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Horizontal Distributions of Temperature and Salinity in Owase Bay

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Abstract

Owase Bay locates at eastern coast of Kii Peninsula in central Japan. Hydrographic condition of Owase Bay is characterized by the effluent of warm water from thermal electric power plant and fresh water from water-power generation. Thirteen times observations on temperature and salinity were conducted in Owase Bay during the periods from April 1986 to September 1991. Most of the observations are made in summer. Horizontal distributions of the observed temperature and salinity are presented in the present paper. It is revealed that less saline water originated from the effluent of fresh water spreads eastward during ebb and low water and significant change of hydrographic condition occurs depending on tidal periods. The change is confined to surface layer and it is not detected at a depth of 3 m.

Key words: thermal effluent · coastal front and Owase Bay

1 Introduction

Owase Bay is composed of Owase-Ura and Hikimoto-Ura and regions confronting to the Pacific Ocean (Fig. 1). Owase-Ura has a south-north width of 4 km with depth of 5–20 m at the innermost and 5 km with depth of 50 m at the baymouth. The west-east distance of the Owase Ura is about 9 km. It is well-known that precipitation especially in summer is significant over the basin of rivers that flows out into Owase Bay and large river discharge is carried out[1]. It should be also noted that the Kuroshio flows offshore of the Owase Bay and the Kuroshio water sometimes approaches to a eastern coast of Kii Peninsula forming a warm water tongue or warm water stream[2]. Furthermore, oceanic condition of Owase Bay is characterized by two effluent of warm water from thermal electric power plant and of fresh water from water-power generation. The volume transport of these effluent is significant and simple estimation assuming a constant effluent of 50 m^3 sec^{-1} gives that all of the water in the Owase Bay is completely replaced by effluent of water for every 20 days.

Several hydrographic observations have been made in Owase Bay[1]. Tidal current in Owase Bay is relatively weak and constant outflow is about 5 cm sec^{-1} [1]. However, almost of the reported observations were made before the construction of the two electric power generations and results of recent observations forcussing on the thermal effluent have not been well reported. In particular, new system of thermal electric power plant was constructed in June 1987 and effluent of warm water was increased from about 30 m^3 sec^{-1} to 50 m^3 sec^{-1}. From these view points, it is needed to estimate environmental influence of effluent of warm and

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fresh water on oceanic and atmospheric conditions of Owase Bay.

After April in 1986, several routine observations in Owase Bay have been carried out by Owase City Office. In this paper, horizontal distributions of the observed temperature and salinity are presented in the present paper with special reference to advection and diffusion of effluent of warm and fresh water.

2 Observations

Locations of observational points of the present study is shown in Fig. 1. Three observational lines are set to see the horizontal section and some stations are placed at innermost of the bay to see the behavior of fresh

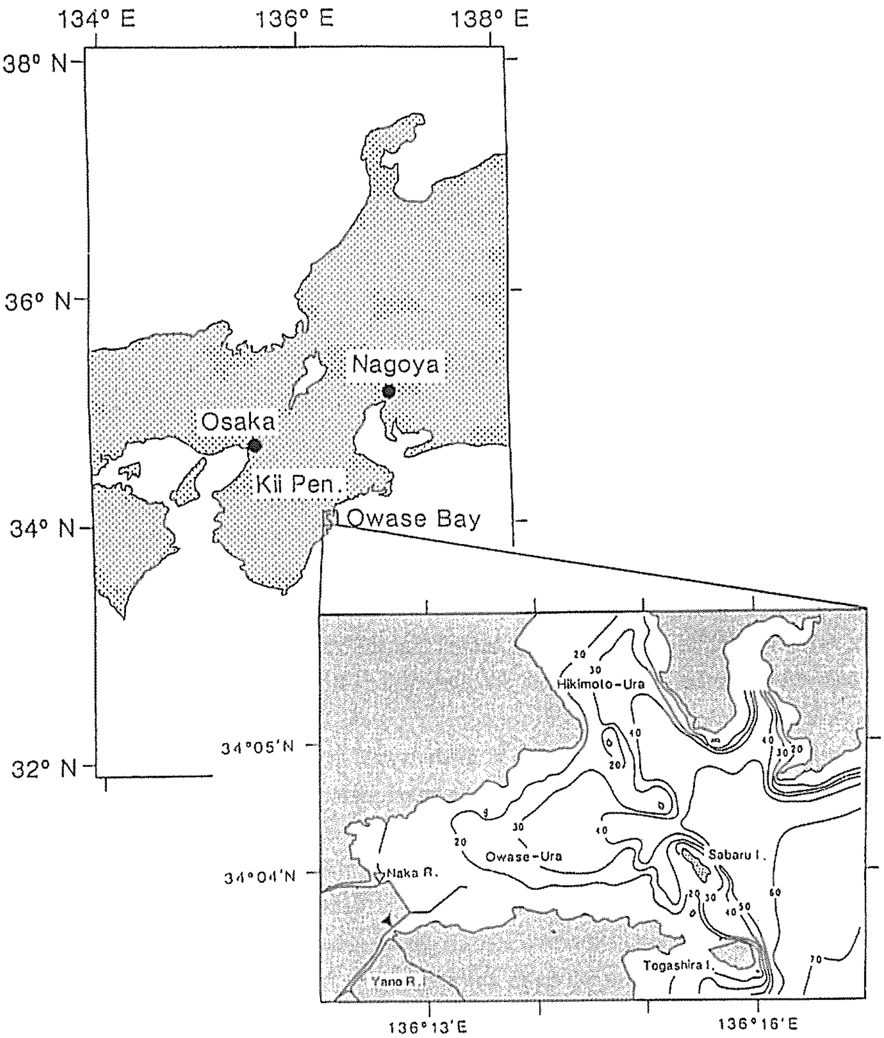


Fig. 1. Location and geometry of western part of Owase Bay and its depth contours (in meter). Open and closed triangles at river-mouth of Naka-Gawa and Yano-Gawa mean the location of inflow and outflow of sea water used in thermal electric power generation, respectively.

Table 1. Details of observations. Blanks show same as above

Observational Name	Date	Tide	Effluent ($m^3\ sec^{-1}$) Warm water	Fresh water
86API	25 Apr. 1986	Ebb	no data	13.0
86APII		Low water		0.3
86APIII		Flood		0.0
86APIV		High water		0.3
86JLI	29 Jul. 1986	Flood	31.6	0.0
86JLII		High water	31.6	16.4
86JLIII		Ebb	31.6	16.8
86JLIV		Low water	31.6	8.1
86AGI	8 Aug. 1986	High water	31.6	0.0
86AGII		Ebb	31.6	0.3
86AGIII		Low water	31.6	16.4
86AGIV		Flood	31.6	24.8
87AGI	11 Aug. 1987	High water	38.8	0.0
87AGII		Ebb	38.8	8.3
87AGIII		Low water	38.8	16.4
87AGIV		Flood	38.8	24.2
87AGV	19 Aug. 1987	Ebb	54.6	0.0
87AGVI		Low water	54.6	0.0
87AGVII		Flood	54.6	8.4
87AGVIII		High water	54.6	16.3
88AGI	26 Aug. 1988	Ebb	46.0	24.7
88AGII		Low water	50.0	24.8
88AGIII		Flood	52.0	24.7
88AGIV		High water	53.0	24.8
88SPI	2 Sep. 1988	High water	48.5	23.6
88SPII		Ebb	53.0	23.7
88SPIII		Low water	53.5	23.7
88SPIV		Flood	53.5	23.8
89API	13 Apr. 1989	Flood	no data	0.0
89APII		High water		15.9
89APIII		Ebb		16.0
89APIV		Low water		24.0
89AGI	25 Aug. 1989	Flood	50.5	23.9
89AGII		High water	53.5	24.0
89AGIII		Ebb	54.3	24.0
89AGIV		Low water	53.5	24.1
89AGV	31 Aug. 1989	Ebb	54.6	24.6
89AGVI		Low water	54.6	24.6
89AGVII		Flood	54.6	24.5
89AGVIII		High water	54.6	24.5
90AGI	20 Aug. 1990	Ebb	54.6	0.0
90AGII		Low water	54.6	9.5
90AGIII		Flood	54.6	23.9
90AGIV		High water	54.6	7.6
90AGV	28 Aug. 1990	Flood	54.6	24.1
90AGVI		High water	54.6	24.1
90AGVII		Ebb	54.6	23.8
90AGVIII		Low water	54.6	23.9
91SPI	2 Sep. 1991	Flood	no data	24.8
91SPII		High water		24.8
91SPIII		Ebb		24.7
91SPIV		Low water		24.8

water discharged into Naka River (Fig. 1). Temperature and salinity are observed at these points by use of EIL Salinometer (MC5/2), in which temperature is also able to be observed to check its contribution on the salinity. Thirteen observations have been carried out and their details are tabulated in Table 1. Here, two total volume of effluent of warm water from thermal electric power plant supplied by Chubu Electric Power Generation L.T.D. and that of fresh water from water-power generation before 3 hours before the observation are also shown.

As for each of thirteen observational periods, four times of temperature and salinity observations over all stations shown in Fig. 2 have been carried out in different tidal periods, ebb, low water, flood and high water. Unfortunately, salinity data of all stations on 25 April in 1986 (86API-86APIV) and those on eastern half of the three observational lines on 20 and 28 August in 1990 (90AGI-VIII) have not been obtained.

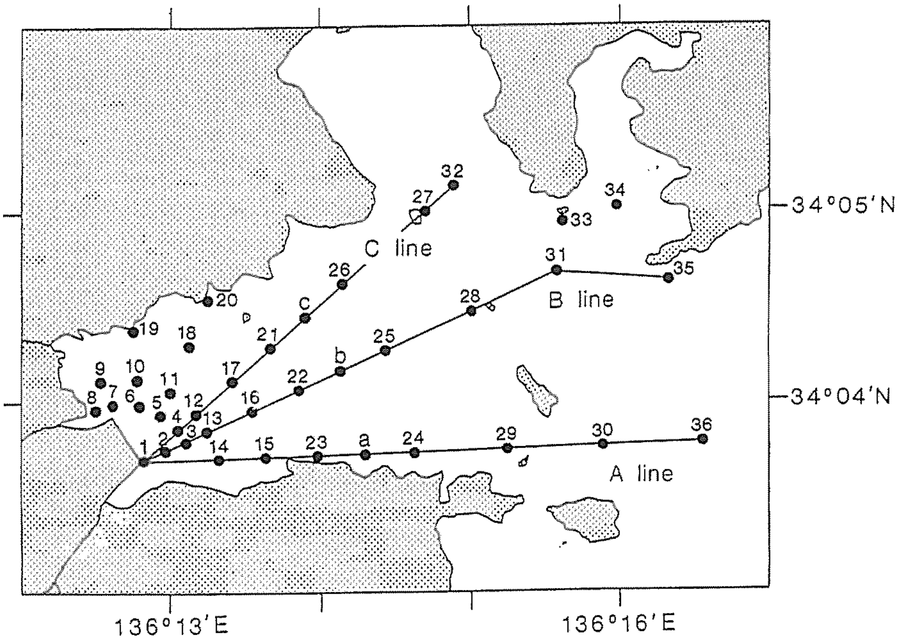


Fig. 2. Locations of observational stations of temperature and salinity of the present study.

