An assessment of the effect of variance in probe weight on the fall-rate of expendable bathythermograph and pure temperature bias

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Motivation

- ✓ *Fall-rate of XBT seems to have changed over time.*

  But, what caused such change?

  There're lots of statistical estimates, but we generally lack physical explanation for them.

- ✓ *A possible known factor is the variance in probe weight. (manufacturers' tolerance in production)*

  Sippican: $\pm$**5g**, *TSK:* $\pm$**1g** *for total probe weight in air*

  Can such weight variance explain the range of suggested fall-rate variation?

  How does fall-rate change with probe weight?

Purpose of this study is to investigate

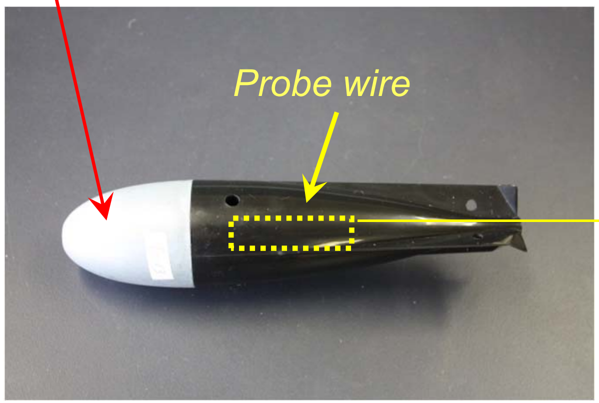
how (T7's) fall-rate depends on difference in probe weight.

Strategy

Scrape a part of the metal nose of TSK T7 by a lathe to reduce its weight by 10g or 20g.

Compare the fall-rates of the modified TSK T7 with those of normal T7 manufactured by TSK and LMS.

Metal nose weight



A photo of TSK T-7

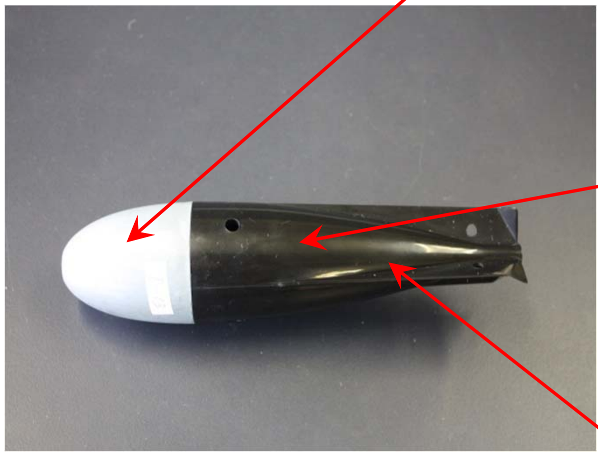
Notes:

- *A normal LMS T7 is lighter than a normal TSK T7 by about 10g (Kizu et al., 2011→ "K11").*
- *So, a 10g-reduced TSK T7 approximately weighs as much as a normal LMS T7.*
- *The two companies' T7 have many structural differences (K11).*

Weight of parts

The 1st line is in the air, and the 2nd line is in the water (K11). The former is averages of two dozens, and the latter is from a couple of pieces.

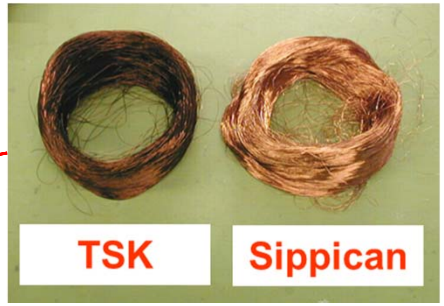
T7 XBT



Nose weight

LMS	*TSK*
575.6g	*575.2g*
(484.7g)	*(485.1g)*

~80%(~85%)of total weight in the air (water)



Probe wire

LMS		*TSK*
101.9g	*12g*	*113.0g*
(76.5g)		*(88.6g)*

gradually paid out during fall (expires at rated depth+)

Total

LMS		*TSK*
729.1g	*12g*	*740.5g*
(564.1g)	*(2%)*	*(576.5g)*

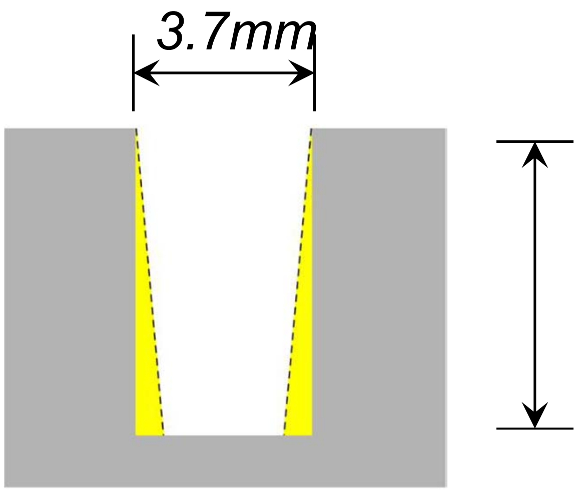
After-body (incl. wire spool)

LMS	*TSK*
51.0g	*52.1g*
(2.9g)	*(2.8g)*

Lightening the nose weight

circular ditch

The alteration was made by TSK.



7.6mm (for cutting 20g)
Half depth for 10g.

The gap is not filled
for technical difficulty.

Total weight of probe (grams; in the air) used in the present test

	n	*MIN*	*MAX*	*AVE*	*SD*	*MAX-MIN*
TSK	24	740.7	742.0	741.7	0.3	1.3
TSK (-10g)	35	730.0	731.1	730.5	0.3	1.1
TSK (-20g)	35	720.1	721.2	720.6	0.3	1.1
LMS	22	728.5	734.2	731.0	1.7	5.7

Similar comparison

Samples used in our previous test (K11)

	n	*MIN*	*MAX*	*AVE*	*SD*	*MAX-MIN*
TSK (2006)	24	739.8	741.1	740.5	0.3	1.3
LMS (2008)	24	725.8	732.4	728.9	1.7	6.6

Weight difference between LMS T-7 and TSK T-7 (K11)

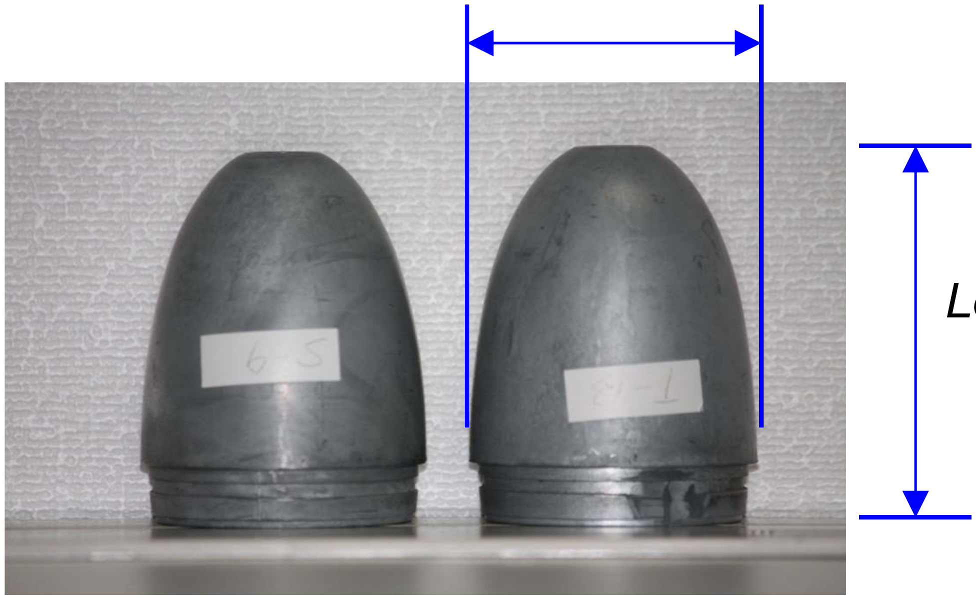
✓ *TSK T-7 is heavier by about 12g (2%) than LMS T-7 .*

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

So, 10g-lightened TSK T-7 and LMS T-7 have different mass balance though they weigh the same as a total.

Structural differences (nose weight; outer shape)

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

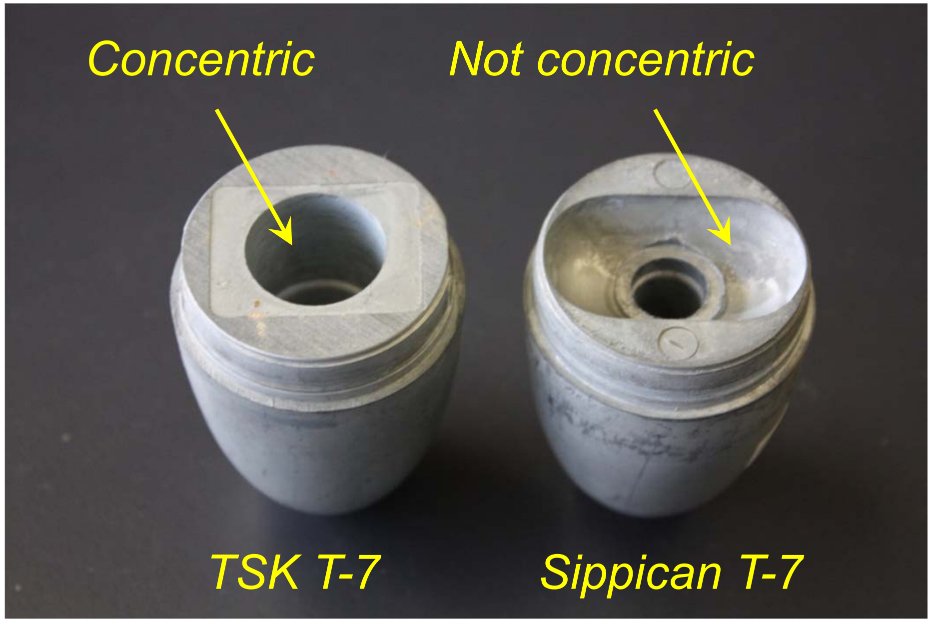


Length: TSK T-7 is 1mm (1.7%) longer

Sippican T-7 *TSK T-7*

Structural differences between LMS T-7 and TSK T-7 (K11)

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,

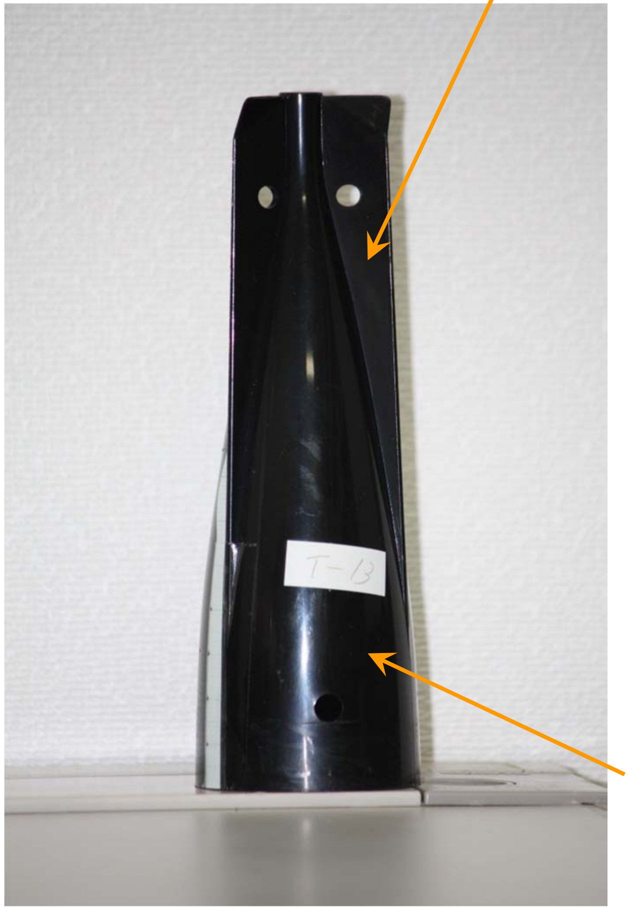
- All TSK's XBT have concentric design.
- Sippican's (now LMS)
  - T-7 and Deep Blue are non-concentric, but
  - T-4, T-5, T-6 and T-10 are concentric.

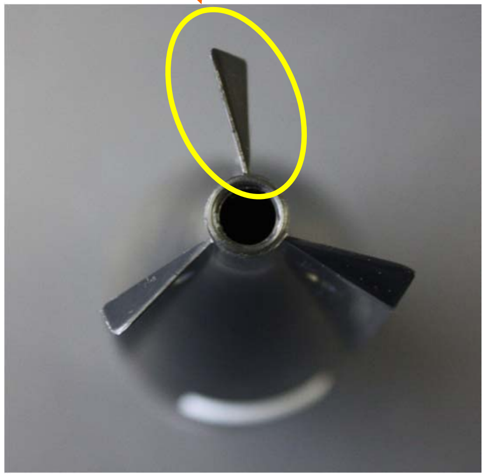
"Never changed."

