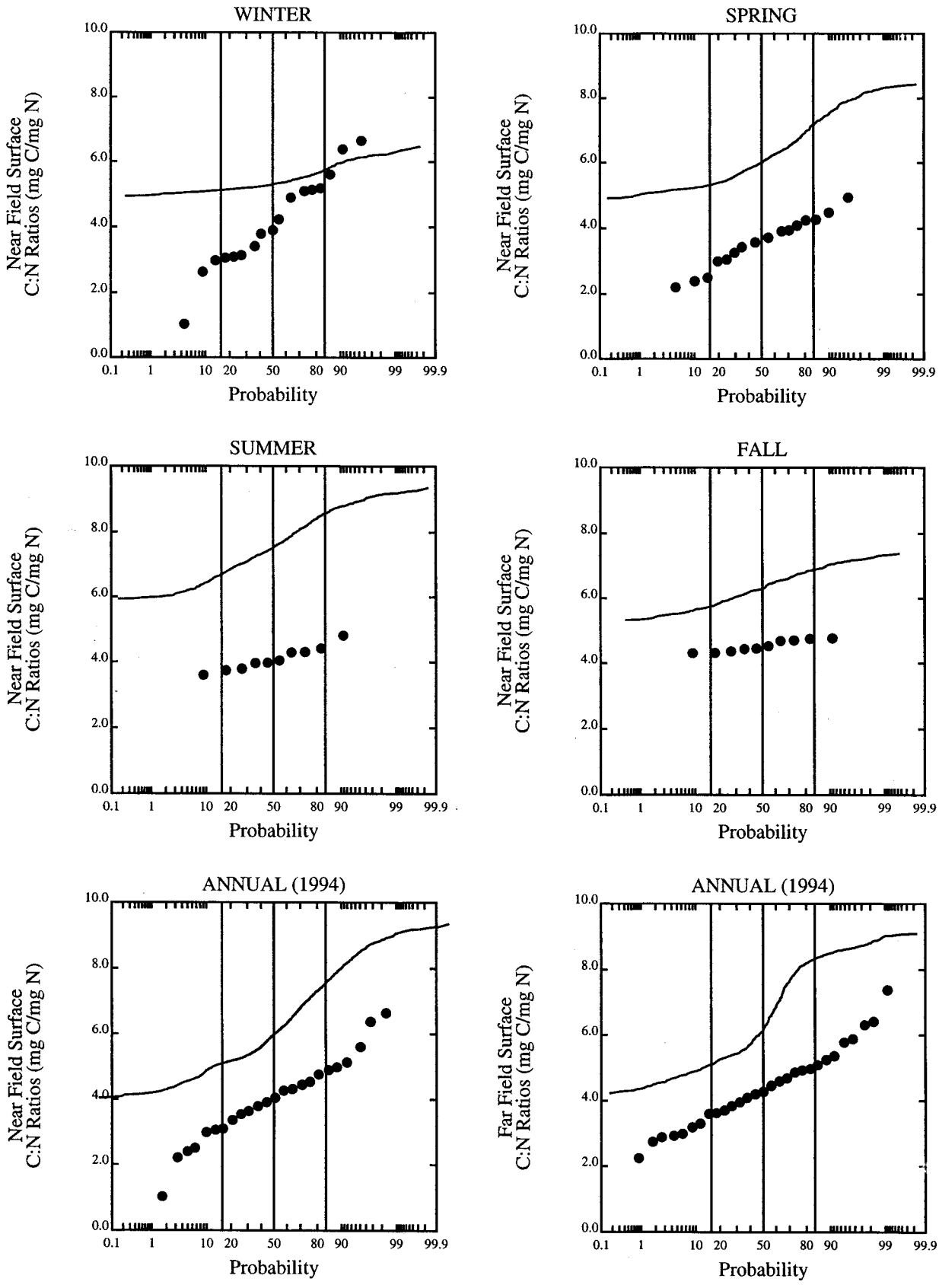
Run description: Sensitivity (F = 0.22)

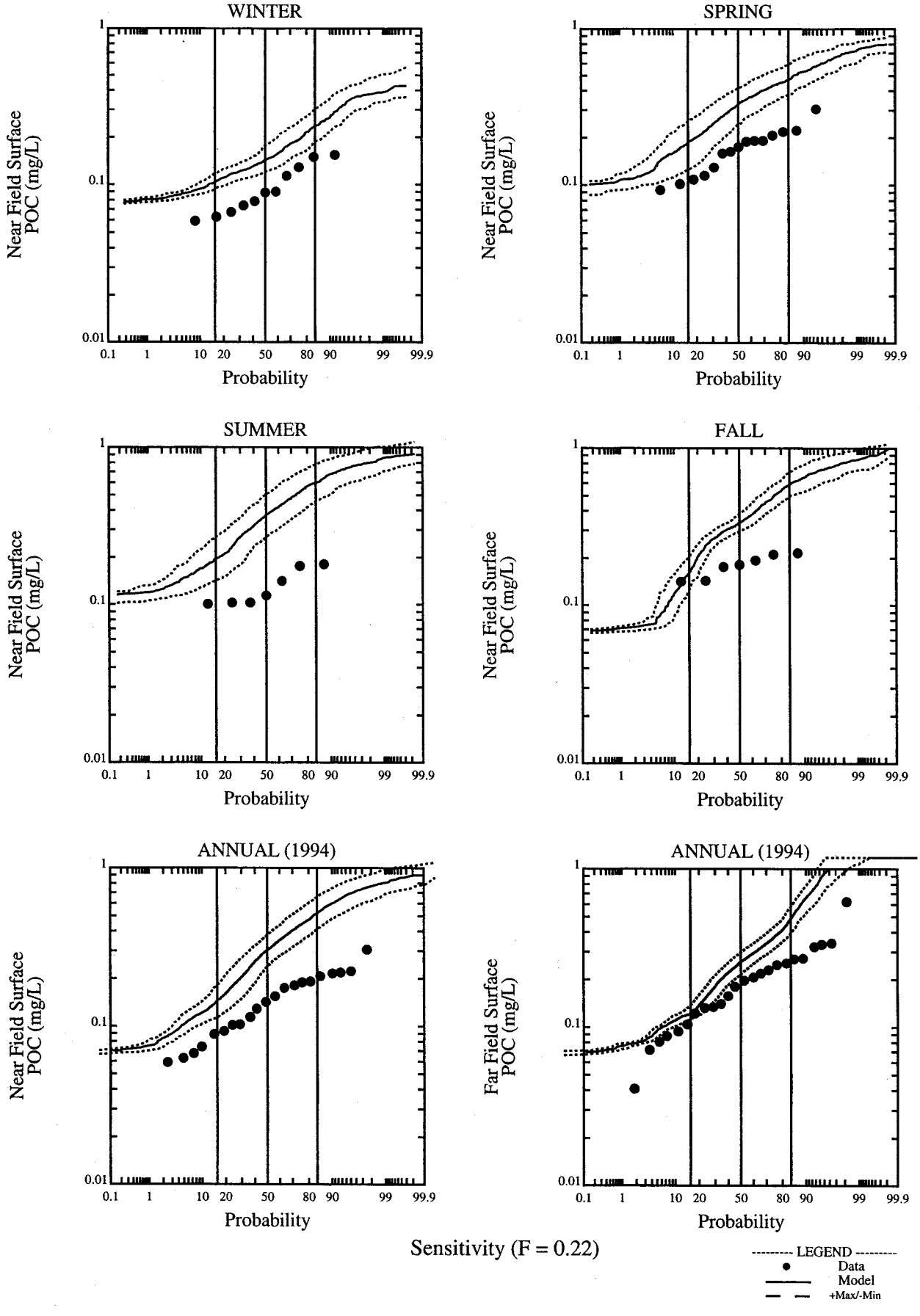
1994 Temporal Calibration Results for
Grid Cell (11,18) Vs Data Station N16P,N17,N21

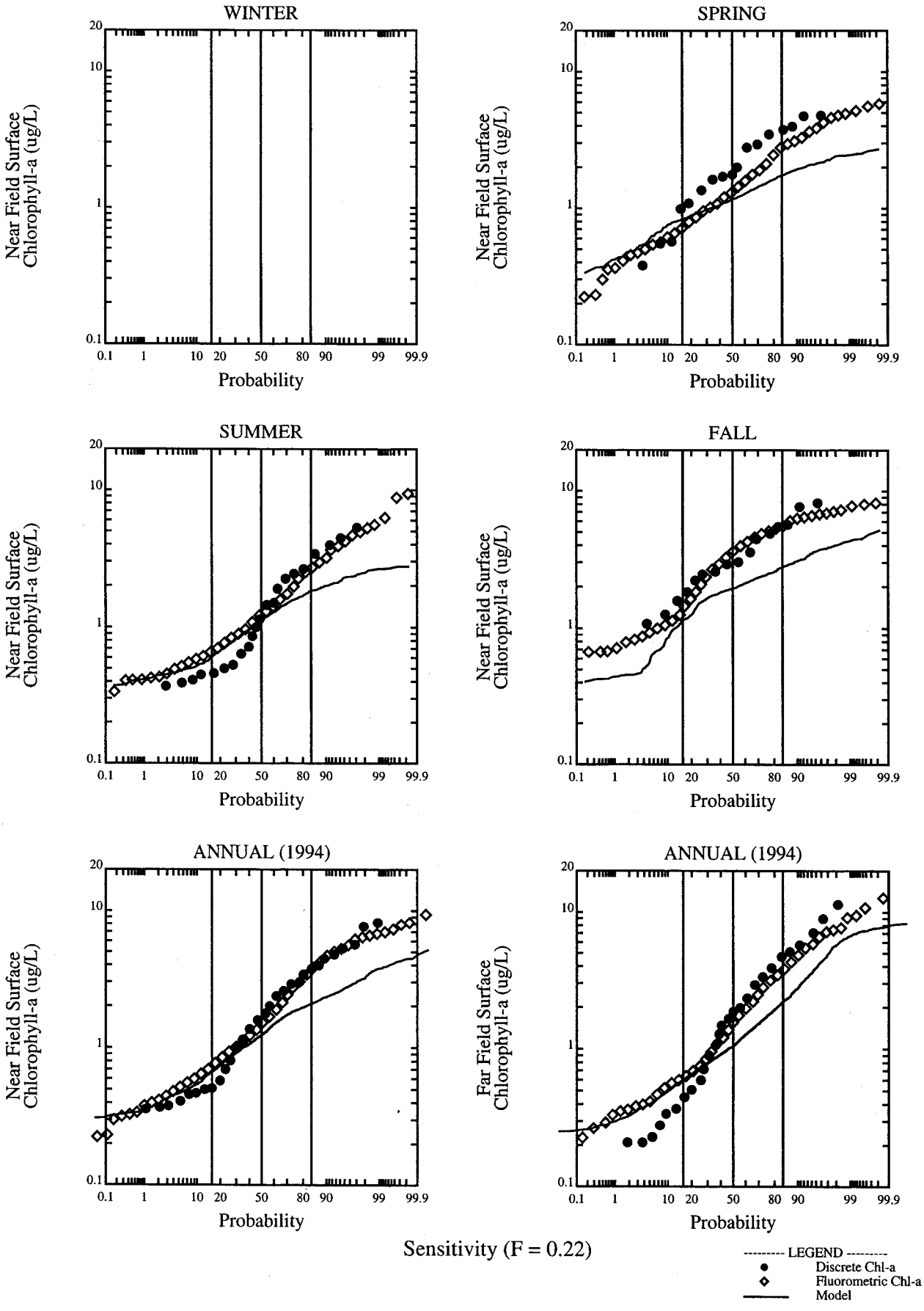


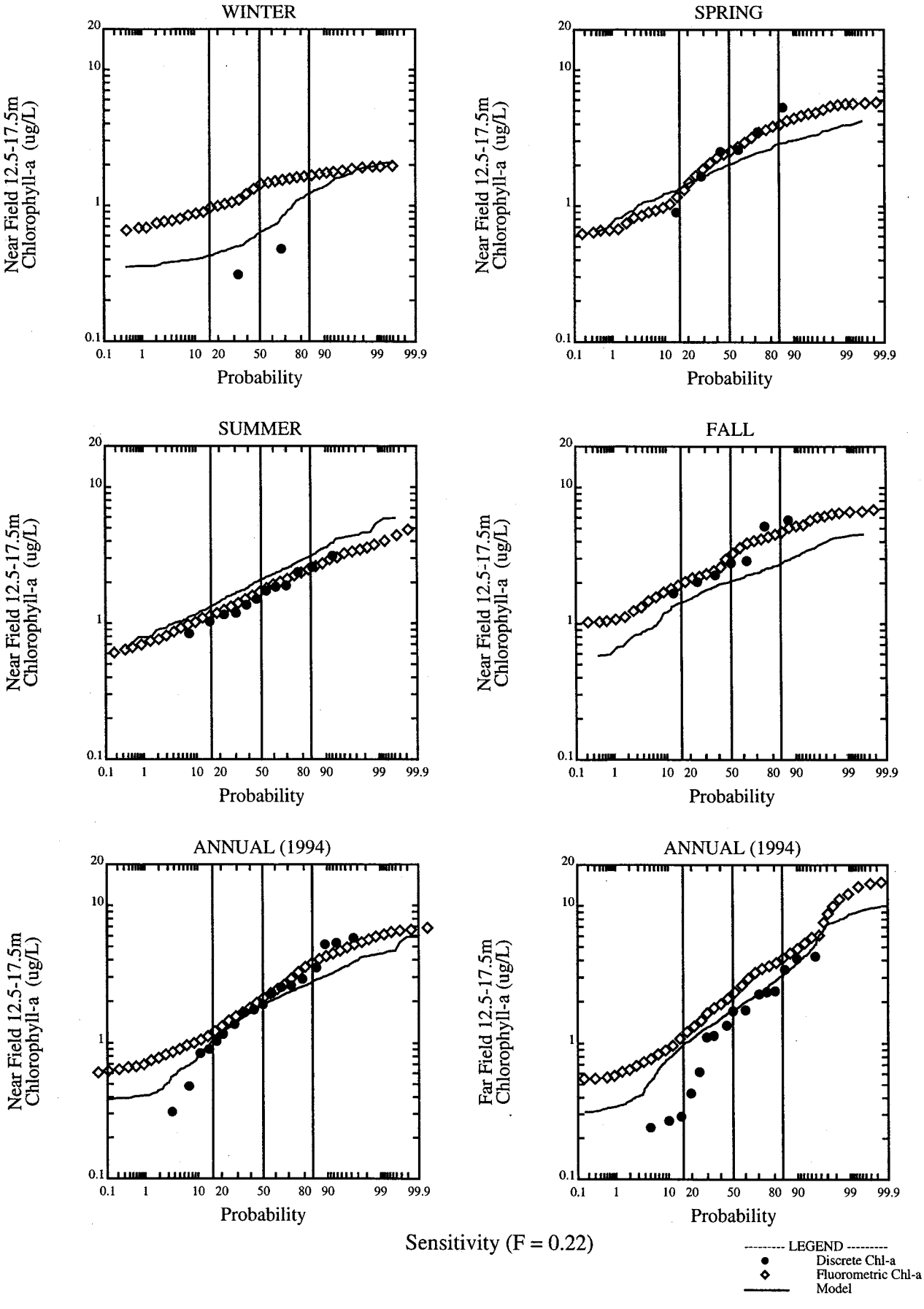
Run description: Sensitivity (F = 0.22)

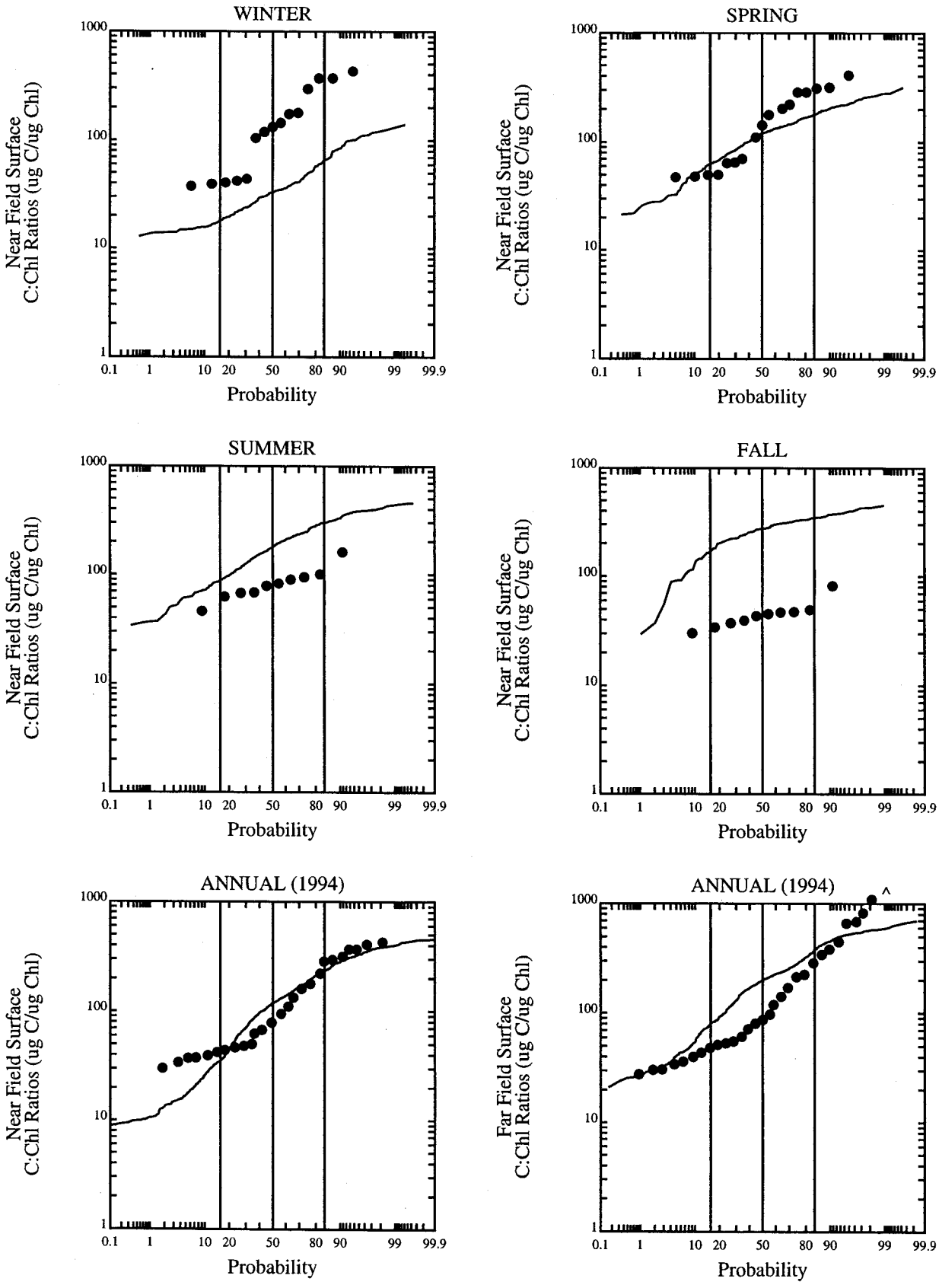
1994 Temporal Calibration Results for
Grid Cell (13,04) Vs Data Station F02P

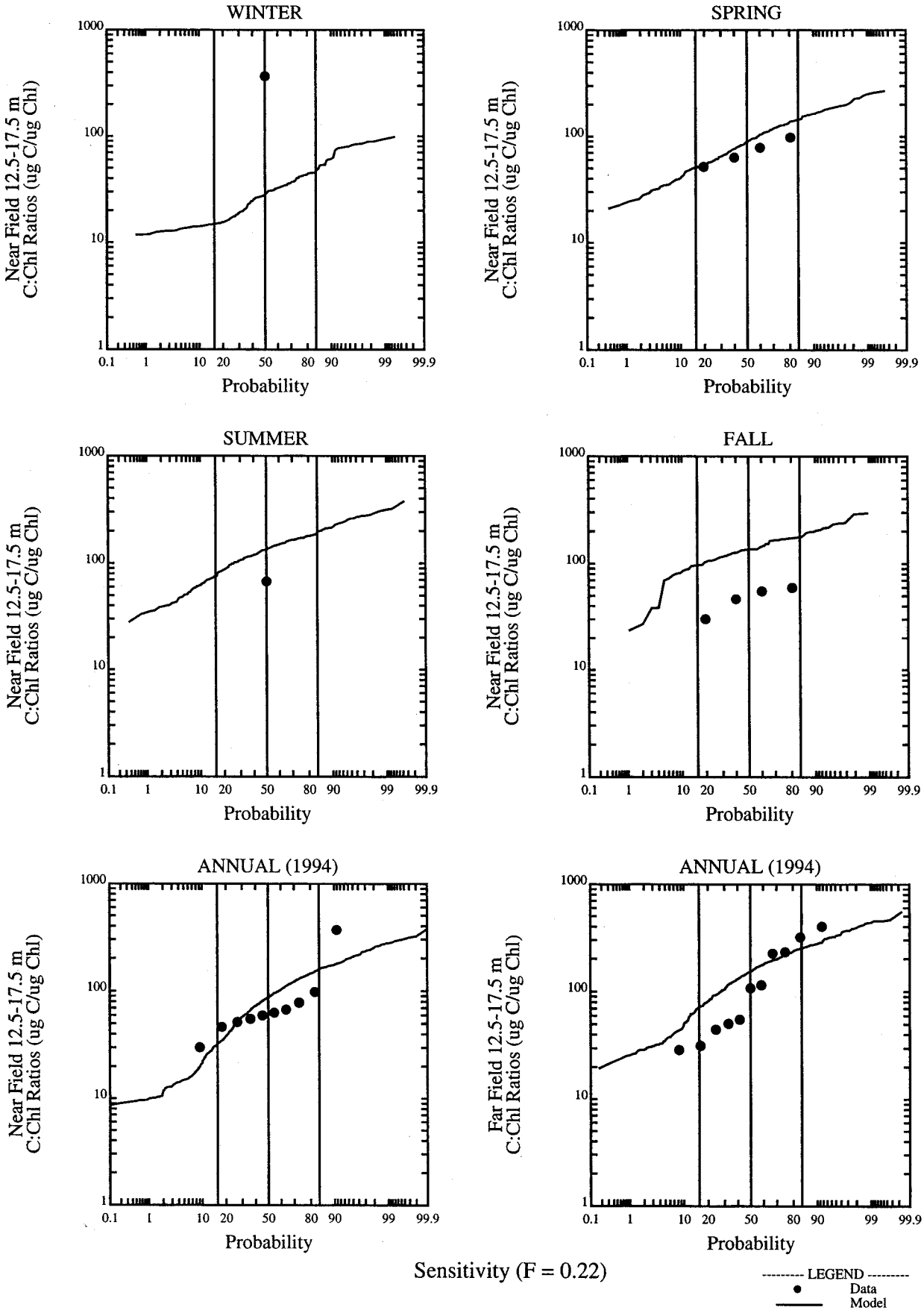

WINTER
SPRING
SUMMER
FALL
ANNUAL (1994)
ANNUAL (1994)
Near Field Surface C:N Ratios (mg C/mg N)
Far Field Surface C:N Ratios (mg C/mg N)
Probability
0.0
2.0
4.0
6.0
8.0
10.0
0.1
1
10
20
50
80
90
99
99.9
Sensitivity (F = 0.22)
LEGEND
Data
Model

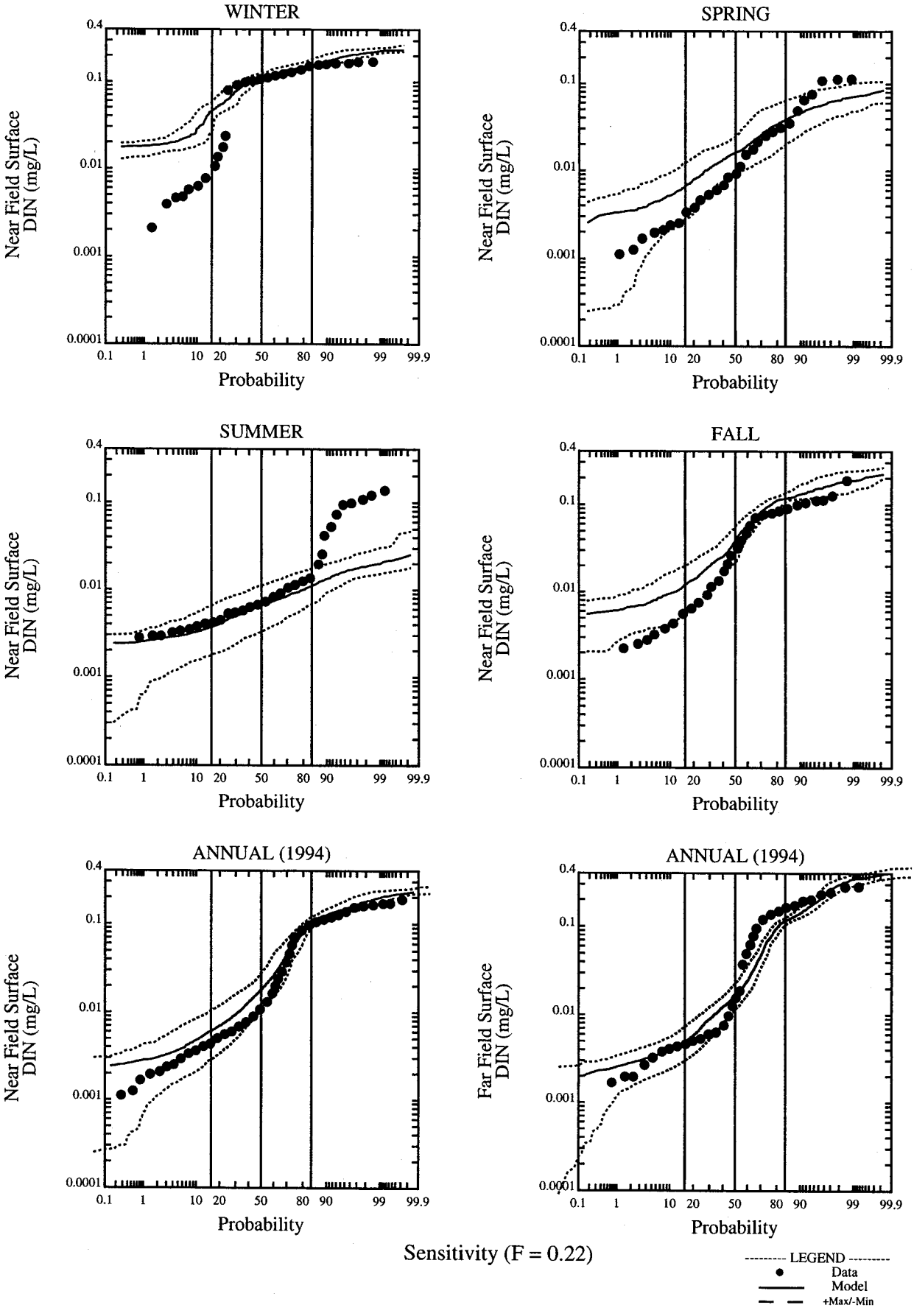

WINTER
SPRING
SUMMER
FALL
ANNUAL (1994)
ANNUAL (1994)
Near Field Surface POC (mg/L)
Far Field Surface POC (mg/L)
Probability
1
0.1
0.01
0.1 1 10 20 50 80 90 99 99.9
Sensitivity (F = 0.22)
LEGEND
Data
Model
+Max/-Min