3 Results

Horizontal distributions of temperature and salinity at depths of 0 m and 3 m are shown in Figs. 3–15. Here, if we consider the observational season and difference in volume of effluent of warm water and fresh water, the oceanic conditions are mainly classified into four cases tabulated in Table 2. Namely, almost of the observation were carried out in summer, however two observation were made in spring (Table 1). So, these two observations in spring are referred to as Group (I). Other three groups are classified by the different effluent of warm and fresh water: relatively small effluent of warm water is made in observations of Group II. Owing to the increment of thermal electric power plant in June 1987, large effluent of warm water was carried out. Groups III and IV are classified by the difference in effluent of fresh water (Table 2). In the following,

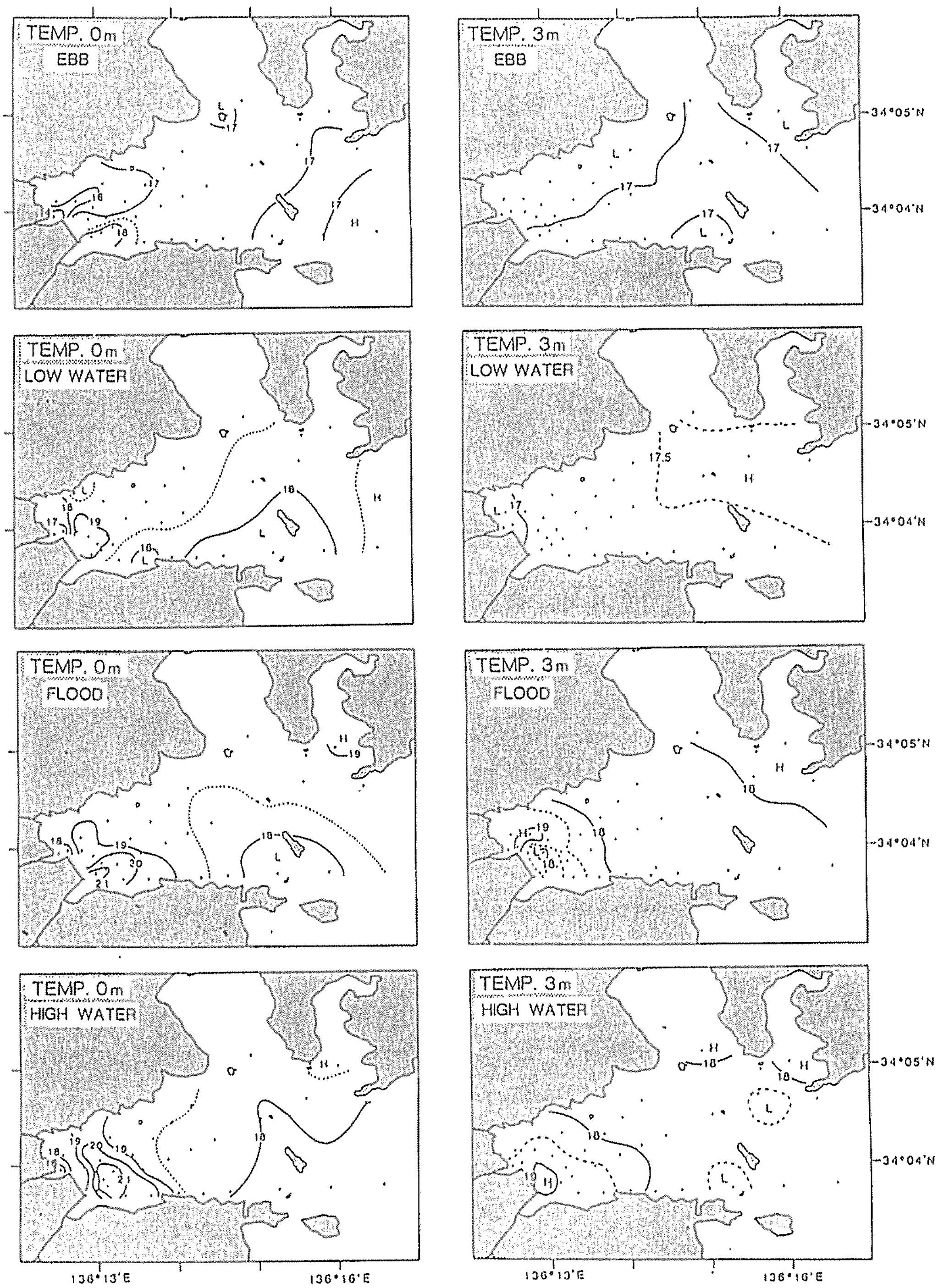
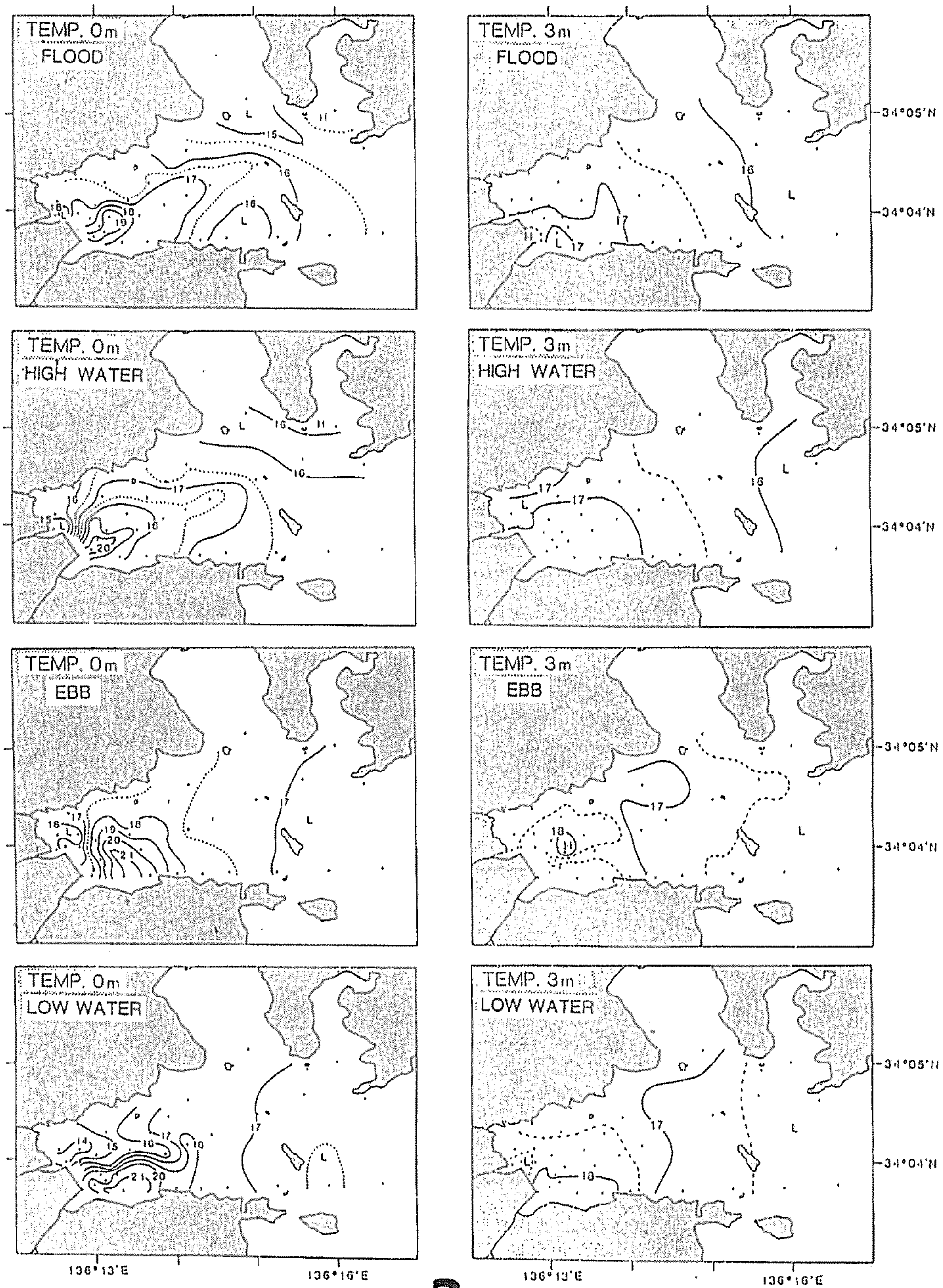


