Observation of Spatial and temporal variability of sea skin surface temperature by a Thermal Infrared Camera

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Abstract: The MUBEX (MUtsu Bay sea surface temperature validation EXperiment) campaign has been held from 1995 to 1997 in summer. During the MUBEX campaign, a thermal infrared camera (TIC) installed on a research vessel, which was also equipped with other various observation devices, was intensively used to observe microscopic structure of sea skin surface temperature (SSST) behavior. We have now a total number of 500,000 images observed by the TIC under various weather conditions, i.e., very calm or wavy sea condition, and clear, patchy or cloudy sky condition. In this paper, we show typical SSST patterns observed by the TIC, and describe the result of statistical analysis of SSST.

Devices

TIC:	Thermal Infra-red Camera	JP
VCS:	Video Camera System	JP
THI:	Thermal Infra-red Radiometer(8-12um)	JP
SISTeR:	Scanning Infra-red Surface Temperature Radiometer	RAL
MSSO:	Moving-type Sea Surface Observer	JP
CTD:	Conductivity-Temperature-Depth	UoL
COMPASS:		JP
SR:	Solar Radiometer	JP
M-STA:	Meteorological Station	RAL
JM-STA:	Japan Meteorological Station	JP
GPS:	Global Psitioning System	JP/UoL
YOUNG:		JP
PtT:	Pratinum Temperature	JP

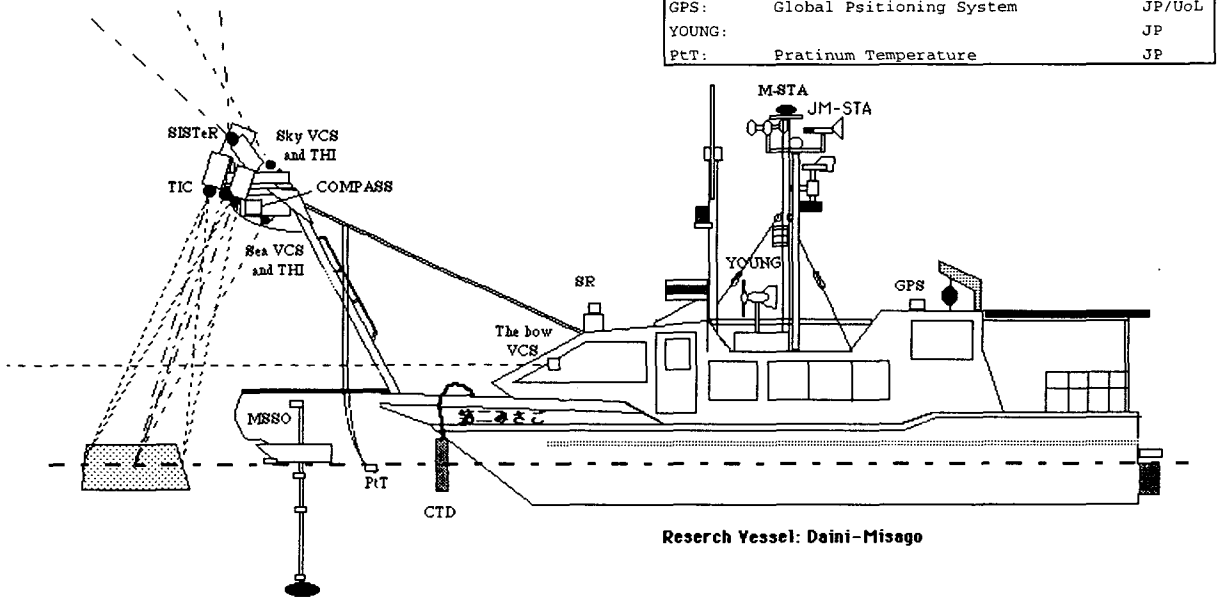

Figure 1 The schematic view of the instrumentation on the research vessel of MUBEX'97.

1. Introduction

MUBEX is a Japan-UK joint research project for validating SSST observed by satellite and investigating into the physical behavior of heat exchange at the ocean surface [1]. During the MUBEX campaign of three years, a special vessel was prepared to collect various data related to air-sea interaction in Mutsu Bay, Japan.