Structural differences between LMS T-7 and TSK T-7 (afterbody; K11)

Three fins: TSK T-7 is thinner

Angled part of the tail fins: Shape is different



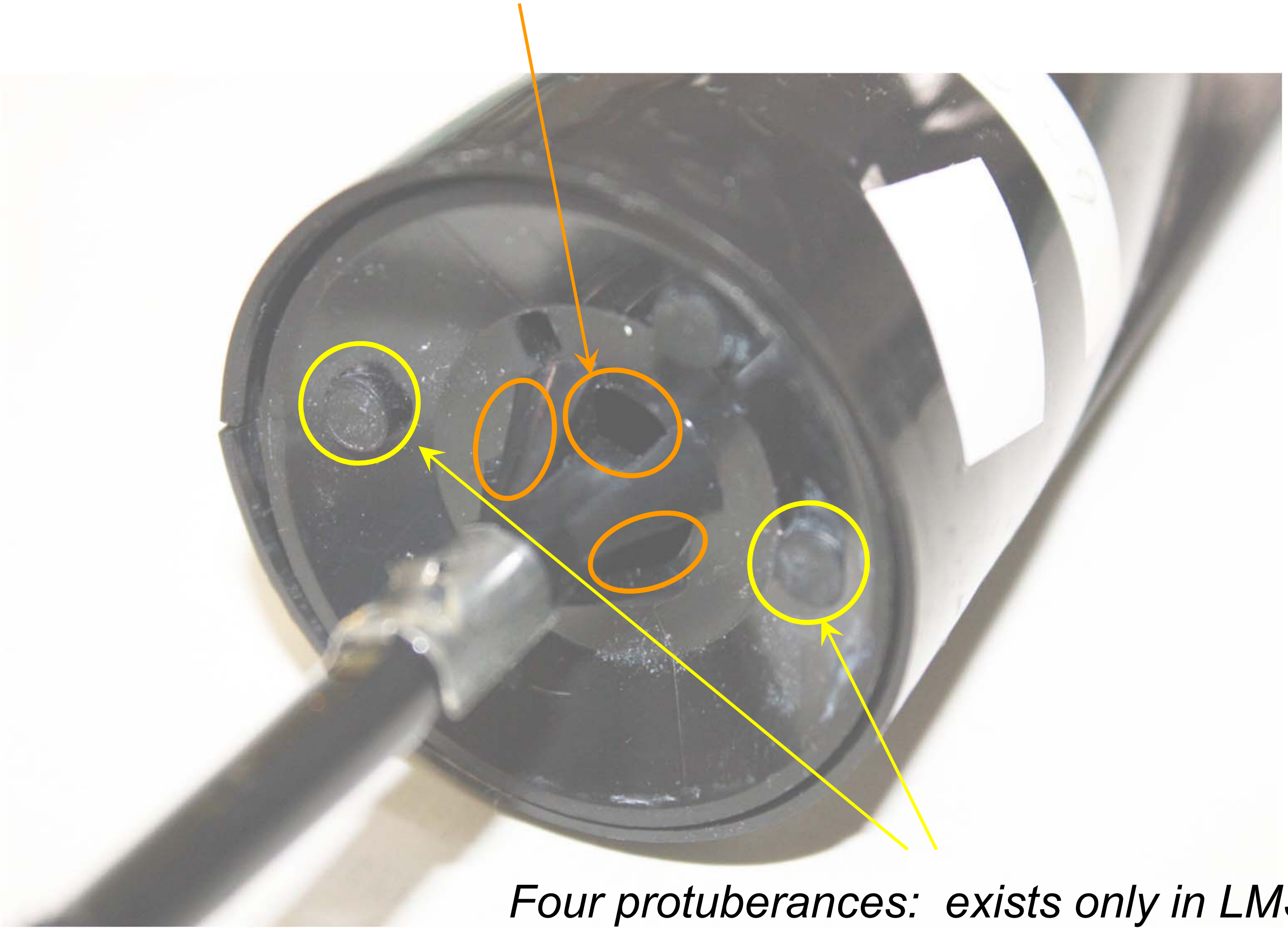


Inner volume of afterbody: TSK T-7 is smaller by about 5 cm^3.

Structural differences between LMS T-7 and TSK T-7 (more with afterbody)

Water pass (four holes around the central rod):

TSK T-7 is smaller



Four protuberances: exists only in LMS's probes

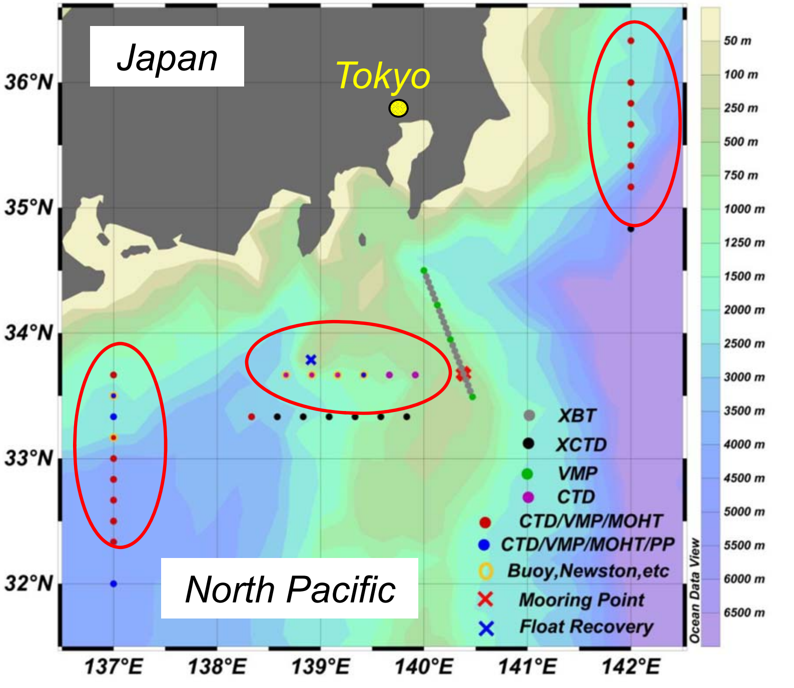
Rough summary of the probes tested (only for weight)

The weight differences between LMS and TSK T7 is rounded to 10g.
The structural differences are dismissed here.

		TSK(NML)	TSK (-10g)	TSK (-20g)	LMS
			Compared to TSK(NML)		
surface	nose	–	10g lighter	20g lighter	same
	wire	–	same	same	10g lighter
	total	–	10g lighter	20g lighter	10g lighter
at rated depth+	nose	–	10g lighter	20g lighter	same
	wire	–	same	same	10g lighter
	total	–	10g lighter	20g lighter	same

The test

R/V Hakuho Maru
(3991t , 100m long)



- *Conducted during Feb 27-Mar 6 2011, south-southeast of Japan, as a part of KH11-3 cruise (Feb.25-Mar.10) of R/V Hakuho Maru (JAMSTEC).*
- *Two or three dozens for each of normal TSK T7, 10g-reduced TSK T7, 20g-reduced TSK T7, and normal LMS T7 were deployed during CTD observations.*
- *Two launching/acquisition systems were used in parallel in most cases.*
  - *To minimize the time difference, and*
  - *To test many probes in limited ship time.*
- *A regularly-calibrated CTD (Sea-Bird Electronics SBE-9) was used as a truth.*

Number of probes tested

Paired tests

Non-paired tests

			System #2				Total tested
			TSK	-10g	-20g	LMS	
System #1	TSK	1	0	7	7	0	24
	-10g	3	1	0	9	2	35
	-20g	3	5	6	0	3	35
	LMS	1	3	7	2	2	22

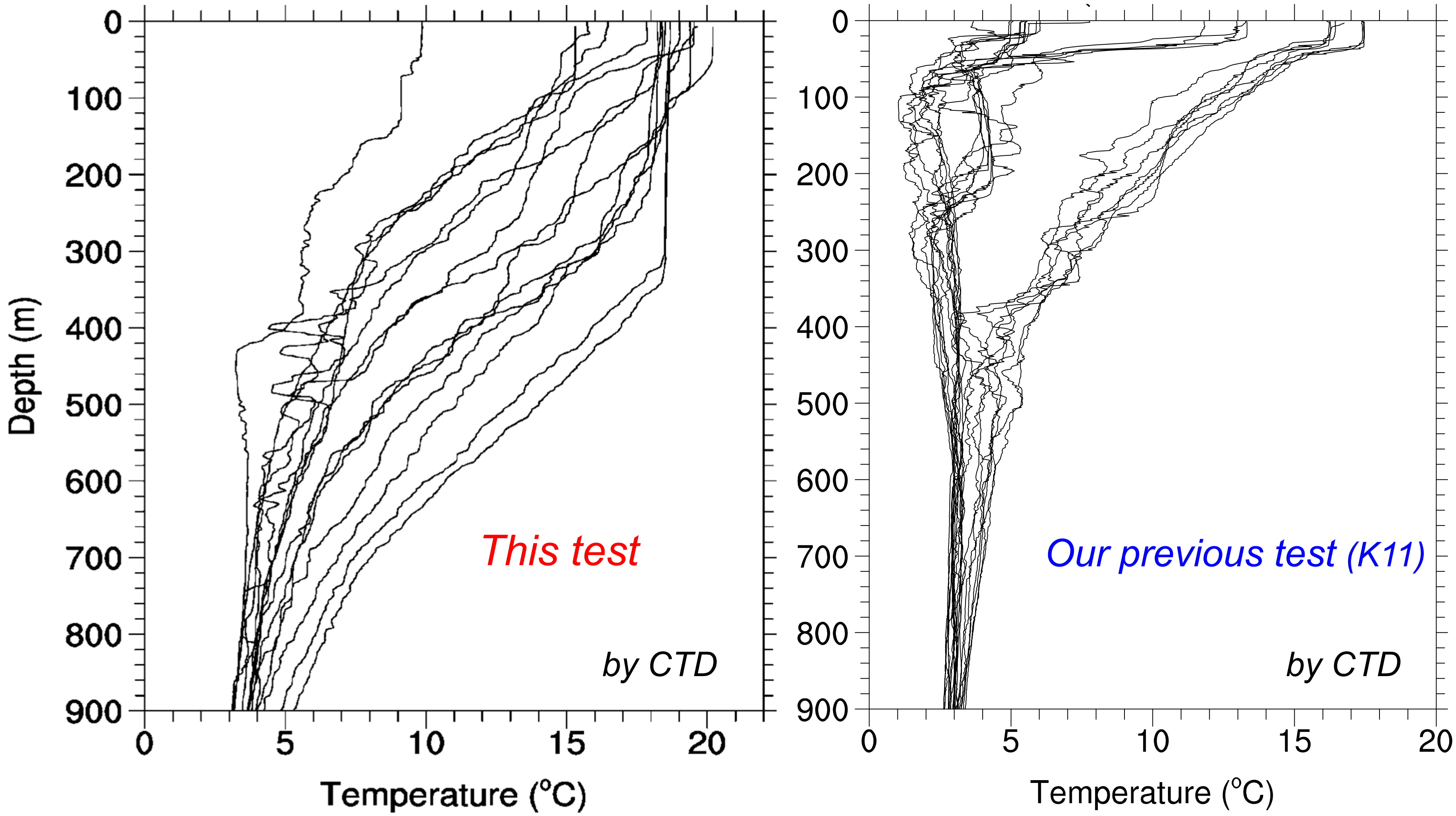
- *TSK's handheld launcher and MK-130 were used in either systems.*
- *All XBT's were deployed during CTD measurements.*

Number of profiles with good depth coverage:

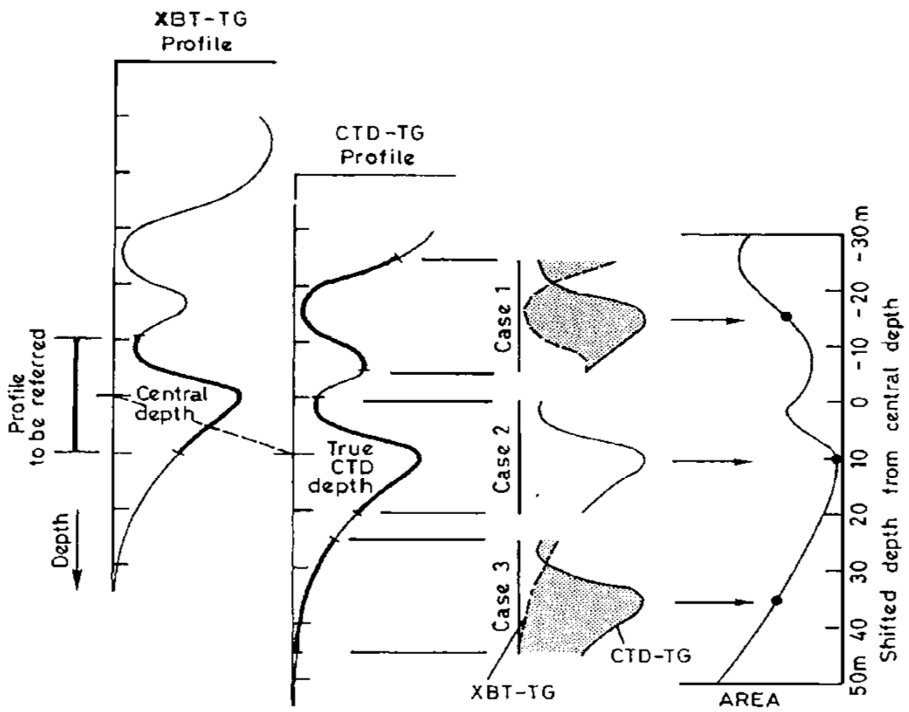
TSK(normal): 23, TSK(-10g): 32, TSK(-20g): 32, LMS: 19

Temperature profiles at the test sites

Most profiles are obtained from areas with relatively high subsurface temperature.



