Evaluation of the fall-rate of recent T-7 probes manufactured by Sippican and TSK

Shoichi Kizu
(Tohoku University, Japan)

XBT Bias and Fall-rate Workshop
25-27 August 2010, Hamburg, Germany

Major part of this talk is
submitted to Ocean Science

“Comparison of the fall rate and structure of recent T-7 XBT manufactured by Sippican and TSK”

S. Kizu, C. Sukigara, and K. Hanawa

To begin with,

There are two (acknowledged) manufacturers.

- *Sippican (now, Lockheed Martin Sippican, Inc.)*
  - *Since 1960s*
  - *Sold in US, Europe, Australia, …**
- *TSK (Tsurumi Seiki Co., Ltd.)*
  - *Since April 1978 (under license agreement with Sippican)*
  - *Sold in Asia**

**Strictly speaking, the sales territories are not on continental-basis, and also differ between military and civilian uses.*

Product lineup

**As of August 2010*

Sippican	Ship speed (kt)	Depth (m)
T-4	30	460
T-5	6	1830
Fast Deep	20	1000
T-6	15	460
T-7	**15**	**760**
Deep Blue	20	760
T-10	10	200
T-11	6	460

TSK	Ship speed (kt)	Depth (m)
T-6	15	460
T-7	**15**	**760**
T-7 (20kt)	20	760
T-10	10	300

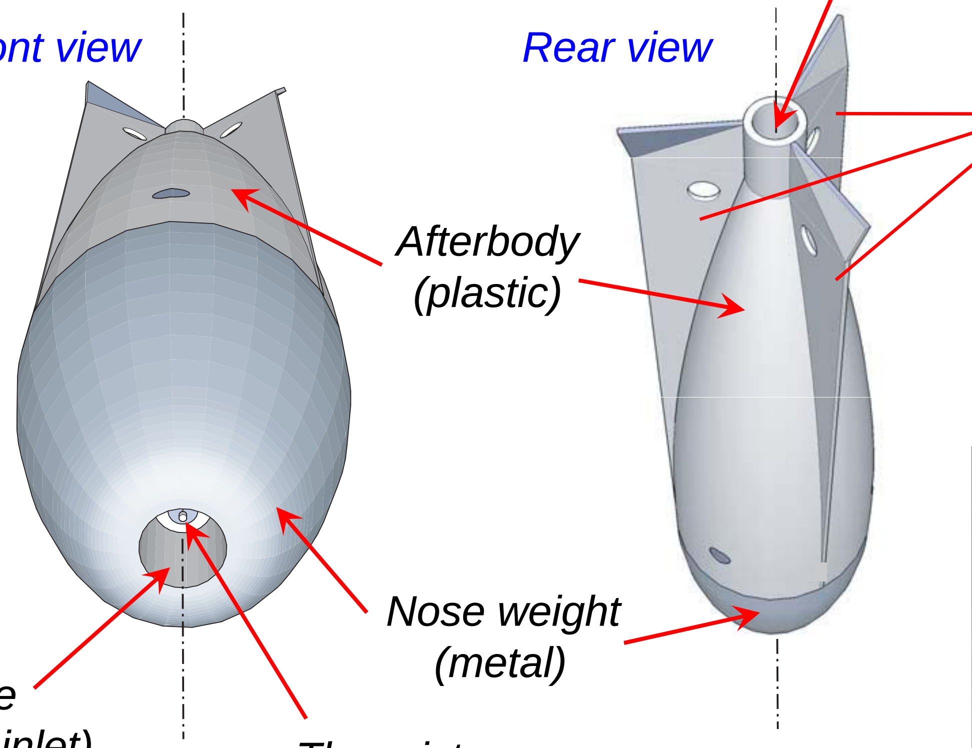
1) T-4 and T-6 have shorter probe wire (lighter nose weight) than T-7 and Deep Blue.

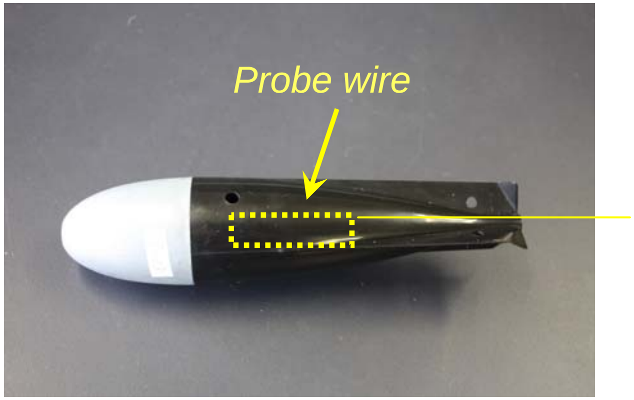
2) Deep Blue (T-4) has longer canister wire than T-7 (T-6) to allow higher ship speed.

3) The two companies produce by their own (not selling product of the other).
The thermistor, exported from Sippican to TSK, is the only truly-common part.

Hanawa et al.(1995; H95)'s FRE is for all types in color-filled rows, which should have been originally designed to fall at an identical rate.

The XBT



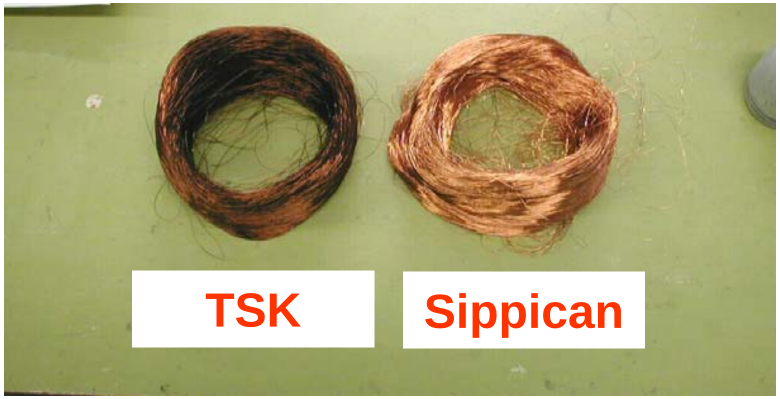


A photo of TSK T-7

Facts that had been known about the two manufacturers’ XBT

- ✓ *Wire is different.*

  TSK’s wire coating is thicker than Sippican’s.



- ✓ *Yet, their total weight is kept identical.*

  The difference in wire weight is compensated by adjusting nose weight (by different inside hollowing).

- ✓ *Therefore, they (should) fall at an identical rate.*

  Actually, difference in FR was not detected by Hanawa et al.(1995).

However,

- ✓ *FR of the two companies' T-7 had never been compared directly in sea tests. They were tested only individually.*

- ✓ *Their structure had never been compared directly.*

- ✓ *We had some lessons from T-5.*

  The Sippican T-5 and TSK T-5 had been believed to have identical fall-rate, but that was wrong. And, there were multiple differences that even the manufacturer did not know (Kizu et al., 2005).

How about T-7?

Do they really fall at the same rate?

Are they really designed to have the same fall rate?

In addition,

- ✓ *Many recent articles show that H95's FRE has bias for T-7 and its relatives produced in (at least) some periods in the past.*

However,

- ✓ *Most of the previous studies were not based on side-by-side comparisons (* as of 2008).*
- ✓ *We (in Tohoku) had never visited this issue since H95.*

We needed to (re-*)examine by ourselves.

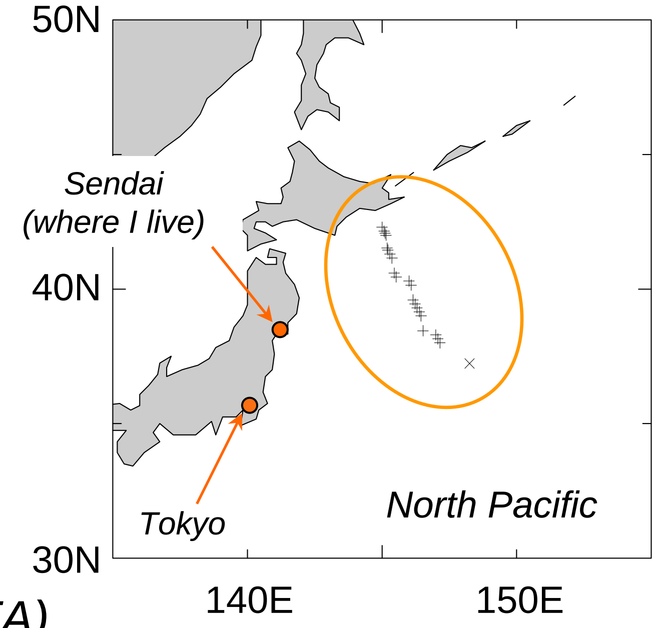
** I was not involved in the work of former TT/QCAS team, which resulted in H95. So, for me, this is the first examination of T-7.*

Outline of this talk

- *Sea test*
  - *Side-by-side comparison with CTD*
  - *Direct comparison between Sippican and TSK T-7*
- *Detail inspection of the probes*
  - *Weight measurement*
  - *Structural measurement*

The sea test

Kaiyo Maru (2630 t, 93 m)

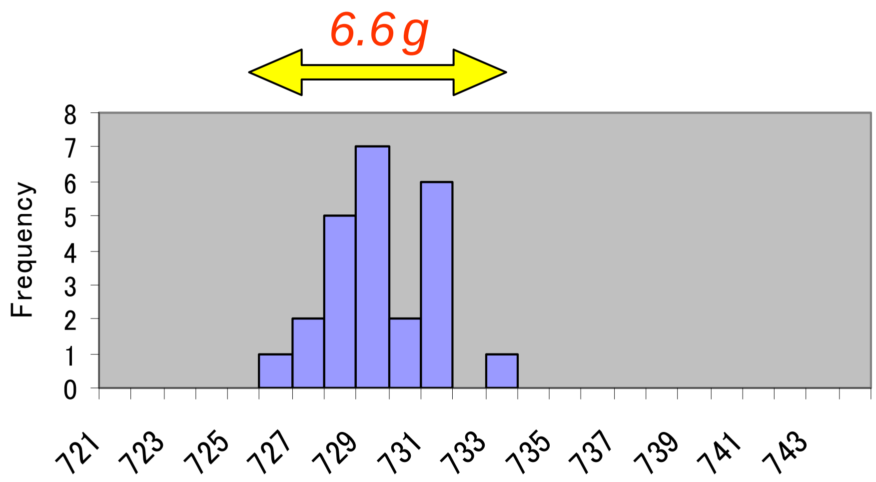


- *Conducted during 4-8 May 2008, east of Japan, as a part of KY0805 cruise of R/V Kaiyo Maru (JFA).*
- *Two dozens of T-7 were provided by each of the manufacturers.*
  (Sippican: 1083882-1083905, TSK: 066313-066324)
- *A pair of Sippican and TSK T-7 were dropped consecutively during a single CTD operation. ($\Delta T < 10$ min, $\Delta X < 700$ m)*
- *A regularly-calibrated CTD (Sea-Bird Electronics SBE-9) was used as a truth.*
- *Error of XBT depth calculated by H95's FRE is estimated by the method of Hanawa and Yasuda (1992).*

Pre-cruise measurement

The total weight of probe in air (24 pieces for each manufacturer)

Sippican T-7



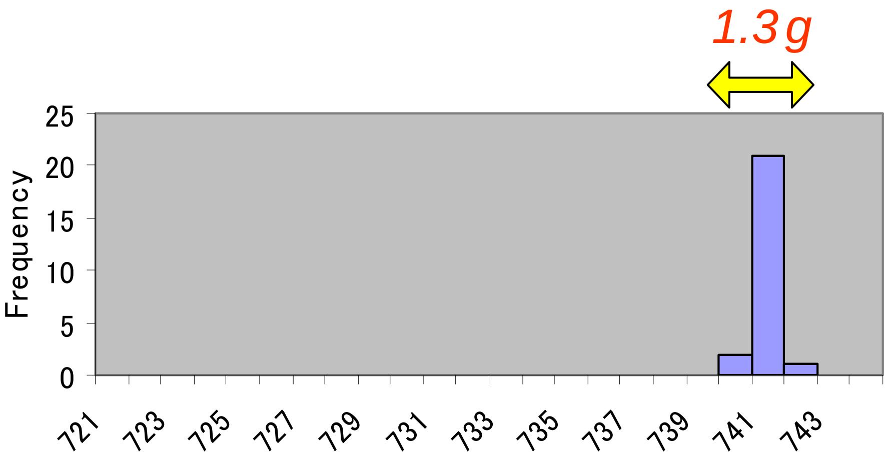
Mean = 728.9 g

difference

11.6 g

(1.6%)

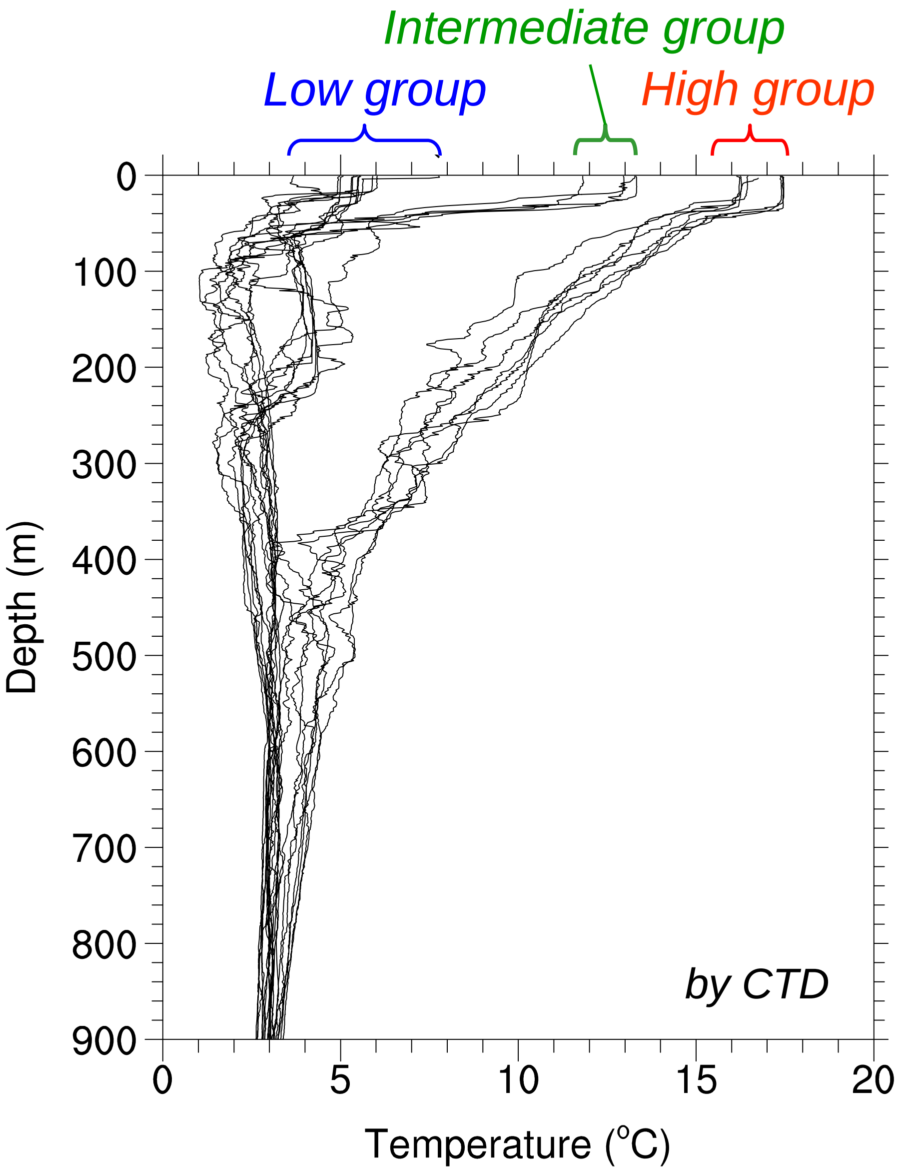
TSK T-7



Mean = 740.5 g

Two Sippican T-7 (the lightest and the heaviest) and one TSK T-7 (median) were saved for later detail inspection including in-water check and decomposition.