Table 1 Specifications of the TIC
(TH3102 of NEC San-ei)

temperature range	-20~+80 deg.C
temperature resolution	0.075 deg.C
wave length	8~13 micro m
IFOV	1.5 m rad
FOV	(H) 30 deg. x (V) 28.5 deg.
image size	255 pixel x 239 line
scanning time	0.8 sec
scanning mode	Image mode Line mode

Figure 1 shows the vessel and the instruments used in the summer campaign of 1997. On the stage in the bow, a thermal infrared camera (TIC: TH3102 of NEC San-ei) and two video cameras were set. TIC, which was set at 5 m above the sea level, was looking down the sea surface of 2.5 m x 2.5 m and providing SSST image with a pixel resolution of 1 cm. One video camera was to look the same area of TIC, and the other was to look up sky. A digital camera looking sea state ahead was set at the bow. The images collected by those four devices were combined to record into one recorder synchronously. The specifications of TIC are shown in Table 1.

Furthermore, a portable thermal infrared radiometer (THI: THI-500L of Tasco Co.) to measure the sky temperature, a Met-Station for meteorological data collection, and a M-SSO (Moving-type sea surface observer) to measure vertical water temperature profile observation were installed on the vessel.

2. Typical SSST patterns observed by TIC

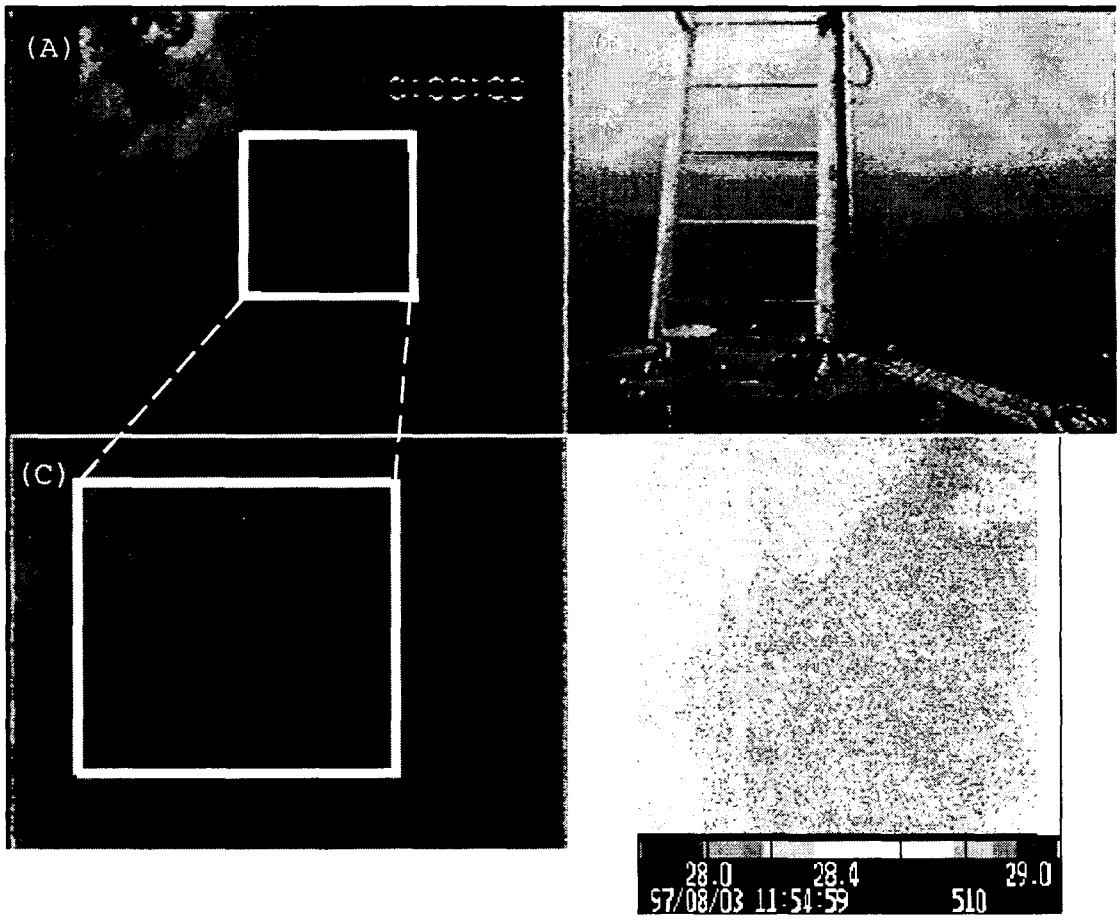

Figure 2 Images by TIC, two video cameras for sky and sea surface, and digital camera.

Table 2 Temperature of sea surface and sky observed and calculated emissivity.