Error of XBT depth is estimated by the method of Hanawa and Yasuda (1992).



Depth error estimation

(Hanawa and Yasuda, 1992)

1) Assume CTD temperature profile as truth.

2) Find Δz that gives the minimum of

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

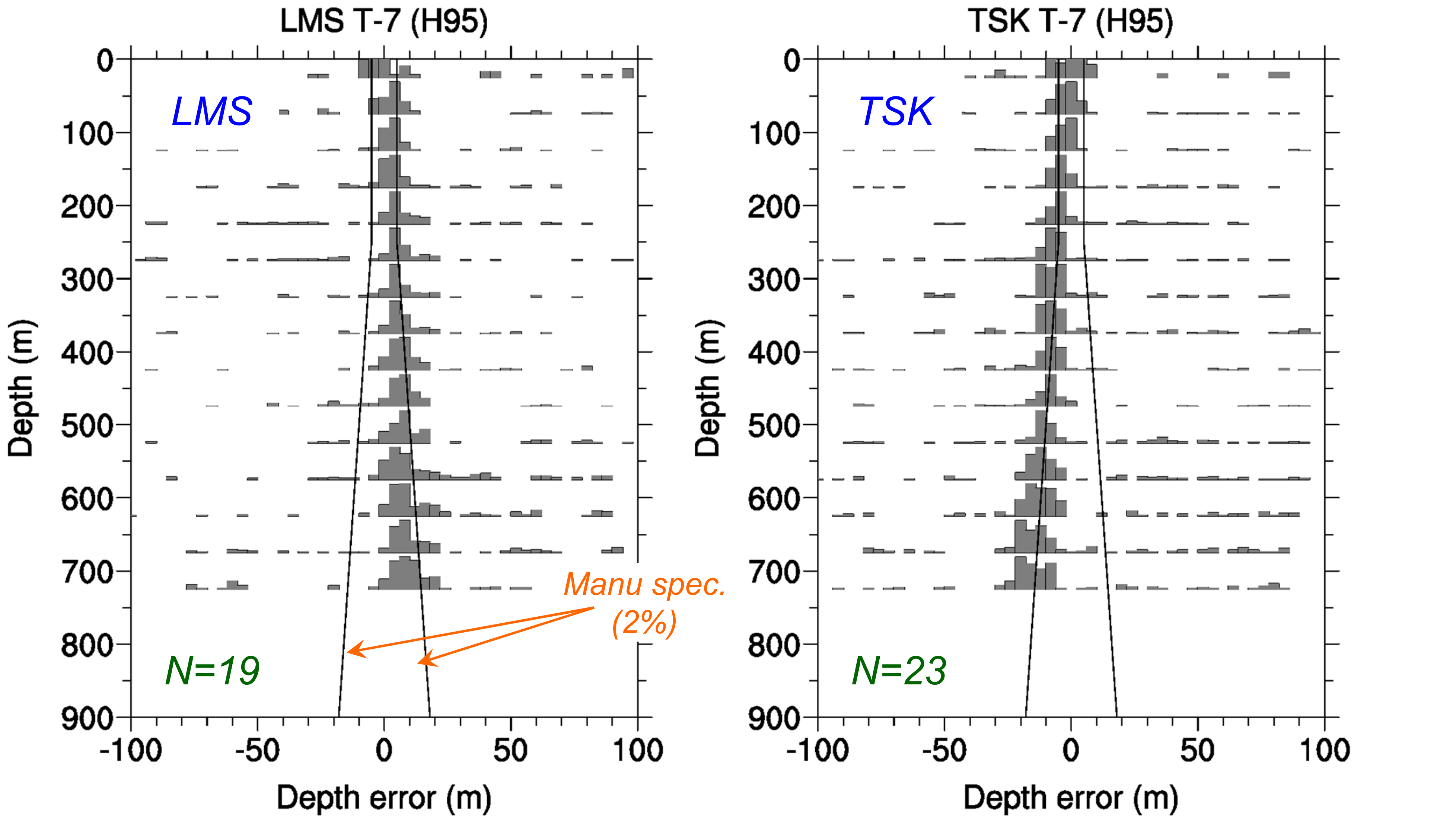
for each depth.

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.

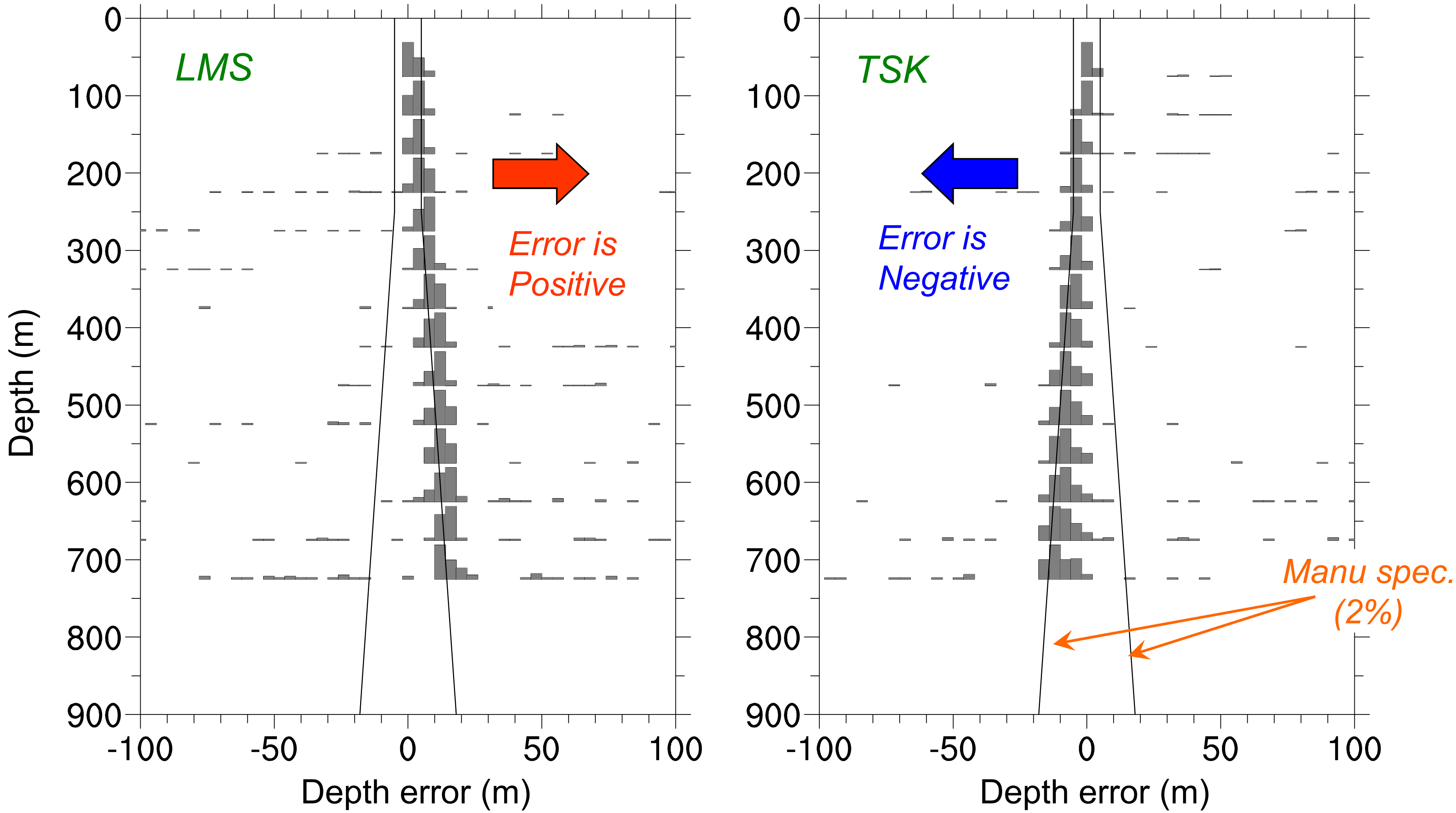
Depth error of H95 for each type



LMS: Depth error is positive. True fall rate is <2% smaller than H95.

TSK: Depth error is negative. True fall rate is 2% greater than H95.

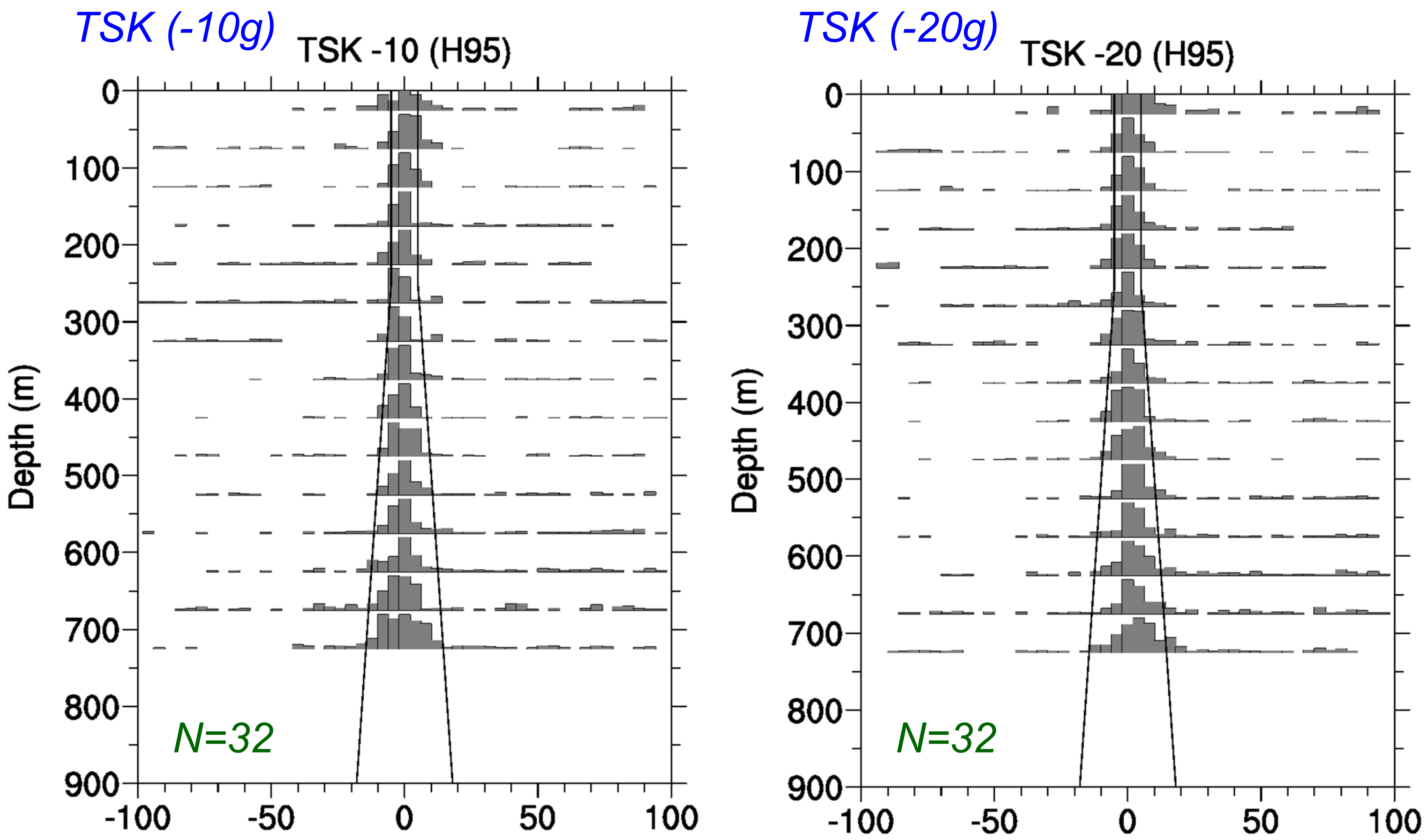
Our previous test (May 2008; East of Japan; K11)



Sippican: Depth error is positive. True fall rate is >2% smaller than H95.