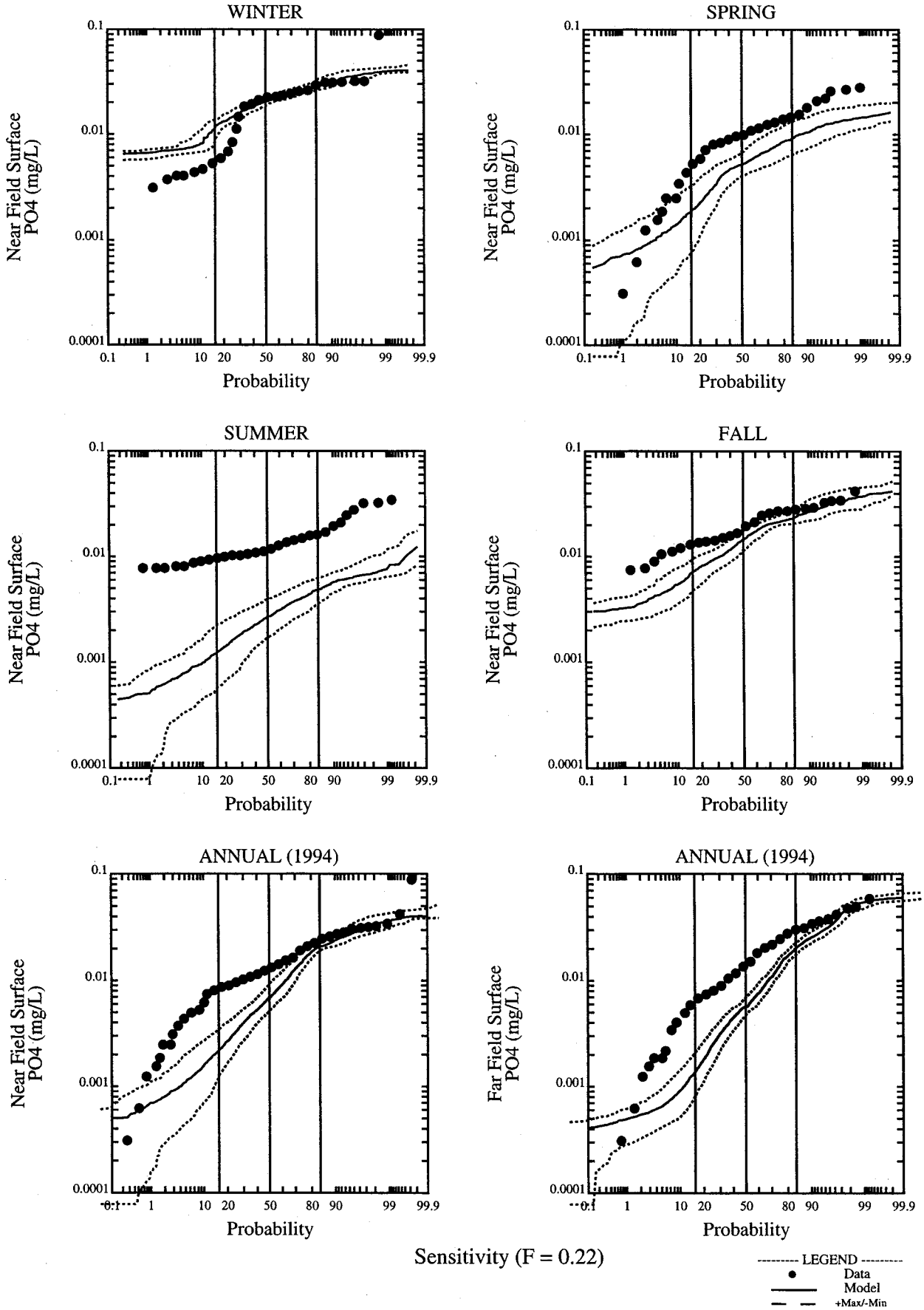

WINTER
SPRING
SUMMER
FALL
ANNUAL (1994)
ANNUAL (1994)
Near Field Surface Chlorophyll-a (ug/L)
Far Field Surface Chlorophyll-a (ug/L)
Probability
20
10
1
0.1
0.1 1 10 20 50 80 90 99 99.9
Sensitivity (F = 0.22)
LEGEND
Discrete Chl-a
Fluorometric Chl-a
Model

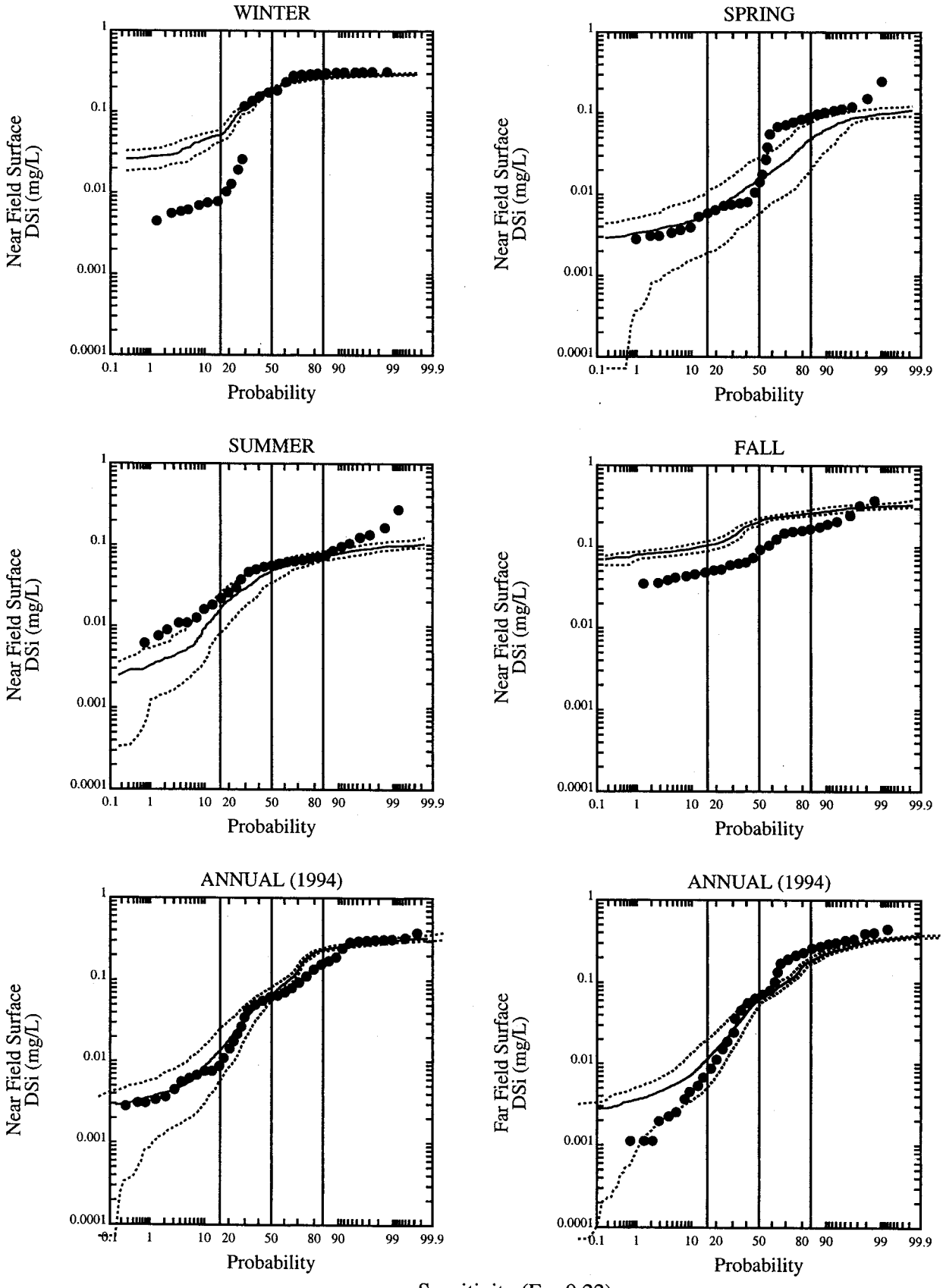

WINTER
SPRING
SUMMER
FALL
ANNUAL (1994)
ANNUAL (1994)
Near Field 12.5-17.5m Chlorophyll-a (ug/L)
Far Field 12.5-17.5m Chlorophyll-a (ug/L)
Probability
20
10
1
0.1
0.1 1 10 20 50 80 90 99 99.9
Sensitivity (F = 0.22)
LEGEND
Discrete Chl-a
Fluorometric Chl-a
Model

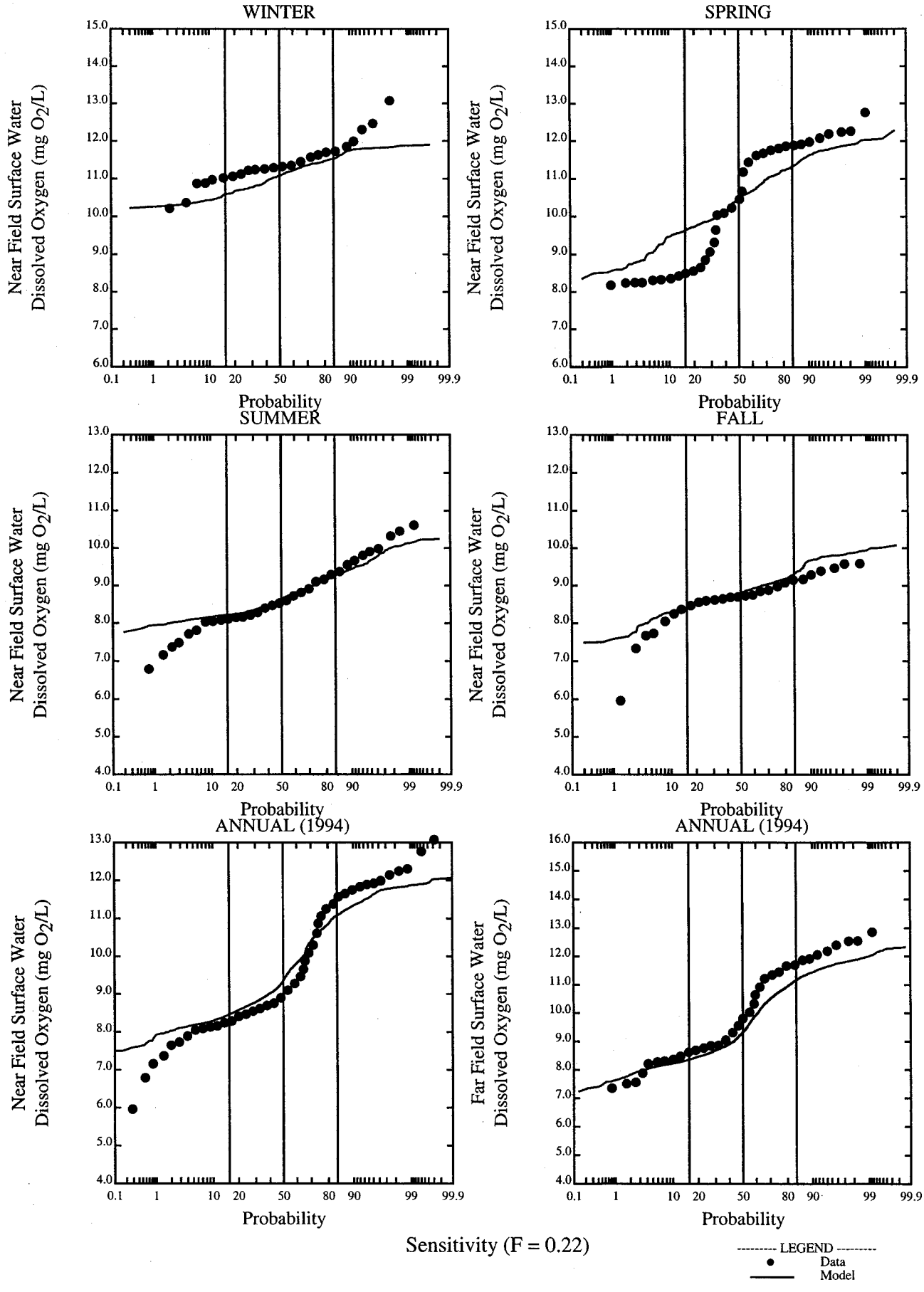

WINTER
SPRING
SUMMER
FALL
ANNUAL (1994)
ANNUAL (1994)
Near Field Surface C:Chl Ratios (ug C/ug Chl)
Far Field Surface C:Chl Ratios (ug C/ug Chl)
1000
100
10
1
0.1 1 10 20 50 80 90 99 99.9
Probability
Sensitivity (F = 0.22)
LEGEND
Data
Model

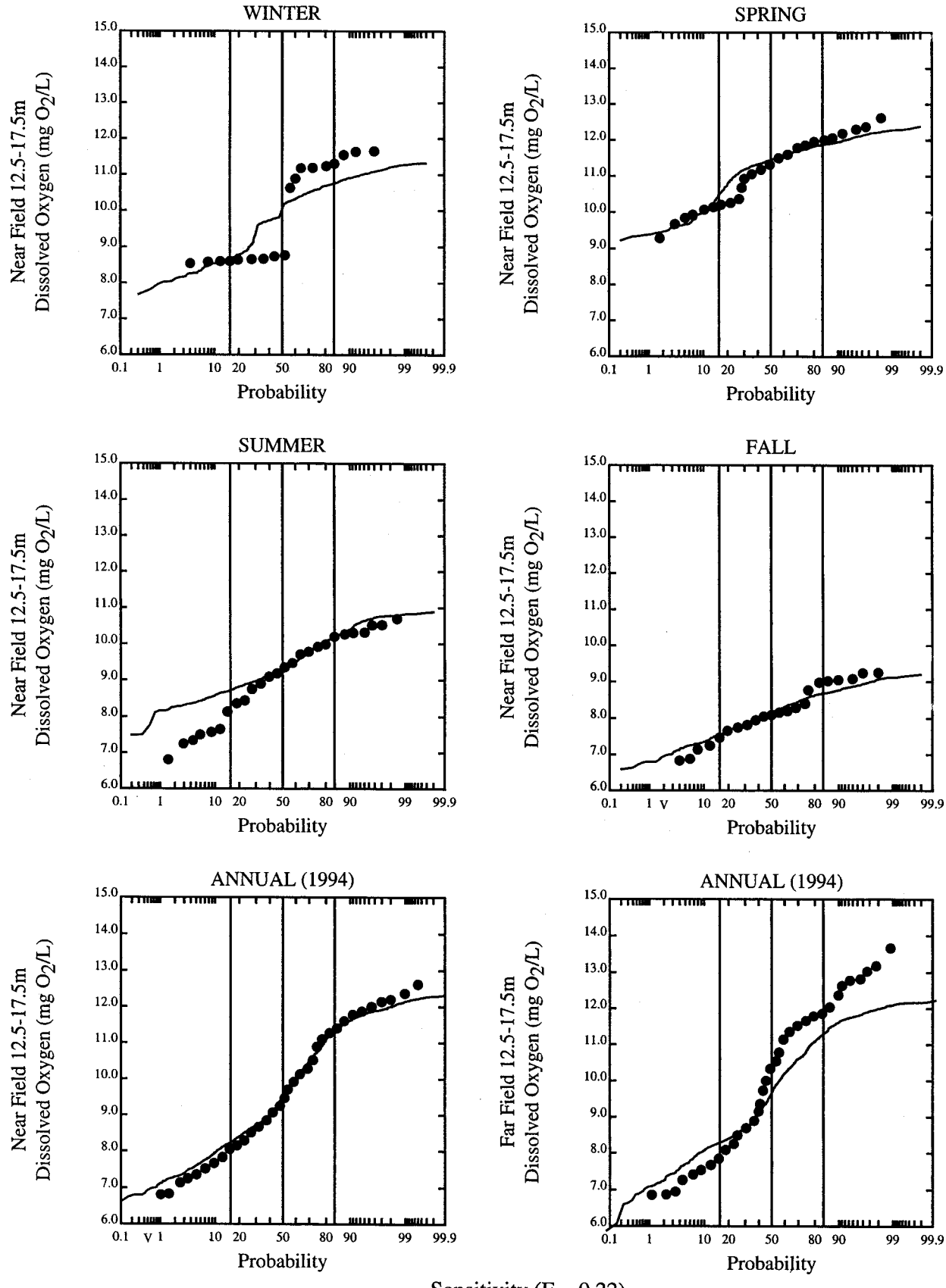

WINTER
SPRING
SUMMER
FALL
ANNUAL (1994)
ANNUAL (1994)
Near Field 12.5-17.5 m C:Chl Ratios (ug C/ug Chl)
Far Field 12.5-17.5 m C:Chl Ratios (ug C/ug Chl)
1000
100
10
1
0.1
1
10
20
50
80
90
99
99.9
Probability
Sensitivity (F = 0.22)
LEGEND
Data
Model

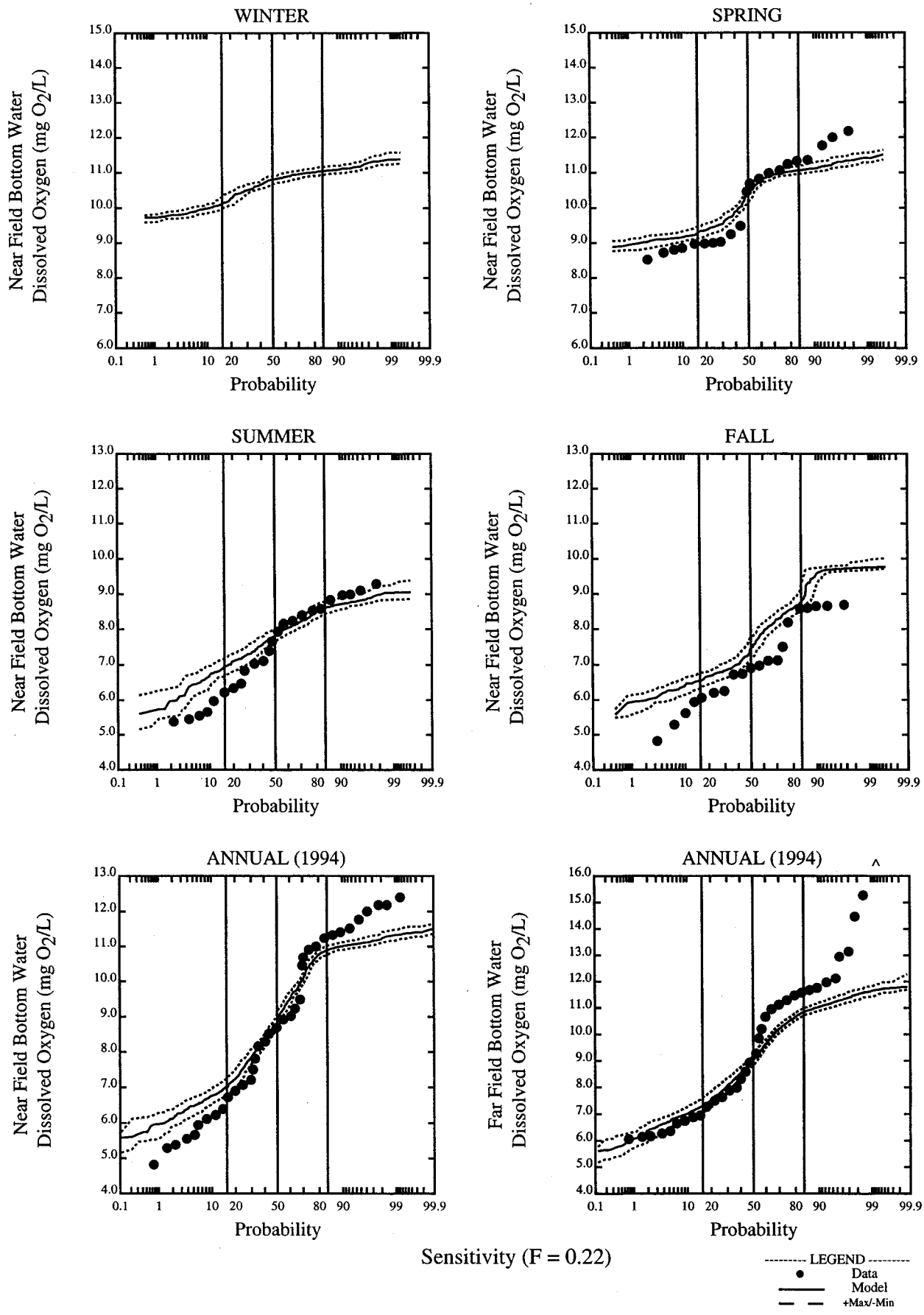

WINTER
SPRING
SUMMER
FALL
ANNUAL (1994)
ANNUAL (1994)
Near Field Surface DIN (mg/L)
Far Field Surface DIN (mg/L)
0.4
0.1
0.01
0.001
0.0001
0.1 1 10 20 50 80 90 99 99.9
Probability
Sensitivity (F = 0.22)
LEGEND
Data
Model
+Max/-Min


WINTER
SPRING
SUMMER
FALL
ANNUAL (1994)
ANNUAL (1994)
Near Field Surface PO4 (mg/L)
Far Field Surface PO4 (mg/L)
0.1
0.01
0.001
0.0001
0.1 1 10 20 50 80 90 99 99.9
Probability
Sensitivity (F = 0.22)
LEGEND
Data
Model
+Max/-Min

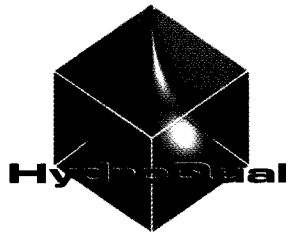

WINTER
SPRING
SUMMER
FALL
ANNUAL (1994)
ANNUAL (1994)
Near Field Surface DSi (mg/L)
Far Field Surface DSi (mg/L)
Probability
1
0.1
0.01
0.001
0.0001
0.1
1
10
20
50
80
90
99
99.9
Sensitivity (F = 0.22)
LEGEND
Data
Model
+Max/-Min


WINTER
SPRING
SUMMER
FALL
ANNUAL (1994)
ANNUAL (1994)
Near Field Surface Water Dissolved Oxygen (mg O2/L)
Near Field Surface Water Dissolved Oxygen (mg O2/L)
Near Field Surface Water Dissolved Oxygen (mg O2/L)
Near Field Surface Water Dissolved Oxygen (mg O2/L)
Near Field Surface Water Dissolved Oxygen (mg O2/L)
Far Field Surface Water Dissolved Oxygen (mg O2/L)
Probability
Probability
Probability
Probability
Probability
Probability
0.1 1 10 20 50 80 90 99 99.9
Sensitivity (F = 0.22)
LEGEND
Data
Model


WINTER
SPRING
SUMMER
FALL
ANNUAL (1994)
ANNUAL (1994)
Near Field 12.5-17.5m Dissolved Oxygen (mg O2/L)
Far Field 12.5-17.5m Dissolved Oxygen (mg O2/L)
15.0
14.0
13.0
12.0
11.0
10.0
9.0
8.0
7.0
6.0
0.1 1 10 20 50 80 90 99 99.9
Probability
Sensitivity (F = 0.22)
LEGEND
Data
Model

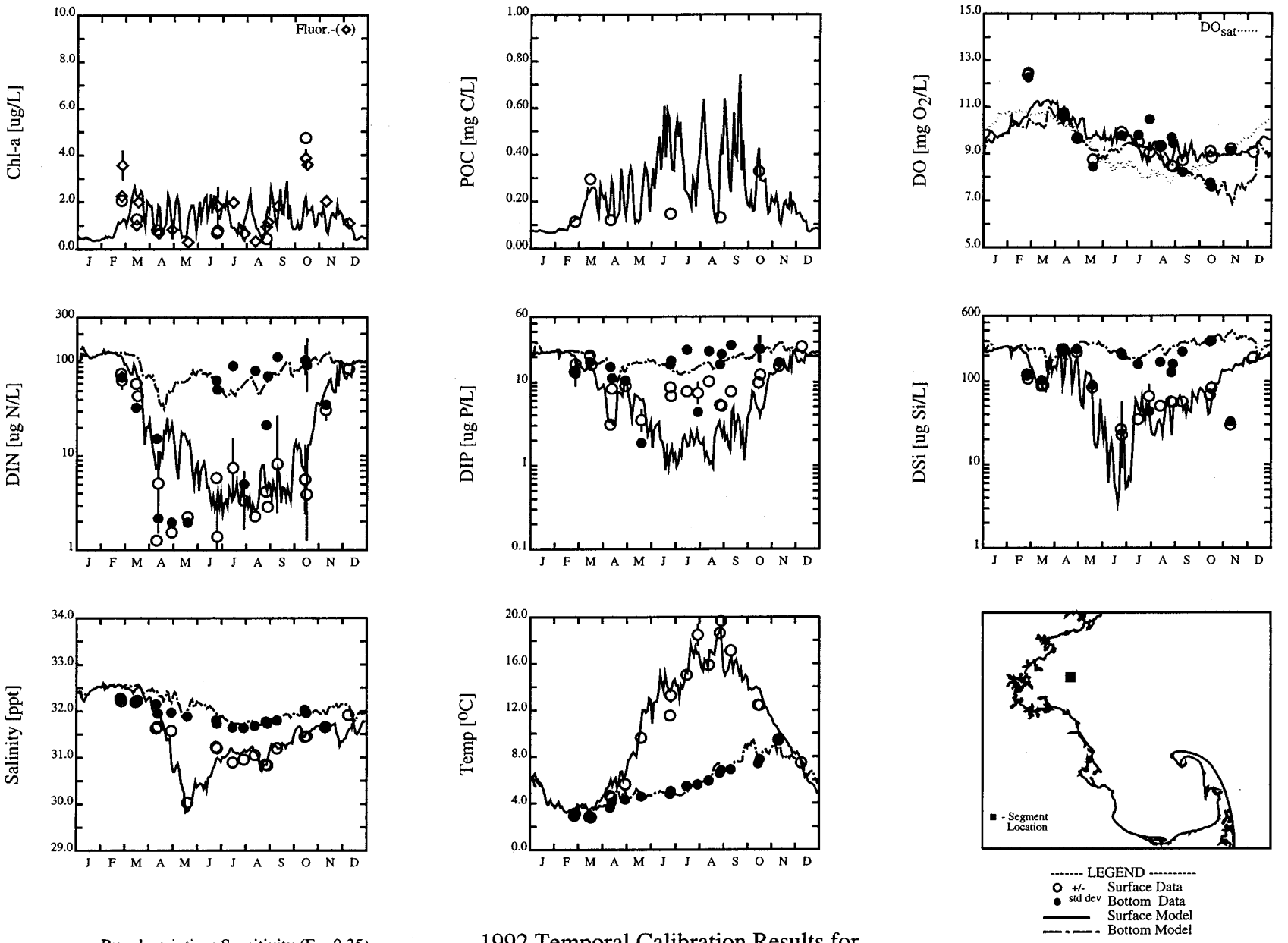

WINTER
SPRING
SUMMER
FALL
ANNUAL (1994)
ANNUAL (1994)
Near Field Bottom Water Dissolved Oxygen (mg O2/L)
Far Field Bottom Water Dissolved Oxygen (mg O2/L)
Probability
0.1 1 10 20 50 80 90 99 99.9
Sensitivity (F = 0.22)
LEGEND
Data
Model
+Max/-Min