	Sea Surface		Sky		
time	warm	cold	cloud	clear	emis.
11:41:17	28.33	28.05	11.07	-7.26	0.979
11:41:23	28.18	27.97	11.07	-7.26	0.984
11:41:32	28.22	27.90	11.07	-7.26	0.976
11:42:35	28.23	27.92	11.07	-7.26	0.976
11:41:32	28.22	27.90	11.07	-7.26	0.976
11:42:37	28.21	27.90	11.07	-7.26	0.976
11:54:59	28.46	28.04	18.01	-4.01	0.975
Units: [deg. C]				mean=	0.977
emis.: emissivity				s.d.=	0.003
				min.=	0.975
				max.=	0.984

2.1. Emissivity effect.

Figure 2 shows an example of combined four images at 11:54:59 on August 3rd, 1997. Those are (A) sky by video camera, (B) sea state by digital camera, (C) sea surface by video camera, and (D) SSST distribution by TIC. From image (A), the cloud cover was about 70% but the center of the sight was clear. From images (B) and (C), the sea state was very calm. Image (C) is just a reflection of Image (B).

In Image (D), the region reflecting cloud is warmer than the region reflecting clear sky. Table 2 shows SSST of cold and warm regions, and sky temperature of cloud and clear regions by THI at various time on the day. The emissivity of the sea surface calculated by using those is also shown in the table.

2.2. Skin effect

Figure 3 shows the TIC images at 13:37:29, on July 21st. The sky was very clear, but wind speed was 5.8 m/s, and there were whitecaps in the center of the image. Figure 4 shows the vertical temperature profile measured by M-SSO at the same instant. Water temperature was almost homogeneous in the upper 1 m vertically. In TIC image, the region of whitecap is warmer than the region of non-whitecap. The cold region is covered by the skin sea surface, but bulk water is exposed to the surface in the warm region. The temperature difference between the cold and the warm region was evaluated as Table 3 for the data on the day.

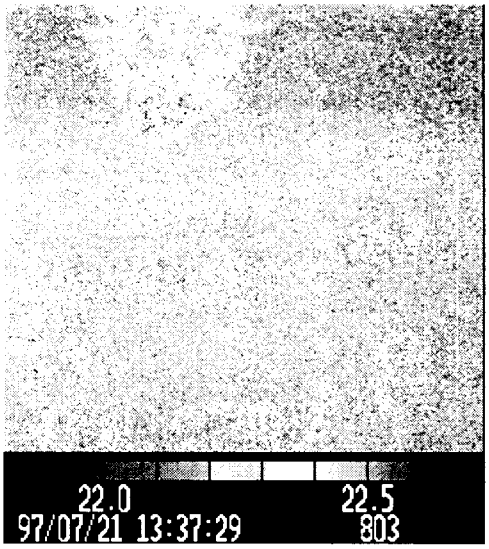

Figure 3 TIC image with whitecaps.

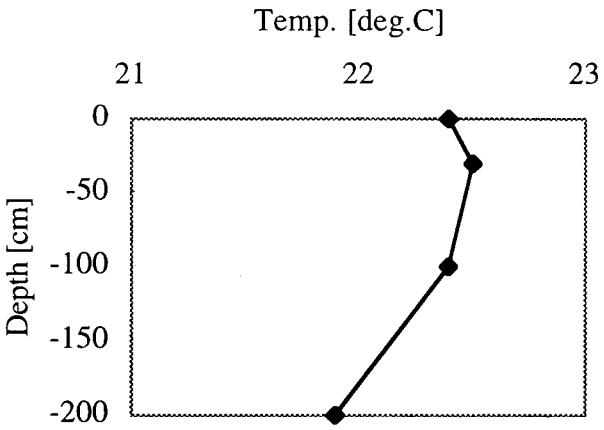

Figure 4 Vertical temperature profile at white caps.

Table 3 Statistic of SST of cold and warm regions.

time	warm area	cold area	temp. diff.
9:40:29	23.471	23.153	0.318
11:11:02	22.549	22.257	0.292
13:06:10	22.246	22.097	0.149
13:22:41	22.349	22.155	0.193
13:37:29	22.434	22.068	0.366
	[deg. C]	mean=	0.264
		s.d.=	0.080
		min.=	0.149
		max.=	0.366

