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US/PRC CTD Intercalibration Report 1986-1990

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D.Schaaf, K. Yang, H. Yu and L. Zhao

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Technical Report

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Abstract

A series of laboratory intercalibrations of a CTD system were undertaken between 1986 and 1990 as part of cooperative research program between the United States (US) and People's Republic of China (PRC). A comparison of US and PRC calibration facility standards is carried out using a NBIS/EG&G Marine Instruments Mark IIIb CTD system as a "quasi-transfer standard." When compared with the quoted accuracy of the calibration facilities, pressure was found to be more accurate and temperature was about as accurate as stated. The conductivity standard differences between facilities are difficult to assess because of the CTD conductivity sensor drift.

Introduction

A science and technology agreement between the governments of the United States (US) and the People's Republic of China (PRC) signed in 1983 created a cooperative research program to investigate the western equatorial Pacific Ocean. The agreement in part called for a series of eight joint scientific cruises to the western Pacific, a program of personnel training, and an exchange of scientific equipment. One central element of the sea-going scientific program was hydrographic observations using CTD/O_2 (Conductivity-Temperature-Depth-Oxygen) profilers. The agreement was later amended in 1986 to include a series of joint intercomparisons of laboratory calibration facilities between the US and PRC. The National Oceanic and Atmospheric Administration (NOAA) in the US and the State Oceanic Administration (SOA) in China have been charged with administering the research effort which is now considered a component of the international Tropical Ocean – Global Atmosphere (TOGA) program.

The CTD conductivity, temperature, and pressure sensors required accurate calibration in order make state-of-the-art hydrographic measurements. This is particularly true in the deep water where the variations of temperature and salinity are small. The standard practice in oceanography is to calibrate the CTD conductivity, temperature, and pressure sensors in the laboratory before and after each cruise against traceable transfer standards. This study was intended to compare the methodology and results of laboratory calibrations performed in the US and the PRC using the CTD before use at sea as a means of comparison. In addition to these laboratory calibrations, the CTD conductivity sensor has been found to drift significantly at sea thereby requiring recalibration on a regular basis against water sample salinities. In fact, all of the CTD sensors calibrations have been observed to show some drift with time (Millard, 1982), and for this reason frequent laboratory recalibration is required. The present intercalibration between the EG&G Marine Instruments and Institute of Ocean Technology (IOT) calibration facilities will use the NBIS/EG&G Mark IIIb, described in Brown and Morrison (1978), as a "quasi-transfer standard," keeping the drift of the CTD sensors in mind.

The general procedure followed for the laboratory calibration of the CTD conductivity and temperature channels is to immerse its sensors in close proximity to a temperature or conductivity transfer standard in a well- stirred bath and record their values over the CTD sensors' range of use. The pressure calibration is done by coupling a dead-weight tester to the pressure port of the CTD and recording the values of the CTD pressure and that of the standard over the range of the CTD sensor. The pressure calibration is usually repeated at more than one temperature. The number of standard and CTD sensor values taken over the sensor range of each variable depends on the linearity of the sensor. The best fit NBIS/EG&G Mark IIIb CTD sensor calibration curves have been found to be normally linear in conductivity, quadratic in temperature, and third order in pressure. The details of the calibration methodology and equipment used are given for both IOT, Tianjin, China and EG&G Marine Instruments, Cataumet, Massachusetts, USA in the Appendix. The final intercalibration reported herein involved measurements at the Woods Hole Oceanographic Institution (WHOI); these calibration procedures are documented by Fofonoff *et al.* (1974).

There are several noteworthy differences in the calibration methods used by the facilities which may have bearing on the results. IOT fully immerses the CTD fish in the bath as does WHOI, while EG&G immerses only the lower $\frac{1}{4}$ of the CTD in the bath. If temperature changes in the electronics affect CTD measurement values, then differences between the two facilities might be expected. These differences should be minimal at room temperature. The conductivity calibration method used by IOT utilizes temperature changes in the bath at a fixed salinity to obtain conductivity variations. Measurements of bath salinity and temperature are made and converted to "standard" conductivity values using the 1978 Practical Salinity Scale (PSS-78) for comparison with the CTD conductivity data. EG&G and WHOI calibrate conductivity directly against a conductivity transfer standard in baths of various salinities at a fixed temperature.

The first US/PRC intercalibration took place in September and October of 1986 prior to the second joint cruise. The experimental procedure followed for each intercalibration was to first calibrate the CTD at Neil Brown Instrument Systems/EG&G Marine Instruments prior to a cruise and then air-freight the CTD and a deck unit half way around the world to the IOT in Tianjin for a follow-up calibration. A total of seven intercalibration comparison experiments were carried out prior to joint cruises. These are summarized together in Table 1 with several additional post cruise calibrations carried out only at EG&G.

Table 1

Comparison Number	EG&G	IOT	Cruise Number
	----- Dates -----		
1	April, 1986		Post-PRC 1
	September, 1986	October, 1986	Pre-PRC 2
	February, 1987		Post-PRC 2
2	July, 1987	September, 1987	Pre-PRC 3++
	November, 1987		Post-PRC 3
3	February, 1988	April, 1988	Pre-PRC 4***
4	July, 1988	September, 1988	Pre-PRC 5
5	February, 1989	March, 1989	Pre-PRC 6
6	August, 1989	August, 1989	Pre-PRC 7
7	February, 1990	April, 1990	Pre-PRC 8***

++CTD temperature sensor drifted significantly, intercomparison discarded.
***Temperature sensor replaced prior to EG&G calibration.

In this report we will describe the processing methods applied to the calibration data. An assessment is made of the time stability of the CTD sensors and their suitability for use as "pseudo-transfer standards," We will then present the results of the various calibrations for each sensor and finally assess the intercomparability of the two calibration facilities standards to the extent that CTD sensor stability allows.

1. Processing Methods

The following processing methods and algorithms were used to process the Institute of Ocean Technology in Tianjin and EG&G Marine Instruments in Cataumet, Massachusetts calibration data. The units used are: pressure in decibars (1 decibar = 10^4 pascals); temperature is reported on the 1968 International Practical Temperature Scale (IPTS-68) in degrees Celsius and conductivity in mS/cm (mS represents millisiemens where 1 mS = 1 mmho) using an absolute conductivity value of 42.914 mS/cm for a conductivity ratio of one at a salinity of 35 psu, 15°C and atmospheric pressure. All differences between laboratory standards and CTD values are displayed as the value of the standard minus the instrument value. Thus the differences are interpreted as corrections to the CTD, and not the convention sometimes adopted of a CTD error difference which has the opposite sign.

Conductivity

The IOT standard conductivity estimates were obtained by inverting measurements of bath salinity to a conductivity using the Practical Salinity Scale of 1978 (PSS-78). The Fortran algorithm for this conversion is described by Fofonoff and Millard (1983). The standard temperature is used together with atmospheric pressure and water sample salinity data obtained with an Autolab model 8400 salinometer to obtain conductivity. The standard conductivity at EG&G and WHOI was obtained using an NBIS Automatic temperature bridge model ATB-1250 described by Brown *et al.* (1982) with the conductivity cell option, standardized with IOS standard water.

The EG&G/NBIS Mark IIIb CTD conductance measurement is corrected for temperature effects on the conductivity cell as shown in the equation below from Fofonoff *et al.* (1974)

$$C \;=\; C_i[1 \;+\; 6.5\;E-6\;(24-\;T)]$$

where C_i and T are the measured conductance and temperature. The temperature of 24°C for the conductivity cell geometry temperature correction was chosen as this was a typical temperature at which the conductivity calibration was performed at EG&G.

Temperature

No corrections were done here to either the CTD or standard temperature data from IOT or EG&G. The observations provided by each facility were simply differenced to obtain the CTD correction curves.

Pressure

No corrections were performed to the CTD pressure data reported by each facility. The standard pressure from EG&G is reported in pounds per square inch (psi) which were converted to decibars as follows:

$$P\ (\text{dbars}) = P\ (\text{psi})/1.45038$$

It was assumed that the standard dead-weight tester values of both IOT and EG&G were otherwise correct as reported. The February, 1990 WHOI pressure calibration was corrected as described by Fofonoff *et al.* in Woods Hole Oceanographic Institution Technical Report 74-89. The following dead-weight pressure corrections applied to these data are detailed in Technical Report 74-89: local gravity correction from standard gravity = 9.80665 m/s^2; air buoyancy correction to weights; fluid head offset; thermal expansion of the piston; elastic distortion of the piston with loading.

2. Time Stability of the CTD Sensors

A single NBIS/EG&G Marine Instruments Mark IIIb CTD underwater unit Serial No. 1104 was used exclusively in this intercalibration. The only modification made to the standard instrument setup was removal of the fast response thermistor from the temperature circuit. The calibration history of CTD No. 1104 covers nearly four years between April, 1986 and February, 1990. The same conductivity and pressure sensors were used without adjustment over the four years and no routine adjustments were made to any sensor electronics during calibrations. Adjustments were made in February, 1988 and February, 1990 when the temperature interface was replaced together with failed temperature sensors. Only the temperature sensor circuit was readjusted at these times, but we have noticed in past calibrations that other sensors can be affected by opening the underwater unit housing.

In order to assess how well the calibrated CTD sensors can be used as a "quasi-transfer standard" between calibration facilities, we will first examine the time sequence of calibrations of conductivity, pressure, and temperature from one laboratory. The calibration results of the EG&G facility are chosen because more calibration runs occurred at this site than at IOT. The EG&G calibration facility's stated accuracy and resolution are shown in Table 2 . Details of the EG&G calibration procedures and a description of their facilities can be found in the Appendix.

Table 2

Variable	Range	Accuracy	Resolution
Temperature	0 to 32°C	0.0025°C	0.00001°C*
Conductivity	0 to 100 mS/cm	0.0025+	0.000002 mS/cm*
Pressure	0 to 10000 psi	0.10%×	

*EG&G ATB/CSA 1250 temperature/conductivity bridge
+accuracy tied to standard water (.001) and bath stability
× EG&G Chandler Engineering dead-weight tester

CTD Conductivity

The conductivity sensor calibration variations for the nine laboratory calibrations over the four years are shown in Figure 1. Six of the conductivity calibrations show extreme variations of less than 0.01 mS/cm while the other three indicate extreme values of conductivity difference as large as 0.035 mS/cm. The changes between successive calibrations are without pattern. Changes occurred in both positive and negative directions with three of the eight changes in calibration consistent with the conductivity cell interior being coated with material (*i.e.*, CTD conductance being reduced with time). The three conductivity cell fouling (coating) examples are shown on Figure 1 with starting dates of September, 1986, February, 1988, and August, 1989. The data of Figure 1 suggest an extreme drift rate for the conductivity sensor of 0.003 mS/cm/month.

CTD Pressure

The time changes in the loading calibration curve for the pressure transducer are shown in Figure 2. Again, the changes between successive calibrations are without pattern. The range of pressure sensor bias change (ΔP observed at zero pressure) is 3 decibars while the range of pressure variations at 6000 decibars is 5.5 decibars. Some of this variation could be uncorrected temperature changes during the calibration run. The 5.5 decibar variation at 6000 decibars is within the ± 0.10% specification of the strain gauge transducer. The extreme drift rate of the pressure transducer calibration is 1 decibar/month.