Obtained profiles



Success rate

Sippican: 18 of total 22 tested. (82%)

(incl. five partially damaged)

TSK: 23 of total 23 tested. (100%)

Size of sample

Sippican: total 18

7 from Low SST group,

8 from High SST group,

and 3 from intermediate.

TSK: total 23

11 from Low SST group,

8 from High SST group,

and 4 from intermediate.

Depth error estimation

(Hanawa and Yasuda, 1992)

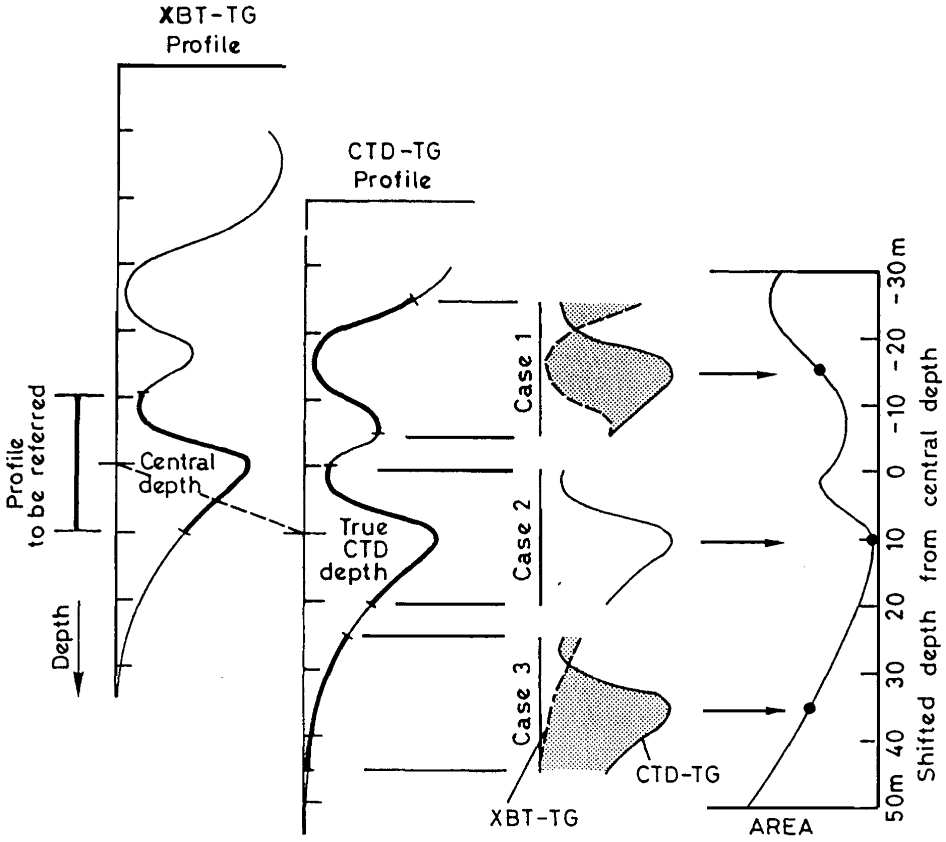


Figure 3. Explanatory picture of the detection method adopted to determine the XBT depth-error (adapted from Hanawa and Yasuda, 1992). See section 3. I .1, *step* 4, in the text for details. In this figure, only three examples are shown. Since the area has its minimum value in Case 2, its shifted CTD central depth is the actual depth of the reference central XBT point, and its depth-shift (+10m) is regarded as the depth correction of the XBT data.

1) Assume CTD temperature profile as truth.

2) Find Δz that gives the minimum of

$$\int_{z+\Delta z-dz}^{z+\Delta z+dz} \left| \frac{dT}{dz}_{XBT} - \frac{dT}{dz}_{CTD} \right| dz$$

for each depth.

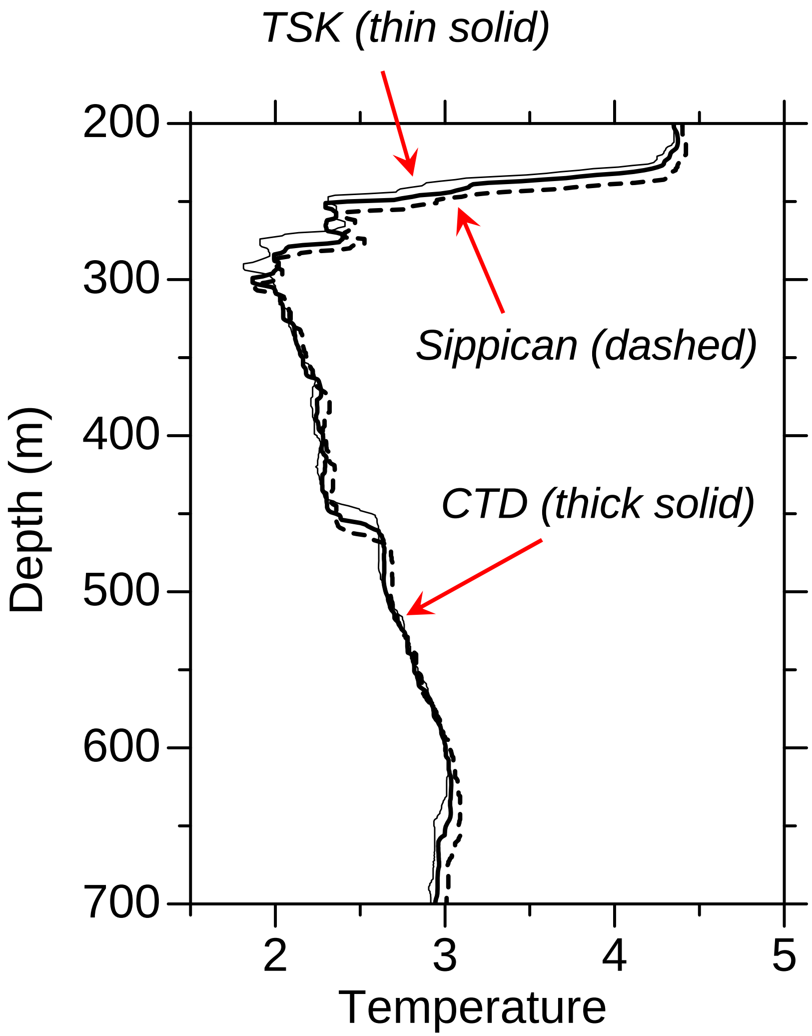
3) $\Delta z(z)$ gives the depth error profile for that probe.

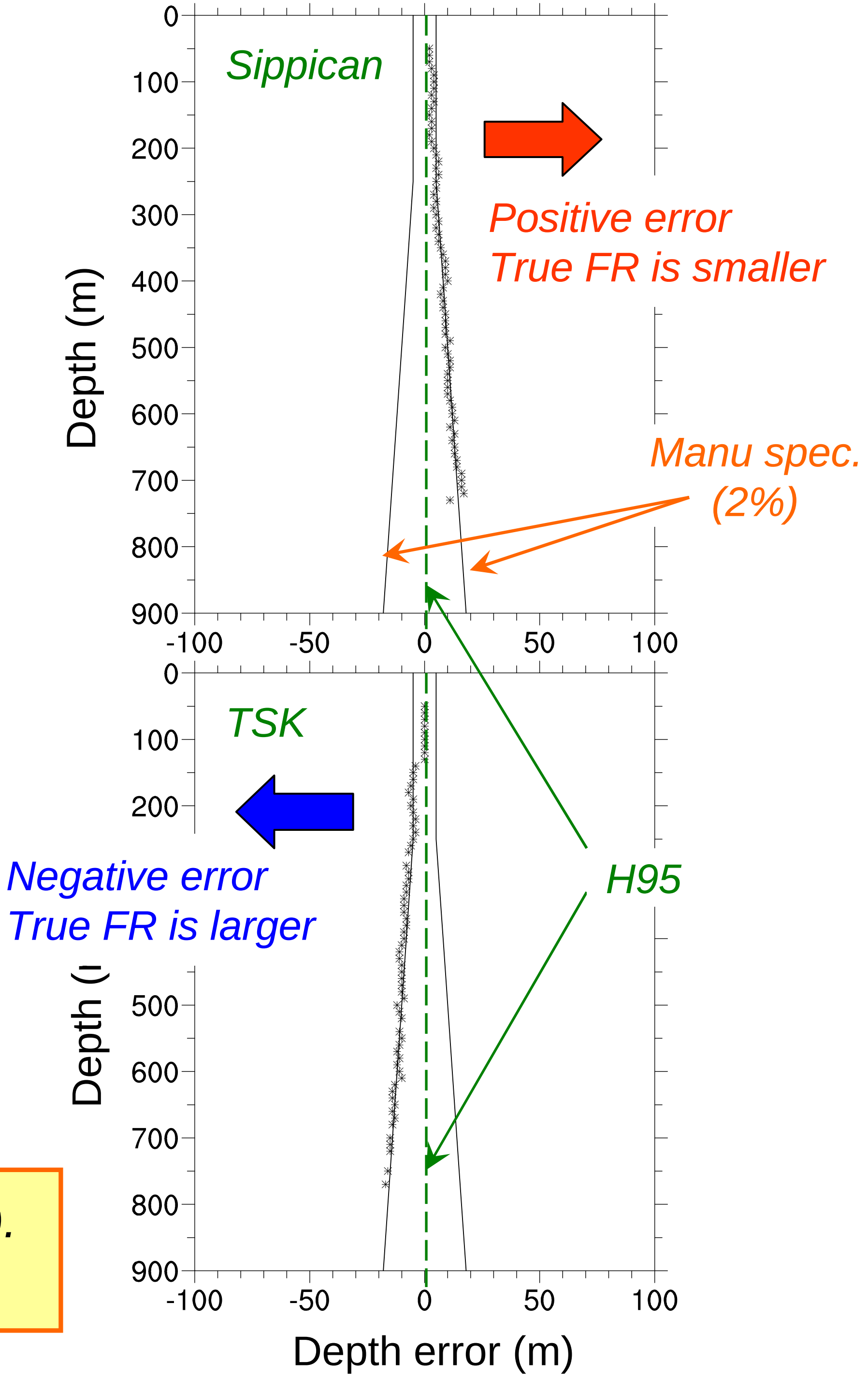
*) Resistive to errors in temperature.

*) Does not work well in areas with weak thermal stratification.

Sample result

Stn #04 (L)

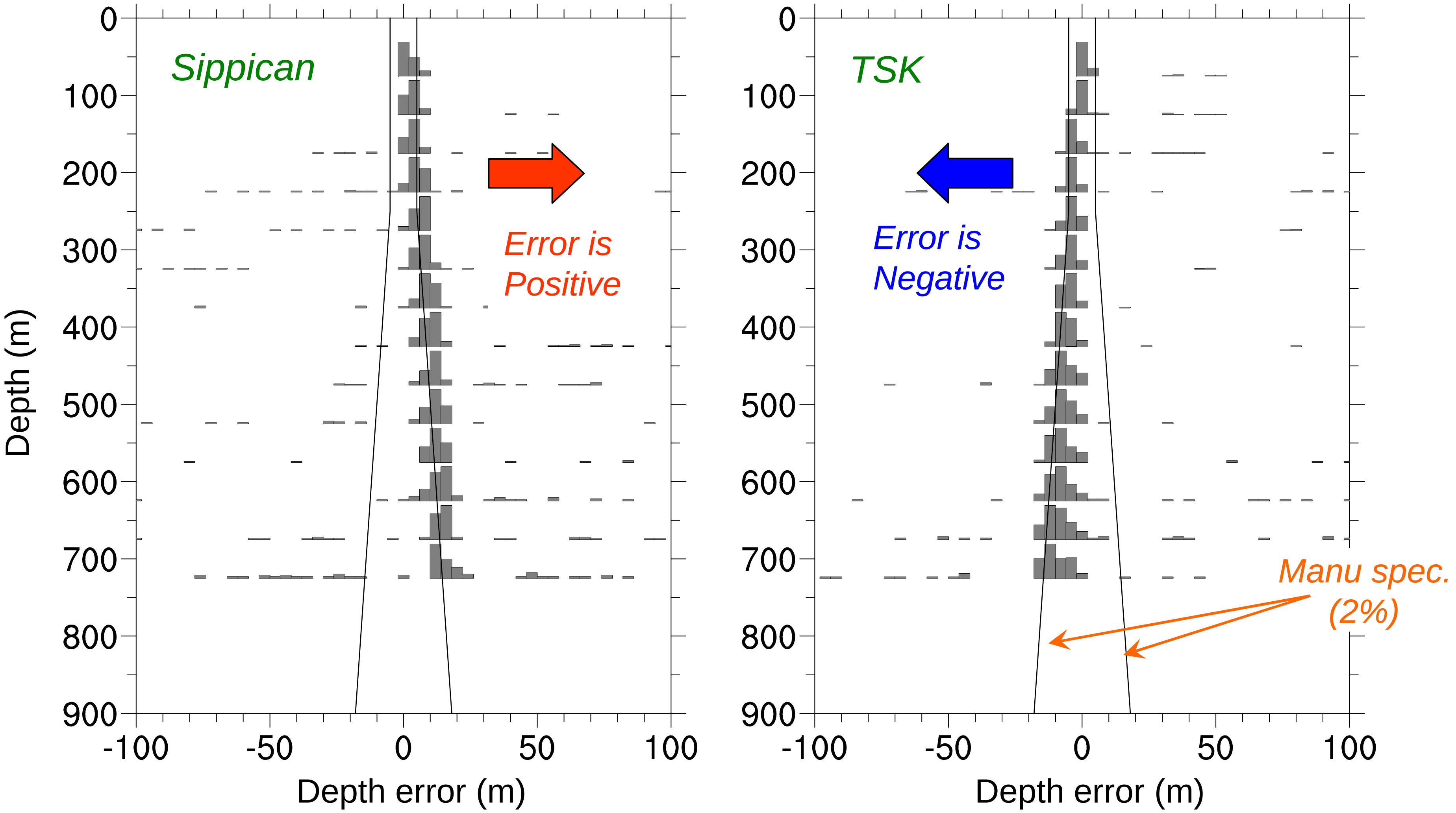




Sippican: positive depth error (and T error).

