Academic Article

Estimation of sea breeze fronts using satellite imagery

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ABSTRACT

Sea breezes can mitigate the effects of heat islands in Japan, where most big cities are located in coastal areas. It is important to know the locatiom of the sea breeze front in order to define the regions affected by sea breezes. Although this locatiom can be simulated, in this study we examined the use of satellite imagery to define the sea breeze front through its relationship to cumulus cloud cover. Particularly in the summer season, it is possible to easily estimate the location of the sea breeze front by visual observation of satellite imagery.

Key Words : Urban heat island, Sea breeze front, Satellite imagery, Cumulus clouds

１. Introduction

In Japan where many major cities are located in coastal areas, sea breezes can act as countermeasures against the heat island effect. Regarding the effect of sea breeze, there are studies that reported on the effect of sea breeze by actually measuring for Hiroshima City and Nagoya City and studies on the effect of wind on the river from invasion of the sea breeze front[1,2,3]. There are also studies on the effect of high temperature mitigation when sea breezes are planarly captured in Sendai and Hiroshima[4,5]. In order to obtain such a temperature mitigation effect of the sea breeze, it is important to define areas where this can happen. On the other hand, There are studies that clarified the cause of the occurrence of a row of cumulus clouds (circle Yakumo) appearing above the Tokyo Route 8 Route using observation and simulation[6,7]. There are also studies on the relationship between the local wind and movement of cloud for Shikoku and considering movement of cloud involving local winds such as valley winds and sea breeze[8]. These studies suggest that there is a possibility to estimate the locatiom of the sea front fronts from the distribution of cumulus clouds; in this study we investigate a method for more easily estimating the locatiom of sea breezes using the satellite-derived distribution of cumulus clouds, and examine the frequency of cumulus clouds distributions that can estimate the locatiom of sea breezes.

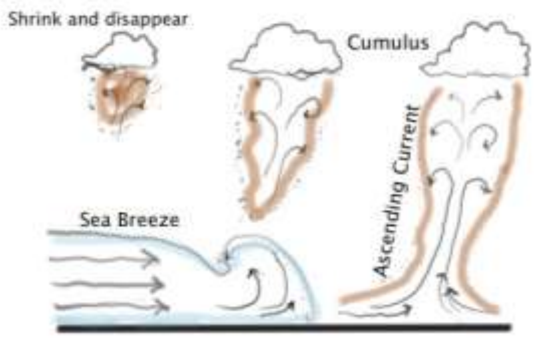

Fig.1, The relationship between sea breeze, updrafts, and cumulus clouds.

２. Comparison of satellite images and observed wind speed and direction

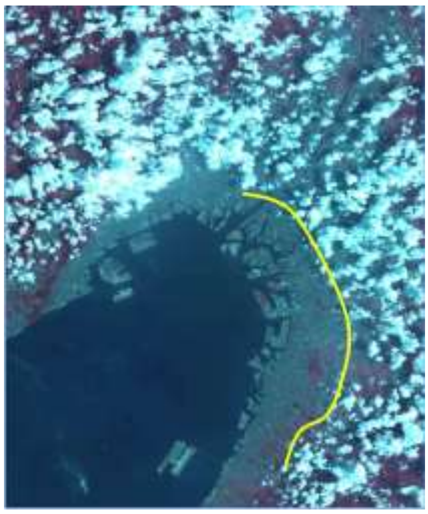

Fig.2, Satellite imagary showing the sea breeze front defined by a cloud-free belt along the coast.

The circulation of sea breezes is caused by the difference in surface temperature between the sea and land. Updrafts are generated over land where the temperature becomes higher in daytime. Generally, when these moisture-containing updrafts reache a certain height, water vapor condenses to form cumulus clouds. In areas affected by a sea breeze, such updrafts are weakened, and cumulus clouds often disappear (Fig. 1).

