Measurement Accuracy at Triple Point of Water and Gallium Melt Point supports a Total Measurement Uncertainty of 0.0006 degrees C

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Triple-Point-of-Water Cell

The Triple-Point-of-Water (TPW) Cell consists of a cylinder of borosilicate glass with a reentrant tube serving as a thermometer well, filled with high-purity, gas-free water, and sealed. When an ice mantle is frozen around the well, and a thin layer of this ice mantle is melted next to the well, the triple point of water temperature can be measured in the well. The three states of water in equilibrium can only occur at the assigned value on the International Temperature Scales of 0.01 degrees C (273.16 K).
(Figures 1 and 2)

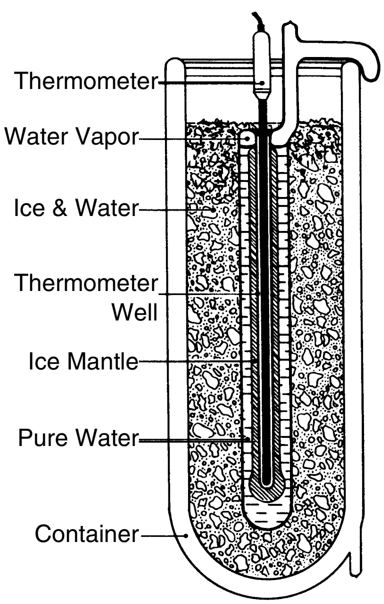

Figure 1. Triple-Point-of-Water Cell

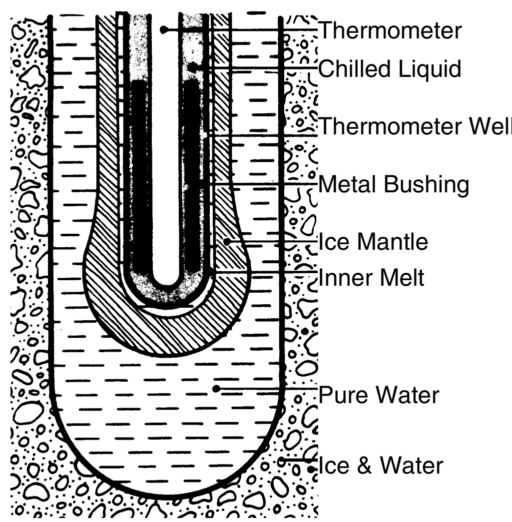

Figure 2. Cross Section of Triple-Point-of-Water Cell

Gallium Melt Cell

The gallium melt cell is a closed-end Teflon tube with a Teflon-tube reentrant well, aluminum shell, and Teflon jacket, filled with high-purity gallium metal. The frozen cell is heated above the gallium melt point (GaMP) temperature, establishing the gallium melt plateau, and allowed to melt over a period of 8 to 12 hours, achieving the assigned gallium melt temperature of 29.7646 degrees C. (Figure 3)

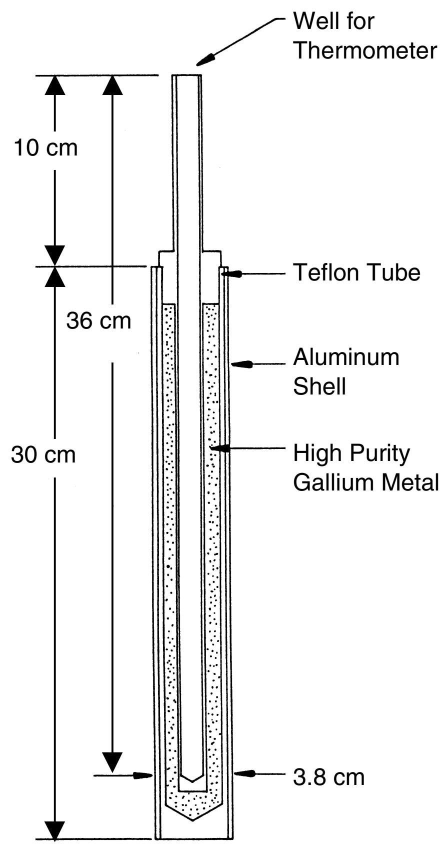

Figure 3. Gallium Cell

Measurement Uncertainties

Uncertainties in the achievement of high-accuracy temperature measurements for a Laboratory Standard Platinum Resistance Thermometer (SPRT) in the normal oceanographic temperature range include:

- **Accuracy of the measurement system at the fixed points**
  The NIST uncertainty budget was used to evaluate Sea-Bird measurements at the fixed points of GaMP and WTP. Included in the evaluation is over three years of data measurements at Sea-Bird in the fixed point cells. State-of-the-art SPRT, automatic balancing bridge, and external standard resistor reference were used to make the measurements. The uncertainty budget table provides the summary results. (Figures 4, 5, 6, and 7; Table 1)
- **Accuracy of the measurement system between the fixed points**
  Evaluation of the performance of the measurement system between the GaMP and WTP fixed points is not possible, but inferring from other subrange inconsistency evaluations and the narrowness of this range, the uncertainty would be very small.

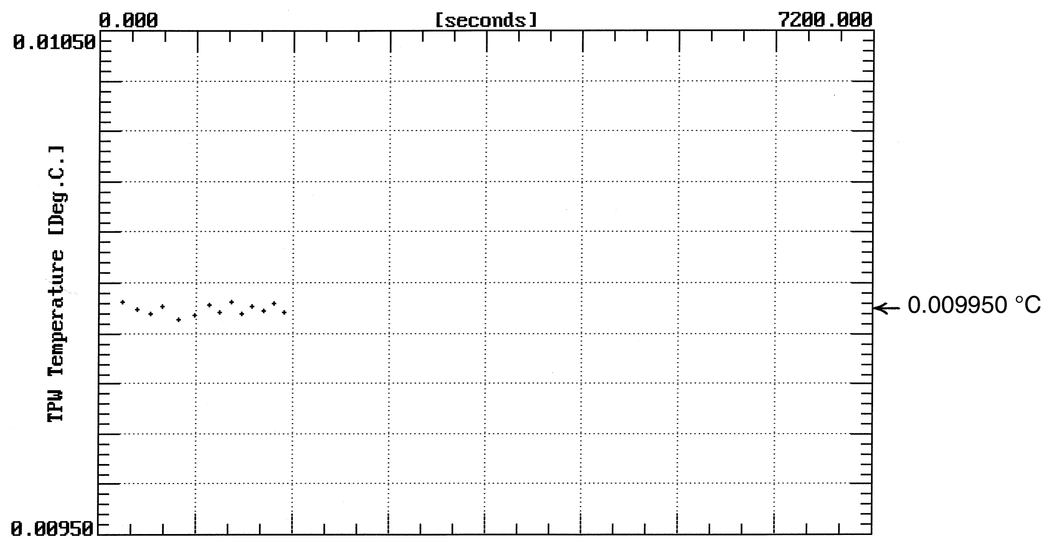

Figure 4. Triple Point of Water Measurements -
YSI SPRT S/N 4747 in Jarrett TPW Cell S/N 1866, 02 January 1998