APPENDIX A.4
F = 0.35 SENSITIVITY ANALYSIS



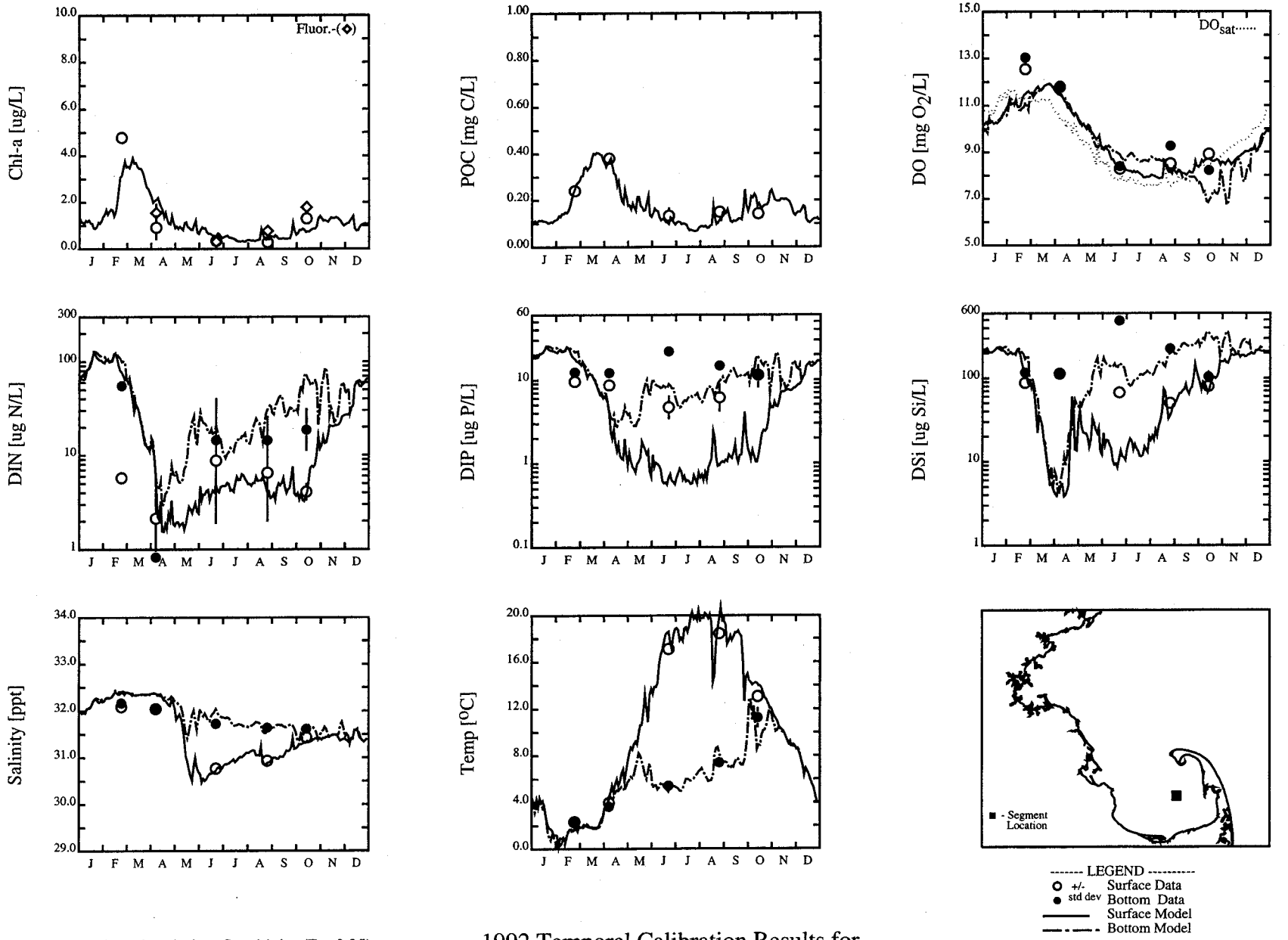
Environmental

Engineers & Scientists



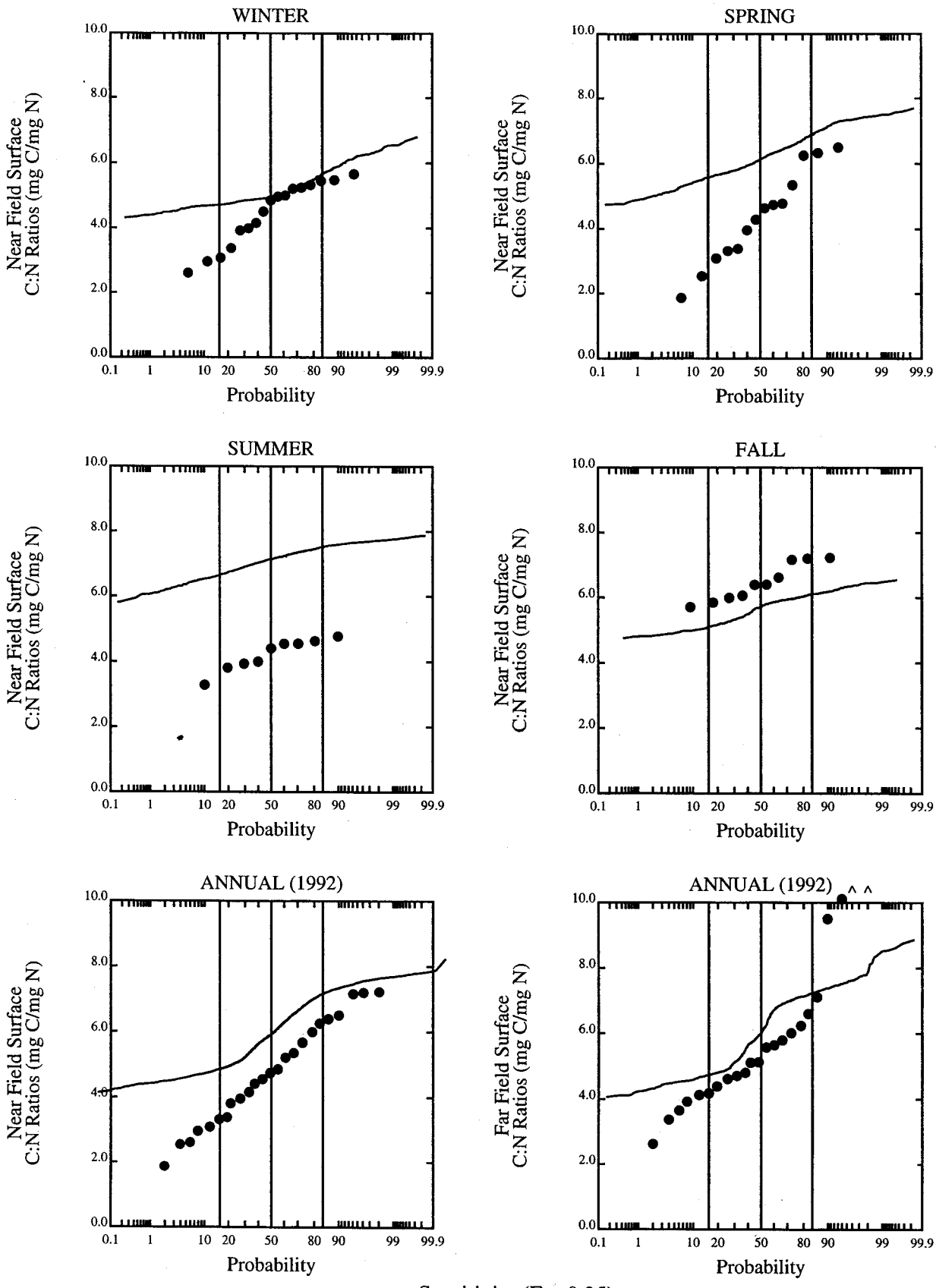
Run description: Sensitivity (F = 0.35)

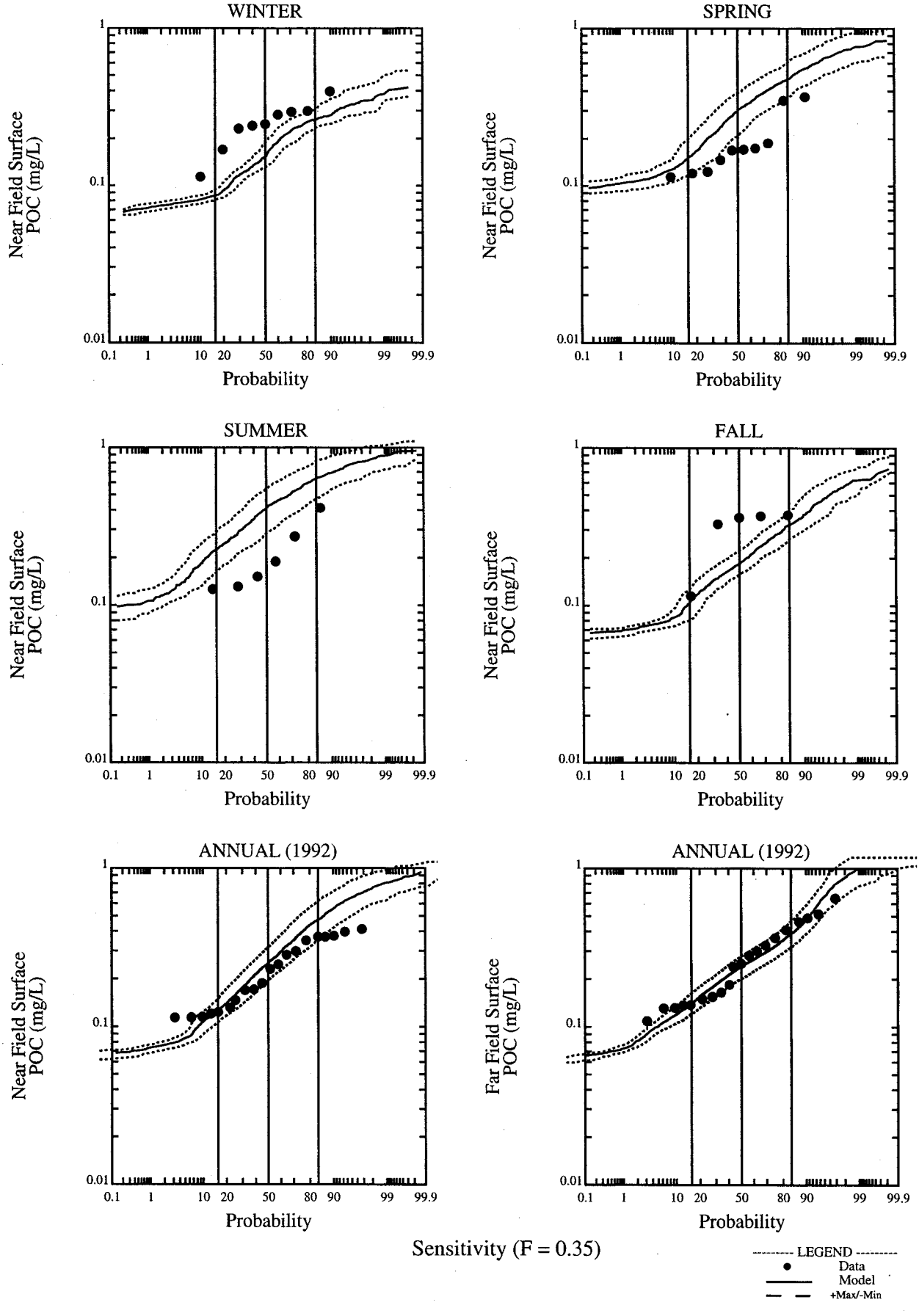
1992 Temporal Calibration Results for
Grid Cell (11,18) Vs Data Station N16P,N17,N21

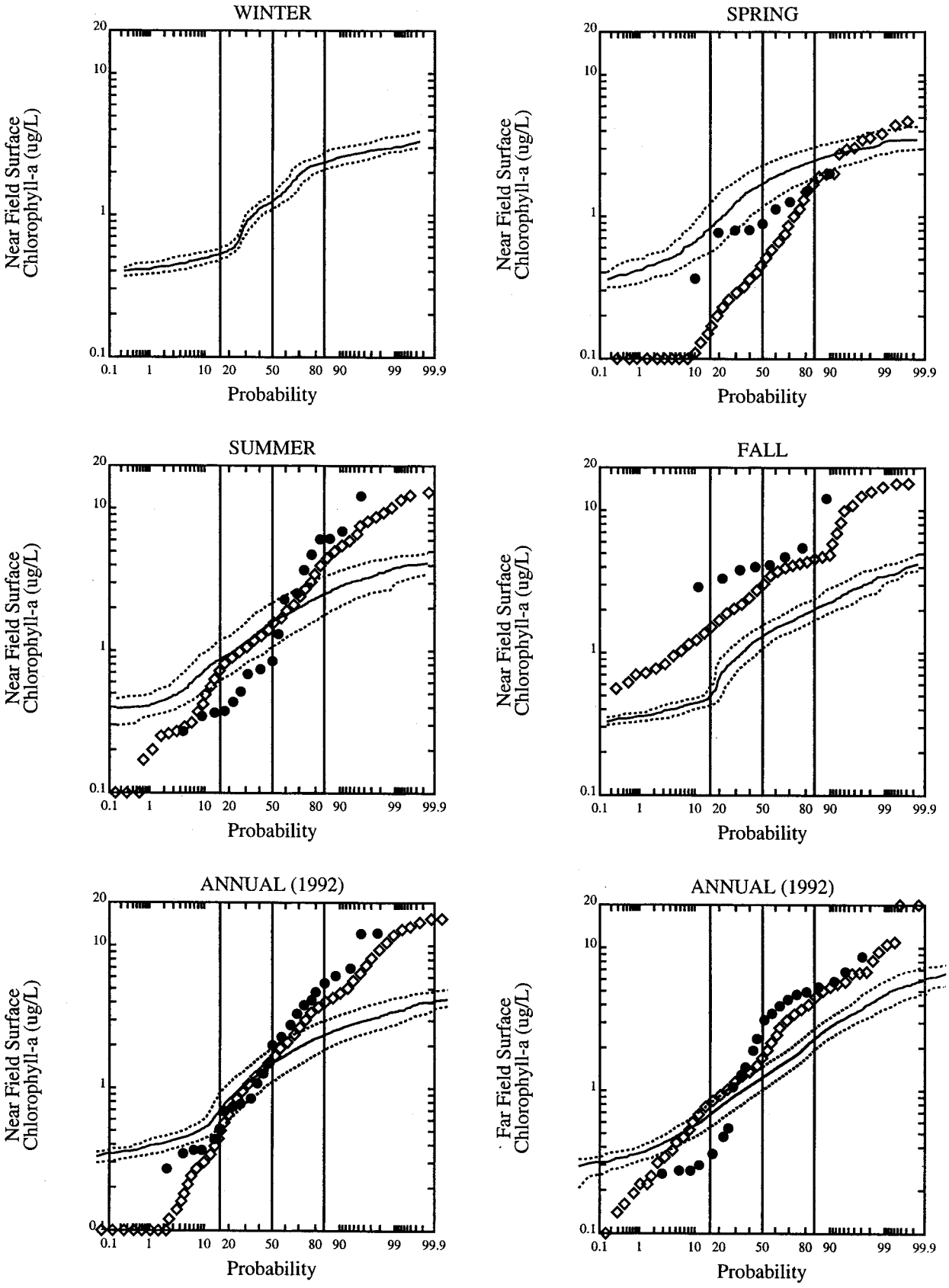


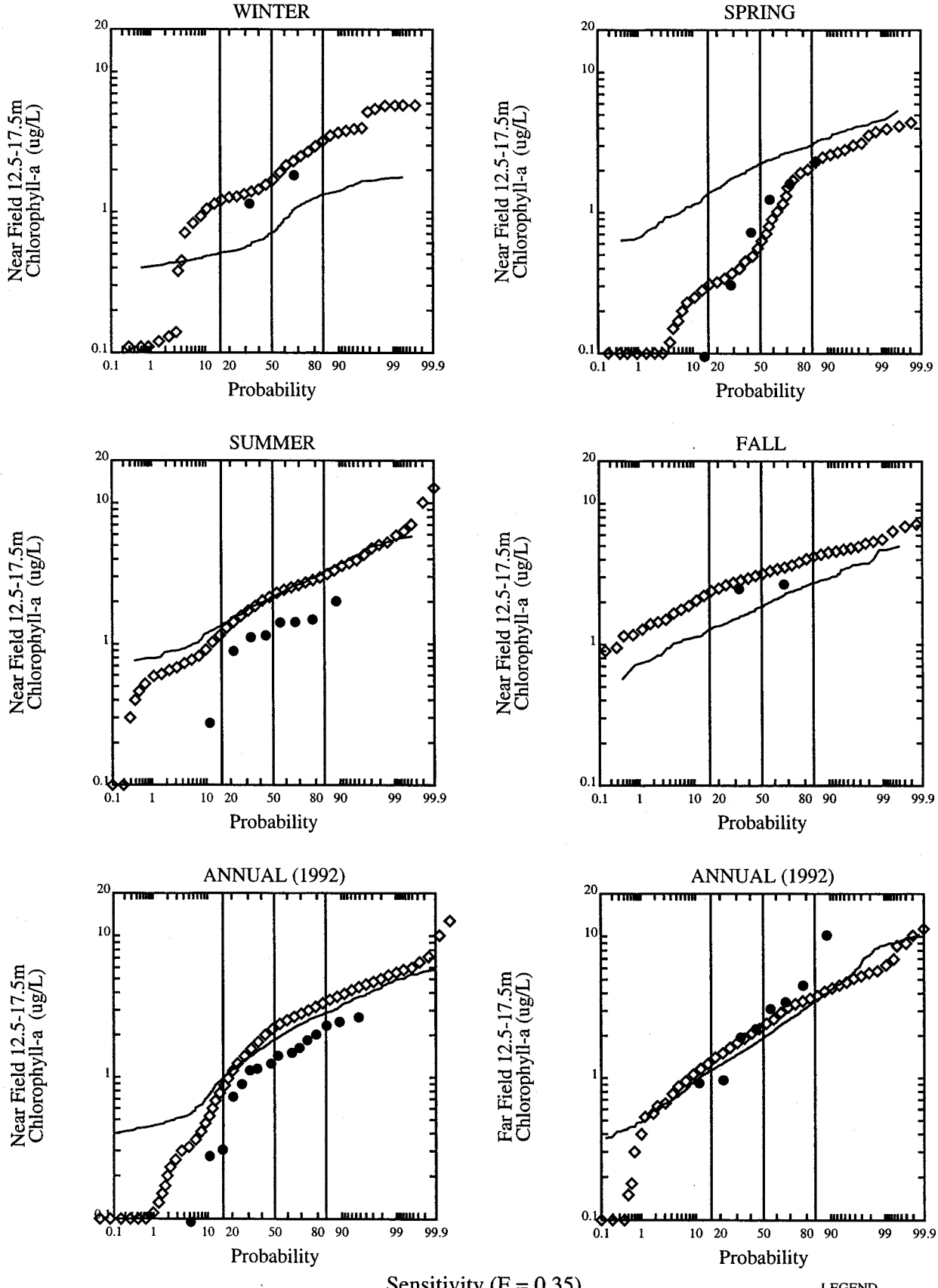
Run description: Sensitivity (F = 0.35)

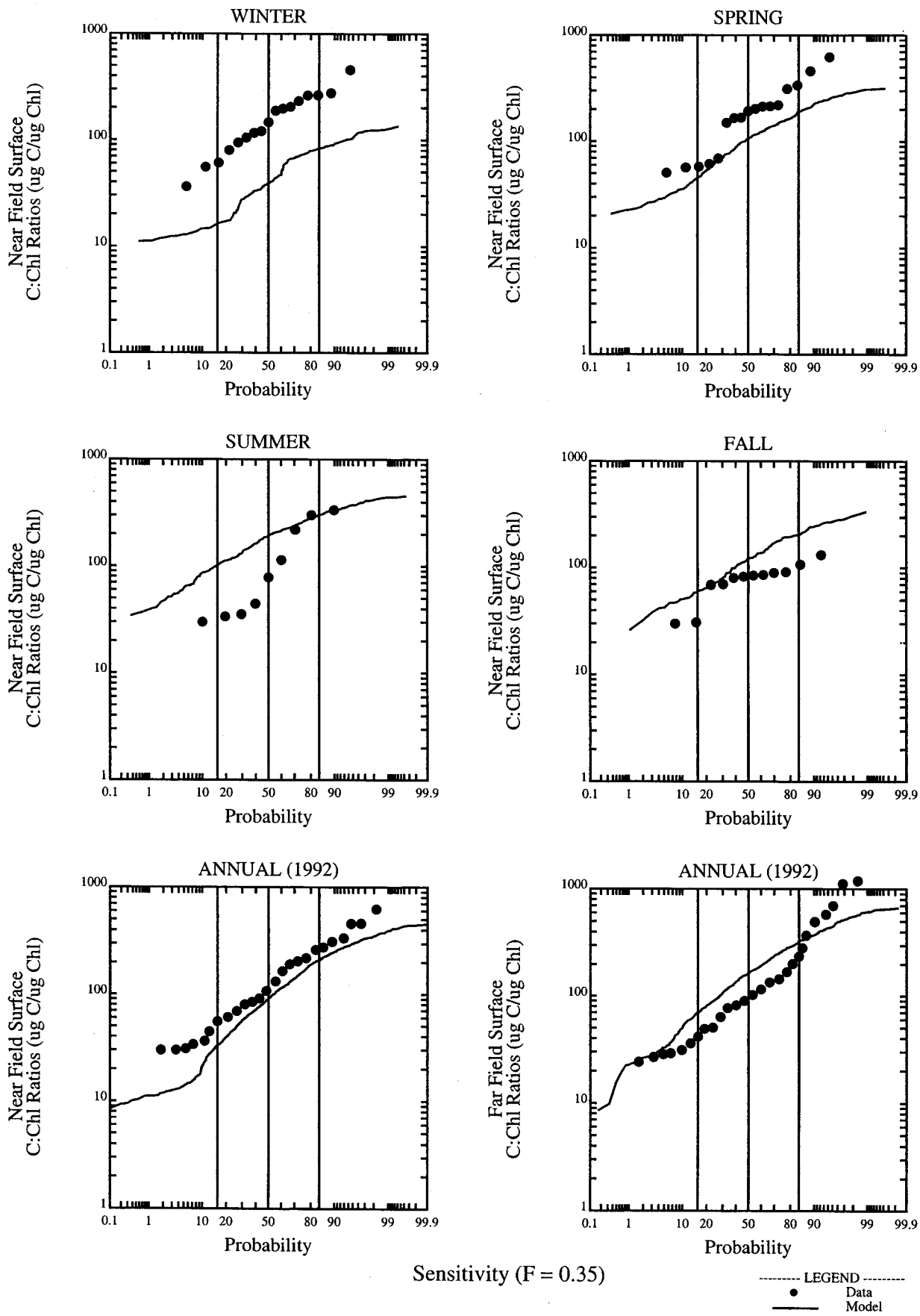
1992 Temporal Calibration Results for Grid Cell (13,4) Vs Data Station F02P

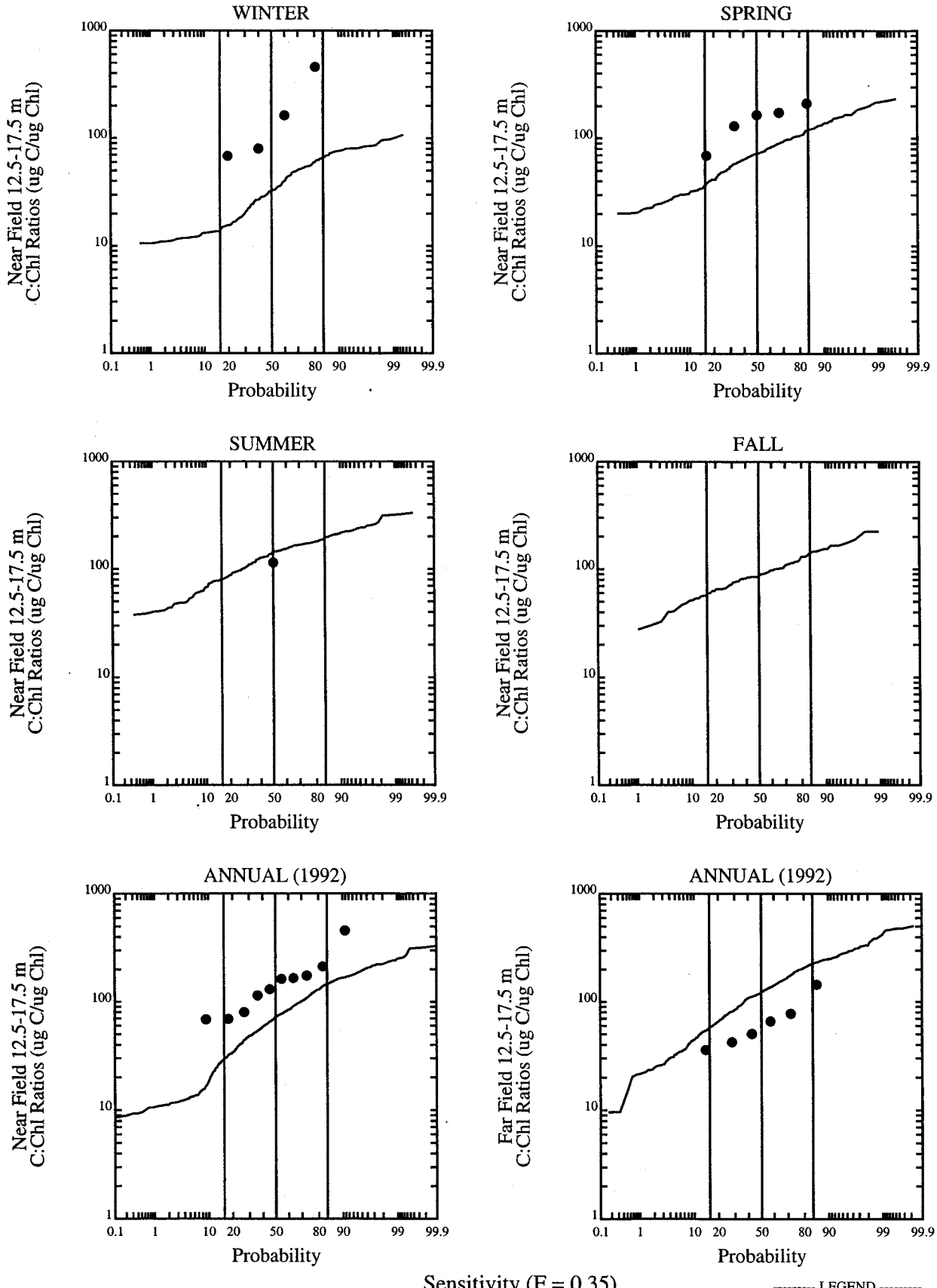

WINTER
SPRING
SUMMER
FALL
ANNUAL (1992)
ANNUAL (1992) ^ ^
Near Field Surface C:N Ratios (mg C/mg N)
Far Field Surface C:N Ratios (mg C/mg N)
10.0
8.0
6.0
4.0
2.0
0.0
0.1 1 10 20 50 80 90 99 99.9
Probability
Sensitivity (F = 0.35)
LEGEND
Data
Model

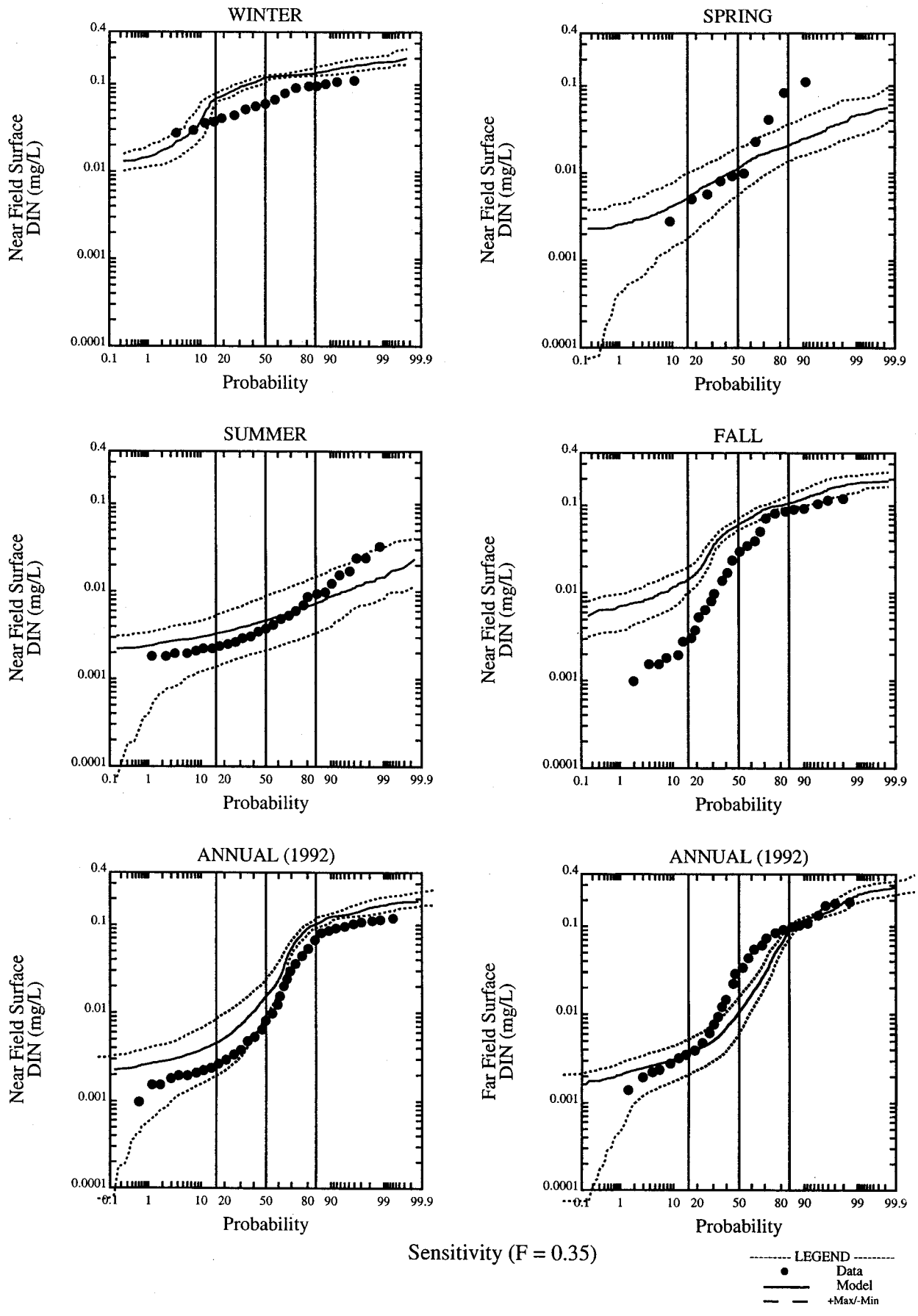

WINTER
SPRING
SUMMER
FALL
ANNUAL (1992)
ANNUAL (1992)
Near Field Surface POC (mg/L)
Far Field Surface POC (mg/L)
Probability
1
0.1
0.01
0.1 1 10 20 50 80 90 99 99.9
Sensitivity (F = 0.35)
LEGEND
Data
Model
+Max/-Min