TSK: negative depth error (and T error).

Statistical summary



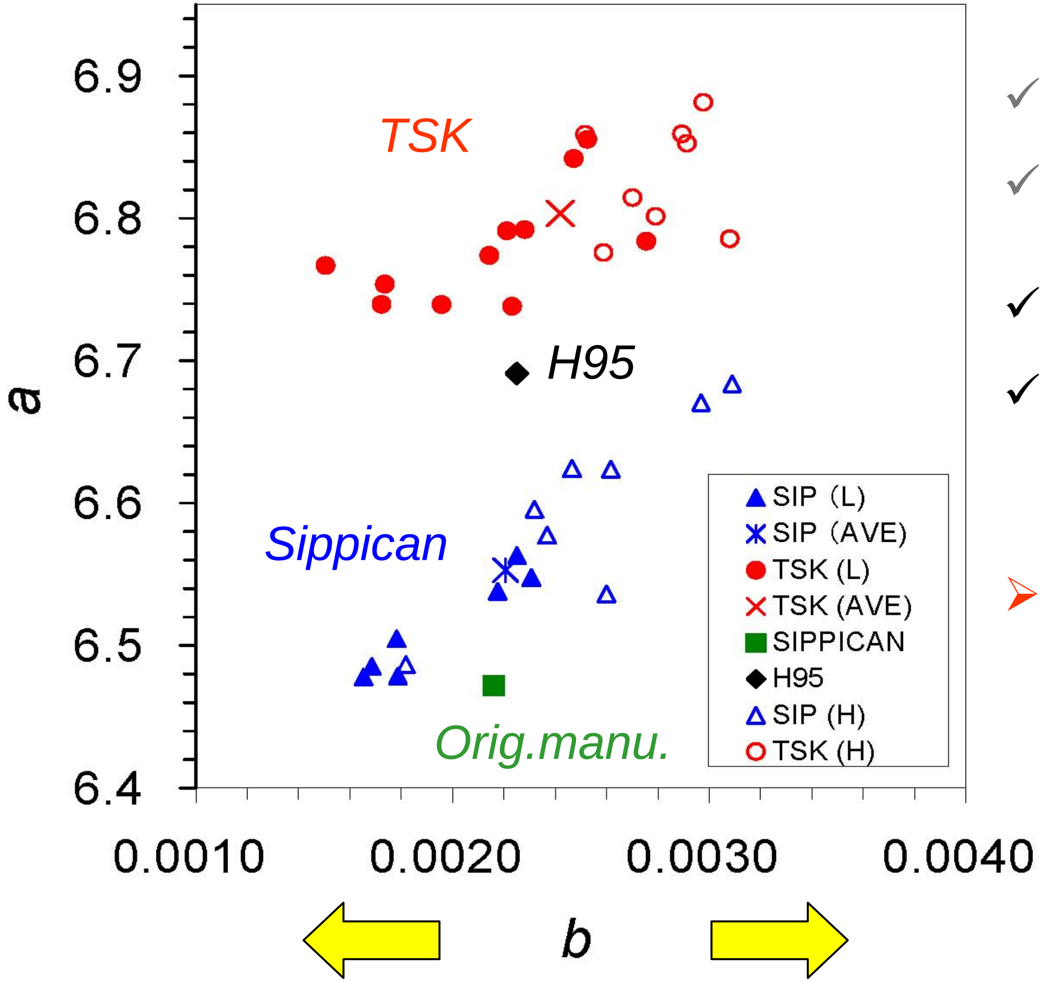
Sippican: Positive depth error. True fall rate is >2% smaller than H95.

TSK: Negative depth error. True fall rate is <2% greater than H95.

Scatter of probe-by-probe FR coefficients

** The traditional quadratic form is assumed.*

Depth (m) = $a\,t - b\,t^2$ ***t*** *: elapsed time (sec)*



Smaller deceleration

Greater deceleration

- ✓ *Sippican T-7 falls slower than H95.*
- ✓ *TSK T-7 falls faster than H95.*

- ✓ *H95 is located just in-between.*
- ✓ *Sippican T-7 has still greater fall rates than the manufacturers' orig. FRE.*

- ➢ *High SST group (open symbols) has larger **a** and **b** for both SIP & TSK.*

  It means that initial fall rate is larger, but deceleration is also larger.

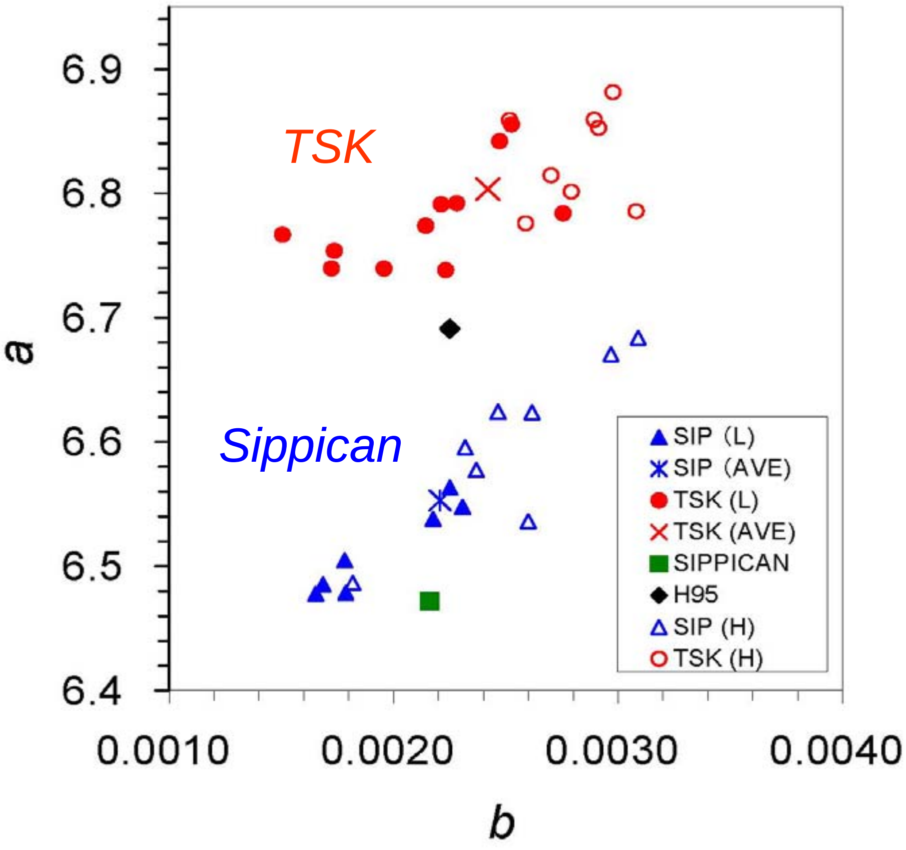
Temperature-dependency of fall rate (viscosity effect)

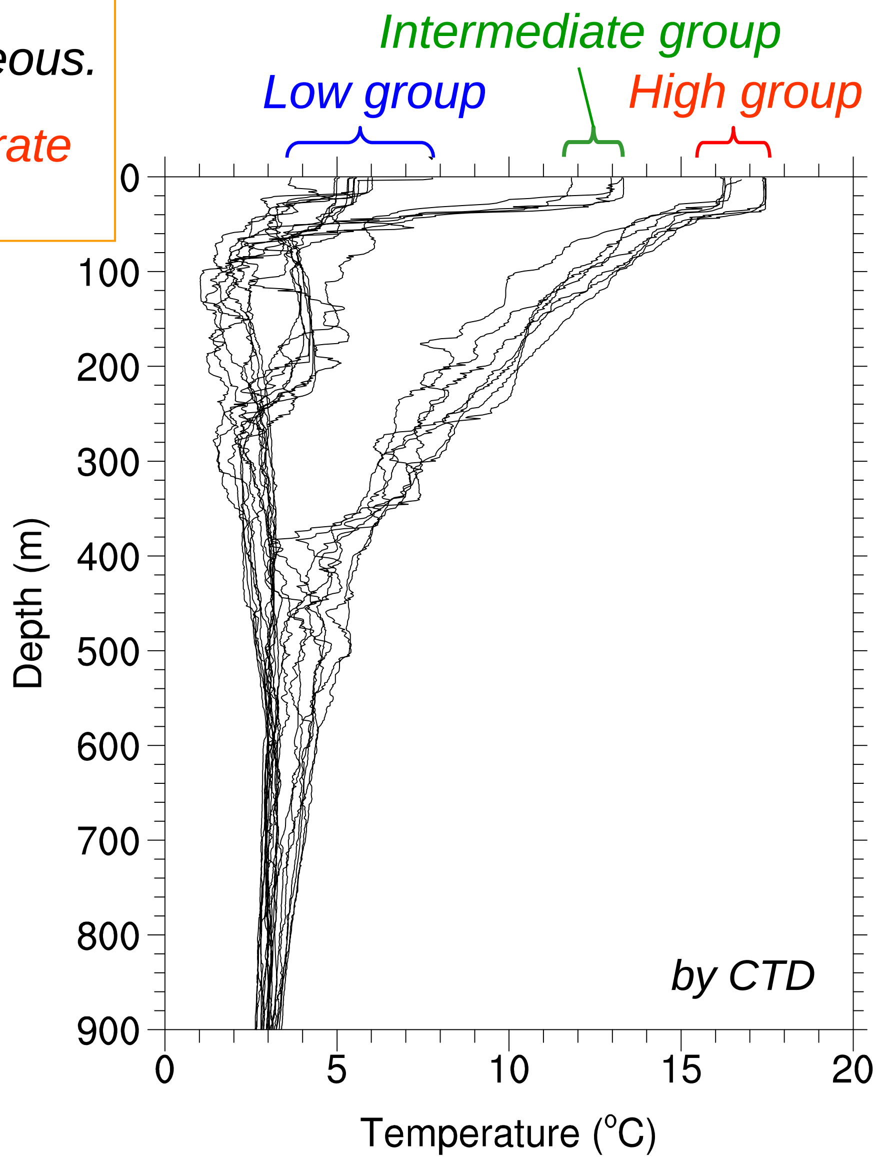
Temperature-dependency of T-7's fall rate

In Low group (closed circles and triangles),

Temperature is vertically more homogeneous.

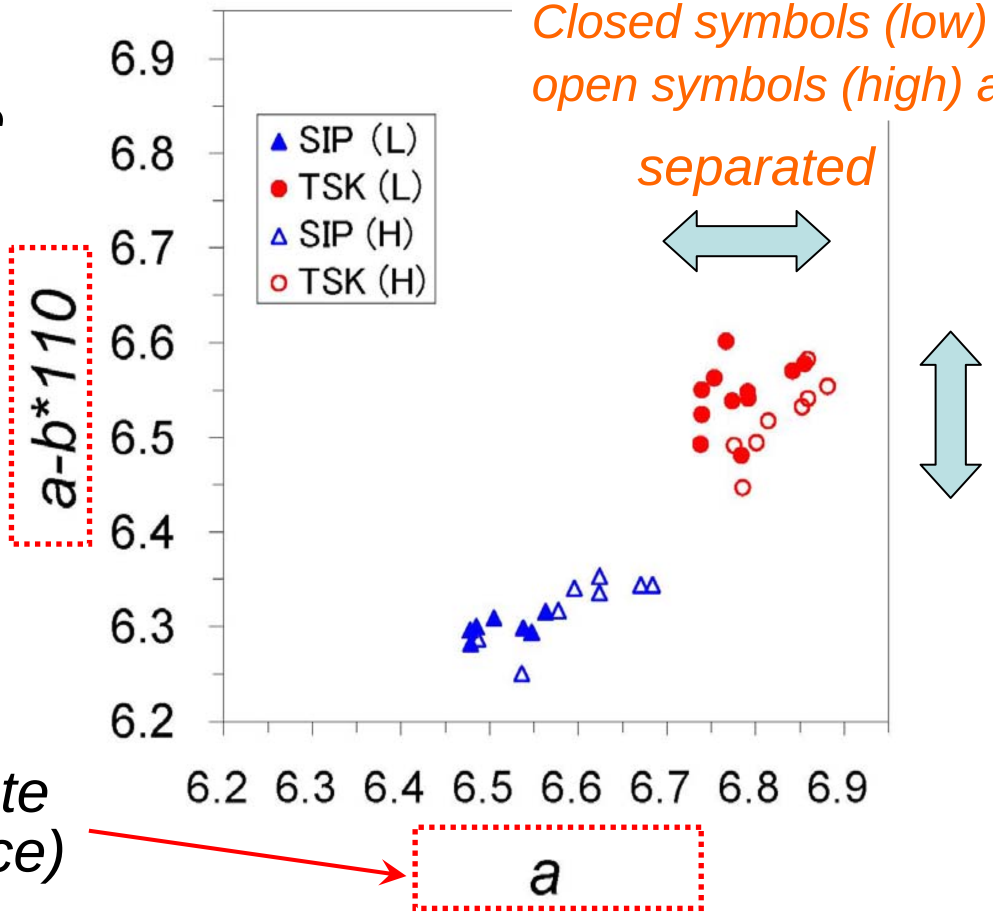
Probes fall slower, but the change of fall-rate during descent is also smaller.





