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CHARACTERISTICS OF PENETRATION OF SEA BREEZE FRONTS ALONG A RIVER

By

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SYNOPSIS

Meteorological field observations were conducted along the Sagami river to investigate the characteristics of penetration of sea breeze fronts along a river. Four modes of local wind circulation were defined by analyzing the temporal and spatial variations of temperature and humidity observed on the ground level along the river. The estimated speed and thickness of the sea breeze front agree well with those predicted by Ishikawa's theory (1986(2)). The captive balloon data and doppler sounder data revealed the vertical structure of the sea breeze front.

INTRODUCTION

Wind channel effect of urban rivers is one of the most important factors to control the atmospheric environments of the surrounding regions. Especially, in Japan, where there are many mountainous regions adjacent to small plains, a river basin plays an important role for transport of heat, moisture and the other scalars such as NO_x and CO_2. In Kofu basin, for example, it has been found that two kinds of sea breeze penetration along two rivers (one is from Tokyo metropolitan area along the Sagami river, and the other from the Pacific Ocean along the Fuji river) are dominant factors to determine the meteorological conditions around that area(Kanda and Tsunoi,1995(3)). Although many previous researches in Boundary layer Meteorology were focusing general features of characteristics of sea breeze behaviors, very few of them pays attention to the effect of rivers on the atmospheric environment.

The purpose of this study is to investigate the structures and characteristics of sea breeze penetration along a river. For this purpose, meteorological field observation were conducted along the Sagami river in summer 1995. The main reasons of focusing on the river basin in performing experiments are as follows ; 1) Experimental instruments can be concentrated two-dimensionally along the river, which means spatially high resolution meteorological data can be obtained, 2) lateral advection across the river axis can be ignored and two dimensional analysis can be adopted along the river and 3) hydraulic engineers can reflect these results to river planning in the future.

EXPERIMENTAL PROCEDURES

Experimental Design

(a) Observations along the Sagami river

To investigate the horizontal characteristics of sea breeze penetration, seven meteorological stations near the ground surface were selected along the Sagami river from Sagami Bay and Yamanashi Prefecture. The total length of the observations along the river axis was about 100km and the distance between each station was about 10 to 20 km. Fig.1 shows the map of the observation points and Table.1 the distance from Sagami Bay to individual station. The observation periods were twelve days from July 2 to August 2 in 1995. Temperature, humidity, wind velocity and wind direction above 2m

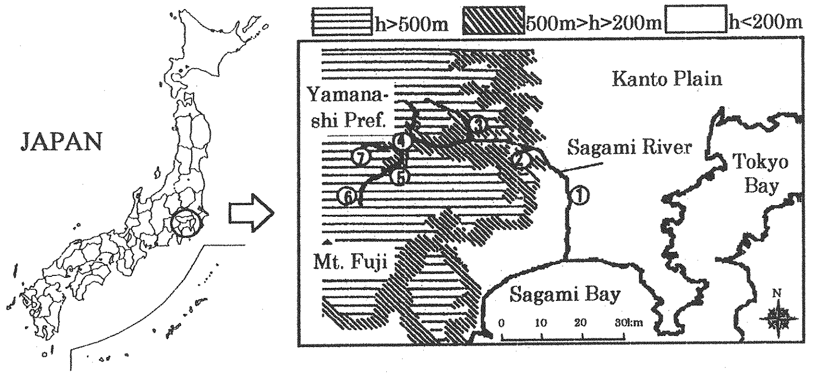

Fig.1 Map of the observation points

Table 1 Distance from Sagami Bay

Station name	Distance from Sagami Bay
① Zama	19km
② Tsukui	39km
③ Uenohara	57km
④ Ootsuki	75km
⑤ Tsuru	86km
⑥ Fujiyoshida	97km
⑦ Sasago	84km

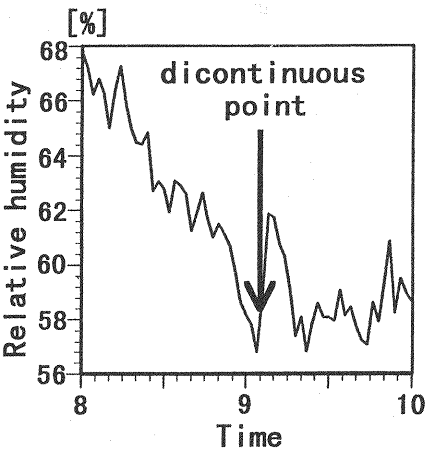

Fig.2 Definition of discontinuous point

from the ground surface were observed at 1-second intervals, and the values averaged over 2-minutes were recorded automatically to a data logger.