Fig. 3. Observed horizontal distribution of sea surface temperature (SST) and at a depth 3 m (°C) on 25 April 1984.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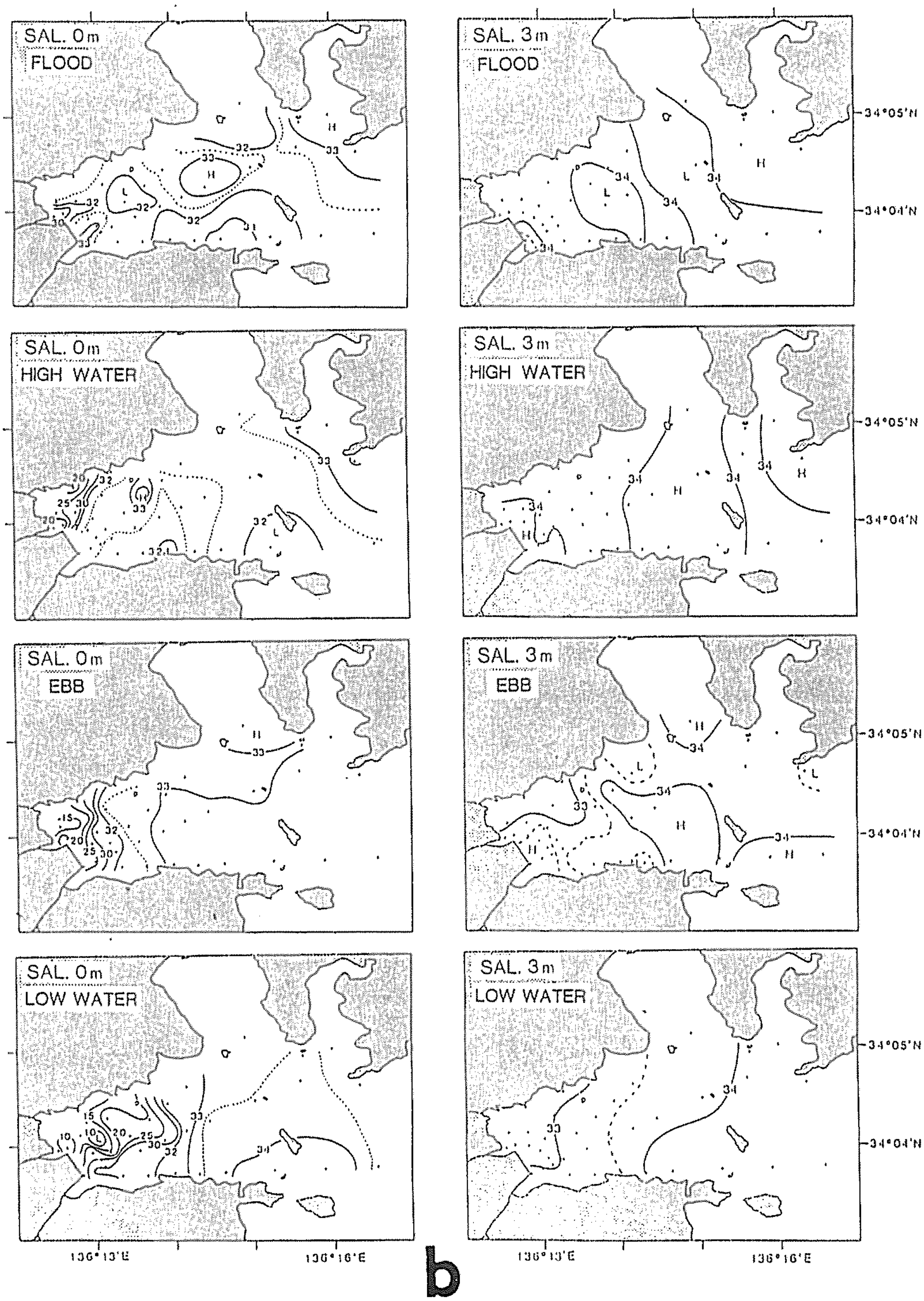
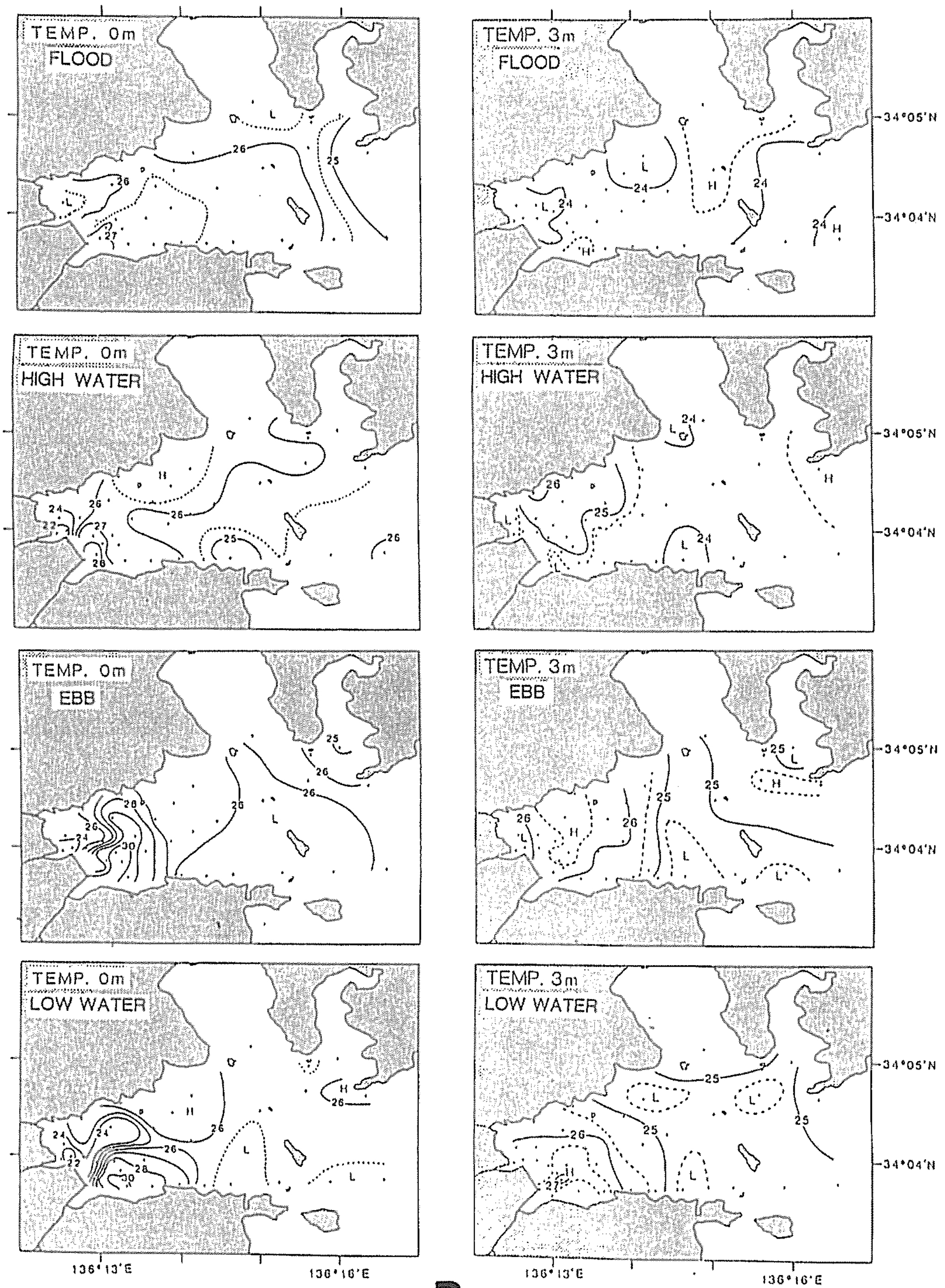


Fig. 4. (a) Observed horizontal distribution of sea surface temperature (SST) and at a depth 3 m (°C) on 13 April 1989 and (b) those of salinity.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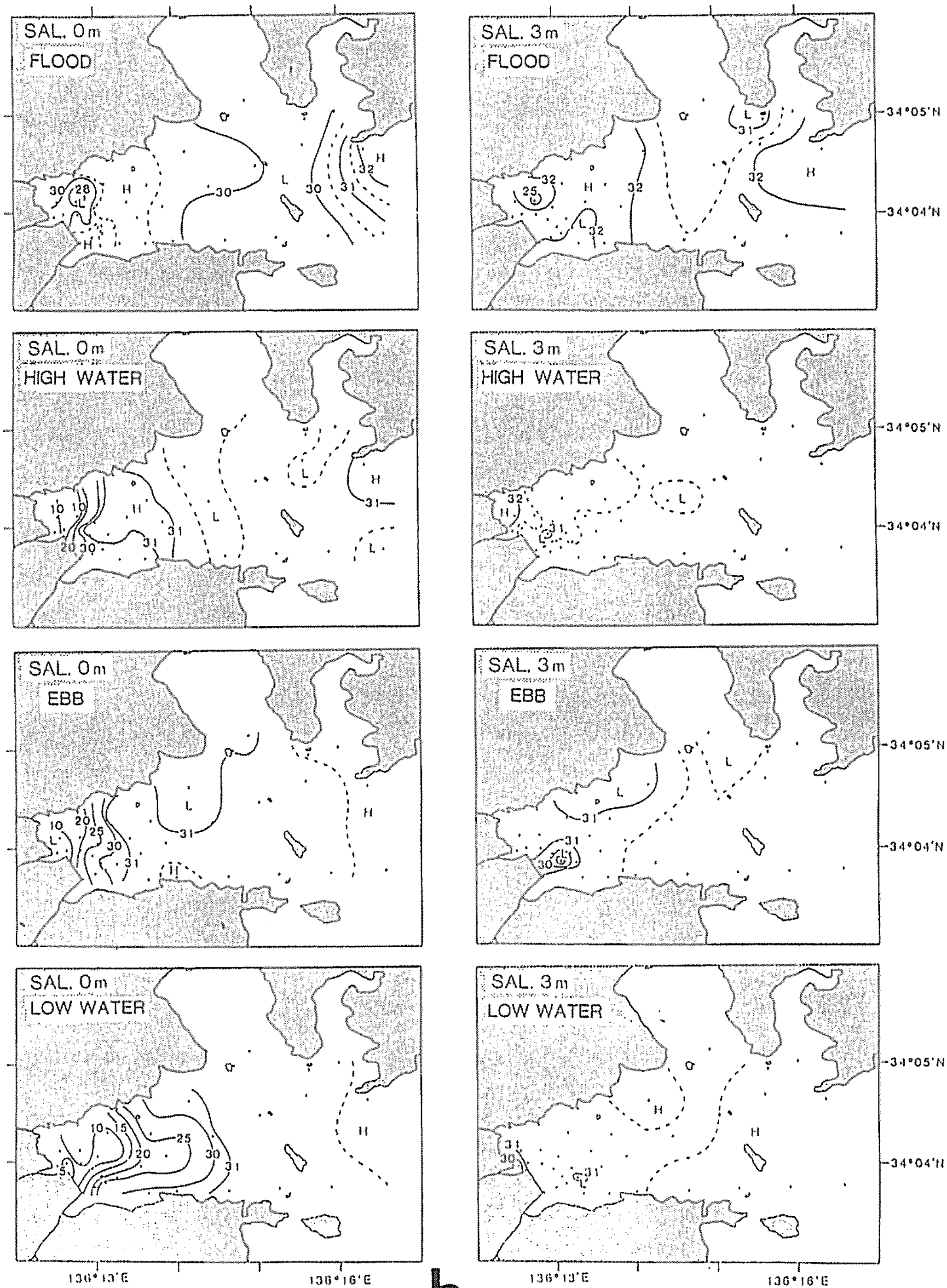

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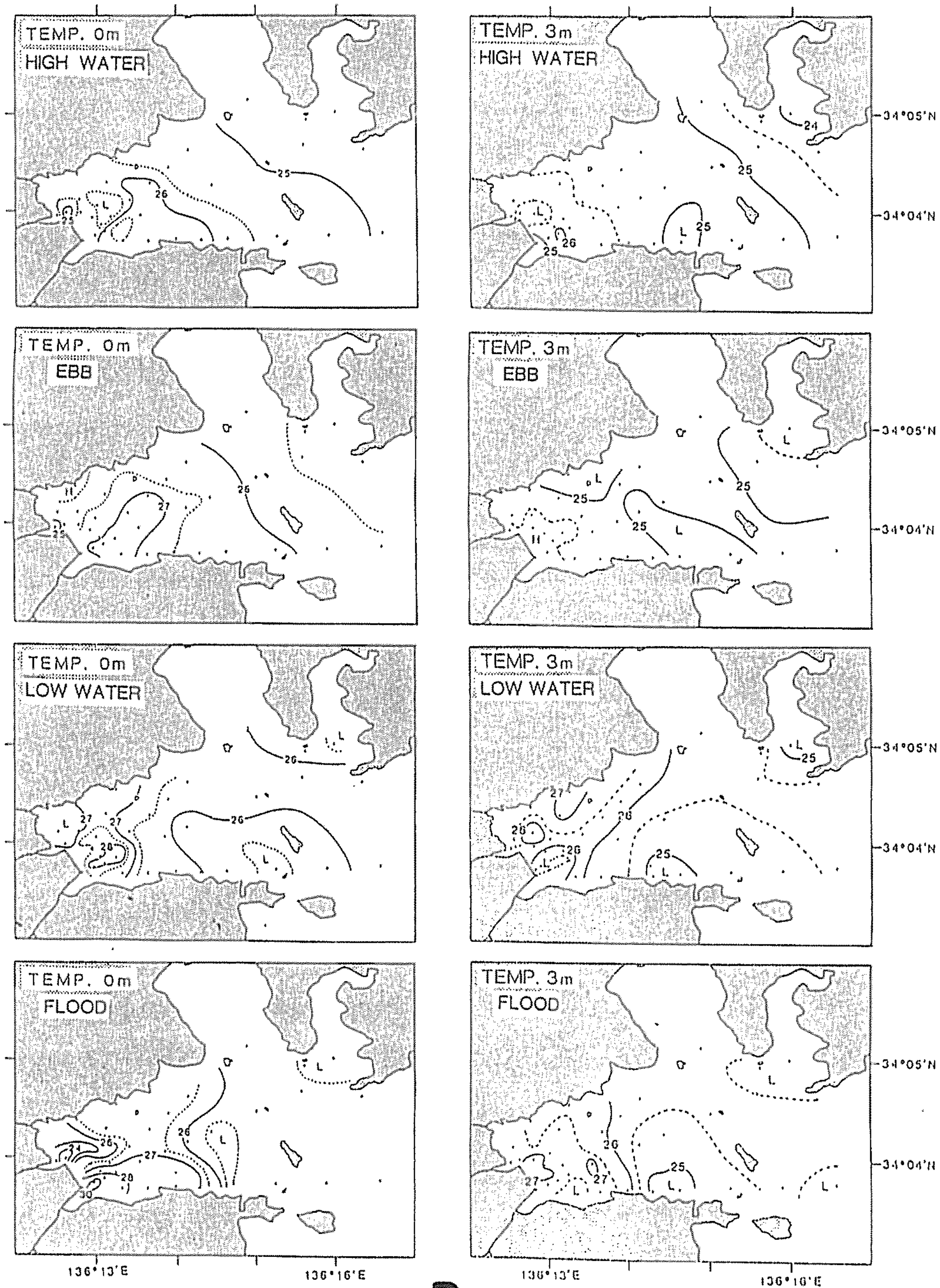
Fig. 5. Same as Fig. 4 but for 29 July in 1986.