Change of fall rate in water of different thermal stratification

Instantaneous fall rate (m/s) = a - b t



Terminal fall-rate
(at depth > 700m)

Closed symbols (low) and open symbols (high) are

separated

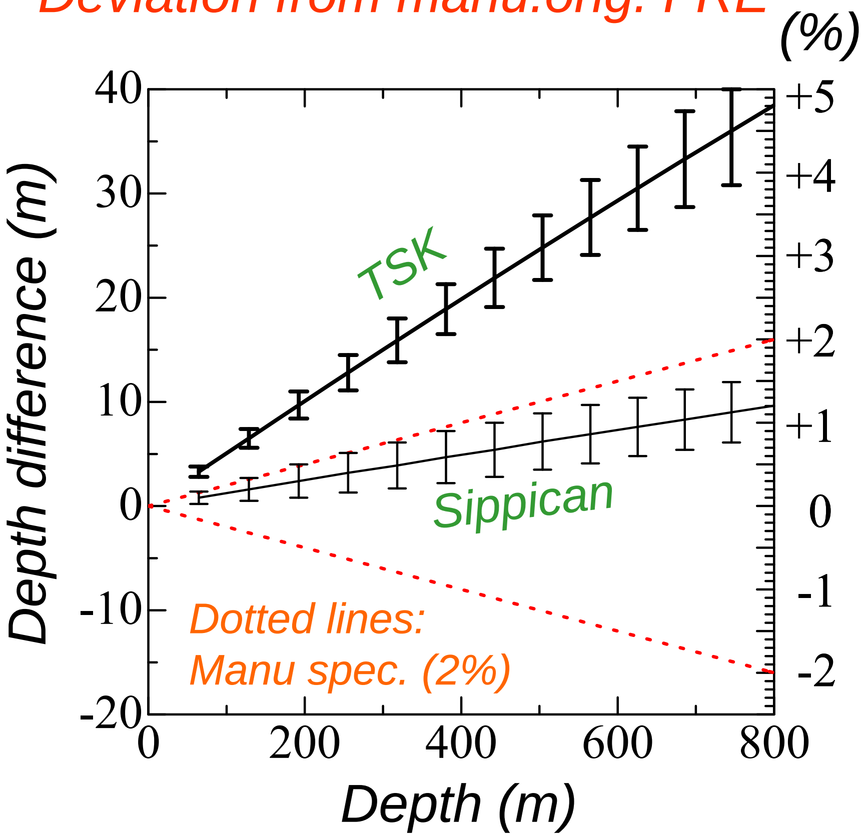
merged

Initial fall-rate
(near surface)

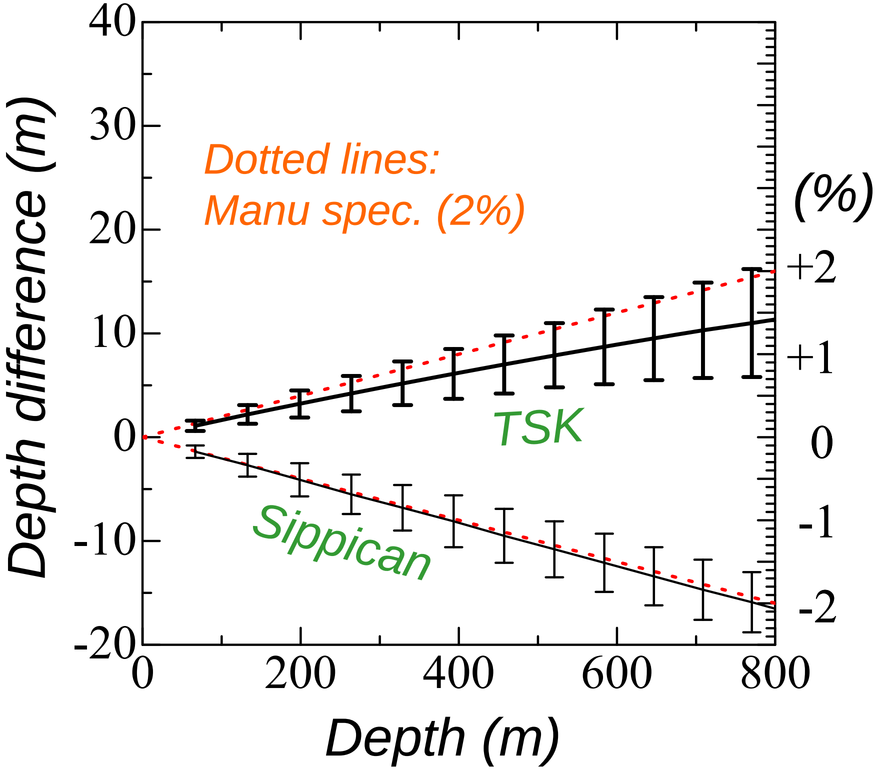
Initial variation (temp.-dependency) of fall-rate is almost lost in the deepest part of the profiling-range where temperature difference becomes negligible.

Relative difference among published FREs and present ones.
(the temperature-dependency is omitted here)

Deviation from manu.orig. FRE



Deviation from H95's FRE



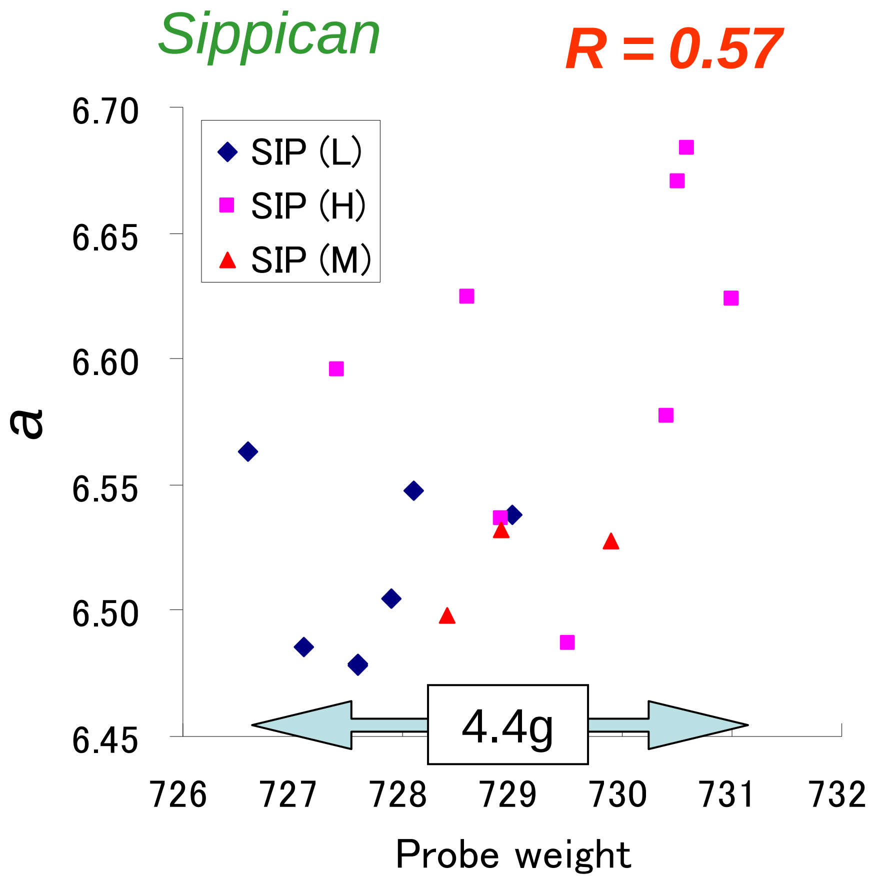
Sippican T-7 mean: ***$D = 6.553\ t - 0.00221\ t^2$*** *(n=18)*

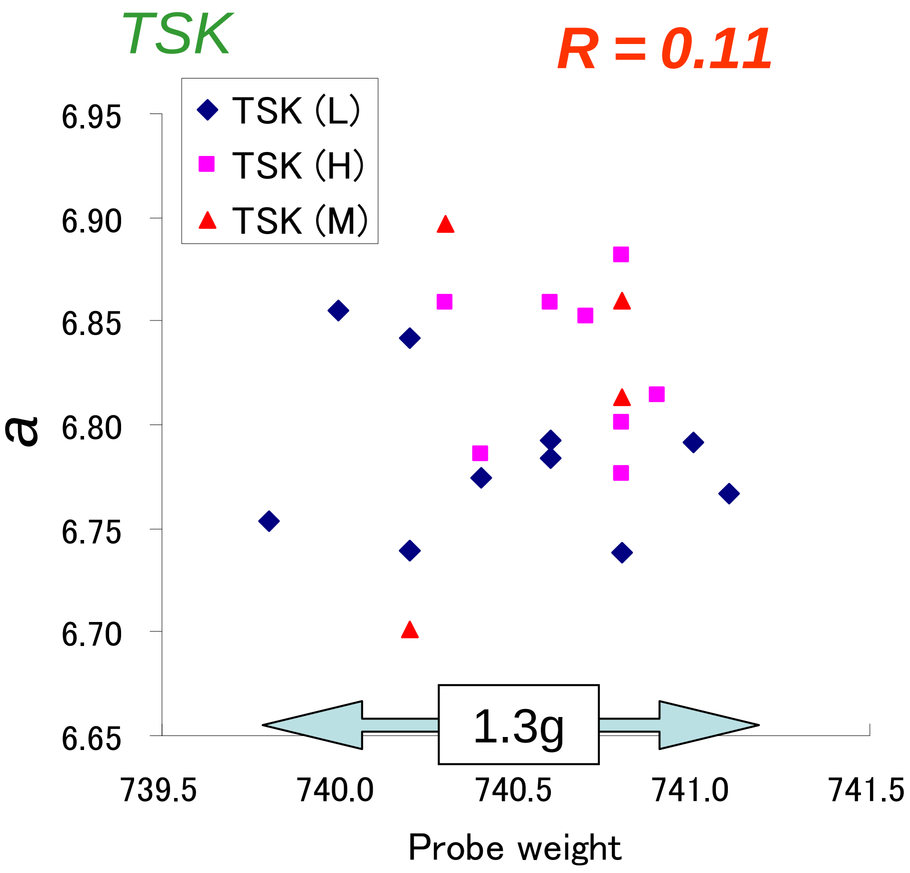
TSK T-7 mean: ***$D = 6.803\ t - 0.00242\ t^2$*** *(n=23)*

Diff. 3.5%

*Dependency of **a** coefficient on total probe weight (in air)*

** Symbols show temperature groups*





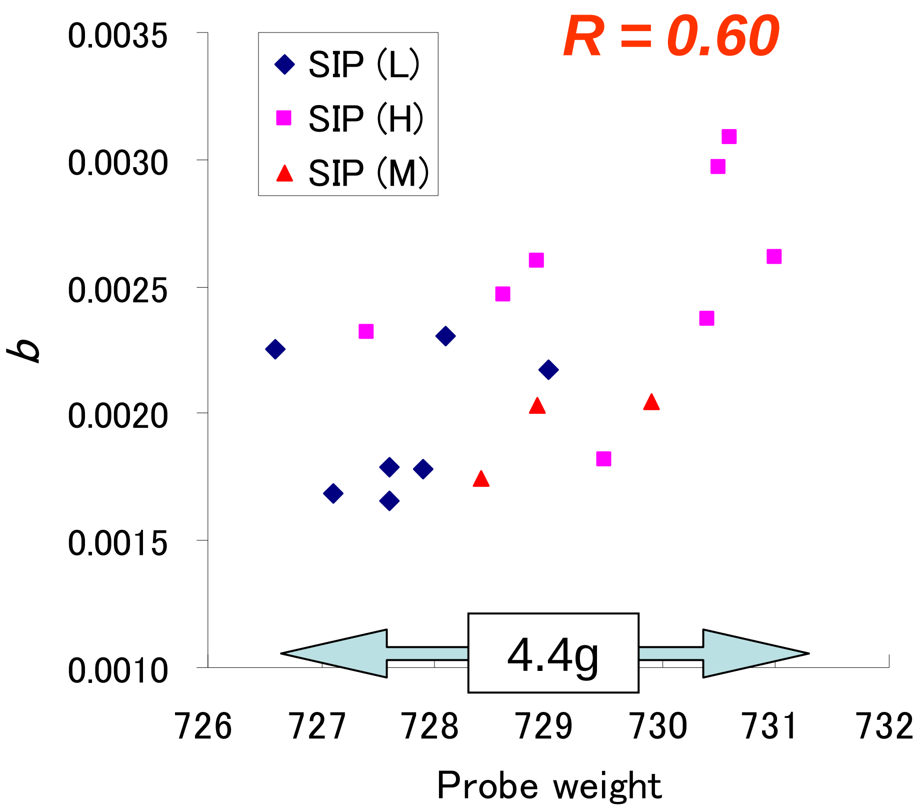
** High correlation between probe weight and **a** coefficient for **Sippican T-7** seems to be at least partially caused by the temperature dependency.*

** Insignificant correlation for **TSK T-7** with much smaller weight variation.*

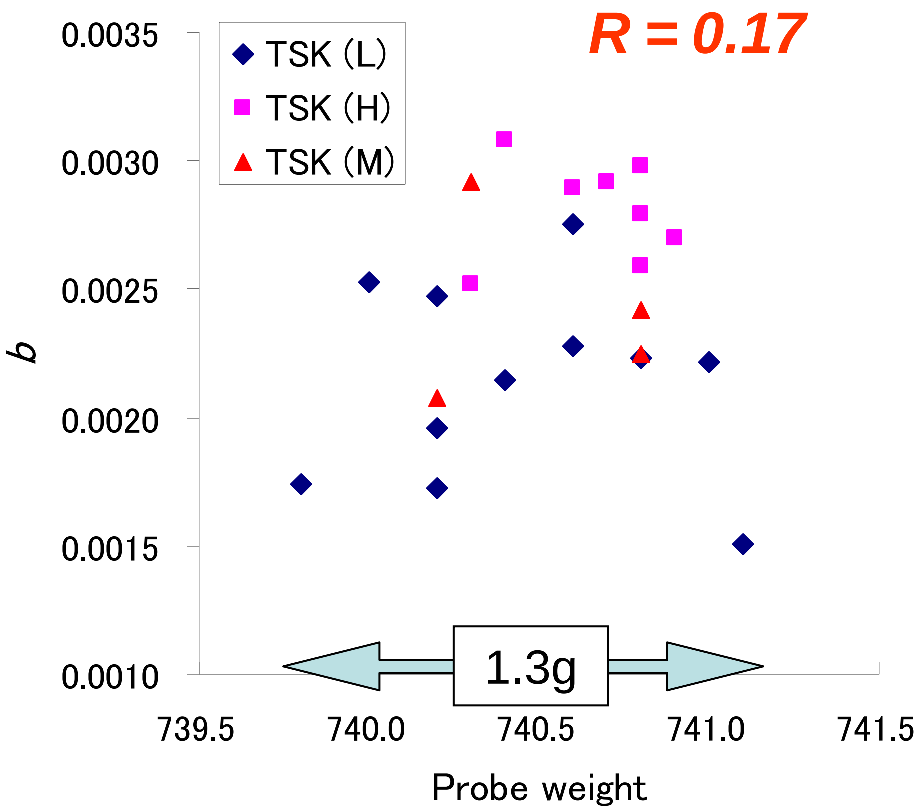
*Dependency of **b** coefficient on total probe weight (in air)*

** Symbols show temperature groups*

Sippican



TSK



** High correlation between probe weight and **b** coefficient for **Sippican T-7** seems to be at least partially caused by the temperature dependency.*

** Insignificant correlation for **TSK T-7** with much smaller weight variation.*

So,

- ✓ *Dependency of fall-rate on probe weight is not clearly seen in either set of probes made by a single manufacturer, perhaps because of other factors (e.g. the temperature-dependency, sea condition, …).*

But

- ✓ *Mean difference between Sippican and TSK T-7 is large (3.5%), and it is larger than the difference in probe weight (about 2%).*

The difference in total weight (in air) can not explain all of the fall-rate difference.

