Continuous Moving Measurement Method for Thermal Environmental Distributions in Streets

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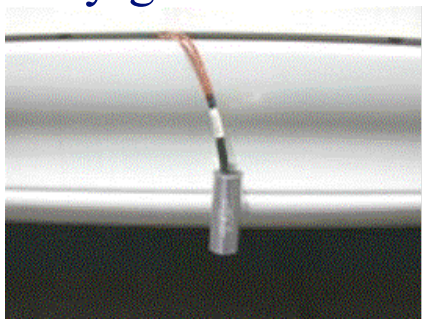
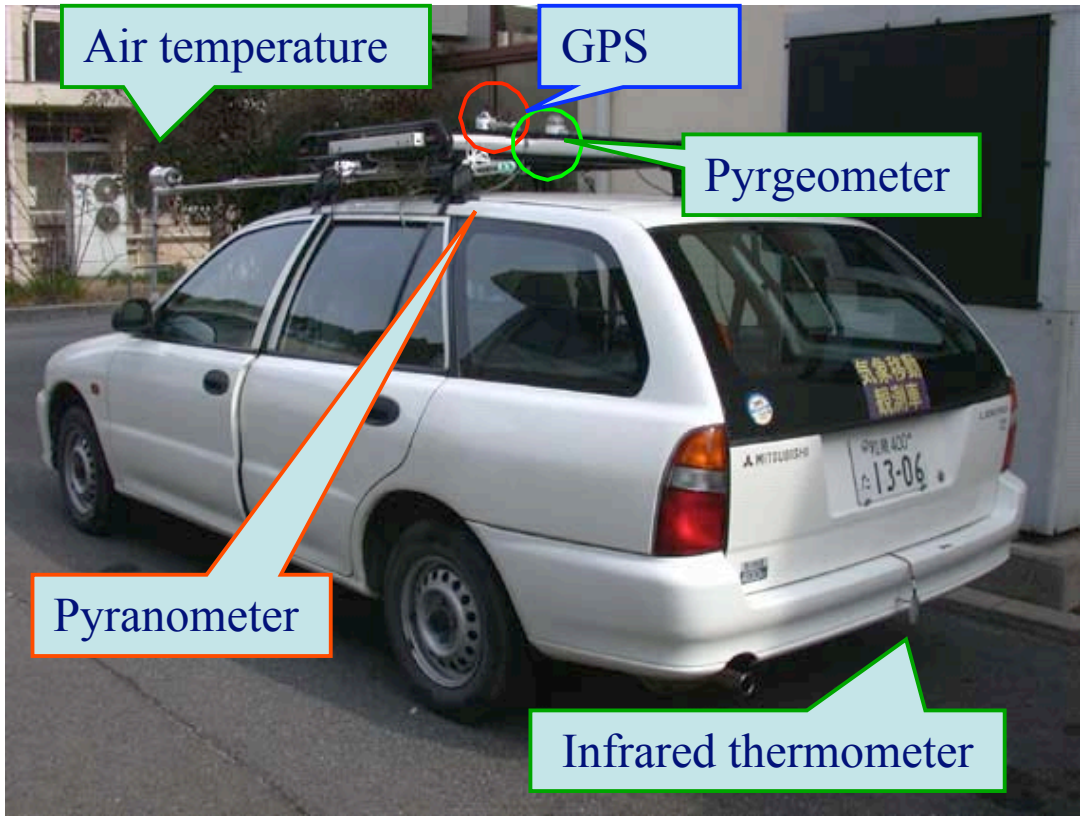
Vehicle for continuous moving measurent

