Latest L-band Seawater Dielectric Measurements

Y. Zhou[1], R. Lang[1], E. Dinnat[2,3] and D. Le Vine[2]

1. George Washington University, Dept. of Electrical & Computer Engr., Washington, DC, 20052, USA

2. Cryospheric Sciences Laboratory, NASA Goddard Space Flight Center, Greenbelt, MD, 20771, USA

3. CEESMO, Chapman University, Orange, CA 92866, USA

Outline

I. Review of Past Seawater Dielectric Measurements

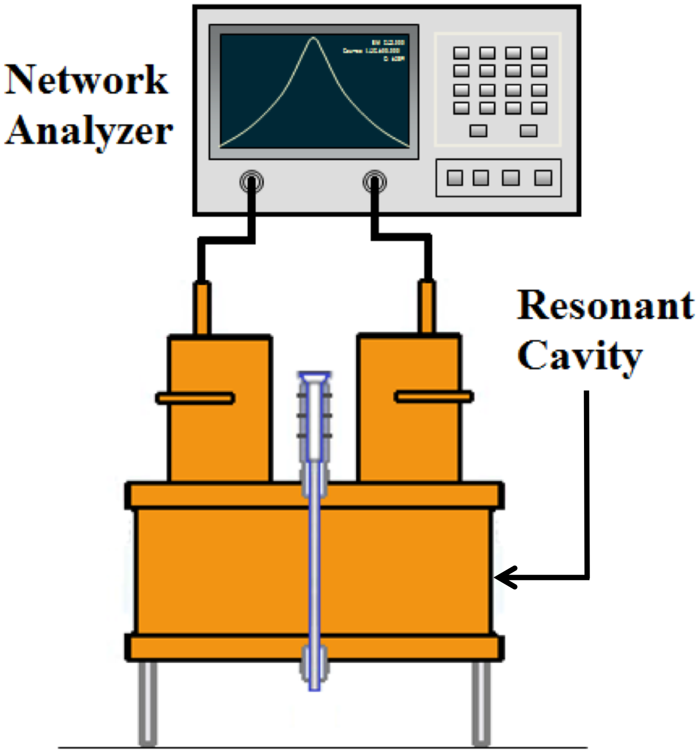
II. Improvements of Accuracy

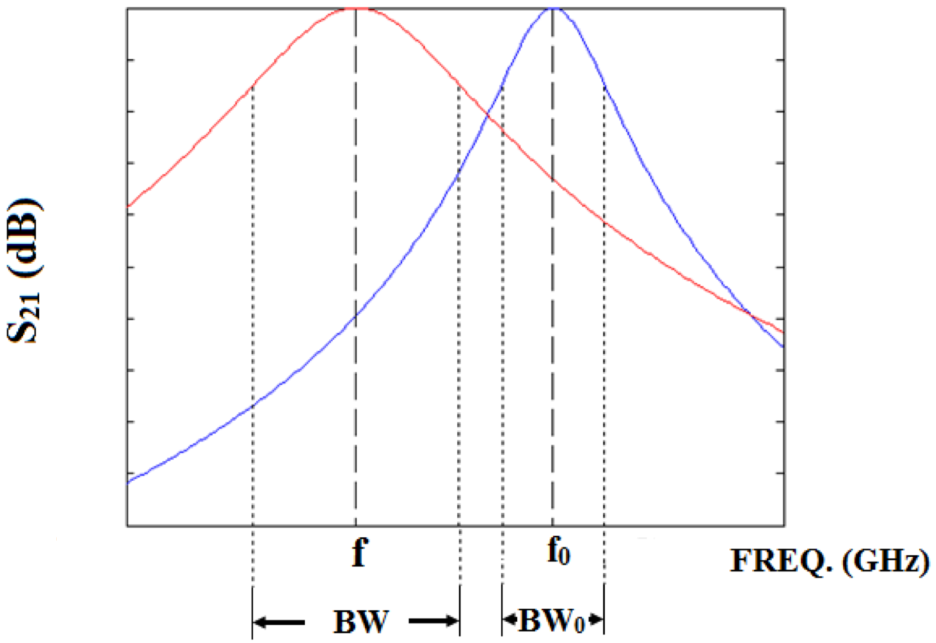
III. Low Temperature Measurements

III. New Measurements at 34 and 36 psu

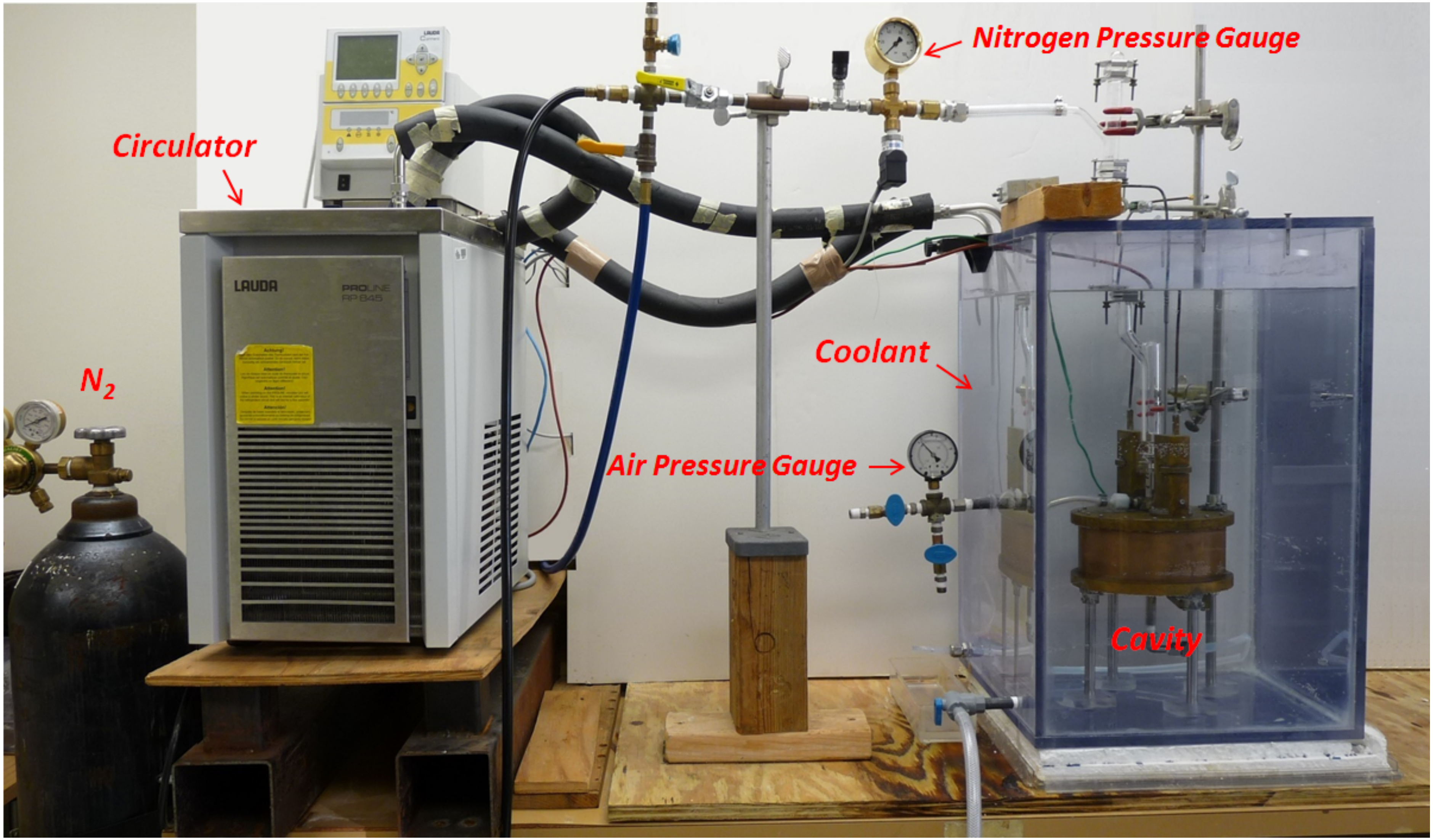
IV. Conclusions

Cavity Technique



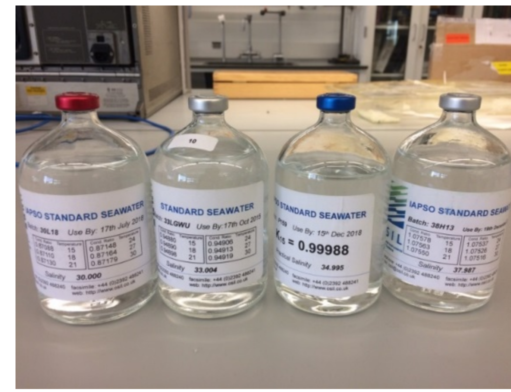


Experimental Setup



Measurements

- **Seawater used in the measurements is purchased from OSIL (Ocean Scientific International ltd)**
  - ✓ Salinity: 30 psu, 33 psu, 35 psu and 38 psu
  - ✓ New Sample: 20 psu, 34 psu and 36 psu



- **Previous measurements were made from 0° C to 35° C in 5° C increments. For one temperature and salinity, at least three measurements were made.**