CTD Temperature

The temperature changes for the first two temperature sensors are shown in Figure 3 with the solid curves being the original sensor and the dashed curves the replacement of

January, 1988. The expected drift of a platinum thermometer from the build up of strain within the resistive element is towards the CTD reading high with increasing time (*i.e.*, increasingly negative differences on Figure 3). The first thermometer does not exhibit this behavior, but rather drifts in the opposite direction. The replacement thermometer begins drifting in the same direction as the first probe but shifts in the direction consistent with strain building after CTD No. 1104 was used extensively in October, 1988. The extreme time change of temperature calibration is 0.0015°C/month.

Table 3 is a summary of extreme drift rates observed between successive laboratory calibrations for CTD No. 1104 over the past four years.

Table 3

Pressure	1.0 dbar/month
Temperature	0.0015°C/month
Conductivity	0.003 mS/cm/month

3. Comparison of EG&G and IOT Facility Standards

There has been no direct exchange or comparison of the standards or substandards between the EG&G and IOT facilities. This would be a worthwhile endeavor in a future cooperative calibration effort. For purposes of these intercomparisons, we have only the CTD sensors as a rudimentary transfer standard between facilities. Table 3 suggests that drift of the CTD sensors must be kept in mind in interpreting the difference of any individual calibration pair but since the observed drifts of all three sensors were in both a positive and negative direction over the four years, average characteristics across all intercalibration pairs may yield significant information. For temperature and pressure, we will look at the aggregate of the comparison data pairs between the two facilities. The variations of conductivity are larger and they are only compared on an individual basis.

Reference Temperature

Observations of EG&G and IOT temperature calibration comparisons for only six of the seven comparison dates are possible. We exclude the July–September, 1987 calibrations as the temperature sensor of CTD No. 1104 drifted by 0.02°C within a few days at IOT and 0.05°C from the pre-cruise to the post-cruise calibration at the EG&G facility. Figure 3 shows the various EG&G temperature calibration curves while Figure 4 shows the same plots for those temperature calibrations carried out at IOT. Notice that the same symbols are used for corresponding pairs of pre-cruise calibrations. Figure 5 shows the difference between corresponding pre-cruise EG&G and IOT temperature calibration curves. If we assume that the CTD temperature sensor does not drift in shipment to IOT, Tianjin, China, then Figure 5 represents a comparison of the laboratory temperature standards. In Figure 5, the ordinate is defined as [EG&G – CTD] – [IOT – CTD]. The CTD observations must be stable for this to reduce to the difference of facility temperature standards. If we exclude the difference for February/March, 1988 (it is not clear why it is anomalous), a fairly consistent cruise-to-cruise variation emerges with an average difference of 0.002°C at 0°C with the EG&G standard reading warmer. This is somewhat larger than the difference of ± 0.00025°C that is the stated accuracy of a well-maintained, good quality triple-point-of-water reference cell, but within the stated overall temperature accuracy for the EG&G facility. The least squares linear fit line (large dashes on Figure 5) shows a difference which grows to 0.0035°C at 30°C. The distribution of differences, excluding the February/March, 1988 calibration, is summarized in the histogram of Figure 6. The standard deviation of the differences is 0.0021°C for all temperatures, and appears to be a minimum at the 15 and 20°C values: the room temperature range. One interpretation of the temperature scatter is that bath temperature gradients and temporal variations in one or both facilities cause an uncertainty with an RMS variation of 0.002°C. A second possible explanation is that slight changes in the temperature circuit linearity created by partially versus fully immersing the CTD cause changes in the shape of the calibration curve. The fully immersed IOT calibration curves in Figure 4 appear to have slightly more curvature than the EG&G curves in Figure 3.

Reference Pressure

The individual pairs of EG&G and IOT pre-cruise pressure calibration curves are shown in Figures 7a–g. The loading calibration curves are solid while the unloading curves are dashed. Both the EG&G and IOT calibrations show that the unloading calibration curve is up to 5 decibars below the loading curve in a very predictable and characteristic manner. Comparisons between the two facilities are carried out on the loading calibrations. The loading pressure calibration curves are shown on Figure 8, with the IOT calibrations dashed and EG&G's as solid curves. The IOT data appear to lie above the EG&G points in Figure 8. A set of differences between each pair of pre-cruise calibration curves has been formed at 1000 decibar intervals and the results are shown in Figure 9. A linear interpolation of the EG&G pressure calibration was performed to obtain calibration values at pressure values coincident with the IOT observations. As before, the difference is defined as [EG&G – CTD] – [IOT – CTD]. If we again can assume a stable CTD pressure, the plots represents the "reference pressure difference" for the two laboratory dead-weight testers. The "reference pressure difference" of Figure 9 shows that the EG&G dead-weight tester standard values read lower than IOT for nearly all observations. The July–September, 1988 data comparison is anomalously low and is excluded when forming the least-squares linear regression line shown in Figure 9. The regression equation is $P = -0.00013p - 0.64$ decibars. The regression bias of -0.64 implies that either the fluid head bias correction is not correct for one or both pressure standards or there is a systematic change in the CTD calibration between EG&G and IOT. Many of IOT the pressure calibrations were performed at several temperatures and the warmer calibration is chosen for display in Figures 8 and 9. The temperature of this pressure calibration for IOT varies between 25 and 32°C as indicated on Figures 7a–g but are always warmer than the 22 to 24°C of the EG&G pressure calibrations. Two pressure calibration runs at 0 and 32°C performed at IOT are shown in Figure 10. The sense of the temperature induced CTD calibration shift is consistent with the average difference shown on Figure 9, that is, the −0.64 decibar difference implies that the temperature of the IOT pressure calibrations averaged 4°C warmer than EG&G. This difference is of both the correct sense and magnitude to be an uncorrected thermal effect in the CTD pressure transducer. The pressure differences on which the linear fit was computed have a standard deviation of 1.3 decibars. The histogram of the differences in Figure 11 shows the most probable difference is 1.5 decibars. The mean pressure difference and standard deviation between EG&G and IOT dead-weight testers suggests that both facilities maintain these standards to an accuracy of 0.05% which is better than the stated accuracy of both facilities' standards.

Reference Conductivity

The IOT and EG&G conductivity calibration methods are most different, as are the results. The CTD No. 1104 conductivity cell's lack of time stability as shown earlier in Figure 1 contributes to the lack of comparability of the conductivity results. The calibration results are displayed with an IOT conductivity calibration curve displayed together with the time bracketing EG&G conductivity calibrations in Figures 12a–e. Differences as large as 0.01 mS/cm between pre-cruise IOT and EG&G calibrations are observed. The September, 1986 IOT conductivity calibrations show changes of 0.005 mS/cm between successive days' calibrations in a direction consistent with the CTD conductivity cell fouling. The IOT conductivity calibration runs show the standard data to be larger than the CTD observations at high conductivities when compared with the EG&G conductivity calibrations. Both the IOT and the EG&G conductivity variations show the need for continual monitoring of the CTD conductivity sensor at sea with rosette water sample salinity data.

Summary

Of the CTD sensor calibration conducted at the EG&G and IOT facilities for pressure, temperature, and conductivity, those for pressure give the most consistent results with an average difference of less than 1 decibar. Most of the pressure difference represents an offset of roughly 0.6 decibars which is likely due to the absence of proper thermal correction in the CTD pressure transducer. The temperature calibrations between the EG&G and IOT facilities differ on average by between 0.002°C at 0° and 0.0035°C at 30°C with the EG&G temperature standard reading warmer. The temperature difference is eight times as large as the expected temperature uncertainty of triple-point-of-water cells. The poorest comparison is between conductivity calibrations of the two facilities due in large part to the lack of stability of the CTD conductivity sensor. Some difference may also be due to how the two facilities derive standard conductance information.

The results of this series of intercalibrations between US and PRC calibration facilities indicate that cooperative international field programs such TOGA and WOCE can obtain field measurements with a fairly uniform accuracy using geographically widely separated calibration facilities. Future intercalibrations would be enhanced by the more direct exchange of portable transfer standards.

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APPENDIX

Assessment of Calibration Facility Accuracies

The following contains descriptions of IOT Tianjin and EG&G Ocean Products calibration equipment and methodology. The author of each section is a member of the staff of that facility and has included their personal assessment of the overall accuracy of the calibration facility. The Woods Hole calibration methodology can be found in WHOI Technical Report 74-89. N. L. Brown has visited or worked at all three facilities and provides the following overall comments on accuracy:

The accuracy of the IOT temperature calibration facility as stated in the appendix (0.001°C) is not consistent with the generally accepted accuracy of this type of calibration equipment. Furthermore the gradients in the Tianjin calibration baths (0.002°C) as stated in the appendix would suggest that larger errors should be expected. It was the observation of one of the authors (Brown) that the calibration facility at Tianjin was not air conditioned at the time of his visit in September 1987. The lack of air conditioning, along with the temperature effects on the resistors in the Smith bridge and the stated gradients in the calibration bath would suggest that an accuracy of 0.003 to 0.004°C is perhaps more realistic.

The EG&G calibration facility is in a temperature controlled room and uses a bridge where the critical resistors are in a thermally regulated enclosure inside the bridge which is kept to within .025°C. The ratio measurement is performed using precision ratio transformers which have initial errors of less than 0.3 ppm and have essentially no drift with temperature or time. The Tronac calibration baths are very stable and have gradients which are typically less than .001°C, although the heat conduction through the partially immersed CTD housing likely increases the temperature gradients in the bath .0020°C. Hence it is felt that the accuracy stated in the appendix (0.0025°C) is realistic.

The present report notes difficulty intercomparing conductivities between EG&G and IOT. During a visit to IOT by another author (Schaaf), he observed that cell wetting, cleaning, and debubbling procedures employed at EG&G prior to calibration were not performed at IOT in April 1988. The lack of debubbling could result in a high concentration of air bubbles in the conductivity bath which would almost certainly cause instability in the measurements.

IOT STD/CTD Calibration Facility

Submitted by Yu Houlong, Tang Yuo Xin, and Jia Zhaoji

Introduction

IOT has maintained an oceanographic salinity, temperature, and pressure calibration laboratory since 1970. In order to improve calibration of CTD/STD instruments, IOT developed a calibration facility (IOT Model Number JZA2-1) for the evaluation of salinity, temperature, and pressure instruments in 1986.

Performance Specifications:

Variable	Range	Accuracy	Resolution
Temperature	−2 to 40°C	± 0.001°C	0.0005°C
Salinity	0 to 40 ppt	± 0.001 ppt	0.0002 ppt
Pressure	0 to 60 Mpa	± 0.05% +	

\+ Percent full scale

Description of the Facility:

A Smith Bridge (Model 4162) with a standards grade platinum resistance thermometer, Autosal Model 8400 salinometer, and a dead-weight tester are used to measure the standards of temperature, salinity, and pressure, respectively. These instruments are located in air-conditioned rooms where temperature is maintained at 20°C (± 1°). The calibration seawater bath, the seawater storage tanks, the primary bath, and the microcomputer control unit are located in rooms which are air-conditioned.