Pyranometer

Pyrgeometer

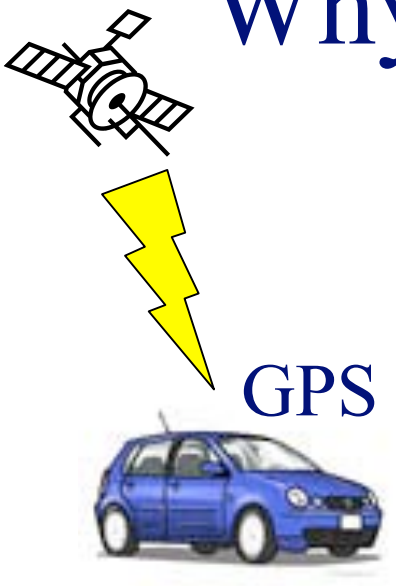


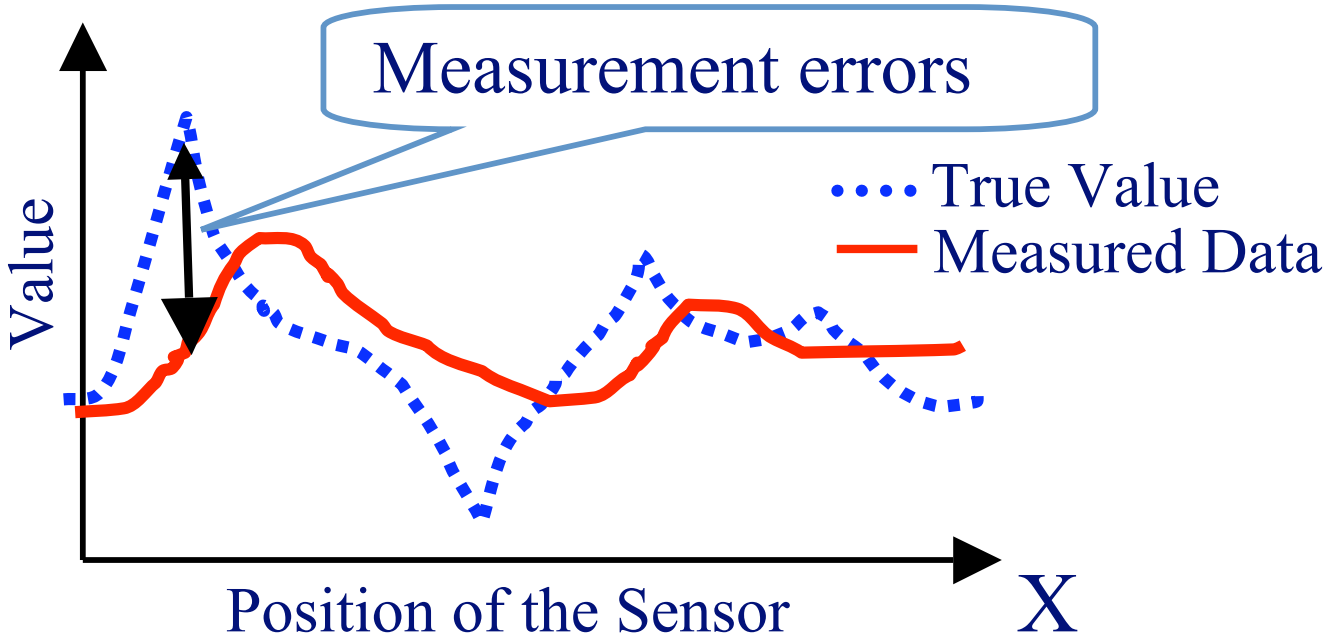
Infrared thermometer



Sensors and GPS attached

Why error occurs



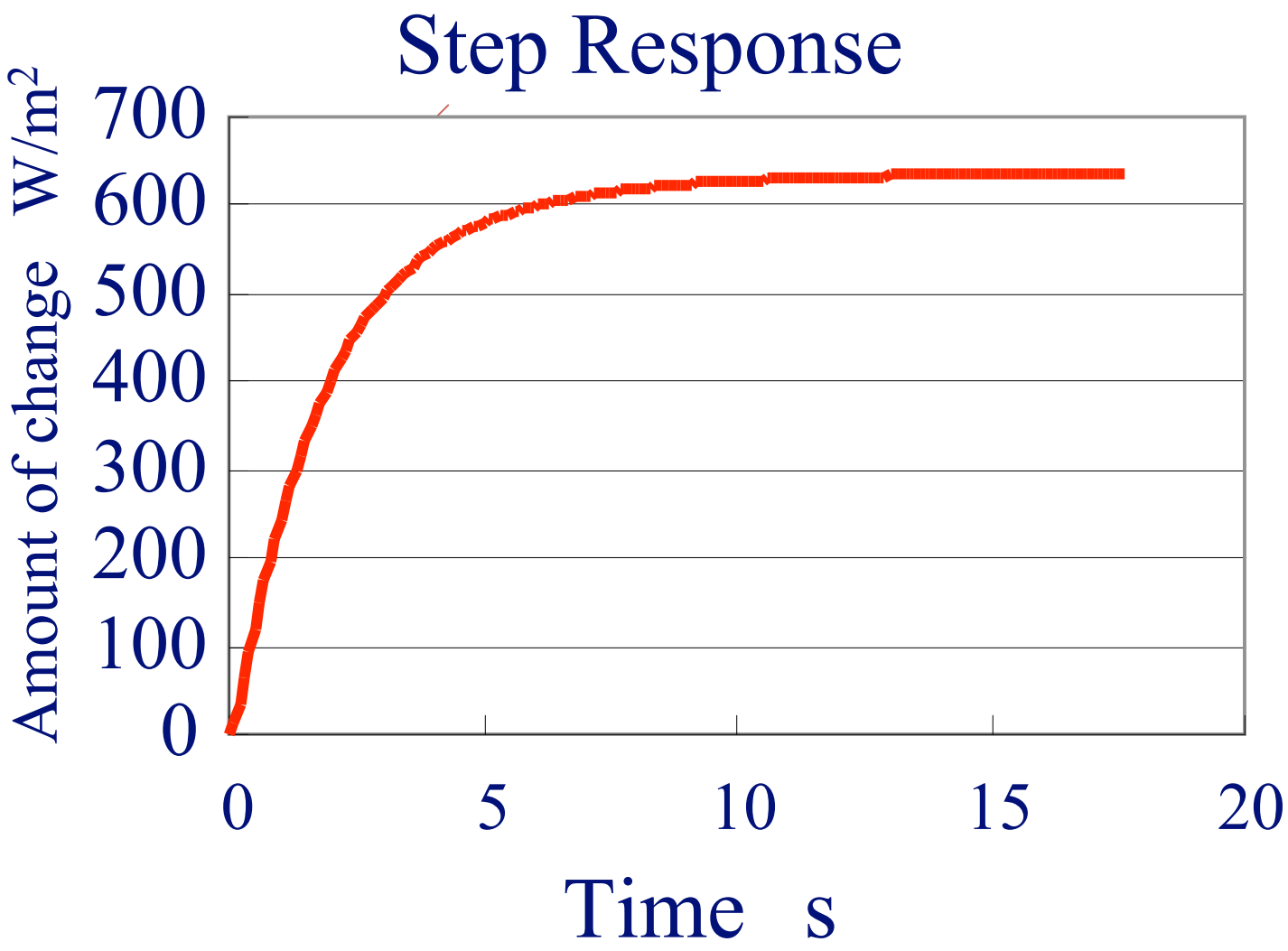


① Time lag of the sensors

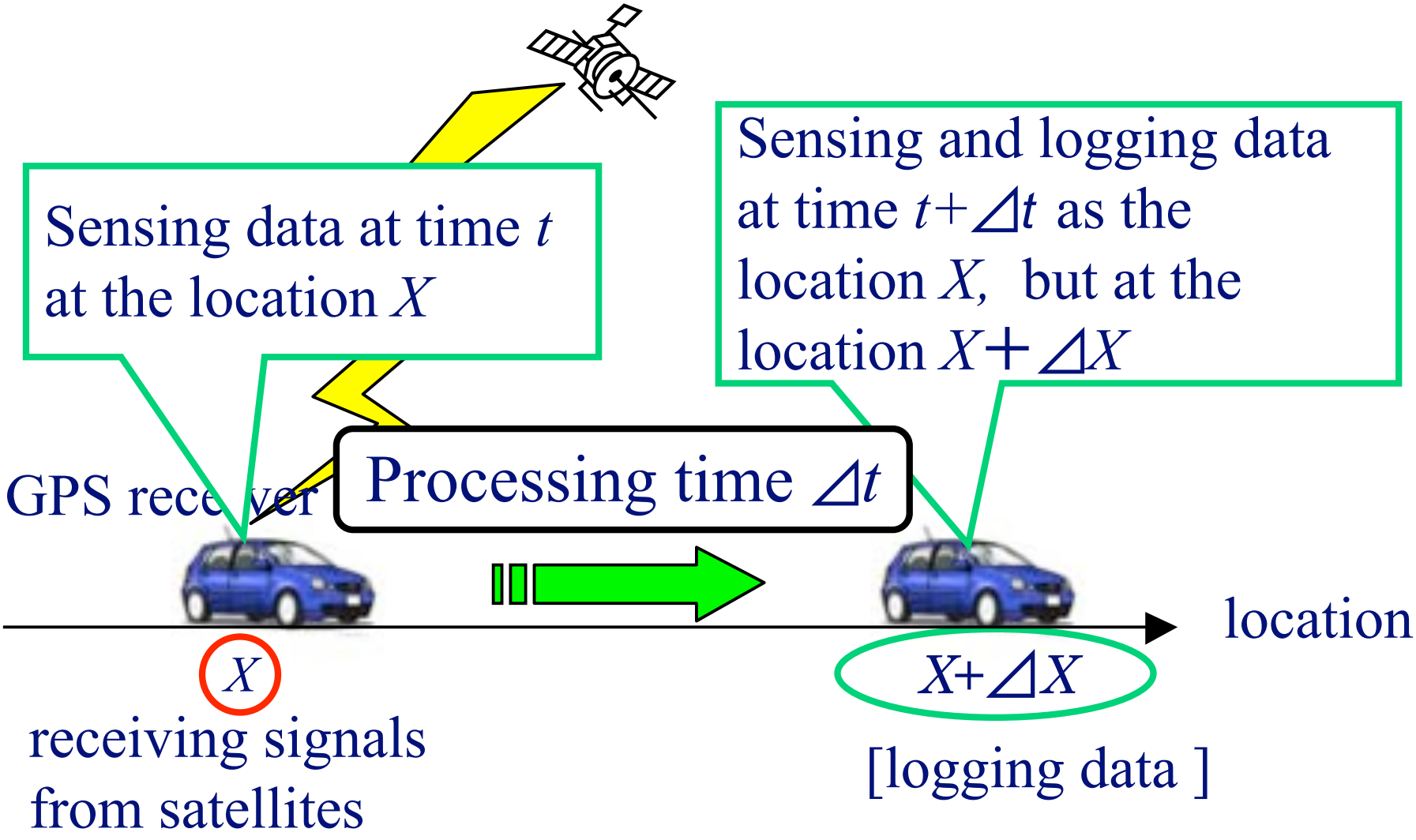
②Delay time in the GPS terminal

① Time lag of the sensors

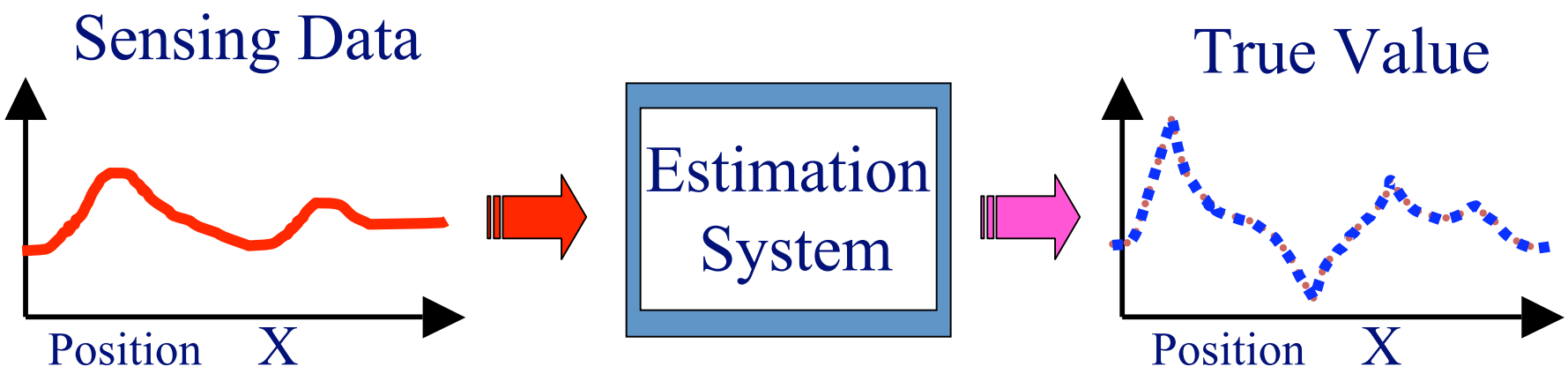
Pyranometer



②Delay time in the GPS terminals



Estimation system



Data measuring position x

The sensor position x_p at time t :

$$x_p = x_0 + V(t - t_0) \qquad (1)$$

Data measuring position x at time t :

$$x = x_0 + V(t - t_0) - Vt_d \qquad (2)$$

t : Time

x : Data measuring position at time t

x_0 : Initial position of the sensor

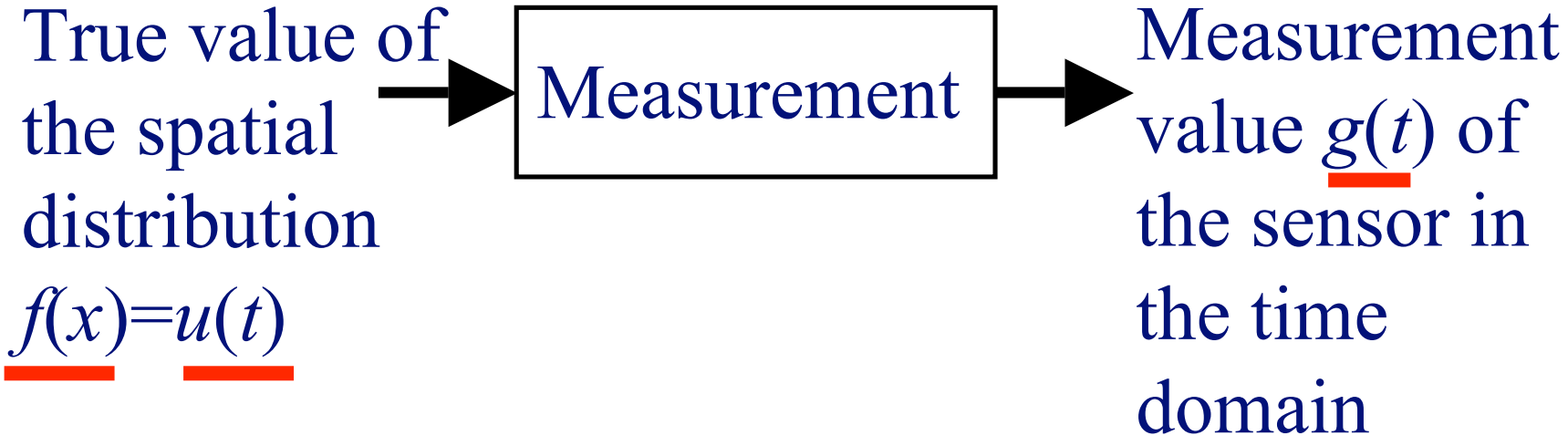
V : Moving speed of the sensor

t_0 : Initial time

t_d : GPS delay time from receiving from the satellites to outputting the positioning information