GW Model Function

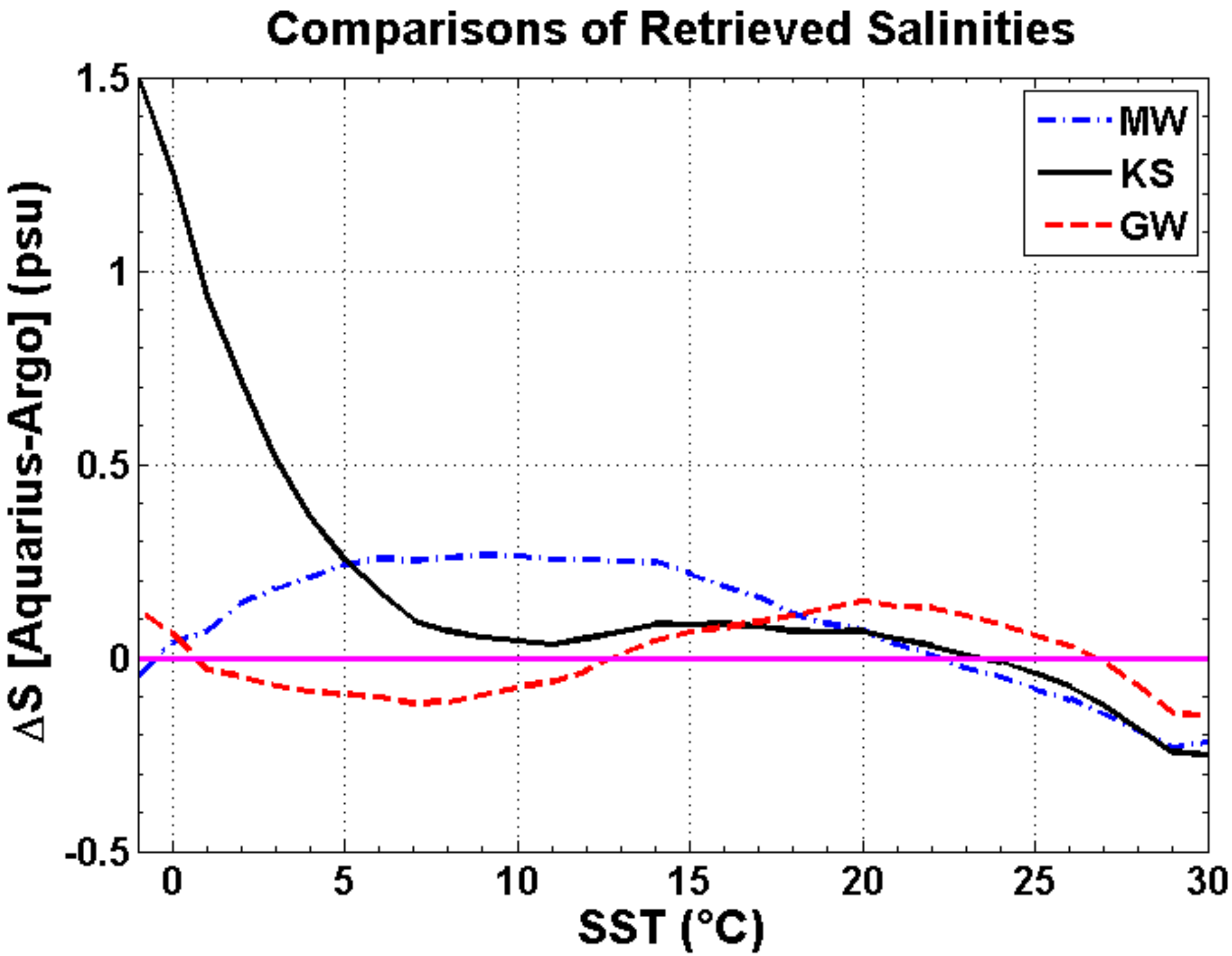
Express GW model function as a polynomial in S and T

$$\varepsilon_{GW}(S,T) = \sum_{m=0}^{3}\sum_{n=0}^{3} p_{m,n} S^m T^n$$

find the coefficients $p_{m,n} = p'_{m,n} + jp''_{m,n}$ from measured data

Zhou et al., TGRS (2017)

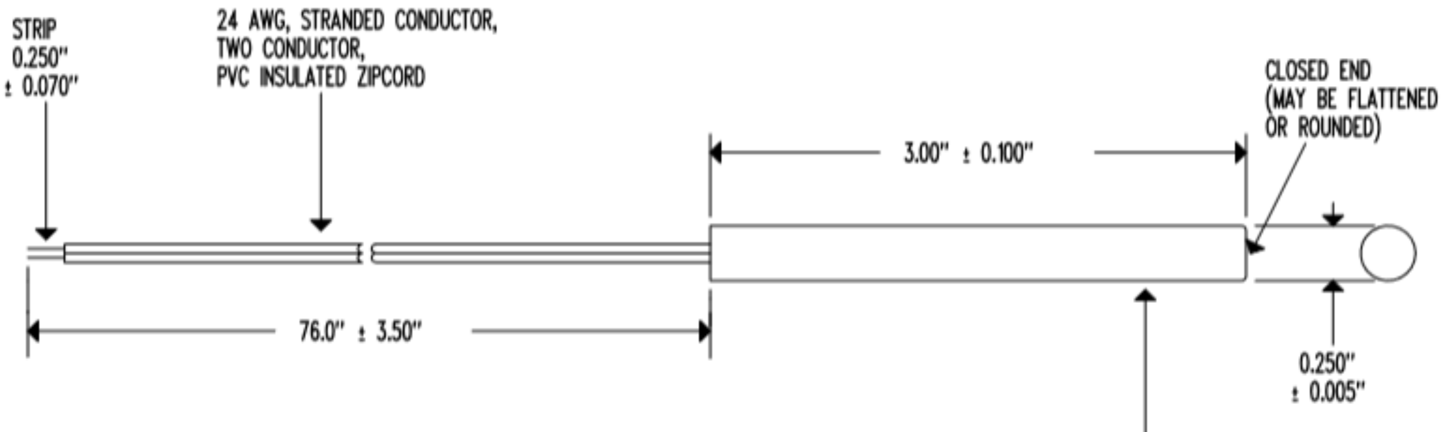
Salinity Retrieval Results



Zhou et al., TGRS (2017)

Improvements

New Thermistor and Temperature Recalibration



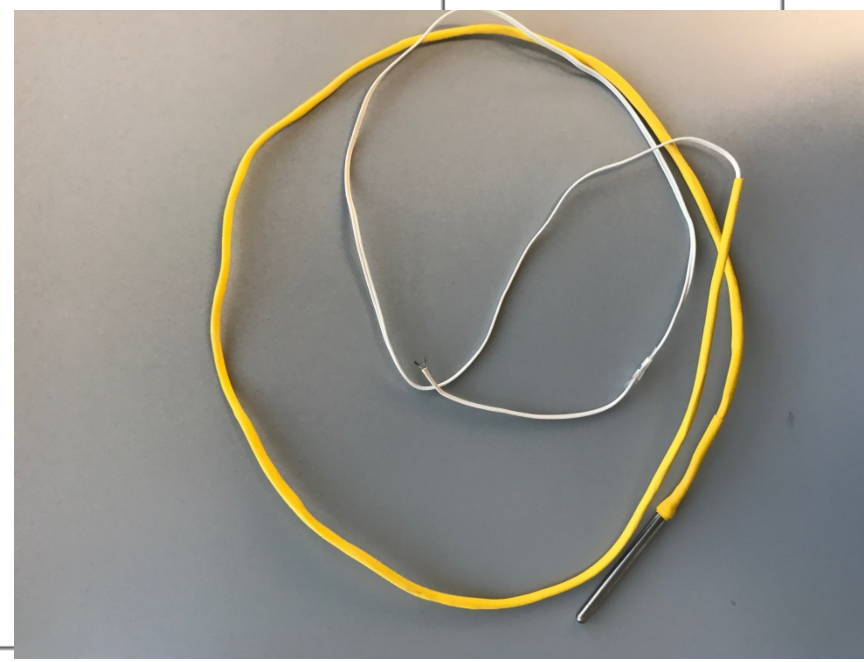
RESISTANCE • +25°C = 10,000 Ω ± 3%

ACCURACY (-3 TO +35°C) = ± 0.01°C (VERSUS R-T TABLE SUPPLIED WITH PROBE)