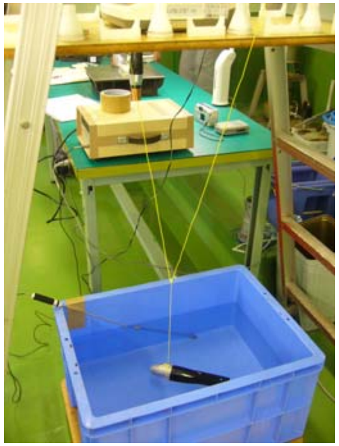
What else?

How do they differ, actually?

Then,

- ➢ *We made detail inspection of two Sippican T-7 and one TSK T-7 that were not used in the sea test.*

Anatomy *-Detail inspection of expendable probes-*



We investigated

- *weight of probe w/wo wire in air*
- *weight of probe w/wo wire in water*
- *position of the center of gravity*
- *shape and structure of probes*
- *line density of wire*
- *quality of wire coating (i.e. electric insulation)*

for some sample of

- *T-5 from both TSK and Sippican*
- *T-7 from both TSK and Sippican*
- *XCTD-1, 2 from TSK*

And, we learned that

- *weight was different,*
- *shape was different,*
- *structure was different, …*

though we had only known that wire was different.

**Photos are taken during inspection of T-5.*

Weight difference

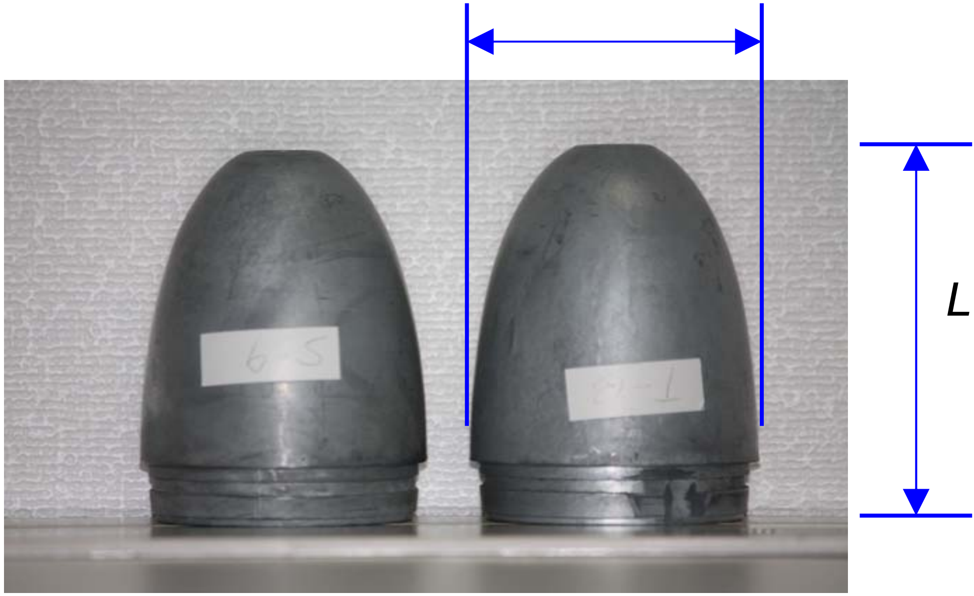
- ✓ *Probe weight in water: TSK T-7 is heavier by about 12g (2%).*

  This weight difference came from difference in weight of probe wire.

  The differences in weight of the other parts (nose weight, afterbody and probe wire spool) are very small (not shown here individually).

Structural differences (nose weight; outer shape)

Diameter: TSK T-7 is 0.2mm (0.4%) larger

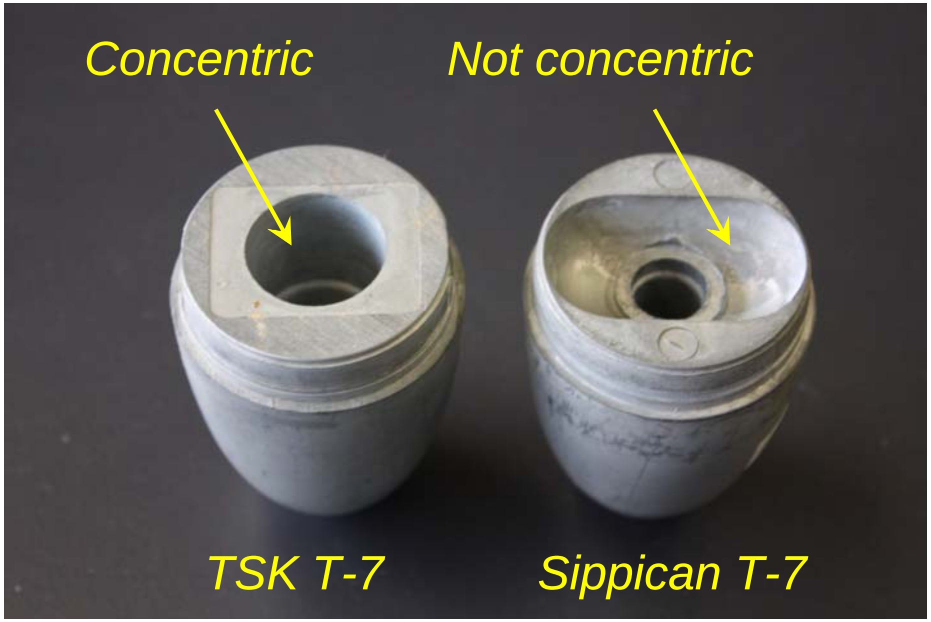


Length: TSK T-7 is
1mm (1.7%) longer

Sippican T-7 *TSK T-7*

Structural differences (nose weight; inner structure)

Inside hollowing: Very different



Diameter of central hole (water inlet):

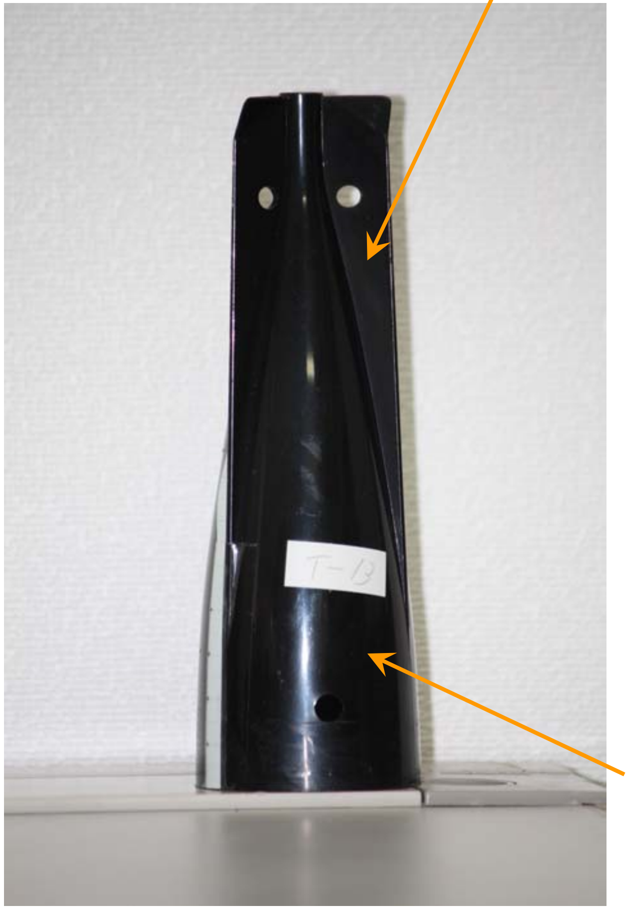
TSK T-7 is 0.5 mm (4.6%) smaller

According to the manufacturers' info,

- ➢ *All TSK XBT takes concentric design.*
- ➢ *For Sippican XBT,*
  - *T-7 and Deep Blue are non-concentric, but*
  - *T-4, T-5, T-6 and T-10 are concentric.*

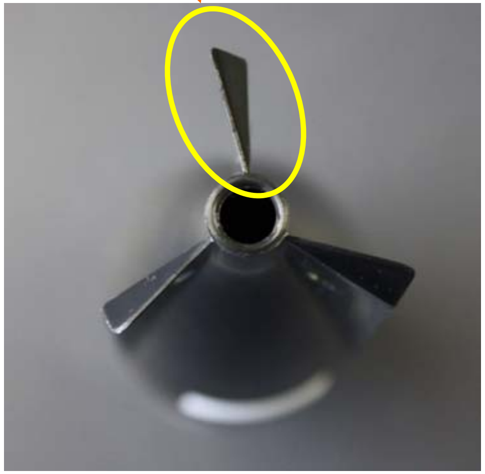
Structural differences (afterbody)

Fins: TSK T-7 is thinner



Angled part of the tail fins:

Shape is different

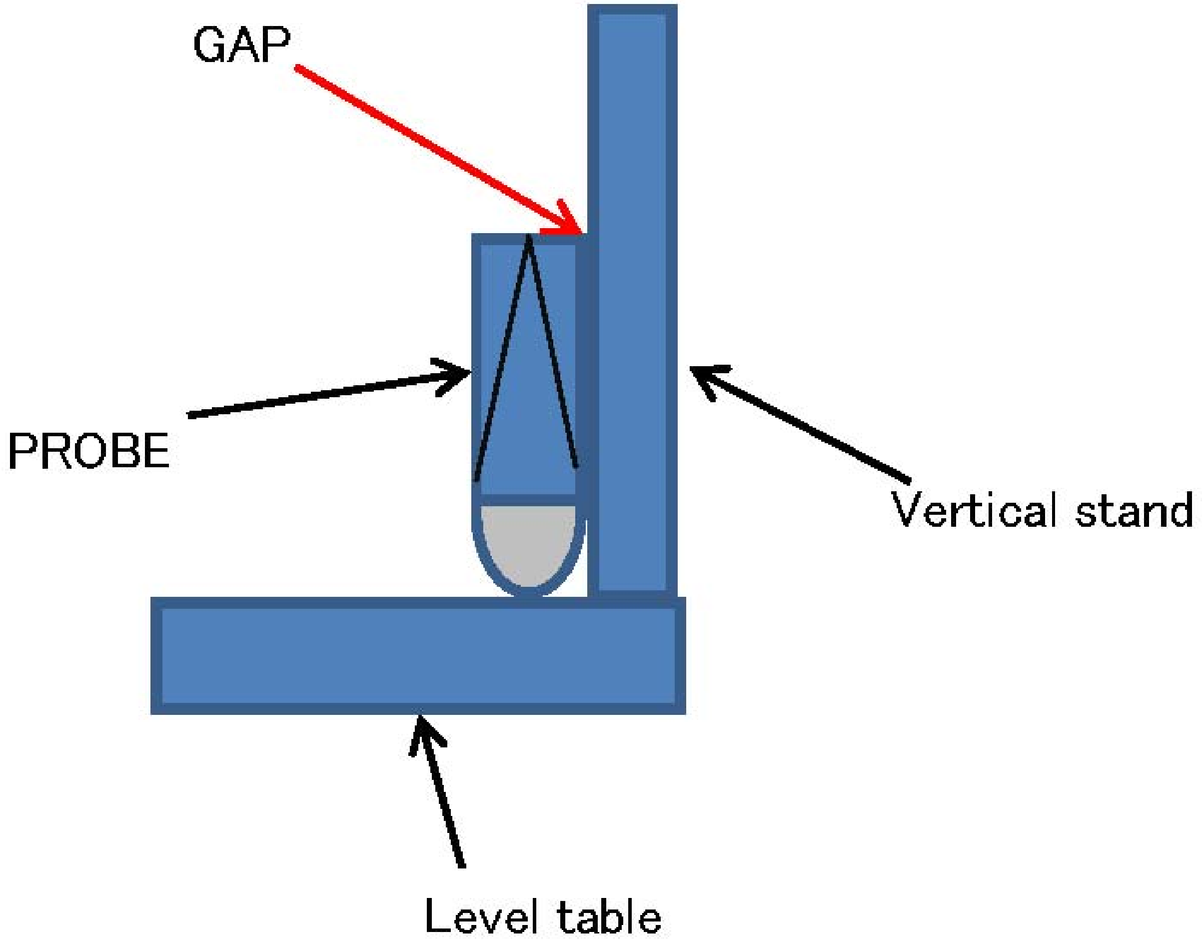


Inner volume of afterbody:

TSK T-7 is smaller by about 5 cm^3.

Sometimes not symmetric

Sippican T-7 has larger variance in off-vertical gaps in three direction.



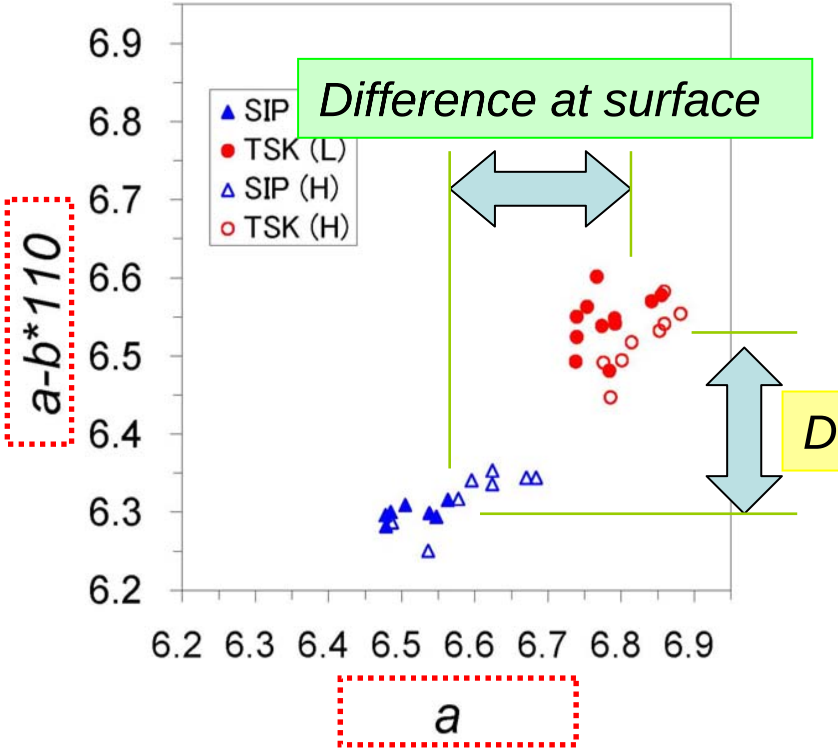
Summary of probe inspection, and some guess

- ✓ *There are many differences. It is very difficult to tell how each of those affects the fall rate, but I think such structural differences could explain at least some of the inter-manufacturer difference in the fall-rate.*

- ✓ *As an evidence for this …*

  If the weight determines everything, the difference in fall-rate at depth should become small because the weight difference is mostly originated from the difference in probe wire. But the truth is not like that.

Instantaneous fall rate



Difference at surface

Difference at depth

The question is,

From when, and which did change (either or both)?