x_p : The sensor position at time t

Input/output relation of the sensor



$u(t)$: True value of the measured property at time t

$f(x)$: True value of the measured property at the positon x

$g(t)$: Instantaneous value of the data measured by the sensor at time t

Assuming the sensor response as a first-order lag system,

$$T\frac{dg(t)}{dx}+g(t)=u(t) \qquad (3)$$

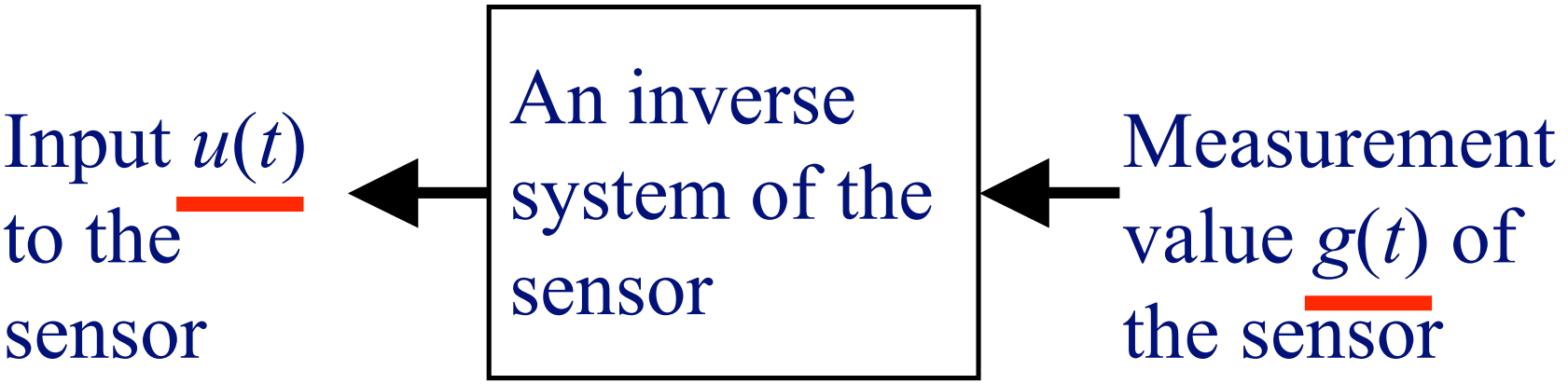
the solution is the following equation.

$$g(t)=\exp\{-(t-t_0)/T\}g(t_0)+\int_{t_0}^{t}\exp\{-(t-s)/T\}/T\times u(s)ds \qquad (4)$$

Assuming $u(t)$ is constant over the time interval, this equation is transformed to the following discrete system.

$$g(t+\Delta t)=e^{-\frac{\Delta t}{T}}g(t)+(1-e^{-\frac{\Delta t}{T}})u(t) \qquad (5)$$

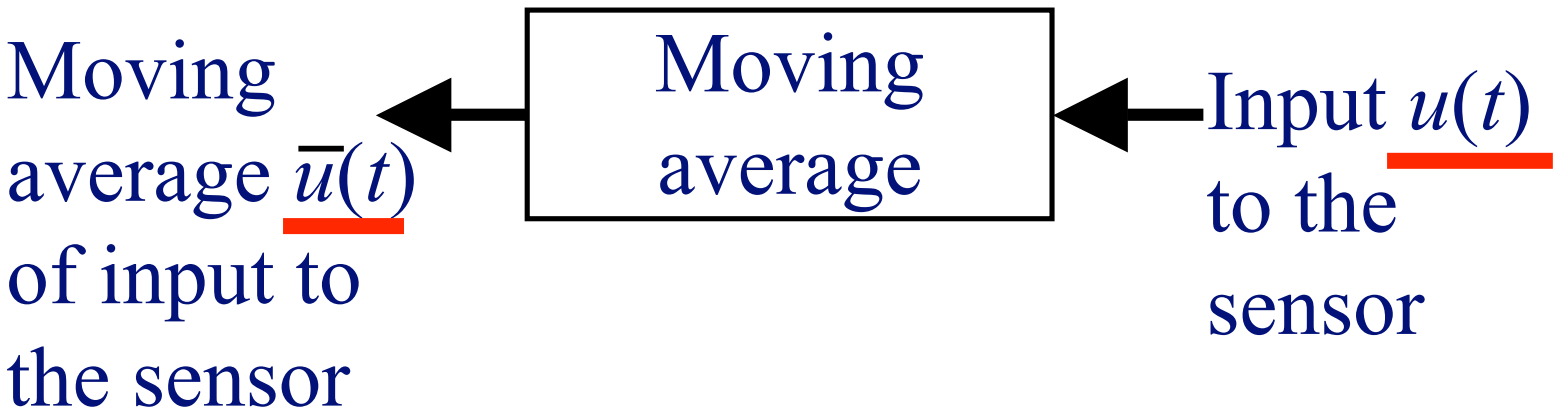
An Inverse system of response characteristics of the sensor



The inverse system of the equation will be the following equation.

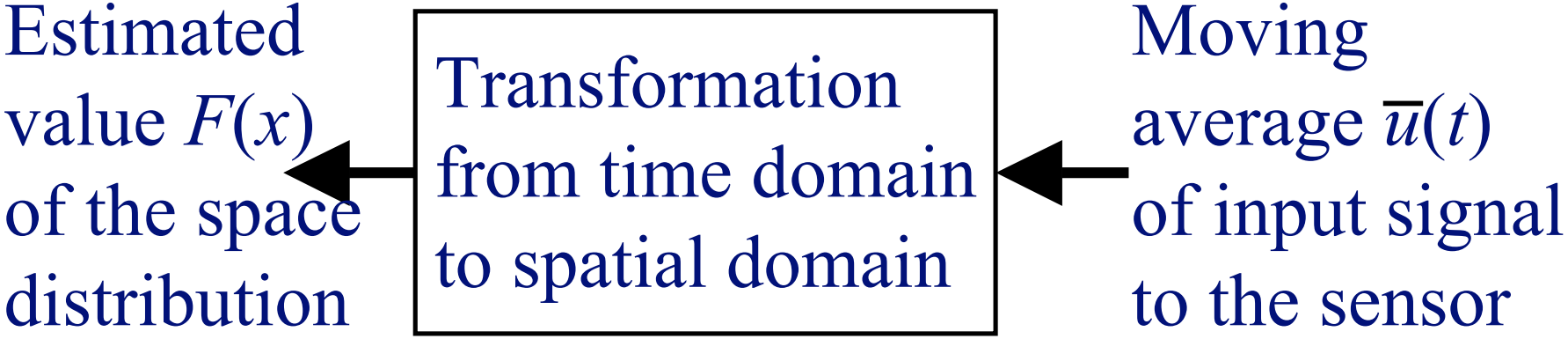
$$u(t) = \left\{ g(t + \Delta t) - e^{-\frac{\Delta t}{T}} g(t) \right\} / (1 - e^{-\frac{\Delta t}{T}})$$

Moving average



$$\overline{u}(t) = \sum_{i=-N}^{N} u(t + i\Delta t) / (2N + 1)$$

Transformation of the input signal of the sensor to the spatial distribution



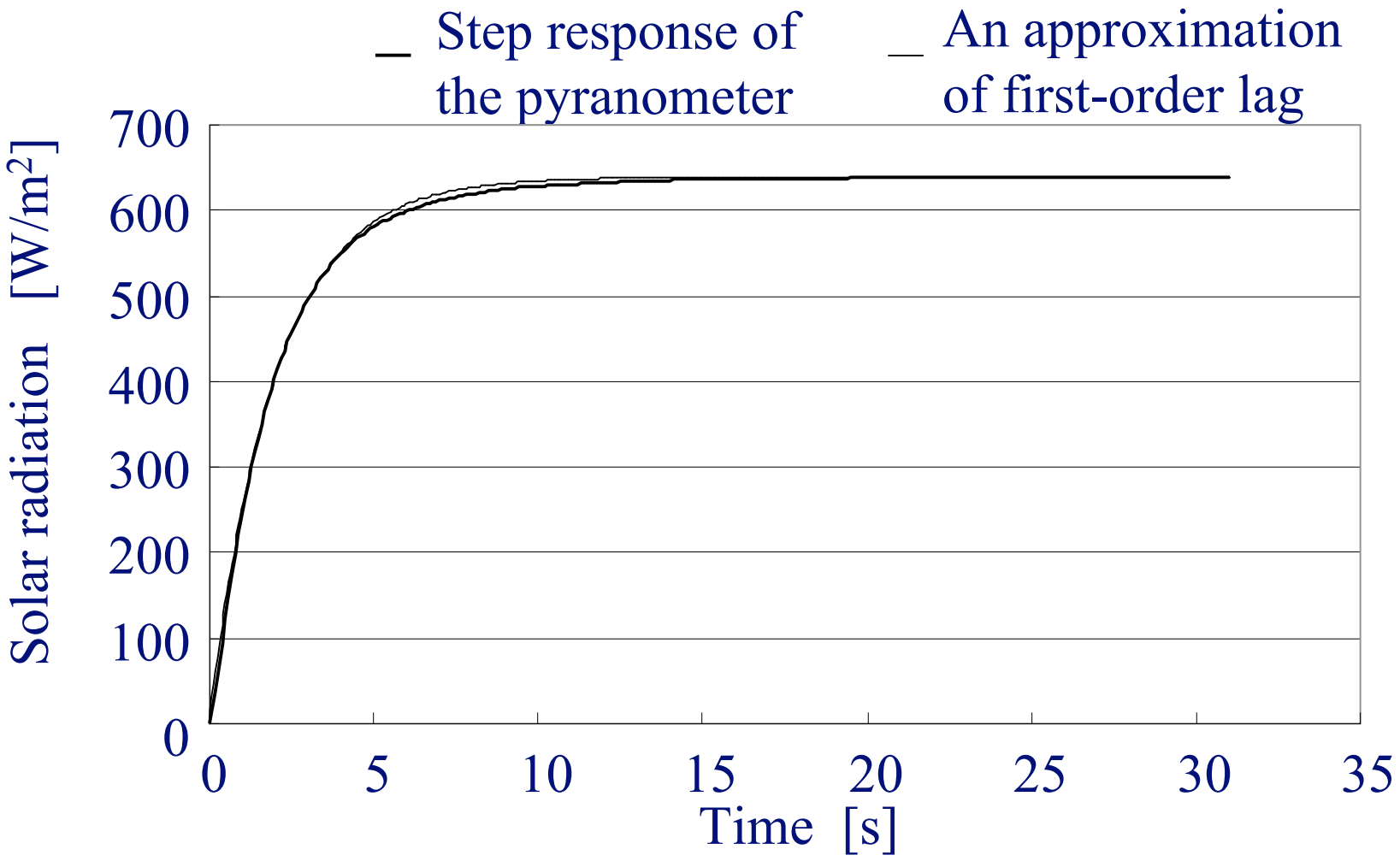
Also, a transformation from time to space is made by substituting