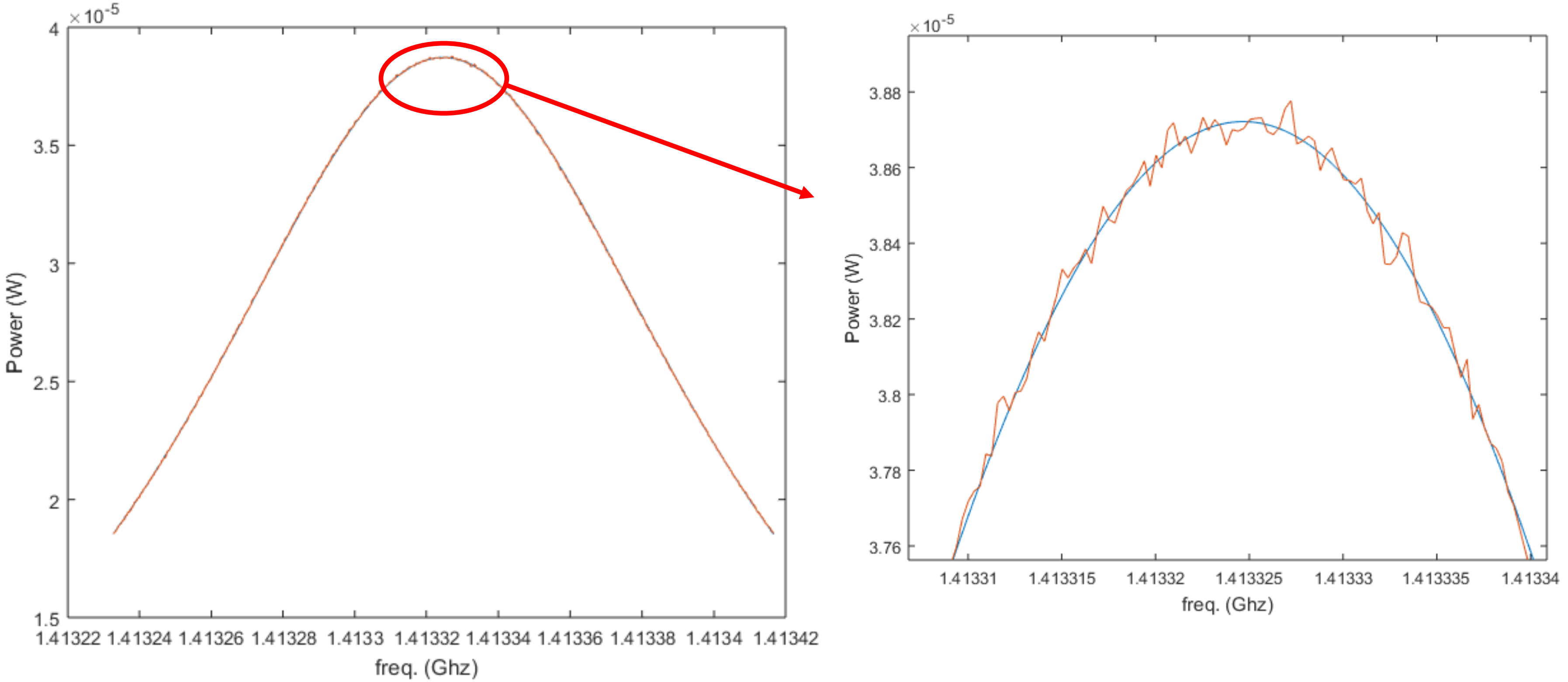
RESISTANCE/TEMPERATURE CURVE = "J"
BETA "β" (0 TO +50°C) = 3,892°K NOMINAL
TEMPERATURE COEFFICIENT • +25°C = -4.4%/°C NOMINAL
MAXIMUM TEMPERATURE RATING = +105°C

EACH INDIVIDUAL PROBE SUPPLIED WITH A NIST TRACEABLE CALIBRATION CERTIFICATE, UNIQUE STEINHART-HART CONSTANTS FOR THE TEMPERATURE RANGE OF -3°C TO +35°C, AND WITH ITS OWN UNIQUE RESISTANCE VERSUS TEMPERATURE TABLE FROM -3°C TO +35°C IN 0.005°C INCREMENTS

SEE MANUFACTURING SPECIFICATION (LAYER 1)