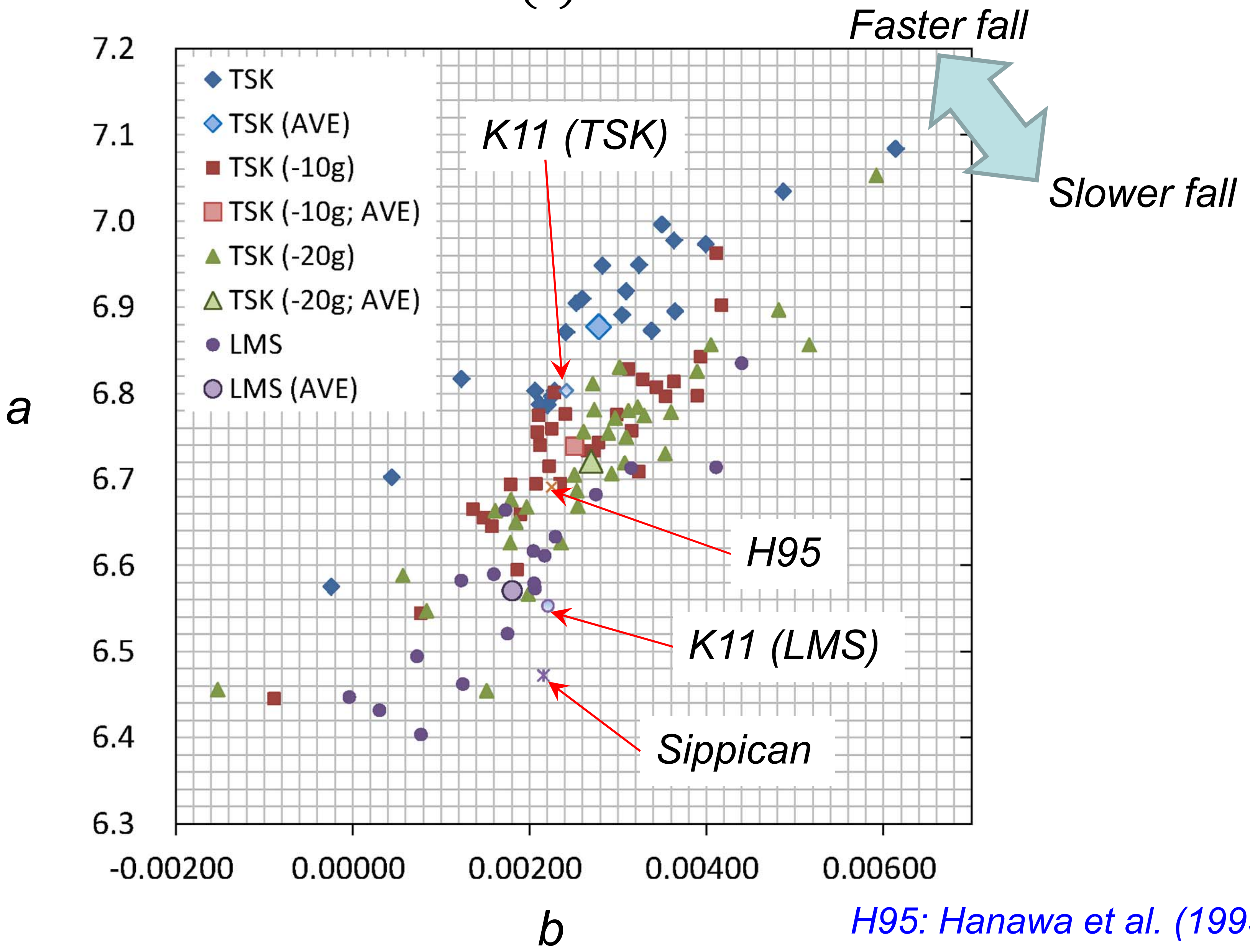
TSK: Depth error is negative. True fall rate is <2% greater than H95.

Depth error of H95 for each type



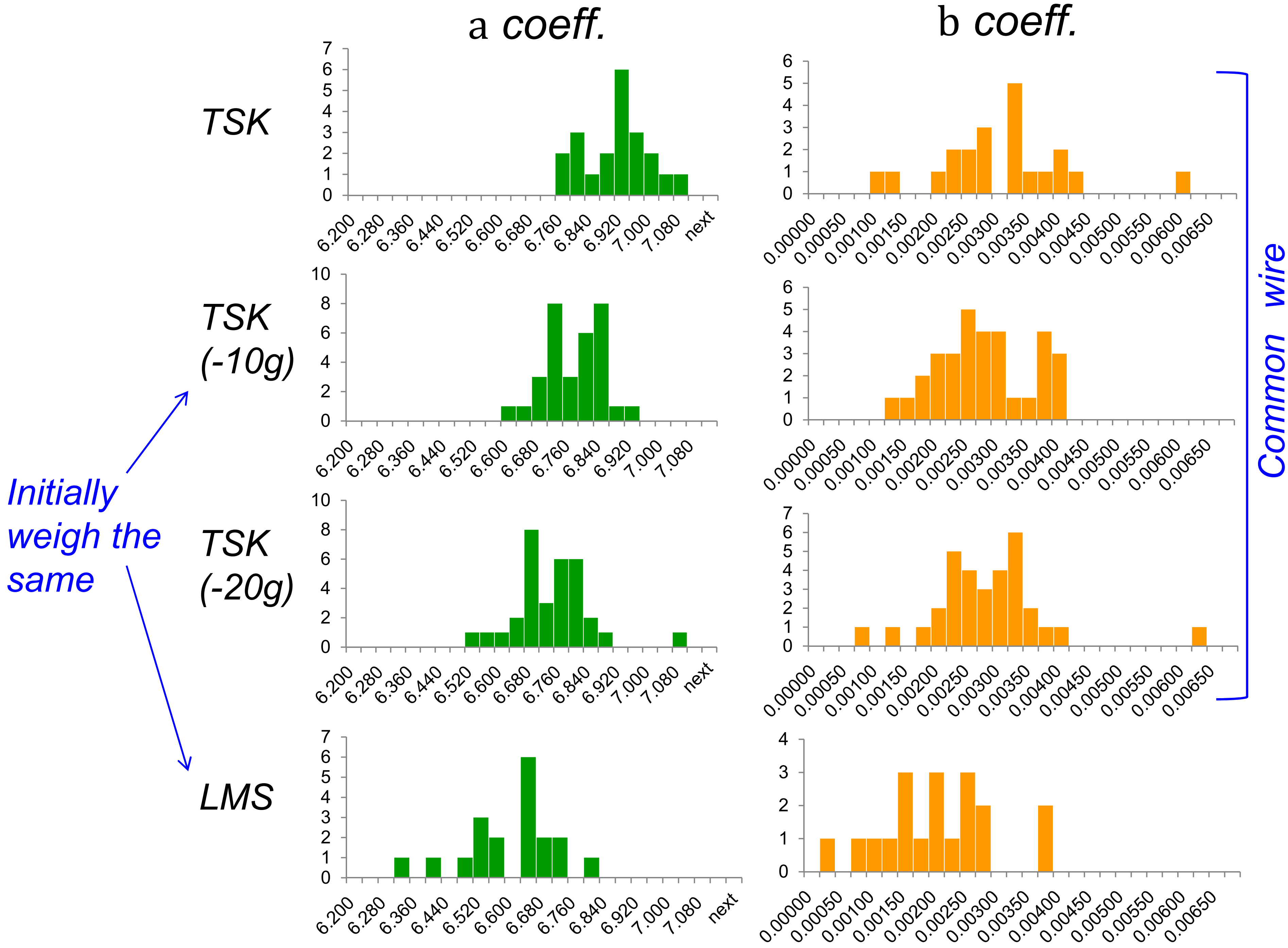
Fall-rate (depth averaged): TSK > TSK(-10g) > TSK (-20g) > LMS

Obtained FR coefficients $z(t) = at - bt^2$



H95: Hanawa et al. (1995)

K11: Kizu et al. (2011)



a coeff.
b coeff.
TSK
TSK (-10g)
TSK (-20g)
LMS
Initially weigh the same
Common wire

Obtained fall-rate coefficients (summary)

	This study		K11	
	a	$b \times 10^3$	a	$b \times 10^3$
TSK	6.877 ± 0.114	2.78 ± 1.36	6.803 ± 0.052	2.42 ± 0.44
TSK (-10g)	6.739 ± 0.100	2.51 ± 1.06		
TSK (-20g)	6.721 ± 0.123	2.70 ± 1.36		
LMS	6.570 ± 0.130	1.81 ± 1.23	6.553 ± 0.064	2.21 ± 0.43

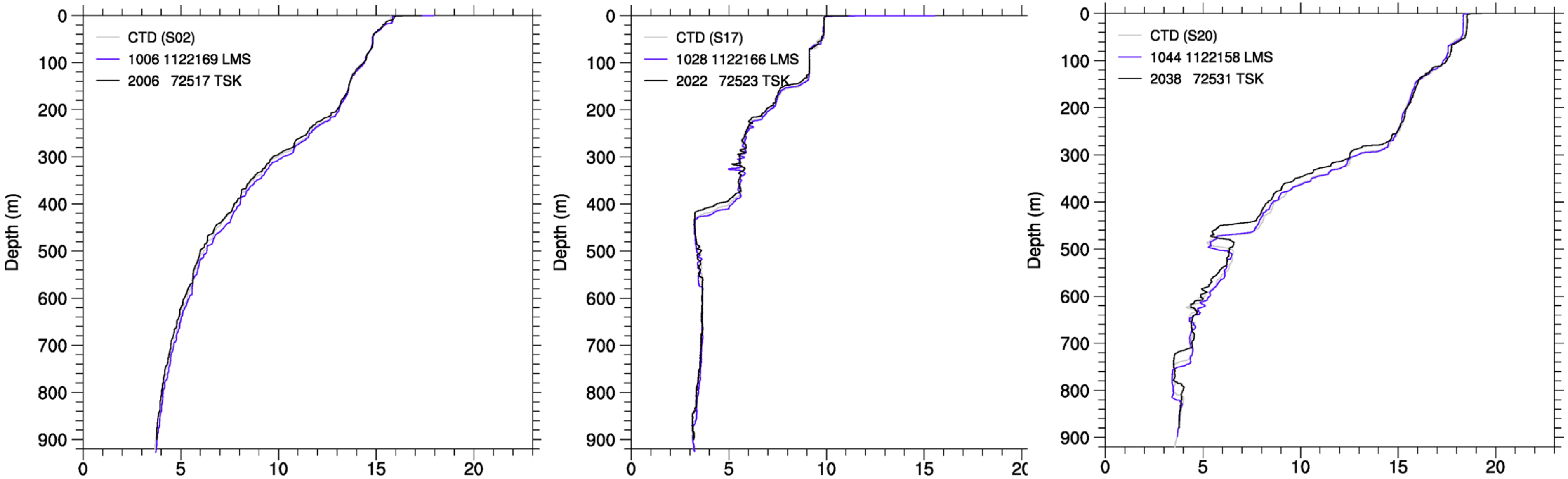
- *The coefficients obtained are similar to those by K11.*
- *The b coefficients of the three TSK subtypes are similar (c.f. common wire).*
- *LMS T7 falls systematically more slowly than 20g-reduced TSK T7.*
  (The former is heavier than the latter by about 10g initially,
  and by about 20g when the probe wire is expired.)
- *The effect of weight is not proportional. The fall-rate difference between 10g-reduced TSK T7 and 20g-reduced TSK T7 is smaller than that between normal TSK T-7 and 10g-reduced TSK T7.*

The effect of weight difference is minor (the actual manufacturers' weight tolerance is much smaller than this!). It doesn't explain the systematic difference in fall rates between LMS T7 and TSK T7.