For example, in AVNIR-2 imagery from the ALOS satellite (taken at 11:03 on August 13, 2006) a belt-like area without cumulus clouds is clearly visible along the coastline (Fig. 2). In this study, we assumed that this pattern is a result of the sea breeze, and thus that the boundary between the clear and cloudy areas can be considered the sea breeze front.

2.1 Methods

We chose the Osaka Plain for this analysis and compared the cumulus cloud line derived from satellite imagery with the locatiom of the sea breeze front obtained from observational data for wind speed and direction. The locatiom of the sea breeze front can be simulated using various methods with these data; we used data which easily obtained the sea breeze front at the shooting date and time of the satellite image. These data were collected from 6 locations of the Japan Meteorological Agency's Automated Meteorological Data Acquisition System (AMeDAS) and 60 locations of the Osaka Atmosphere Observatory. Identification of the locatiom of the sea breeze front using observation data is confirms the wind direction of the observation point in order from the sea side to the inland side, and assumption there are sea breeze until the observation point on the inland side of the observation point where the westward wind is continuous, and the line connecting the observation points was taken as the sea breeze front. We also used satellite images observed by the MODIS sensor on the Earth Observation Satellites Aqua and Terra (specifications shown in Table 1). With two satellites, two to three daytime images can be obtained almost daily. It is assumed that the sea breeze has entered until the cumulus cloud located on the sea side, and the line connecting the cumulus clouds was taken as the sea breeze front.

2.2 Results

We superimposed wind speed and direction onto the satellite images as shown in Figs. 3-8.

In Fig. 3, the wind speed is weakest in the eastern and northeastern areas. The wind direction is also disturbed: no sea

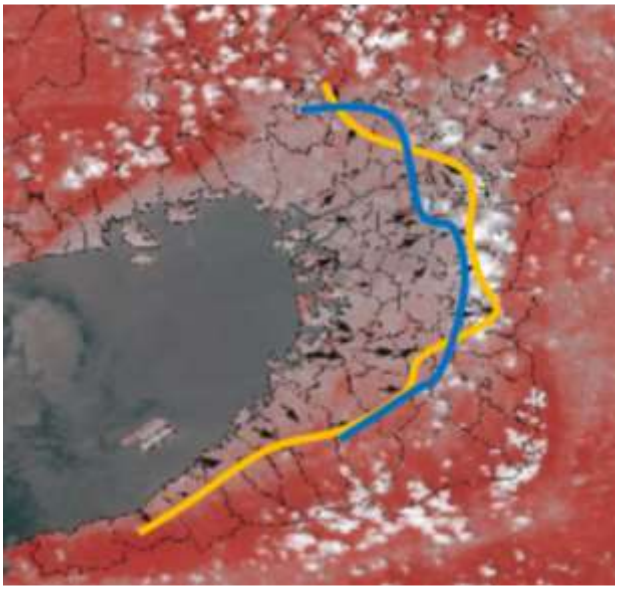

Fig.3, Sea breeze front from meteorological data (Yellow Line) and cumulus cloud line (Blue Line), 2006/08/04 13:00

Fig.4, Sea breeze front from meteorological data (Yellow Line) and cumulus cloud line (Blue Line), 2006/08/05 10:00

Table 1, The main specifications of each satellite

Satellite	Terra	Aqua
Launch date	1999/Dec/18	2002/May/4
Orbit	Solar synchronous semi-regressive orbit	Solar synchronous semi-regressive orbit
Time of passage	10:30 (satellite traveling direction: north to south)	13:30 (Satellite traveling direction: South to North)
Altitude (km)	705	705
Tilt angle (degree)	98	98
Regression days (days)	16 (233 laps)	16 (233 laps)
Period (min)	99	99
Observation equipment	MODIS,ASTER,CERES,MISR,MOPITT	MODIS,AIRS,AMSR-E,AMSU,CERES,HSB

breeze is entering but in other areas the sea breeze is in the end of the Osaka Plain. In this case, the sea breeze front appears to be located behind about 2-3 km (Max. 5-6 km in central north) the cumulus cloud line, but there is agreement in the general pattern.