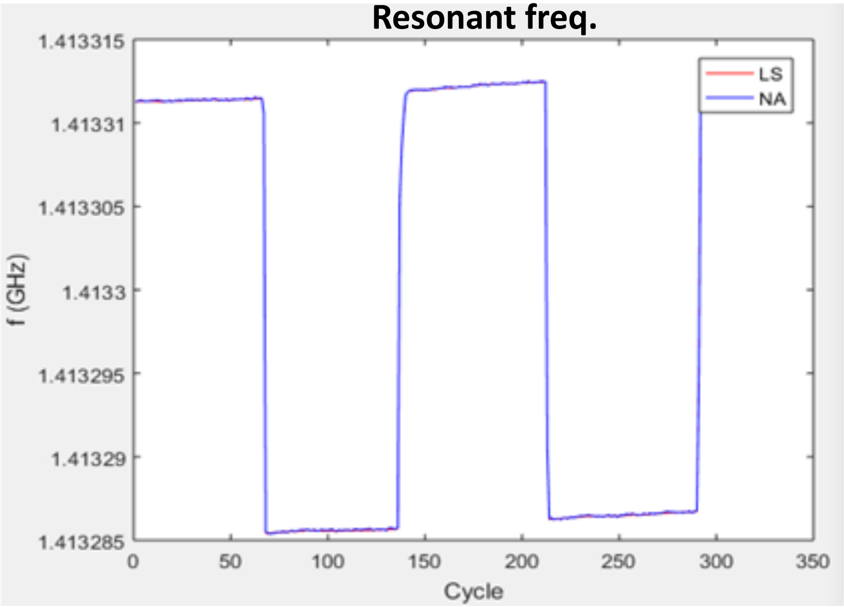


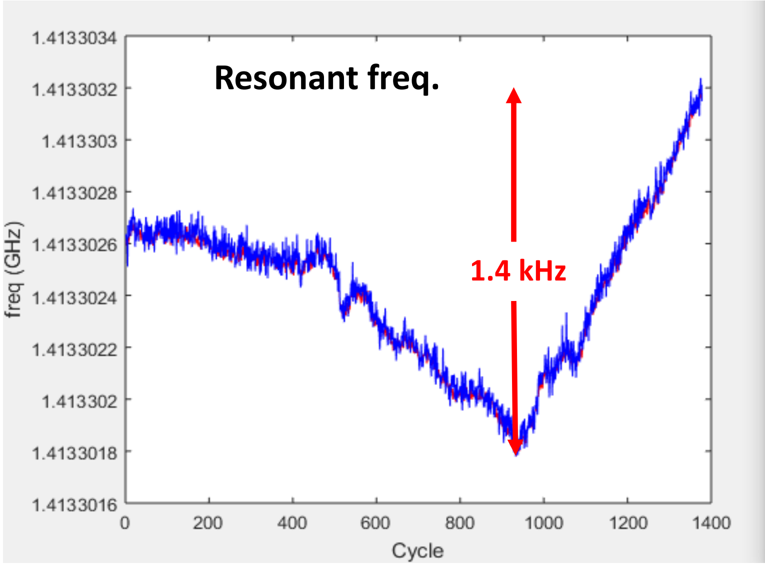
New Fitting Technique

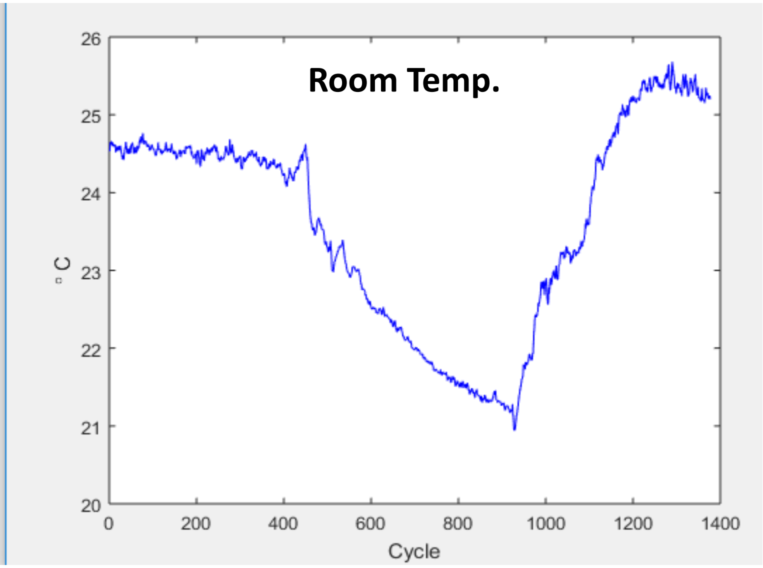


Average of 8 sweeps

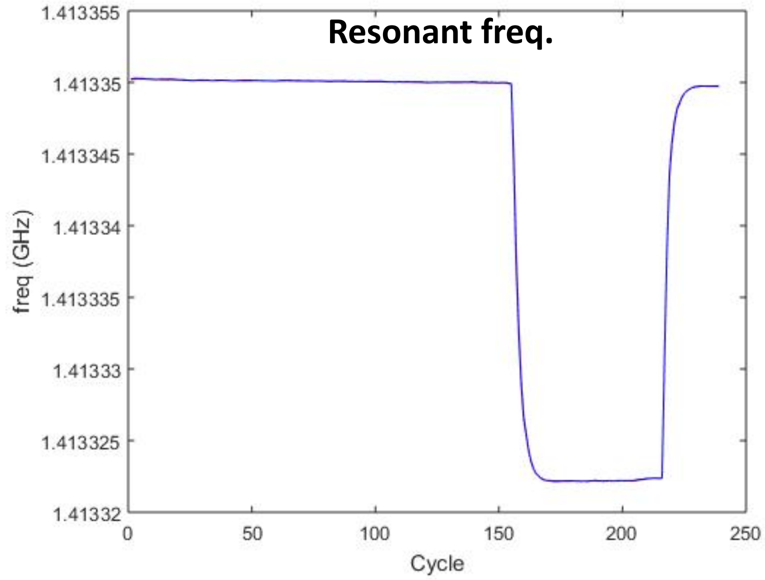
Frequency Drifting Problem

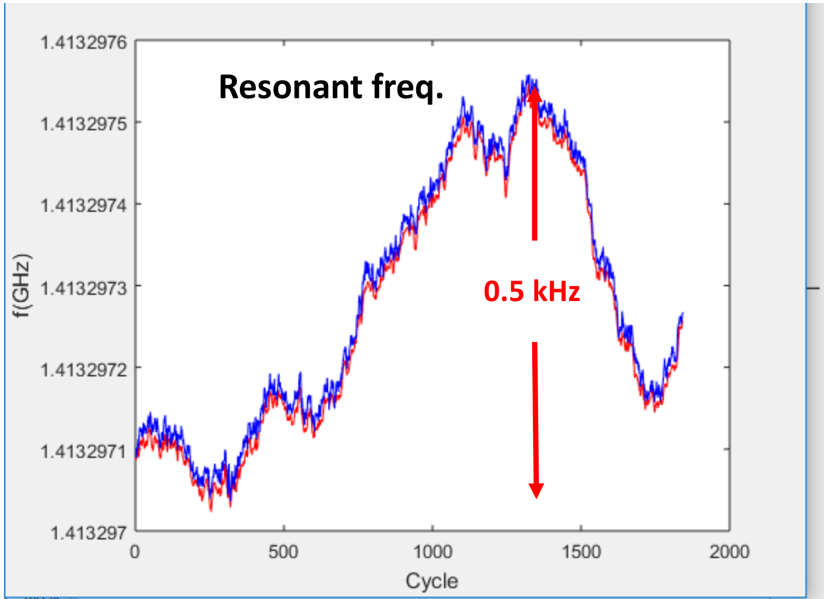


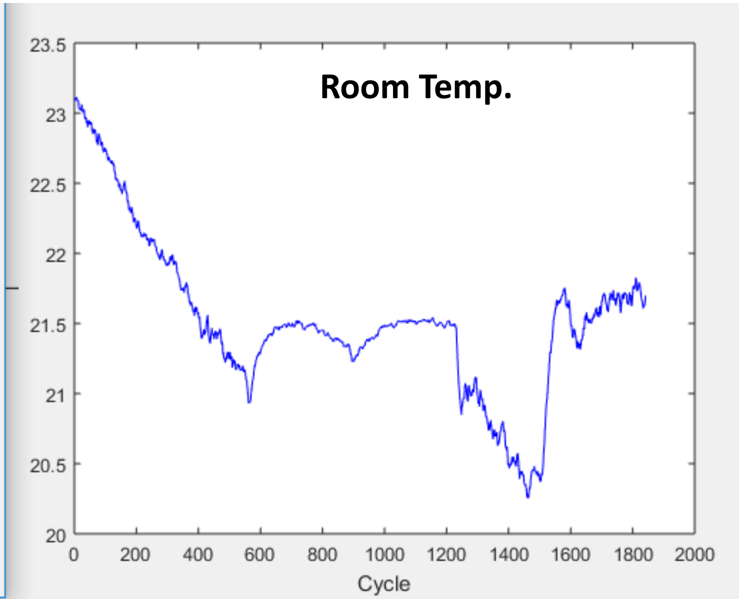




10 MHz Counter as External Source

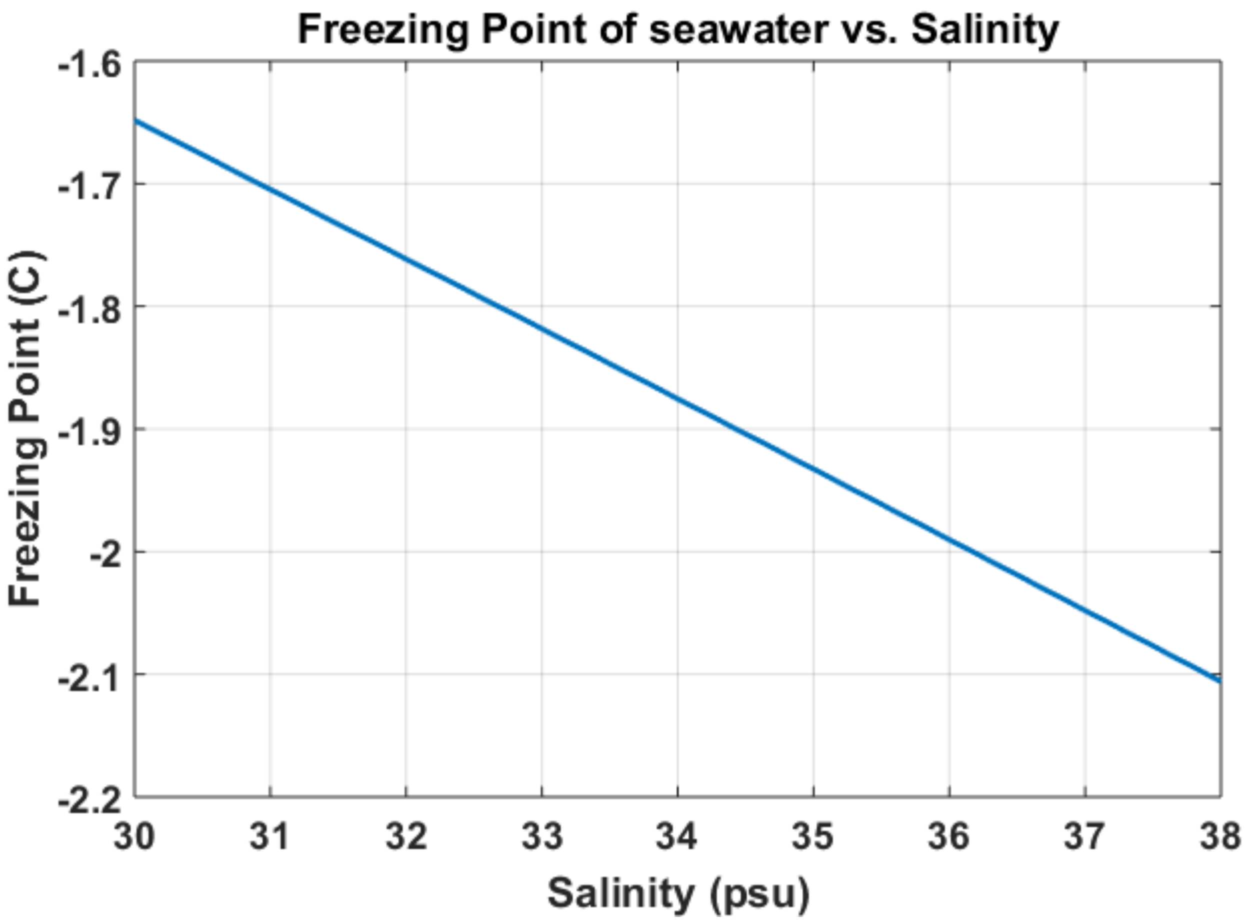






Low-Temperature Measurements

Freezing Point of Seawater



Algorithms for computation of fundamental properties of seawater (UNESCO 1983)