STD/CTD Calibration Bath

The heart of the facility is the calibration bath which is filled with natural seawater. The temperature of the bath is controlled by a microprocessor with a resulting stability of ± 0.001°C (see Performance Specifications above) through the ocean temperature range (−2 to 40°C). When the temperature difference between the bath temperature and the set temperature is large, the computer switches on the heaters or opens the cooling fluid valve to decrease the difference. When the difference is sufficiently small, the computer enters the "proportional control mode." First, all "coarse control" heaters are switched off, and the cooling valve is closed. In accordance with the control algorithm, the computer opens the cooling valve at an appropriate angle to give a small amount of cooling. Then, the computer controls power to the "fine control heater" to balance the effect of the cooling water, thus establishing dynamic temperature equilibrium at the set point. The calibration bath is big enough to accept the commonly used STD/CTD instruments fully immersed. The design of the bath, stirrer, and control system result in good thermal homogeneity and stability.

The specifications of the bath are as follows.

Capacity : 700 Liters
Dimensions of Bath : 900 x 1200 mm
Dimensions of the Inner Bath : 700 x 1000 mm
Temperature Stability : ± 0.001°C
Horizontal Temperature Gradient : 0.002°C
Vertical Temperature Gradient : 0.001°C
Average Temperature Falling Rate : 0.20°C per minute
Average Temperature Rising Rate : 0.2°C per minute

Pressure Calibration

Pressure is calibrated using a dead-weight tester. Measurements are made by stacking weights on top of the tester's piston, increasing pressure and taking readings from the CTD instrument. This procedure is done in ascending and descending order until the instrument has been cycled at least 2 to 3 times from zero to full scale and back to zero at several temperature points (0 and 30°C).

Certification of the Transfer Standards

Temperature

The National Institute of Metrology certifies the Smith Bridge and the standards grade platinum resistance thermometer every two years.

Salinity

The Autosal 8400 salinometer is calibrated with the use of IAPSO International Standard Seawater.

Pressure

Verification of the dead-weight tester is performed by Tianjin Metrological Service every other year.

Comments

The following comments were added as this report was going to press by Yu Houlong:

(1) The Smith Bridge which was used by IOT is put in a well conditioned room (20 ± 1°C) and the critical resistors in the Smith Bridge are in a fine thermally regulated (25 ± 0.5°C). The IOT facility temperature accuracy is 0.002–0.003°C considering all of the effects.

(2) The conductivity Calibration Data in April 1988 recorded after cell wetting, cleaning, and debubbling done by Mr. Dan Schaaf.

(3) One of the three EG&G Tronac calibration Baths (room temperature bath) is very stable as EG&G stated, but the 0°C and the 30°C Tronac calibration bath not as stable as the first one (it was the observation of one of the authors (H. Yu).

EG&G Calibration Procedures

Submitted by Dan Schaaf

Laboratory Standards Equipment

The laboratory standards equipment for temperature and conductivity measurements at EG&G Marine Instruments is the Model ATB-1250 Automatic Thermometer Bridge and the Model CSA-1250 Conductivity Salinity Adaptor.

The ATB-1250 includes an IEEE-488 interface for automatic data collection to a computer. For the measurement of temperature the ATB-1250 is connected to a standards grade platinum resistance thermometer (Model 162CE made by Rosemount Engineering).

For the measurement of conductivity the ATB-1250 is connected to a 5-electrode quartz conductivity cell via the CSA-1250 interface module. The ATB-1250 collects data at the rate of one sample every 1.25 seconds.

The ATB-1250 bridge and CSA-1250 conductivity interface contribute negligibly to the total error of conductivity. The errors due to factors external to the bridge such as calibration against primary standard, gradients in the bath, drift in the thermometer or conductivity cell, operator skill and other factors are conservatively estimated to be:

Variable	Range	Accuracy	Resolution
Temperature	0 to 32°C	.0025°C*	.00001°C
Conductivity	1 to 100 mS/cm	.0025* mS/cm	.000002 mS/cm

Pressure Calibration

Pressure calibration at EG&G is performed using a Chandler Engineering Deadweight Tester Model 58-001J-T-5. The accuracy claimed by the manufacturer (NBS traceable calibration) is 0.1%* and the range is 0 to 10,000 psi.

Temperature Calibration Bath

The temperature baths used at EG&G are the Tronac Model CTB-1000A constant temperature bath. The capacity of each bath is 20 gallons of water. The electronic control unit and sensing probe maintain the temperature of the water to better than ± 0.001°C. A unique feature of

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*Since these intercalibration experiments were performed, the following improvements to the calibration laboratory have been implemented: insulation of the conductivity baths, improved mixing techniques, refinements to the acquisition and processing of calibration data, temperature control, and the addition of a Ruska Dead-Weight Tester. This has resulted in a significant improvement to the EG&G calibration process accuracy.

the Tronac bath is that the expansion coil used for cooling is also used simultaneously as the heater element. This eliminates the separate "hot" and "cold" streams and the problems of adequately mixing them to minimize gradients. Data from the CTD and ATB-1250 bridge are simultaneously collected by a desk top computer (PC compatible). The data taken at each temperature is averaged for 1 minute.

Conductivity Calibration Baths

Conductivity calibrations at EG&G Marine Instruments are performed using five saltwater baths (at room temperature) each of different salinities such that the resulting conductivities range from 25 to 55 mS. These baths have circulating pumps and filters to remove particulate matter and are well stirred using laboratory stirring motors and propellers imparting both vertical and horizontal motion. A correction is made to take into account the difference in thermal coefficient of linear expansion of the alumina CTD cell relative to the quartz conductivity cell on the CSA-1250 expanding around a temperature of 15°C.

Pressure Calibration Procedure

Pressure calibration of the CTD is performed by connecting a stainless steel pipe from the dead-weight tester to the CTD pressure port or directly to the pressure transducer (transducer removed from CTD) via a special mounting block. Weights are added or removed to generate pressures in ascending and descending increments for 2 to 3 calibration cycles. To determine the effect of temperature, the transducer is cooled using crushed ice and the above pressure calibration cycles are repeated.

Calibration Of Transfer Standards

Temperature Transfer Standard

The ATB-1250 Automatic Thermometer Bridge is calibrated monthly by first checking it against the internal and external resistance standards. The thermometer is then placed in the triple-point-of-water cell to check resistance of the thermometer at the triple point (0.0100°C). The R_o value of the thermometer is then calculated and entered into the ATB-1250 as one of the calibration coefficients.

Conductivity Transfer Standard

The CSA-1250 conductivity/salinity adaptor and standard quartz cell are calibrated by filling the cell with standard seawater, closing off the the cell and immersing it in a stable 15°C bath. As soon as the cell and contained sea water are in thermal equilibrium with the bath, conductivity and temperature readings are taken and compared with conductivity calculated from the stated salinity and the measured temperature of the standard seawater. The above calibration is performed monthly.

Figure Captions

Figure 1: CTD serial number 1104 conductivity sensor calibration variations using EG&G standard between April, 1986 and February, 1990.

Figure 2: CTD serial number 1104 pressure sensor calibration variations when compared to EG&G dead-weight tester standard between April, 1986 and February, 1990.

Figure 3: CTD serial number 1104 temperature sensor calibration variations using EG&G temperature standard between April, 1986 and August, 1989.

Figure 4: CTD serial number 1104 temperature sensor calibration variations using IOT temperature standards between October, 1986 and September, 1989.

Figure 5: Differences between corresponding EG&G and IOT temperature calibration curves. The temperature difference is the variation of the two standards if the CTD is stable.

Figure 6: Histogram of "temperature standard differences" in m°C, assuming a stable CTD temperature sensor.

Figure 7a–g: Individual pairs of EG&G and IOT pre-cruise pressure loading and unloading (dashed) calibration curves.

Figure 8: Loading pressure calibration curves for EG&G and IOT (dashed).

Figure 9: Differences between corresponding EG&G and IOT pressure calibration curves. This difference represents variations between dead-weight tester calibrations for EG&G and IOT if the CTD pressure transducer remains stable.

Figure 10: IOT loading and unloading (dashed) pressure calibration curves run at 0°C and 32°C. Note the temperature induced pressure calibration change of between 3 and 5 decibars.

Figure 11: Histogram of "pressure standard differences" in decibars, assuming a stable CTD pressure transducer.

Figure 12a–e: Comparison of EG&G and IOT conductivity calibrations over time. Note each IOT calibration is bracketed by pre/post cruise EG&G conductivity calibrations.

Figures

FIGURE 1

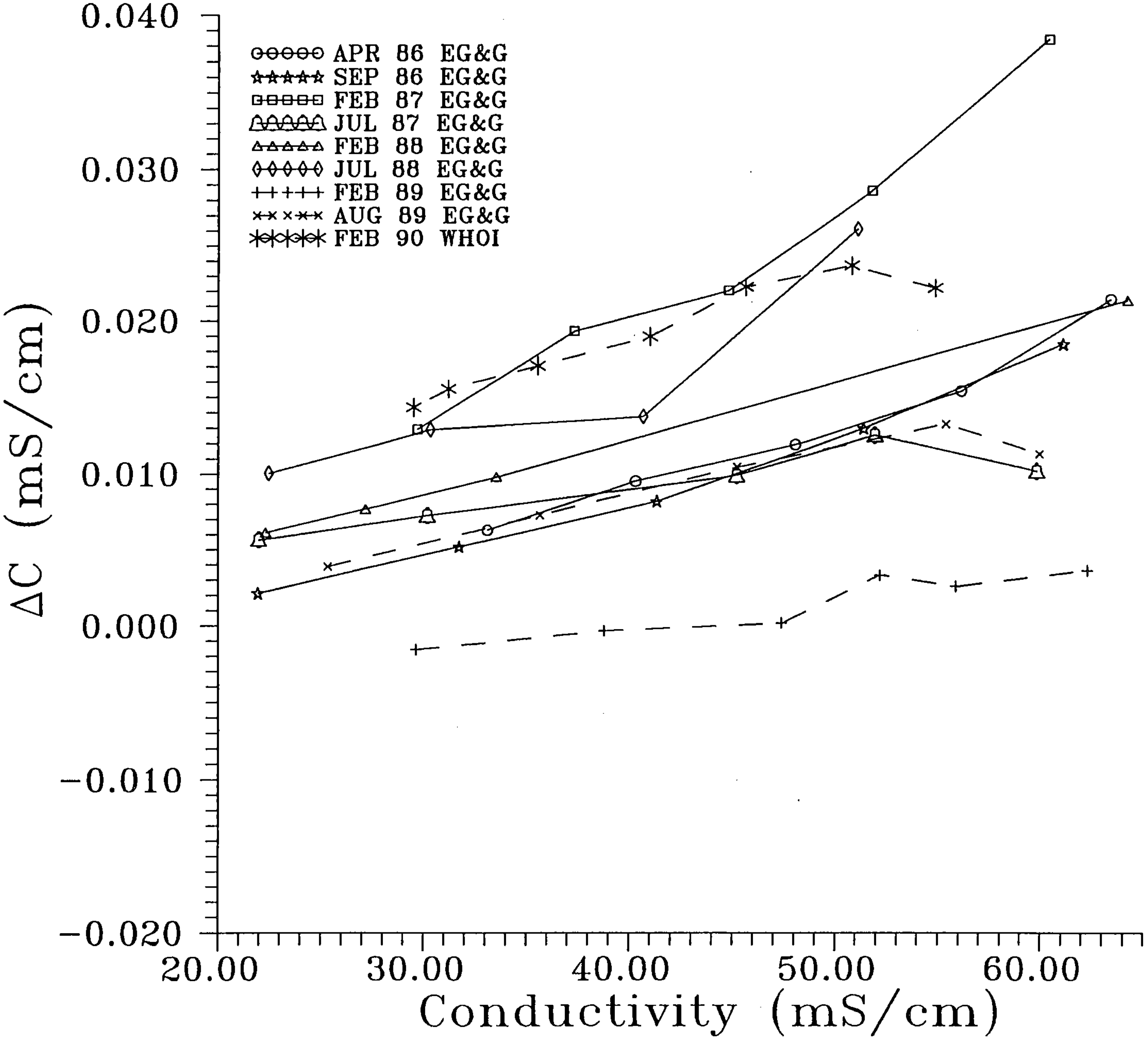

APR 86 EG&G
SEP 86 EG&G
FEB 87 EG&G
JUL 87 EG&G
FEB 88 EG&G
JUL 88 EG&G
FEB 89 EG&G
AUG 89 EG&G
FEB 90 WHOI
0.040
0.030
0.020
0.010
0.000
−0.010
−0.020
ΔC (mS/cm)
20.00
30.00
40.00
50.00
60.00
Conductivity (mS/cm)

