Next Generation Automobiles in Miyagi

Measuring Coefficient of Friction in Ski

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Significance of Tools in Ski

Winning record at the Olympic Games

	1924 Paris 1924 Chamonix	2012 London 2014 Sochi	Speed up
Marathon 42.195km	2:41:22 15.7km/h	2:08:01 19.8km/h	x 1.26
XC Ski 50km	3:44:32 13.4km/h	1:46:55 28.1km/h	x 2.10

XC: Cross-Country
UHMW: Ultra High Molecular Weight

Progress of Tools in Ski

	1924	2014
Ski Plate	Wood	Resin＋Plywood＋Hollow Honeycomb
Ski Base	Wood	UHMW-Polyethylene
Poles	Bamboo	Carbon
Wax	Pine Resin	Fluorine Compound
Boots	Leather	Plastic＋Carbon
Wear	Wool	Elastic Chemical Fiber
Trail	Tread down	Snow Groomer＋Tracksetter

Glory shines for one who obtains and masters excellent tools before anyone else in the world


勝利の秘密は「ワックス」!
メダルへのキーマンの謎に迫る!
7秒56
Race Wax
+0.28秒
7秒84
Common Wax
+0.54秒
8秒10
No Wax

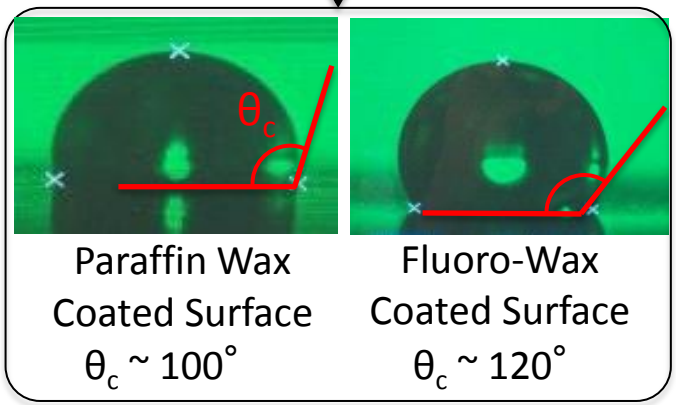
Requirements of Ski Wax

Skier ① Glide ② Retention

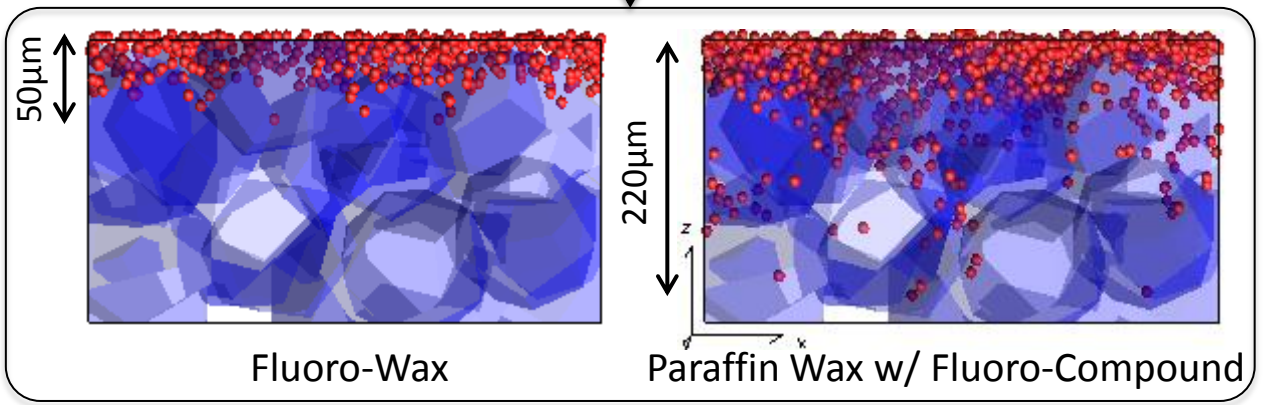
Feeling test

Science ① Friction ↓ ② Water Repellency ↑ ③ Infiltration ↑

Quantitative evaluation



Contact Angle of Water on Wax-Coated Surface

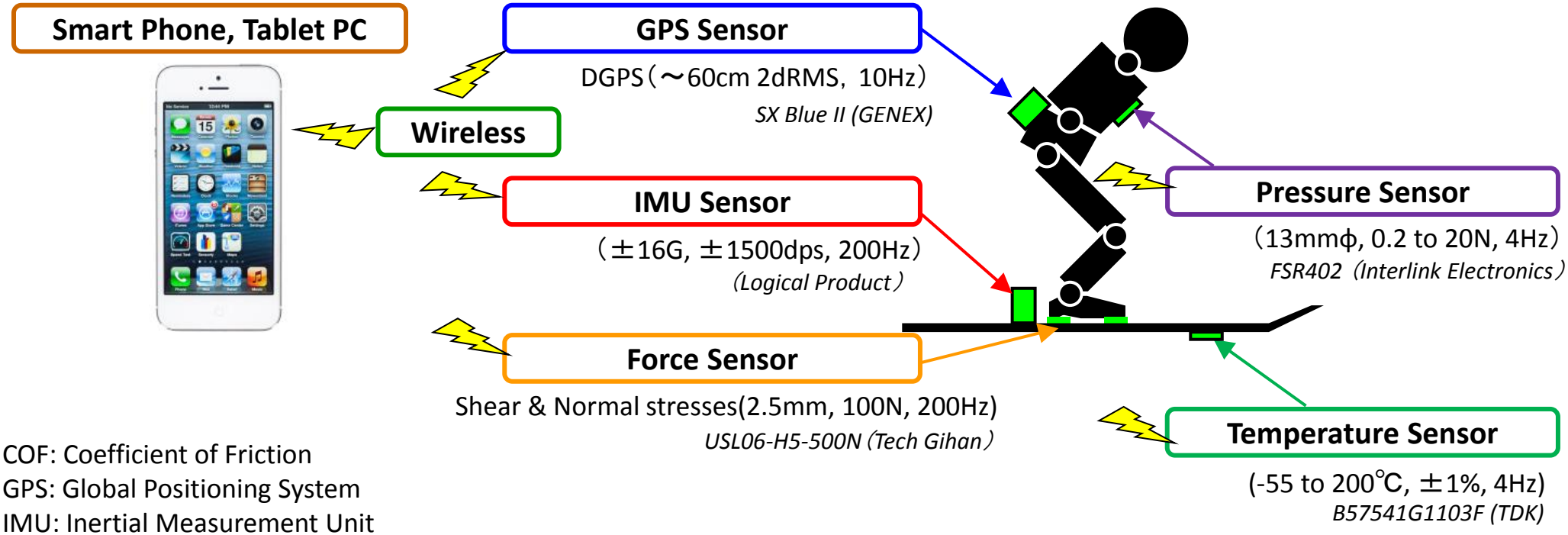


Wax Molecules Permeate UHMW-Polyethylene for 300 sec. at 120 ℃ Simulated by Computational Chemistry