- *Both the manufacturers claim, "we have not made any change, at least in a way that the fall-rate changes". If so, why is there sizable difference in the fall-rate of those recent probes in spite of that H95 found no detectable systematic difference?*

- *Is it just a sort of batch-to-batch variance? Obviously, we need more data to answer this question, but 3.5% is quite large…*

- *It sounds that the manufacturers' routine quality check made in their factories has been based on "weights". Has anyone been keeping constancy of shape and structure?*

Concluding remarks

Now I think it is important to

1) *Recognize that LMS and TSK probes are different even if they share the same model name for some types,*
2) *Keep regular check of fall rate error of the probe hopefully in areas of various water temperature (incl. probe inspection),*
3) *Compare and improve the method of fall rate estimation, and*
4) *Record and keep serial product number (PN) in data archives because that is the only way to identify a probe later.*

Technical difficulties are, however,

- *The present XBT system does not record PN automatically.*
- *The present common protocols (e.g. BATHY) for data transfer do not include PN as a part of metadata.*

Thank you.

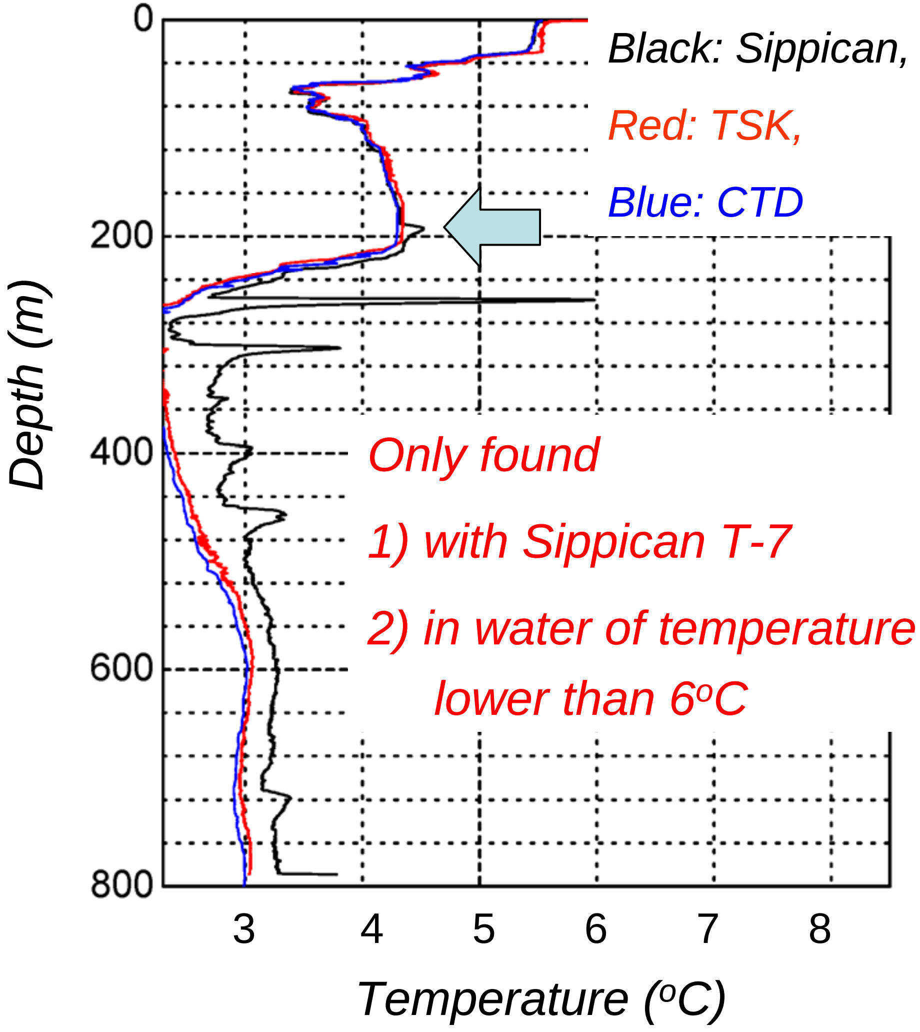
Shoichi Kizu

kizu@pol.gp.tohoku.ac.jp

東北大学
TOHOKU UNIVERSITY

Wire test

Some spiky or positively-biased profiles



Case 1

Black: Sippican,

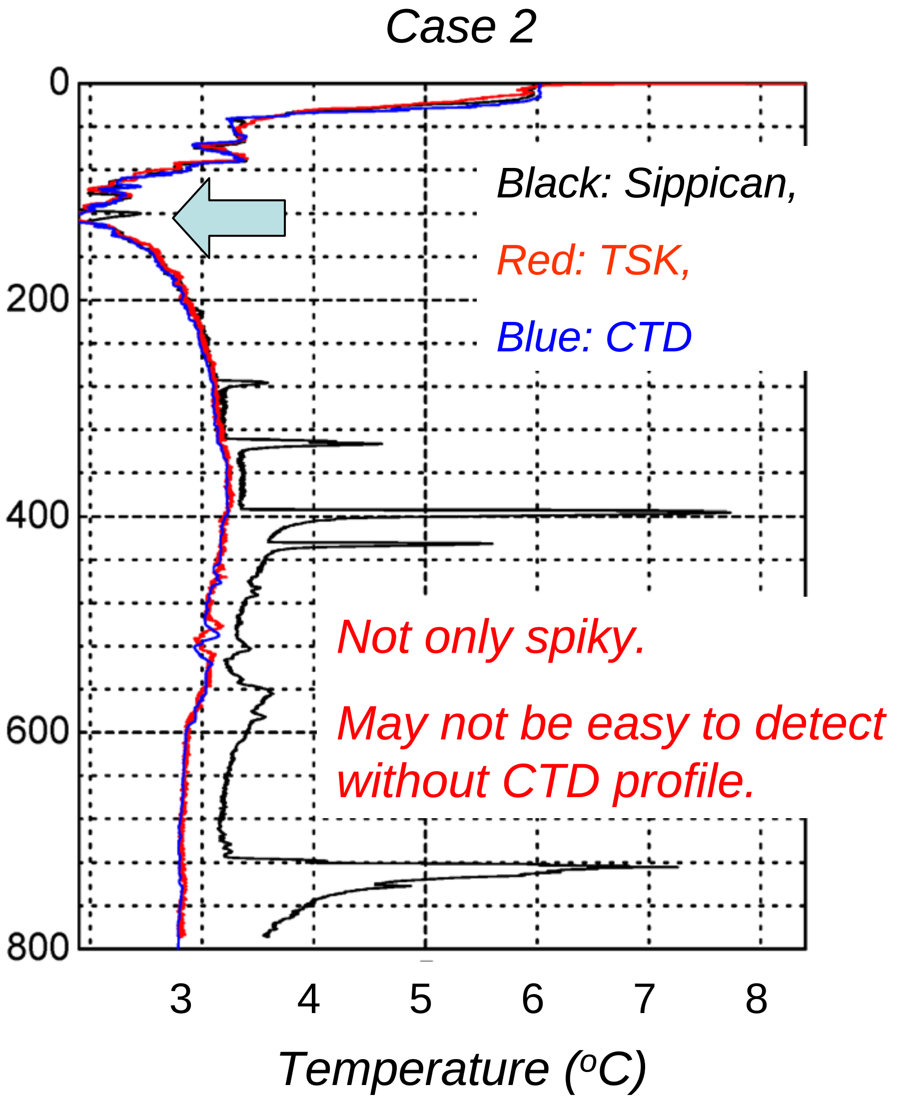
Red: TSK,

Blue: CTD

Only found

1) with Sippican T-7

2) in water of temperature lower than 6^{o}C



Case 2

Black: Sippican,

Red: TSK,

Blue: CTD

Not only spiky.

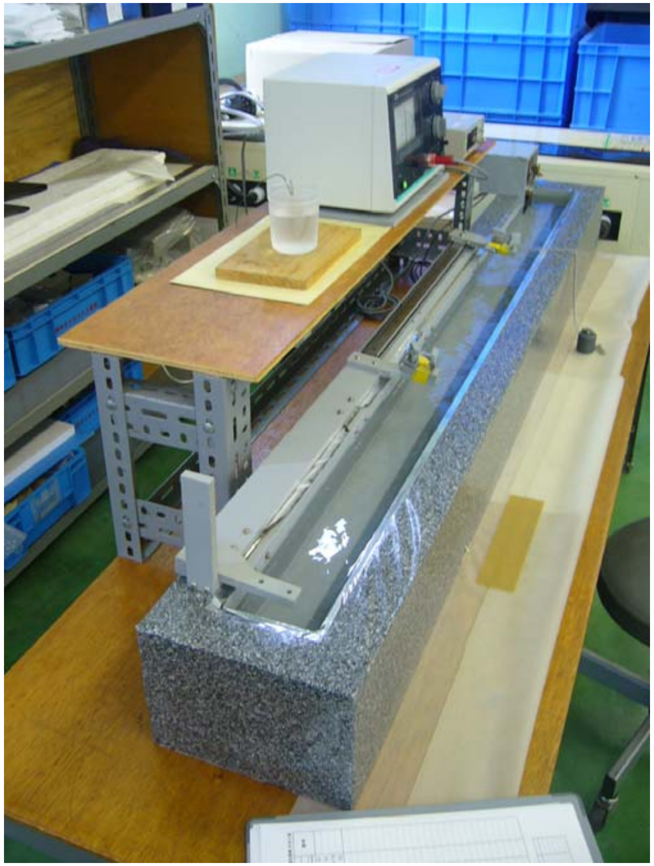
May not be easy to detect without CTD profile.

Some extreme "pull" test of wire

<Method>

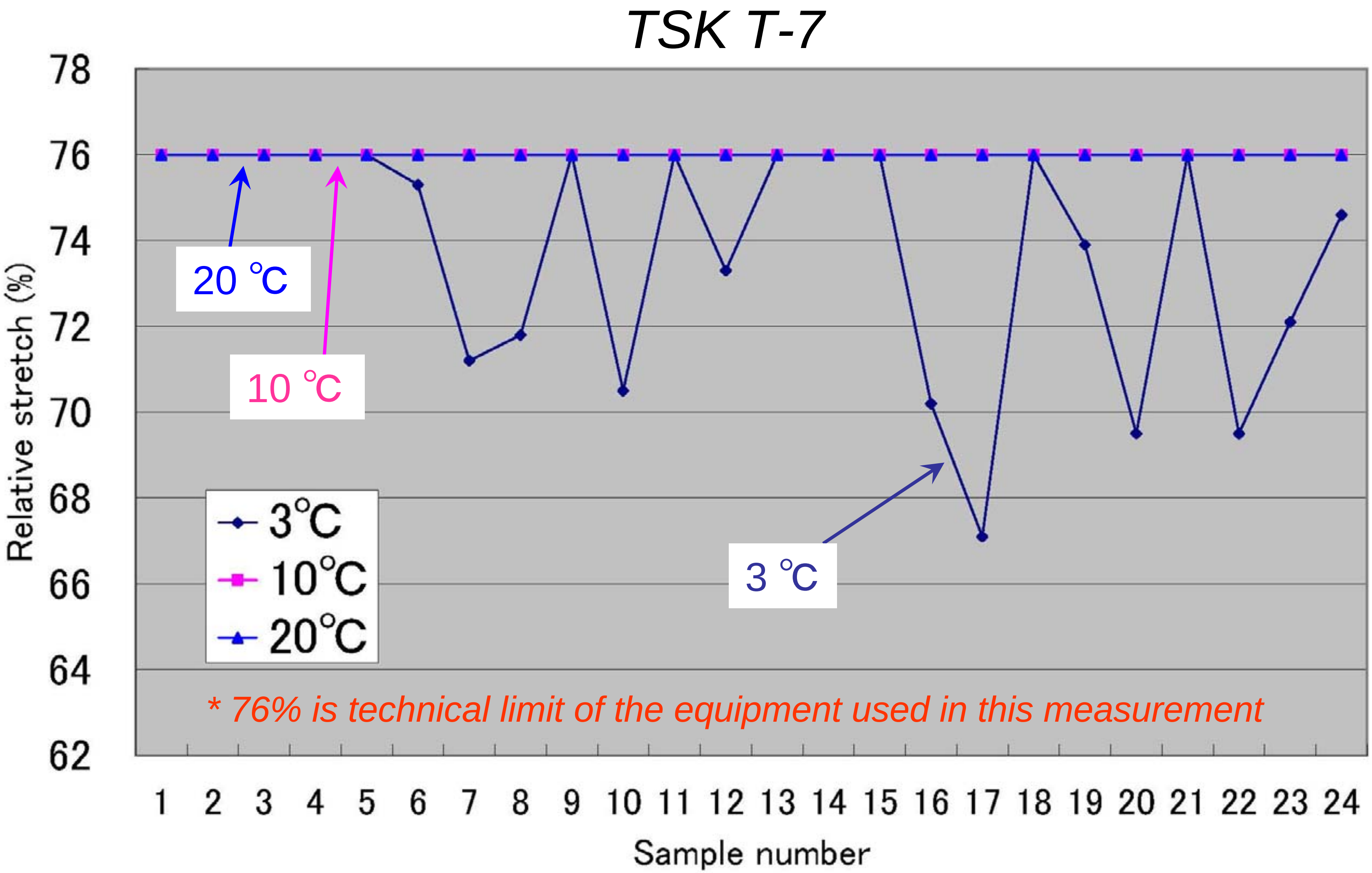
One end of a piece of canister wire (50cm length) was fixed in a water tub (right photo), and the other end was gradually pulled until its electric insulation to water is lost.

The stretch of wire at the time of insulation breaking was measured.



This test was repeated at three water temperatures (3^{o}C, 10^{o}C and 20^{o}C) for each of the 24 probes provide by each manufacturer.