$$t = t_0 + \left(x - x_0 + V\,t_d\right)/V$$

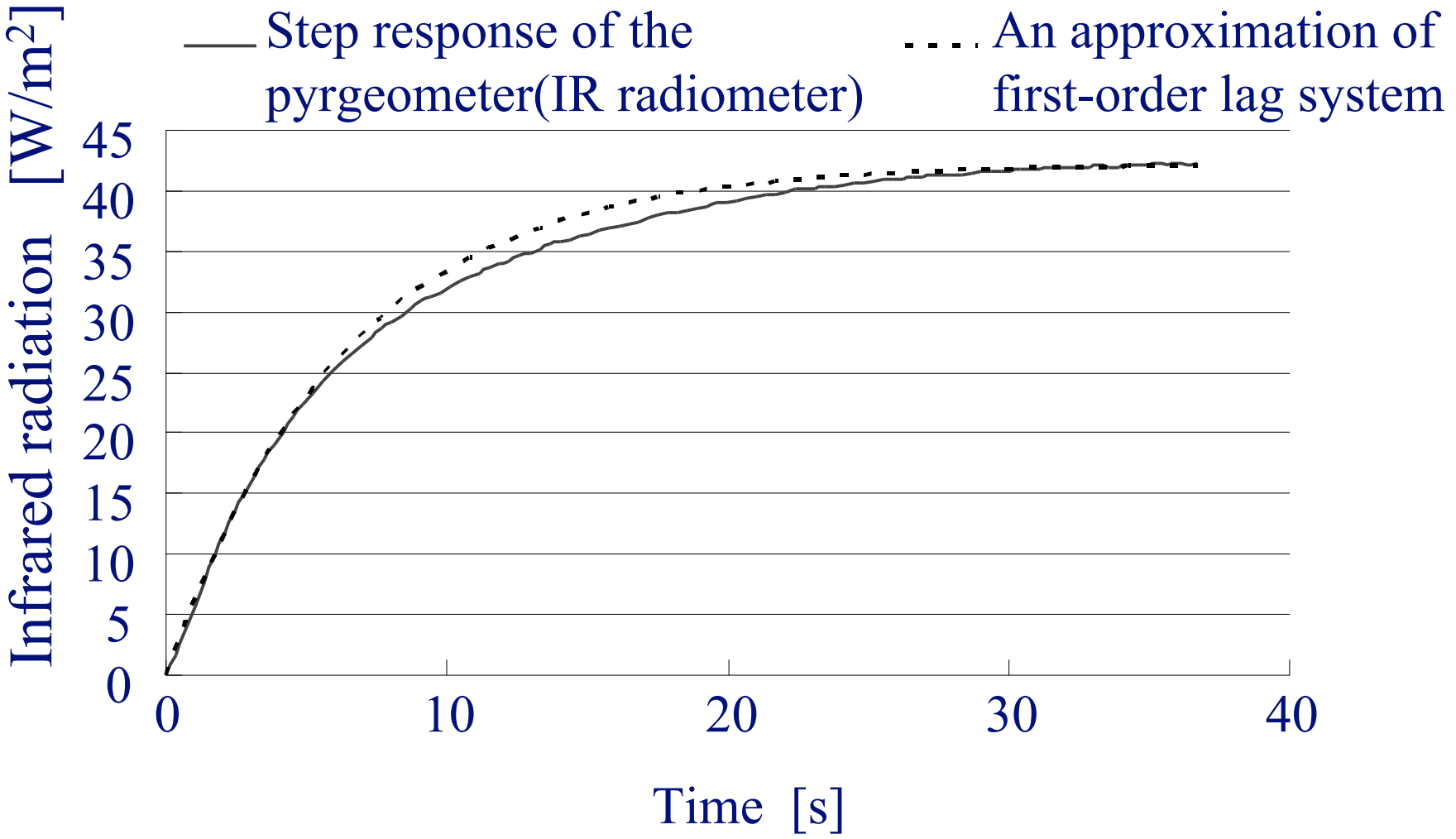
The spatial distribution $F(x)$ will be obtained.

$$F(x) = \overline{u}(t_0 + \left(x - x_0 + V\,t_d\right)/V)$$

Step responses of the pyranometer



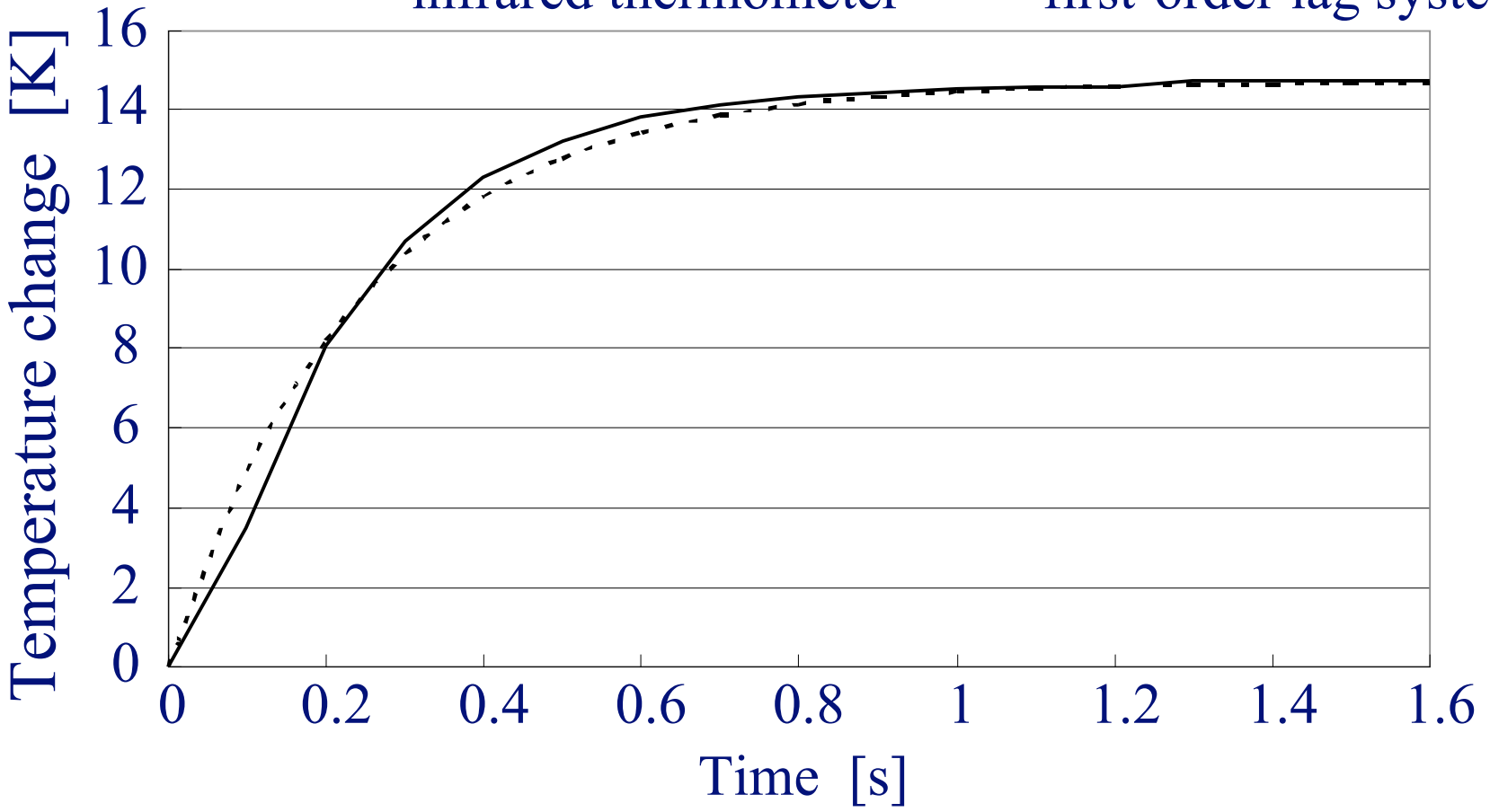
Step responses of the pyrgeometer(IR radiometer)