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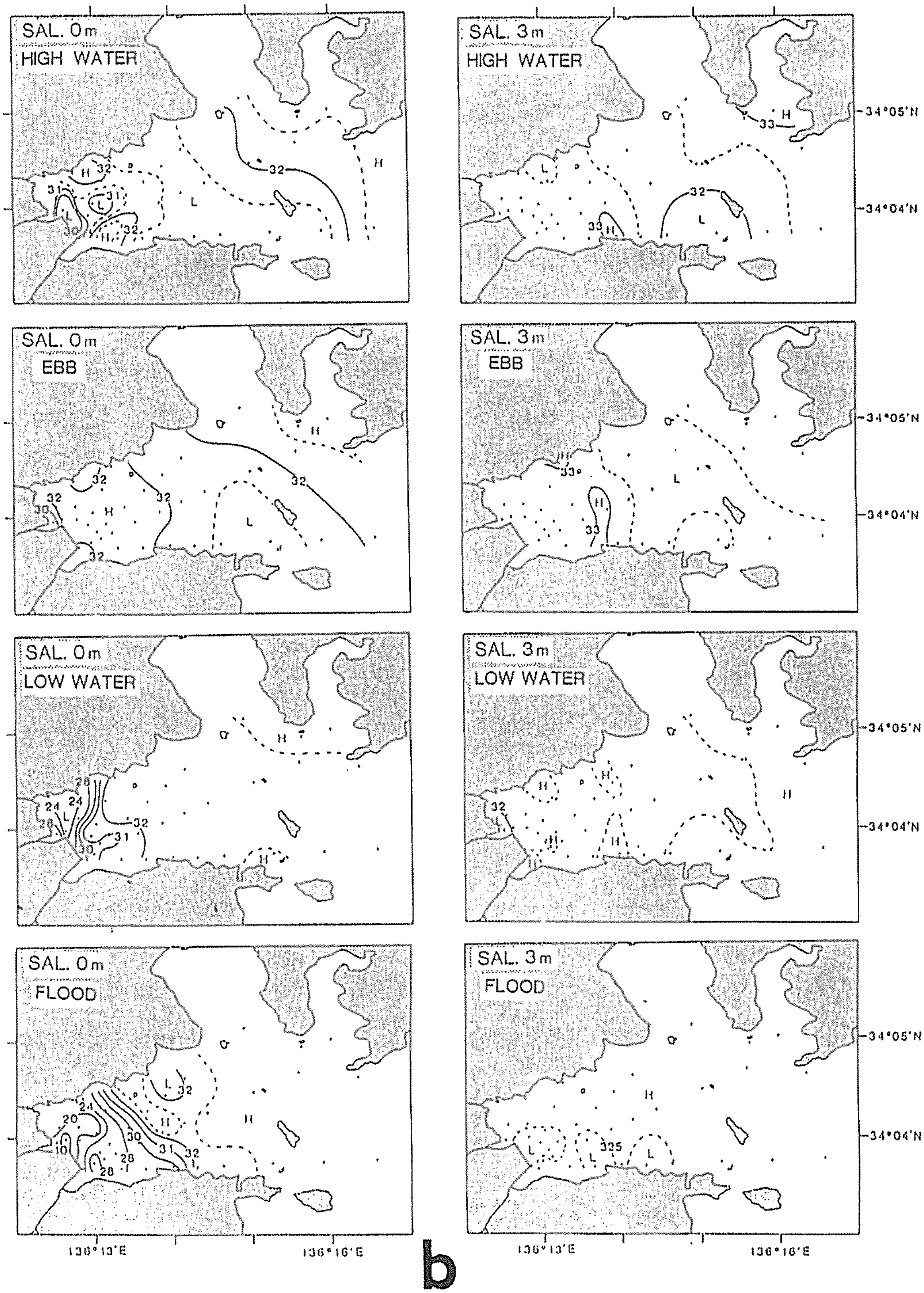
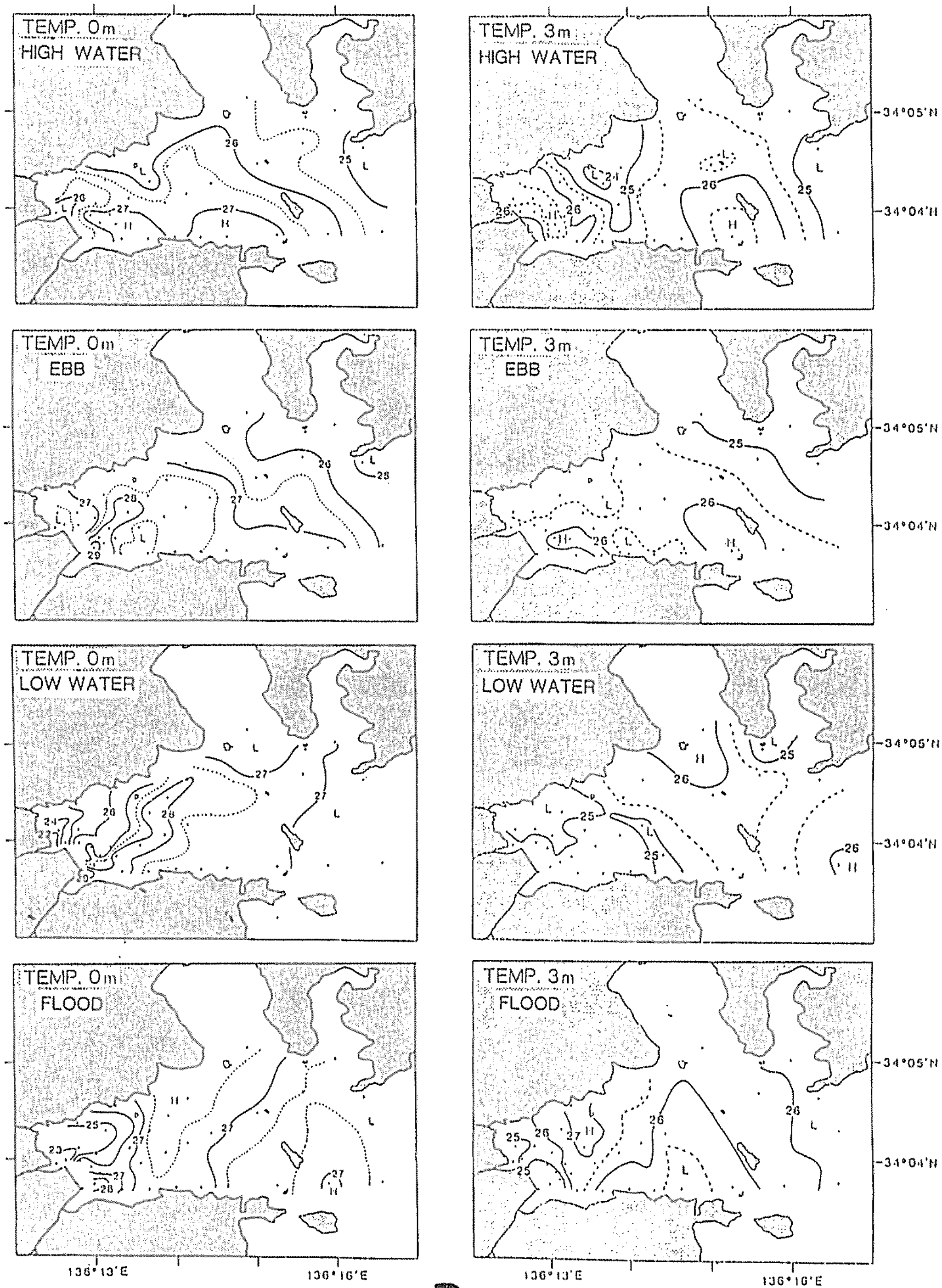


Fig. 6. Same as Fig. 4 but for 8 August in 1986.