In Fig. 4, the sea breeze cannot be seen other than outside the southern part of the coastal area. The cumulus clouds are distributed in the southeastern part of the Osaka Plain. In this case, it seems that the sea breeze front is located behind about 2-3 km the cumulus cloud line in the southern part of the Osaka Plain, but they roughly conform.

In Fig. 5, the sea breeze is entering the southern part of the Osaka Plain. The wind direction is disturbed in the northwest and the entry of the sea breeze cannot be confirmed, but in the northeast a westerly wind is blowing and the sea breeze is entering. We interpret this pattern to be influenced by the sea breeze running up the river. The sea breeze front is located behind about 2-5 km the cumulus cloud line in the south, but they generally agree. In the northeast the cumulus clouds are gone, but we cannot judge whether the sea breeze is entering. Using the cumulus distribution alone, it is difficult to capture the projecting sea breeze front running up the river, although it is shown by observational data. The distance between sea breeze front from meteorological data and cumulus cloud line is more

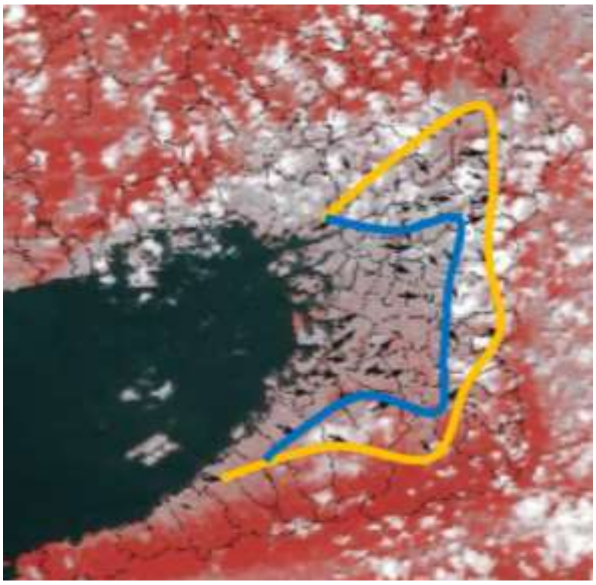

Fig.5, Sea breeze front from meteorological data (Yellow Line) and cumulus cloud line (Blue Line), 2006/08/09 13:00

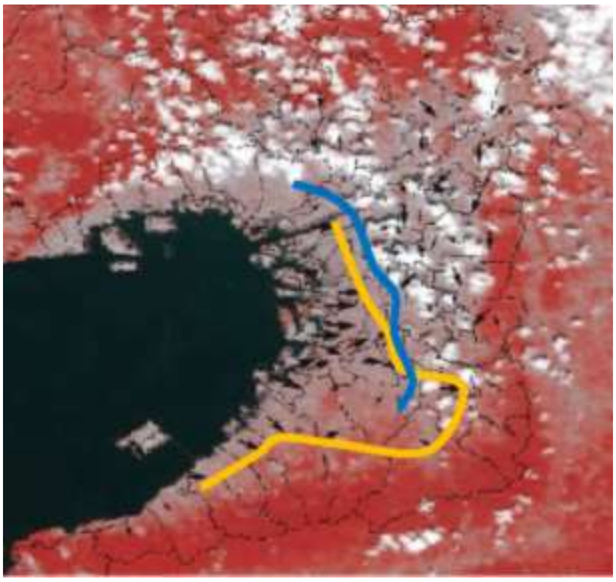

Fig.6, Sea breeze front from meteorological data (Yellow Line) and cumulus cloud line (Blue Line), 2006/08/25 13:00