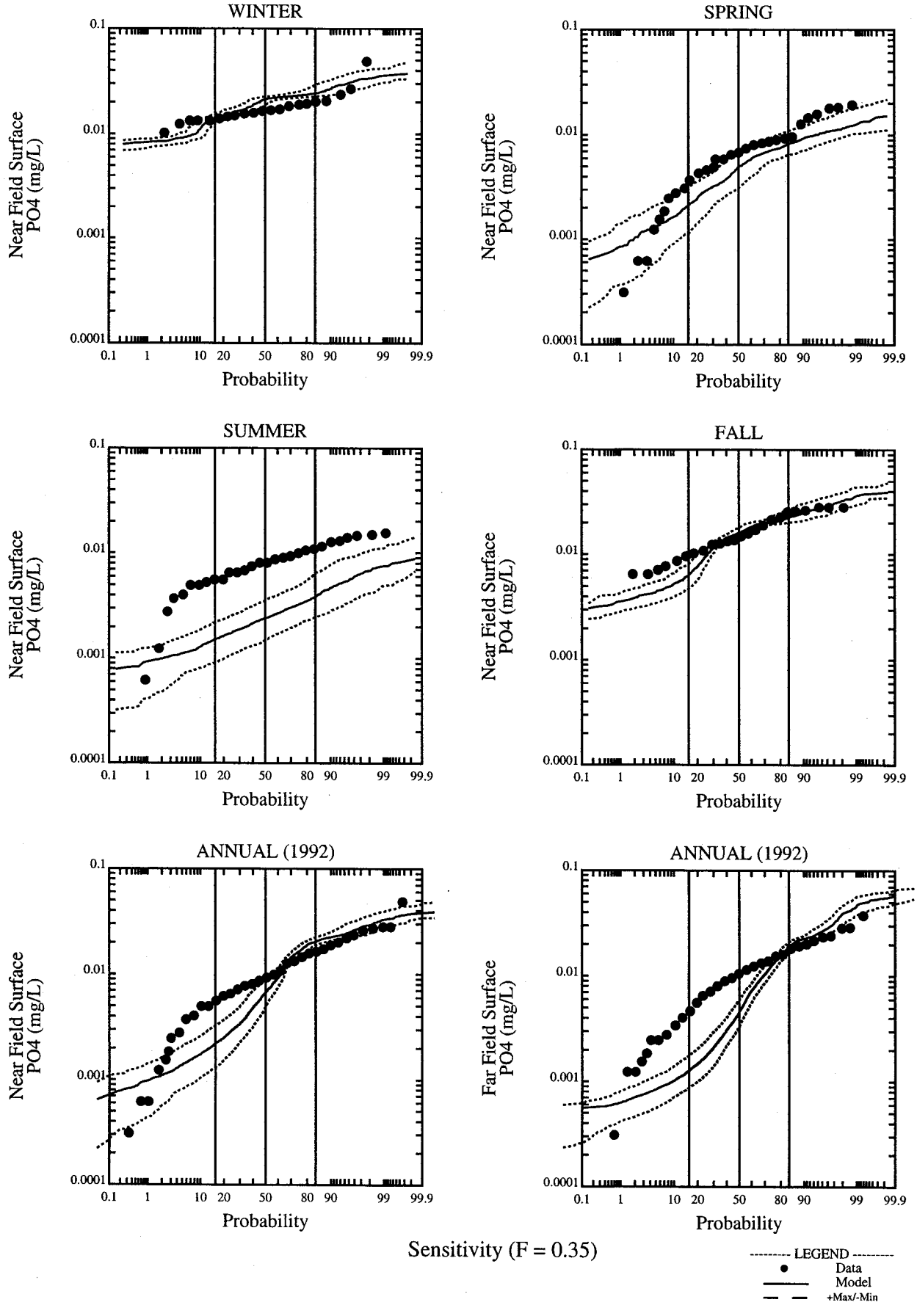

WINTER
SPRING
SUMMER
FALL
ANNUAL (1992)
ANNUAL (1992)
Near Field Surface Chlorophyll-a (ug/L)
Far Field Surface Chlorophyll-a (ug/L)
Probability
0.1 1 10 20 50 80 90 99 99.9
20 10 1 0.1
Sensitivity (F = 0.35)
LEGEND
Discrete Chl-a
Fluorometric Chl-a
Model

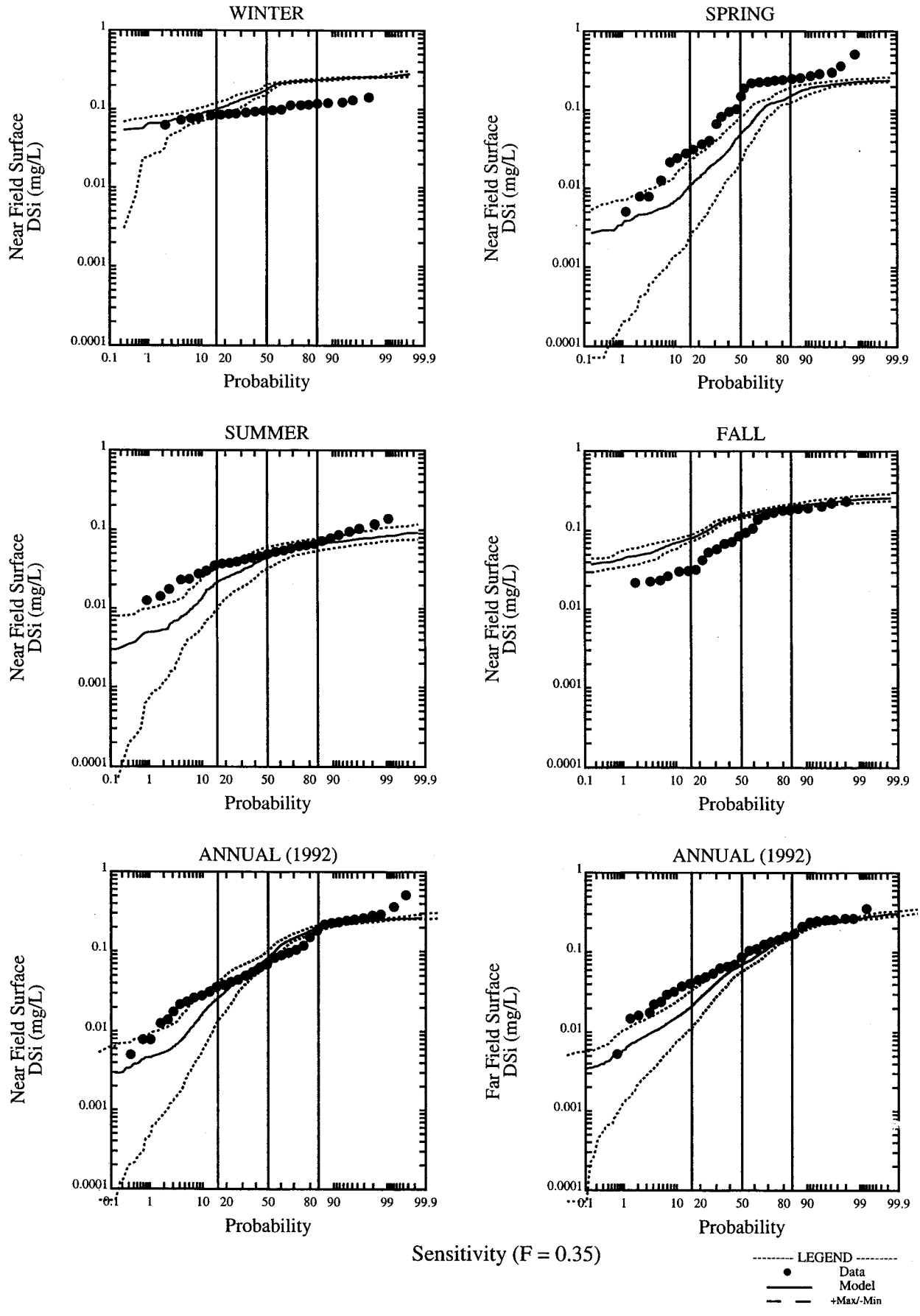

WINTER
SPRING
SUMMER
FALL
ANNUAL (1992)
ANNUAL (1992)
Near Field 12.5-17.5m Chlorophyll-a (ug/L)
Far Field 12.5-17.5m Chlorophyll-a (ug/L)
Probability
0.1 1 10 20 50 80 90 99 99.9
20 10 1 0.1
Sensitivity (F = 0.35)
LEGEND
Discrete Chl-a
Fluorometric Chl-a
Model

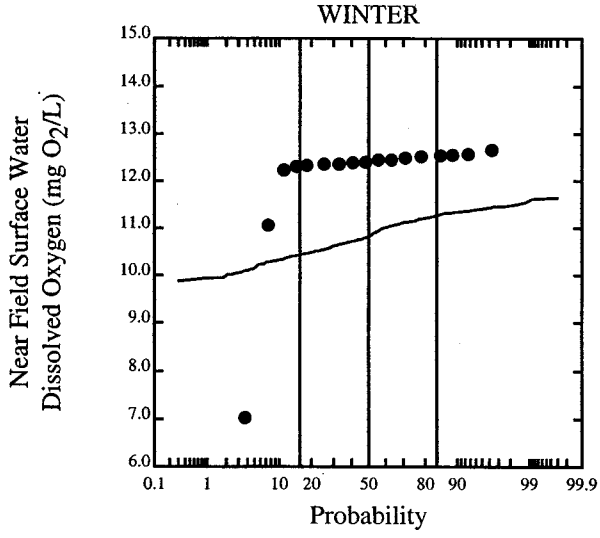

WINTER
SPRING
SUMMER
FALL
ANNUAL (1992)
ANNUAL (1992)
Near Field Surface C:Chl Ratios (ug C/ug Chl)
Far Field Surface C:Chl Ratios (ug C/ug Chl)
1000
100
10
1
0.1
1
10
20
50
80
90
99
99.9
Probability
Sensitivity (F = 0.35)
LEGEND
Data
Model

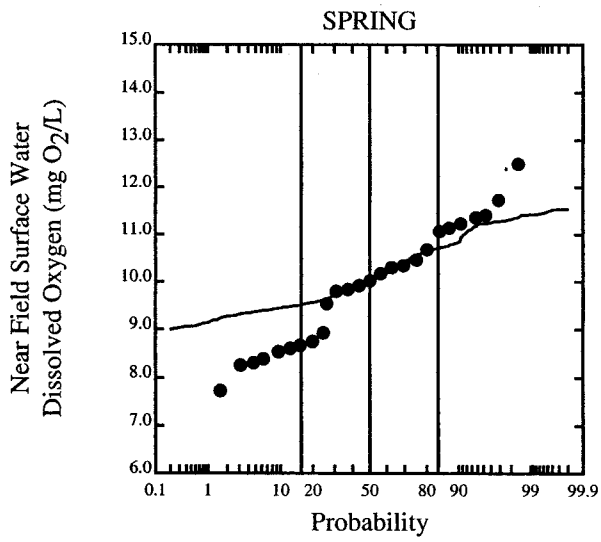

WINTER
SPRING
SUMMER
FALL
ANNUAL (1992)
ANNUAL (1992)
Near Field 12.5-17.5 m C:Chl Ratios (ug C/ug Chl)
Far Field 12.5-17.5 m C:Chl Ratios (ug C/ug Chl)
1000
100
10
1
0.1
1
10
20
50
80
90
99
99.9
Probability
Sensitivity (F = 0.35)
LEGEND
Data
Model

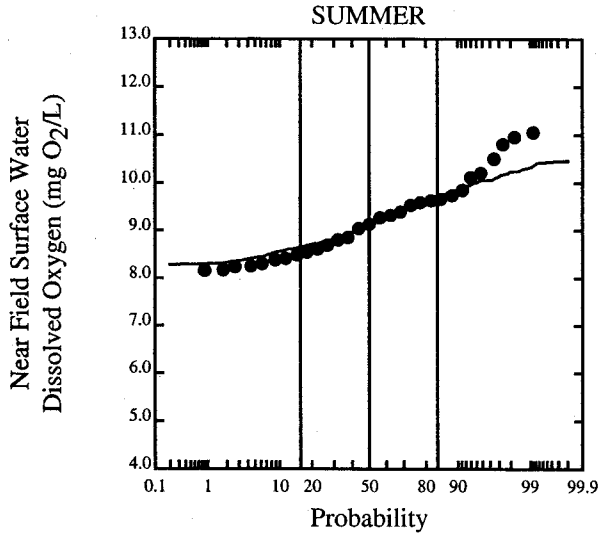

WINTER
SPRING
SUMMER
FALL
ANNUAL (1992)
ANNUAL (1992)
Near Field Surface DIN (mg/L)
Far Field Surface DIN (mg/L)
0.4
0.1
0.01
0.001
0.0001
0.1 1 10 20 50 80 90 99 99.9
Probability
Sensitivity (F = 0.35)
LEGEND
Data
Model
+Max/-Min

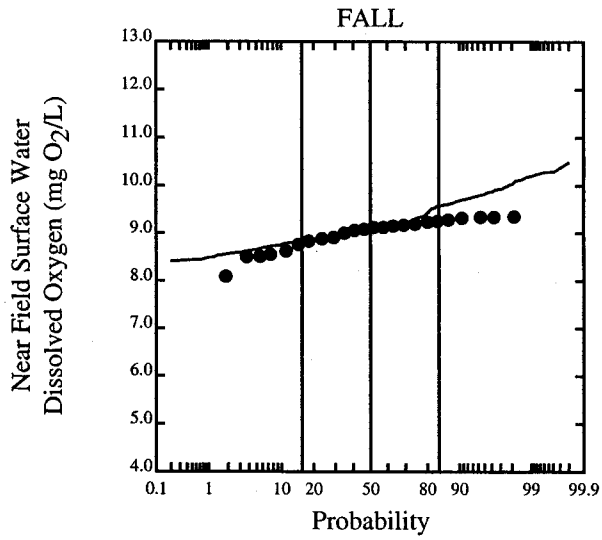

WINTER
SPRING
SUMMER
FALL
ANNUAL (1992)
ANNUAL (1992)
Near Field Surface PO4 (mg/L)
Far Field Surface PO4 (mg/L)
0.1
0.01
0.001
0.0001
0.1 1 10 20 50 80 90 99 99.9
Probability
Sensitivity (F = 0.35)
LEGEND
Data
Model
+Max/-Min

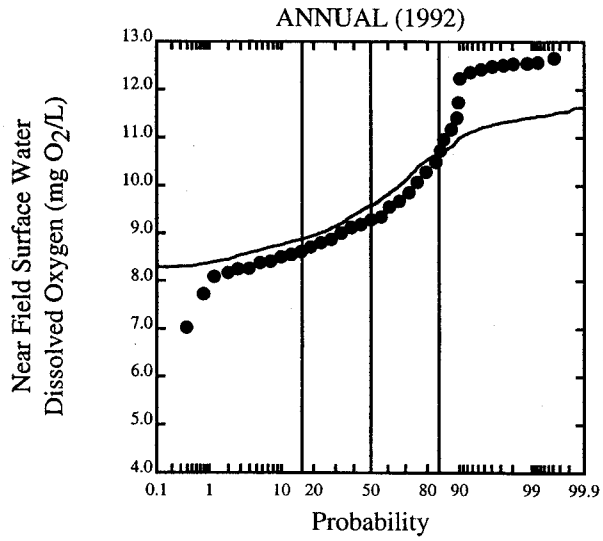

WINTER
SPRING
SUMMER
FALL
ANNUAL (1992)
ANNUAL (1992)
Near Field Surface DSi (mg/L)
Far Field Surface DSi (mg/L)
1
0.1
0.01
0.001
0.0001
0.1 1 10 20 50 80 90 99 99.9
Probability
Sensitivity (F = 0.35)
LEGEND
Data
Model
+Max/-Min

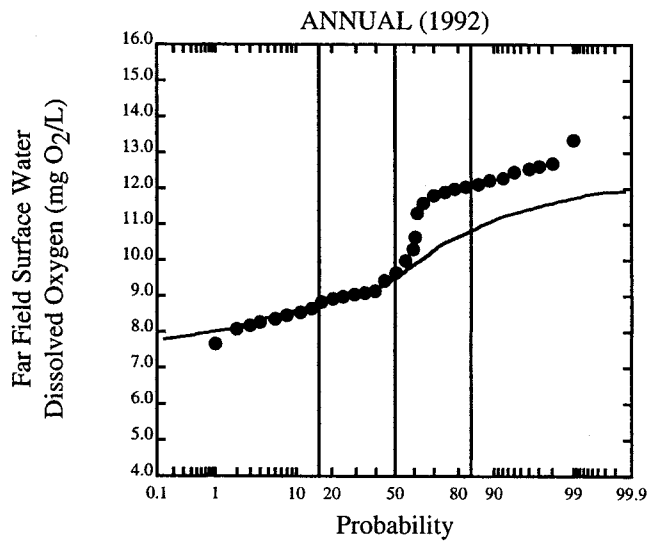






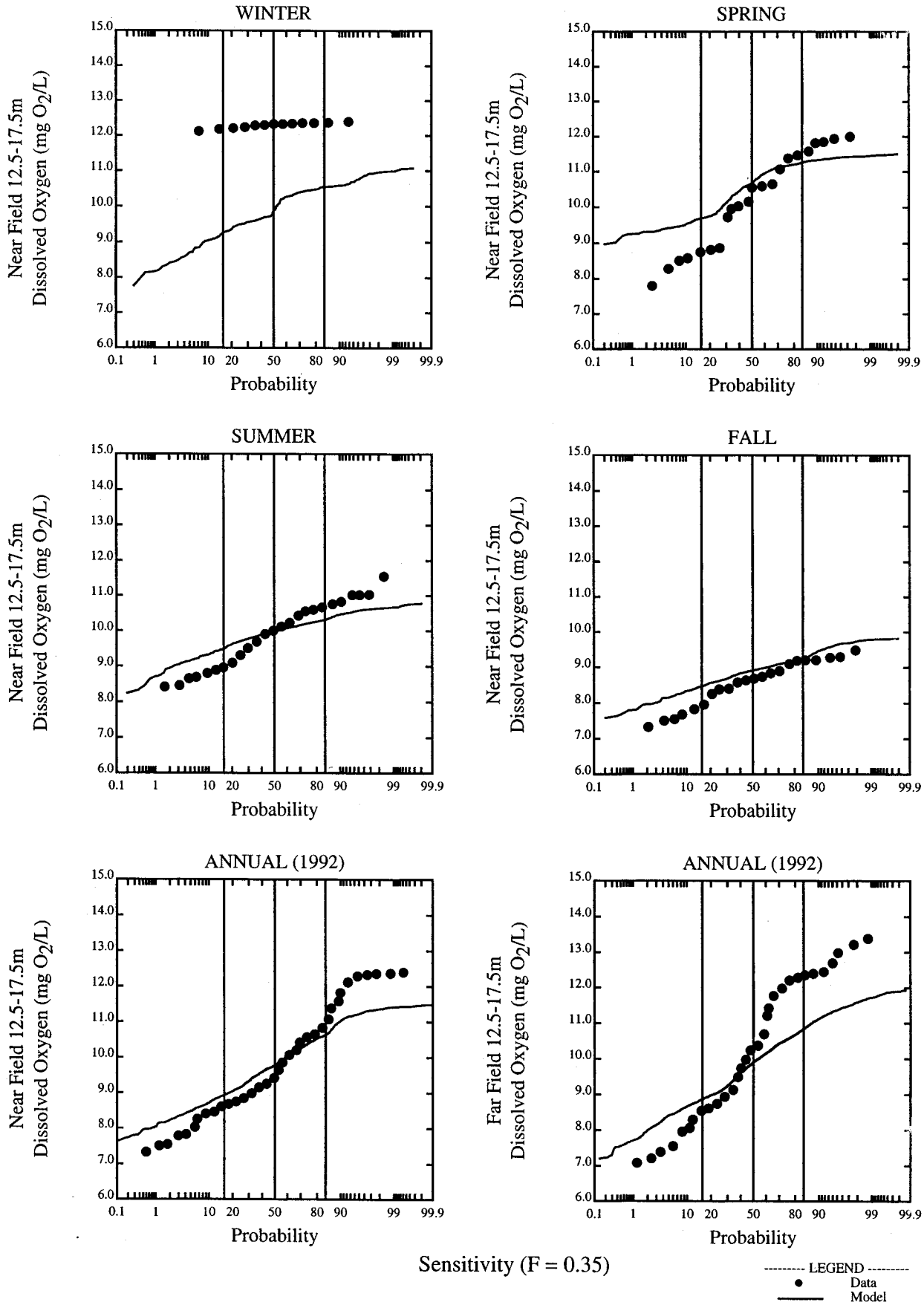


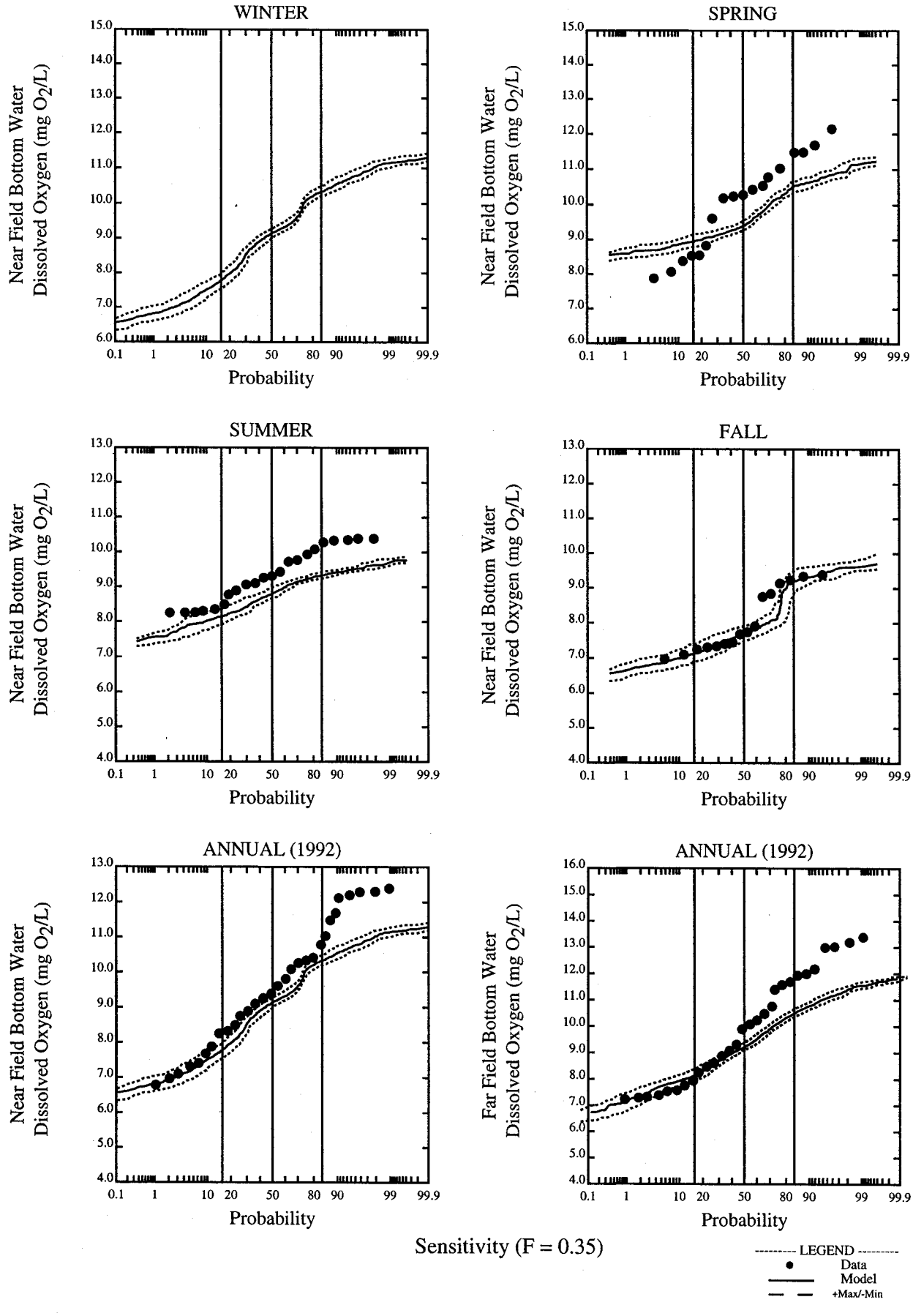


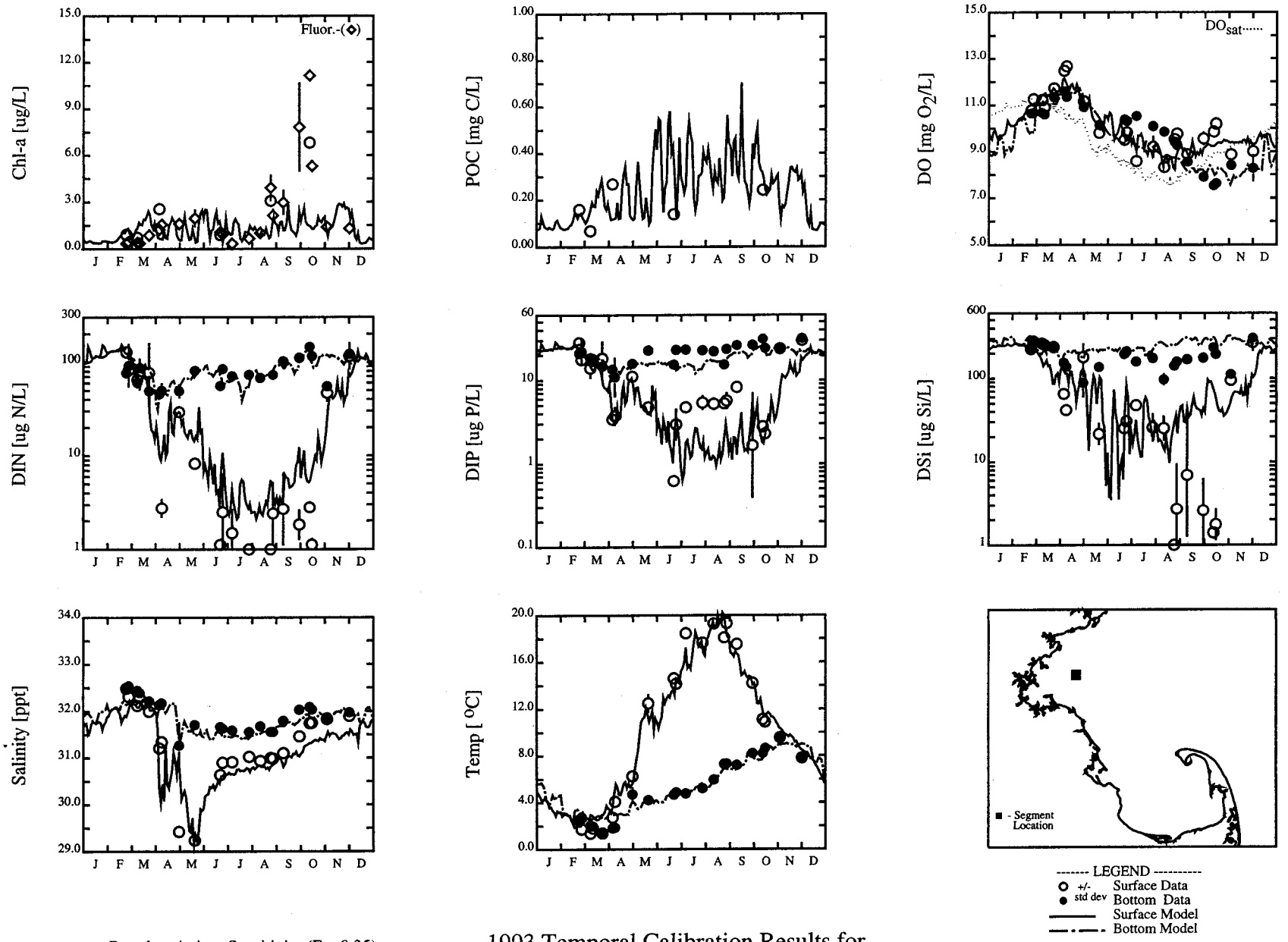


Sensitivity (F = 0.35)