(b) Observations in a vertical axis

To investigate the vertical structures of the sea breeze fronts, upper air observations from the ground surface to 500m above the ground were conducted by a doppler sounder and a pilot balloon at Uenohara (see Fig.1) from July 26 to 28 in 1995. Vertical profiles of temperature, humidity, ozone were observed by the pilot balloon at 1.5 hour intervals, and those of wind velocity, wind direction and turbulence intensity were observed by the pilot balloon at 30-minutes intervals.

RESULTS AND DISCUSSION

Behavior of Sea Breeze Penetration

(a) Modes of local circulation

Fig.2 shows an example of temporal change of humidity, in which some abrupt change can be seen. It is well known that these temporal discontinuity of variables such as humidity and temperature are usually due to passages of local winds. Therefore, those signals at each station can make us to estimate the arrival times of sea breeze fronts, Figs.3 and Figs.4 present diurnal changes of temperature and humidity, respectively, at each station, with vectors of wind velocity averaged over 30-minutes. On the right hand side of Figs.3, the directions of river streams, which mean the river axes, at each station, are shown. Actually, it can be seen that more than 85 % of observed wind

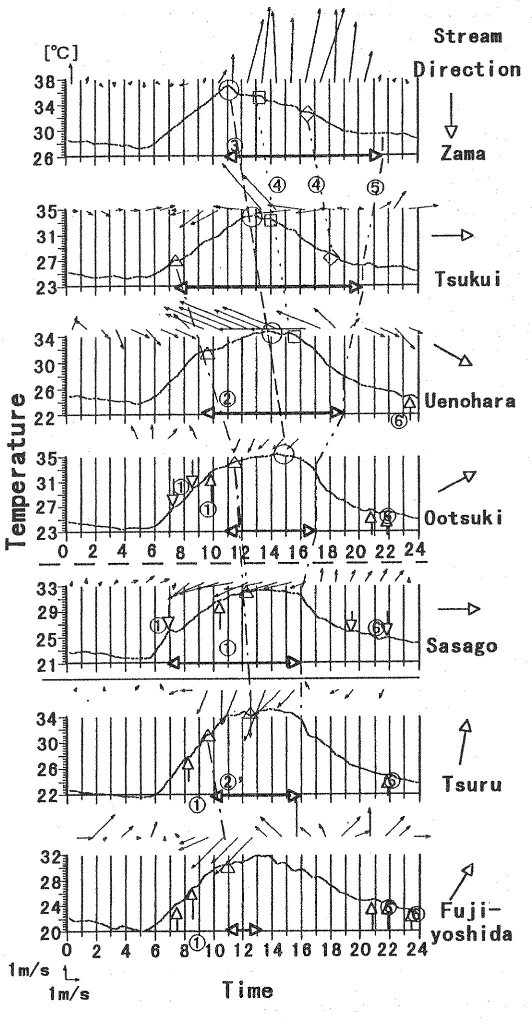

Fig.3 Diurnal variations of temperature and wind velocity vector

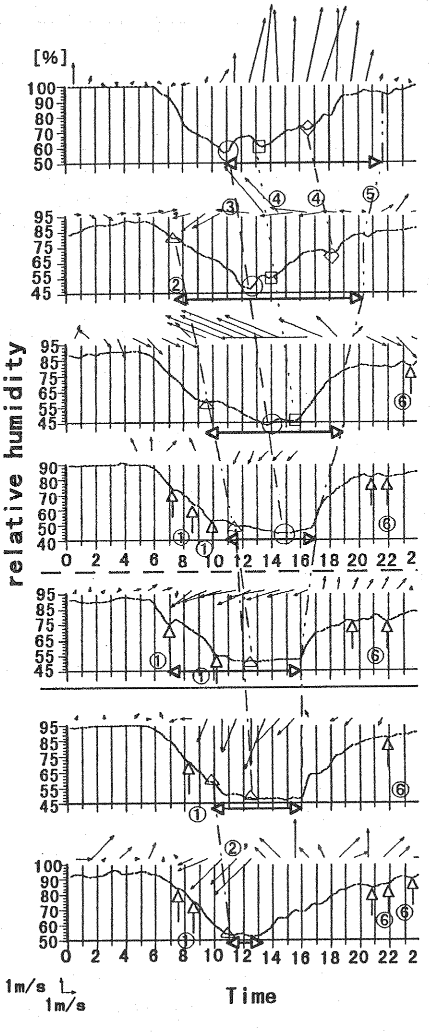

Fig.4 Diurnal variations of humidity and wind velocity vector

the directions of river stream at each station are marked by arrwos on the right side of Fig.3.