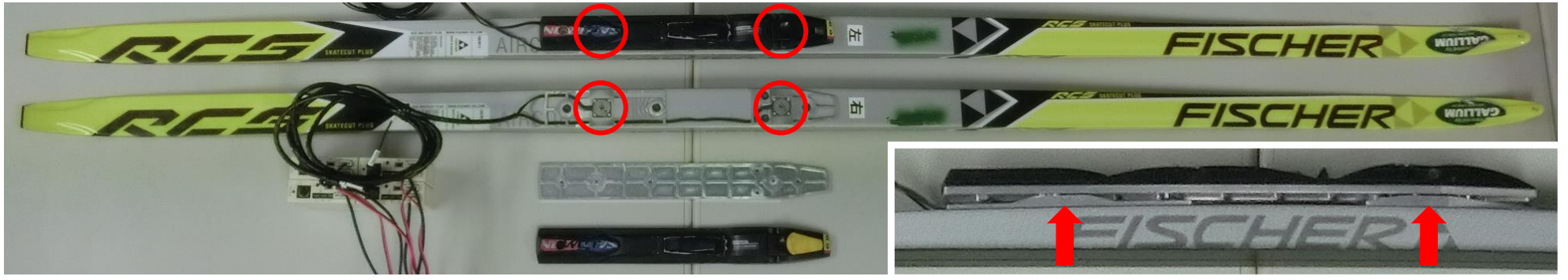
Motivation of Friction Measurement

- **Factors that affect wax selection include Temperature, Snow crystals, Humidity, Wind, Course, and Sunshine.**
- **Currently, national team accompanies a wax expert called "Waxman" who selects race wax from several hundreds of combinations based on the factors.**
- **But he keeps the wax selection secret, and never leak even to ski player what kind of wax was used.**
- **Therefore coefficient of friction (COF) of wax has never been subject to systematic research.**
- **COF can be estimated using sensor fusion, though it is difficult to measure sliding friction directly.**
- **We have started developing a wearable COF estimator with which ski player does not feel uncomfortable during skiing.**

Measurement Equipment of COF during Skiing

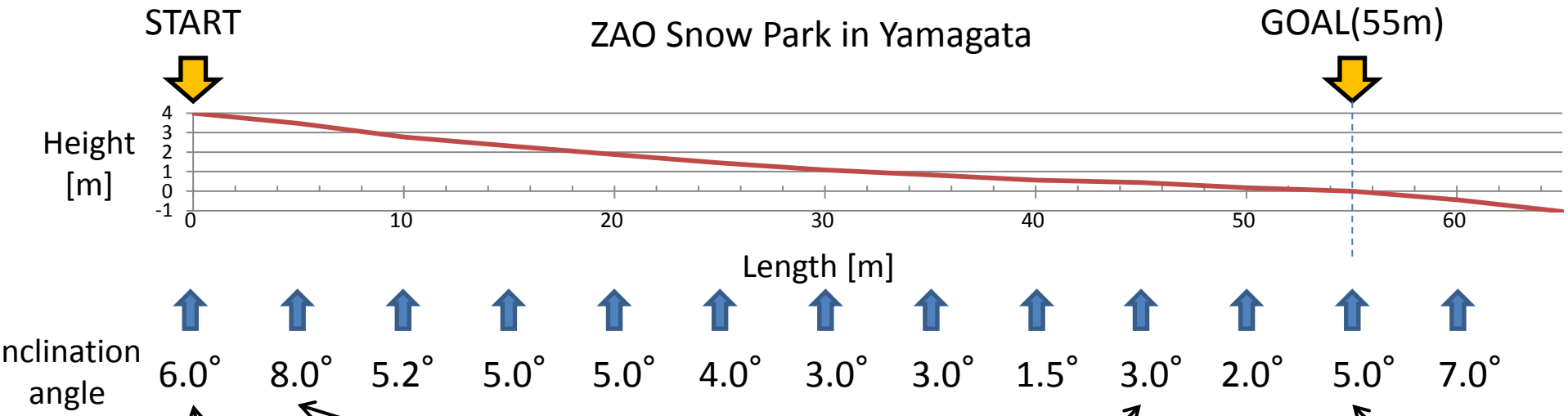


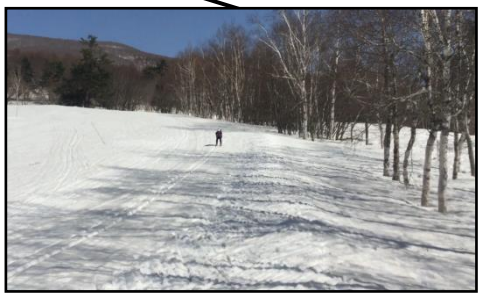
COF: Coefficient of Friction
GPS: Global Positioning System
IMU: Inertial Measurement Unit