--------- LEGEND ---------
Data
Model

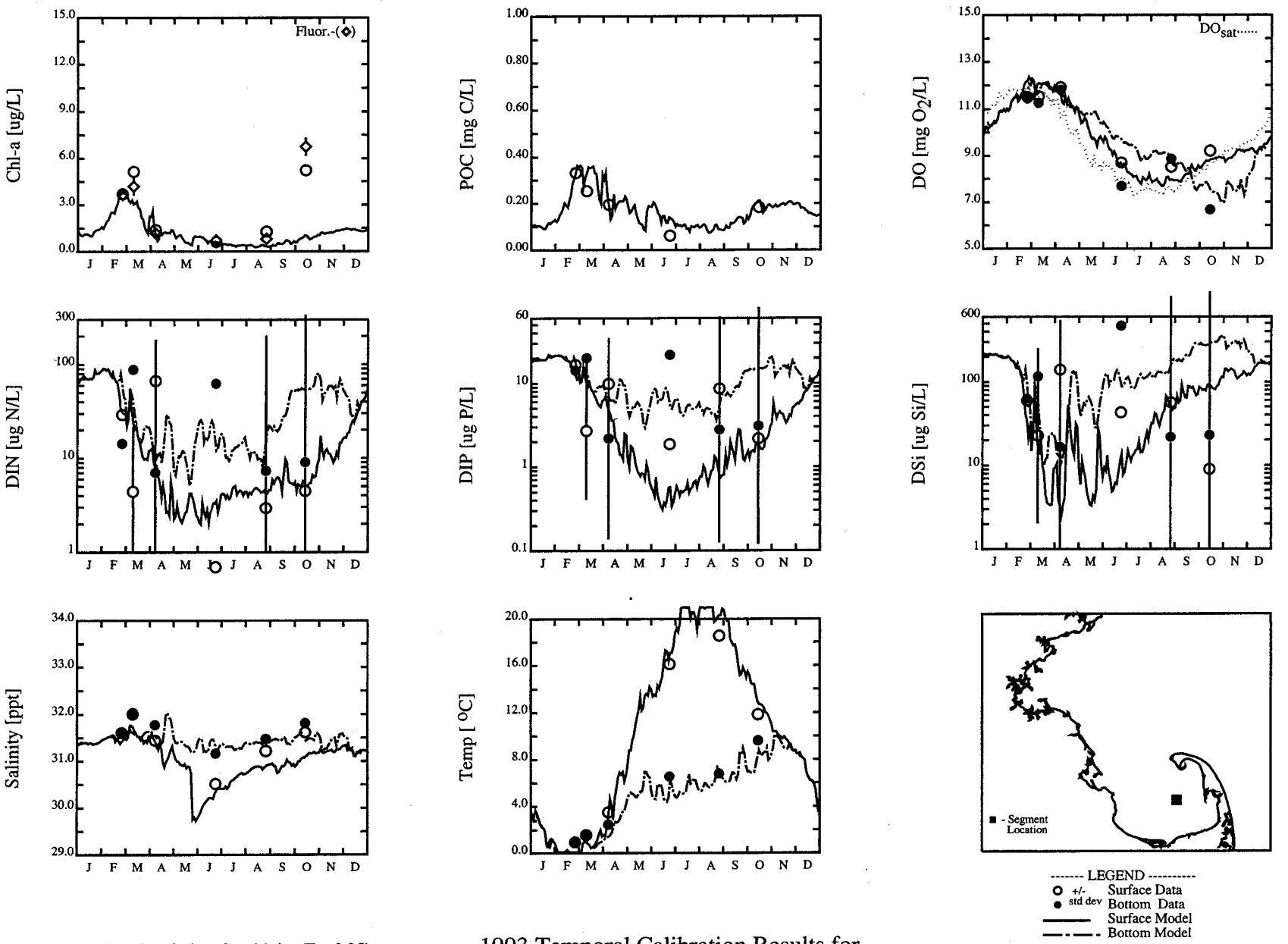

WINTER
SPRING
SUMMER
FALL
ANNUAL (1992)
ANNUAL (1992)
Near Field 12.5-17.5m Dissolved Oxygen (mg O2/L)
Far Field 12.5-17.5m Dissolved Oxygen (mg O2/L)
15.0
14.0
13.0
12.0
11.0
10.0
9.0
8.0
7.0
6.0
0.1 1 10 20 50 80 90 99 99.9
Probability
Sensitivity (F = 0.35)
LEGEND
Data
Model


WINTER
SPRING
SUMMER
FALL
ANNUAL (1992)
ANNUAL (1992)
Near Field Bottom Water Dissolved Oxygen (mg O2/L)
Far Field Bottom Water Dissolved Oxygen (mg O2/L)
Probability
0.1 1 10 20 50 80 90 99 99.9
Sensitivity (F = 0.35)
LEGEND
Data
Model
+Max/-Min



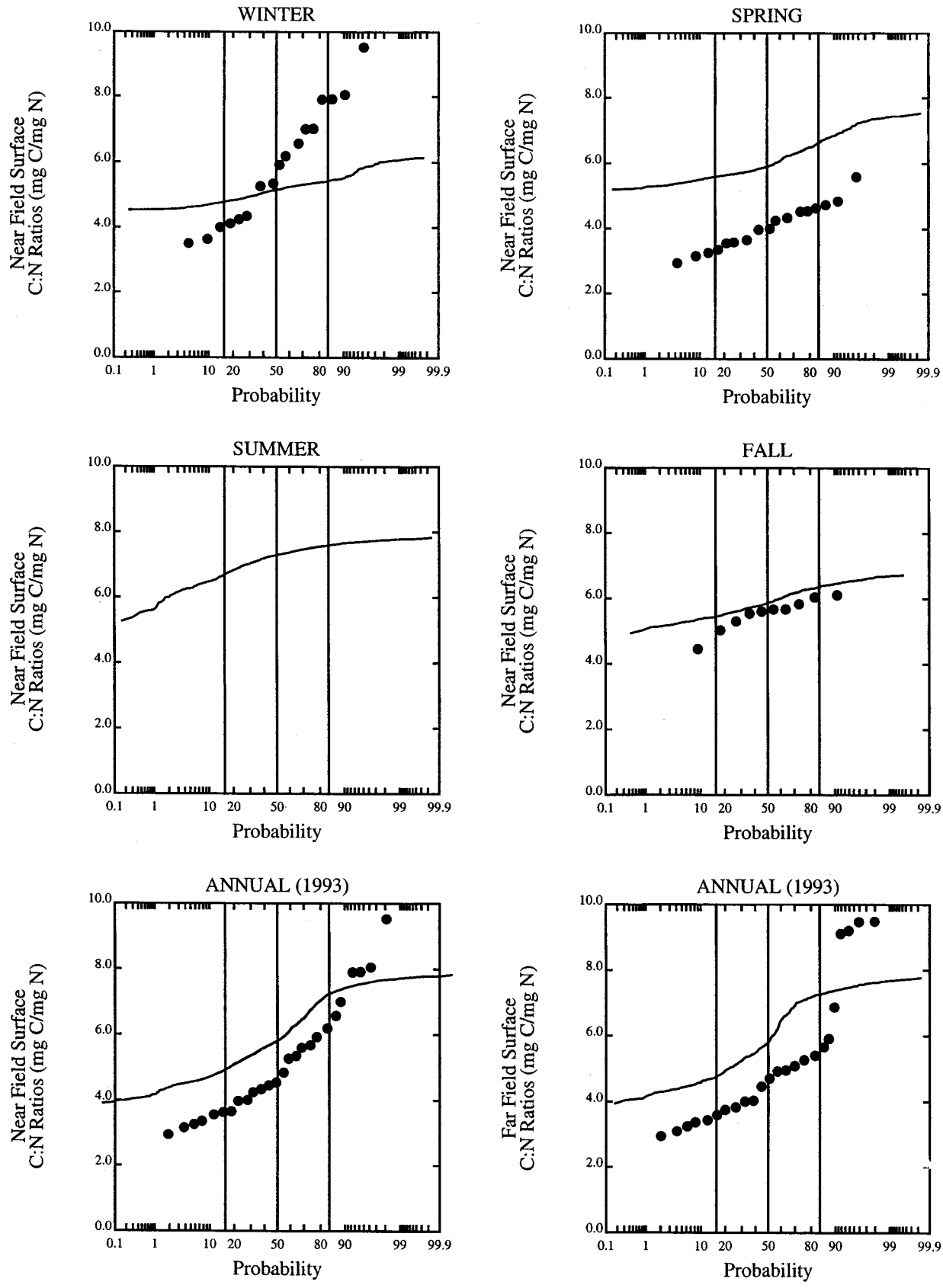
Run description: Sensitivity (F = 0.35)

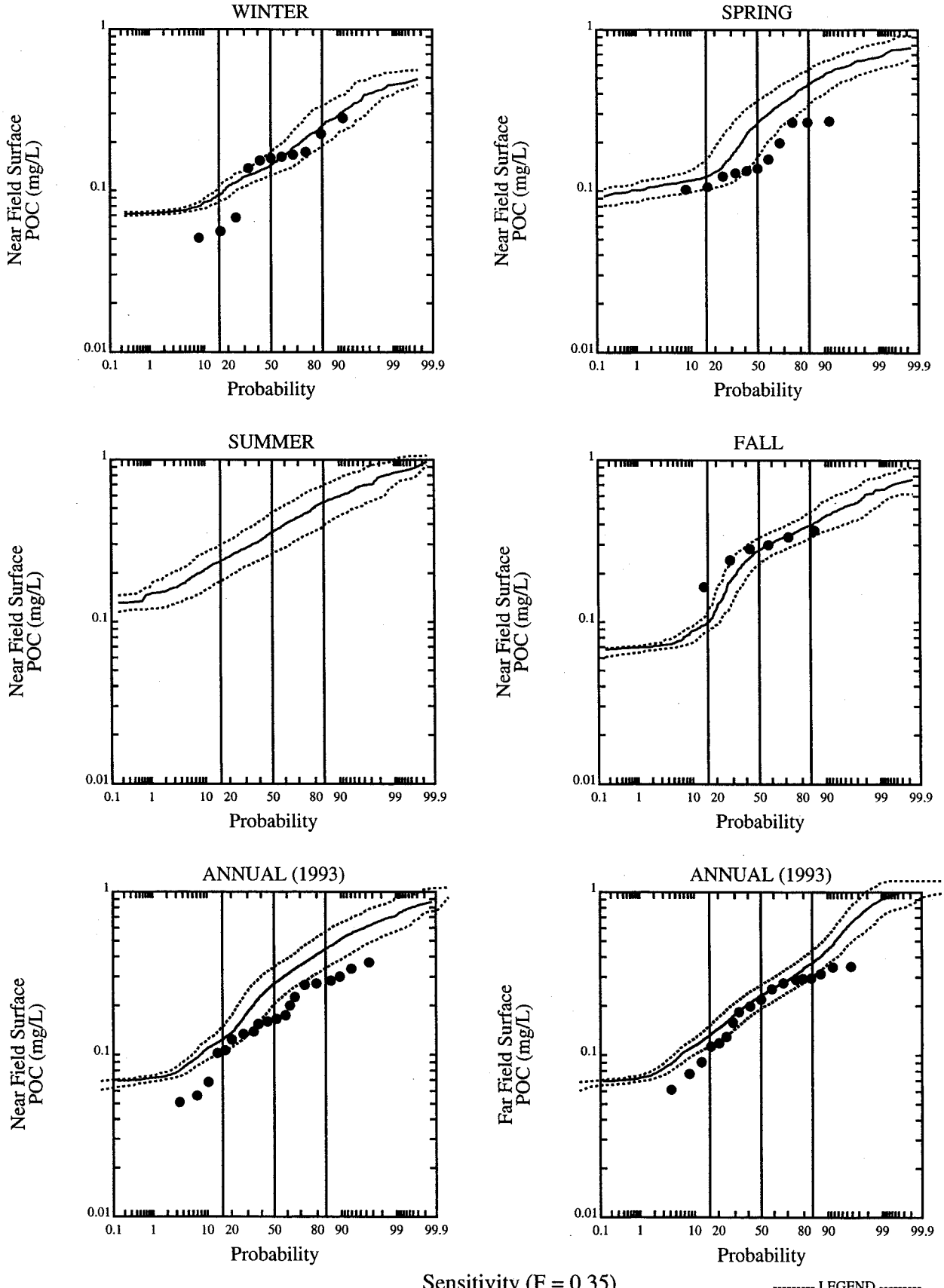
1993 Temporal Calibration Results for
Grid Cell (11,18) Vs Data Station N16P,N17,N21

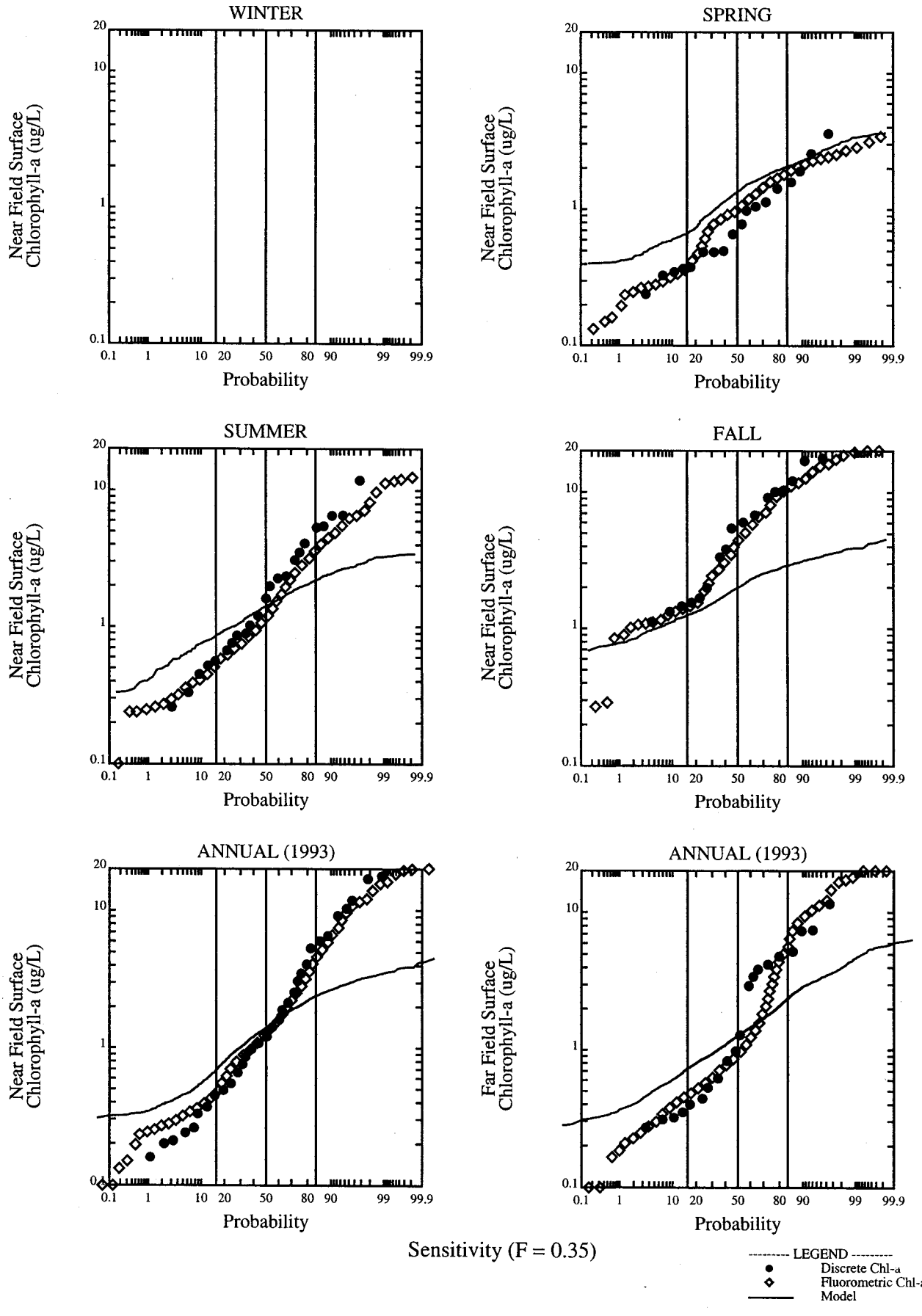


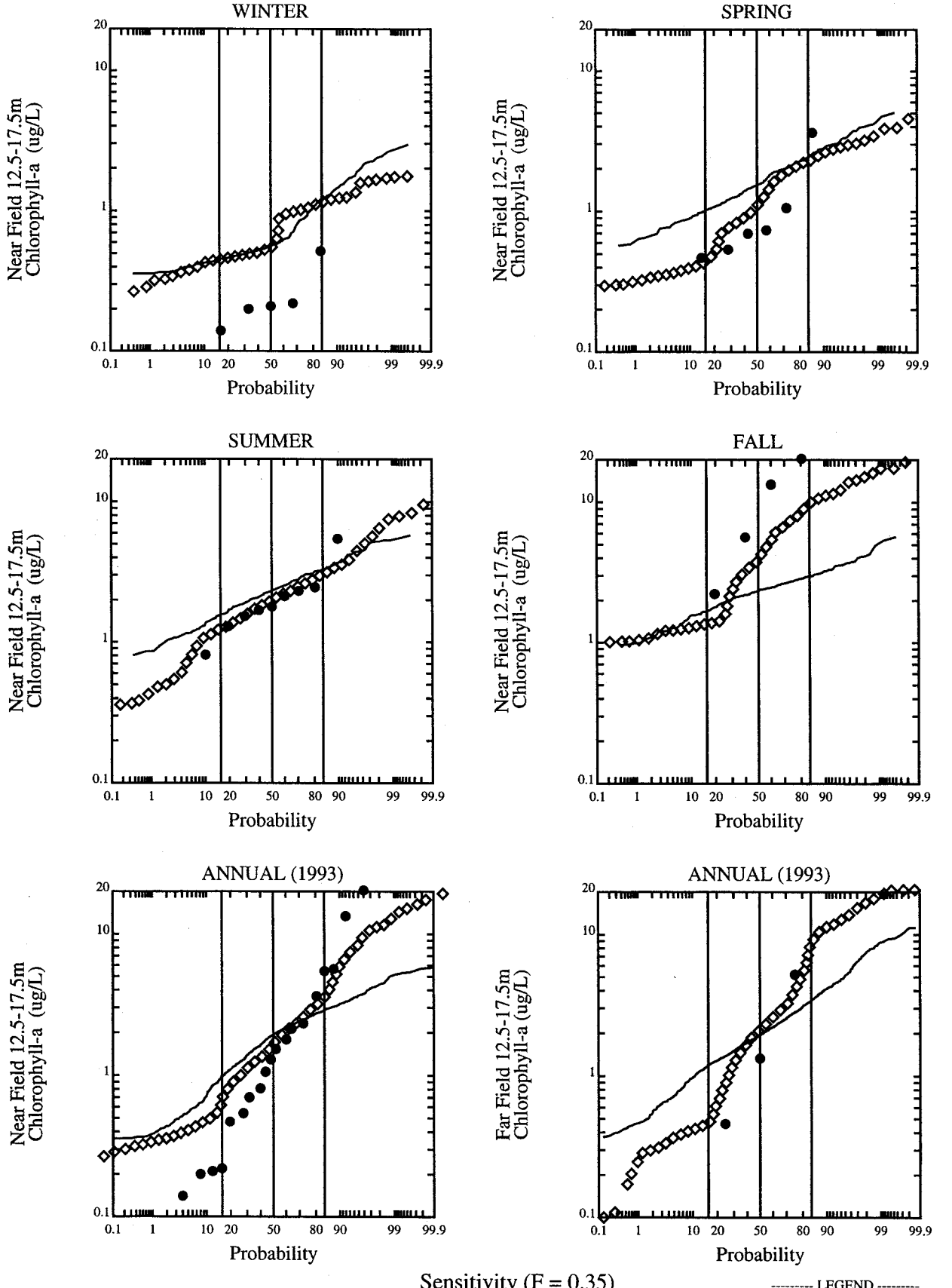
Run description: Sensitivity (F = 0.35)

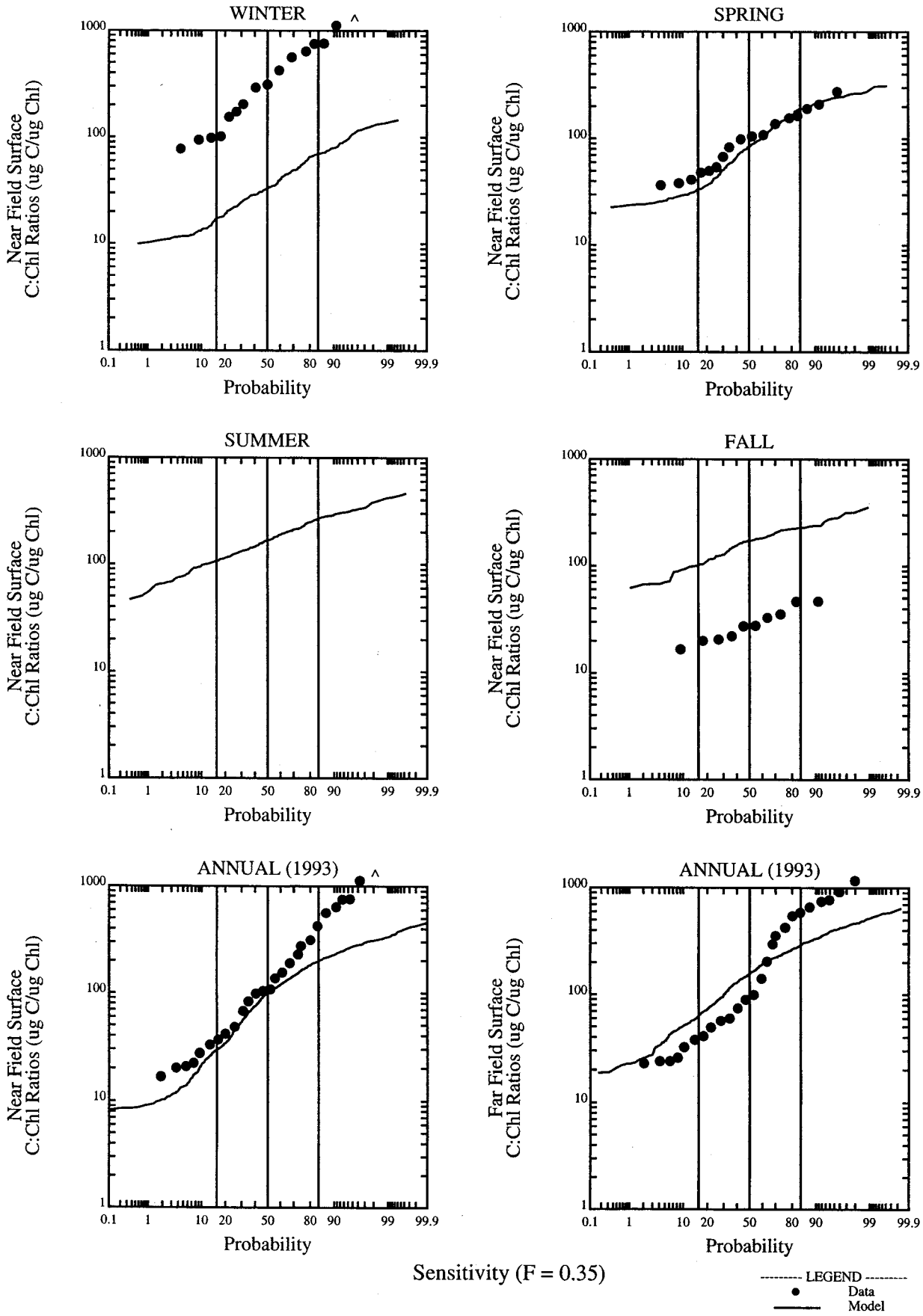
1993 Temporal Calibration Results for
Grid Cell (13,4) Vs Data Station F02P

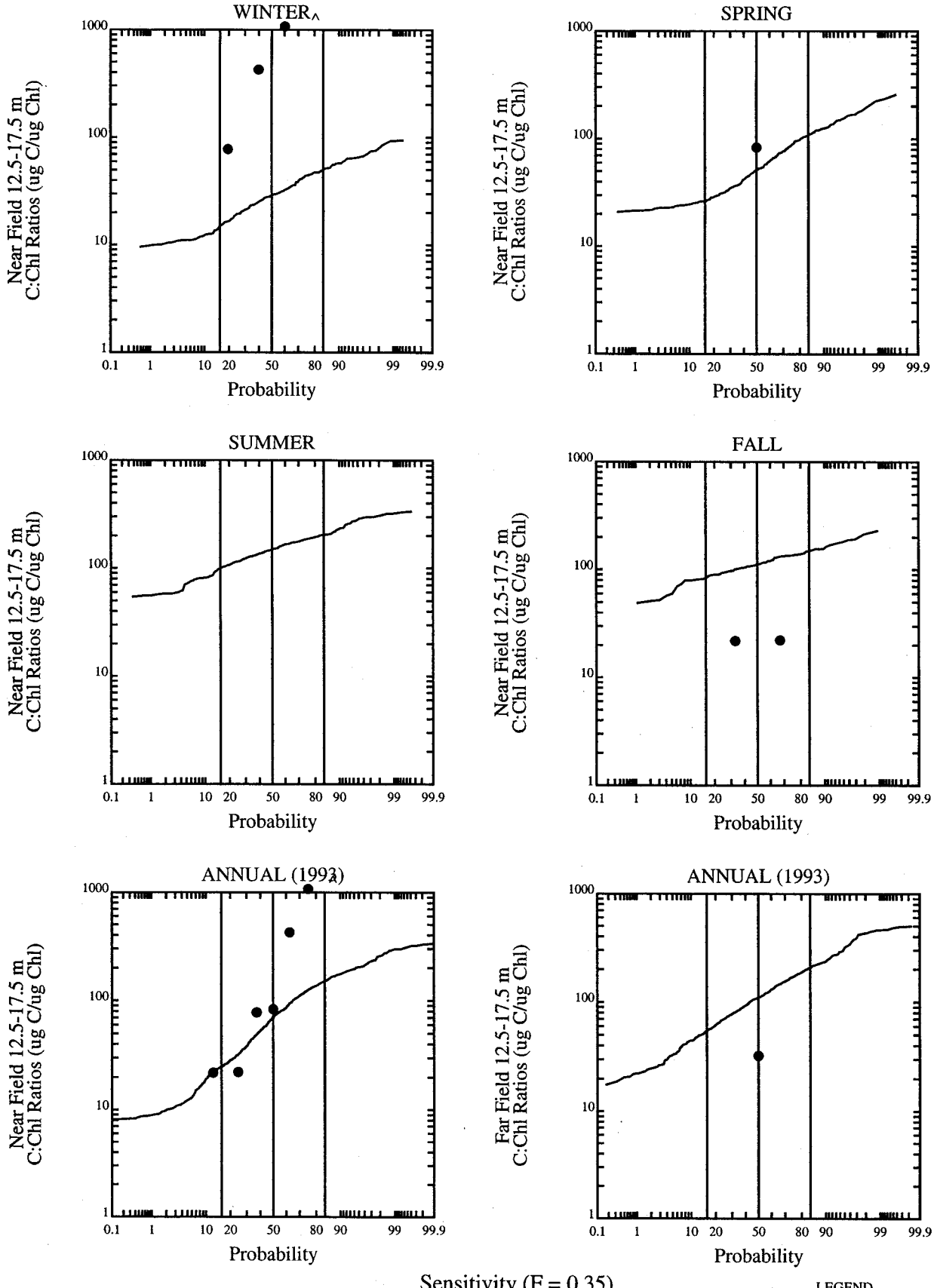

WINTER
SPRING
SUMMER
FALL
ANNUAL (1993)
ANNUAL (1993)
Near Field Surface C:N Ratios (mg C/mg N)
Far Field Surface C:N Ratios (mg C/mg N)
Probability
0.1 1 10 20 50 80 90 99 99.9
0.0 2.0 4.0 6.0 8.0 10.0
Sensitivity (F = 0.35)
LEGEND
Data
Model