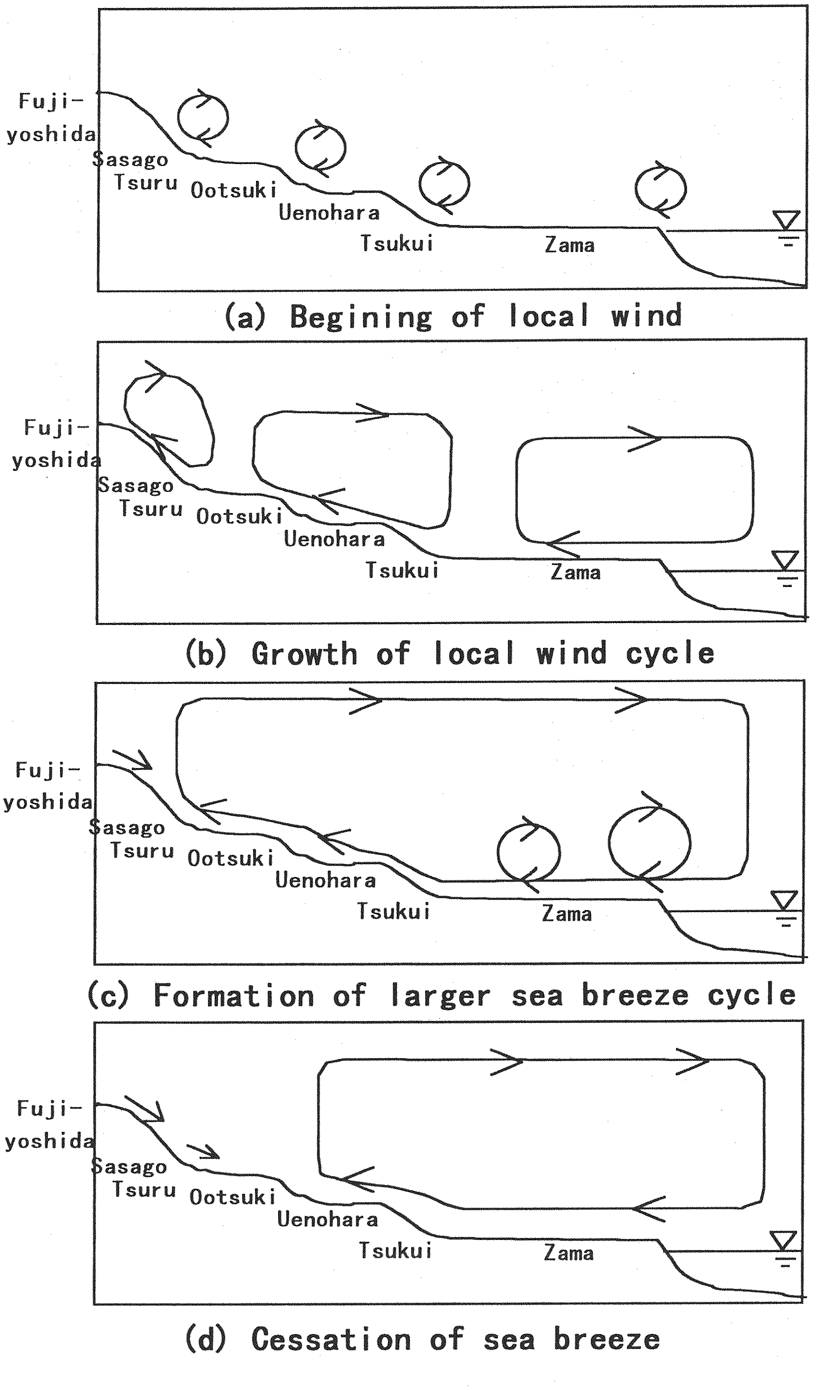

Fig.5 Schematics of four modes of local wind circulation along the Sagami river

directions are parallel to the river axes. It suggests that the river basin acts as a wind channel as expected. Several kinds of lines across the figures ,which are made by connecting the related discontinuous points at each station, illustrate the trajectories of sea breeze fronts. It can be seen in Figs.3 and Figs.4 that at least four fronts of local winds exist. Figs.5 display the schematics of those local circulation along the Sagami river.

1) local anabatic wind (Fig.5(a)) : During the early morning periods, the discontinuous points of temperature and humidity as mentioned above, can be seen only in the data at mountainous stations, but not in those at stations near coastal regions (see ① in Figs.3 and Figs.4). This suggests that small anabatic winds will be generated only in the mountainous regions early in the morning.

2) middle anabatic wind (Fig.5(b)) : As shown by the line ② in Figs.3 and Figs.4, a propagation of local winds can be seen between Tsukui and Uenohara, but still not in Zama. This local wind in the mountainous region is larger that that in the early morning and can be defined as a middle anabatic wind. This circulation seems to separate into two different stream. One is in the southern direction to Tsuru, and the other in the west direction to Sasago.

3) sea breeze circulation (Fig.5(c)) : It can be seen from the line ③ in Figs.3 and Figs.4 that a very large circulation occur between coastal region such as Zama and mountainous region such as Otsuki. This can be defined as a large circulation of sea breeze. Apart from this big circulation, we can see some discontinuous points in the afternoon as shown by ④ corresponding to small Benard convection.

4) sea breeze convergence (Fig.5(d)) : The line ⑤ in Figs.3 and Figs.5 represents the time-line at which the upstream flow along the river axes stopped at each station. It can be clearly seen that the convergence of the sea breeze begins at mountainous regions and then moves to the coastal regions.