2 force sensors per 1 ski plate

Measurement Condition

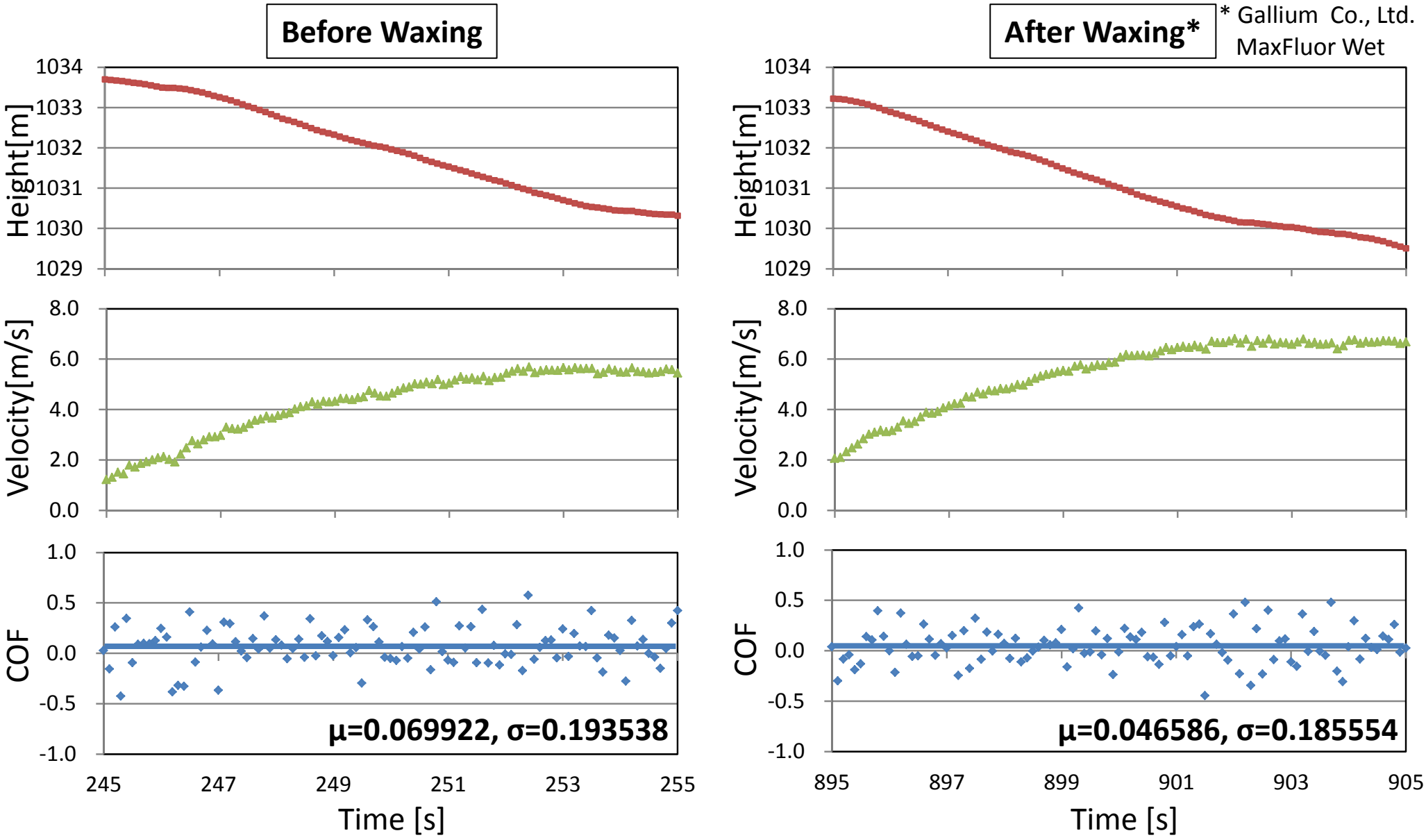




Date: 4th Apr. 2015　13:35～14:14
Weather : Fine
Wind Speed : 0～3m/s
Air Temperature : 15℃

Snow Temperature : +0.3℃@Surface,
-0.2 to -0.4℃@5cm Below Surface
Snow Quality : Granulated, Sintered　0.5365g/cc
Skier : Junichi Sato（an expert of wax test）

Measurement Results



Measurement Results (Cont'd)