Measurement Points

T(C)	-1.5	-1	0	2	3	5	10	15	20	25	30	35
30												
33												
34												
35												
36												
38												

Original Measurements

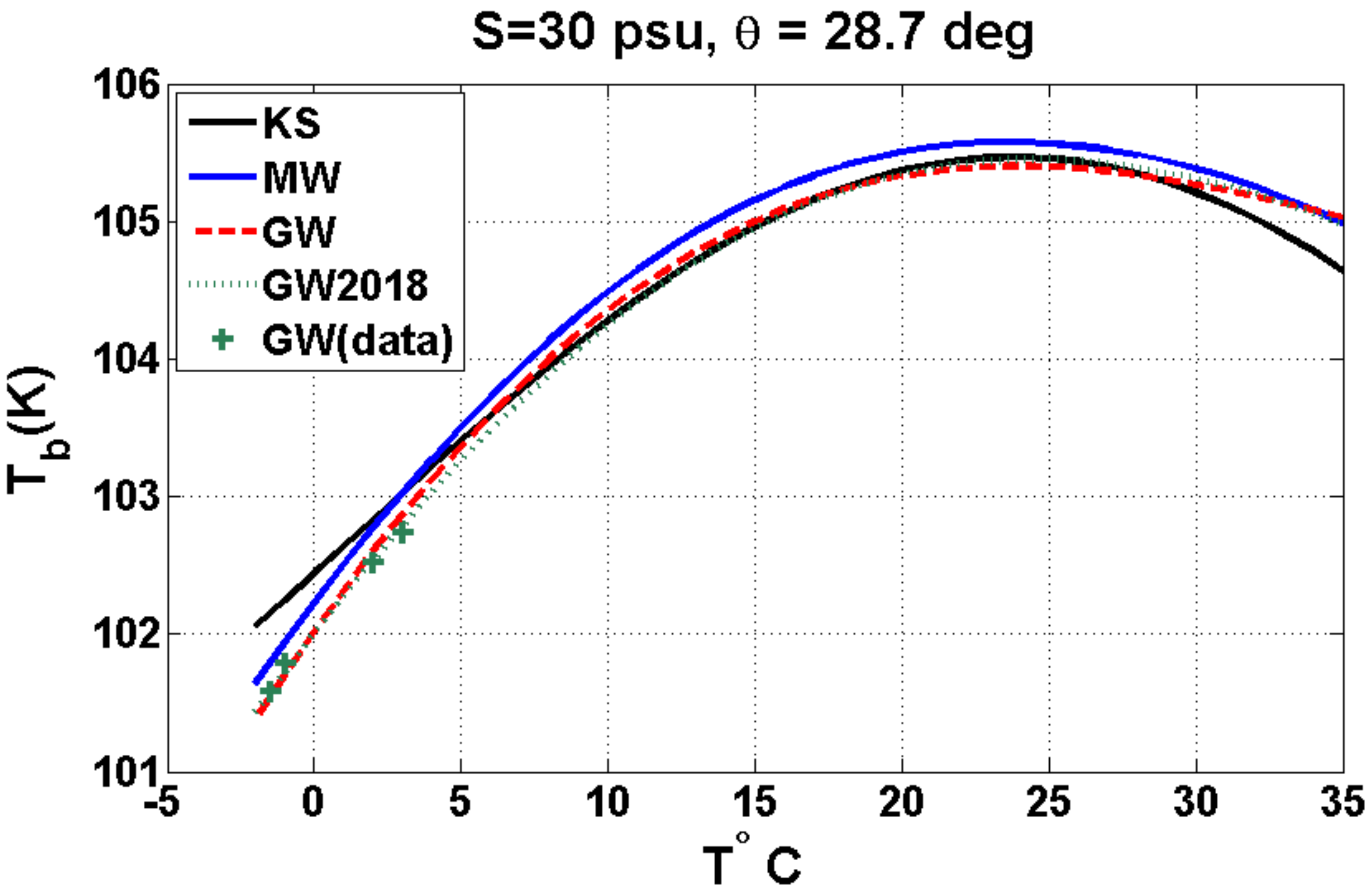
Low Temperature measurements

New Measurements at 34 and 36 psu

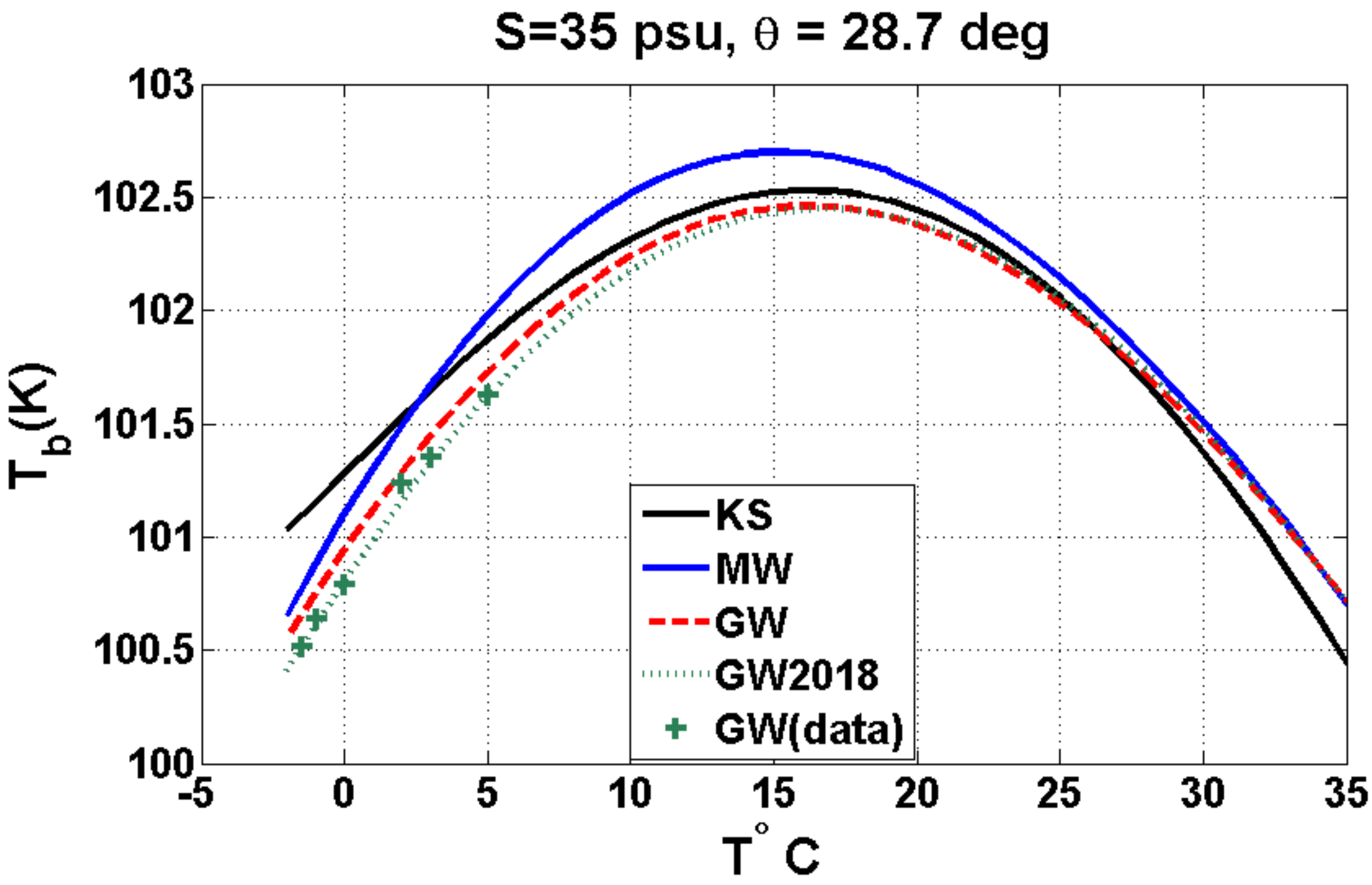
Measurement Results

Temp	psu	ε’($u_{ε’}$)	ε”($u_{ε”}$)	psu	ε’($u_{ε’}$)	ε”($u_{ε”}$)
-1.5	29.969	78.67 (0.03)	42.76 (0.03)	34.992	77.46 (0.06)	47.24 (0.21)
-1	29.969	78.48 (0.08)	42.95 (0.18)	34.992	77.36 (0.08)	47.52 (0.11)
2	29.969	77.91 (0.06)	44.70 (0.13)	34.992	76.78 (0.07)	49.52 (0.24)
3	29.969	77.69 (0.01)	45.38 (0.13)	34.992	76.63 (0.10)	50.36 (0.29)
10	34.004	75.08 (0.02)	55.44 (0.31)	36.002	74.76 (0.04)	57.20 (0.30)
20	34.004	72.26(0.16)	65.09 (0.27)	36.002	71.90 (0.13)	67.99 (0.21)

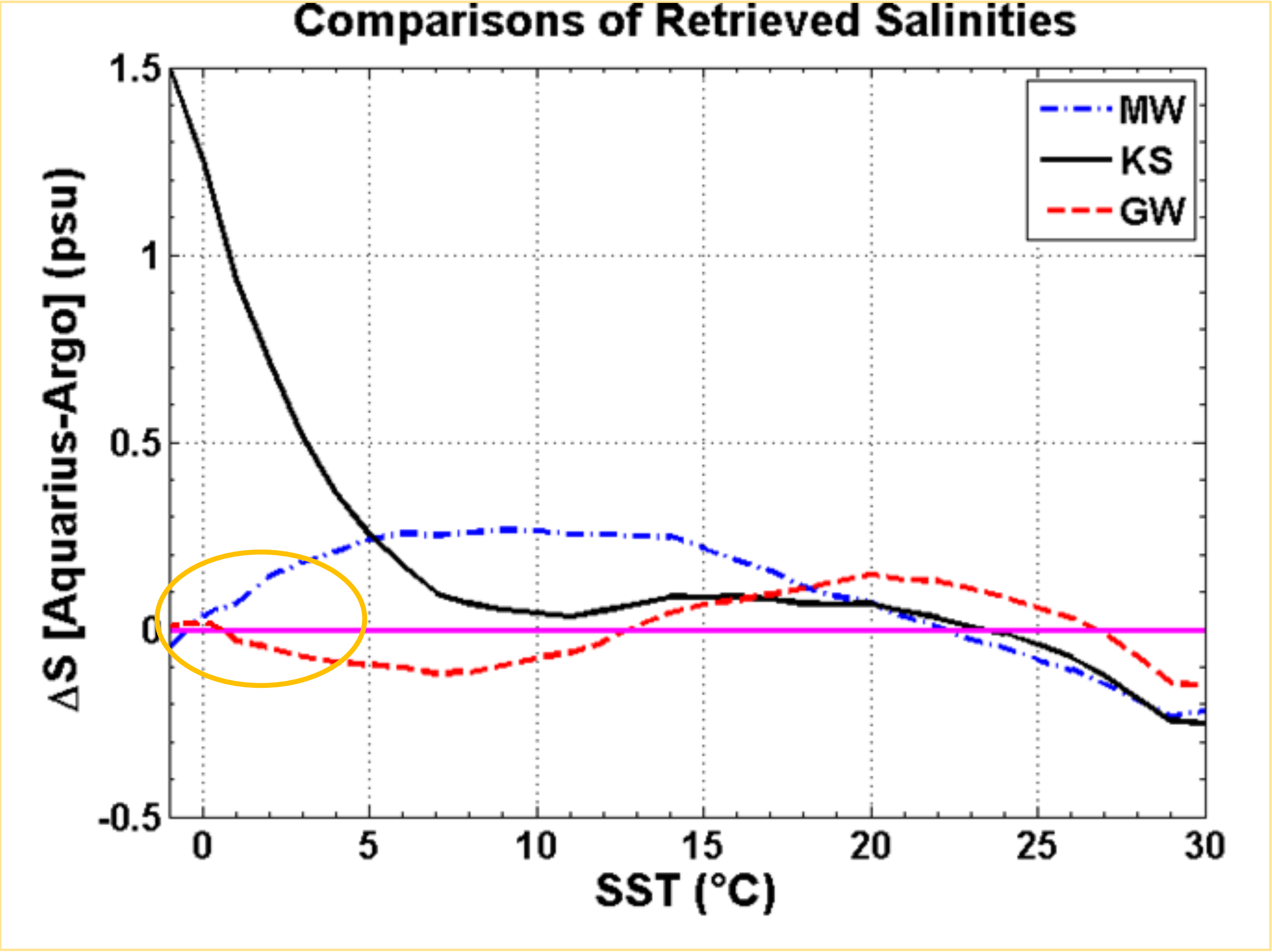
T_b vs. T


S=30 psu, θ = 28.7 deg
KS
MW
GW
GW2018
GW(data)
T_b(K)
106
105
104
103
102
101
-5
0
5
10
15
20
25
30
35
T° C