(b) Speed of penetration

Fig.6 shows the relationships between the distance from Sagami Bay and the time the fronts of local winds have passed. The linear relationships indicate that the fronts penetrate at almost constant speeds along the Sagami river. The speeds of the middle anabatic wind, the sea breeze circulation and the convergence of the sea breeze can be estimated about 2.6(m/s), 3.6 (m/s) and 2.8(m/s), respectively, from the inclinations of the lines in Fig6.

Ishikawa(1986) proposed a theoretic solution of speed of sea breeze fronts on the basis of a two dimensional analysis. He assumed that disturbance due to thermal instability would be a dominant factor of drag against sea breeze penetrations, and deduced the following relationship,

$$V = K \left(g / \alpha \rho \right)^{1/4} Q_p^{\ 1/2} \qquad (1)$$

Where g : the acceleration due to gravity (m/s^2)、 ρ : the density of air (g/m^3), α : the pressure gradient between the sea and the land, Q_p : the sensible heat flux at the ground surface (g/m^2s), K: a model parameter (= 0.59). α and Q_p are estimated 0.025 and 0.69, respectively, from the vertical temperature profiles as shown in Fig.7. The speed of sea breeze front can be estimated 3.6(m/s) from Eq.(1), which agree well with the observed value as mentioned above.

Vertical Structure of Sea Breeze

Fig.7 shows the vertical profiles of potential temperature observed by pilot balloon measurements. The gradient of potential temperature at 8:00 am is about 0.008 (K/m), which is a typical value of stable atmospheres. The vertical profiles of potential temperature in daytime are made almost constant by the convective mixing due to ground surface heating.

It is well known that a thin and unstable layer can be observed in about 10% depth of the convective layer. In Fig.7, however, those kinds of unstable layer can not be clearly recognized near ground surface. This can be explained by the existence of a cooler boundary layer due to the river water.