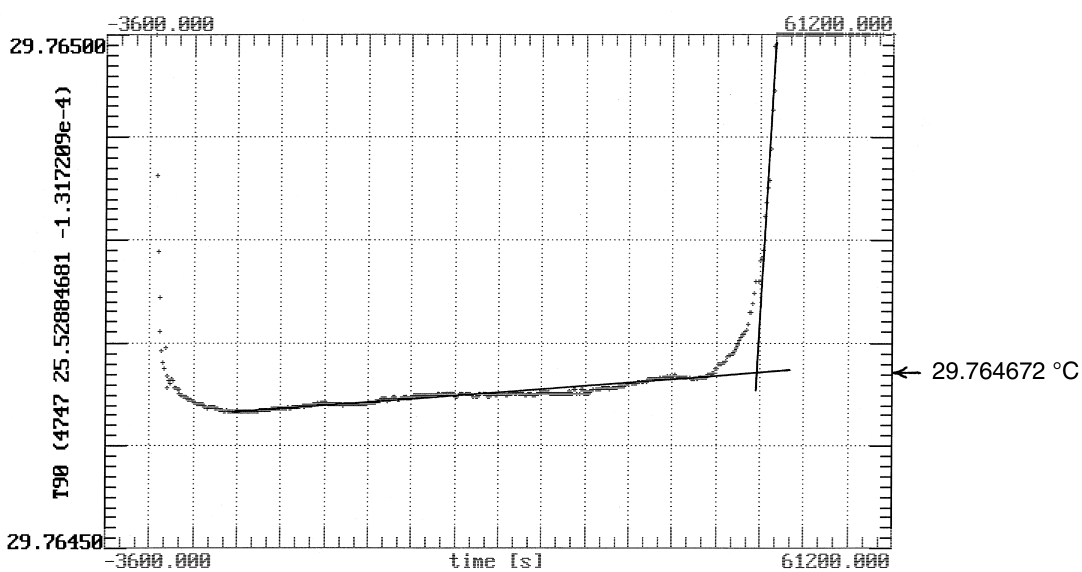

Figure 5. Gallium Melts -
YSI SPRT S/N 4747 in Isotech GaMP Cell S/N 114, 01 May 1996

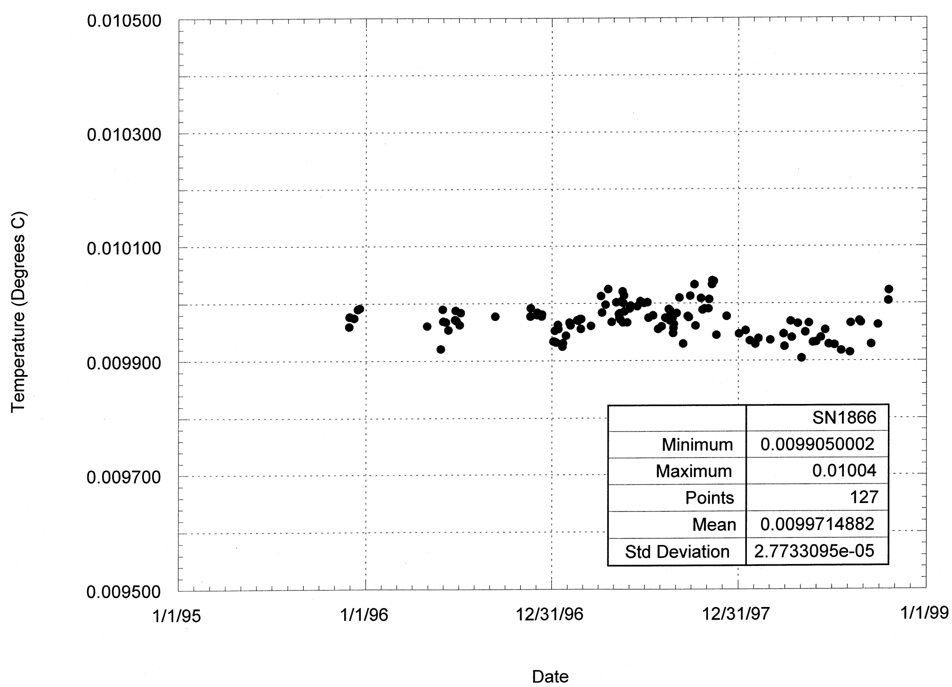

Figure 6. Triple Point of Water Temperature -
YSI SPRT S/N 4747 in Jarrett TPW Cell S/N 1866, 20 October 1998