T_b vs. T

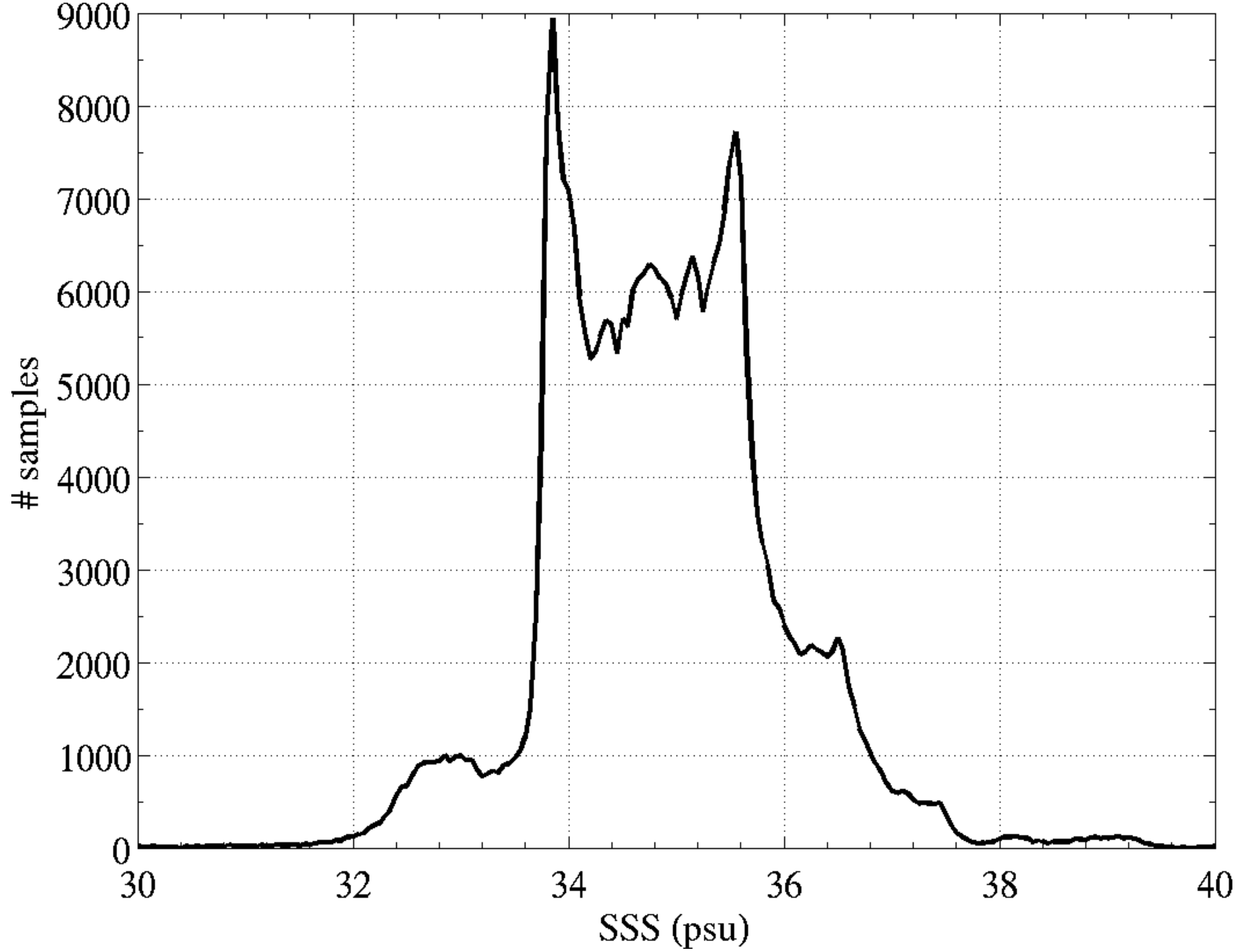

S=35 psu, θ = 28.7 deg
103
102.5
102
101.5
101
100.5
100
-5
0
5
10
15
20
25
30
35
T_b(K)
T° C
KS
MW
GW
GW2018
GW(data)