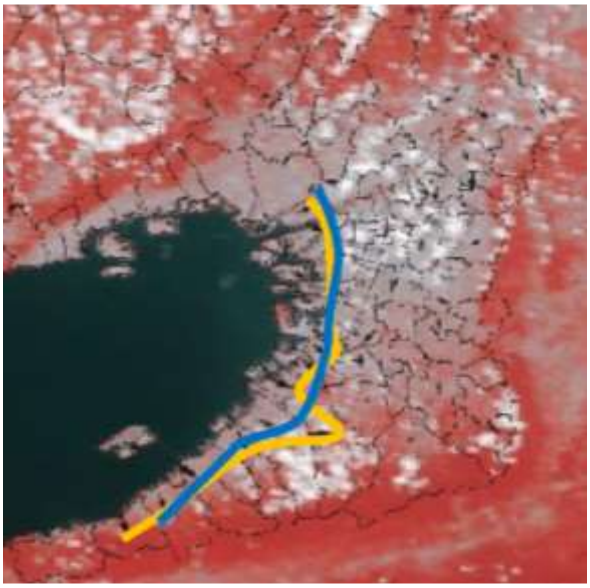

Fig.7, Sea breeze front from meteorological data (Yellow Line) and cumulus cloud line (Blue Line), 2008/08/12 10:00

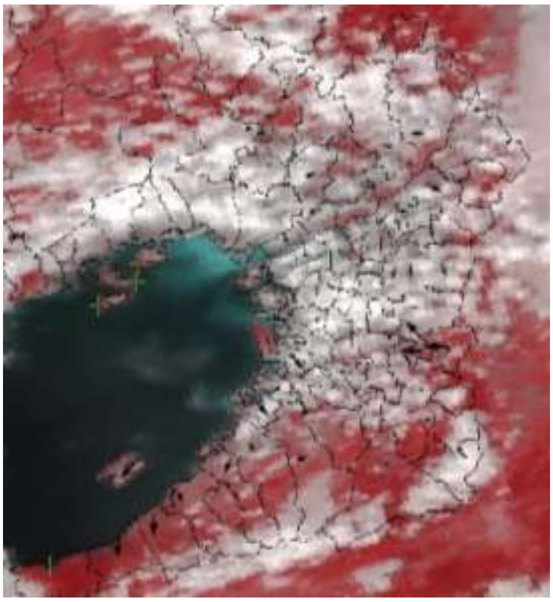

Fig.8, Sea breeze front from meteorological data (No Line) and cumulus cloud line (No Line), 2009/08/02 12:00

than 10 km away.

In Fig. 6, the sea breeze has entered the coastal area of the Osaka Plain, but the wind direction is disordered in the eastern part, so the sea breeze has not penetrated deeply. The sea breeze does reach further into the southern part. The cumulus clouds are mostly distributed in the northern and eastern parts of the Osaka Plain. In this case, it seems that the sea breeze front is located behind about 2-3 km the cumulus cloud line, but they generally agree.

In Fig. 7,the sea breeze has entered the coastal area of the Osaka Plain, but the wind direction is disturbed in most other areas, so the sea breeze has not penetrated further. The cumulus clouds are distributed throughout the non-coastal areas. The sea breeze front and the cumulus cloud line generally agree.

In Fig. 8, the wind direction is disturbed in most areas of the Osaka Plain, and the sea breeze is not entering. The cumulus clouds are distributed in most areas from the coast to deep inland. Both data sets show no sea breeze at this time.

2.3 Considerations

In most of these images, the cumulus cloud line and the sea breeze front generally agree, with a tendency for the latter to be located somewhat behind the former (The distances are about 2-3 km). As the air warmed on the ground surface forms updrafts, it is cooled at higher elevations and becomes cumulus clouds. While the updraft exists, cumulus clouds gradually grow, but when the updraft is weakened by the sea breeze entering, it gradually dissipates and finally disappears. Since there is a time lag between the entrance of the sea breeze enters and the disappearance of the cumulus clouds, the sea breeze front is located somewhat behind the cumulus cloud line.