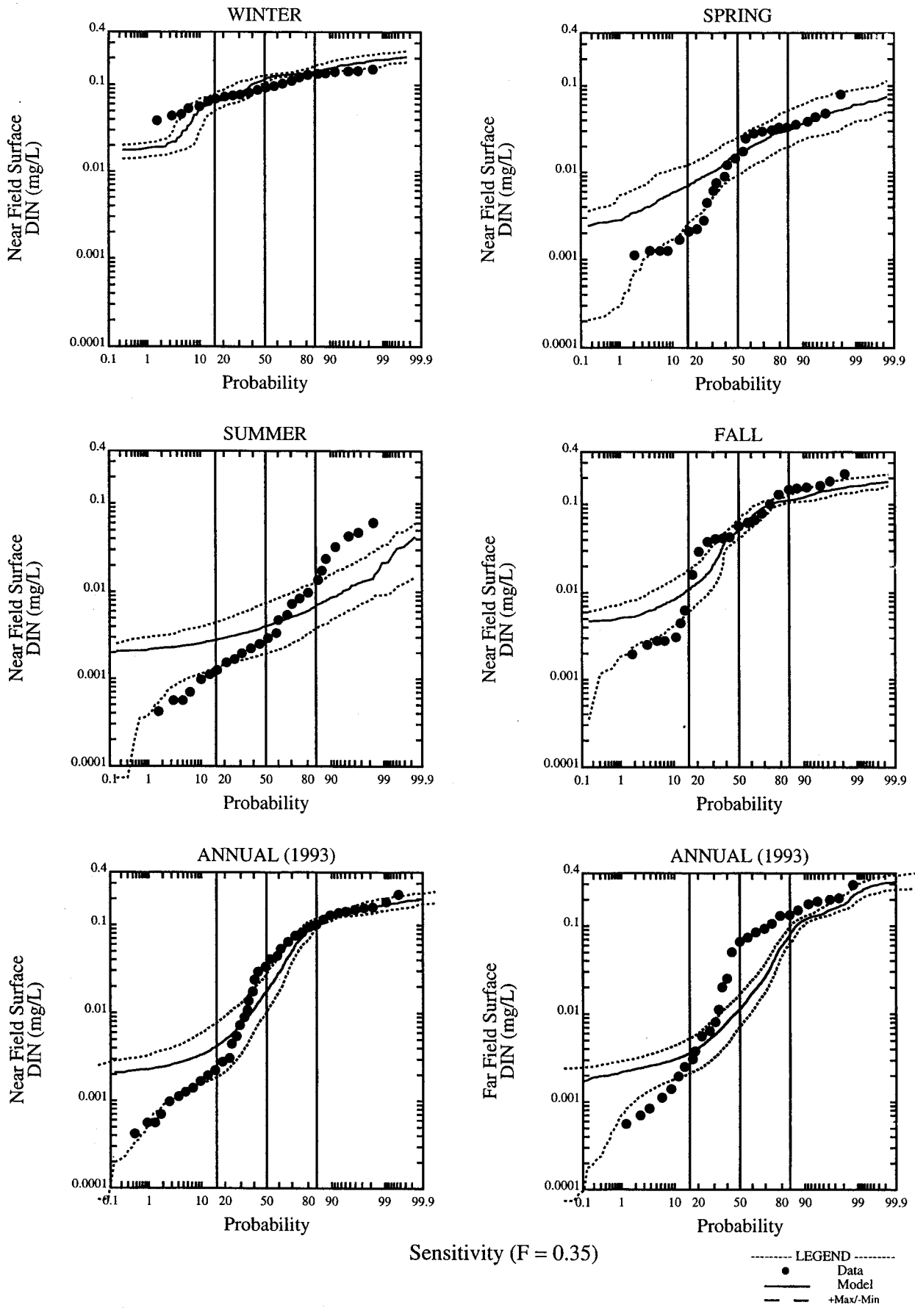

WINTER
SPRING
SUMMER
FALL
ANNUAL (1993)
ANNUAL (1993)
Near Field Surface POC (mg/L)
Far Field Surface POC (mg/L)
Probability
1
0.1
0.01
0.1 1 10 20 50 80 90 99 99.9
Sensitivity (F = 0.35)
LEGEND
Data
Model
+Max/-Min

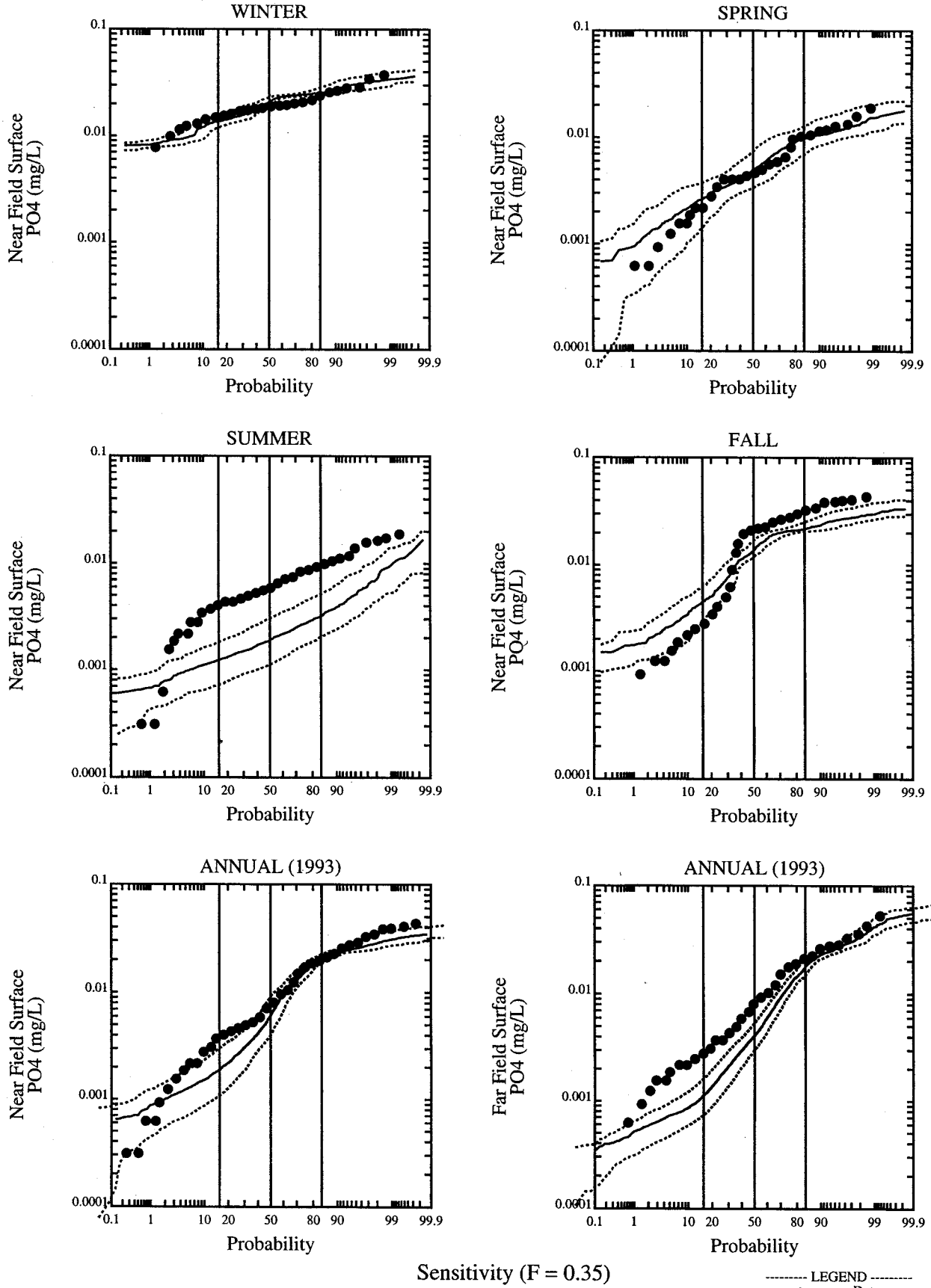

WINTER
SPRING
SUMMER
FALL
ANNUAL (1993)
ANNUAL (1993)
Near Field Surface Chlorophyll-a (ug/L)
Far Field Surface Chlorophyll-a (ug/L)
20
10
1
0.1
0.1 1 10 20 50 80 90 99 99.9
Probability
Sensitivity (F = 0.35)
LEGEND
Discrete Chl-a
Fluorometric Chl-a
Model

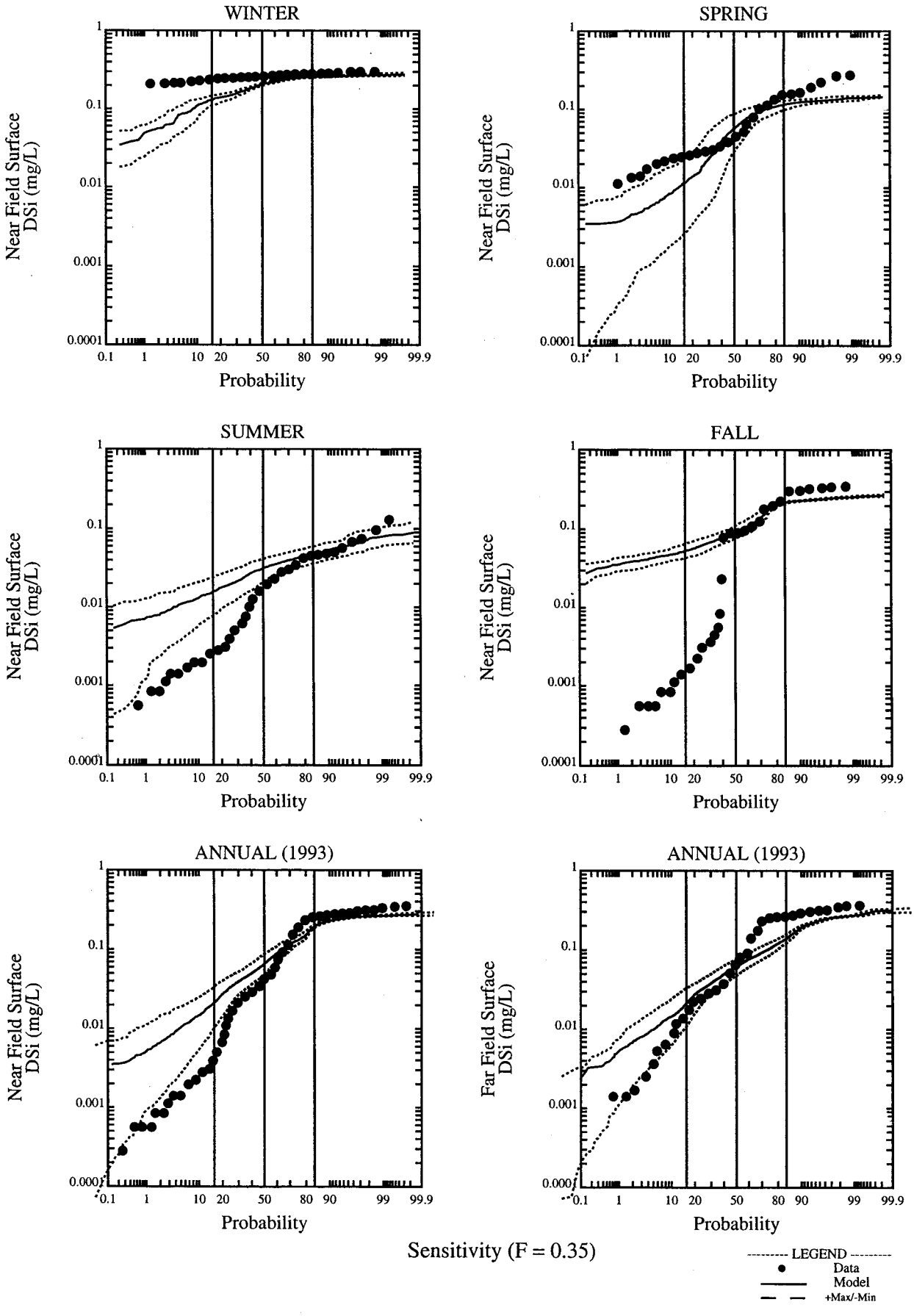

WINTER
SPRING
SUMMER
FALL
ANNUAL (1993)
ANNUAL (1993)
Near Field 12.5-17.5m Chlorophyll-a (ug/L)
Far Field 12.5-17.5m Chlorophyll-a (ug/L)
Probability
0.1 1 10 20 50 80 90 99 99.9
20 10 1 0.1
Sensitivity (F = 0.35)
LEGEND
Discrete Chl-a
Fluorometric Chl-a
Model

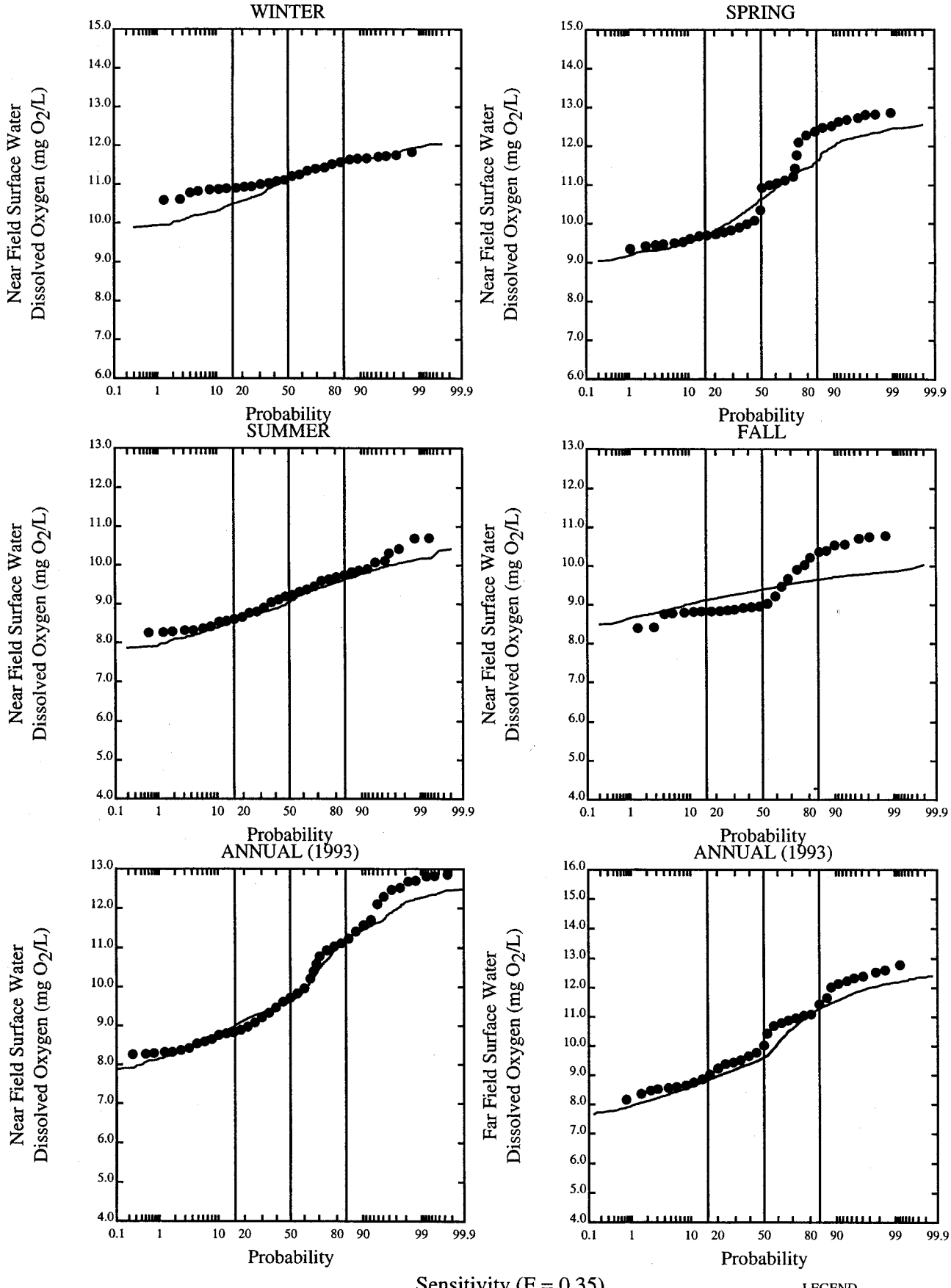

WINTER
SPRING
SUMMER
FALL
ANNUAL (1993)
ANNUAL (1993)
Near Field Surface C:Chl Ratios (ug C/ug Chl)
Far Field Surface C:Chl Ratios (ug C/ug Chl)
Probability
1000
100
10
1
0.1
1
10
20
50
80
90
99
99.9
Sensitivity (F = 0.35)
LEGEND
Data
Model

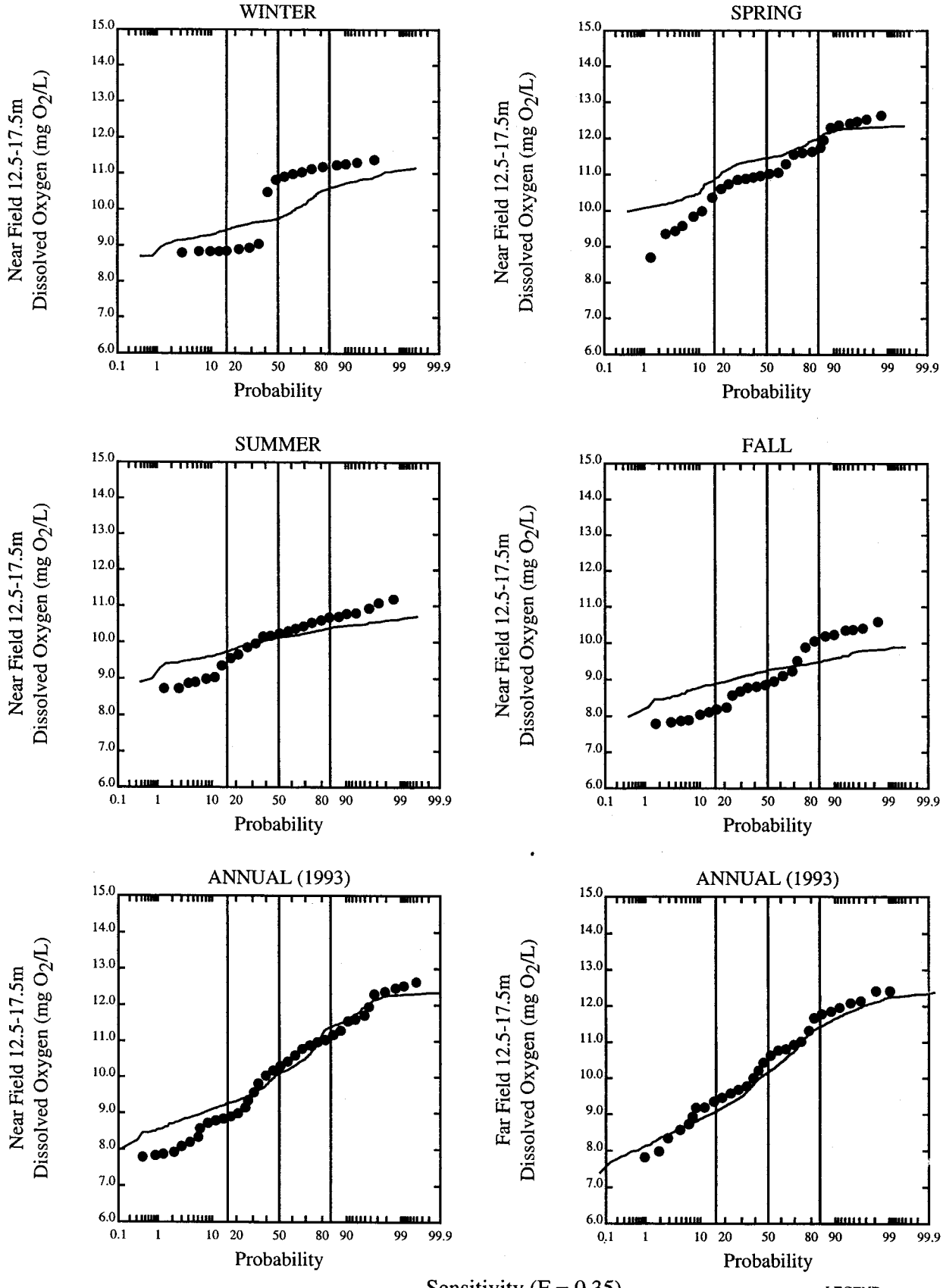

WINTER
SPRING
SUMMER
FALL
ANNUAL (1992)
ANNUAL (1993)
Near Field 12.5-17.5 m C:Chl Ratios (ug C/ug Chl)
Far Field 12.5-17.5 m C:Chl Ratios (ug C/ug Chl)
1000
100
10
1
0.1 1 10 20 50 80 90 99 99.9
Probability
Sensitivity (F = 0.35)
LEGEND
Data
Model

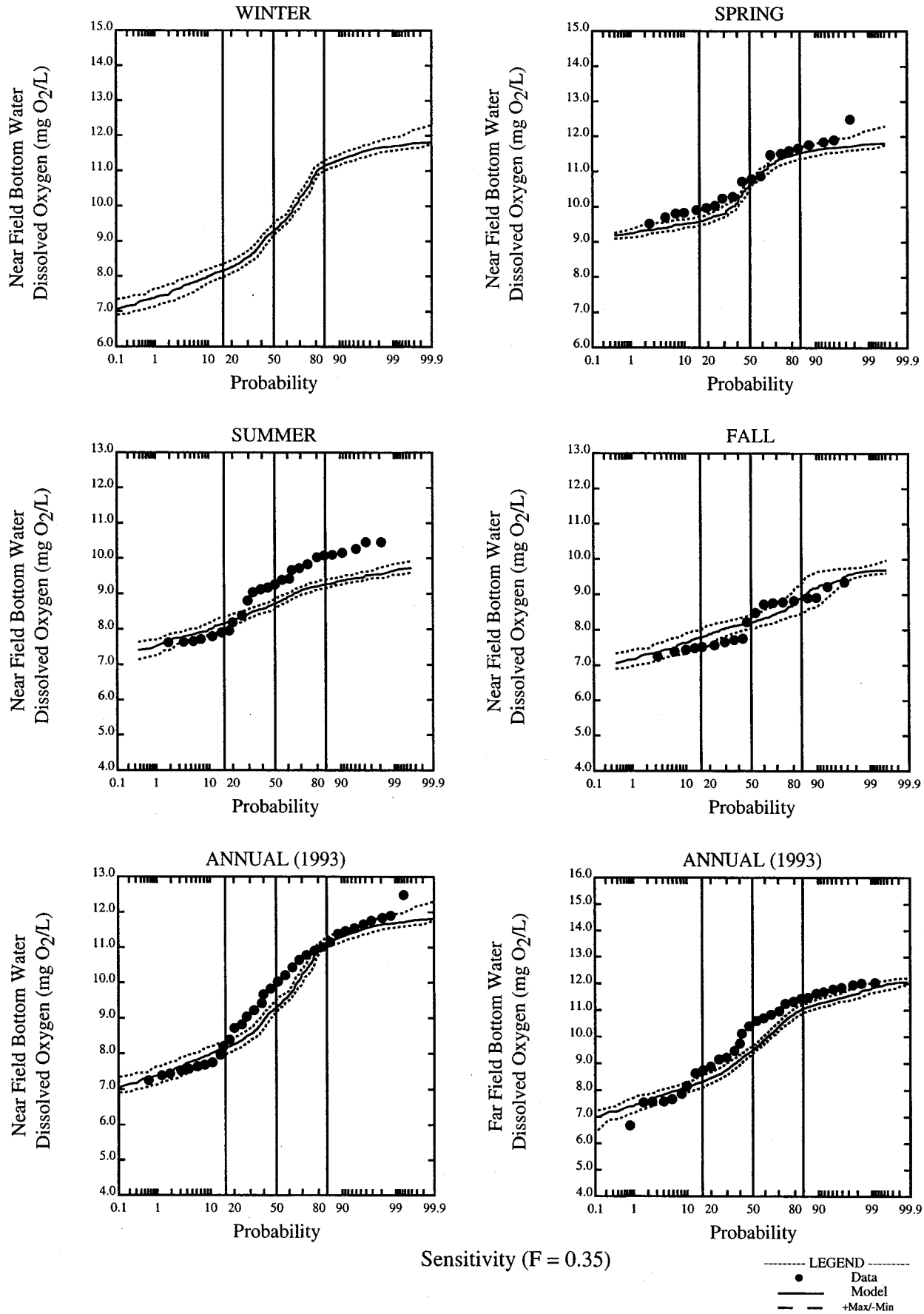

WINTER
SPRING
SUMMER
FALL
ANNUAL (1993)
ANNUAL (1993)
Near Field Surface DIN (mg/L)
Far Field Surface DIN (mg/L)
0.4
0.1
0.01
0.001
0.0001
0.1 1 10 20 50 80 90 99 99.9
Probability
Sensitivity (F = 0.35)
LEGEND
Data
Model
+Max/-Min

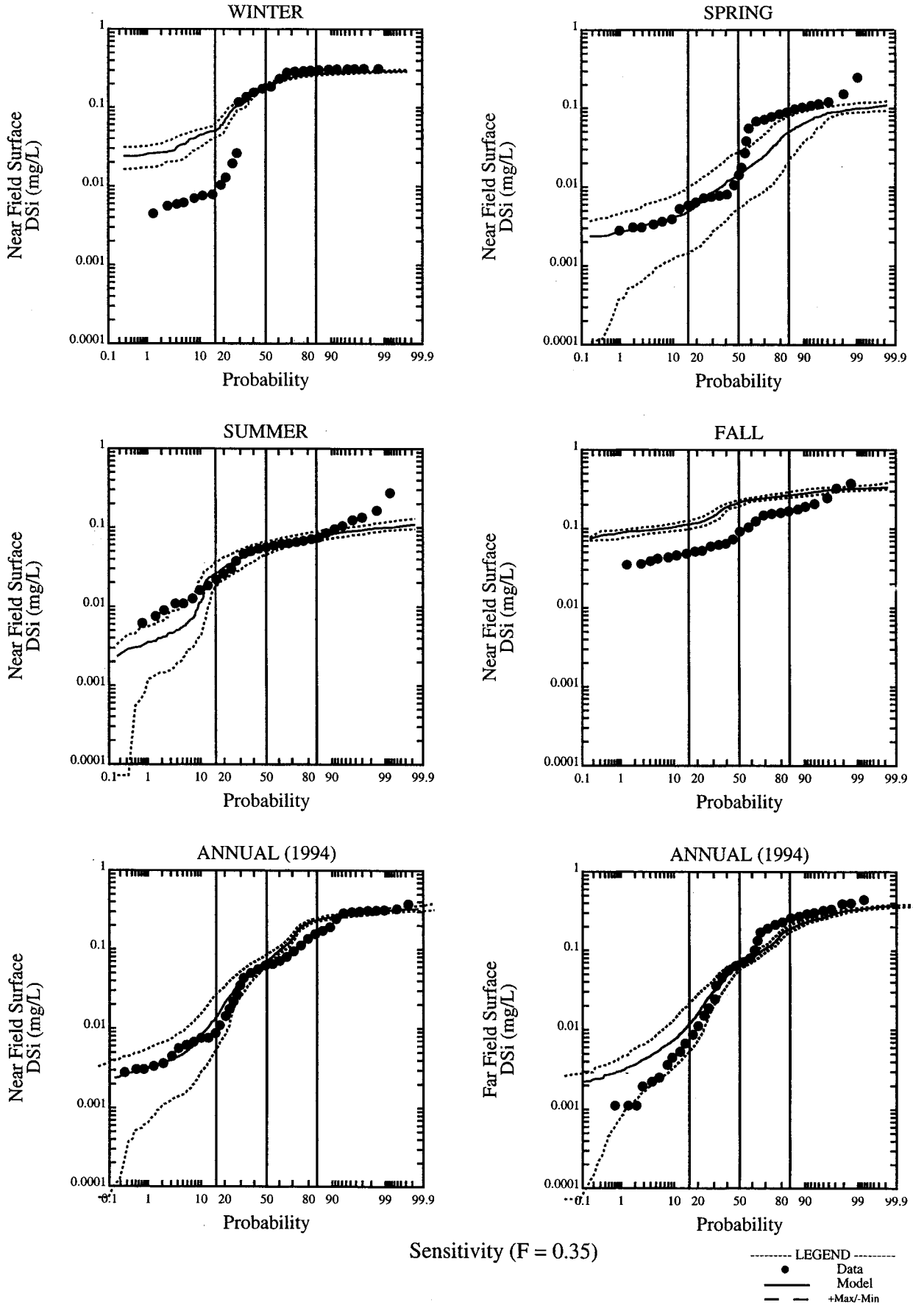

WINTER
SPRING
SUMMER
FALL
ANNUAL (1993)
ANNUAL (1993)
Near Field Surface PO4 (mg/L)
Far Field Surface PO4 (mg/L)
0.1
0.01
0.001
0.0001
0.1 1 10 20 50 80 90 99 99.9
Probability
Sensitivity (F = 0.35)
LEGEND
Data
Model
+Max/-Min