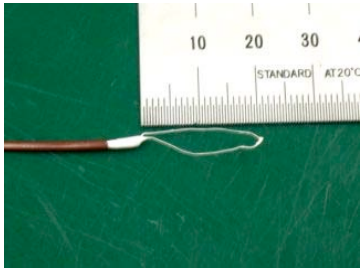


Step responses of the infrared thermometer

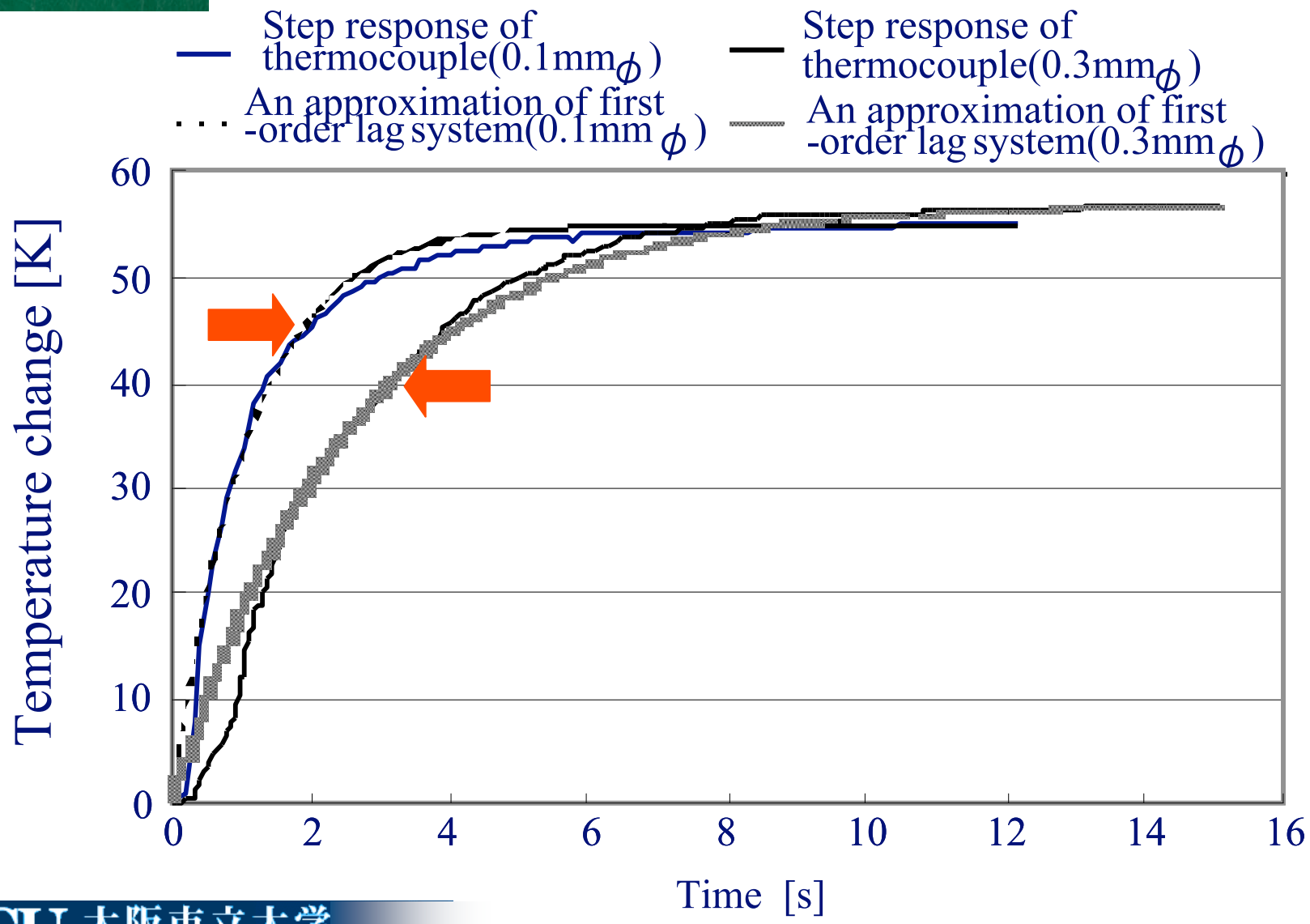
— Step response of the infrared thermometer

- - - An approximation of first-order lag system





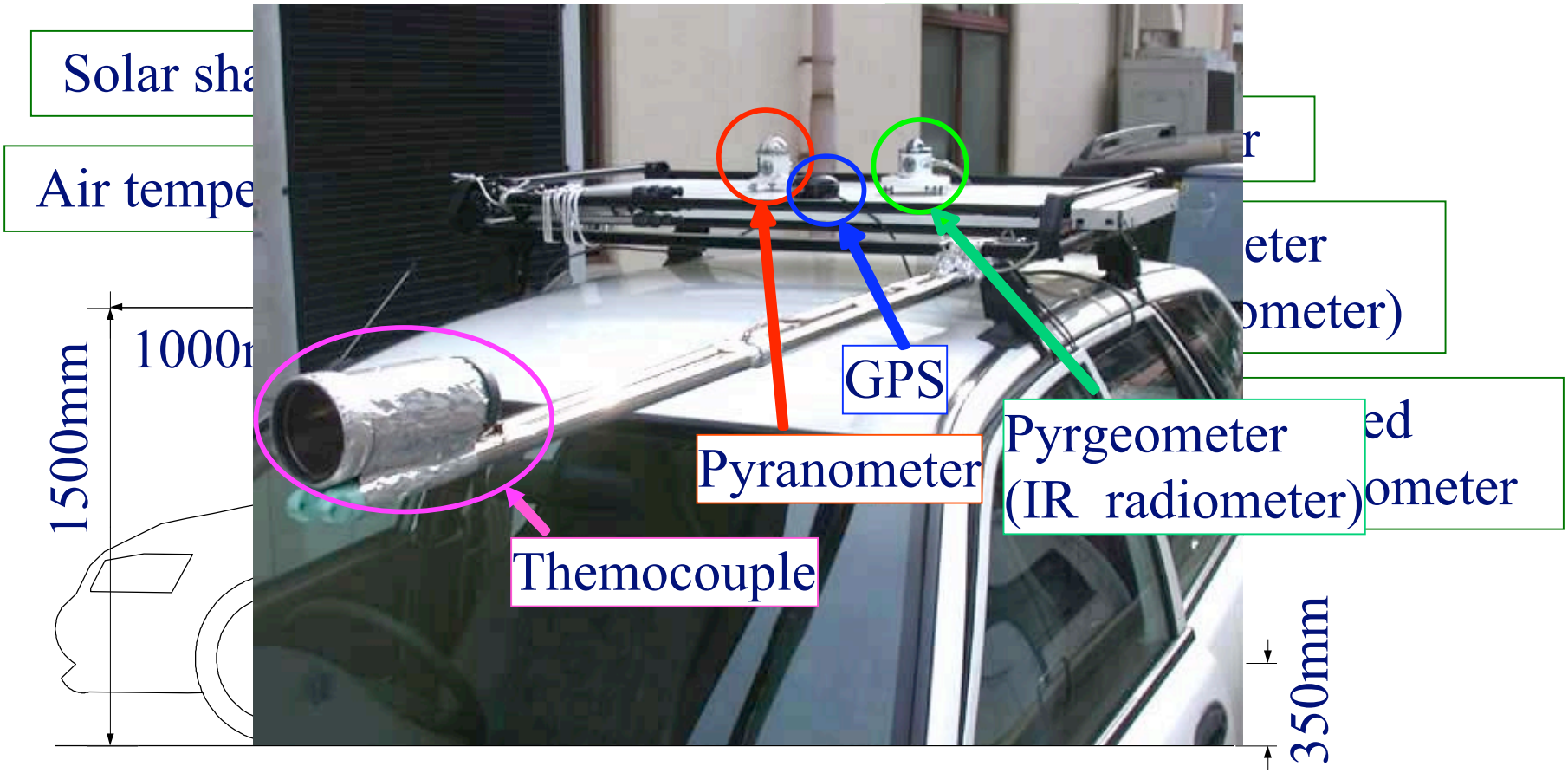
Step responses of the thermocouple



Time constants of the sensors

Instruments		The time constant[s]
Pyranometer MS-802		2
the pyrgeometer(IR radiometer) MS-202		6.7
Infrared thermometer IRTS-P		0.25
T type thermocouple	ϕ0.1	1.1
	ϕ0.3	2.6

