RESEARCH ON EFFECT OF URBAN THERMAL MITIGATION BY HEAT CIRCULATION THROUGH TOKYO BAY

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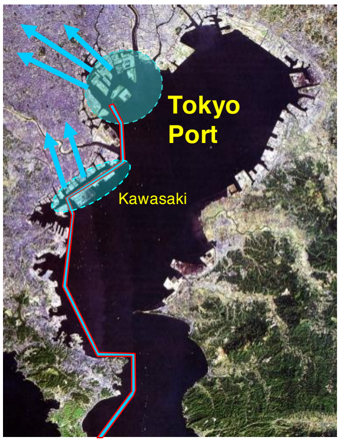
Abstract

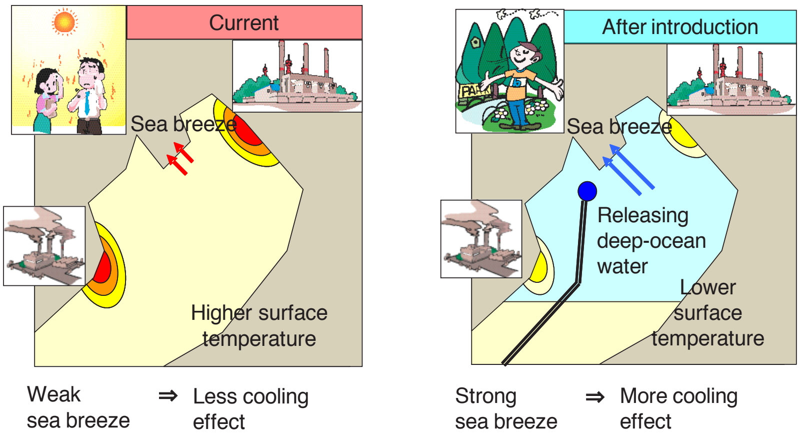
Tokyo Bay can develop high sea surface temperatures in response to high daily levels of anthropogenic heat discharge. To decrease the bay surface temperatures and thus to enhance the cooling effect of the sea breezes, we need to bring deep-ocean water (from 300 m below the surface) to the surface. The authors demonstrated (1) a mechanism of heat exchange between the bay surface and the atmosphere; (2) a mechanism for keeping the bay surface cool after introduction of the deep-ocean water; and (3) the advantage over with already well known counteractions like rooftop vegetation and water retentive pavement.

Key words: Tokyo Bay, deep-ocean water, sea breeze

1. INTRODUCTION

The Japanese Ministry of the Environment recently has clarified that only 1 deg. C drop in the temperature during daytime in central Tokyo might be achieved by the following implementations conducted in all 23 wards in Tokyo: 1) the anthropogenic heat from office buildings (50 %) and traffic (20 %) can be reduced; 2) replacement of 50 % of asphalt-paved surfaces with permeable paving surfaces can reduce the heat; and 3) greenery planted on 50 % of rooftops of buildings can reduce the heat (MoE, 2001). To mitigate urban thermal conditions, we have formulated a new strategy that effectively uses the sea breezes flowing into the Tokyo Metropolitan Area from Tokyo Bay with efficiency, when the temperature goes above 30 deg. C on a typical summer day. Tokyo Bay can develop high sea surface temperatures in response to daily high levels of anthropogenic heat discharge. If cool breezes would flow into the Tokyo Metropolitan Area from Tokyo Bay on a typical summer day, then it would be possible to mitigate the urban heat islands more beneficially (Fig. 1). Therefore, to decrease the bay surface temperatures and thus to enhance the cooling effect of the sea breezes, we need to bring deep-ocean water from about 300 m to the surface (Fig. 2; Fig. 3).





(left one) Fig. 1 Tokyo Bay and expected directions of sea breeze from the Pacific Ocean
(right two) Fig. 2 Concept of mitigation on urban thermal pollution by introducing deep-ocean water from the Pacific Ocean to Tokyo Bay

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2. DELIVERING DEEP-OCEAN WATER TO TOKYO BAY

Figure 3 shows five ways to bring deep-ocean water to the surface of Tokyo Bay. The simplest plan is to use direct splashing (Fig.3, "Direct splashing"). However, ordinary deep-ocean water is nutrients-rich and thus this plan might pose a risk of water pollution. The next plan, called "Radiator", has floating pipelines for returning water to avoid the risk of water pollution. However, it needs to double cost of "Direct splashing" plan. Direct use of the transported water at hot land spots in Tokyo is another plan that we call "For warm discharge". In this case, we need some comparisons with case of using ground water as cooling energy source but it does not aim to decrease the bay surface temperature.