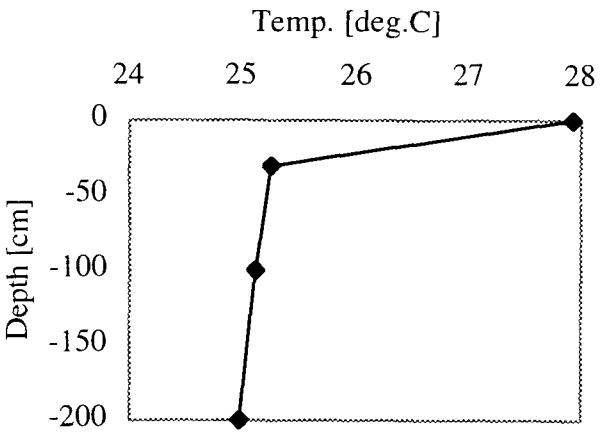

Figure 5 Vertical temperature profile at 10:53:52 on August 3rd

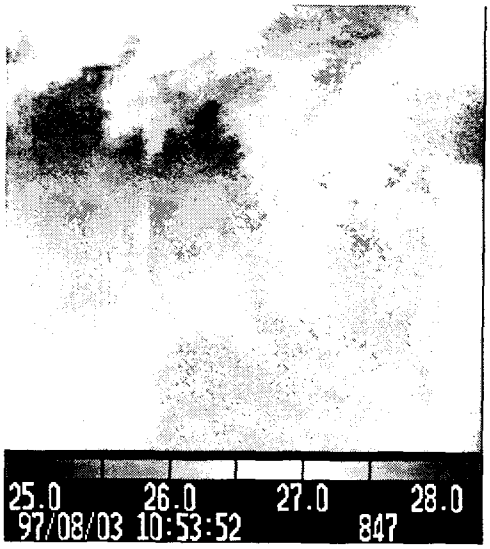

Figure 6 TIC image under sea surface effect.

2.3. Sea surface effect

Figure 5 shows the vertical temperature profile observed by M-SSO at 10:53:52 on August 3rd. The shallower water, the warmer. This is typical under sea surface effect [2]. Figure 6 shows the TIC image at the same instant. SST distribution is mixed with warm and cold regions with rather large temperature difference. As the image was after a motor boat had crossed in front of the vessel, the cold region was caused by deeper water by mixing of the boat.