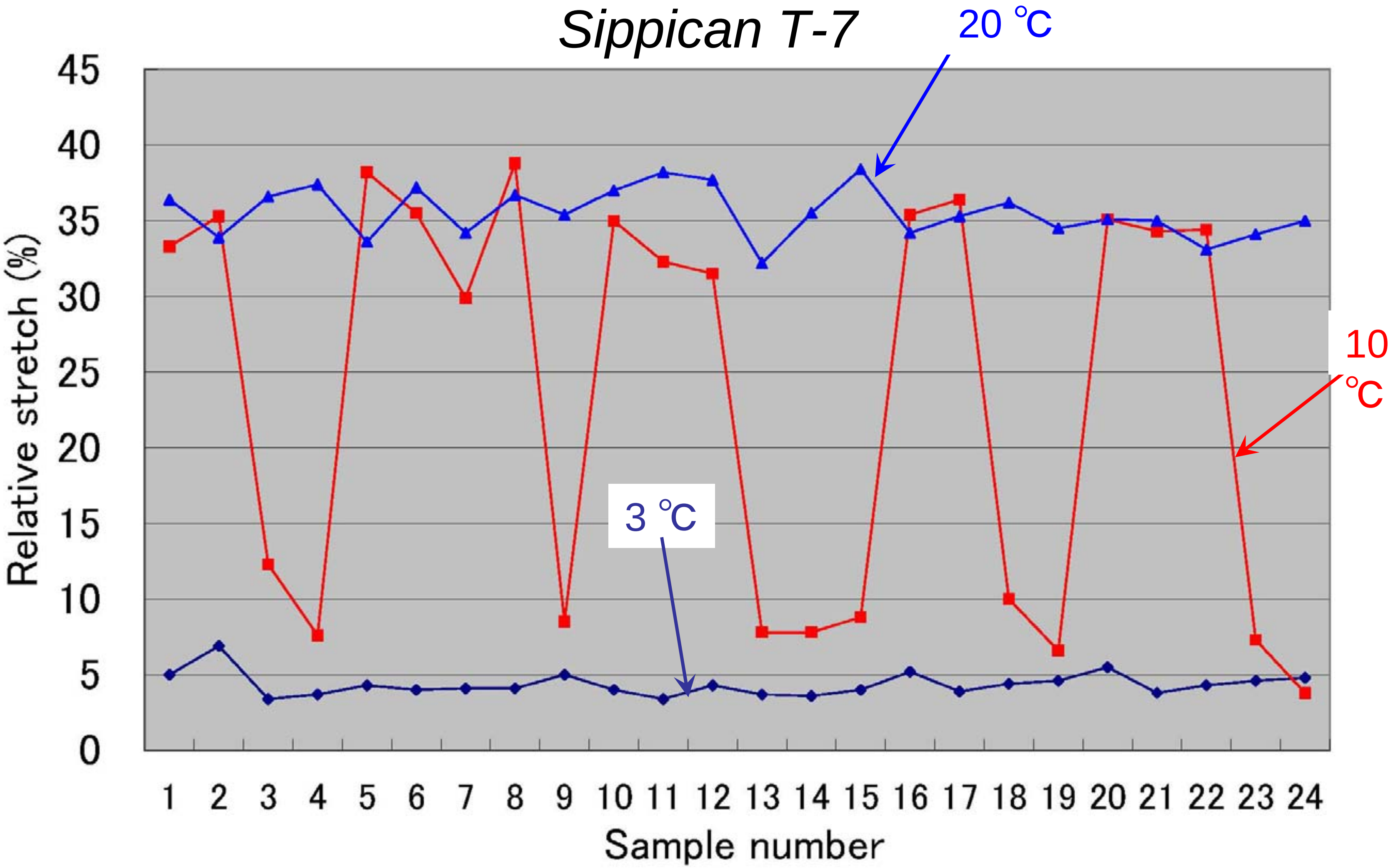
Some extreme "pull" test of wire



** 76% is technical limit of the equipment used in this measurement*

TSK's wire is very "resistive" against losing insulation by wire stretch..

Some extreme "pull" test of wire



Sippican's wire tends to lose its electrical insulation more easily in cold water.

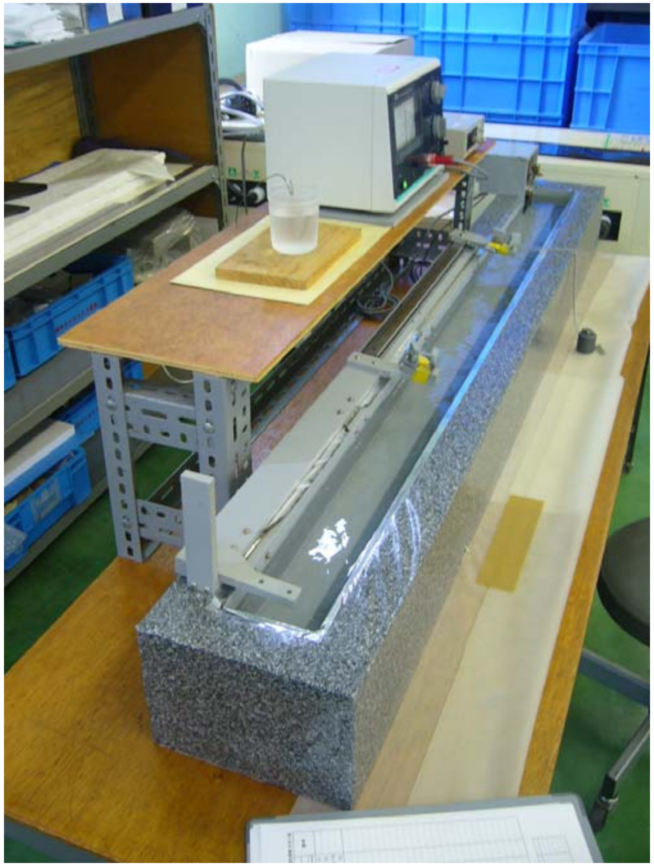
Notes

1) This is a test made by imposing strong stretch on short segments of wire, which is not supposed to happen in actual ocean measurement except when canister/probe wire is expired and physically breaks.

2) At this moment, I have no conclusive interpretation about if/how the result of this test can explain possible temperature bias suggested by many studies*.

*Actually, this was one of the reasons why I hesitated to show this in my talk. I do not want such vague information to walk alone.

3) More convincing explanation/quantification would require further laboratory tests with more realistic settings and proper understanding of the circuit.

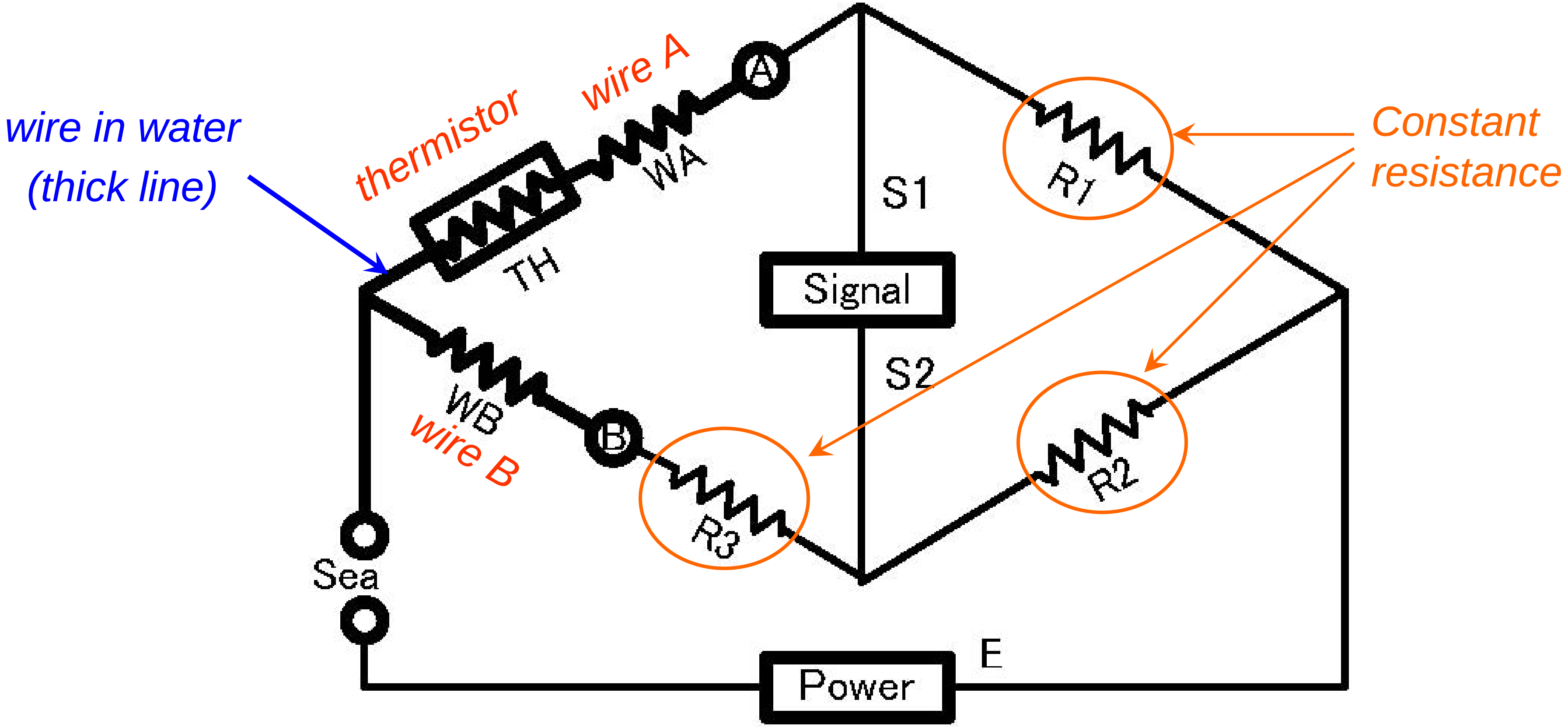


I do not mean (!)

- warm water is completely safe, nor
- TSK’s wire is perfect.

How circuit works…

Suppose WA=WB=W.



wire in water (thick line)

thermistor

wire A

wire B

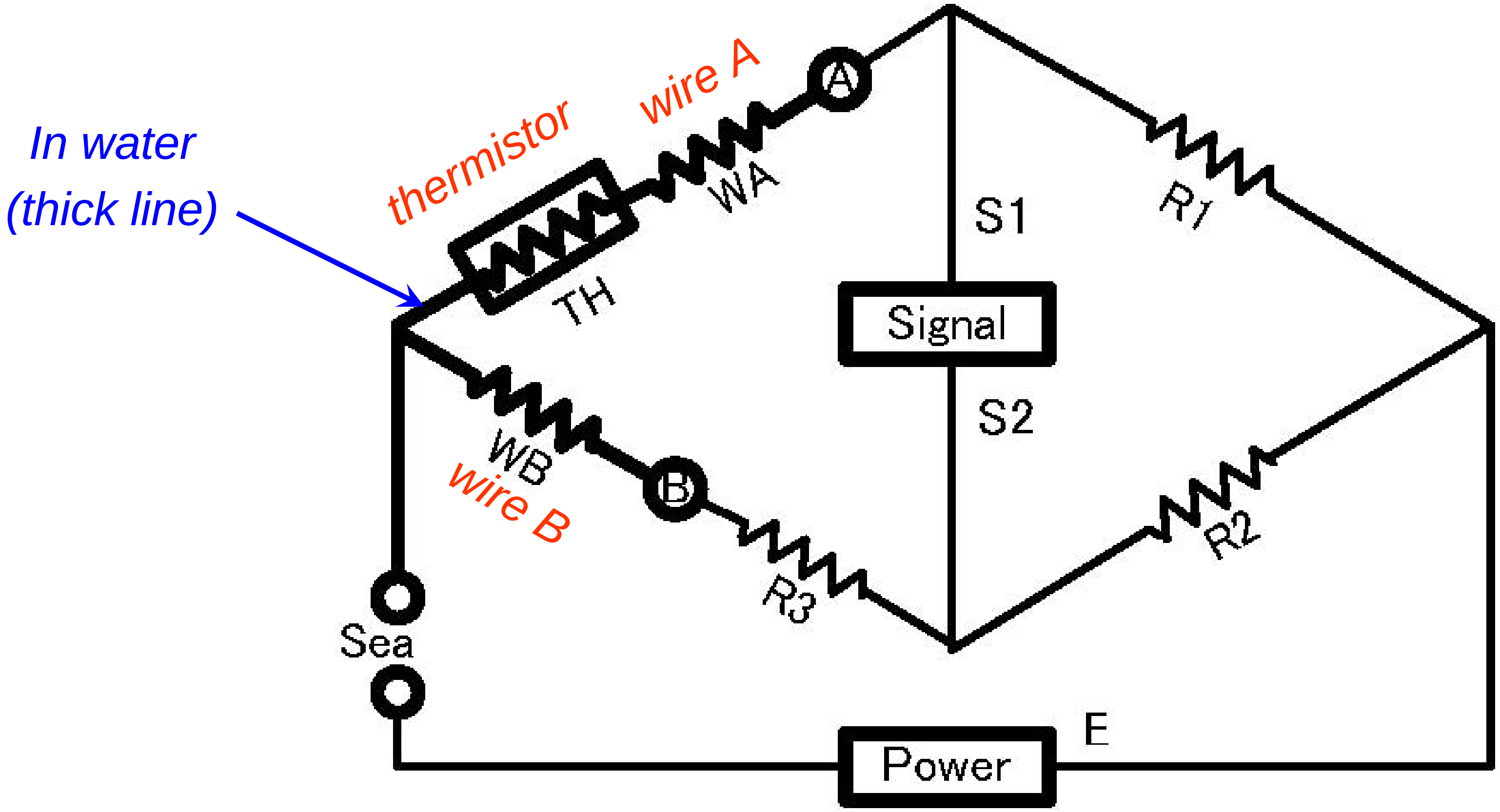
Constant resistance

When R_{TH}=R3 (at some water temperature T_0), S1=S2 (equi-potential).

**The diagram, given by TSK, is simplified. Note that actual one is more sophisticated.*

How circuit works…

Suppose WA=WB=W.