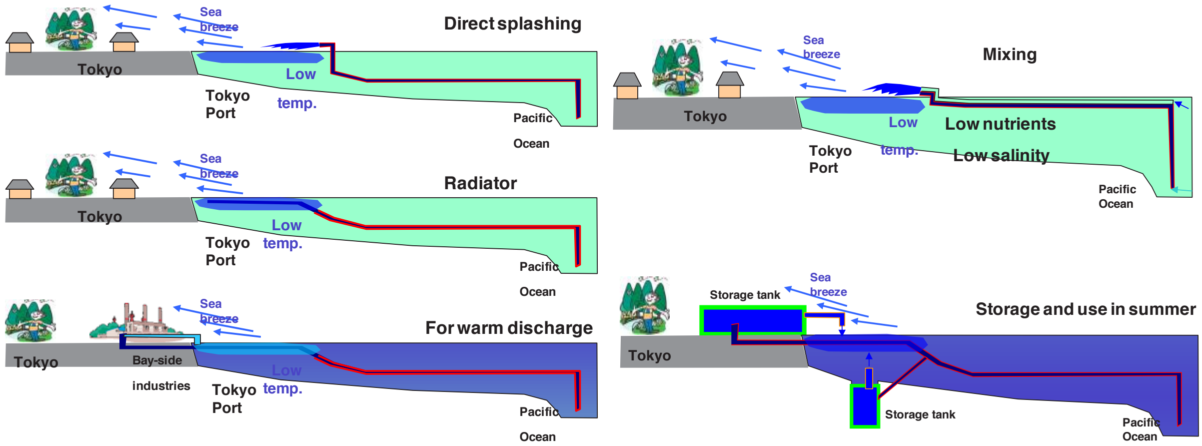


Fig. 3 Five systems expected: Introduction of deep-ocean water to Tokyo Bay

The authors performed interviews with several national experts in relevant disciplines. Most of the experts pointed out the fact that water quality control before releasing deep-ocean water into bay is necessary, especially in summer season, when the water is nutrients-poor. On the other hand, water in Tokyo Bay actually shows higher concentration of nutrients than deep-ocean water. In case of Tokyo Bay, releasing deep-ocean water into bay might not cause a large negative impact to the water quality (Table 1).

Table 1 Comparison of water qualities: Outer-ocean and Tokyo Bay

Obs. points	Water temp. (deg. C)	DO (mg/l)	COD (ppm)	$N\text{-}NH_4^+$ (mg/l)	$P\text{-}PO_4^{3-}$ (mg/l)
Surface, Nagai-oki Yokosuka *1	27.5	4.7	1.6	0.003	0.0001
- 300m, Nagai-oki Yokosuka *1	8.4	3.4	1.6	0.002	0.001
Upper layer Center of Tokyo Bay *2	25.0	8.3	4.2	0.01	0.006
Lower layer Center of Tokyo Bay *2	23.6	3.9	1.8	0.1	0.05

*1 Sep. 5, 2002: Kanagawa Prefecture (2004) *2 Sep. 14, 2004: Chiba Prefecture (2004)

3. ECONOMIC FEASIBILITY STUDY

Rough estimation of the heat island mitigation project costs for all 23 wards in Tokyo is as follows:

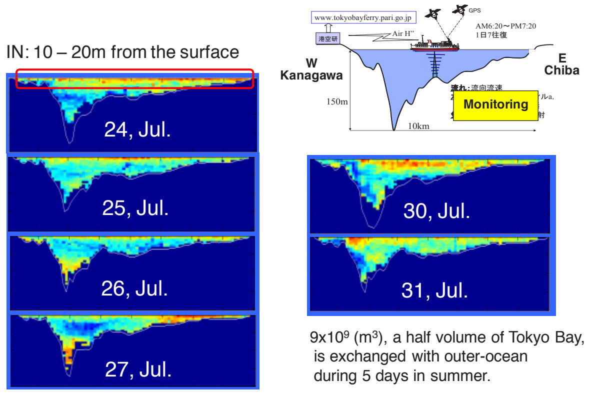
Water retentive pavement: 70 million (m^2) x 18,000 (JPY/m^2) = 1.30 trillion (JPY)
Rooftop vegetation: 140 million (m^2) x 20,000 (JPY/m^2) = 2.80 trillion (JPY)