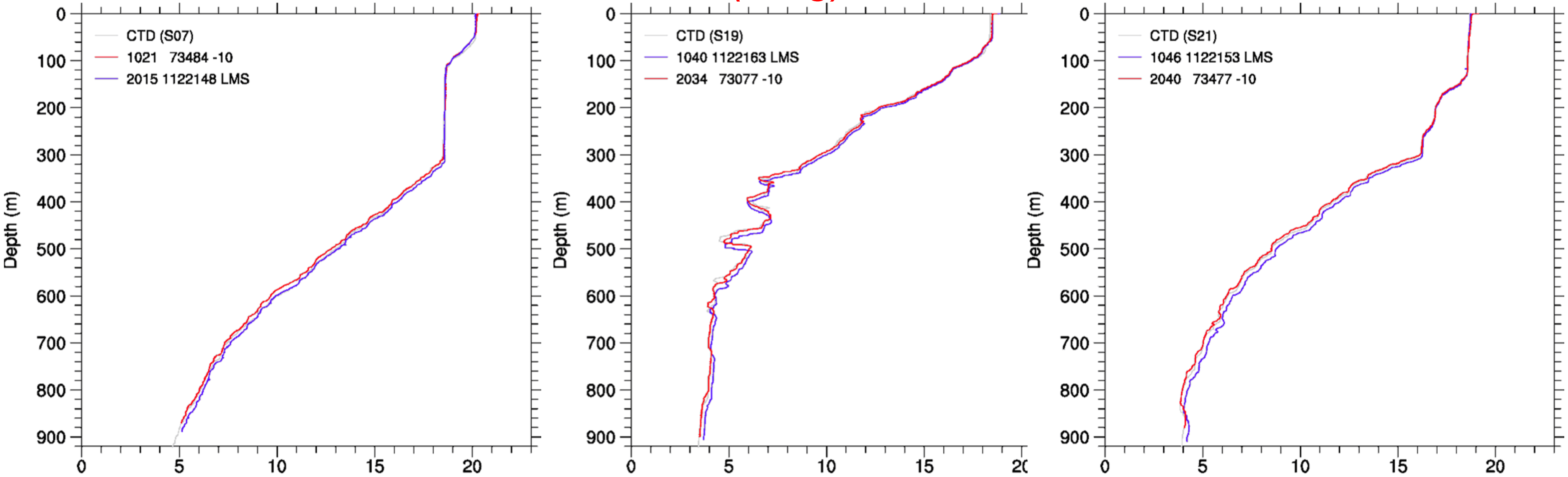
Some samples from paired tests

TSK(NML) vs. LMS

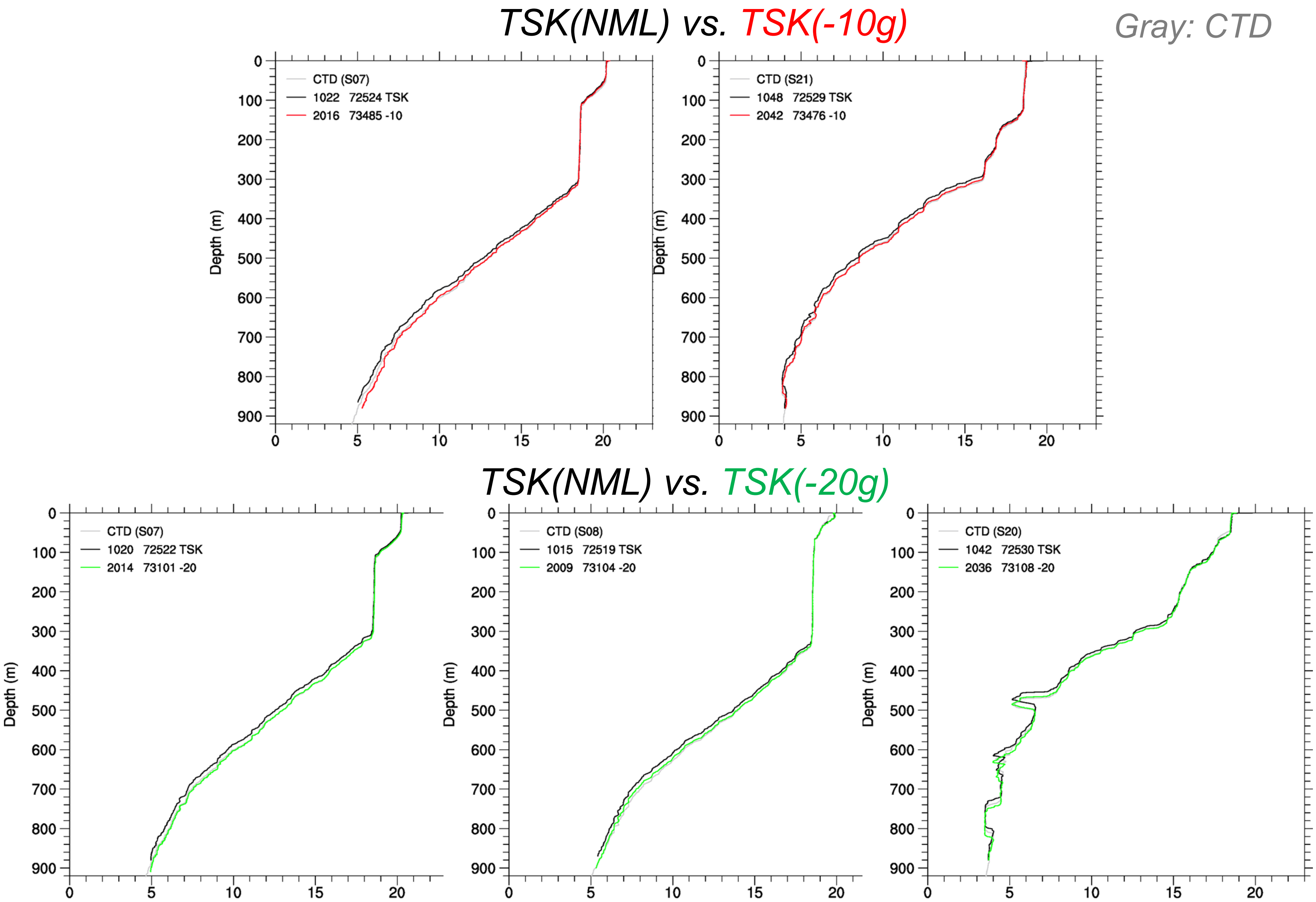
Gray: CTD



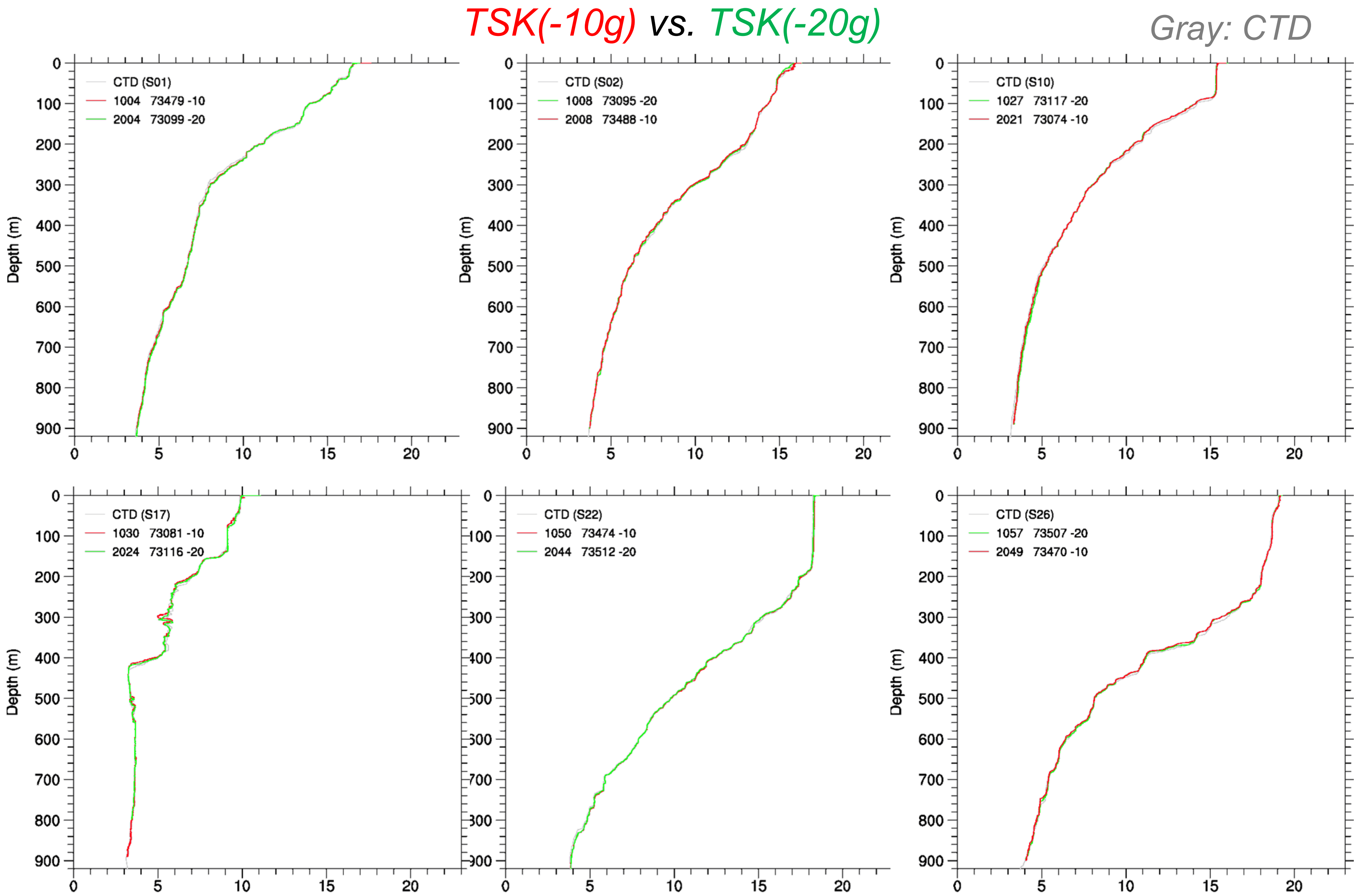
TSK(-10g) vs. LMS



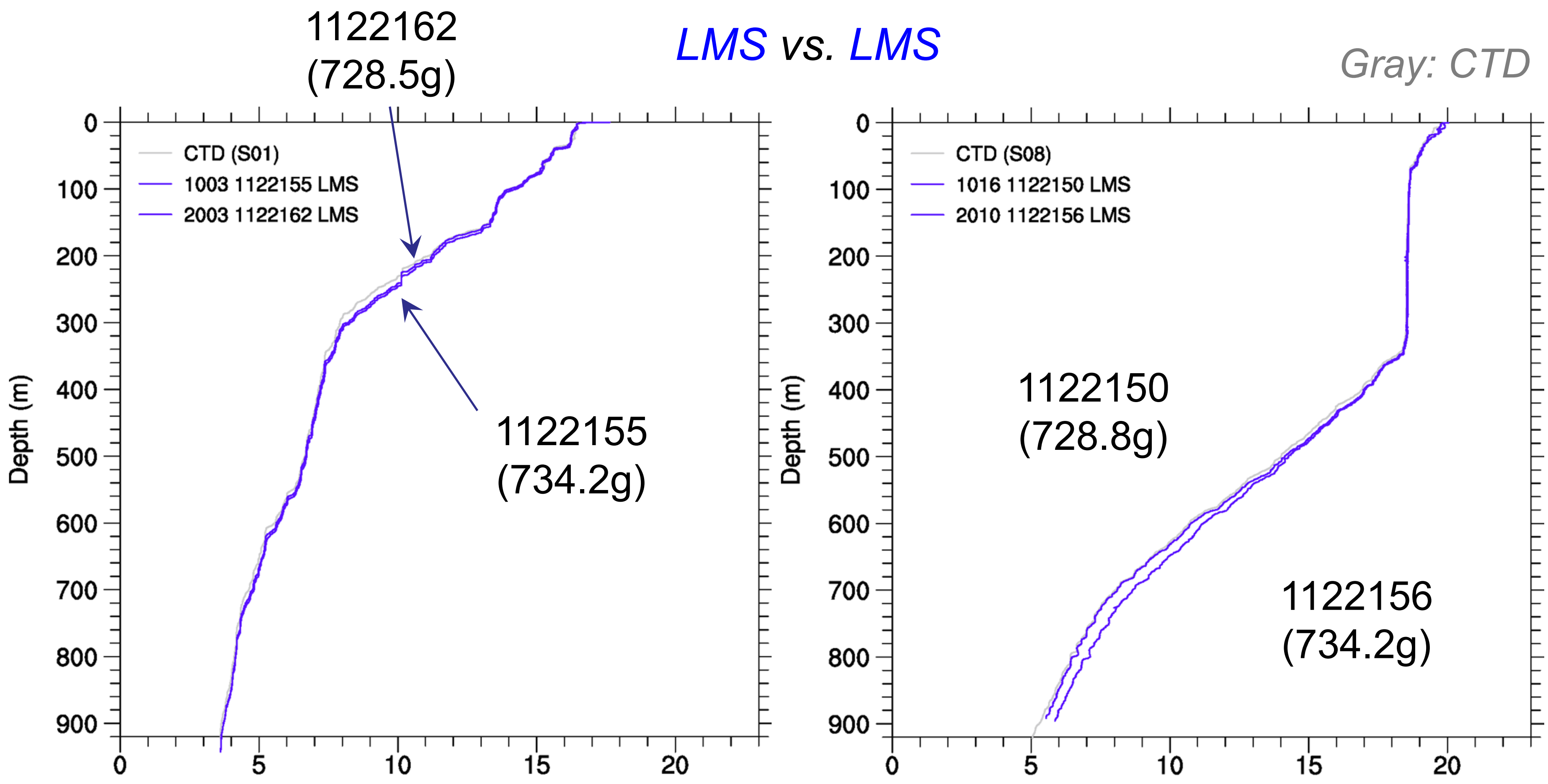
Some samples from paired tests



Some samples from paired tests



Some samples from paired tests



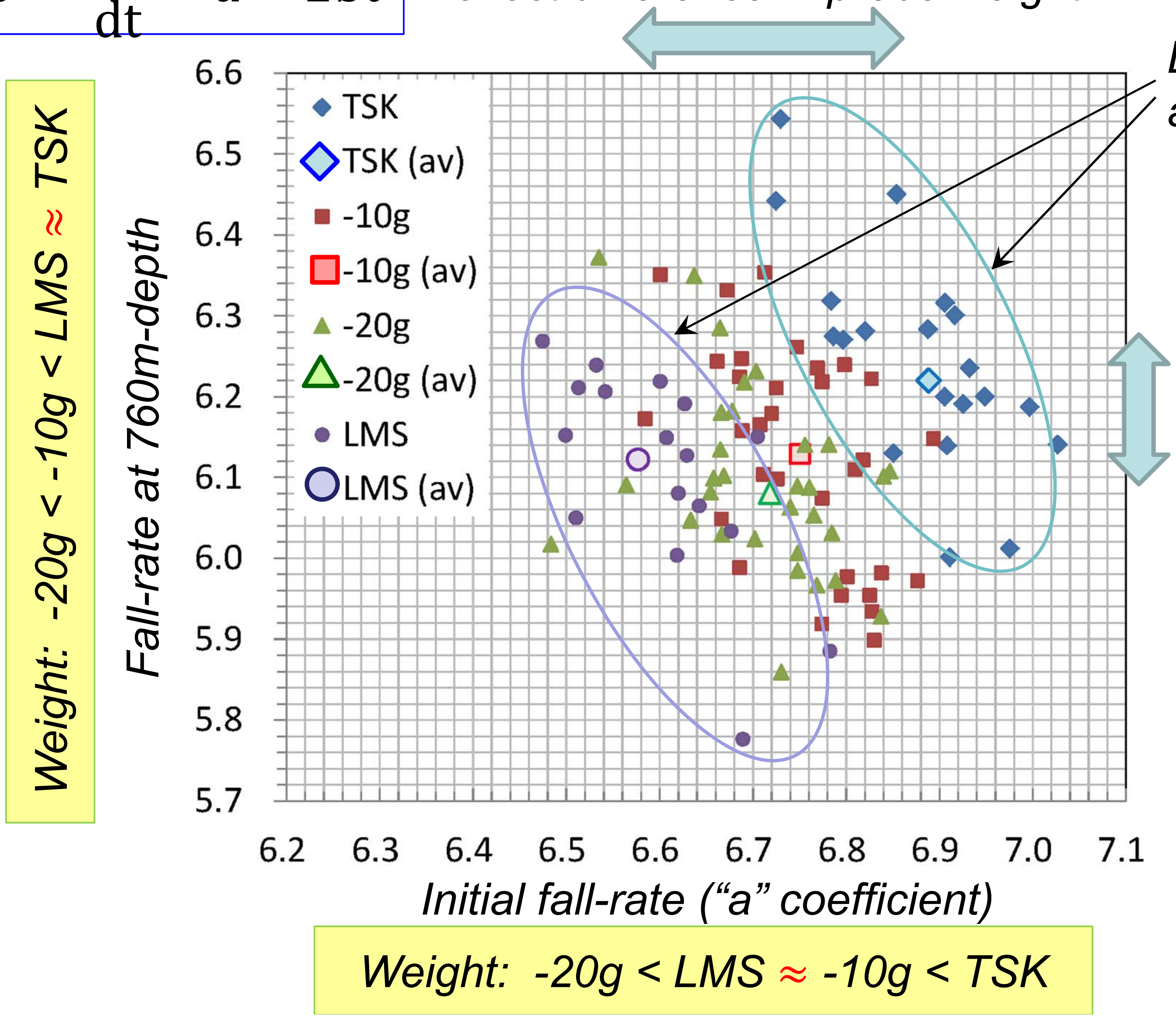
Almost indiscernible, but heavier one fell more slowly.