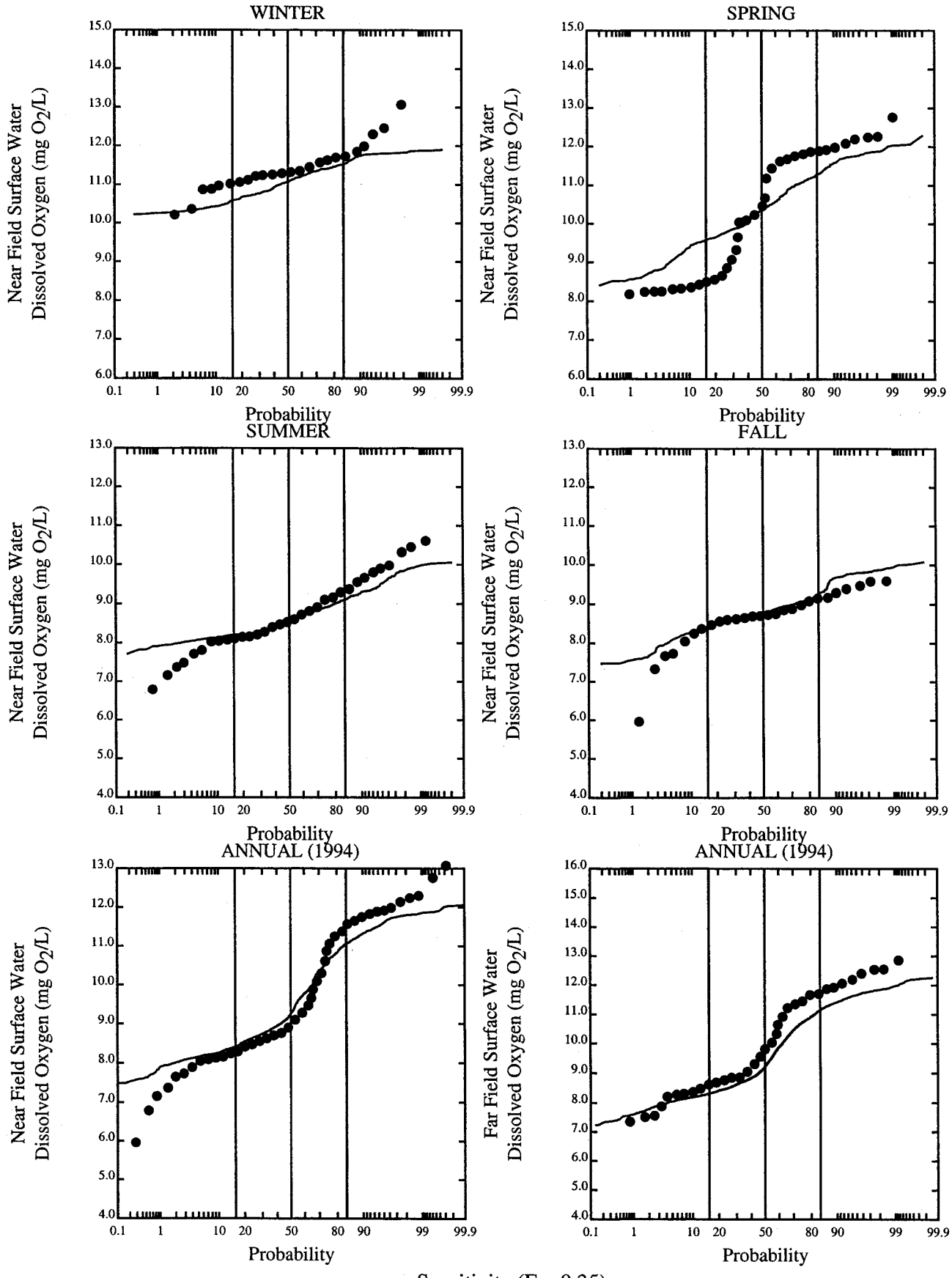

WINTER
SPRING
SUMMER
FALL
ANNUAL (1993)
ANNUAL (1993)
Near Field Surface DSi (mg/L)
Far Field Surface DSi (mg/L)
Probability
1
0.1
0.01
0.001
0.0001
0.1
1
10
20
50
80
90
99
99.9
Sensitivity (F = 0.35)
LEGEND
Data
Model
+Max/-Min

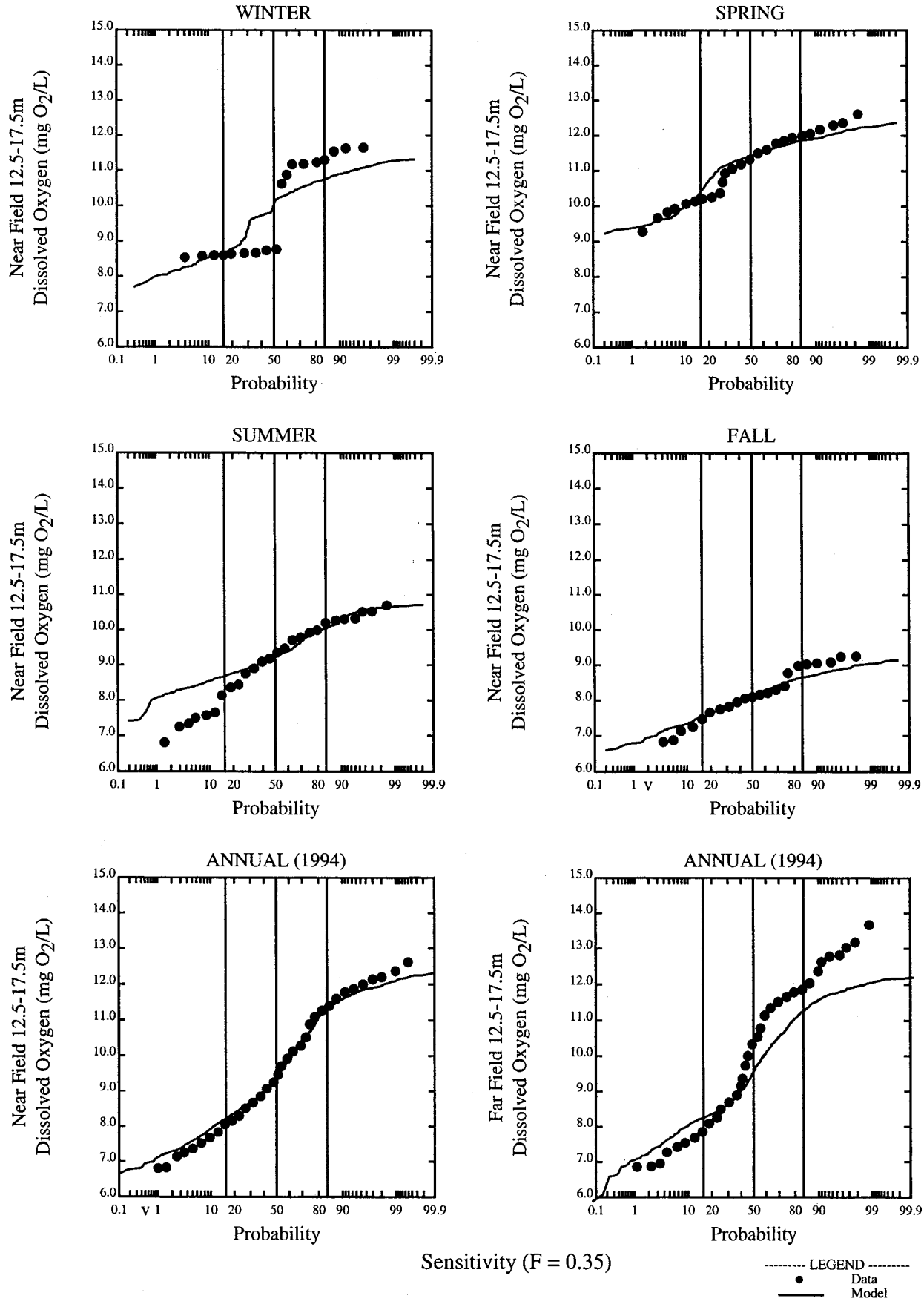

WINTER
SPRING
SUMMER
FALL
ANNUAL (1993)
ANNUAL (1993)
Near Field Surface Water Dissolved Oxygen (mg O2/L)
Far Field Surface Water Dissolved Oxygen (mg O2/L)
Probability
0.1 1 10 20 50 80 90 99 99.9
Sensitivity (F = 0.35)
LEGEND
Data
Model

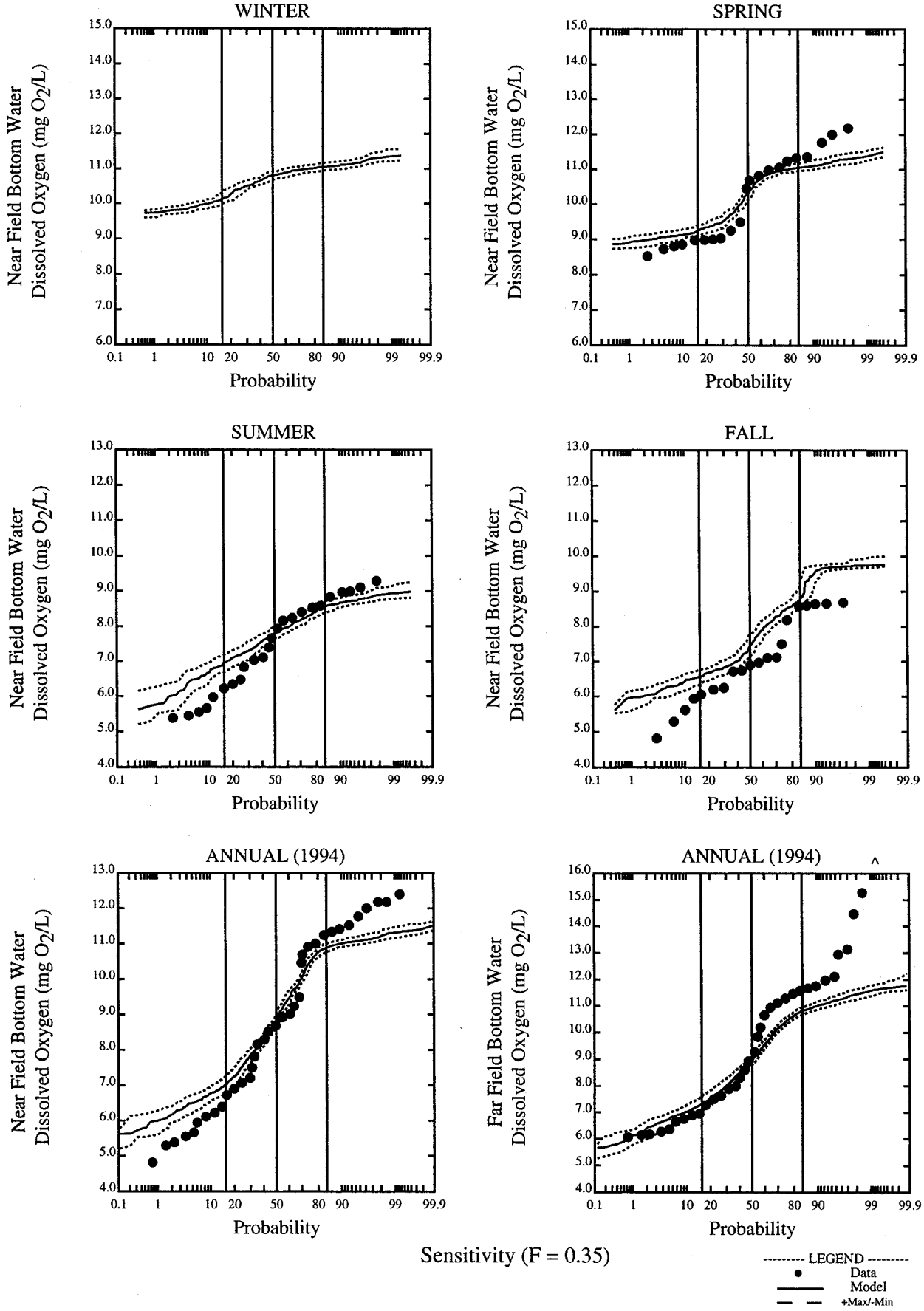

WINTER
SPRING
SUMMER
FALL
ANNUAL (1993)
ANNUAL (1993)
Near Field 12.5-17.5m Dissolved Oxygen (mg O2/L)
Far Field 12.5-17.5m Dissolved Oxygen (mg O2/L)
15.0
14.0
13.0
12.0
11.0
10.0
9.0
8.0
7.0
6.0
0.1
1
10
20
50
80
90
99
99.9
Probability
Sensitivity (F = 0.35)
LEGEND
Data
Model

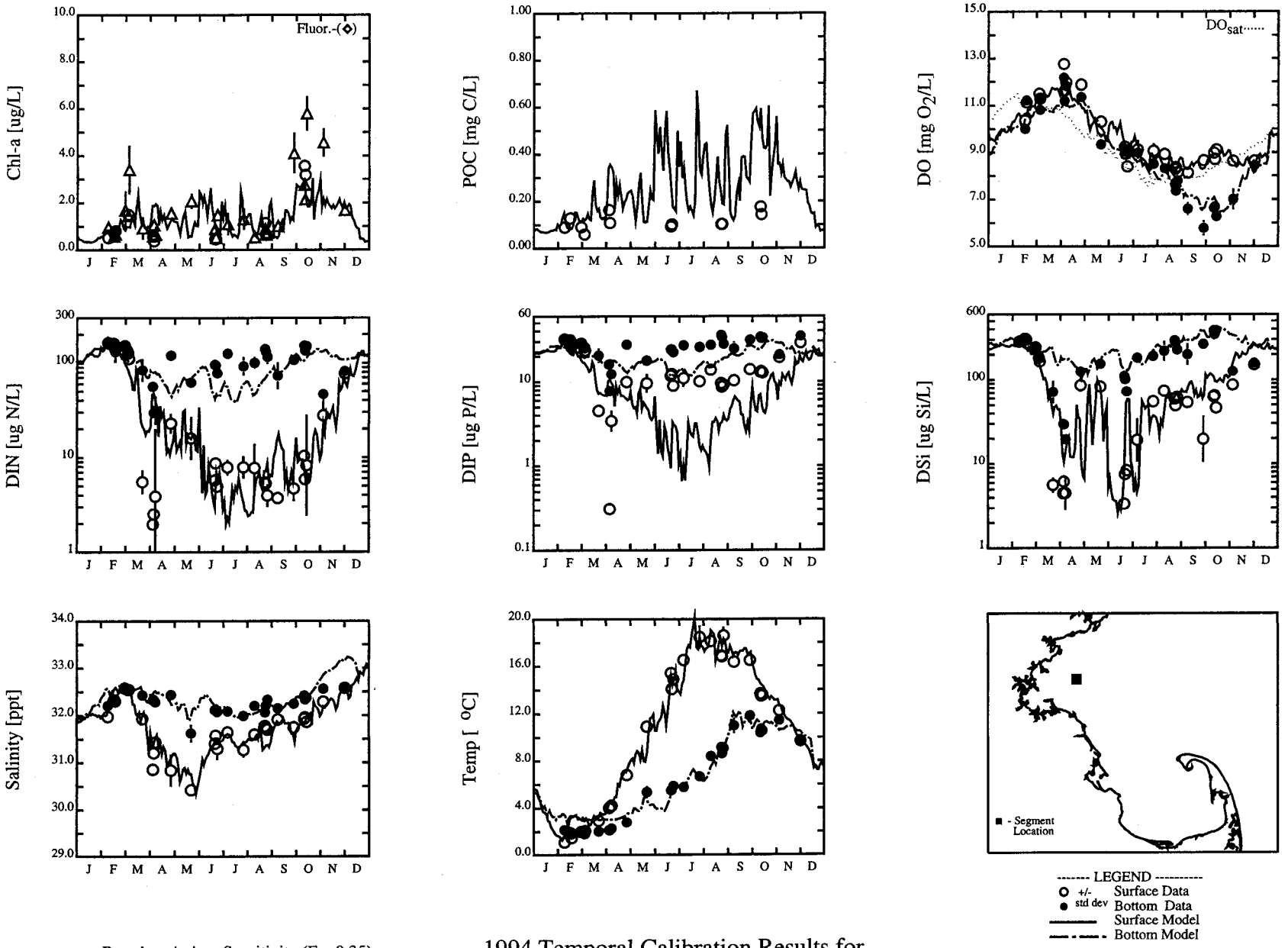

WINTER
SPRING
SUMMER
FALL
ANNUAL (1993)
ANNUAL (1993)
Near Field Bottom Water Dissolved Oxygen (mg O2/L)
Far Field Bottom Water Dissolved Oxygen (mg O2/L)
Probability
0.1 1 10 20 50 80 90 99 99.9
Sensitivity (F = 0.35)
LEGEND
Data
Model
+Max/-Min


WINTER
SPRING
SUMMER
FALL
ANNUAL (1994)
ANNUAL (1994)
Near Field Surface DSi (mg/L)
Far Field Surface DSi (mg/L)
Probability
1
0.1
0.01
0.001
0.0001
0.1 1 10 20 50 80 90 99 99.9
Sensitivity (F = 0.35)
LEGEND
Data
Model
+Max/-Min


WINTER
SPRING
SUMMER
FALL
ANNUAL (1994)
ANNUAL (1994)
Near Field Surface Water Dissolved Oxygen (mg O2/L)
Far Field Surface Water Dissolved Oxygen (mg O2/L)
Probability
0.1 1 10 20 50 80 90 99 99.9
Sensitivity (F = 0.35)
LEGEND
Data
Model

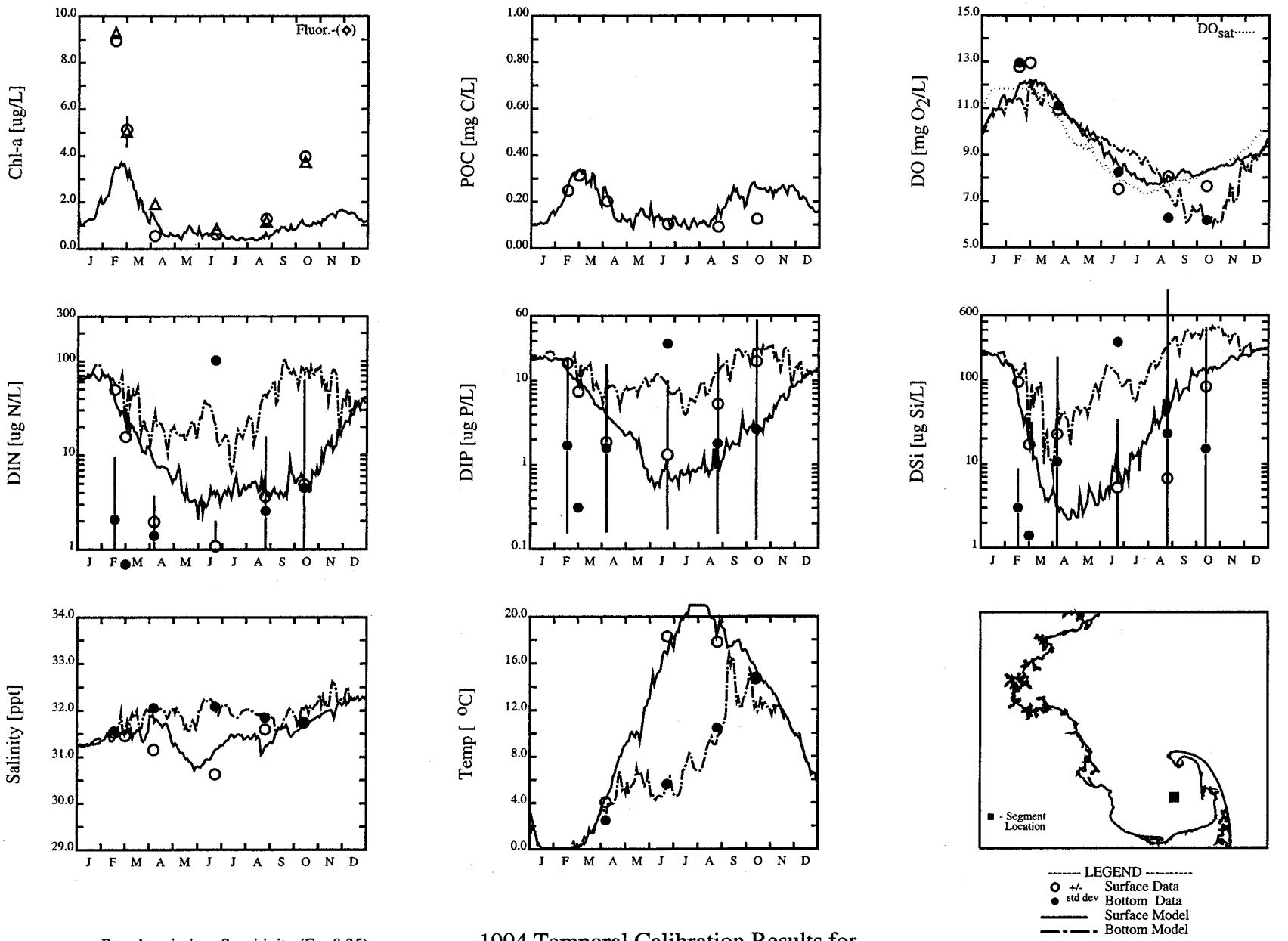

WINTER
SPRING
SUMMER
FALL
ANNUAL (1994)
ANNUAL (1994)
Near Field 12.5-17.5m Dissolved Oxygen (mg O2/L)
Far Field 12.5-17.5m Dissolved Oxygen (mg O2/L)
15.0
14.0
13.0
12.0
11.0
10.0
9.0
8.0
7.0
6.0
0.1
1
10
20
50
80
90
99
99.9
Probability
Sensitivity (F = 0.35)
LEGEND
Data
Model


WINTER
SPRING
SUMMER
FALL
ANNUAL (1994)
ANNUAL (1994)
Near Field Bottom Water Dissolved Oxygen (mg O2/L)
Far Field Bottom Water Dissolved Oxygen (mg O2/L)
Probability
0.1 1 10 20 50 80 90 99 99.9
Sensitivity (F = 0.35)
LEGEND
Data
Model
+Max/-Min



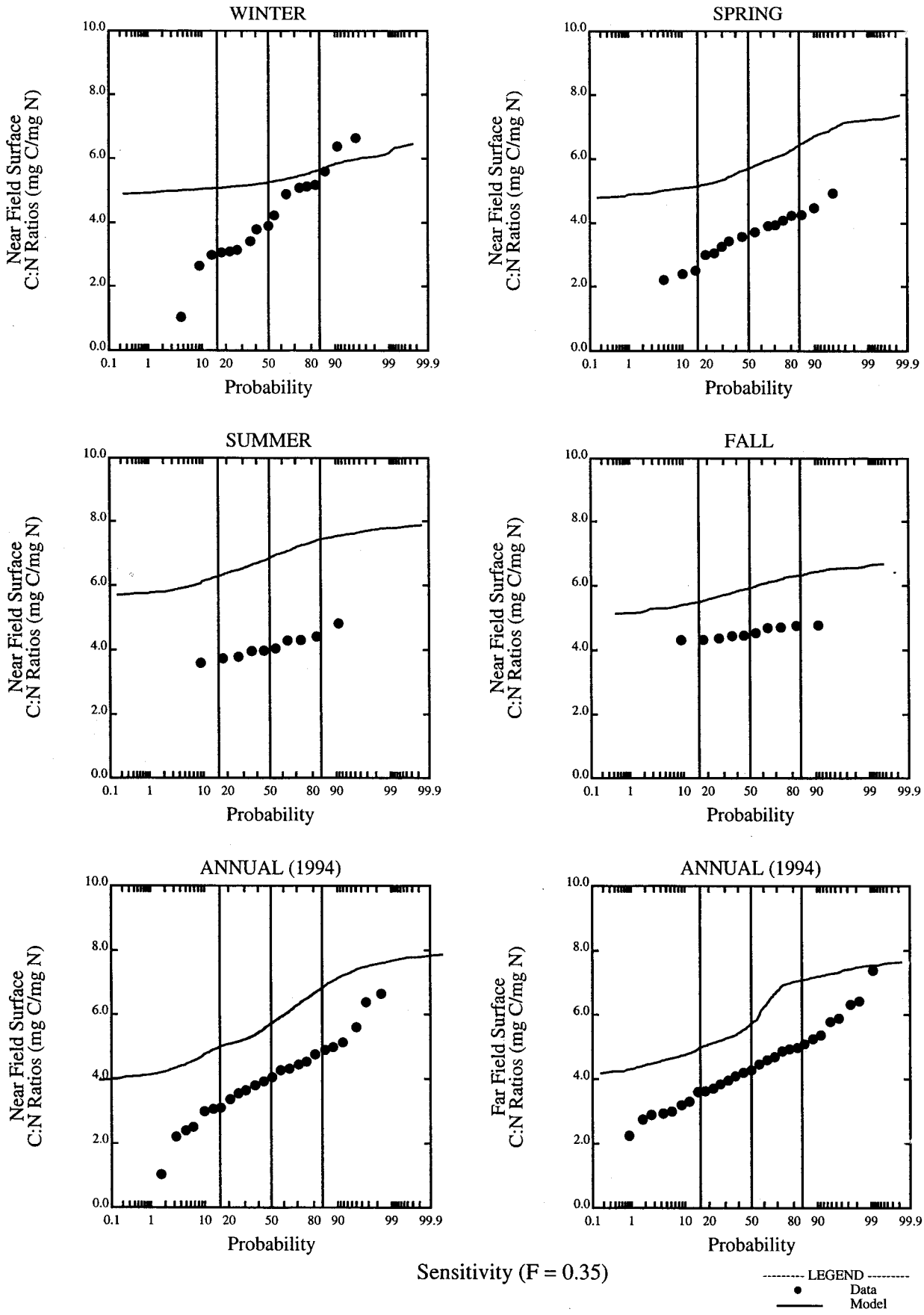
Run description: Sensitivity (F = 0.35)