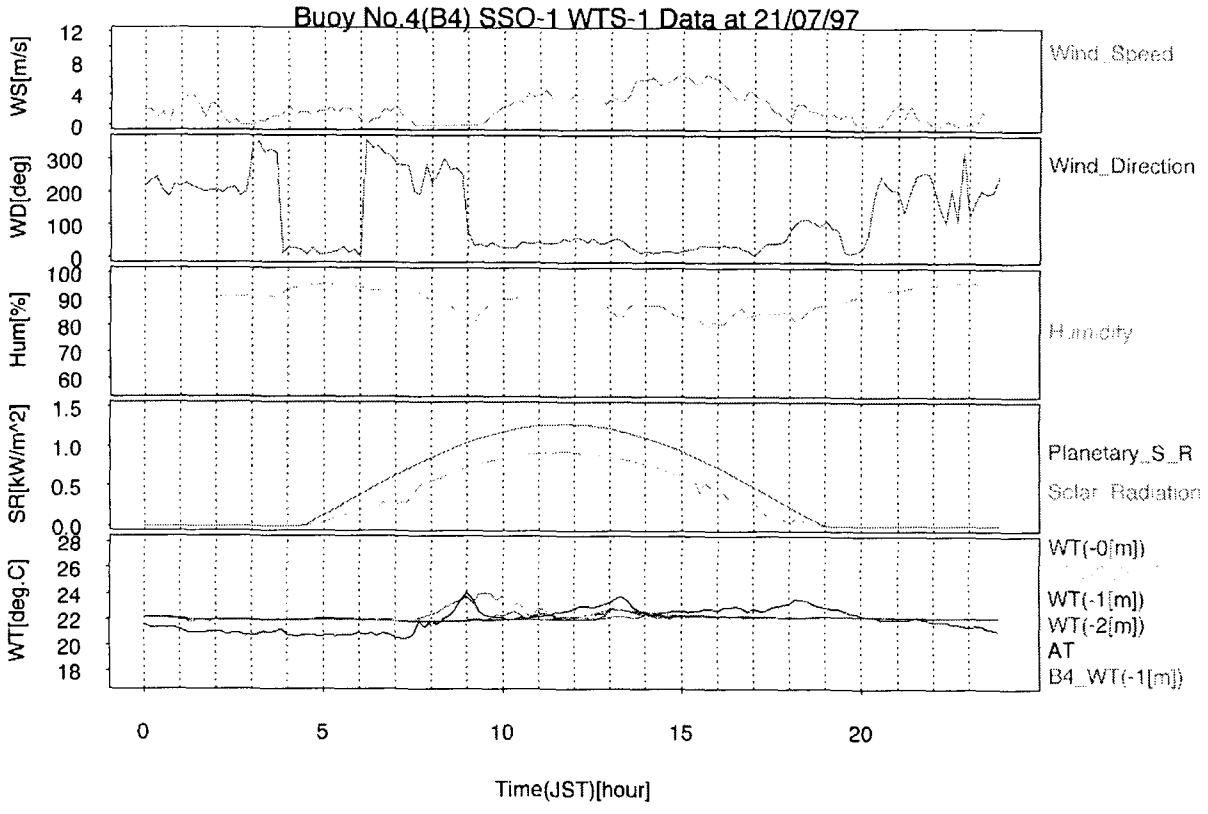

Figure 7 Meteorological record by SSO on No.4 buoy on July 21st, 1997.

Table 4 Group Statistics of SST and Environmental Factors.

Time		# of	Mean of frame SST			s.d. of frame SST			AT	AT-SST	WS
Start	End	samples	mean	s.d.	S.D.	mean	MEAN	s.d.	[deg.C]	[deg.C]	[m/s]
9:39:48	9:54:04	843	22.870	0.205	0.203	0.081	0.039	0.008	24.513	1.643	1.92
9:58:18	10:13:45	900	22.063	0.204	0.202	0.083	0.043	0.014	22.325	0.262	2.73
10:14:15	10:29:24	900	22.433	0.147	0.143	0.080	0.037	0.003	22.498	0.065	3.00
10:30:21	10:45:27	900	21.937	0.050	0.040	0.080	0.036	0.002	22.483	0.546	4.24
10:46:01	11:01:14	900	22.189	0.154	0.151	0.084	0.045	0.004	22.691	0.502	4.62
11:01:38	11:17:01	900	22.254	0.060	0.051	0.086	0.048	0.007	23.071	0.817	4.75
11:17:28	11:32:56	900	22.239	0.112	0.107	0.088	0.052	0.007	23.618	1.378	3.56
11:33:24	11:49:05	930	22.214	0.151	0.148	0.087	0.050	0.011	23.711	1.497	3.43
12:51:04	13:07:11	952	22.179	0.072	0.065	0.082	0.042	0.005	23.516	1.337	3.33
13:08:00	13:23:18	900	22.184	0.042	0.029	0.081	0.039	0.003	23.907	1.723	3.24
13:23:53	13:39:11	903	22.187	0.059	0.051	0.081	0.039	0.003	23.626	1.439	3.51
13:39:35	13:54:48	900	22.012	0.086	0.081	0.080	0.036	0.003	22.765	0.753	5.20
				mean=	0.106	mean=	0.042				
				s.d.=	0.060	s.d.=	0.005				

s.d.: standard deviation

AT: Air Temp.
SST: mean of MEAN SST
WS: Wind Speed

S.D.: s.d. of mean of frame SST corrected by rejection of an instrumental error of TIC
MEAN: mean of standard deviation of frame SST corrected by rejection of an instrumental error of TIC

The maximum temperature difference in the image is about 3 deg.C, and the temperature difference is almost equal to temperature difference between 0 cm and 1 m depth in Figure 5.

3. Statistical analysis

The purposes of this analysis are to estimate spatial and temporal variability of SSST, and to investigate relationship between the variability of SSST and environmental factors.

3.1. Used data

Figure 7 shows the meteorological record by SSO (sea surface observer)[1] on Mutsu Bay buoy of No. 4 on July 21st, 1997. It was clear sky in the daytime. For statistical analysis, we used TIC data observed on the day. The vessel moved slowly around No. 4 buoy, and TIC was operated under image scanning mode with one second interval. The data collection started at 9:00 and ended at 14:00.

3.2. Flow of data processing

First, for each TIC image, the mean and the standard deviation of the total 255 x 239 pixels were calculated. Second, the total image data set was divided into twelve groups within 15 minutes of time elapse. As the vessel speed was kept about 2.0 km/h, each group includes SSST images of 0.5 km distance along the vessel trace. Then, for each group, the standard deviation of mean of frame SSST and the mean of standard deviation of frame SSST was calculated. Table 4 shows the group statistics of SSST and environmental factors.