* Stored in warehouse for several years

** MaxFluor Wet (Gallium Co., Ltd.)

	Before Waxing*			After Waxing**		
Test No.	COF	σ	Top Speed [km/h]	COF	σ	Top Speed [km/h]
1st	0.06992	0.19354	7.3620	0.04659	0.18555	8.8200
2nd	0.06768	0.21690	7.8552	0.04766	0.15475	8.9496
3rd	0.06810	0.19163	7.5780	0.04701	0.16135	8.8560
4th	0.06830	0.16676	7.9236	0.04616	0.19038	8.6472
Average	0.06850	0.19221	7.6797	0.04686	0.17301	8.8182

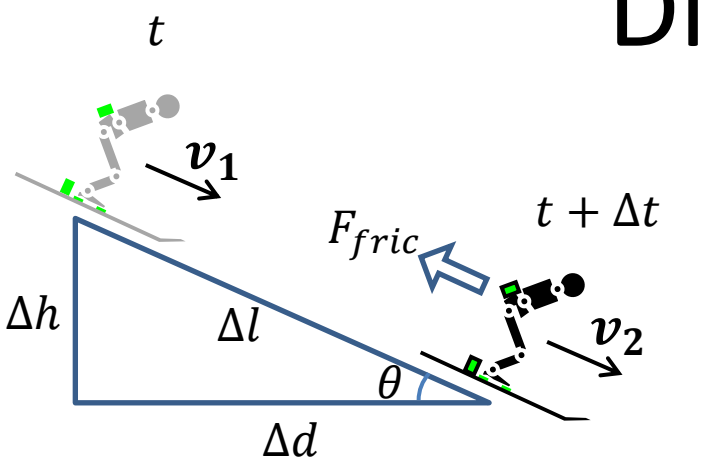
33%↓

15%↑

COF is effective because it is more sensitive than speed.

However standard deviation (σ) is not small enough.