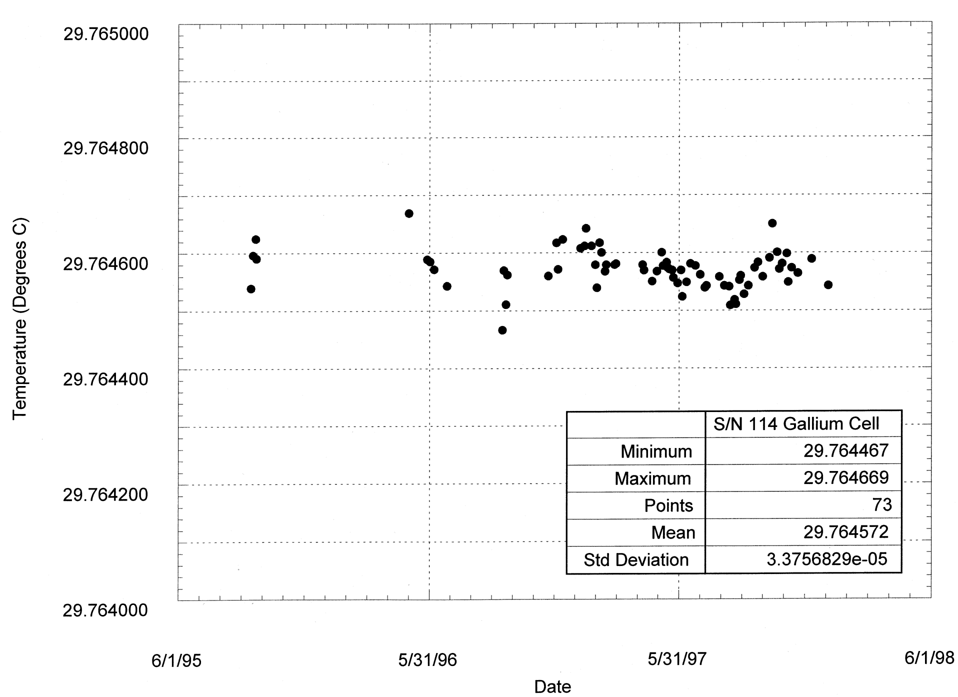

Figure 7. Gallium Melt Temperature -
YSI SPRT S/N 4747 in Isotech GaMP Cell S/N 114, 03 January 1998

Table 1

GaMP Uncertainty Budget

Isotech GaMP Cell S/N 114

Type A			
	Bridge measurement	(0.2ppm)	0.0000005
	Repeatability of bridge readings		0.000026
	Non-linearity		0.000000
	Quadrature effects in ac measurement		~0.000000
	Total A		*0.000027 (assumes ~0 non-linearity)*
Type B			
	Chemical impurities	(6N purity)	0.000137
	Hydrostatic-head	(~-270 microK)	~0.000010 (at end point)
	Propagated TPW		0.000031
	SPRT self-heating	(-420 microK)	0.000010
	Immersion		~0.000000
	Moisture	(Dry Ice Test)	0.000000
	Gas pressure		0.000000 (at GaMP assumed)
	Insulation degradation (mostly high temperature problem)		0.000000
	Total B		*0.000188*
	Total Standard Uncertainty		***0.000190***
	Total Expanded Uncertainty (k=2)		***0.000380***

TPW Uncertainty Budget

Jarrett TPW Cells S/N 1682, 1866, etc.

Type A			
	Bridge measurement	(0.2ppm)	0.0000005
	Repeatability of bridge readings		0.000026
	Non-linearity		0.000000
	Quadrature effects in ac measurement		~0.000000
	Total A		*0.000027* (assumes ~0 non-linearity)
Type B			
	Chemical impurities	(Jarrett aged glass)	0.000001 (bubble <4mm diameter)
	Hydrostatic-head	(-198 microK)	0.000010
	SPRT self-heating	(-360 microK)	0.000005
	Immersion		0.000000
	Moisture	(Dry Ice Test)	0.000000
	Gas pressure		0.000000
	Insulation degradation (mostly high temperature problem)		0.000000
	Total B		*0.000016*
	Total Standard Uncertainty		***0.000031***
	Total Expanded Uncertainty (k=2)		***0.000062***

SBE total calibration uncertainties also include:

- **Uncertainties of applying SPRT defined temperatures to in-house standard**
  Analysis of the drift in Sea-Bird primary reference sensors against the SPRT indicates a variability of less than ±100 micro degrees C around the defined drift. (Figure 8)
- **Uncertainties of applying in-house standard defined temperatures to production sensors**
  Sea-Bird secondary reference sensors indicate a variability of ±100 micro degrees C. (Figure 9)