FIGURE 2

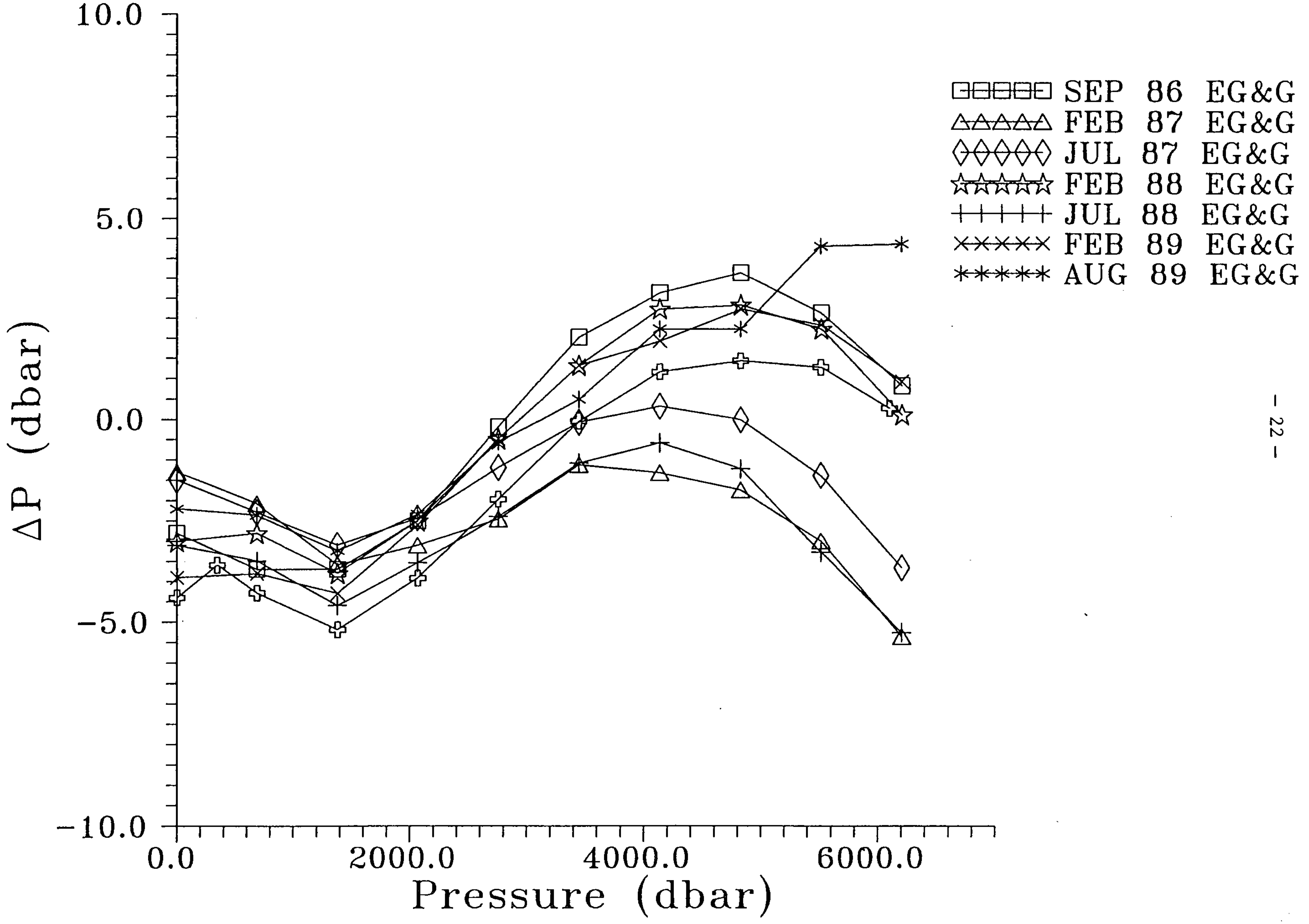

10.0
5.0
0.0
−5.0
−10.0
ΔP (dbar)
0.0
2000.0
4000.0
6000.0
Pressure (dbar)
SEP 86 EG&G
FEB 87 EG&G
JUL 87 EG&G
FEB 88 EG&G
JUL 88 EG&G
FEB 89 EG&G
AUG 89 EG&G

FIGURE 3

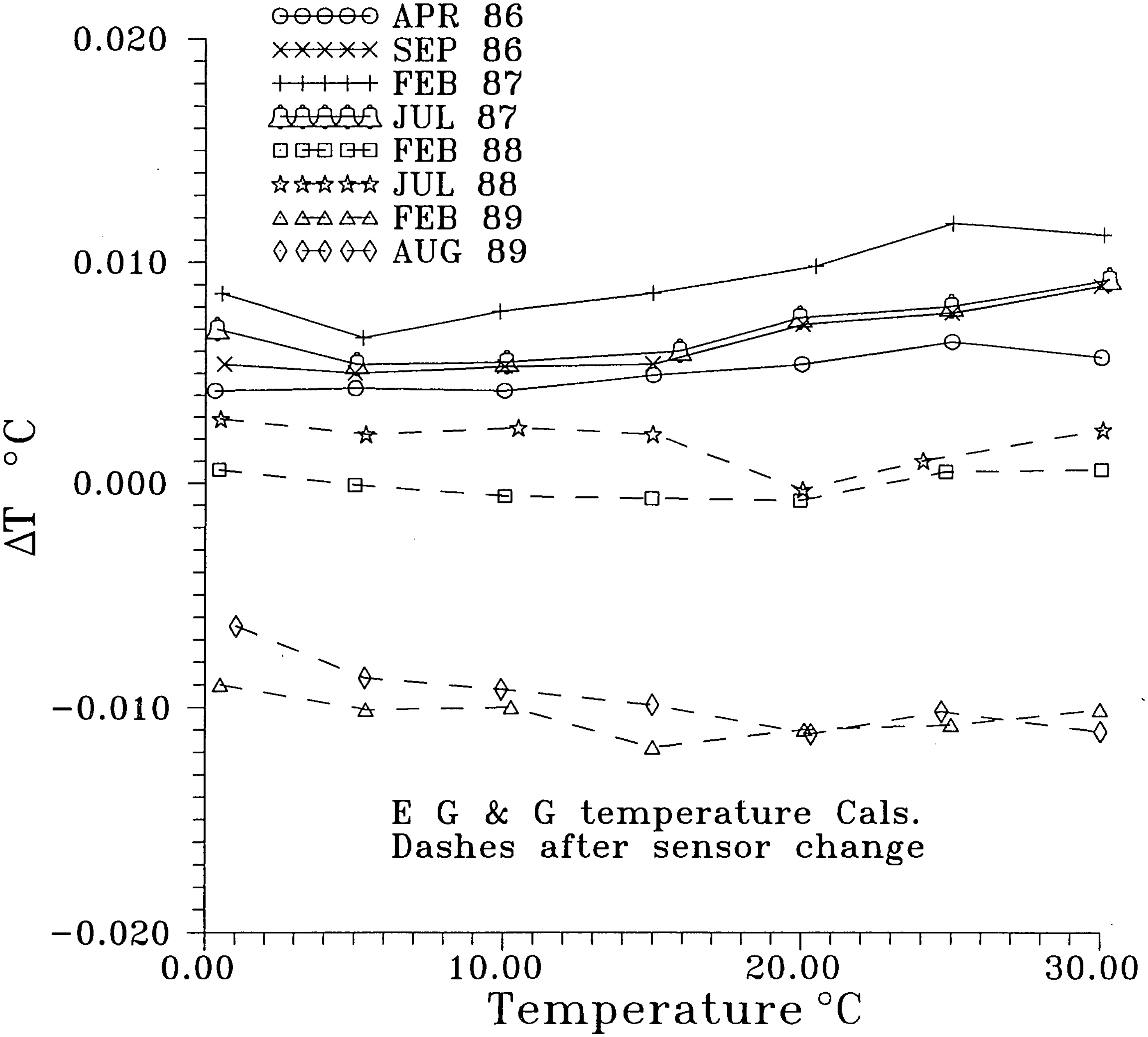

APR 86
SEP 86
FEB 87
JUL 87
FEB 88
JUL 88
FEB 89
AUG 89
0.020
0.010
0.000
−0.010
−0.020
ΔT °C
0.00
10.00
20.00
30.00
Temperature °C
E G & G temperature Cals.
Dashes after sensor change