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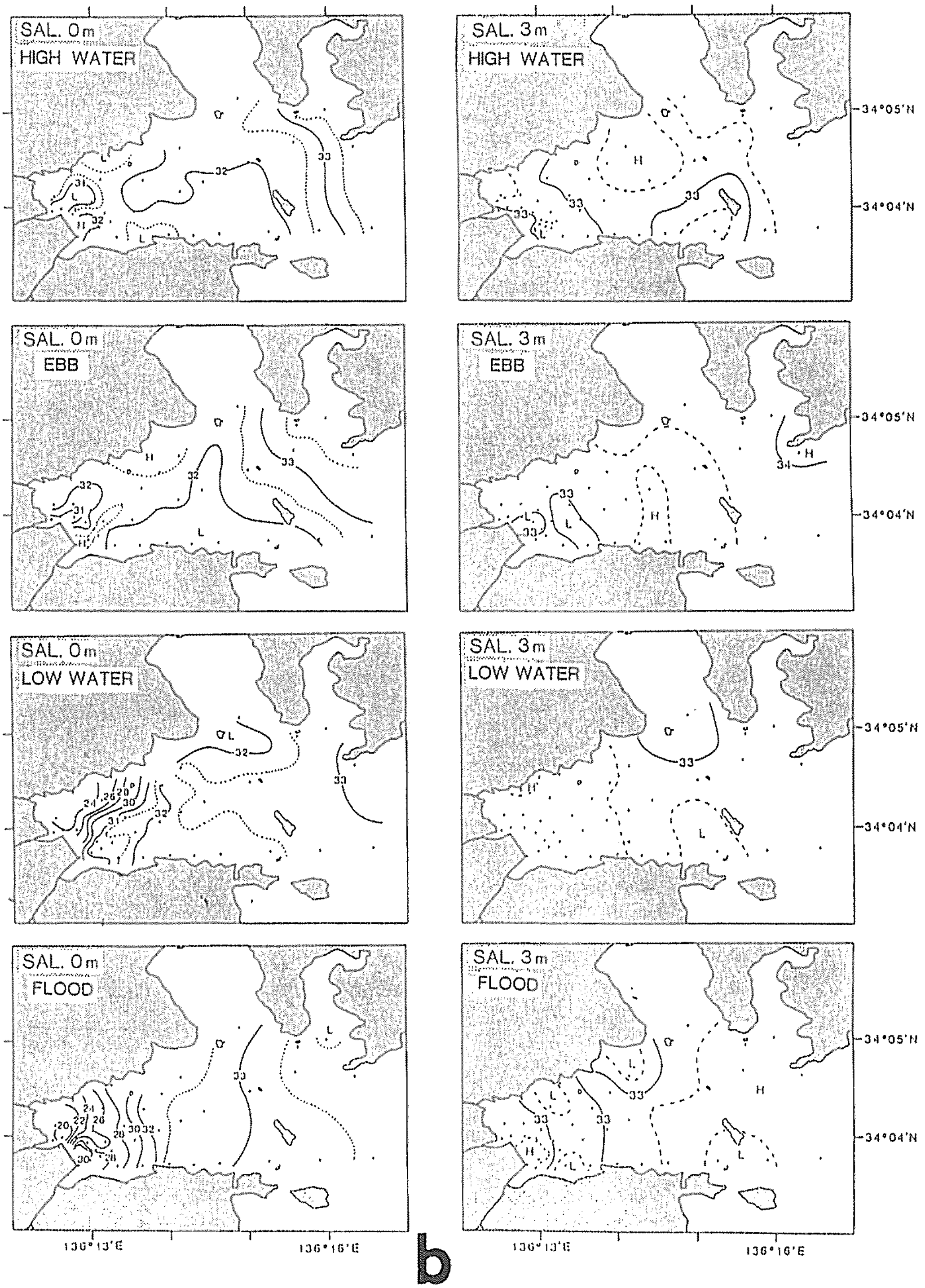
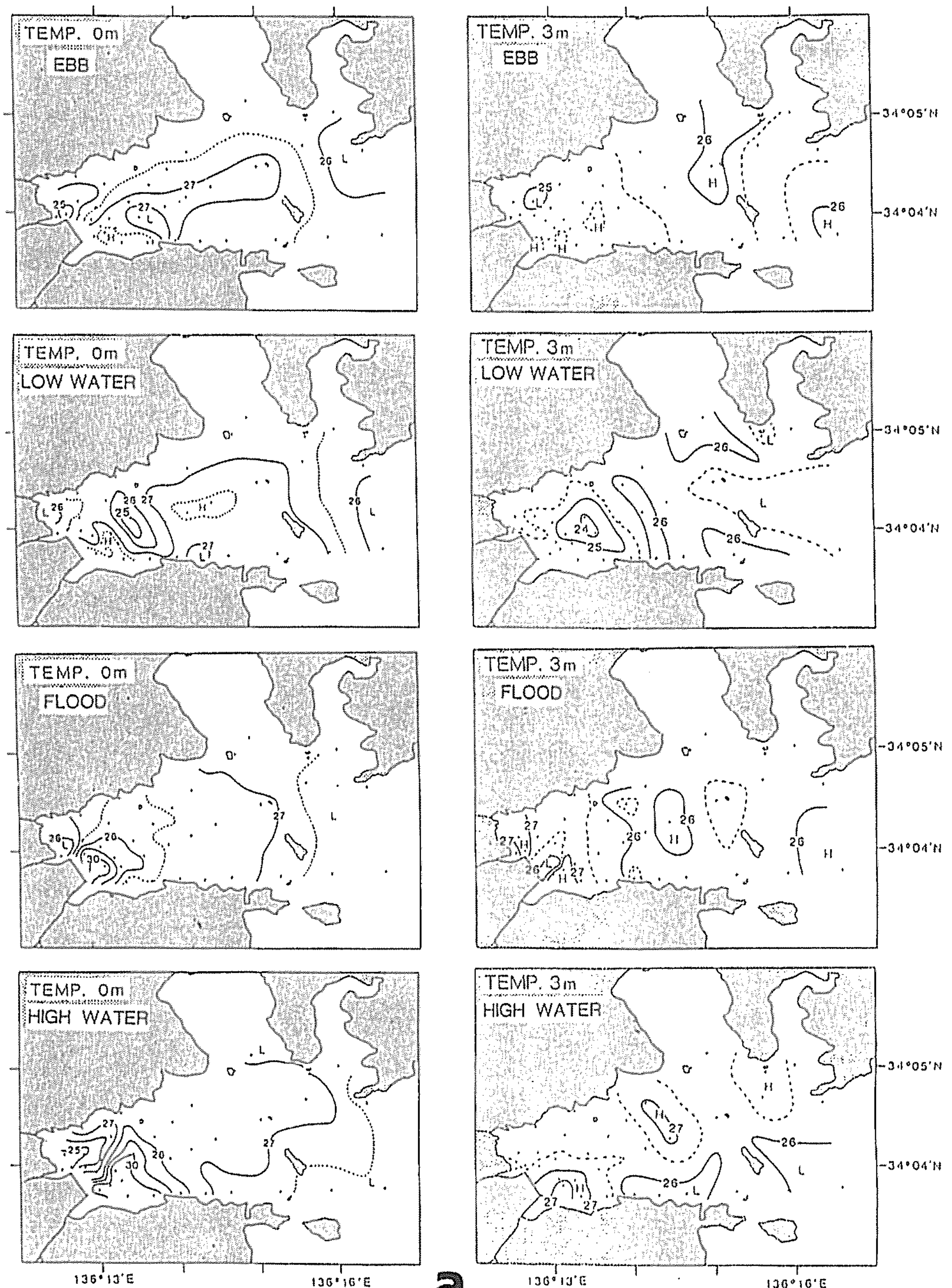


Fig. 7. Same as Fig. 4 but for 11 August in 1987.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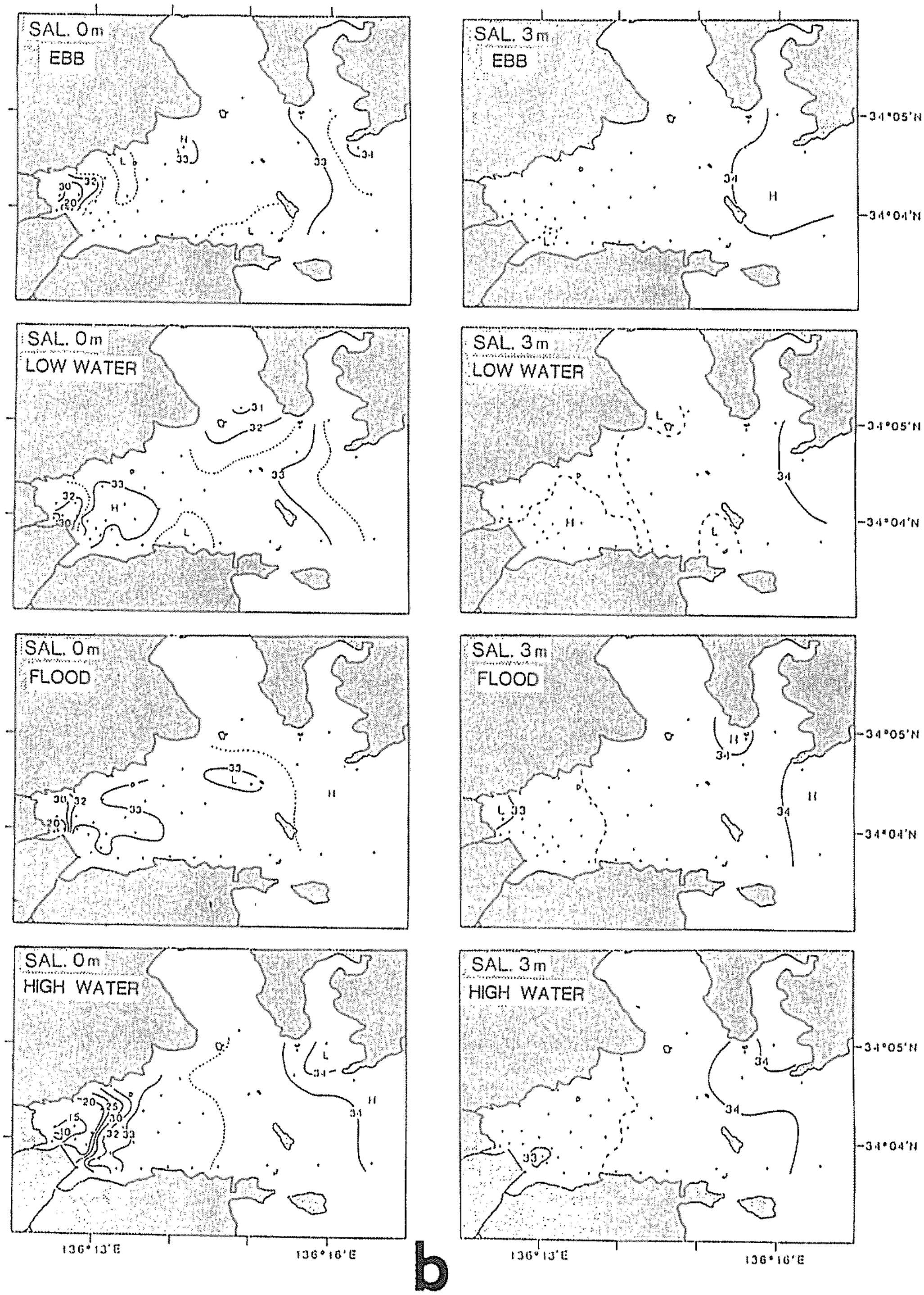
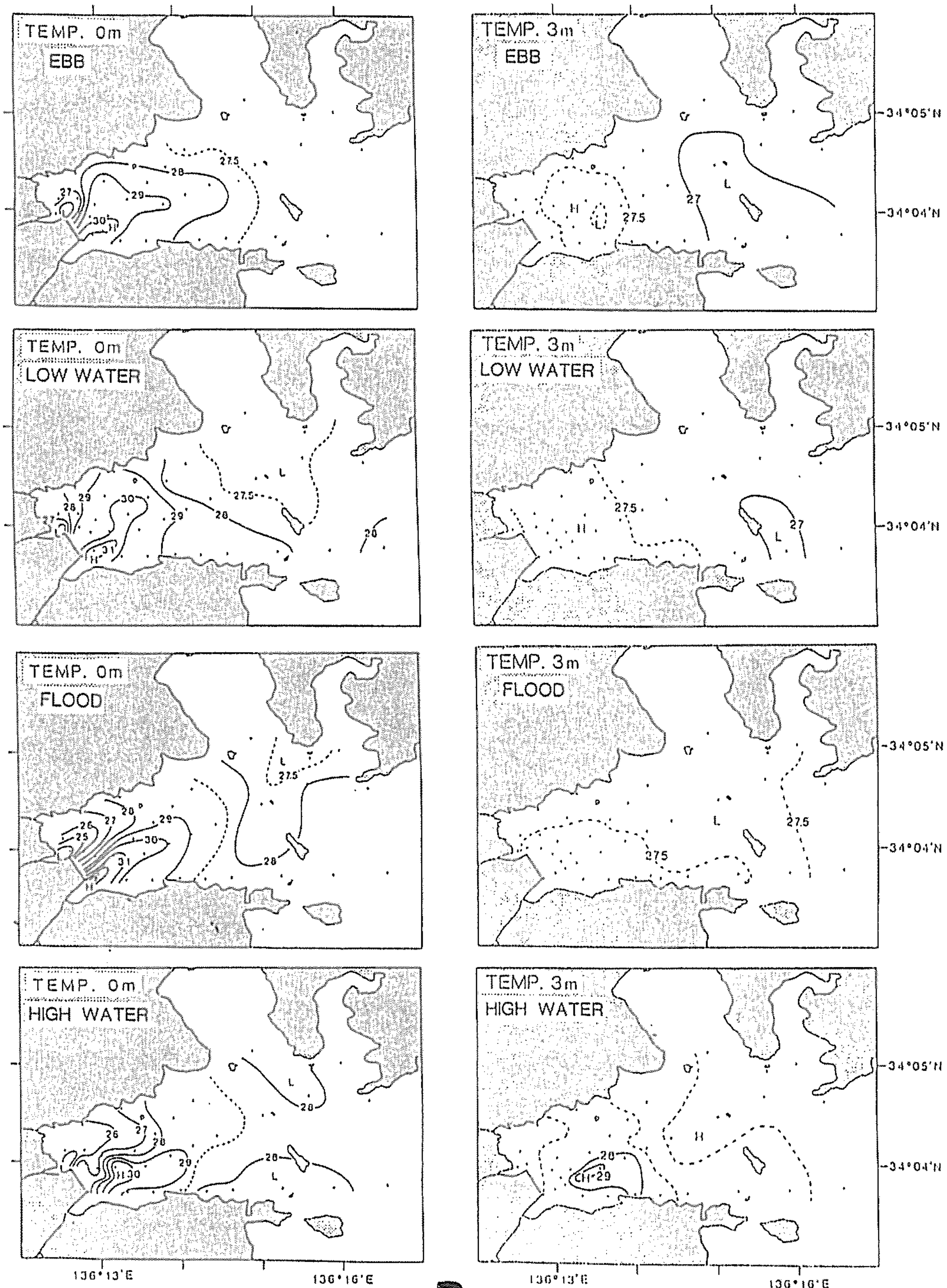