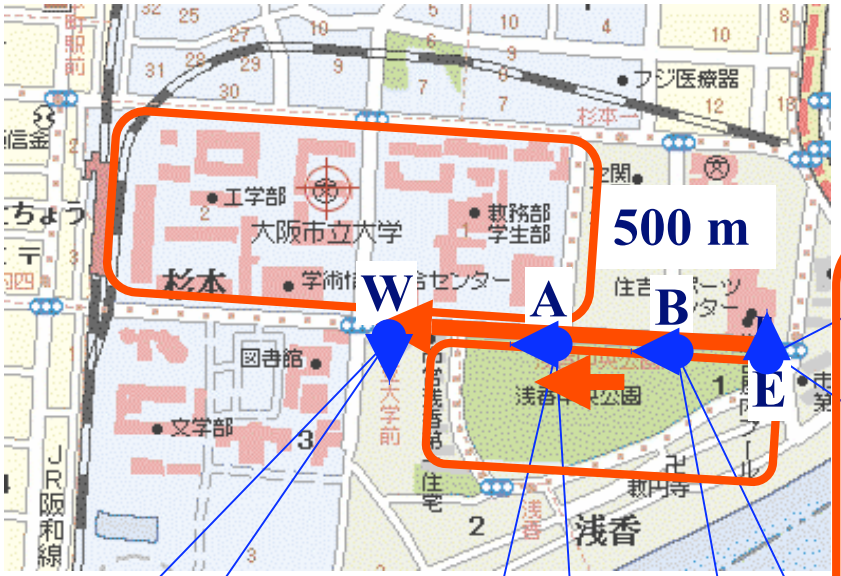
Installation of the sensors

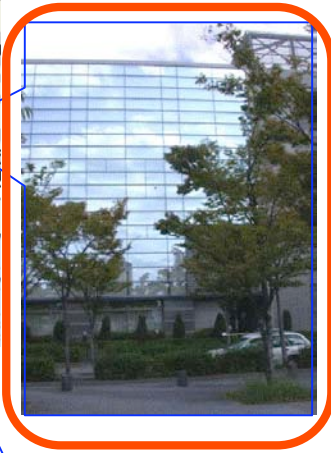


Field test

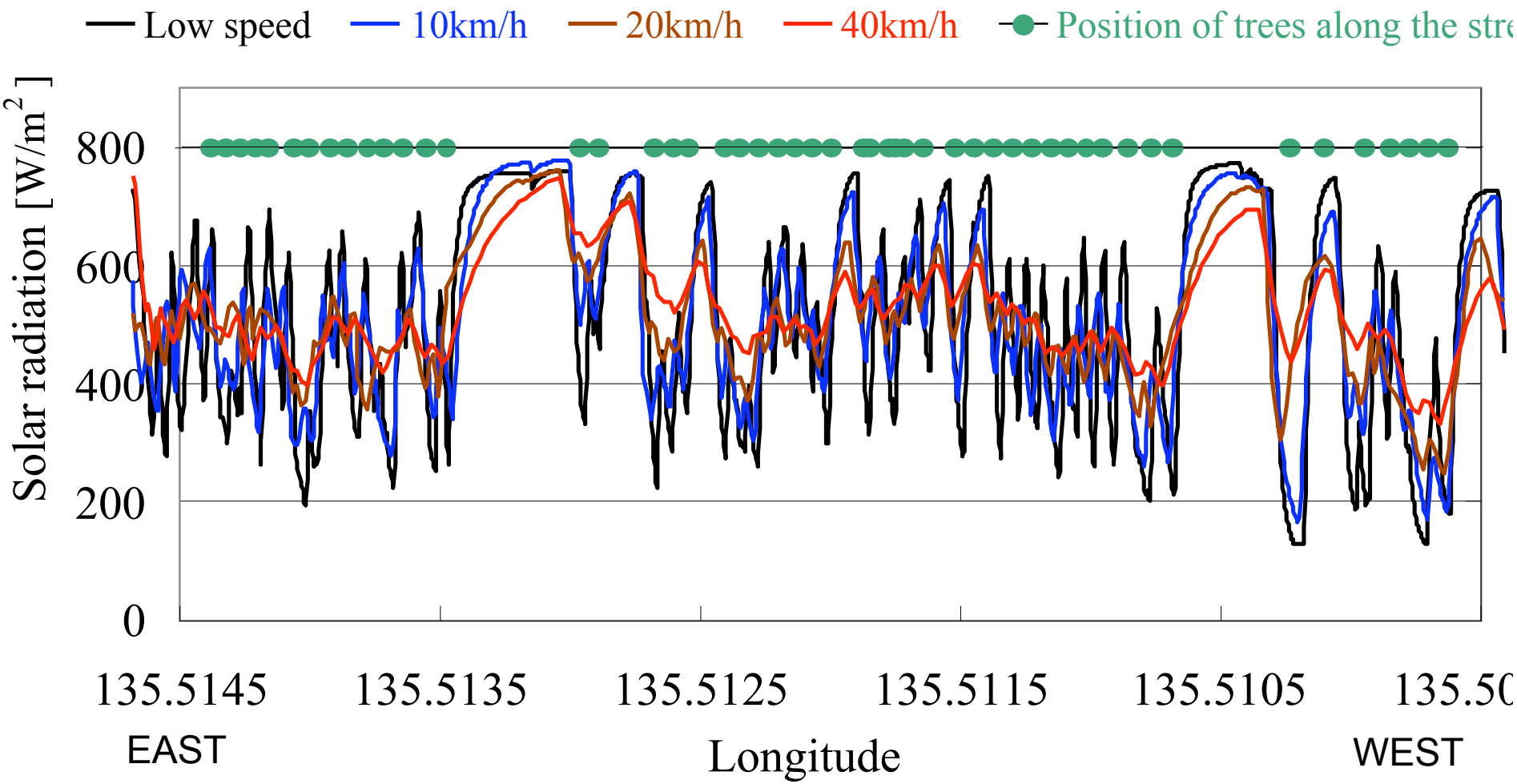
Date: 2005/10/12
Place : Osaka city, Japan
Speed: 5km/h
10km/h
20km/h
40km/h

data sampling interval:0.2 s
1 s

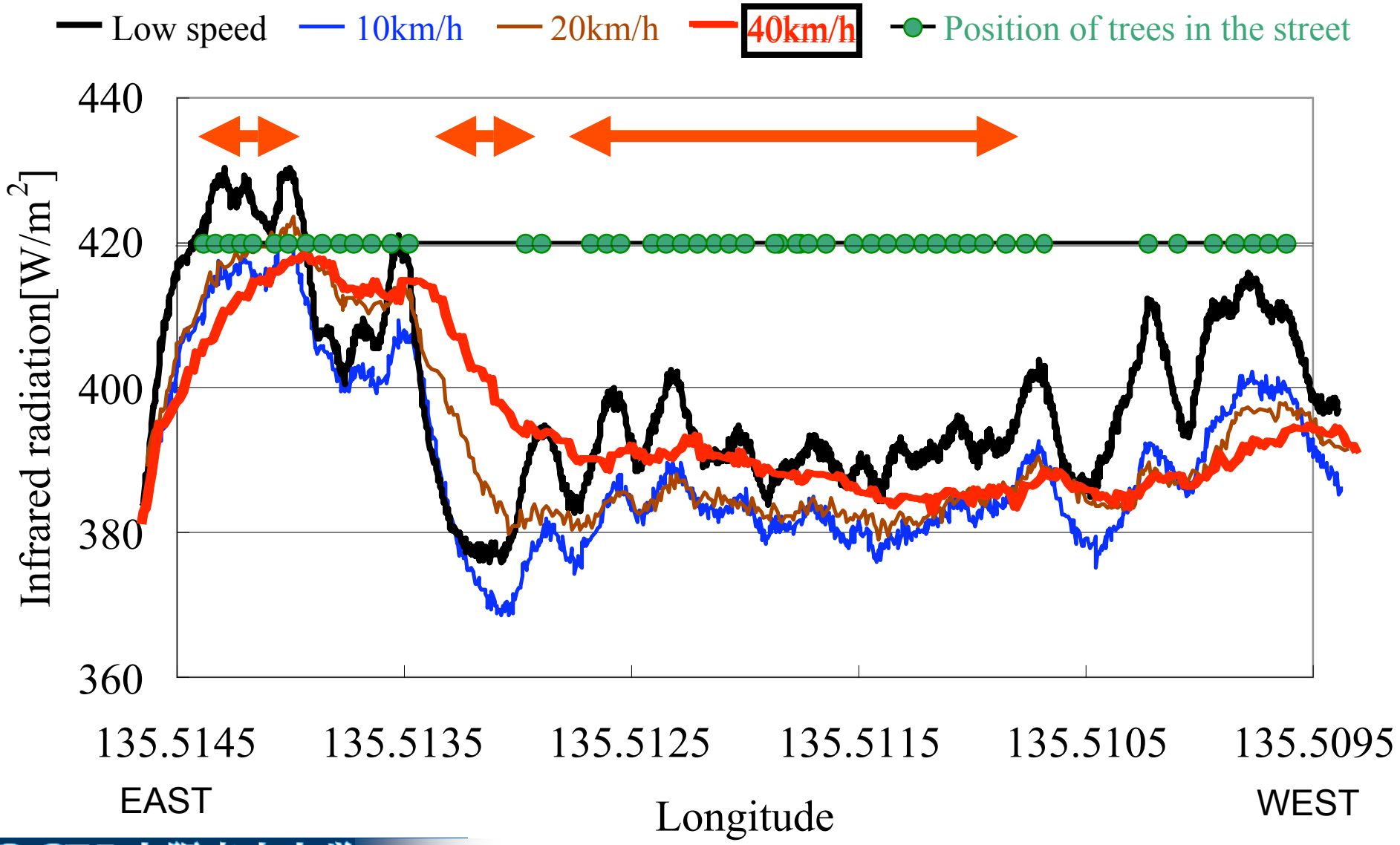




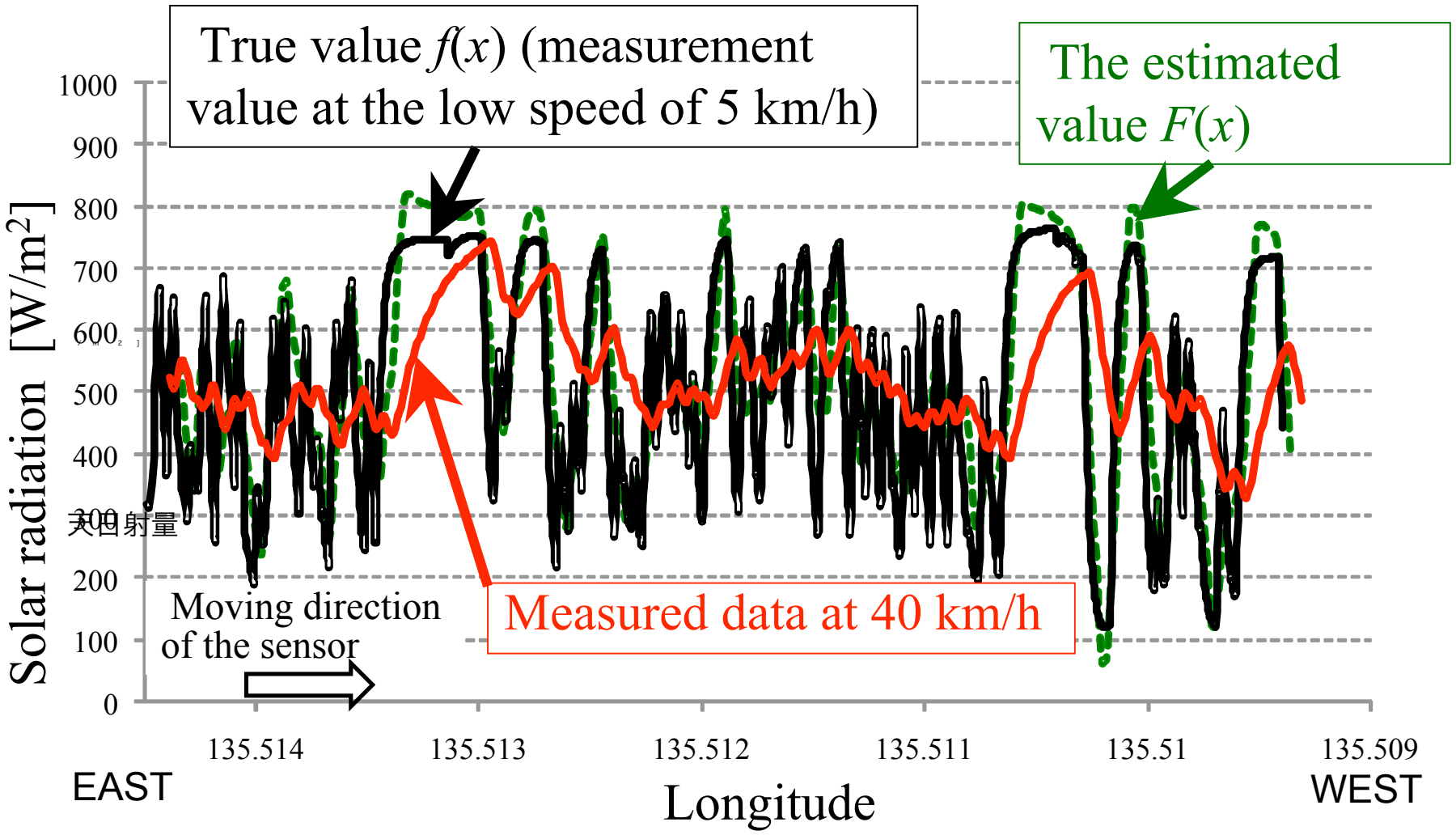
Moving measurement result of the pyranometer