３. Frequency of cumulus cloud line occurrence

In order to confirm the frequency of the cumulus cloud line's occurrence, we studied this visually from 2006 to 2009 (48 months); the frequency of occurrence for each month is shown in Table 2. A cumulus cloud line could be confirmed in 399 of 2884 images, at a rate of about 13.8%. Gray highlights indicate months in which the cumulus cloud line occured in more than 20% of that month. The highest frequencies of occurrence were found in the summer: 24.2% in July and 31.5% in August. On the other hand, the frequency of cumulus cloud line occurrence was lowest in winter: 8.9% in January and 4.5% in December. The frequency of cumulus cloud line occurrence in 2009 was lower than in the other three years. This confirms a tendency for the cumulus cloud line to be better-confirmed in the summer and less-well confirmed in the winter. It is thought that the summer season is due to the strong updraft and high humidity the easy cumulus appearance.

４. Conclusions

We proposed and investigated a method to estimate the relationship between the sea breeze (determined by observational data) and the cumulus cloud line (obtained from satellite imagery). In general, the sea breeze front was located somewhat behind the cumulus cloud line, but they generally

Table 2, Frequency of cumulus cloud line occurrence per month

	2006			2007			2008			2009			2010		
	○	×	Total	○	×	Total	○	×	Total	○	×	Total	○	×	Total
Jan.	6	56	62	10	52	62	4	58	62	2	58	60	22	224	246
			9.7%			16.1%			6.5%			3.3%			8.9%
Feb.	9	47	56	3	53	56	10	48	58	4	52	56	26	200	226
			16.1%			5.4%			17.2%			7.1%			11.5%
Mar.	11	51	62	6	56	62	10	52	62	6	51	57	33	210	243
			17.7%			9.7%			16.1%			10.5%			13.6%
Apr.	4	56	60	8	52	60	6	54	60	1	59	60	19	221	240
			6.7%			13.3%			10.0%			1.7%			7.9%
May	9	53	62	5	57	62	8	54	60	3	59	62	25	223	248
			14.5%			8.1%			13.3%			4.8%			10.1%
Jun.	12	48	60	17	43	60	3	45	48	7	53	60	39	189	228
			20.0%			28.3%			6.3%			11.7%			17.1%
Jul.	14	48	62	9	53	62	31	31	62	6	56	62	60	188	248
			22.6%			14.5%			50.0%			9.7%			24.2%
Aug.	24	38	62	25	24	49	18	44	62	7	55	62	74	161	235
			38.7%			51.0%			29.0%			11.3%			31.5%
Sep.	10	50	60	15	45	60	11	49	60	8	52	60	44	196	240
			16.7%			25.0%			18.3%			13.3%			18.3%
Oct.	10	52	62	3	59	62	6	56	62	9	53	62	28	220	248
			16.1%			4.8%			9.7%			14.5%			11.3%
Nov.	8	52	60	4	56	60	2	57	59	4	55	59	18	220	238
			13.3%			6.7%			3.4%			6.8%			7.6%
Dec.	6	56	62	3	59	62	2	57	59	0	61	61	11	233	244
			9.7%			4.8%			3.4%			0.0%			4.5%
Total	123	607	730	108	609	717	111	605	716	57	664	721	399	2485	2884
			16.8%			15.1%			15.5%			7.9%			13.8%

○ Yes cumulus cloud line

× No cumulus cloud line

agreed in location. Thus it is possible to easily estimate the location of the sea breeze front by visual observation of satellite imagery.

In addition, we studied satellite images from 2006 to 2009 and documented a tendency for the cumulus cloud line to be comparatively well-confirmed in the summer and less-well confirmed in the winter. Our methods will be of most use for estimating the location of the sea breeze front in the summer season. Observation point networks such as AMeDAS can not necessarily ensure sufficient spatial distribution, but this method is possible to complement grasp more detailed spatial distribution.

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