FIGURE 4

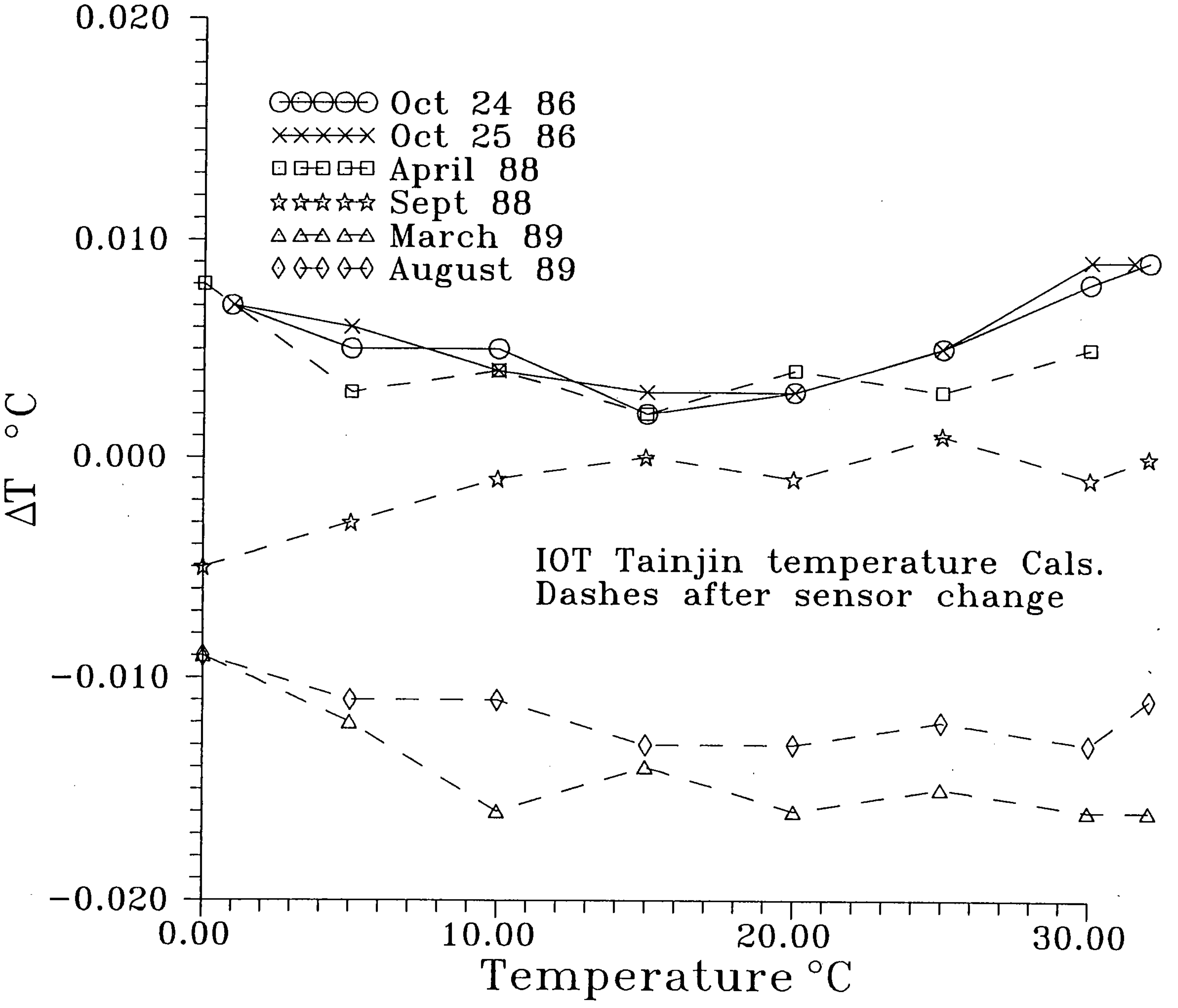

Oct 24 86
Oct 25 86
April 88
Sept 88
March 89
August 89
IOT Tainjin temperature Cals.
Dashes after sensor change
ΔT °C
0.020
0.010
0.000
−0.010
−0.020
0.00
10.00
20.00
30.00
Temperature °C

FIGURE 5

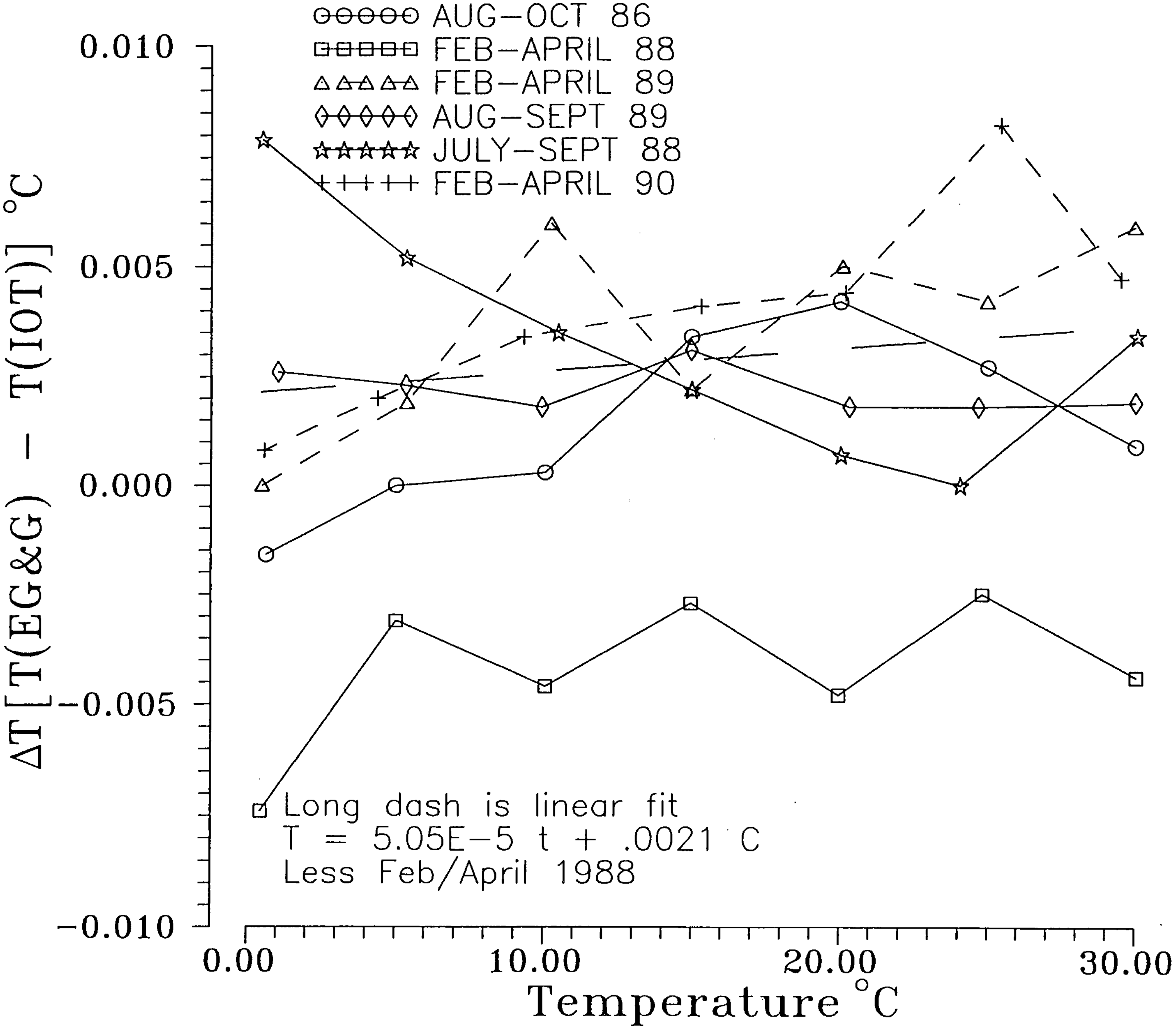
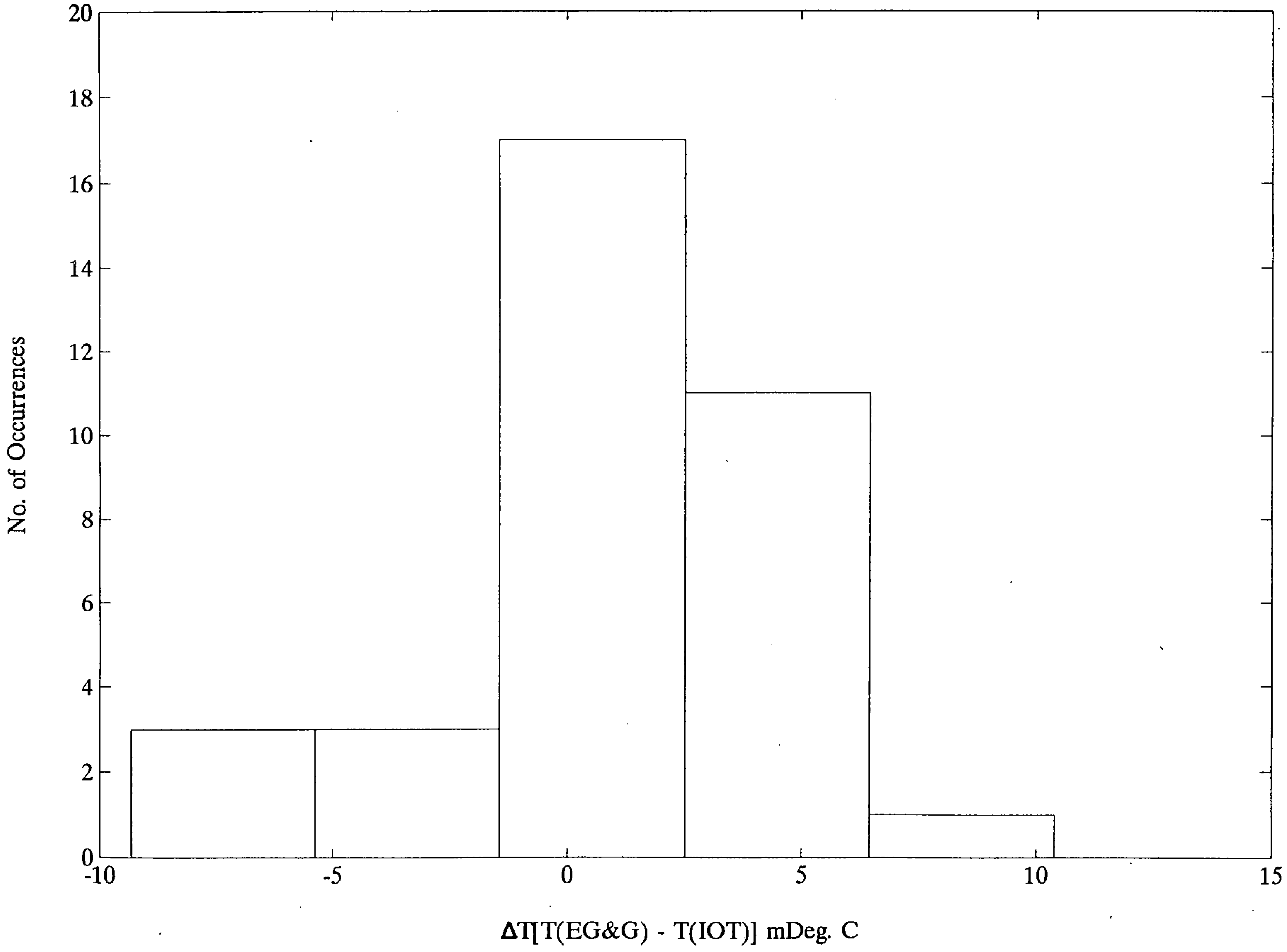

AUG—OCT 86
FEB—APRIL 88
FEB—APRIL 89
AUG—SEPT 89
JULY—SEPT 88
FEB—APRIL 90
Long dash is linear fit
T = 5.05E—5 t + .0021 C
Less Feb/April 1988
0.010
0.005
0.000
−0.005
−0.010
ΔT[T(EG&G) − T(IOT)] °C
0.00
10.00
20.00
30.00
Temperature °C

FIGURE 6


20
18
16
14
12
10
8
6
4
2
0
No. of Occurrences
-10
-5
0
5
10
15
ΔT[T(EG&G) - T(IOT)] mDeg. C