Almost no depth difference, rather there is temperature bias.

Fall-rate at depth

$$v \equiv \frac{dz}{dt} \cong a - 2bt$$

Initial fall-rate does not simply reflect difference in probe weight.



TSK-LMS difference at the rated depth is smaller than the initial one, but still exists.

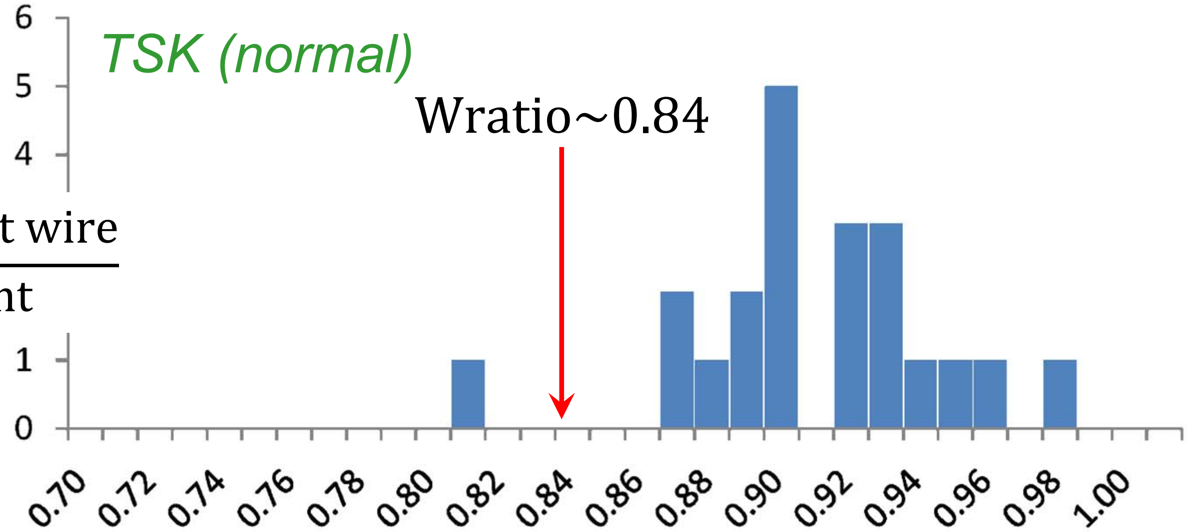
Change of fall-rate during fall

Histogram of V(760m) / V(initial)

Final weight

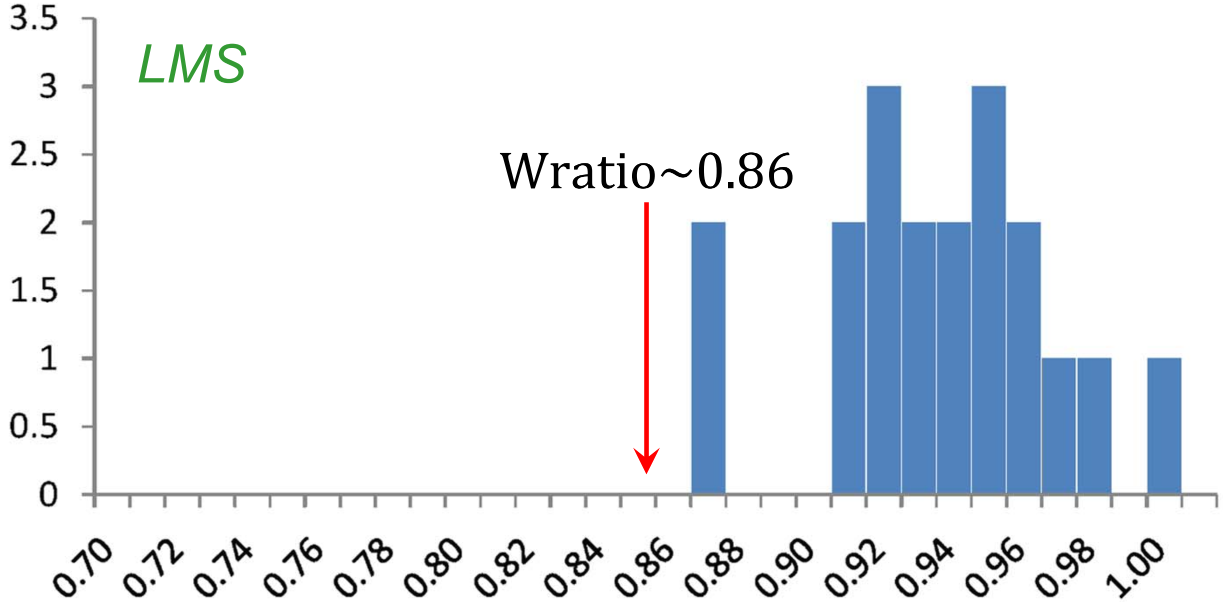
$$\text{Wratio} \equiv \frac{\text{probe weight without wire}}{\text{total probe weight}}$$

Initial weight



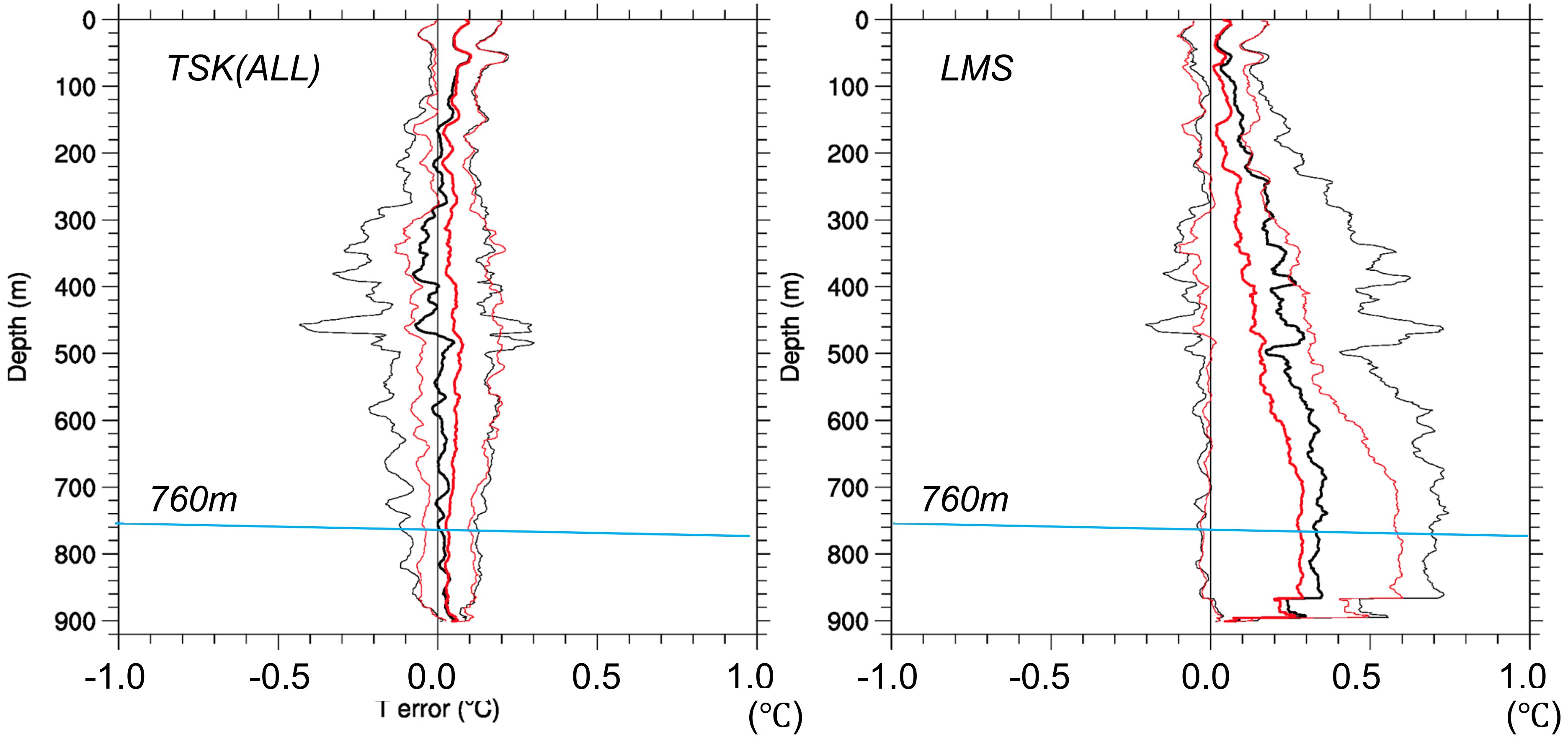
Probes doesn't slow down as much as their weight decreases during fall.

Water drag reduces as the weight balance changes by sending wire out?



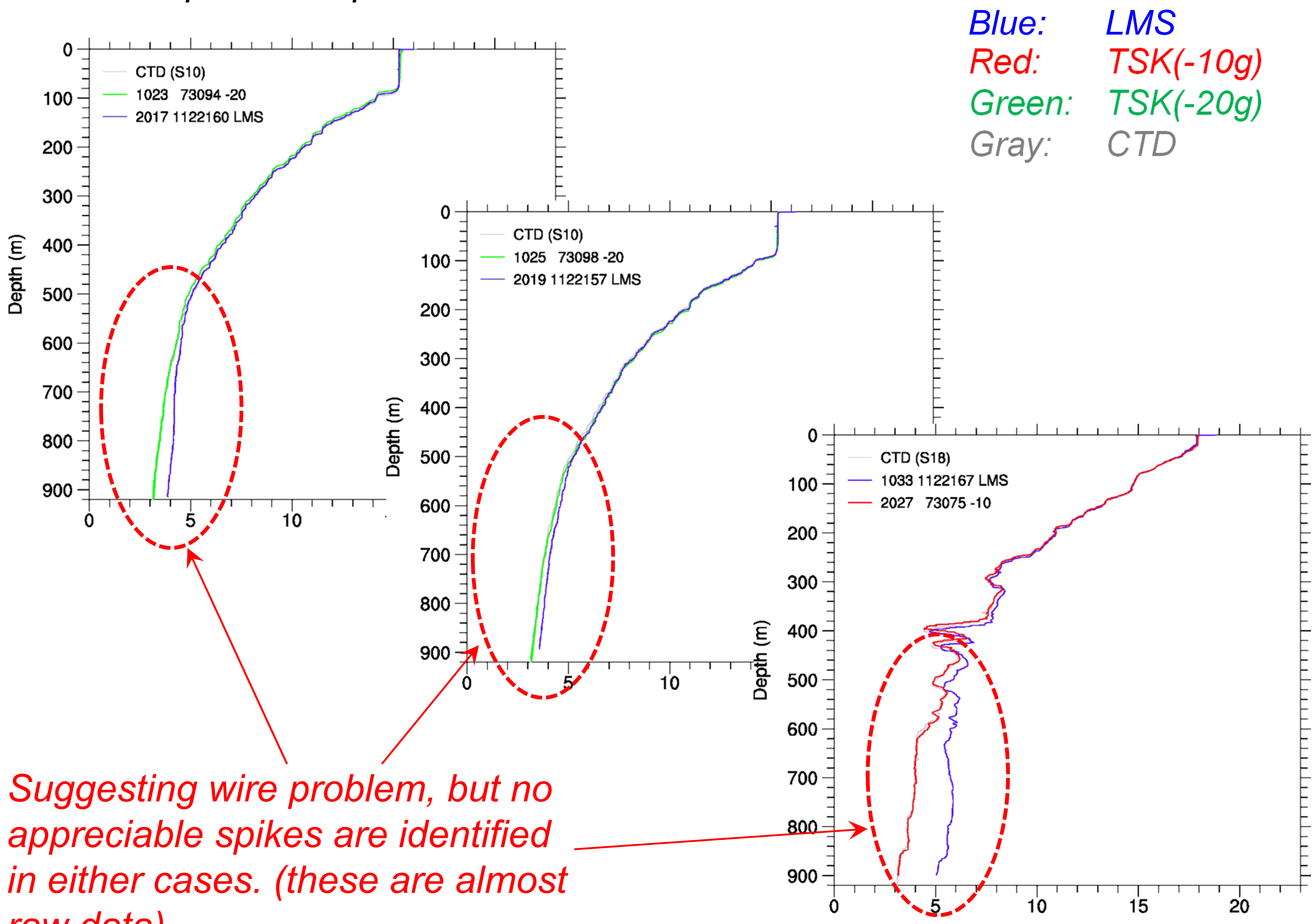
Temperature error before/after depth correction

Black: depth not corrected
Red: depth corrected



- *Scatter is substantially reduced by depth correction.*
- *Reduction of mean error is not impressive.*
- *Positive error remains in both cases..*

Some samples from paired tests



Suggesting wire problem, but no appreciable spikes are identified in either cases. (these are almost raw data)

Conclusions

- *Compared to H95, recent TSK T7 falls more quickly and recent LMS T7 falls more slowly. The relative difference between their depth biases is 3-4% (the results of K11 is confirmed).*
- *Impact of weight reduction (by 10g/20g) is appreciable, but it is still too small to explain the fall-rate difference between TSK T7 and LMS T7.*
- *The manufacturers' weight tolerance ($\pm 1\mathrm{g}/\pm 5\mathrm{g}$) is probably good enough to control the fall-rate of T7 within <1%.*
- *Impact of weight reduction is not proportional to the weight difference, indicating that factors other than total weight (maybe structure) is important.*
- *Large scatter is in every group. It suggests that environmental factors (i.e. waves ,ship motion, probe's attitude at water entry, turbulence, etc.) can modify the fall-rate in invincible way. This can also spoil at-sea-type tests with small sample size (like ours!).*

Still, the biggest question is,

From when, and how did they change?