3.3. Spatial and temporal variability.

In the calibration of TIC before the campaign, the standard deviation of mean of frame SSST was evaluated to be 0.031 deg.C, and the mean of standard deviation of frame SSST was evaluated to be 0.071 deg.C [3]. These values show instrumental errors of TIC, and the former means an absolute error, and the latter means a relative error.

In Table 4, the standard deviation of mean of frame SSST and the mean of standard deviation of frame SSST include those instrumental errors, so that we corrected these values based on absolute and relative error of TIC. In the table, "S.D." means standard deviation of mean of frame SSST corrected, and "MEAN" means mean of standard deviation of frame SSST corrected.

Spatial variability of SSST is shown by mean of S.D., and temporal variability of SSST is shown by mean of MEAN. From the table, we can estimate that spatial variability in 0.5 km distance is 0.11+/-0.06 deg.C, and temporal variability in 15 minutes is 0.04+/-0.01 deg.C.

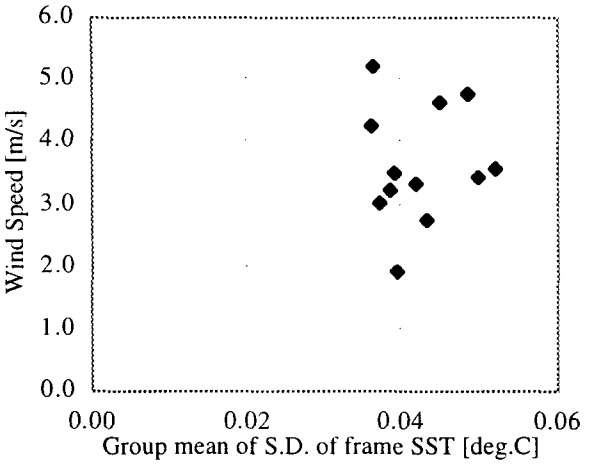

Figure 8 Scatter diagrams of group mean of S.D. of frame SST versus Wind Speed.

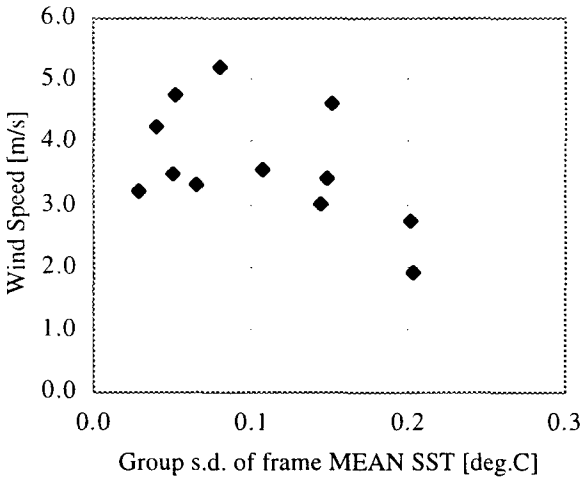

Figure 9 Scatter diagrams of group standard deviation of MEAN of frame SST versus Wind Speed.

3.4. Relationship between variability of SSST and environmental factors.

The group statistics were plotted with respect to environmental factors such as (1) air temperature, (2) difference between SSST and air temperature, and (3) wind speed.

The group mean of S.D. of frame SSST has narrow dynamic range, and we cannot find any relationship between the group mean of S.D. of frame SSST and the environmental factors. This result shows a stability of SSST in small scale under natural condition. Figure 8 is an example of scatter diagram of group mean of S.D. of frame SSST versus wind speed as one of environmental factors.

We found that the group standard deviation of mean of frame SSST related with wind speed as shown in Figure 9. Strong wind makes sea wave, and the wave mixes sea surface water. The result shows that the wind not only mixes sea water vertically but also mixes horizontally.

4. Conclusion

Various aspects of SSST distribution observed by a thermal infrared camera were shown, and spatial and temporal variability of SSST were estimated. The amount of SSST variation in relation with environmental factors should be evaluated for future investigation of air-sea interaction. The data volume collected during all MUBEX campaign is so huge, but the analysis is undertaking intensively.

Acknowledgments

The MUBEX is supported by the grants from National Space Development Agency of Japan, Japanese Scientific Promotion Society, The Royal Society, U.K., National Environmental Research Council, U.K. We want to show sincere appreciation to those organizations.

References

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[2] Yokoyama, R., Tanba, S., and Souma, T., "Sea surface effects on the sea surface temperature estimation by remote sensing," Int. J. Remote Sens., vol. 16, 227-238, 1995.

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