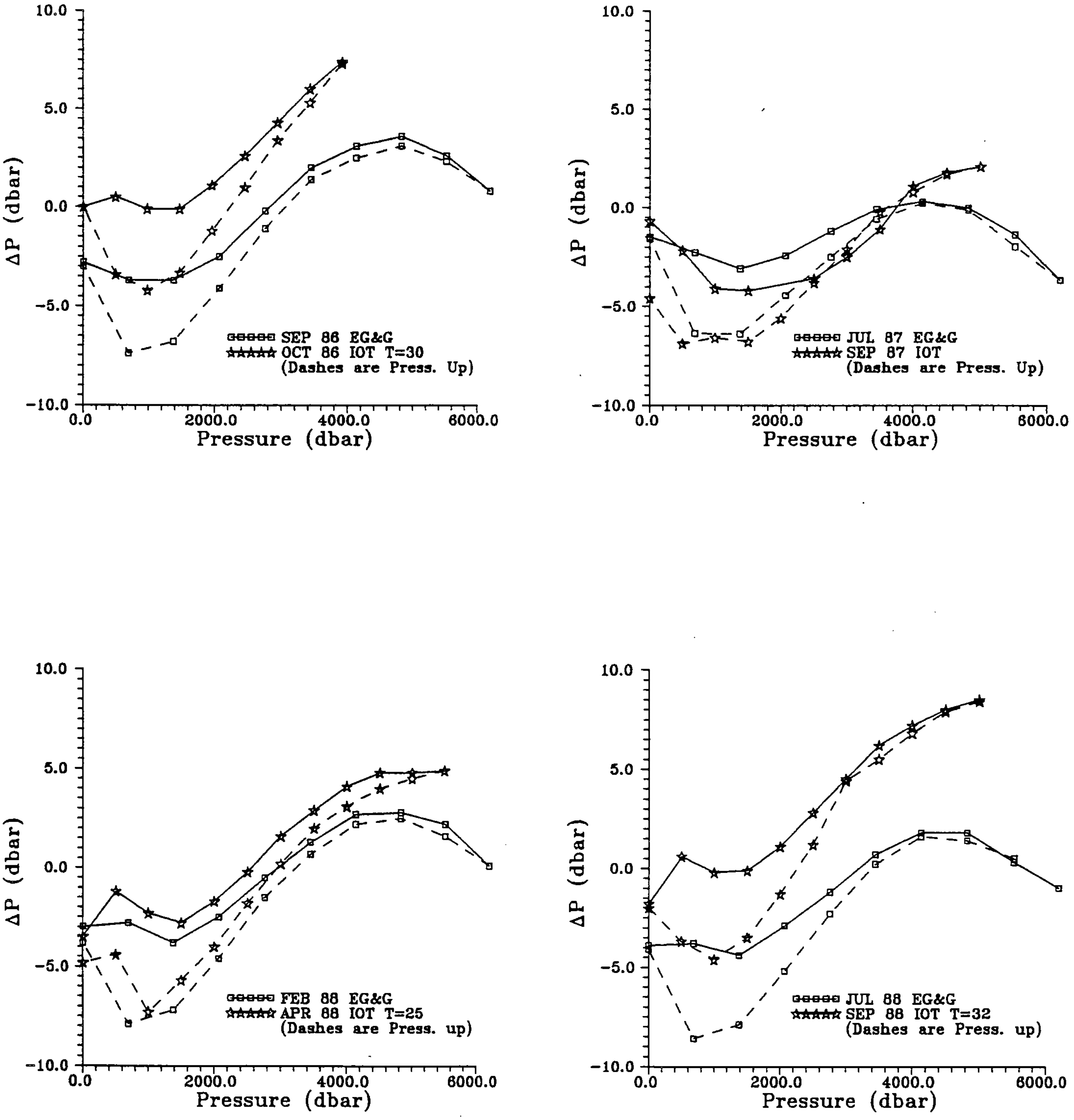

10.0
5.0
0.0
−5.0
−10.0
ΔP (dbar)
0.0
2000.0
4000.0
6000.0
Pressure (dbar)
SEP 86 EG&G
OCT 86 IOT T=30
(Dashes are Press. Up)
JUL 87 EG&G
SEP 87 IOT
(Dashes are Press. Up)
FEB 88 EG&G
APR 88 IOT T=25
(Dashes are Press. up)
JUL 88 EG&G
SEP 88 IOT T=32
(Dashes are Press. up)

FIGURE 7a—d

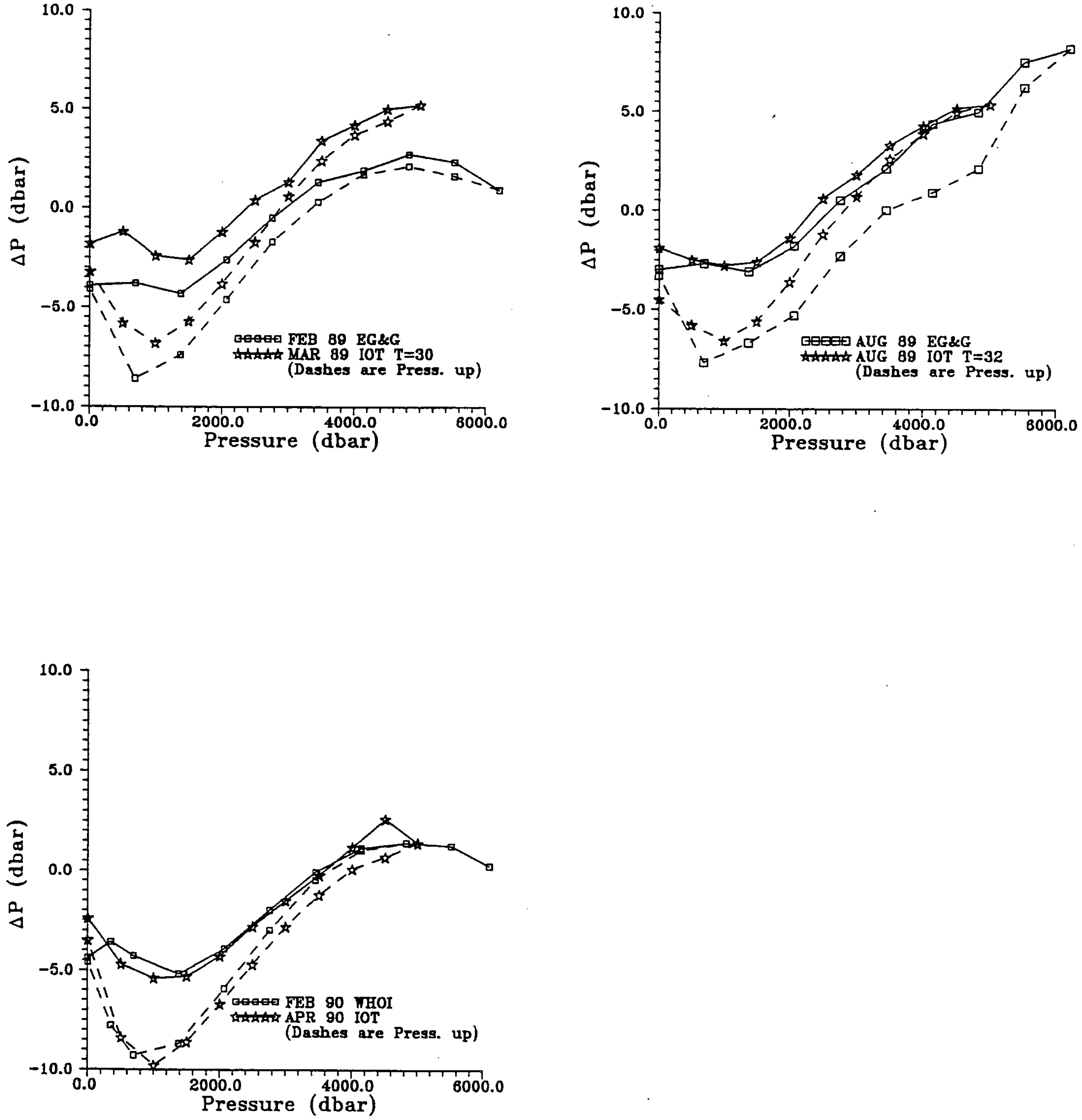

10.0
5.0
0.0
-5.0
-10.0
ΔP (dbar)
0.0
2000.0
4000.0
6000.0
Pressure (dbar)
FEB 89 EG&G
MAR 89 IOT T=30
(Dashes are Press. up)
AUG 89 EG&G
AUG 89 IOT T=32
(Dashes are Press. up)
FEB 90 WHOI
APR 90 IOT
(Dashes are Press. up)