- *Both the manufacturers claim, "we did not make any change, particularly in a manner that the fall-rate is affected" . If so, why is there sizable difference in the fall-rate of recent probes that was not found by H95?*

- *Is it just a batch-to-batch difference? Our sample may be too small to deny this possibility, but 3.5% is quite large.*

- *The weight of probes has been controlled by both the manufacturers. But, how about structure?*

Thank you.

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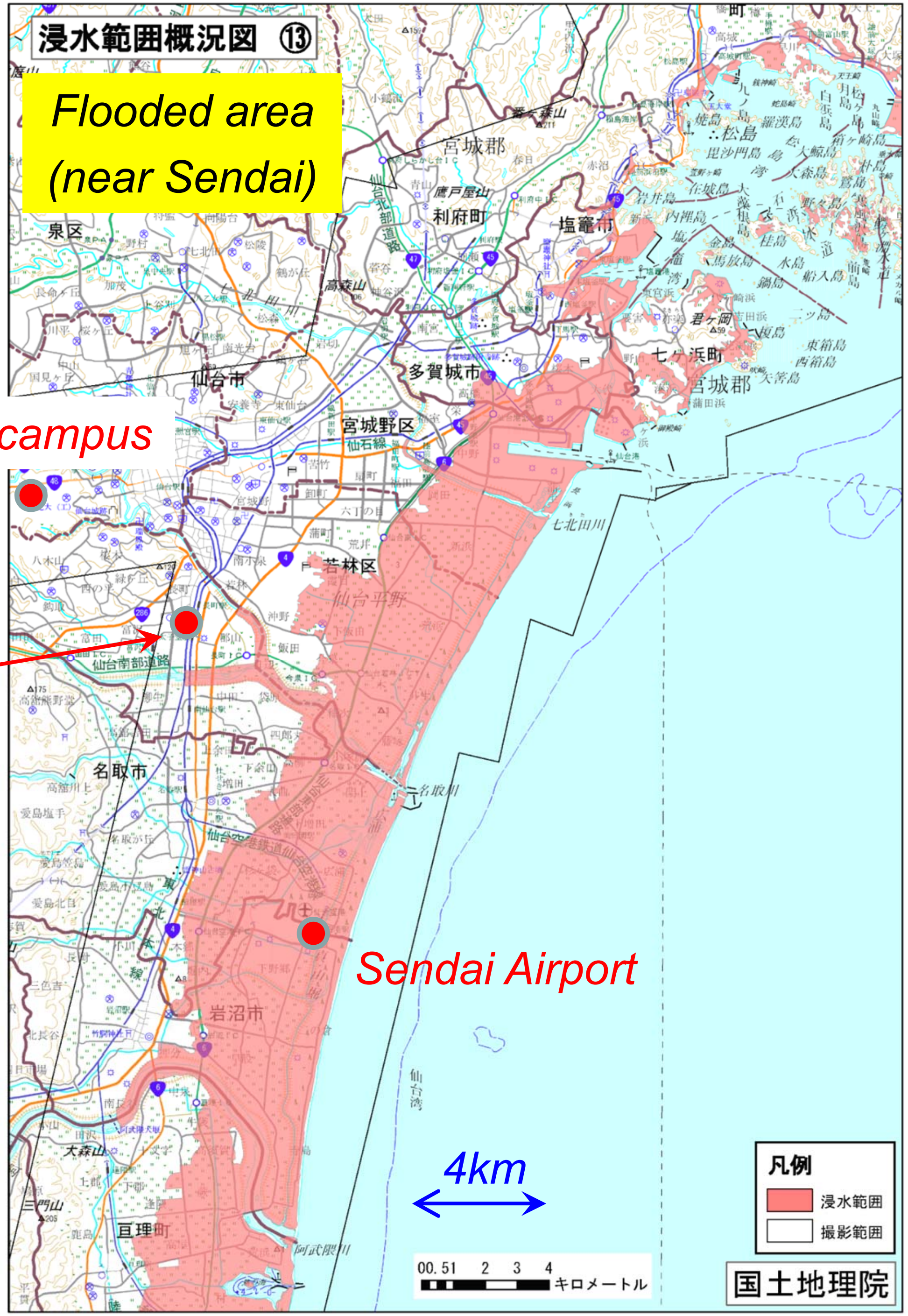
東北大学
TOHOKU UNIVERSITY

Earthquake on March 11, 2011
(Mw=9.0)

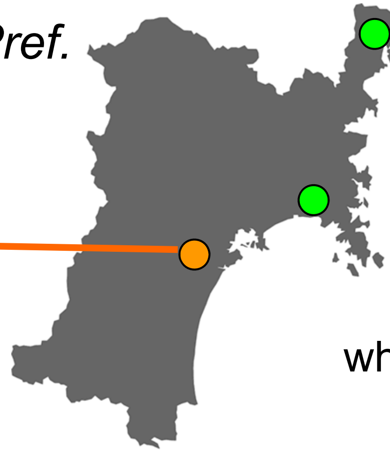
Sendai Station

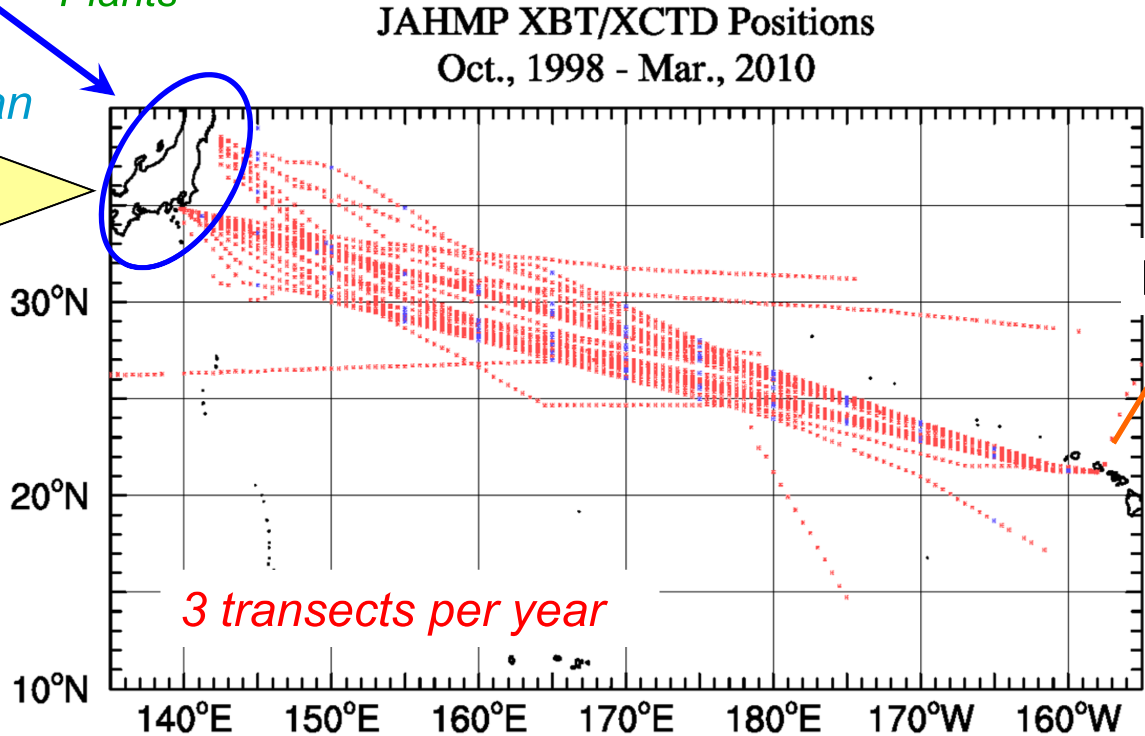
Sendai Airport



Japan-Hawaii Monitoring Program

PX-40





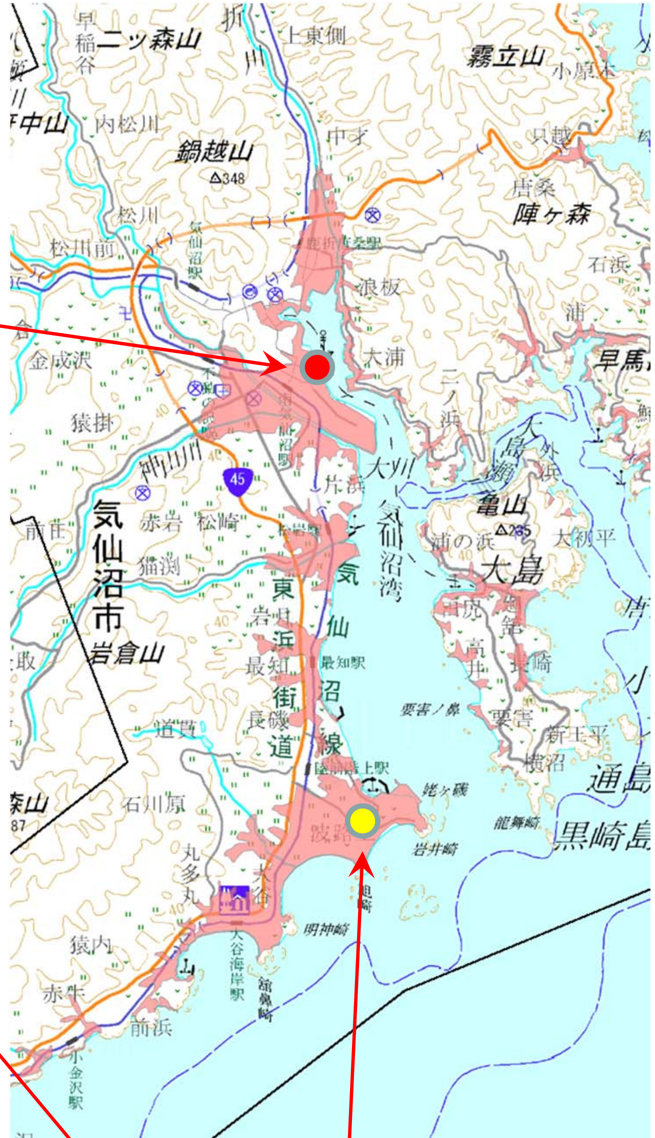
Port changed since 2008
(*Misaki* near *Tokyo*
>>> *Ishinomaki*
or Kesennuma)

Flooded area

Coastal area sank by up to 1.2m.