Salinity Retrieval Results



New Measurements at 34 and 36 psu

Histogram of SSS from Argo Floats

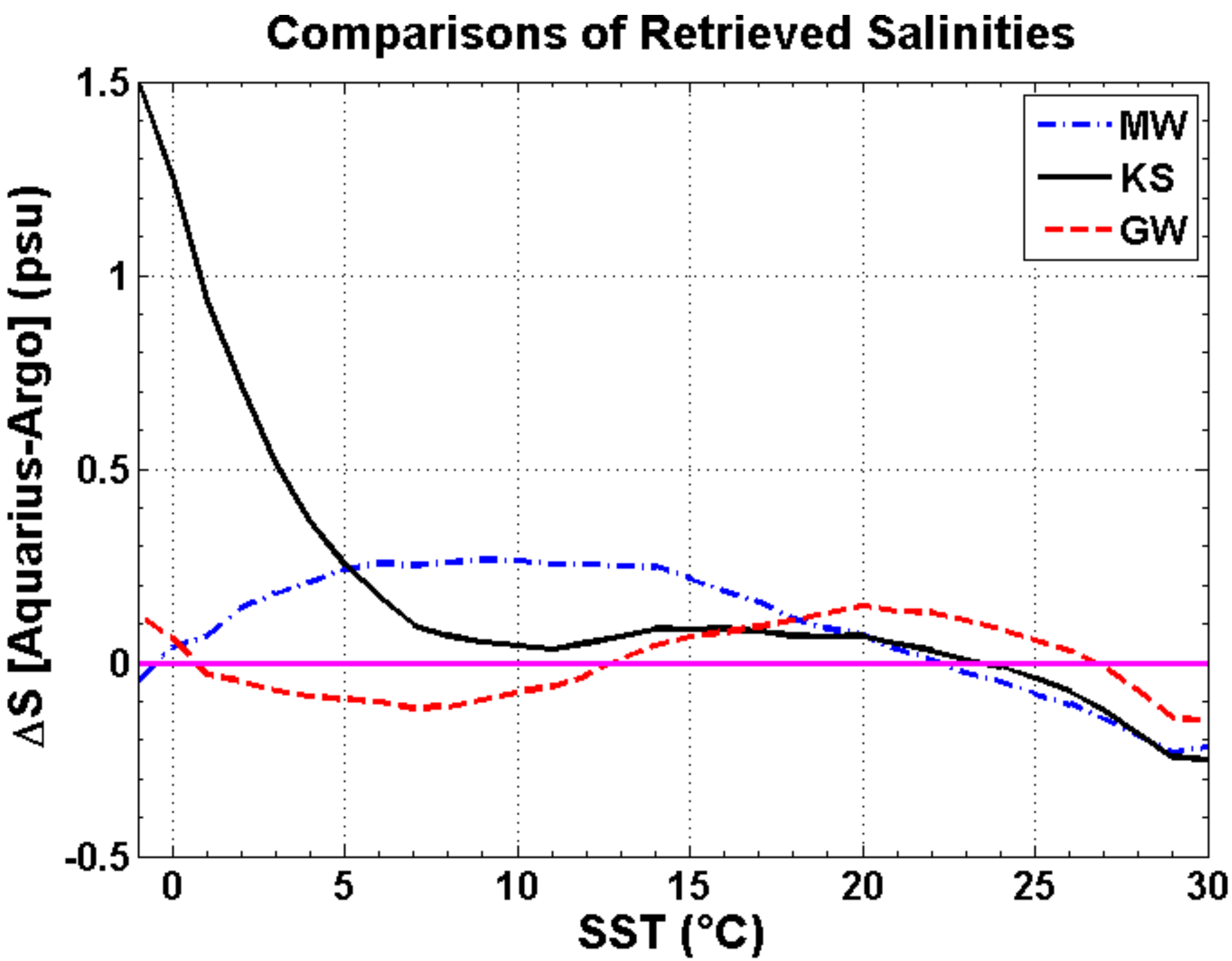


Measurement Points

T(C)	-1.5	-1	0	2	3	5	10	15	20	25	30	35
30												
33												
34												
35												
36												
38												

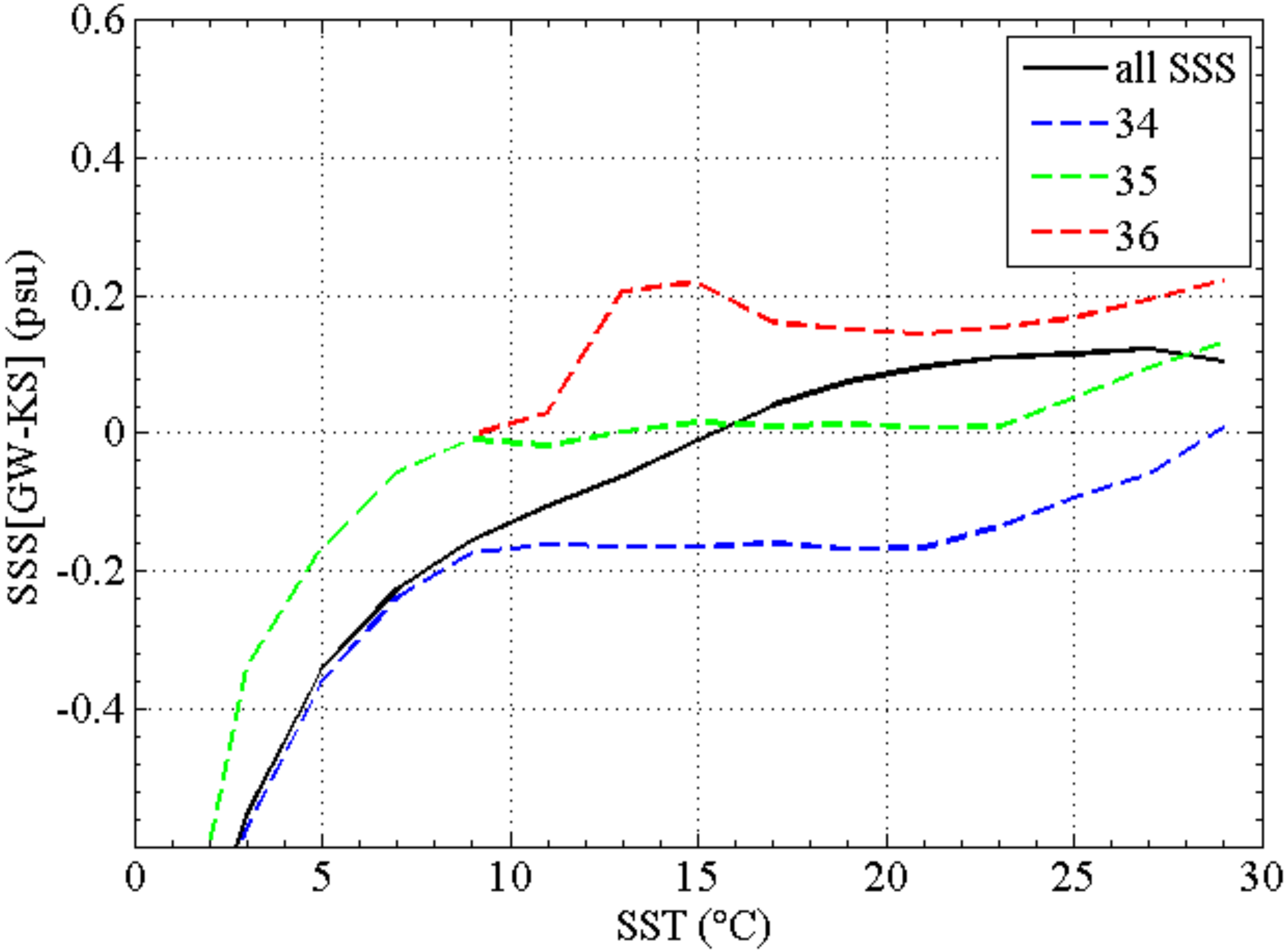
- **Original Measurements**
- **Low Temperature measurements**
- **New Measurements at 34 and 36 psu**

Salinity Retrieval Results



Zhou et al., TGRS (2017)

Salinity Retrieval Results



Seawater: IAPSO Standard with Salinity of 34.004.									
Tube Number: Q35									
Callibration Coefficient: 698,565									
Date	**Temp(˚C)**	**Empty f_0 (Hz)**	**Seawater f (Hz)**	**Δf (Hz)**	**Empty Q_0**	**Seawater Q**	**Δ(1/Q)**	**ϵ'**	**ϵ''**
7/18/2018	15	1,413,463,569	1,413,389,925	73,644	8,063	4,750	8.65E-05	73.79	60.44
7/19/2018	15	1,413,462,672	1,413,389,028	73,644	8,065	4,741	8.69E-05	73.79	60.73
7/23/2018	15	1,413,462,210	1,413,388,512	73,698	8062	4764	8.59E-05	73.85	60.00
7/23/2018	15	1,413,462,193	1,413,388,583	73,610	8062	4739	8.70E-05	73.76	60.76
Average		1,413,462,811	1,413,389,179	73,633	8,063	4,743	8.68E-05	73.78	60.64
STDEV		699	684	20	1.504	5.712	2.52E-07	0.0173	0.177
ERROR(%)		4.942E-05	4.8364E-05	0.0267	0.0186	0.120	0.291	0.0235	0.291
Date	**Temp(˚C)**	**Empty f_0 (Hz)**	**Seawater f (Hz)**	**Δf (Hz)**	**Empty Q_0**	**Seawater Q**	**Δ(1/Q)**	**ϵ'**	**ϵ''**
7/30/2018	25	1,413,150,983	1,413,080,184	70,799	7,997	4,402	1.02E-04	70.96	71.35
7/31/2018	25	1,413,149,243	1,413,078,707	70,536	7,991	4,401	1.02E-04	70.74	71.32
7/3132018	25	1,413,149,443	1,413,078,655	70,788	7,992	4,395	1.02E-04	70.99	71.55
Average		1,413,149,890	1,413,079,182	70,708	7,993	4,399	1.02E-04	70.90	71.41
STDEV		952	868	149	3.215	3.786	1.77E-07	0.1365	0.125
ERROR(%)		6.738E-05	6.1437E-05	0.2104	0.0402	0.086	0.173	0.1925	0.175
Date	**Temp(˚C)**	**Empty f_0 (Hz)**	**Seawater f (Hz)**	**Δf (Hz)**	**Empty Q_0**	**Seawater Q**	**Δ(1/Q)**	**ϵ'**	**ϵ''**
8/8/2018	30	1,412,971,174	1,412,901,803	69,371	7,923	4,239	1.097E-04	69.59	76.63
8/9/2018	30	1,412,970,103	1,412,900,821	69,282	7,918	4,214	1.110E-04	69.51	77.56
8/20/2018	30	1,412,962,104	1,412,893,014	69,090	7,896	4,194	1.118E-04	69.32	78.07
8/22/2018	30	1,412,962,057	1,412,892,763	69,294	7,896	4,197	1.116E-04	69.52	77.97
Average		1,412,964,755	1,412,895,533	69,222	7,903	4,202	1.115E-04	69.45	77.87
STDEV		4632	4582	114.5	12.70	10.79	4.10E-07	0.1127	0.2702
ERROR(%)		3.278E-04	3.243E-04	0.1654	0.1607	0.2567	0.3678	0.1623	0.3471

Seawater: IAPSO Standard with Salinity of 36.002.									
Tube Number: Q35									
Callibration Coefficient: 698,565									
Date	**Temp(˚C)**	**Empty f_0 (Hz)**	**Seawater f (Hz)**	**Δf (Hz)**	**Empty Q_0**	**Seawater Q**	**Δ(1/Q)**	**ϵ'**	**ϵ''**
7/17/18	15	1,413,464,355	1,413,390,943	73,412	8,061	4,692	8.91E-05	73.56	62.24
7/17/18	15	1,413,464,748	1,413,391,355	73,393	8,061	4,679	8.97E-05	73.55	62.65
7/18/18	15	1,413,463,473	1,413,390,093	73,380	8066	4680	8.97E-05	73.53	62.66
7/24/18	15	1,413,461,378	1,413,388,139	73,239	8,063	4653	9.089E-05	73.39	63.48
7/24/18	15	1,413,461,434	1,413,388,049	73,385	8,062	4681	8.959E-05	73.54	62.57
Average		1,413,463,503	1,413,390,110	73,393	8,062	4,683	8.951E-05	73.55	62.53
STDEV		1478	1471	14.059	2.170	6.077	2.92E-07	0.013	0.197
ERROR(%)		1.046E-04	1.041E-04	0.0192	0.0269	0.130	0.326	0.0176	0.316

Date	**Temp(˚C)**	**Empty f_0 (Hz)**	**Seawater f (Hz)**	**Δf (Hz)**	**Empty Q_0**	**Seawater Q**	**Δ(1/Q)**	**ϵ'**	**ϵ''**
7/25/18	25	1,413,175,461	1,413,104,844	70,617	8,025	4,311	1.074E-04	70.82	74.99
7/26/18	25	1,413,165,125	1,413,094,653	70,472	8,019	4,314	1.071E-04	70.67	74.82
7/30/18	25	1,413,151,202	1,413,080,888	70,314	7,997	4,301	1.075E-04	70.52	75.07
Average		1,413,163,929	1,413,093,462	70,468	8,014	4,309	1.073E-04	70.67	74.96
STDEV		12174	12022	151.55	14.742	6.807	1.84E-07	0.1500	0.1277
ERROR(%)		8.614E-04	8.508E-04	0.2151	0.1840	0.1580	0.1715	0.2123	0.1703