Fig. 8. Same as Fig. 4 but for 19 August in 1987.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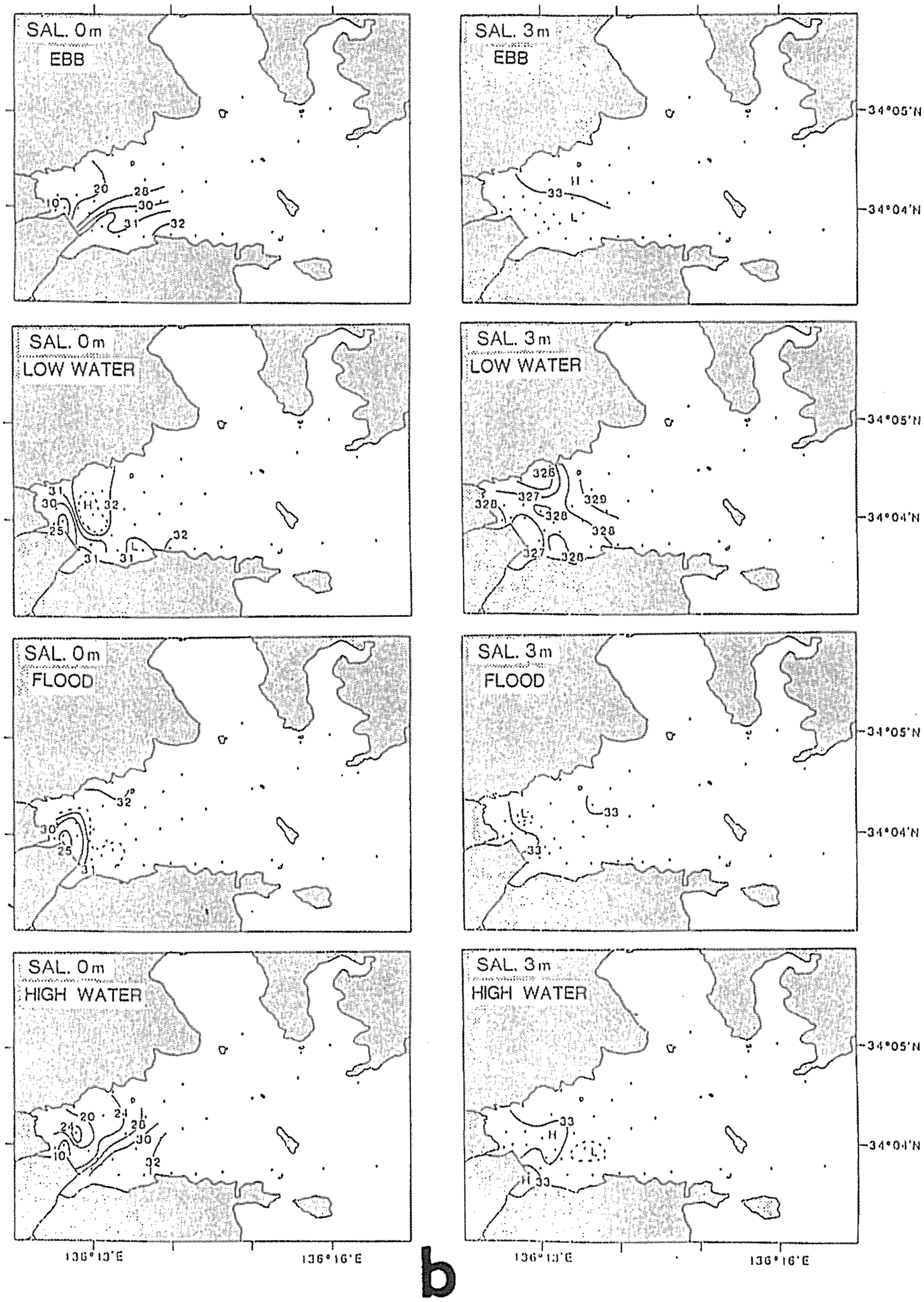
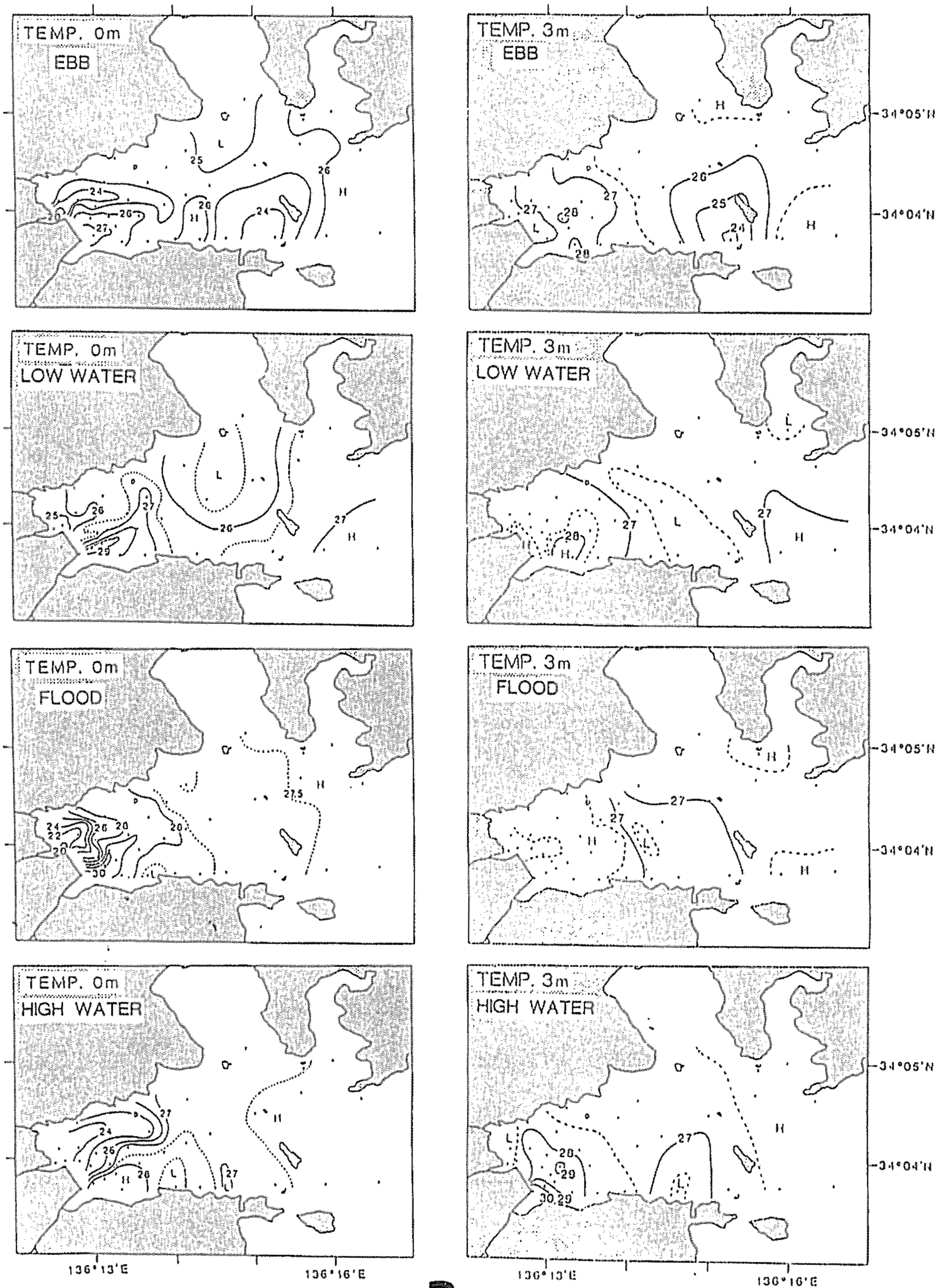