The upper boundary of the internal boundary layer of 12:00 to 14:00 can be

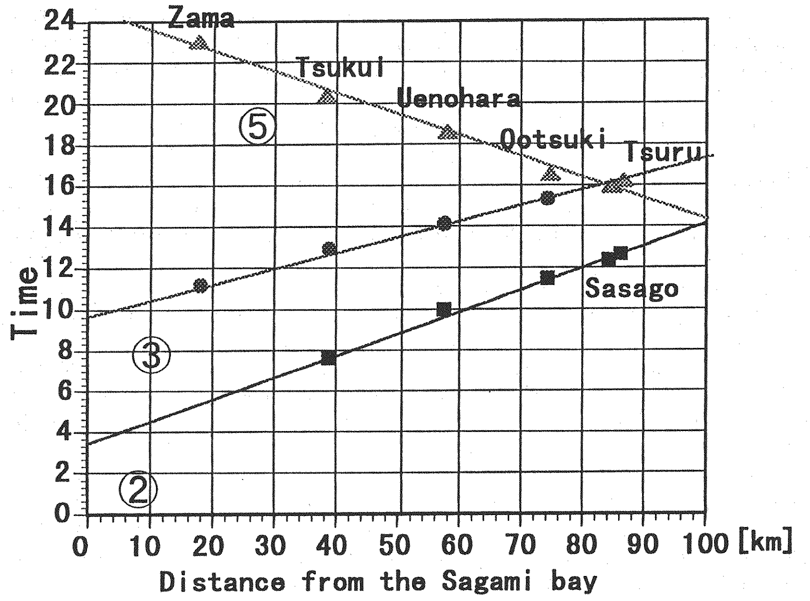

Fig.6 The distance from Sagami Bay versus the arrival time of the local circulation