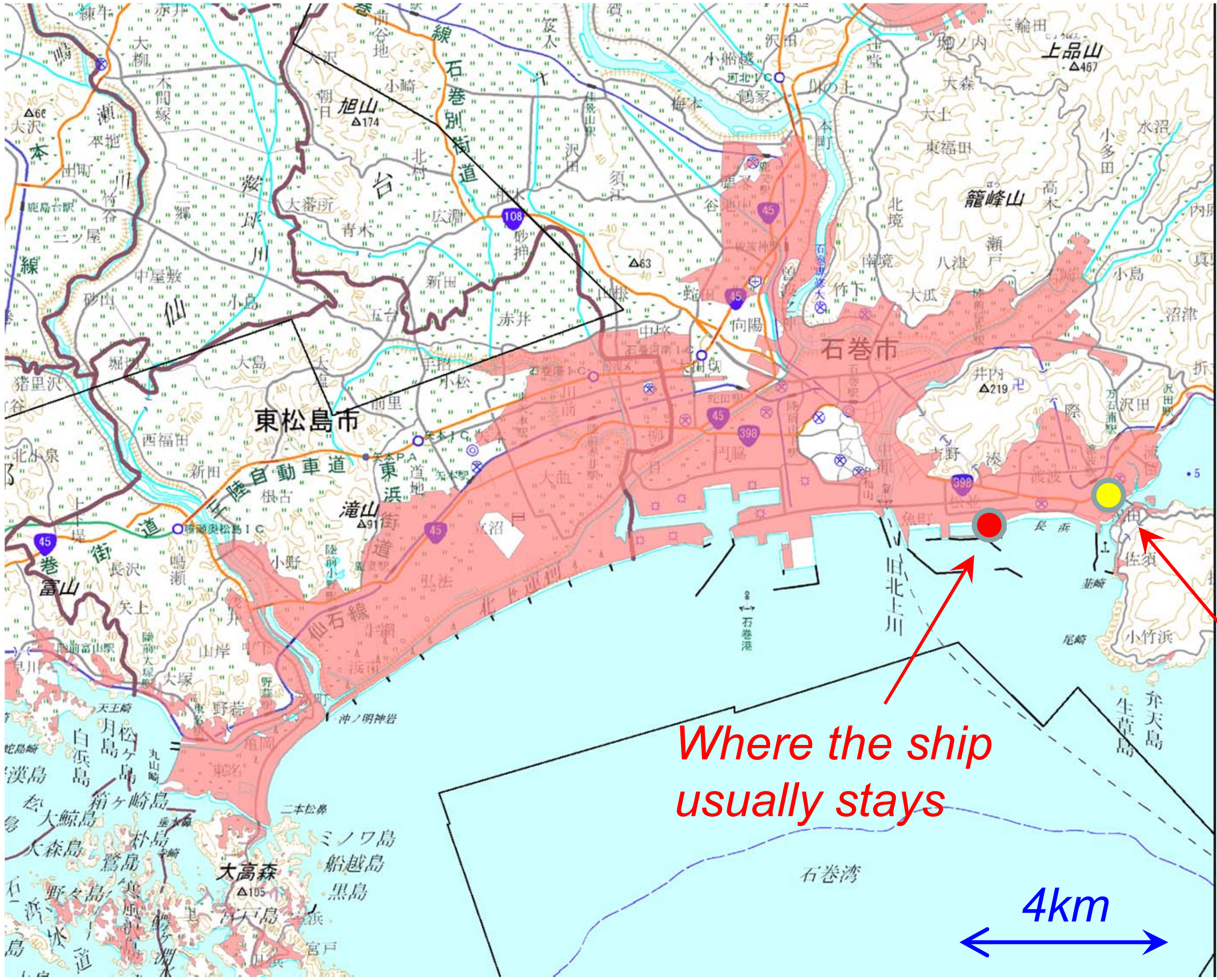
Many towns are still without recovery of drainage.

Kesennuma



Port of Kesennuma

Ishinomaki



Where the ship usually stays

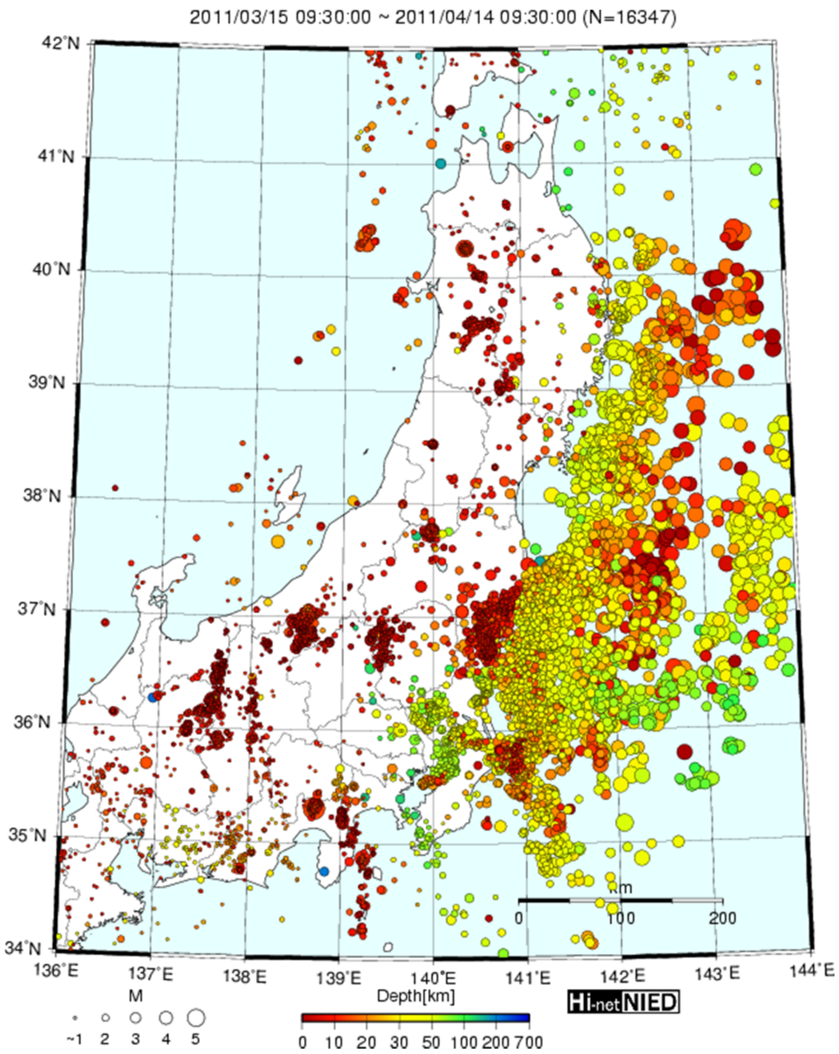
High schools were here

4km

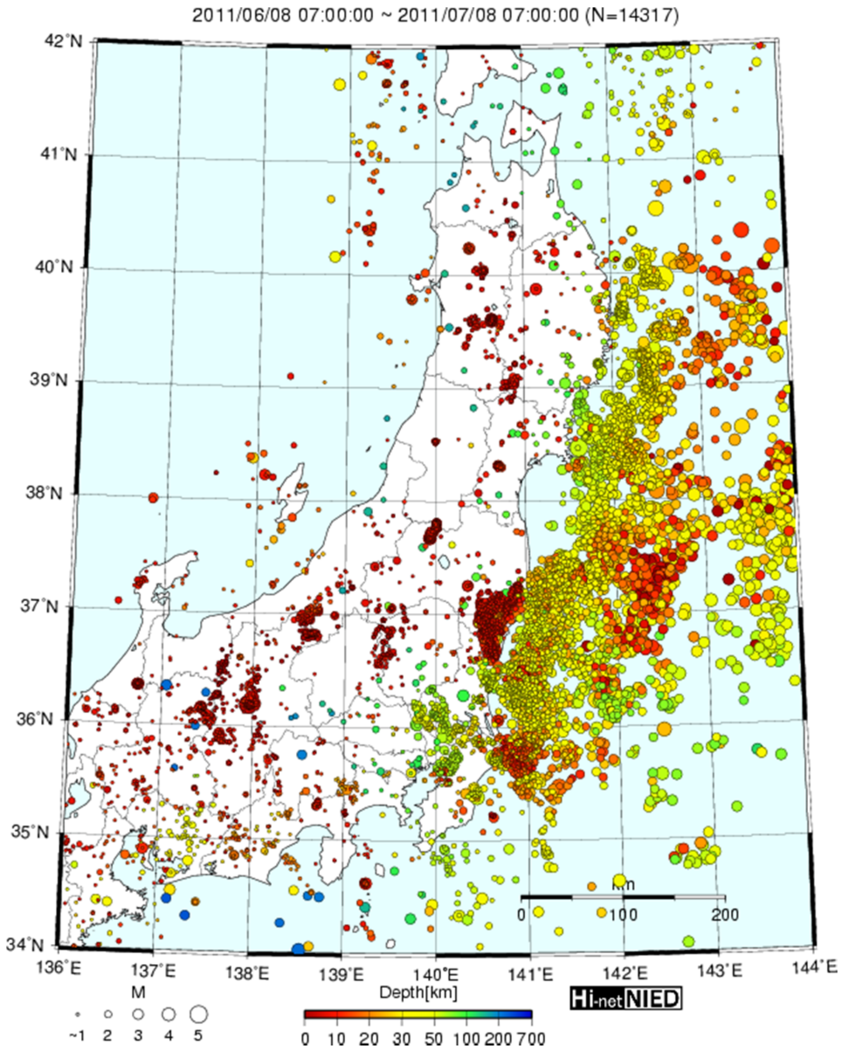
Frequent aftershocks

Size of circles: JMA scale (similar to Richter's scale) of the aftershocks

Color: Depth of their centers



March 15 – April 14 (30 days)

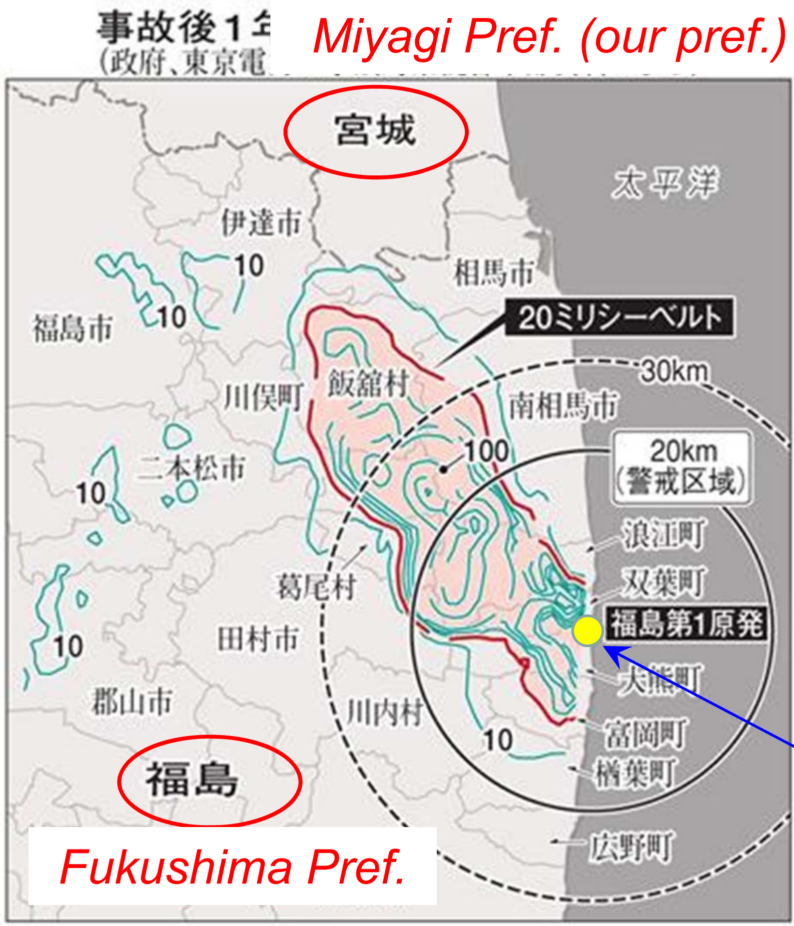


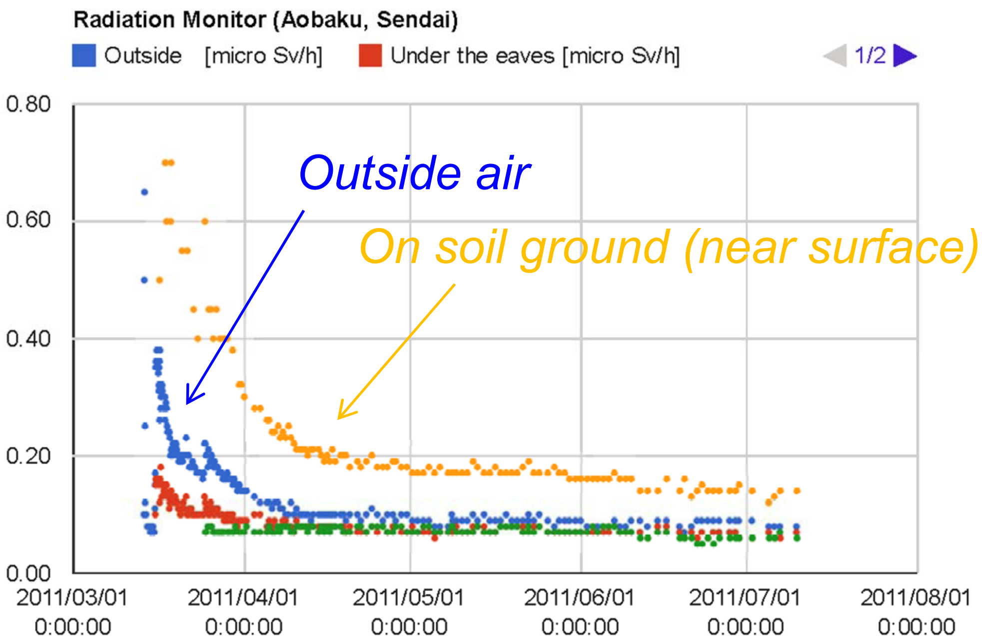
June 8 – July 8 (30days)

The nuclear power plants

In Fukushima 1st Plant, there're 6 of total 54 reactors in Japan (incl. out of operation).

Most of Japan (incl. Sendai) is believed to be safe, but some parts of Fukushima Pref. are not. We're also worrying about power shortage expected nationwide in this summer due to suspension/failure of many power plants (both nuclear and thermal) as a direct/indirect consequence of the earthquake/tsunami.





▲ Measurement near our campus (mSv/h)

▼ Estimated integral dose (mSv) in one year after the accident (by TEPCO; Apr., 26, 2011)