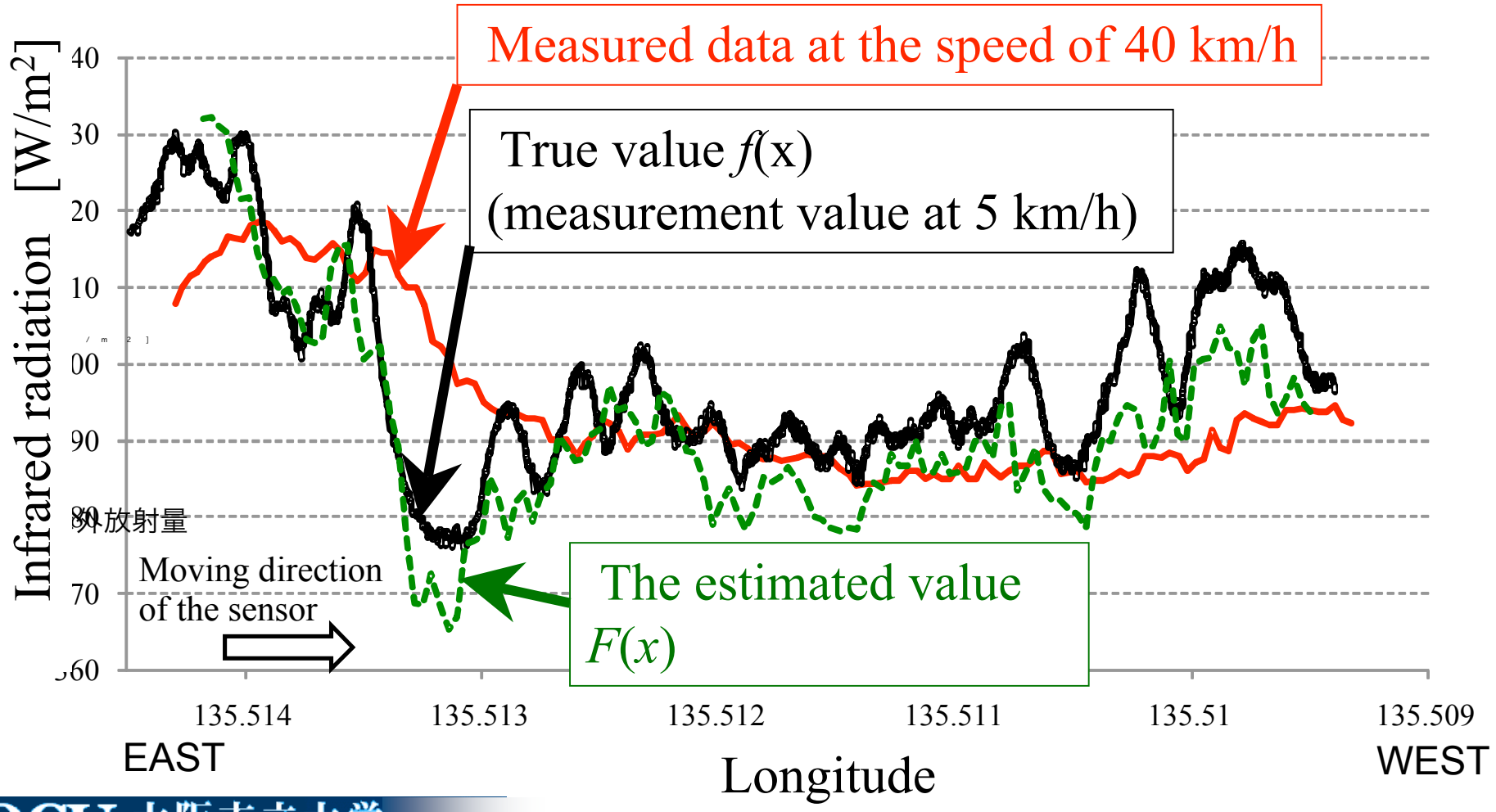
Moving measurement result of the pyrgeometer(IR radiometer)



Comparative result of the moving measurement value, the true value and the estimated value of the pyranometer

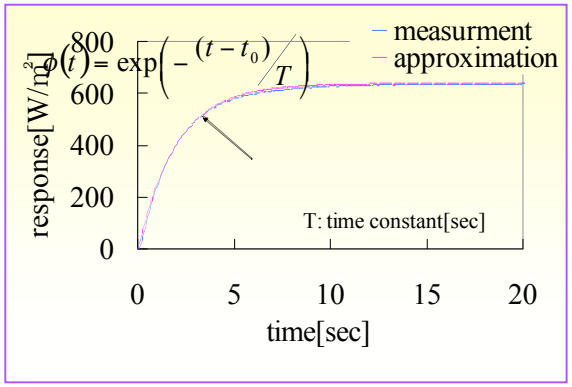


Comparative result of the moving measurement value, the true value and the estimated value of pyrgeometer(IR radiometer)



Conclusion

1. A method to estimate the spatial distribution from data which was obtained by continuously measuring in streets, using sensors which have a response lag and GPS which has a time delay.
2. The measurement error of the pyranometer with a 2.0-second time constant was extremely small.
3. The error was much larger for the pyrgeometer (IR radiometer) with a comparably large 6.7-second time constant.
4. By applying this method, it became obvious that measurement error can be effectively decreased.