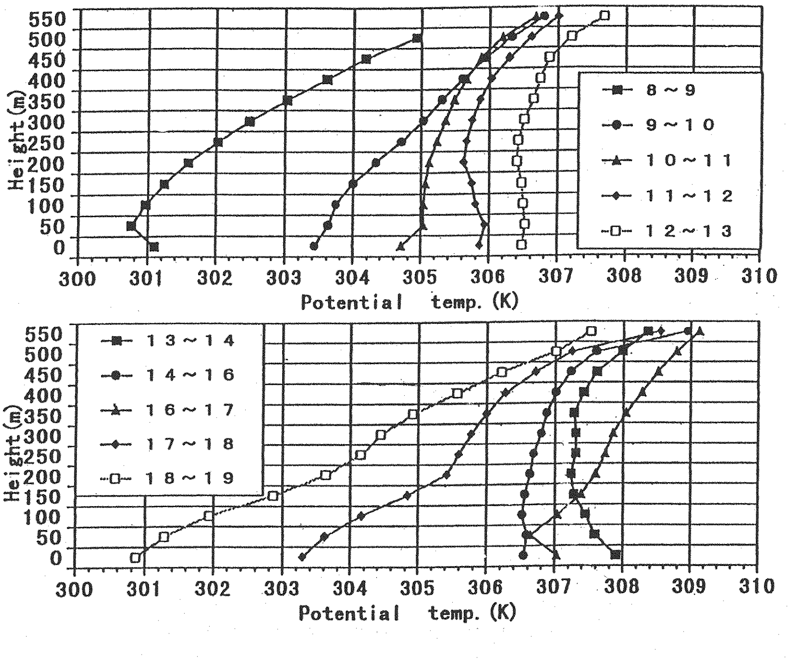

Fig.7 Vertical profiles of potential temperature

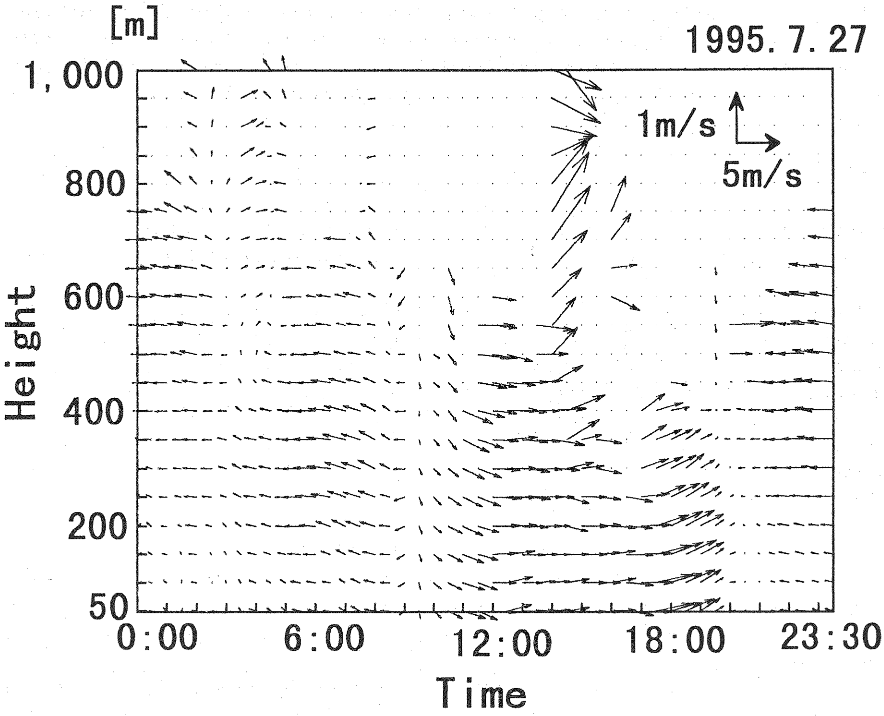

Fig.8 Temporal change of vertical profiles of wind velocity vector

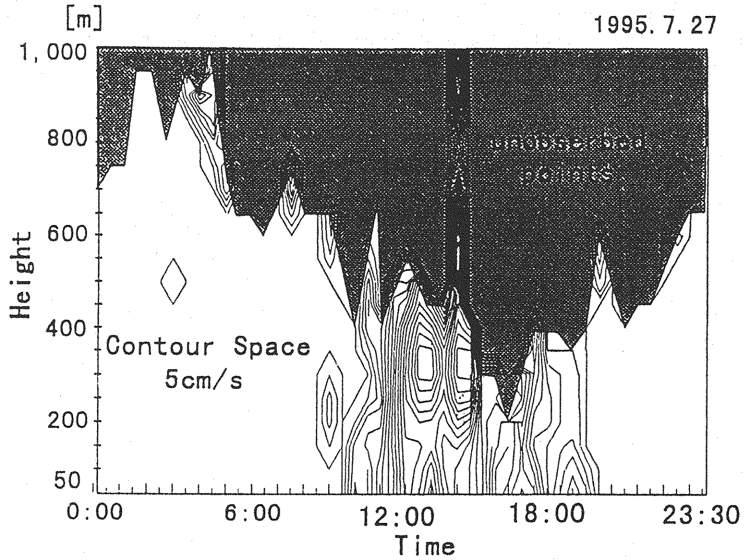

Fig.9 Temporal change of vertical profiles of turbulent intesity

estimated from the inclination of potential temperature, about 500m, which is much lower than the heights of typical convective layers observed inland without effect of sea breeze. The theoretical depth of internal boundary layer generated by sea breeze, which was deduced by Hsu (1986(1)) by assuming the balance of diffusion and advection of sea breeze, is expressed by Eq.(2).

$$H = 1.9 L^{1/2} \tag{2}$$

Where H: the depth of the internal boundary layer, L : the distance from the sea. The calculated depth of the sea breeze layer from Eq.(2) is about 500(m) and agree with the observed.

Fig.8 shows the temporal change of vertical profiles of wind velocity vector. The horizontal wind is taken in the parallel direction to the river axis. The reverse of wind direction was observed at 9:30 and 20:00. The former corresponds to the passage of the middle anabatic wind, and the latter does to the convergence of sea breeze. Fig.9 shows the temporal change of vertical profiles of turbulence intensity. During day time, turbulence intensity has periodic peaks. A peak at 8:00 corresponds to generation of small convections due to surface heating, that at 12:00 the strong convections, and that at 14:00 the passage of the sea breeze front.

CONCLUDING REMARKS

Meteorological field observations were conducted along the Sagami river to investigate the characteristics of penetration of sea breeze fronts along a river, and the following results were obtained.

(1) Four modes of local wind circulation were defined by analyzing the temporal and spatial variations of temperature and humidity observed on ground level along the river.

(2) The estimated speed and thickness of the sea breeze front agree well with those predicted by Ishikawa's theory (1986).

(3) The captive balloon data and doppler sounder data revealed the vertical structure of the sea breeze front.

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