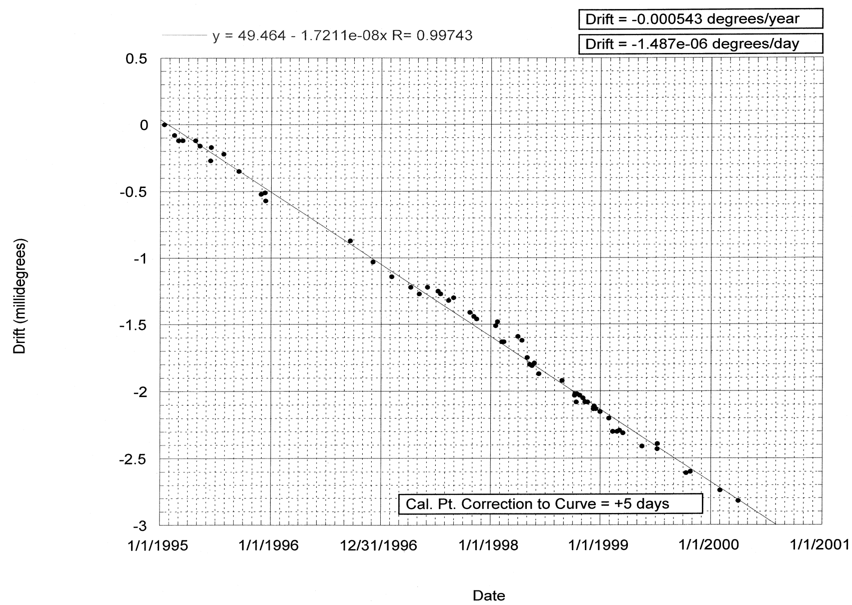

Figure 8. Drift Trajectory -
SBE 3 S/N 1492 YSI SPRT S/N 4747 1 April 2000

SENSOR SERIAL NUMBER = 1187ah
CALIBRATION DATE: 26-Feb-97s

SBE 3 TEMPERATURE CALIBRATION DATA
ITS-90 TEMPERATURE SCALE

ITS-90 COEFFICIENTS
g = 4.88042360e-03
h = 6.78282929e-04
i = 2.71594778e-05
j = 2.18715828e-06
f_0 = 1000.000

IPTS-68 COEFFICIENTS
a = 3.68022875e-03
b = 5.99179223e-04
c = 1.47798642e-05
d = 2.18859293e-06
f_0 = 6624.841

BATH TEMP (ITS-90 °C)	INSTRUMENT FREQ (Hz)	INST TEMP (ITS-90 °C)	RESIDUAL (ITS-90 °C)
-1.4274	6624.841	-1.4274	-0.00003
1.0822	7008.531	1.0823	0.00004
4.5742	7568.684	4.5743	0.00003
8.1723	8178.634	8.1722	-0.00006
11.6050	8792.434	11.6050	-0.00003
15.1630	9462.263	15.1630	0.00002
18.6669	10156.173	18.6669	0.00004
22.1666	10883.928	22.1667	0.00001
25.7253	11660.202	25.7253	-0.00002
29.1407	12440.287	29.1406	-0.00003
32.6732	13283.940	32.6732	0.00002

Temperature ITS-90 $= 1/\{g + h[\ell n(f_0/f)] + i[\ell n^2(f_0/f)] + j[\ell n^3(f_0/f)]\} - 273.15$ (°C)

Temperature IPTS-68 $= 1/\{a + b[\ell n(f_0/f)] + c[\ell n^2(f_0/f)] + d[\ell n^3(f_0/f)]\} - 273.15$ (°C)

Following the recommendation of JPOTS: T_{68} is assumed to be 1.00024 * T_{90} (-2 to 35 °C).

Residual = instrument temperature - bath temperature

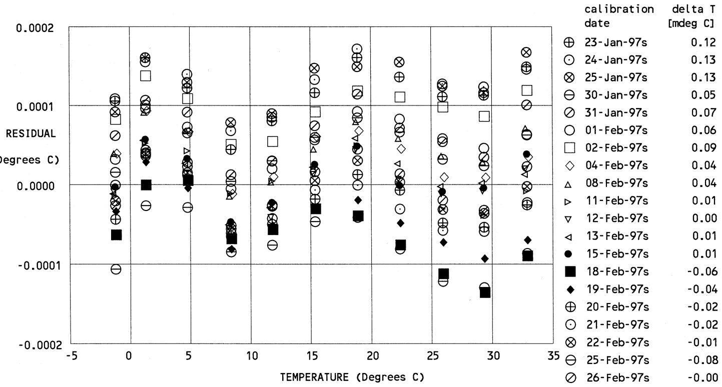

Figure 9. SBE 3 Variability

Adding the known uncertainties in the fixed points, the SPRT measurement system, and the transfer standards and technology yields a total known uncertainty of ±580 micro degrees C.