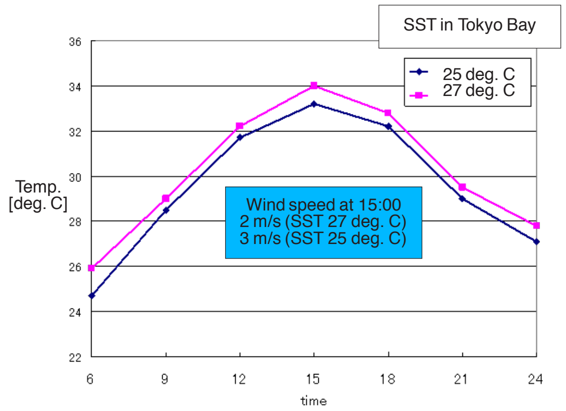
Nowadays water quality problems in Tokyo Bay are not solved completely. Table 1 shows some of the authors view points on water quality in the Bay. The authors' idea is regarded to be available as a part of water pollution control in Tokyo Bay. Rough estimation of the initial costs on the water pollution control actions in Tokyo Bay is estimated to be 1.3 trillion (JPY) for the sewage treatment and 1.2 trillion (JPY) for the river management. On the other hand, cost for installing floating pipelines etc. to bring deep-ocean water to the surface is calculated as follows:

50 (km) x 2.5 billion (JPY/km) = 125 billion (JPY)

4. NUMERICAL SIMULATION WITH CSU-MM

Based on monitoring data, Suzuki *et al.* (2004) showed that 9×10^9 (m^3) of water, which is a half volume of Tokyo Bay, can be exchanged with outer-ocean water during 5 days in summer in an ordinary situation (Fig. 4). This results support the authors' idea that transporting outer-ocean water to Tokyo Bay is reasonable. Southerly wind is a driving force of this in-flow at the surface layer of Tokyo Bay. A numerical simulation with CSU-MM (e.g. Ichinose, 2003) showed that 2 deg. C decrease in bay's sea surface temperature on fine days of late July would lead to 1 deg. C drop in air temperature in central part of Tokyo and to 1 m/s enhancement of the bay breeze.





(left) Fig. 4 In-flow to Tokyo Bay by S-wind (Current velocity; 2004, mid-summer; after Suzuki *et al.*, 2004)
(right) Fig. 5 Numerical simulation with CSU-MM: In central Tokyo (Otemachi): late July

5. COOLING EFFECT OF THE SEA BREEZE IN THE BOUNDARY LAYER ON THE SEA SURFACE

How the air temperature of Tokyo Bay is affected by the sea breeze blowing from the Pacific Ocean to Tokyo?

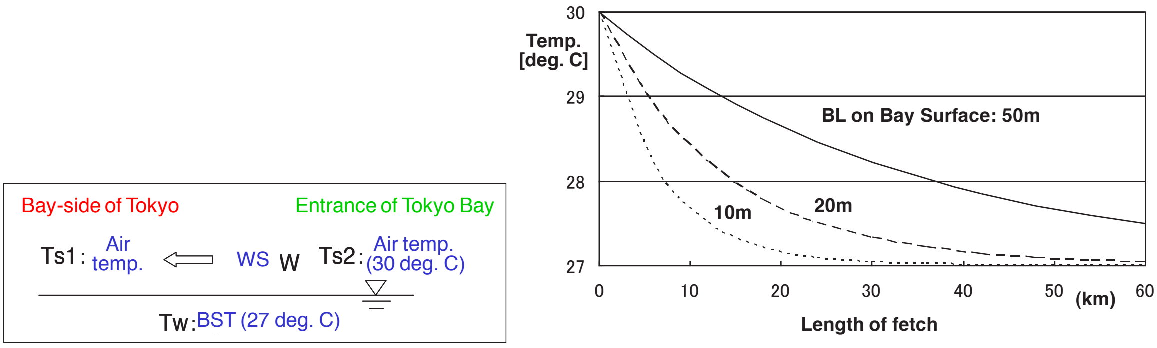


Fig. 6 Cooling effect of the sea breeze in the boundary layer on the sea surface

The authors performed a numerical evaluation of the cooling effect of the sea breeze in the boundary layer on the bay surface. The governing equations were as follows:

Sensible heat flux
$$Q_H = \rho_a c_p C_H (T_W - T_S) W \quad (1)$$

Temperature
$$V_a \rho_a c_p \frac{dT_s}{dt} = Q_H S \quad (2)$$

$$h_a \frac{dT_s}{dt} = C_H (T_W - T_S) W \quad (3)$$

$$\rho_S \left[kg/m^3\right] = 1.293/(1 + 0.00367 T_S [℃]) \frac{H[\mathrm{mmHg}]}{760} \quad (4)$$

$$T_S = T_W + (T_{S0} - T_W)e^{-C_H W t / h_a} \tag{5}$$

where W is the wind velocity (m/s), h_a is the height of boundary layer on the sea surface (m), T_w is the sea surface temperature (deg. C), T_{s2} is the air temperature at the entrance of the bay (deg. C), L is the length of fetch (m), ρ_a = 1.2 kg/m^3 is the density of air, c_p = 1000 J/kg/K is the specific heat capacity of air, C_H = 1.5 x 10^{-3} is the sensible heat transfer coefficient (dimension less), V_a is the unit volume of atmosphere (m^3), S is the unit square touching atmosphere with sea surface (m^2). Figure 6 shows the case when the height of the boundary layer on the bay surface is 10 m, and the length of fetch to decrease the air temperature of the sea breeze on Tokyo Bay from 30 deg. C to 27 deg. C is 30 km. Tokyo Bay stretches for about 60 km from north to south.

6. DOES THE COOLED WATER MASS SINK?

Ordinary deep-ocean water is nutrients-rich and has values of high salinity, low temperature and high density. Does the cooled water mass sink immediately after releasing? The authors performed a numerical study on this question. The governing equations are as follows:

Buoyancy
$$\rho_{cool}\frac{\pi d^3}{6}\frac{dw}{dt} - (\rho_{cool} - \rho_{warm})g\frac{\pi d^3}{6} + C_D\frac{1}{2}\rho_{cool}w^2\frac{\pi d^2}{4} = 0 \tag{6}$$

Drag coefficient
$$C_D = \frac{16}{\mathrm{Re}} \qquad \mathrm{Re} = \frac{wd}{\nu} \tag{7}$$

Density
$$\rho = 1000 + 28.14 - 0.0735T - 0.00469T^2 + (0.802 - 0.002T)(S - 35) \tag{8}$$

where w is the sinking velocity of cooled water mass (m/s), d is the diameter of cooled water mass (m), ρ_{cool} is the density of deep-ocean water (kg/m^3), ρ_{warm} is the density of bay surface water (kg/m^3), C_D is the drag coefficient, v is the kinematic viscosity of ocean water (m^2/s). We assumed that bay sea surface temperature is 30 deg. C and its salinity is 15PSU. Figure 7 shows a possibility for keeping the bay surface cool by controling the diameter of deep-ocean water mass to be released.

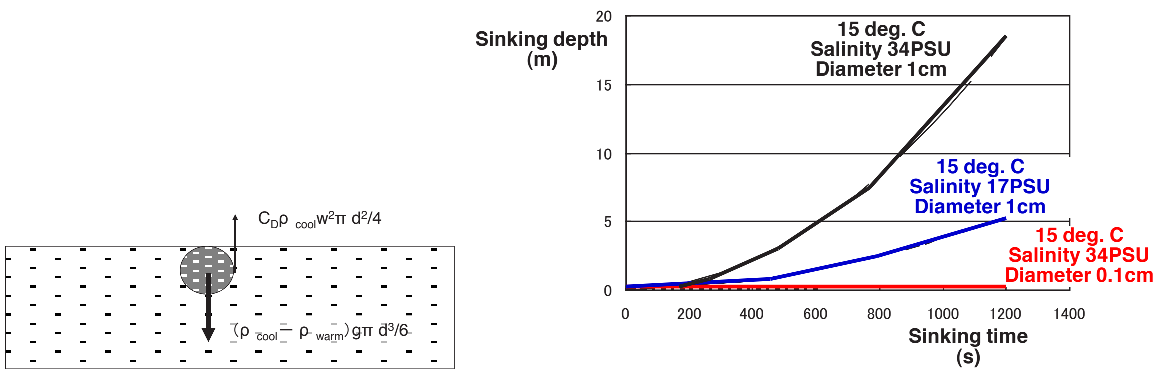


Fig. 7 Does the cooled water mass sink?

7. CONCLUSION

To mitigate urban thermal conditions in the Tokyo Metropolitan Area, we have formulated a new strategy that propose an effective use of the sea breezes flowing into the area from Tokyo Bay on a typical summer day. We also demonstrated (1) the mechanism of heat exchange between the water surface of the bay and the atmosphere; (2) the mechanism for keeping the water surface area of the bay cool after bringing the deep-ocean water up; and (3) the advantage of already well known counteractions, such as the rooftop vegetation and water retentive pavement, over the strategy described in the cost analysis.

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