FIGURE 7e—g

FIGURE 8

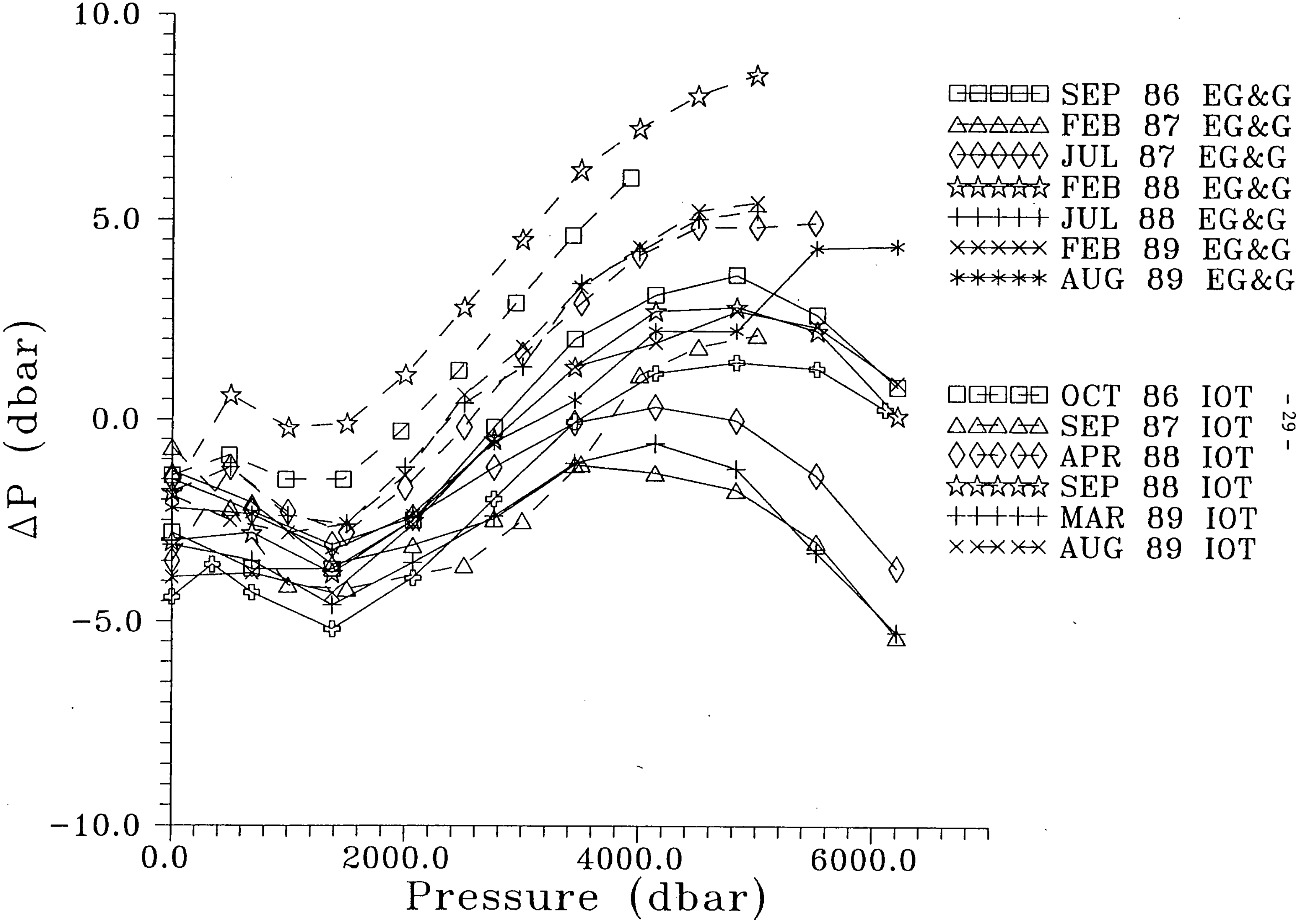
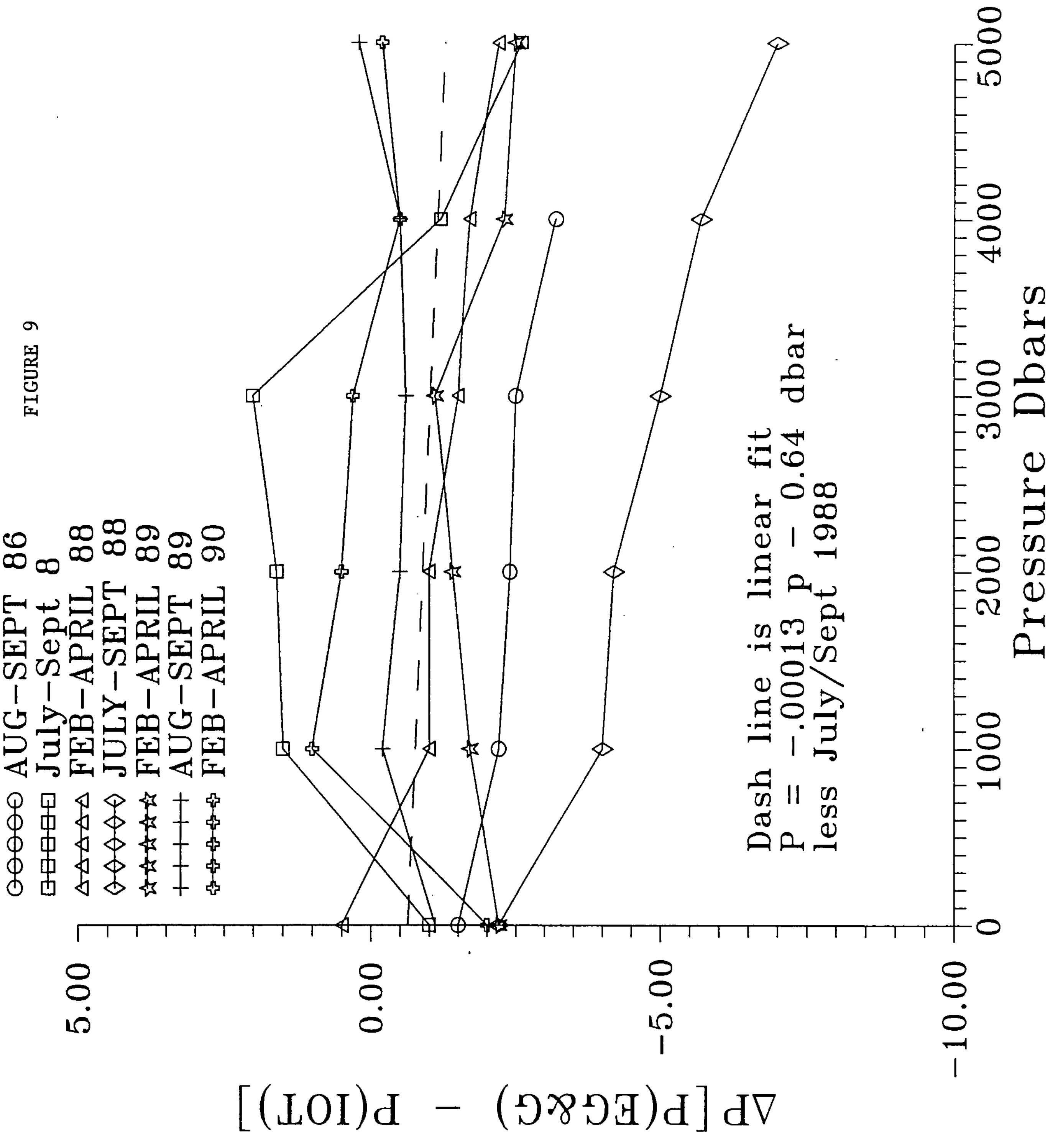

10.0
5.0
0.0
−5.0
−10.0
ΔP (dbar)
0.0
2000.0
4000.0
6000.0
Pressure (dbar)
SEP 86 EG&G
FEB 87 EG&G
JUL 87 EG&G
FEB 88 EG&G
JUL 88 EG&G
FEB 89 EG&G
AUG 89 EG&G
OCT 86 IOT
SEP 87 IOT
APR 88 IOT
SEP 88 IOT
MAR 89 IOT
AUG 89 IOT

FIGURE 9



Dash line is linear fit
P = -.00013 p - 0.64 dbar
less July/Sept 1988

FIGURE 10

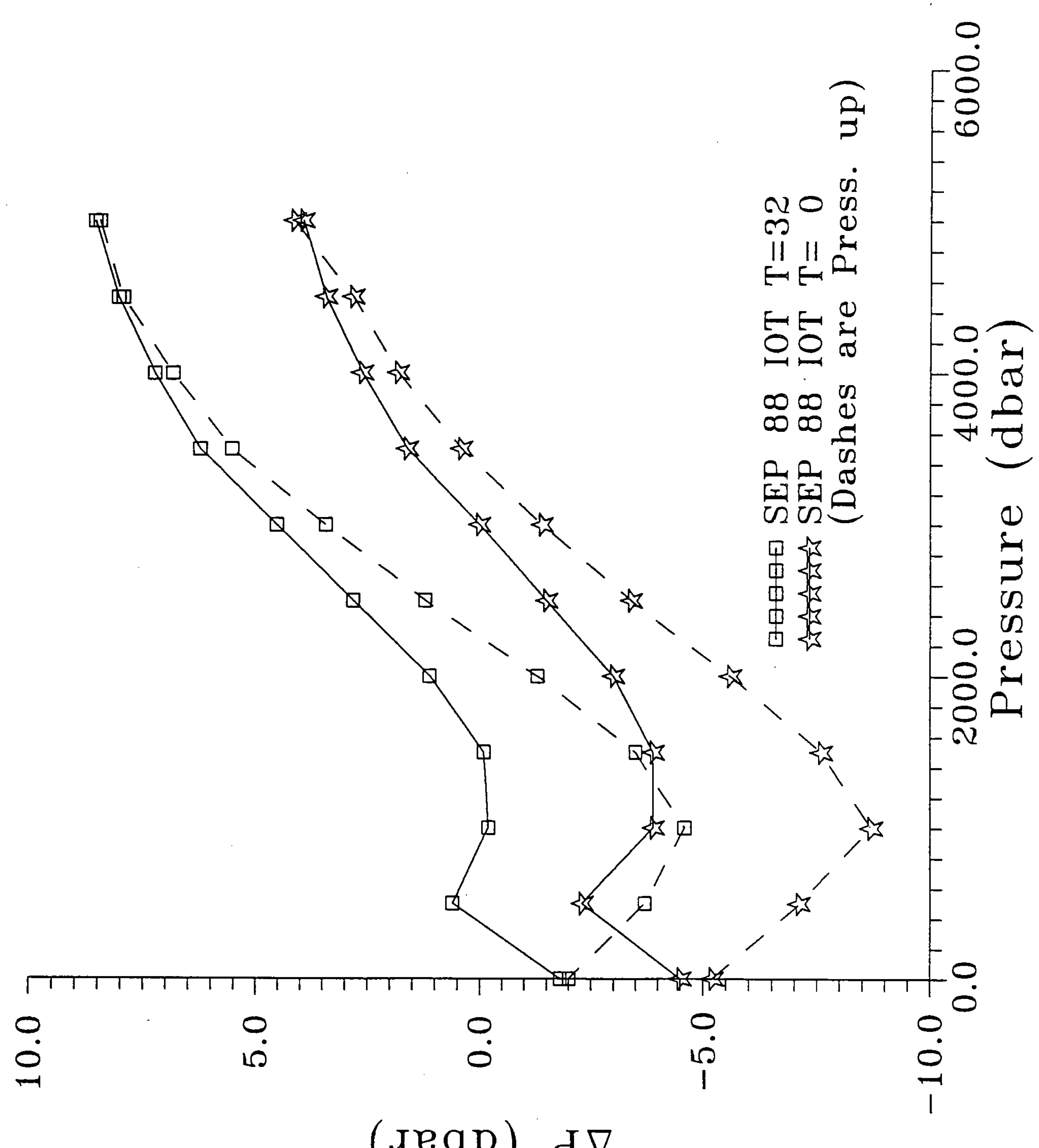
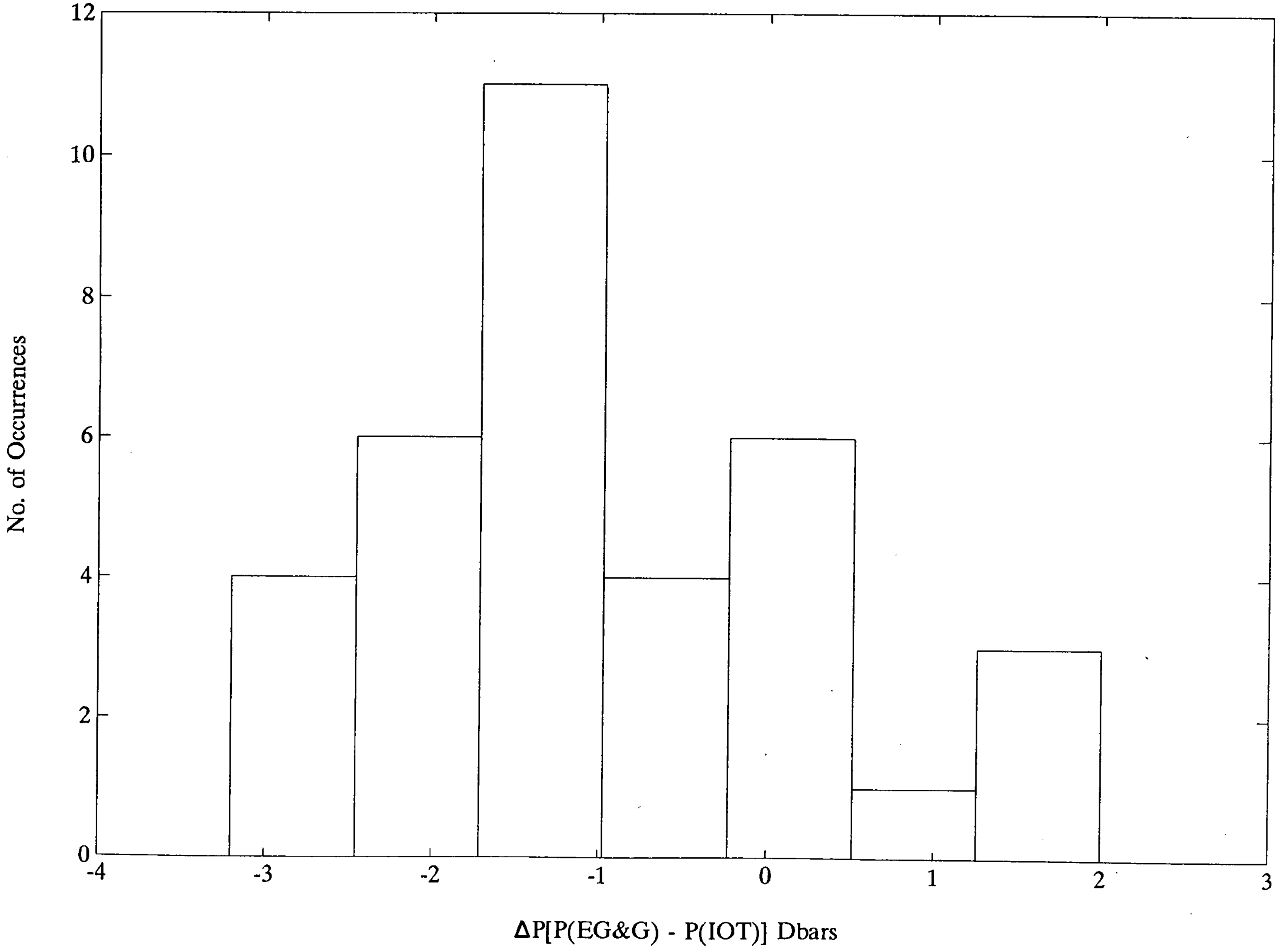