Fig. 9. Same as Fig. 4 but for 20 August in 1990.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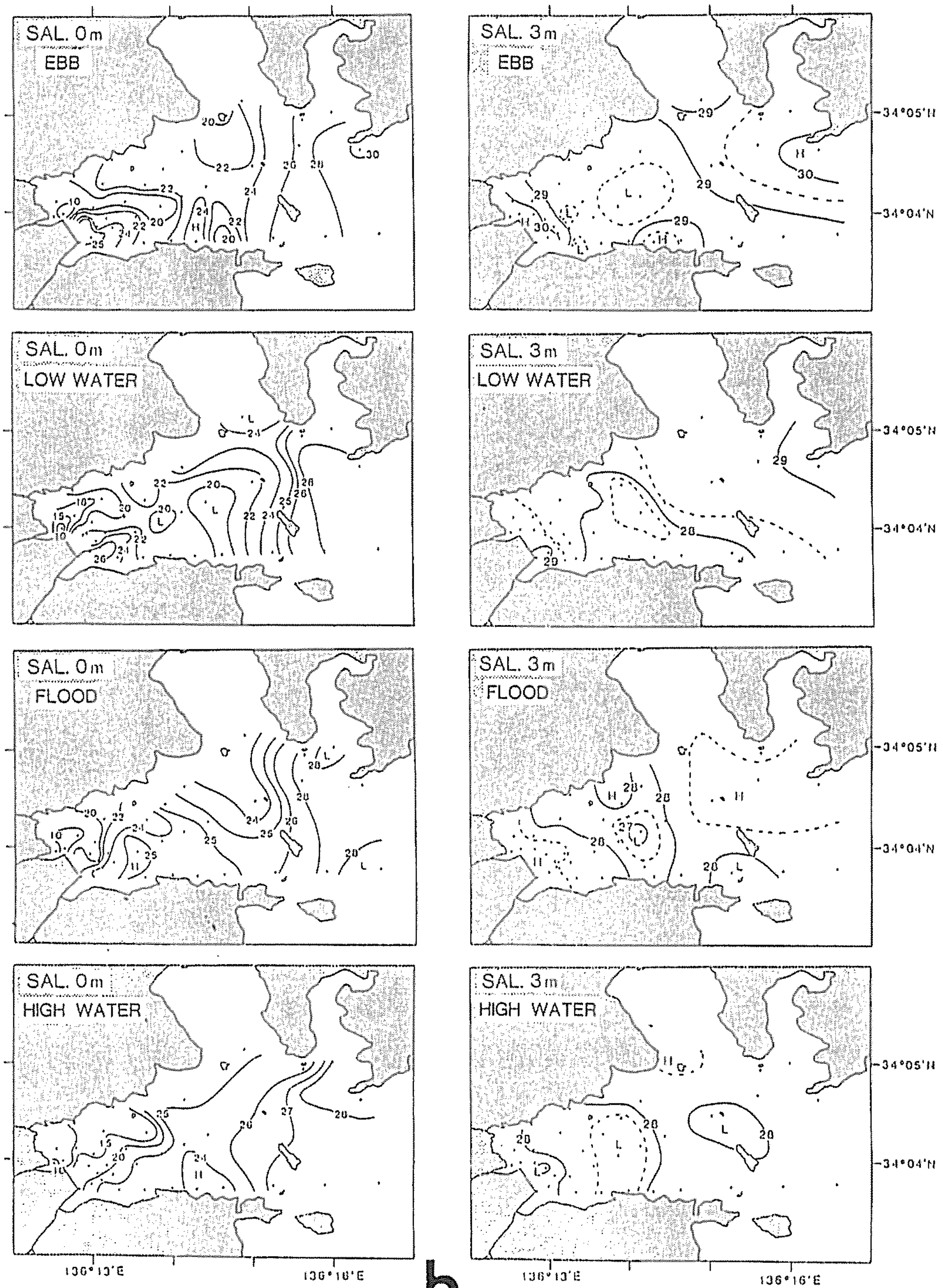

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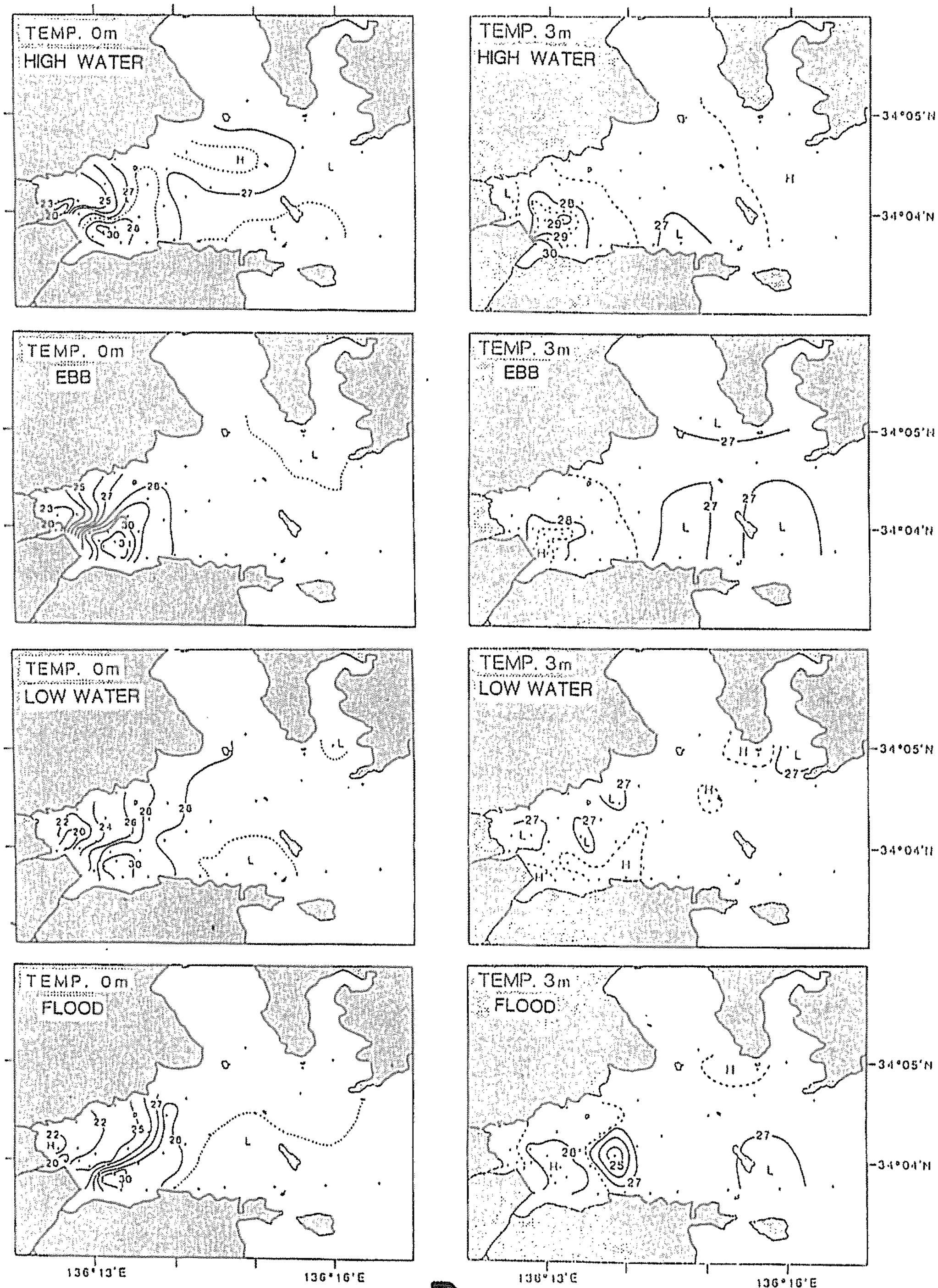
Fig. 10. Same as Fig. 4 but for 26 August in 1988.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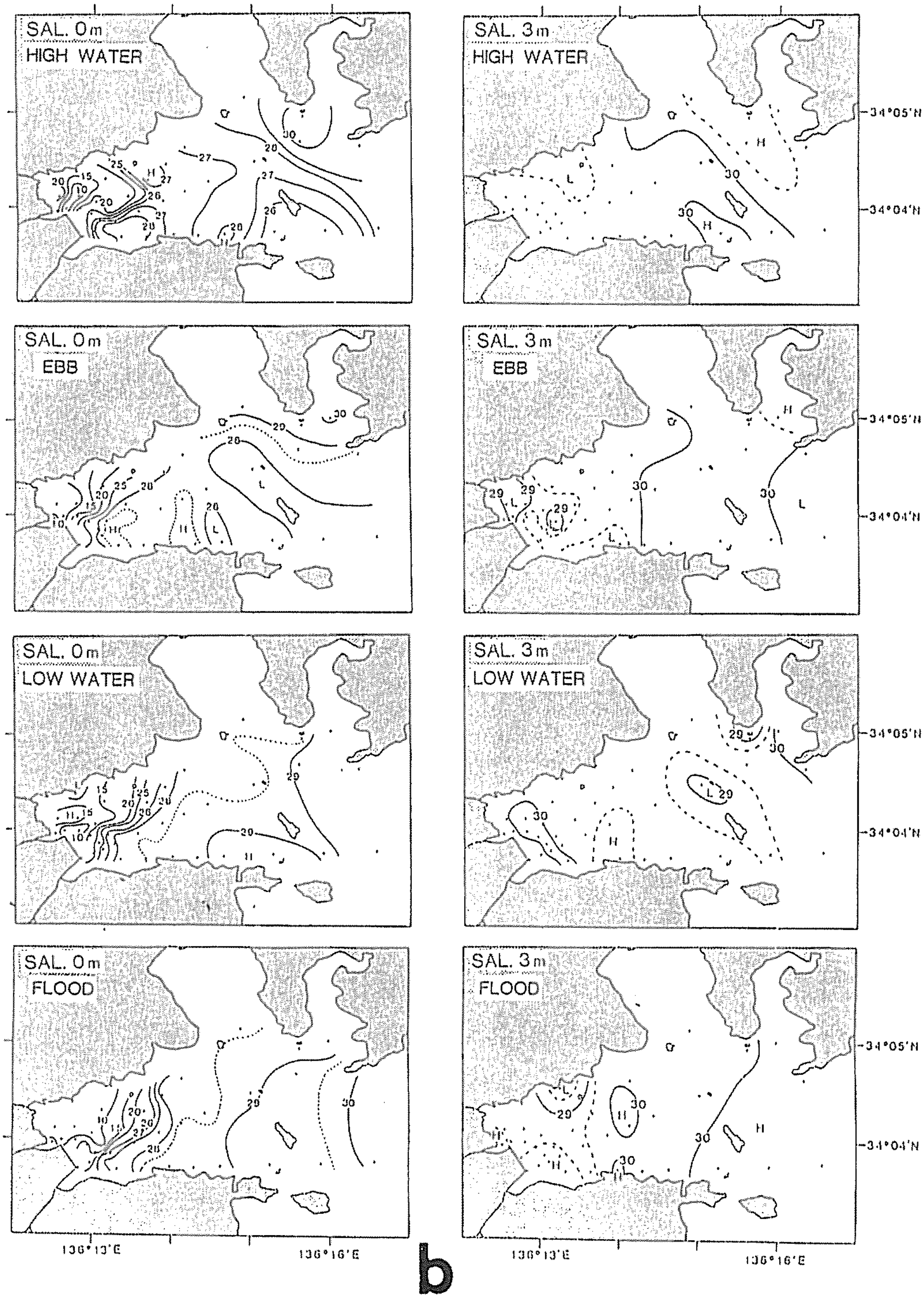
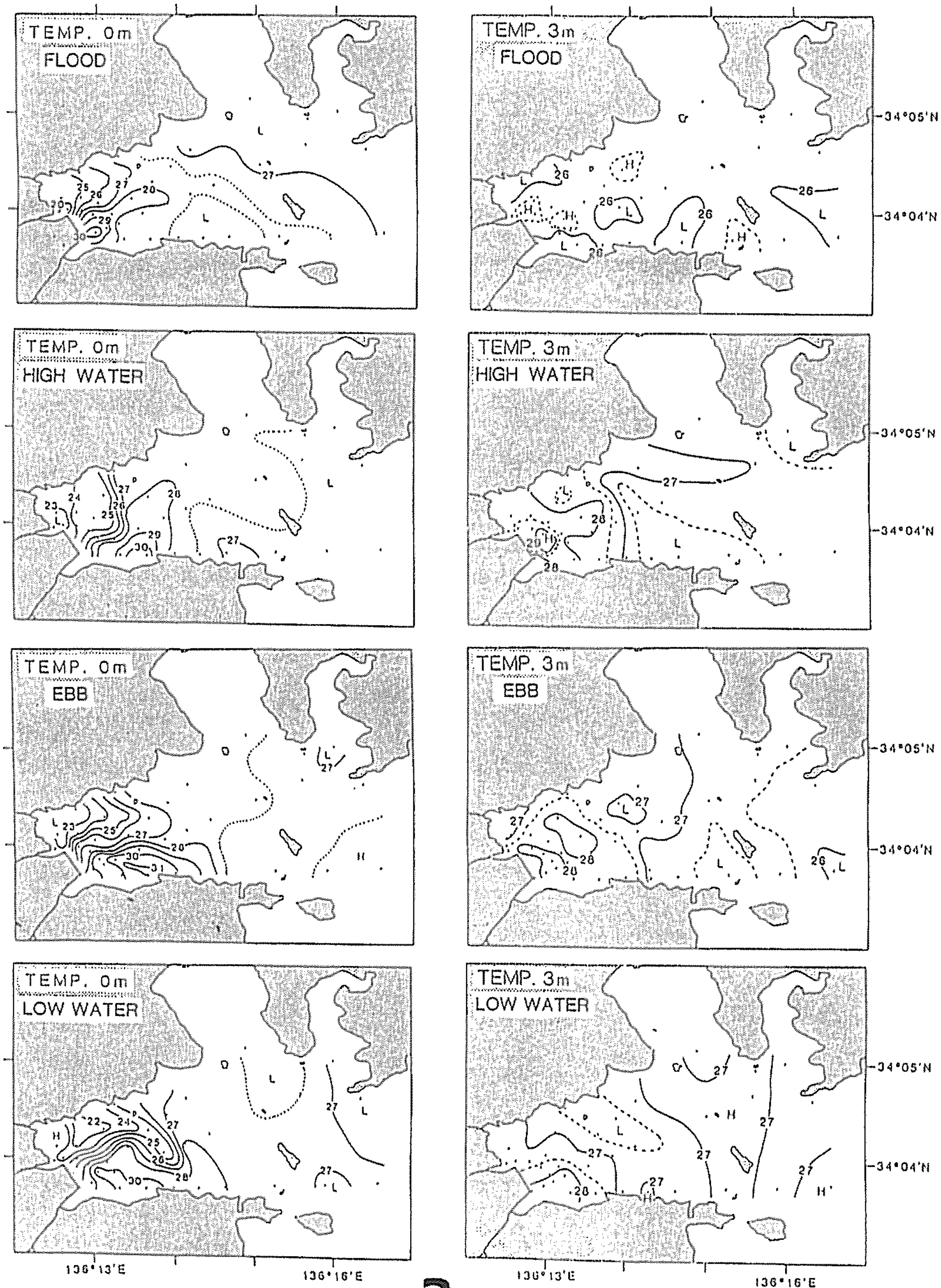