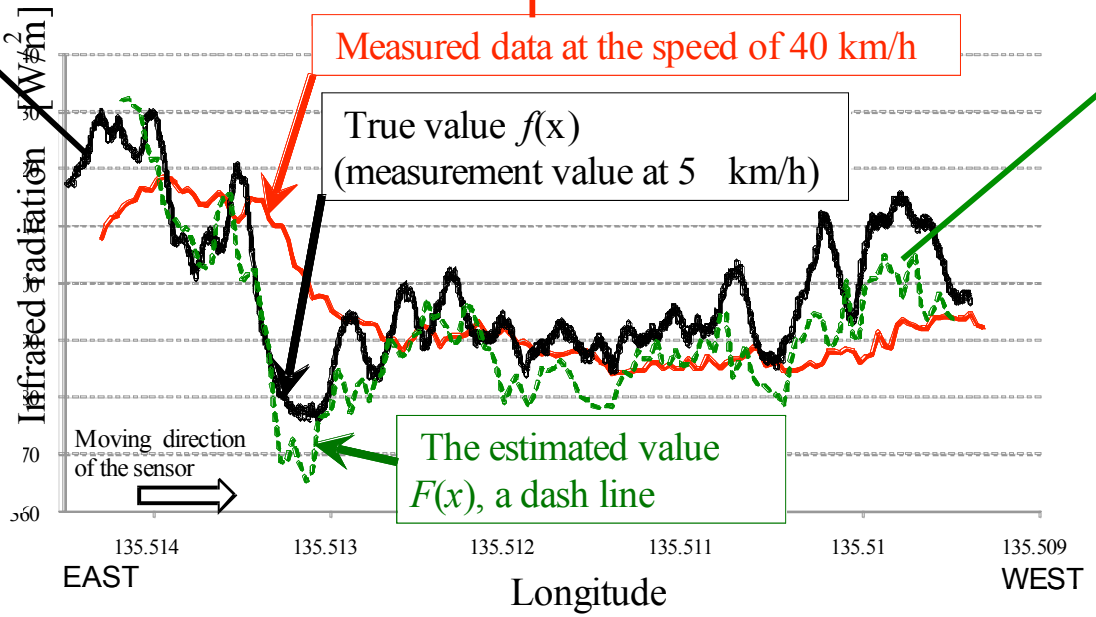
True distribution

Continuous Moving Measurement

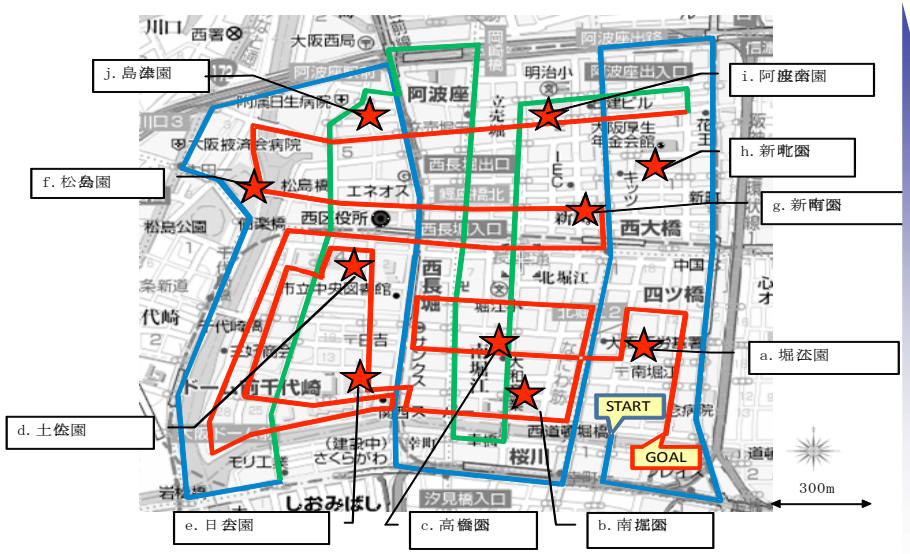
Sensing Data and Location output of GPS

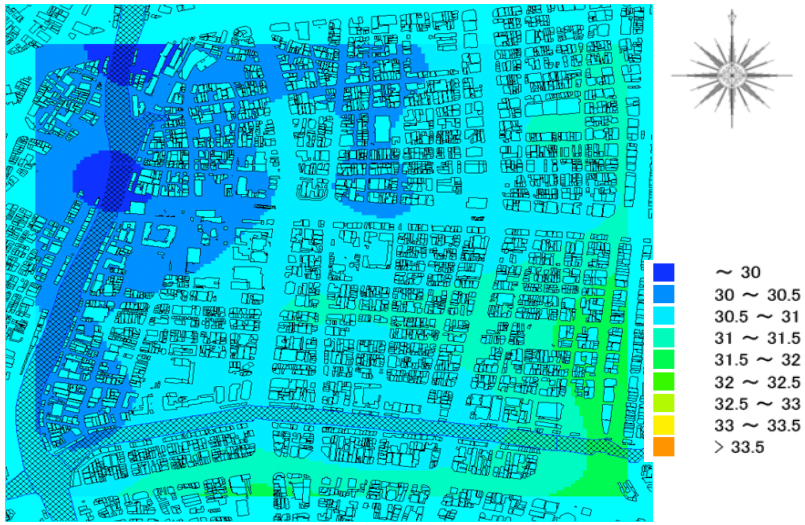
Estimation System

Estimated distribution



Example of continuous moving measurement





※赤☆は定点観測地点、赤・緑・青線は移動観測経路堀江周辺地図

2008年8月2日19時半の気温分布図
（移動観測データ＋定点観測データ）

Measurement plan

Spatial frequency to measure < Cut-off spatial frequency

$$\mu \ [1/\mathrm{m}] < \mu_c = \frac{1}{2\pi TV}$$

Moving velocity V [km/h] $\leq V_0 = \frac{1}{2\pi T \mu}$

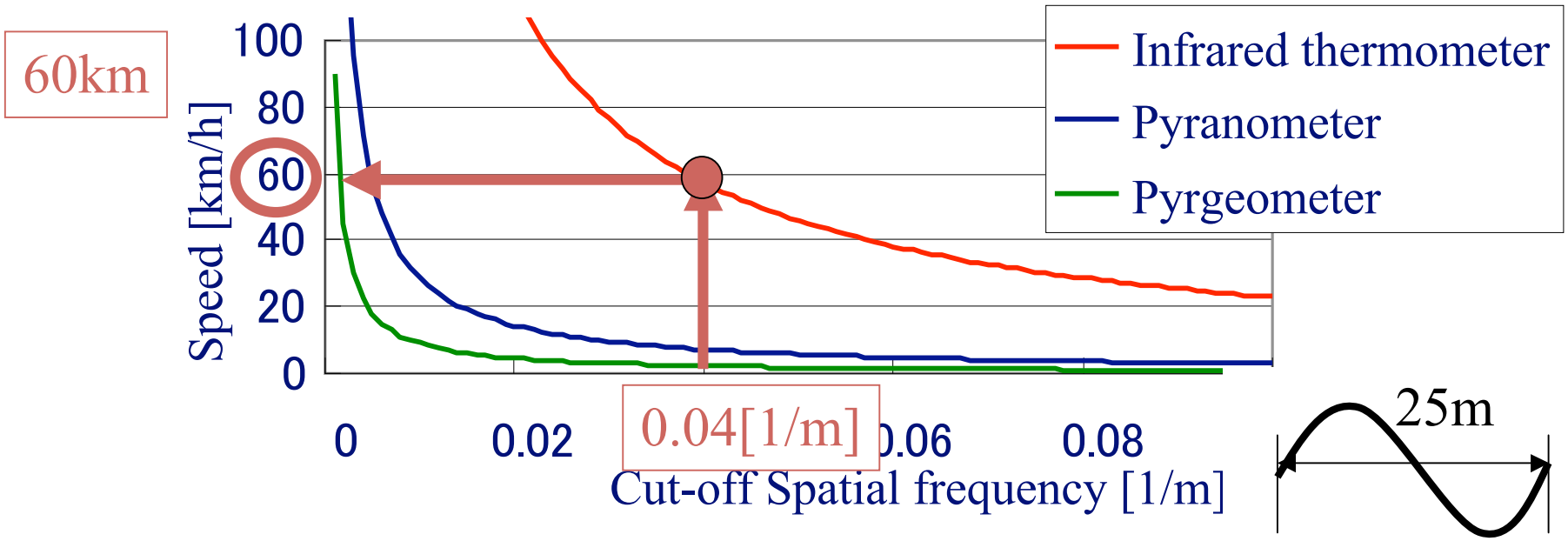
Sampling interval t [s] $\leq t_s = \frac{1}{2\mu V}$

T : Time constant [s]
V : Velocity [m/s]

Measurement Plan

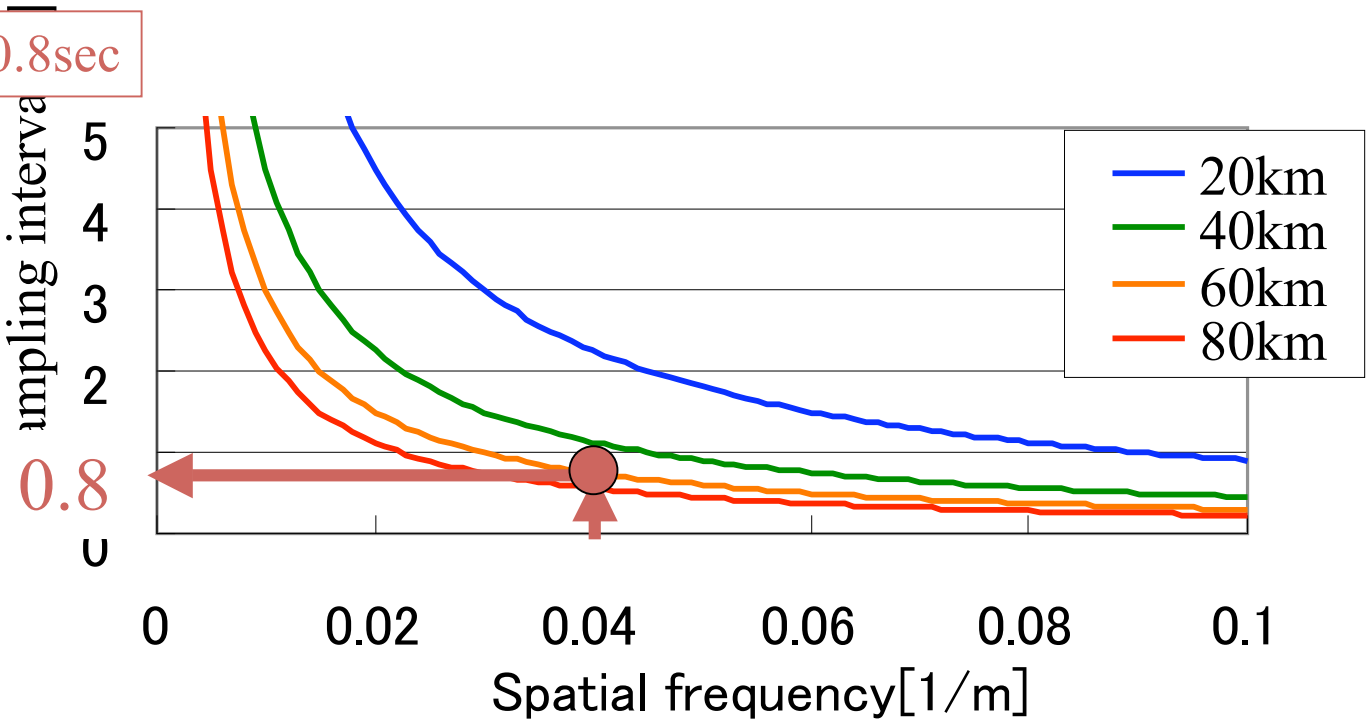
Choice of Speed

Spatial frequency⇒Instrument⇒Speed



Measurement Plan
Sampling interval

Interval＜0.8sec



- 残った誤差の原因は
  - However, the average level of estimated value is different from that of the true value, which seems to be caused by the fact that both measurements were not carried out simultaneously.
- 移動速度が変化した場合に適用できるか.
  - Yes, it can be applied to the variable speed. But the inverse system can not be applied when the vehicle stops.
- 温度計測についてやらなかったのか
  - 温度計測にもこの手法は適用できるが，温度分布は速度を変えて何度か走行すると，大きく変化するので，本手法の検証には温度計測を使用しなかった.
- 温度センサーや放射温度計はこの推定法を適用する必要は無いか.
  - 40km/h程度の速度の場合，センサーの応答が速いので，適用する必要は無いと思う.
  - 観測したいカットオッフ空間周波数による.
- 大気汚染関連のセンサーは時定数が30秒程度とさらに長くなるので，本推定法の効果はさらに大きくなる.