Repeatability of a typical Sea-Bird production sensor is shown. The sensors have typical drift rates of better than 0.001 degrees C in 3 months. (Figure 10)

SENSOR SERIAL NUMBER = 2095rprt
CALIBRATION DATE: 26-Sep-96s

SBE 3 TEMPERATURE CALIBRATION DATA
ITS-90 TEMPERATURE SCALE

ITS-90 COEFFICIENTS

g = 4.13050757e-03
h = 6.28746916e-04
i = 2.09052249e-05
j = 2.16119508e-06
f_0 = 1000.000

IPTS-68 COEFFICIENTS

a = 3.68022327e-03
b = 6.01740124e-04
c = 1.61824678e-05
d = 2.16273895e-06
f_0 = 2080.618

BATH TEMP (ITS-90 °C)	INSTRUMENT FREQ (Hz)	INST TEMP (ITS-90 °C)	RESIDUAL (ITS-90 °C)
-1.4270	2080.618	-1.4270	-0.00002
1.0833	2200.641	1.0834	0.00004
4.5743	2375.766	4.5743	0.00002
8.1721	2566.514	8.1720	-0.00006
11.6049	2758.500	11.6049	-0.00002
15.1618	2967.965	15.1618	0.00004
18.6656	3185.041	18.6656	0.00002
22.1647	3412.715	22.1647	-0.00001
25.7235	3655.661	25.7234	-0.00002
29.1386	3899.830	29.1386	0.00000
32.6713	4163.980	32.6713	0.00000

Temperature ITS-90 $= 1/\{g + h[\ell n(f_0/f)] + i[\ell n^2(f_0/f)] + j[\ell n^3(f_0/f)]\} - 273.15$ (°C)

Temperature IPTS-68 $= 1/\{a + b[\ell n(f_0/f)] + c[\ell n^2(f_0/f)] + d[\ell n^3(f_0/f)]\} - 273.15$ (°C)

Following the recommendation of JPOTS: T_{68} is assumed to be 1.00024 * T_{90} (-2 to 35 °C).

Residual = instrument temperature - bath temperature

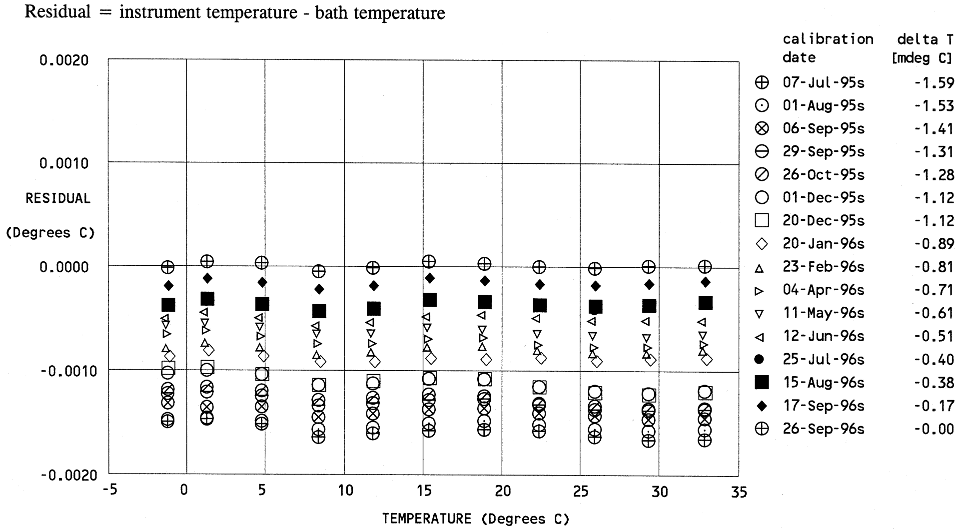

Figure 10. SBE 3 Repeatability