Date	**Temp(˚C)**	**Empty f_0 (Hz)**	**Seawater f (Hz)**	**Δf (Hz)**	**Empty Q_0**	**Seawater Q**	**Δ(1/Q)**	**ϵ'**	**ϵ''**
8/6/18	30	1,412,972,921	1,412,903,944	68,977	7,929	4,133	1.158E-04	69.20	80.92
8/7/18	30	1,412,972,020	1,412,903,141	68,879	7,927	4,125	1.163E-04	69.11	81.22
8/8/18	30	1,412,970,916	1,412,902,036	68,880	7,923	4,122	1.164E-04	69.11	81.30
Average		1,412,971,952	1,412,903,040	68,912	7,926	4,127	1.162E-04	69.14	81.15
STDEV		1004	958	56.29	3.055	5.686	2.91E-07	0.0520	0.2003
ERROR(%)		7.107E-05	6.780E-05	0.0817	0.0385	0.1378	0.2502	0.0752	0.2469

Conclusions

- Continue to improve accuracy. Experimental Setup is now more accurate particularly in measuring the Q.
- Low temperature measurements lead to a small increase in the accuracy of the model function at low temperatures. More measurements at low temperatures are planned.
- New measurements at 34 and 36 psu have been made. More measurements are planned
- New measurements at S=20 psu will be made.

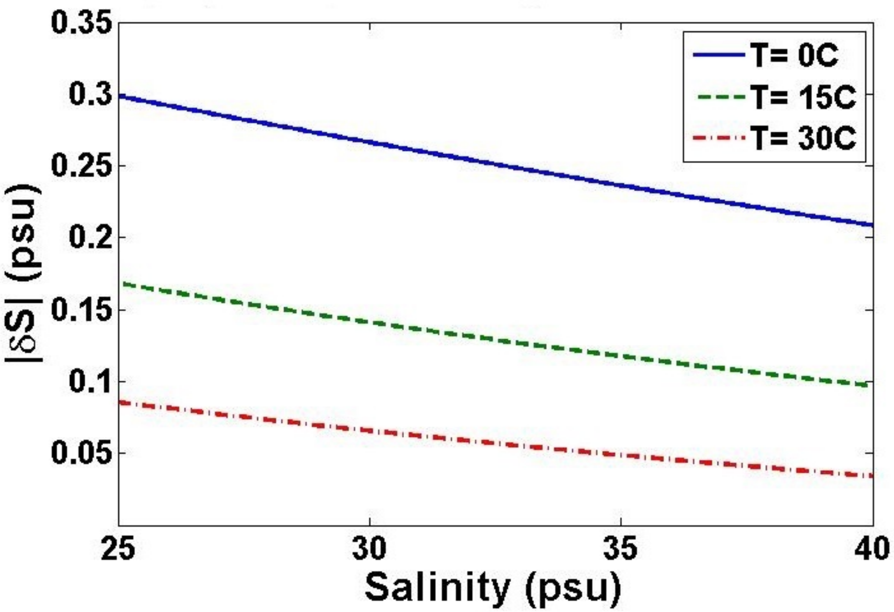
Conclusions

- Exit-Hole Problem: Complicated analytic approach involving modal expansions predicts errors that could impact our results.
- Alterative Approaches:
  1. Employ numerical methods – great accuracy is needed.
  2. Build a TE011 cavity that has a very small exit hole effect.

Thank You

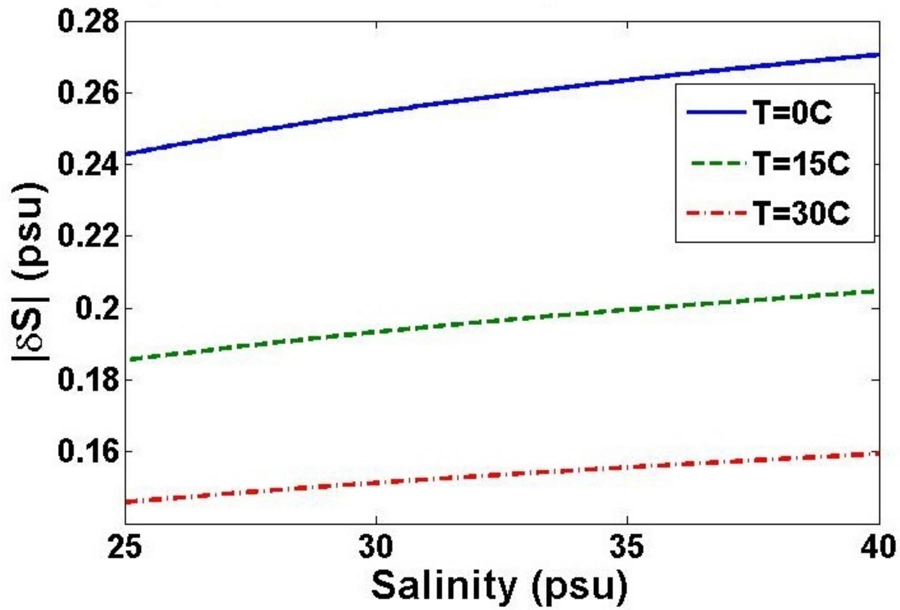
Sensitivity Analysis

Δε=0.3+0j



A

Δε=0+0.3j



B

$$|\delta S| = \left| \frac{\mathrm{Re}\{\varepsilon^{-3/2}\}\delta\varepsilon' + \mathrm{Im}\{\varepsilon^{-3/2}\}\delta\varepsilon''}{\mathrm{Re}\{\varepsilon^{-3/2}\}(\partial\varepsilon' / \partial S) + \mathrm{Im}\{\varepsilon^{-3/2}\}(\partial\varepsilon'' / \partial S)} \right|$$

Lang et al. ,
Radio Science (2016)

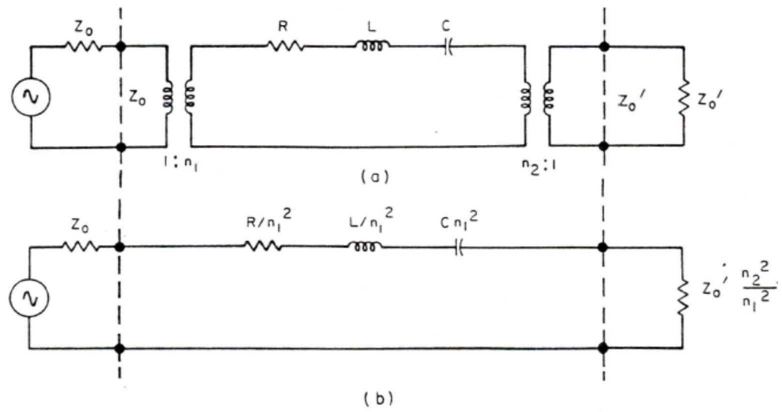
New Fitting Technique

Average of 8 sweeps

9	Frequencies	S21
10	1413550000	-61.0417
11	1413550313	-61.0658
12	1413550625	-61.0768
13	1413550938	-61.0848
14	1413551250	-61.0799
15	1413551563	-61.0736
16	1413551875	-61.0561
17	1413552188	-61.0485

•
•
•

1601	1414047188	-55.0059
1602	1414047500	-55.0186
1603	1414047813	-55.0316
1604	1414048125	-55.0451
1605	1414048438	-55.0587
1606	1414048750	-55.0744
1607	1414049063	-55.0883
1608	1414049375	-55.1033
1609	1414049688	-55.113
1610	1414050000	-55.1427



Let $S = \omega^2$

$$\frac{1}{P} = \frac{Q_L{}^2}{\omega_0^2 T} S + \frac{(1-2Q_L{}^2)}{T} + \frac{Q_L{}^2\omega_0^2}{T}\frac{1}{S}$$

$$= aS + b + c\frac{1}{S}$$

$$\begin{bmatrix} S_1 & 1 & 1/S_1 \\ S_2 & 1 & 1/S_2 \\ \vdots & \vdots & \vdots \\ S_i & 1 & 1/S_i \end{bmatrix} \begin{bmatrix} a \\ b \\ c \end{bmatrix} = \begin{bmatrix} P_1 \\ P_2 \\ \vdots \\ P_i \end{bmatrix}$$

New Fitting Technique

P(dBm)		Q0 (NA)	Q0 (LS)	f0 (NA)	f0 (LS)
-5	AVG	8030	7998	1,413,312,453	1,413,312,306
	STD	6.35	1.36	63.2	29.8
	ERROR(%)	0.08	0.02	4.47E-06	2.11E-06
	DIFF	32		147	
0	AVG	8019	7994	1,413,312,712	1,413,312,561
	STD	4.56	0.81	81.9	39.1
	ERROR(%)	0.06	0.01	5.79E-06	2.77E-06
	DIFF	25		151	
3	AVG	8010	7992	1,413,312,247	1,413,312,197
	STD	4.24	0.46	45	16.9
	ERROR(%)	0.05	0.01	3.18E-06	1.20E-06
	DIFF	18		50	

Q drops as Power increases

$$P_{3db} = P_{max} \cdot 10^{-3/10} = 0.5012 P_{max}$$

Measurement Points