Discussion



F_{fric} : Friction force

$$mg\Delta h = \frac{1}{2}m\Delta v^2 + F_{fric}\Delta l$$

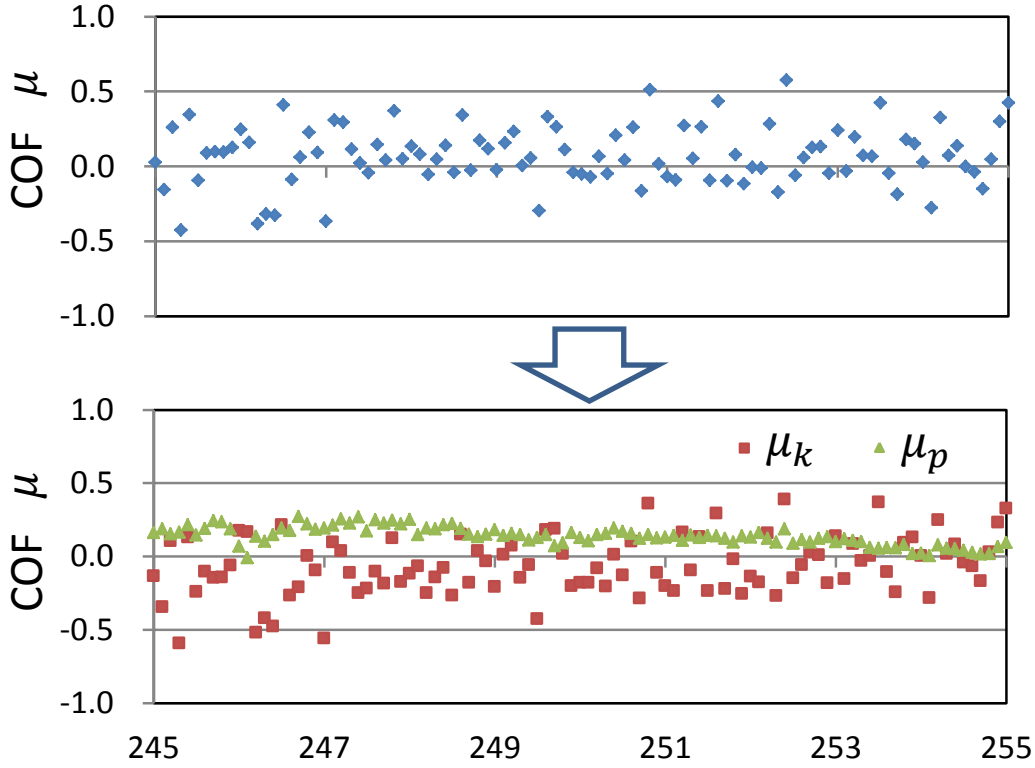
$$\mu = \mu_k + \mu_p$$

where

$$\mu_k = -\frac{1}{2g\Delta d} \cdot ({v_1}^2 - {v_2}^2)$$

$$\mu_k = -\frac{1}{2g\Delta d} \cdot (v_1 + v_2)\,(v_1 - v_2)$$

$$\mu_p = \tan\theta$$



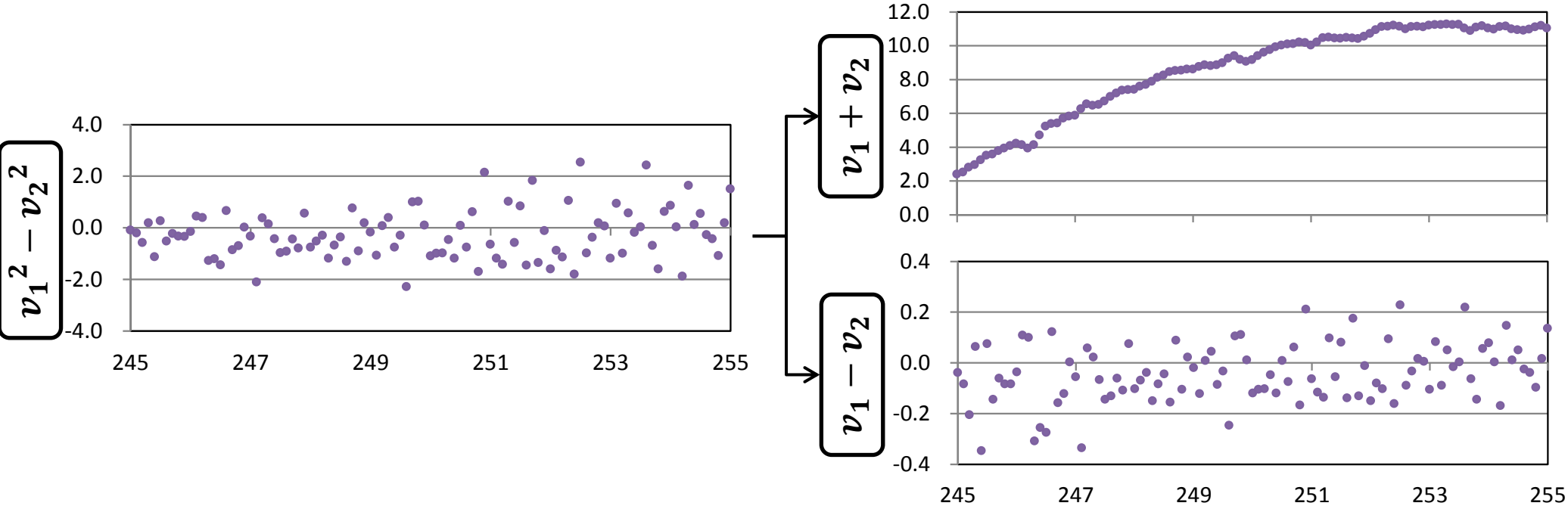
μ_k : COF from kinetic energy

μ_p : COF from potential energy

μ_k is more variable than μ_p

Discussion (Cont'd)

$$\mu_k = -\frac{1}{2g\Delta d} \cdot \left(v_1{}^2 - v_2{}^2\right) = -\frac{1}{2g\Delta d} \cdot (v_1 + v_2)\,(v_1 - v_2)$$



Variability of COF is due to speed difference $\Delta v = v_1 - v_2$
We have developed more accurate GPS with accelerometer in order to reduce the variability

Conclusion

- **Coefficient of friction (COF) is very important in ski**
- **We have successfully measured and estimated COF during skiing**
- **Results show that COF is more than twice as effective as conventional speed test.**
- **Variability in COF estimation is the issue, but we have already developed a solution which we plan to evaluate in this season.**

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