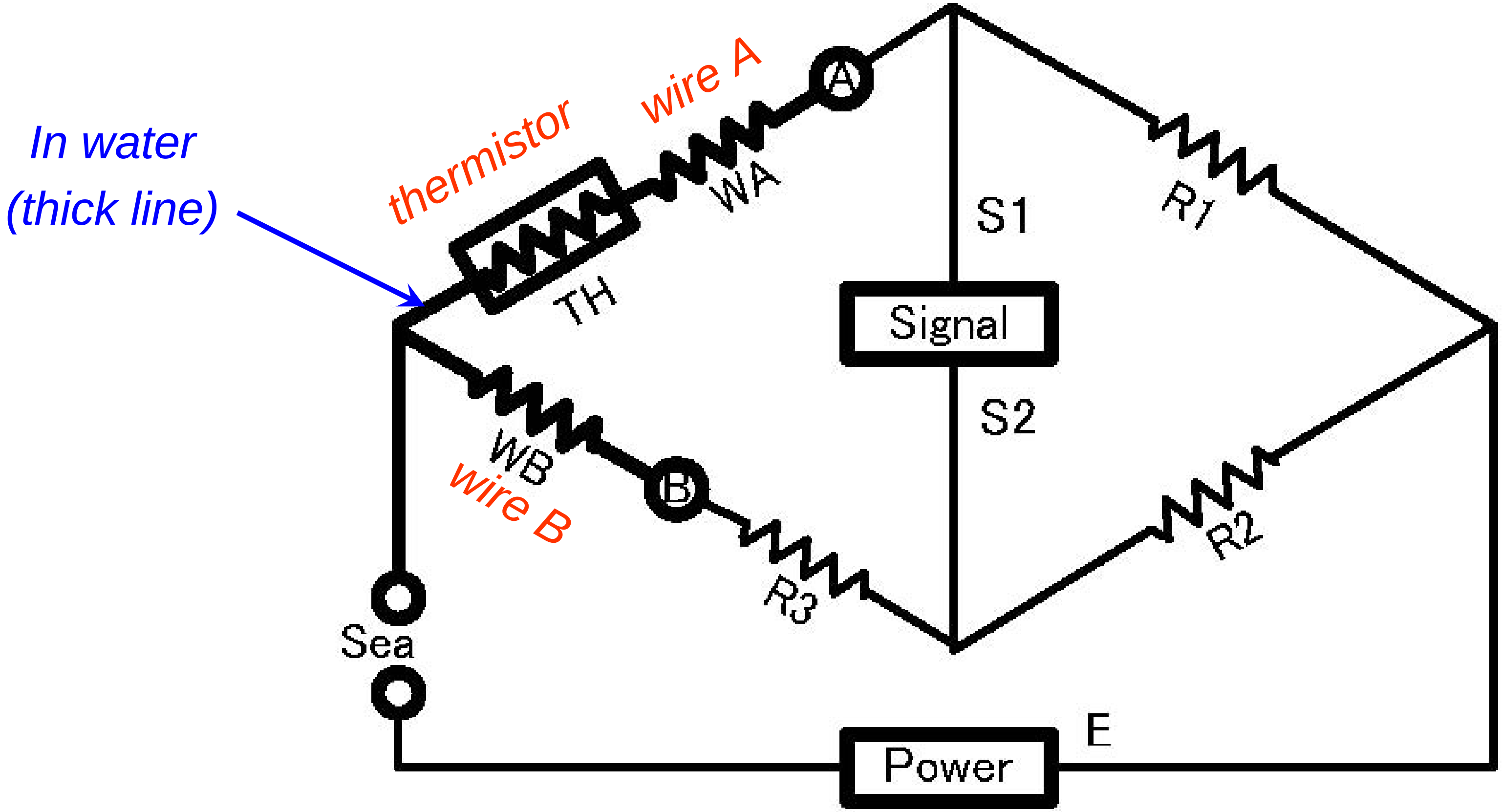


In cold water ($T_1<T_0$), $R_{TH}>R3$, then S1>S2 (indicating "cold").

**The thermistor has negative temperature coefficient (NTC).*

How circuit works…

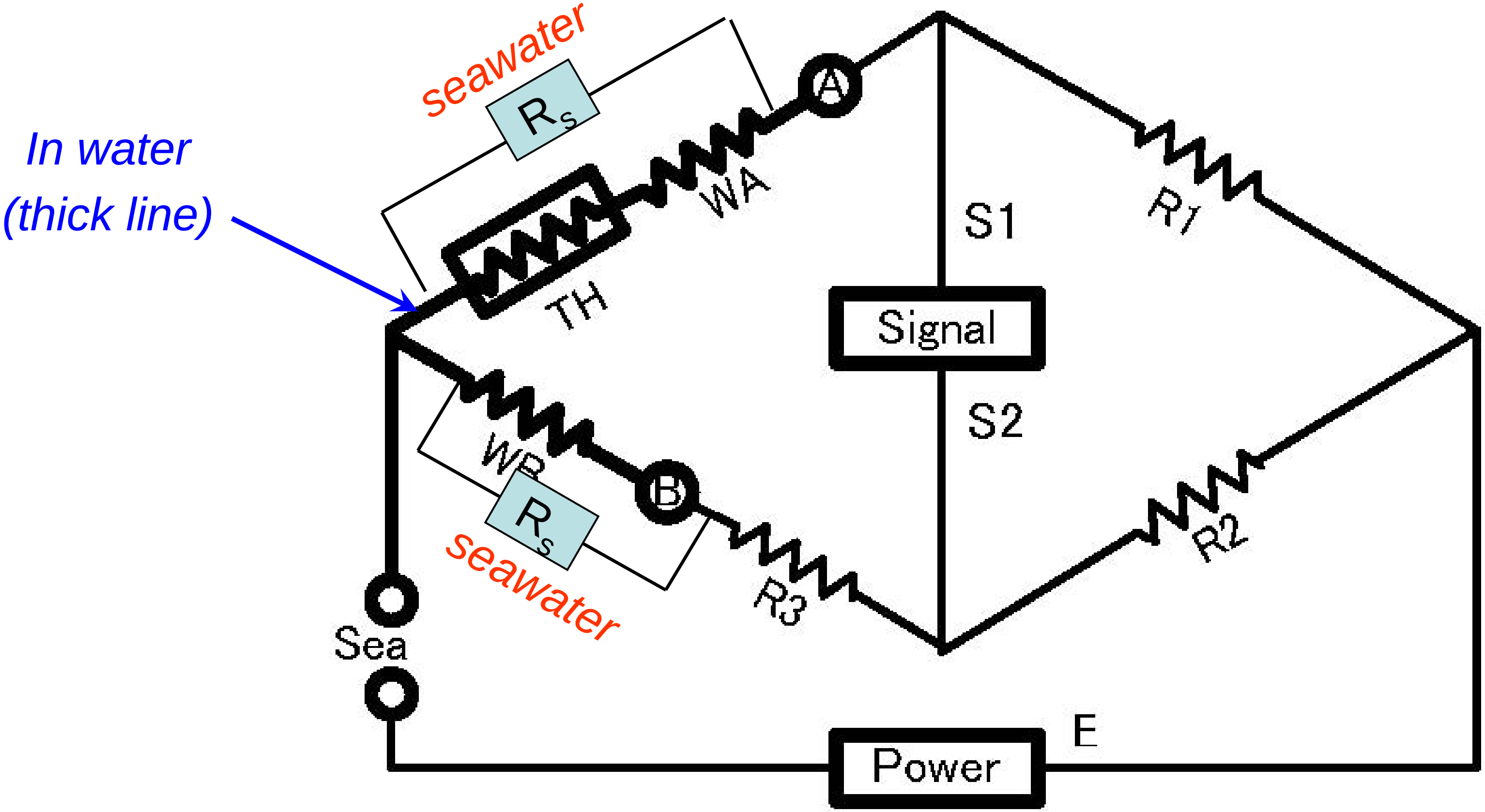
Suppose WA=WB=W.



In warm water ($T_2 > T_0$), $R_{TH} < R3$, then $S1 < S2$ (indicating "warm").

How circuit works…

Suppose WA=WB=W.



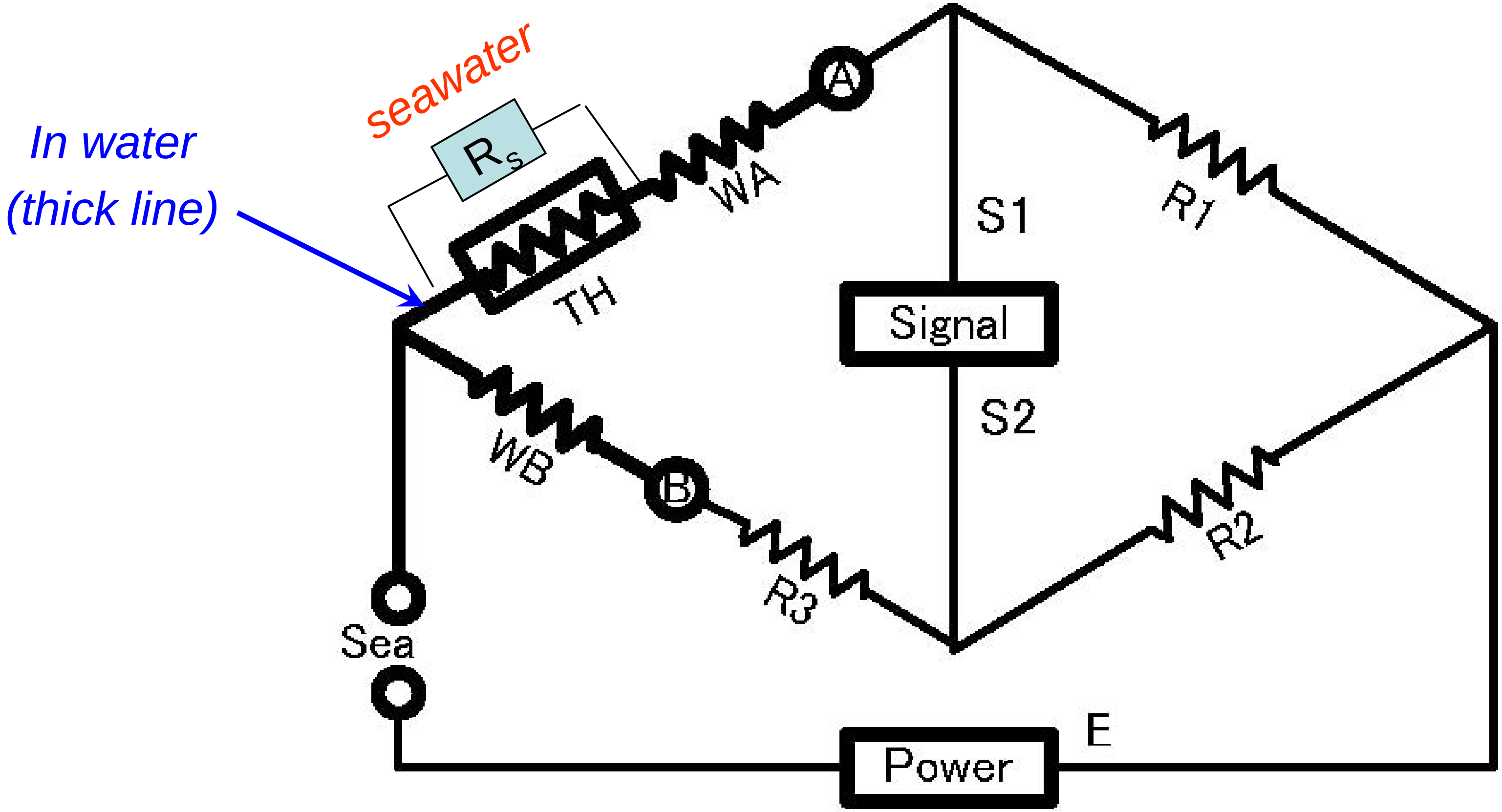
upper-left side lower-left side

When leakage occurs at $T=T_0$, $(R_s+R_{TH}+W) / (R_sR_{TH}) < (R_s+W) / (R_sW)$.

This causes “warm” bias.

How circuit works…

Suppose WA=WB=W.



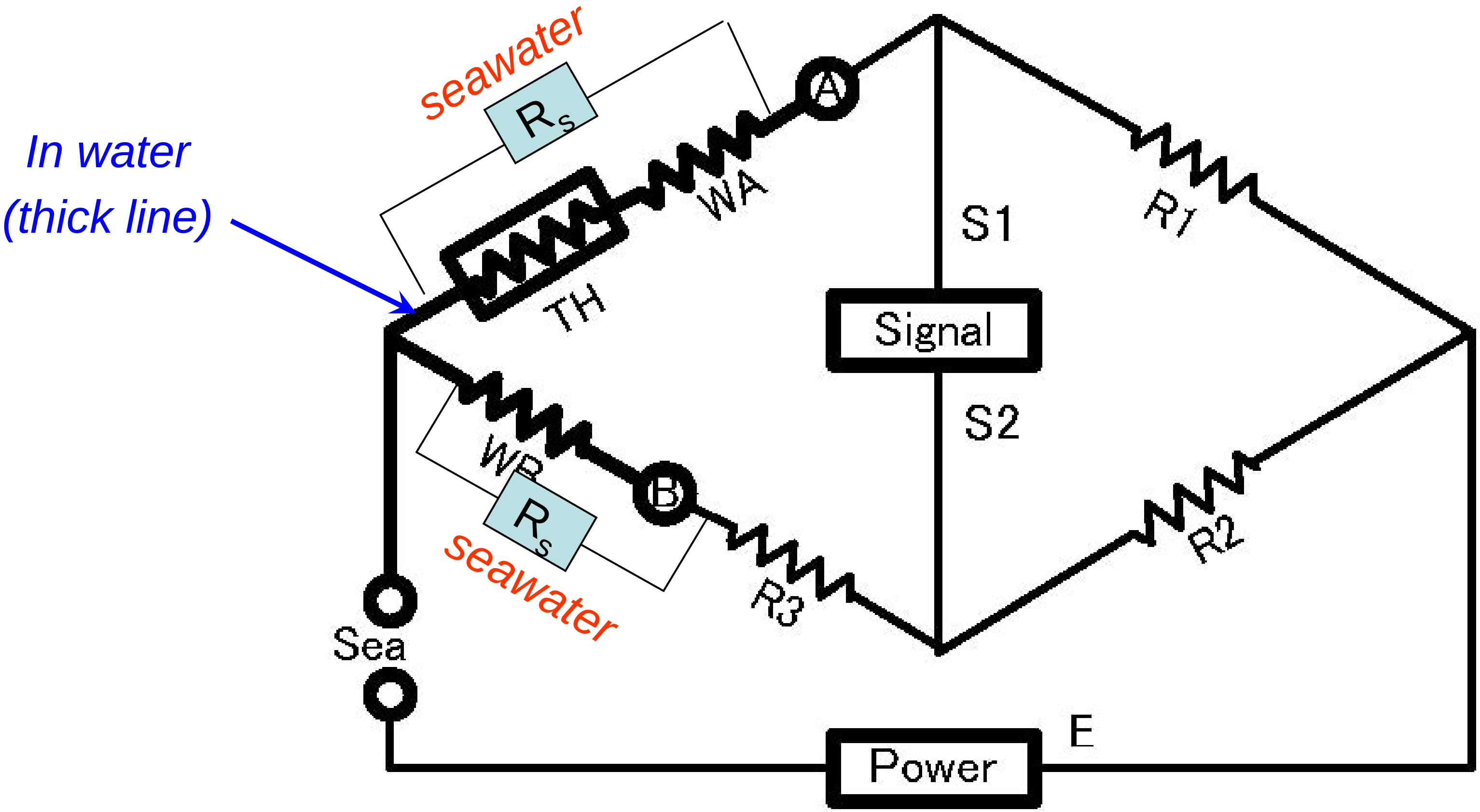
When leakage occurs on thermistor at $T=T_0$, circuit feels like "R_{TH} decreased".

Namely, $R_{TH}' = (R_{TH}+R_s) / (R_sR_{TH}) < R_{TH}$.

This causes "warm" bias, too.

How circuit works…

Suppose WA=WB=W.



Leakage on wire occurring at $T= T_1 <T_0$ and one at $T=T_2>T_0$ will give warm bias of different size because of the exponential decay of R_{TH} with temperature (proof incomplete!).

Things to do

The key issue will be to what extent we can make those ideas quantitative.

< Questions >

What degree of leakage is needed to explain suggested size of temperature bias?

Does suggested temperature dependency agree with those ideas?

Can we reproduce the phenomena in laboratory experiments?