10.0
5.0
0.0
−5.0
−10.0
ΔP (dbar)
0.0
2000.0
4000.0
6000.0
Pressure (dbar)
SEP 88 IOT T=32
SEP 88 IOT T= 0
(Dashes are Press. up)

FIGURE 11



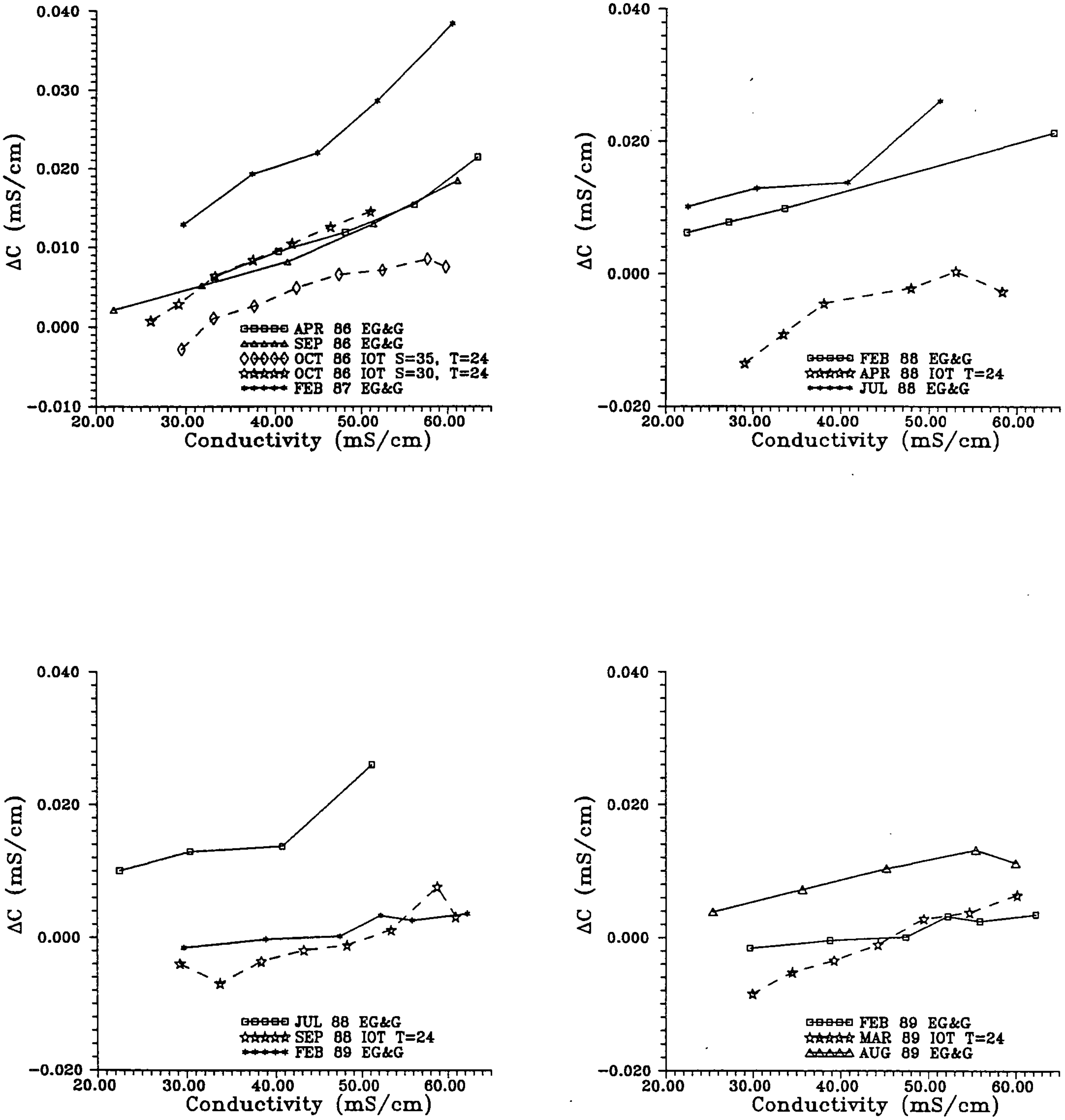
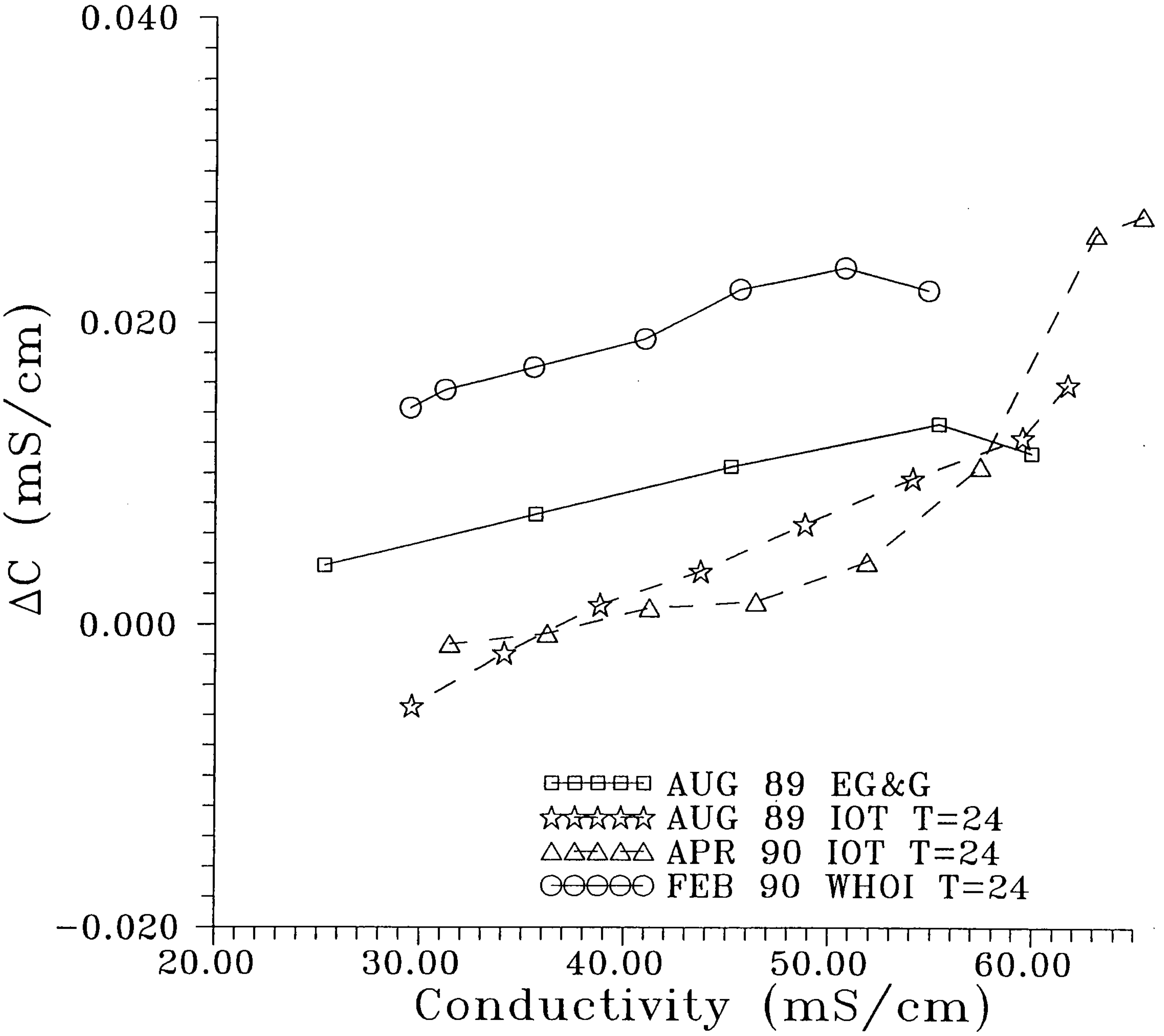

0.040
0.030
0.020
0.010
0.000
−0.010
−0.020
ΔC (mS/cm)
20.00
30.00
40.00
50.00
60.00
Conductivity (mS/cm)
APR 86 EG&G
SEP 86 EG&G
OCT 86 IOT S=35, T=24
OCT 86 IOT S=30, T=24
FEB 87 EG&G
FEB 88 EG&G
APR 88 IOT T=24
JUL 88 EG&G
JUL 88 EG&G
SEP 88 IOT T=24
FEB 89 EG&G
FEB 89 EG&G
MAR 89 IOT T=24
AUG 89 EG&G

FIGURE 12a–d

FIGURE 12e


0.040
0.020
0.000
−0.020
ΔC (mS/cm)
20.00
30.00
40.00
50.00
60.00
Conductivity (mS/cm)
AUG 89 EG&G
AUG 89 IOT T=24
APR 90 IOT T=24
FEB 90 WHOI T=24

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A series of laboratory intercalibrations of a CTD system were undertaken between 1986 and 1990 as part of cooperative research program between the United States (US) and People's Republic of China (PRC). A comparison of US and PRC calibration facility standards is carried out using a NBIS/EG&G Marine Instruments Mark IIIb CTD system as a "quasi-transfer standard." When compared with the quoted accuracy of the calibration facilities, pressure was found to be more accurate and temperature was about as accurate as stated. The conductivity standard differences between facilities are difficult to assess because of the CTD conductivity sensor drift.

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