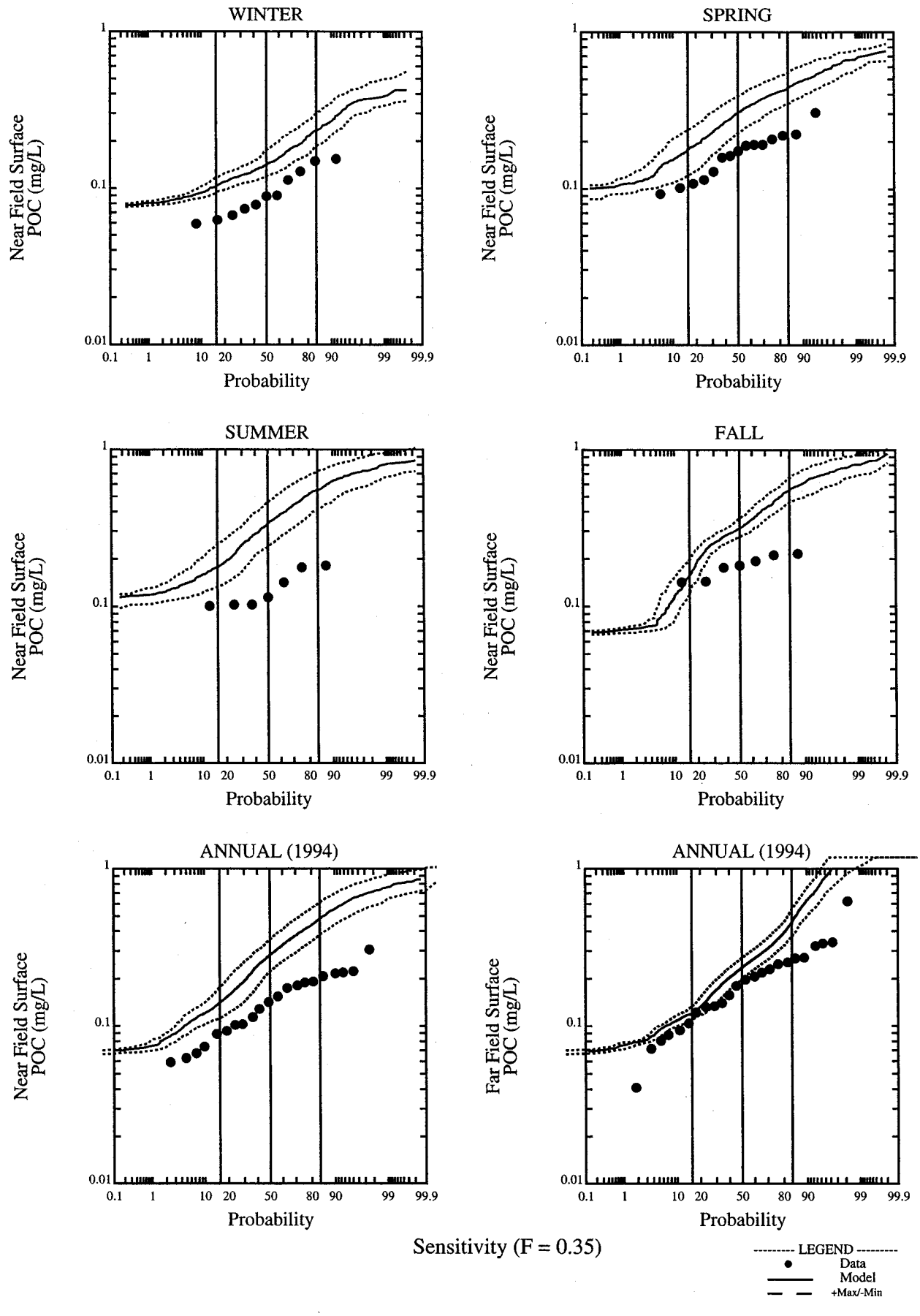
1994 Temporal Calibration Results for
Grid Cell (11,18) Vs Data Station N16P,N17,N21

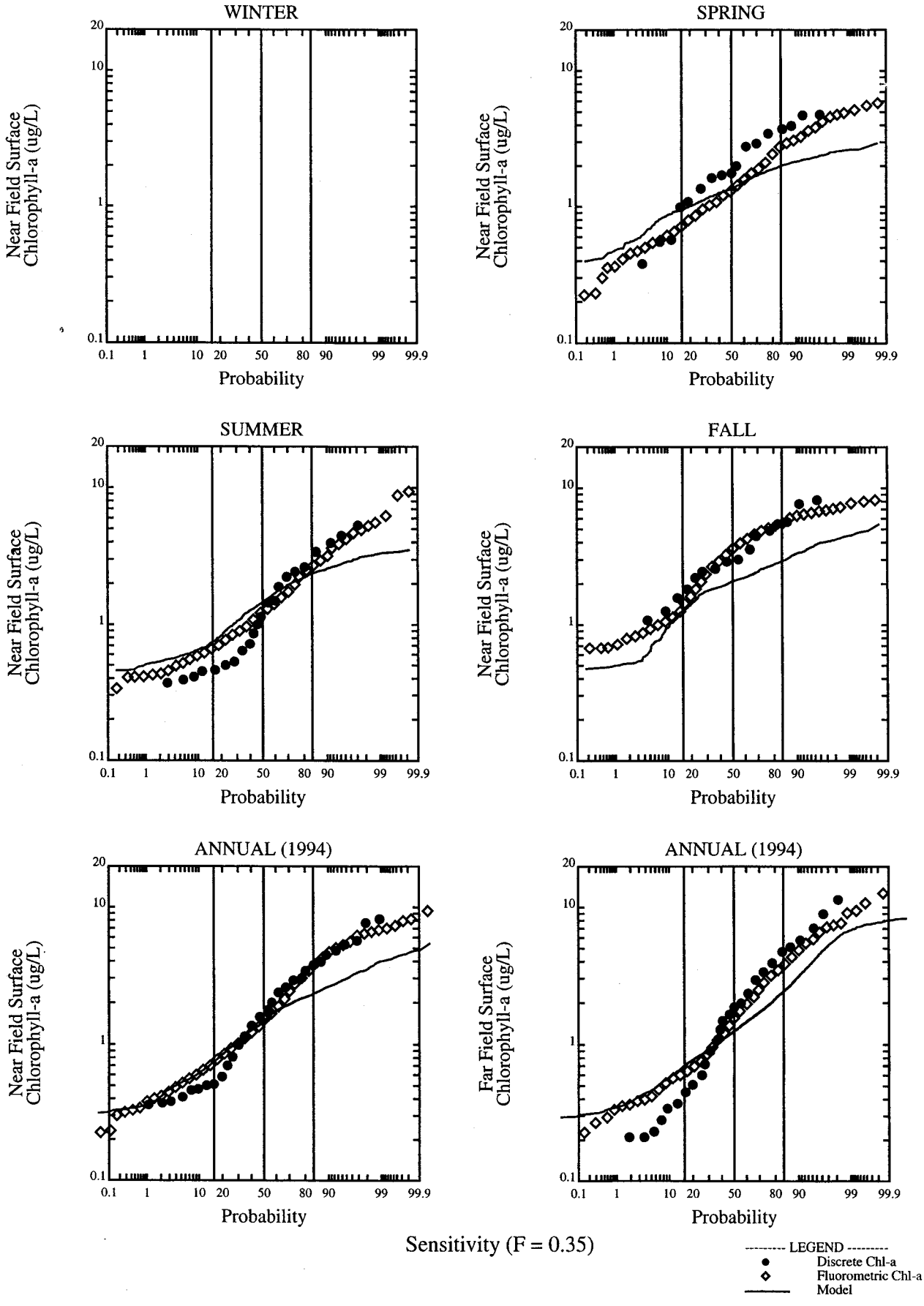


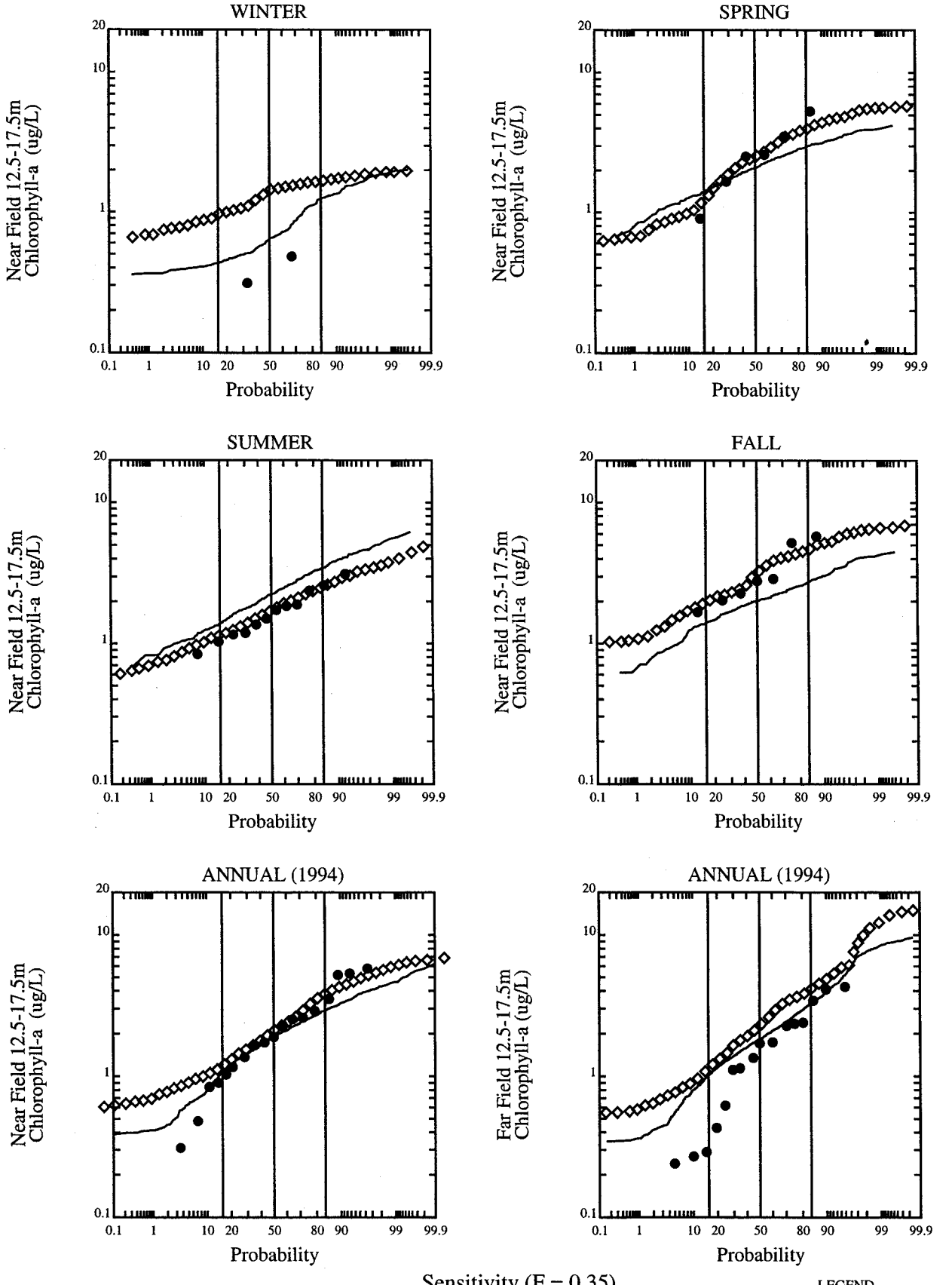
Run description: Sensitivity (F = 0.35)

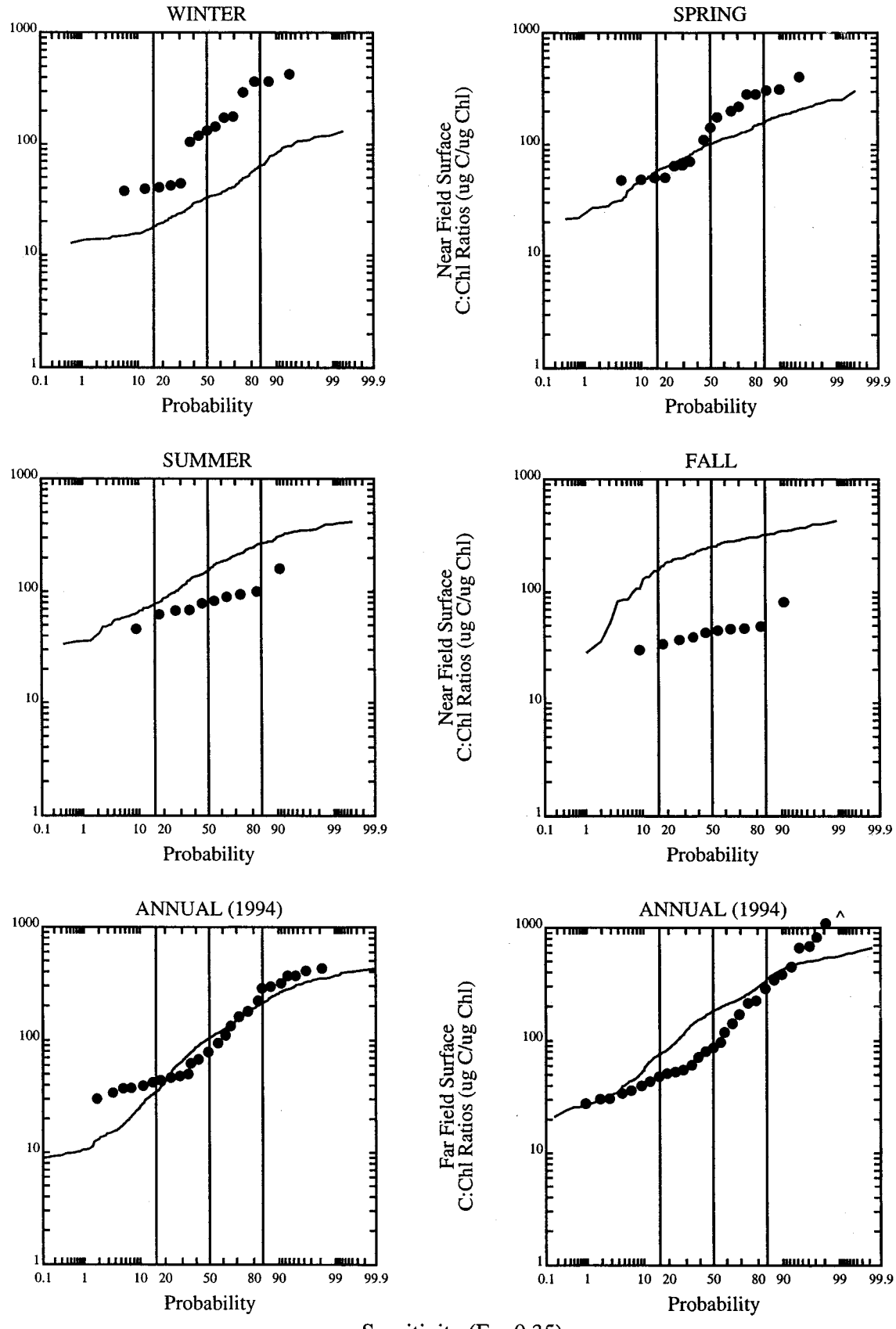
1994 Temporal Calibration Results for
Grid Cell (13,04) Vs Data Station F02P

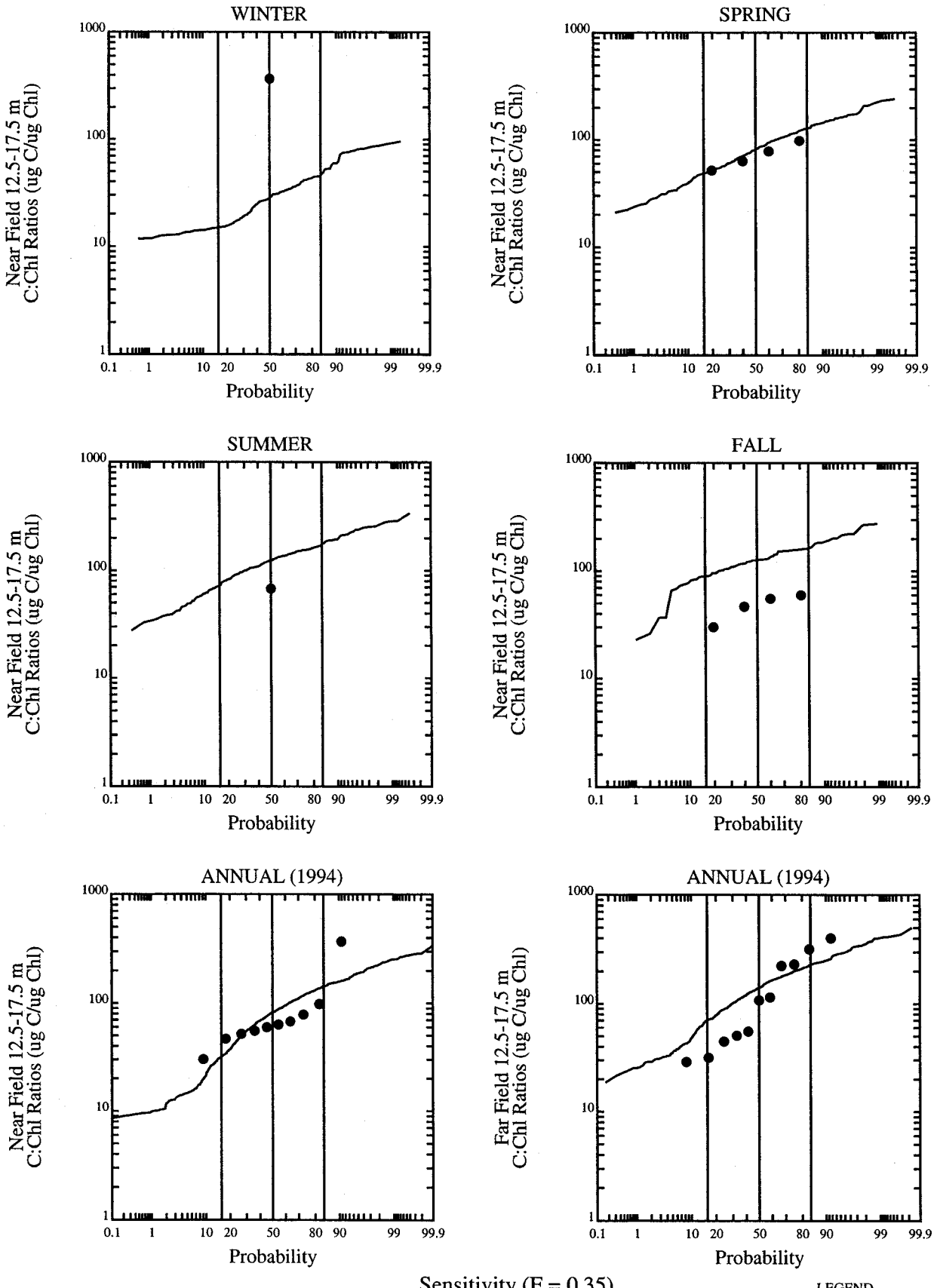

WINTER
SPRING
SUMMER
FALL
ANNUAL (1994)
ANNUAL (1994)
Near Field Surface C:N Ratios (mg C/mg N)
Far Field Surface C:N Ratios (mg C/mg N)
10.0
8.0
6.0
4.0
2.0
0.0
0.1 1 10 20 50 80 90 99 99.9
Probability
Sensitivity (F = 0.35)
LEGEND
Data
Model

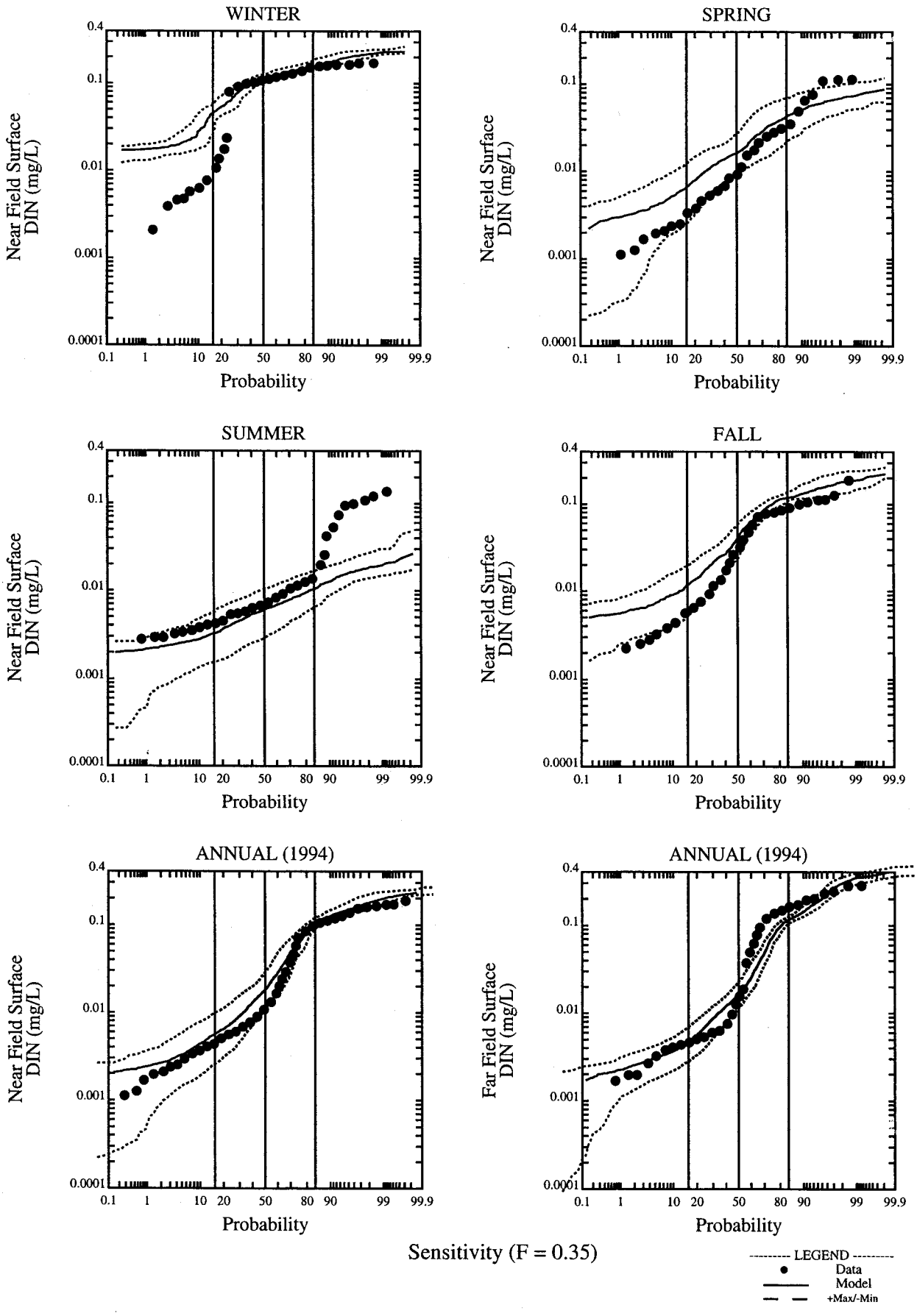

WINTER
SPRING
SUMMER
FALL
ANNUAL (1994)
ANNUAL (1994)
Near Field Surface POC (mg/L)
Far Field Surface POC (mg/L)
Probability
1
0.1
0.01
0.1 1 10 20 50 80 90 99 99.9
Sensitivity (F = 0.35)
LEGEND
Data
Model
+Max/-Min

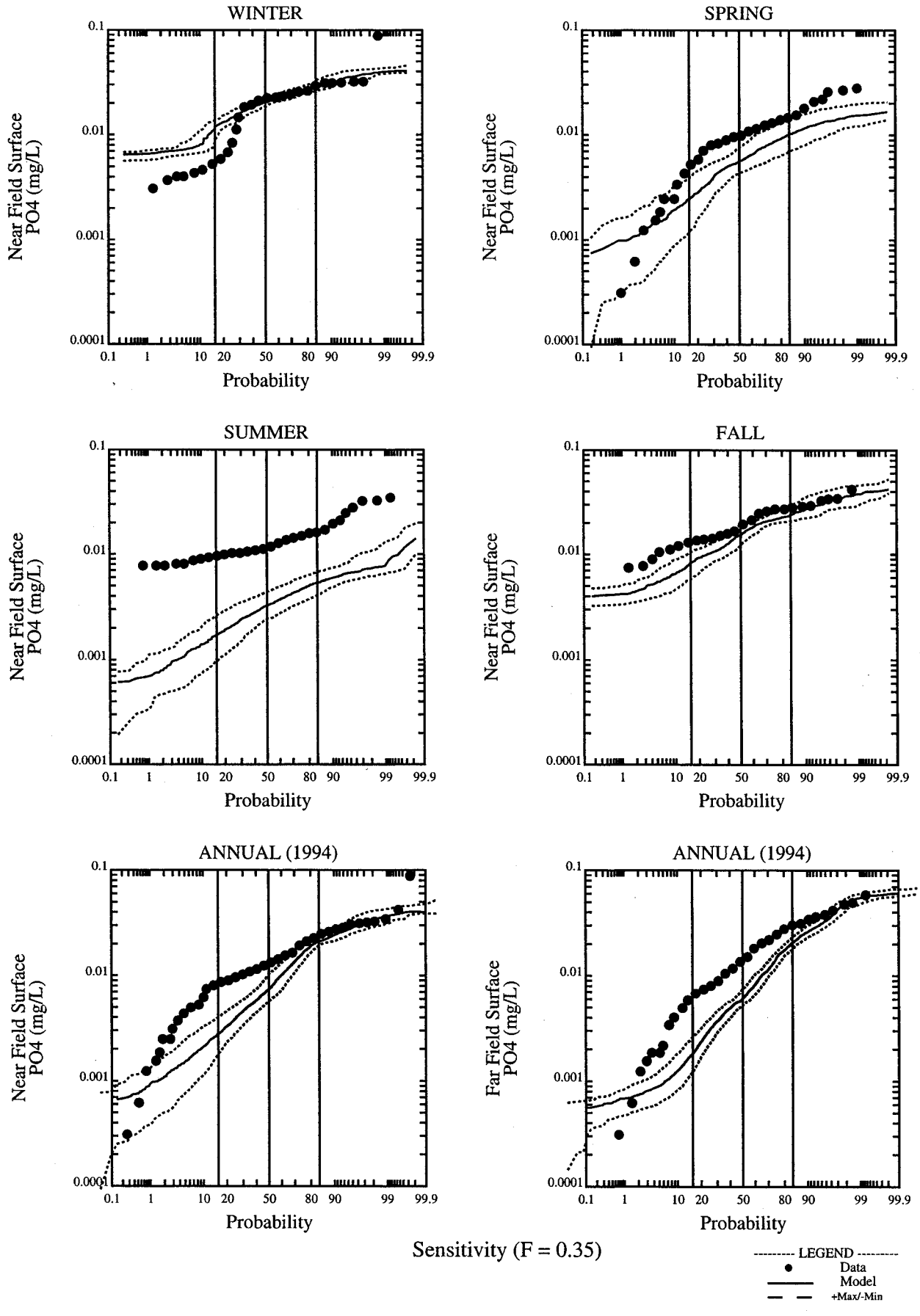

WINTER
SPRING
SUMMER
FALL
ANNUAL (1994)
ANNUAL (1994)
Near Field Surface Chlorophyll-a (ug/L)
Far Field Surface Chlorophyll-a (ug/L)
20
10
1
0.1
0.1 1 10 20 50 80 90 99 99.9
Probability
Sensitivity (F = 0.35)
LEGEND
Discrete Chl-a
Fluorometric Chl-a
Model


WINTER
SPRING
SUMMER
FALL
ANNUAL (1994)
ANNUAL (1994)
Near Field 12.5-17.5m Chlorophyll-a (ug/L)
Far Field 12.5-17.5m Chlorophyll-a (ug/L)
Probability
20
10
1
0.1
0.1 1 10 20 50 80 90 99 99.9
Sensitivity (F = 0.35)
LEGEND
Discrete Chl-a
Fluorometric Chl-a
Model


WINTER
SPRING
SUMMER
FALL
ANNUAL (1994)
ANNUAL (1994)
Near Field Surface C:Chl Ratios (ug C/ug Chl)
Near Field Surface C:Chl Ratios (ug C/ug Chl)
Far Field Surface C:Chl Ratios (ug C/ug Chl)
1000
100
10
1
0.1 1 10 20 50 80 90 99 99.9
Probability
Sensitivity (F = 0.35)
LEGEND
Data
Model


WINTER
SPRING
SUMMER
FALL
ANNUAL (1994)
ANNUAL (1994)
Near Field 12.5-17.5 m C:Chl Ratios (ug C/ug Chl)
Far Field 12.5-17.5 m C:Chl Ratios (ug C/ug Chl)
1000
100
10
1
0.1 1 10 20 50 80 90 99 99.9
Probability
Sensitivity (F = 0.35)
LEGEND
Data
Model


WINTER
SPRING
SUMMER
FALL
ANNUAL (1994)
ANNUAL (1994)
Near Field Surface DIN (mg/L)
Far Field Surface DIN (mg/L)
0.4
0.1
0.01
0.001
0.0001
0.1 1 10 20 50 80 90 99 99.9
Probability
Sensitivity (F = 0.35)
LEGEND
Data
Model
+Max/-Min


WINTER
SPRING
SUMMER
FALL
ANNUAL (1994)
ANNUAL (1994)
Near Field Surface PO4 (mg/L)
Far Field Surface PO4 (mg/L)
0.1
0.01
0.001
0.0001
0.1 1 10 20 50 80 90 99 99.9
Probability
Sensitivity (F = 0.35)
LEGEND
Data
Model
+Max/-Min

Massachusetts Water Resources Authority
Charlestown Navy Yard
100 First Avenue
Boston, MA 02129
(617) 242-6000
http://www.mwra.state.ma.us