Fig. 11. Same as Fig. 4 but for 2 September in 1988.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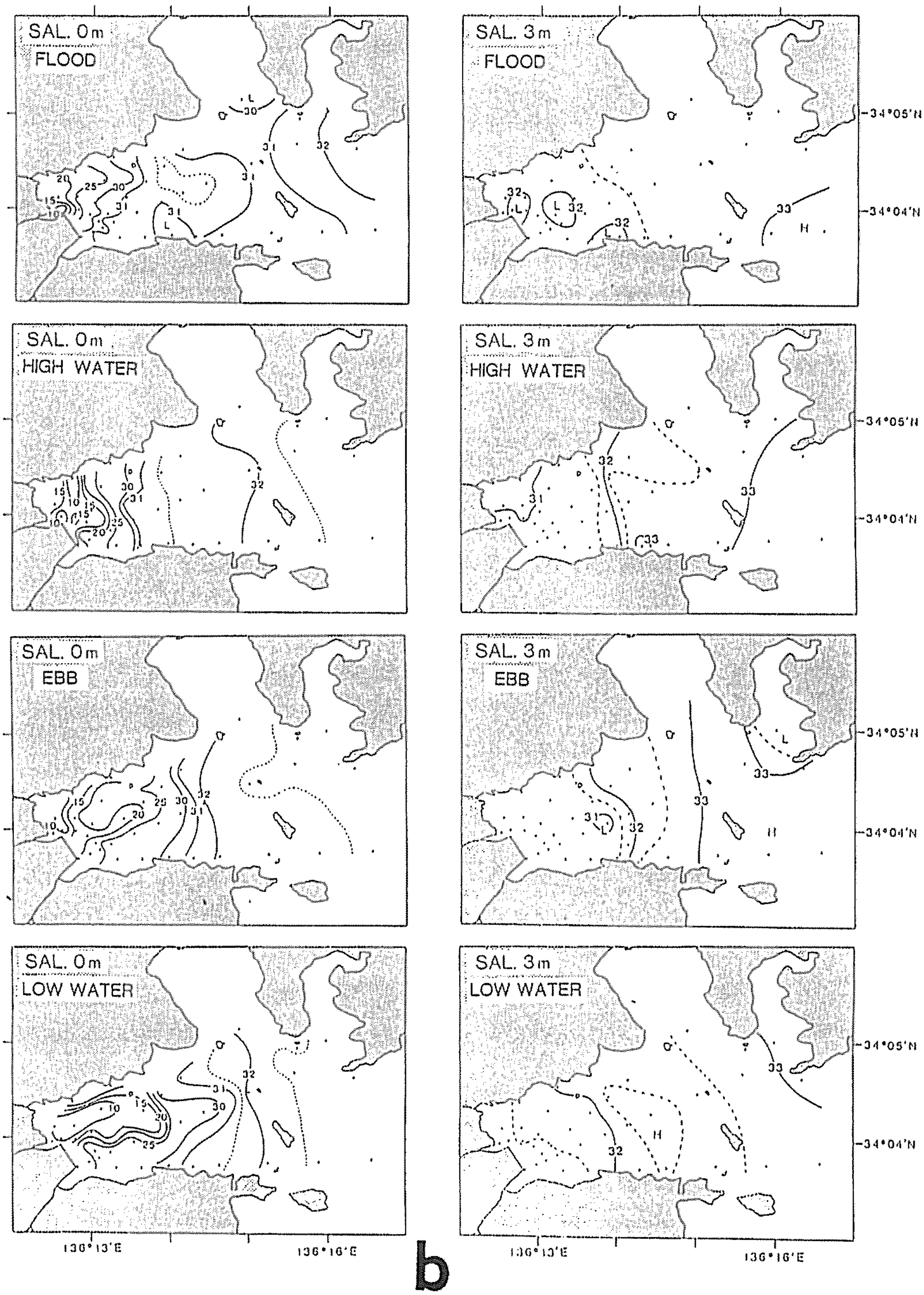
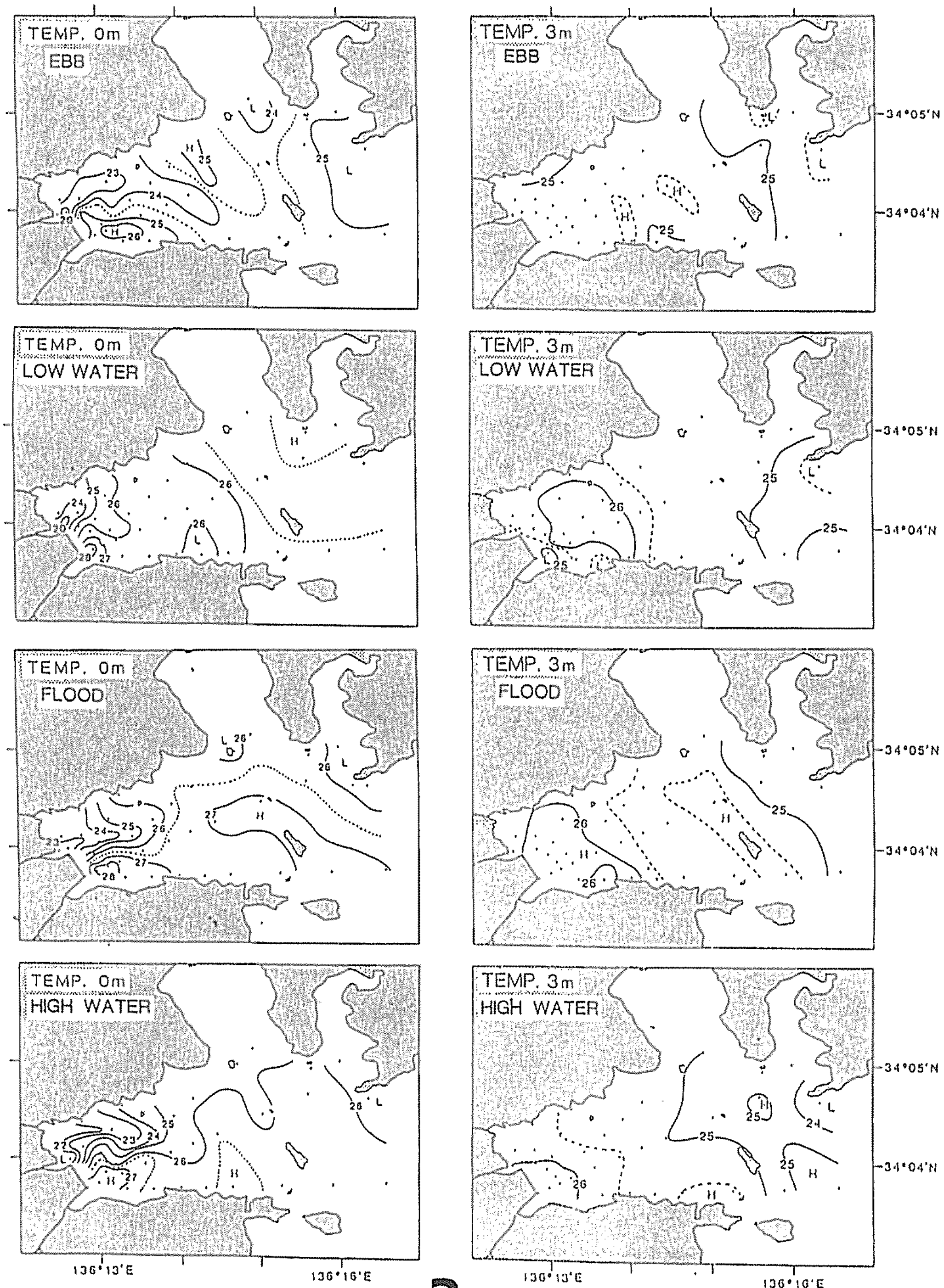


Fig. 12. Same as Fig. 4 but for 25 August in 1989.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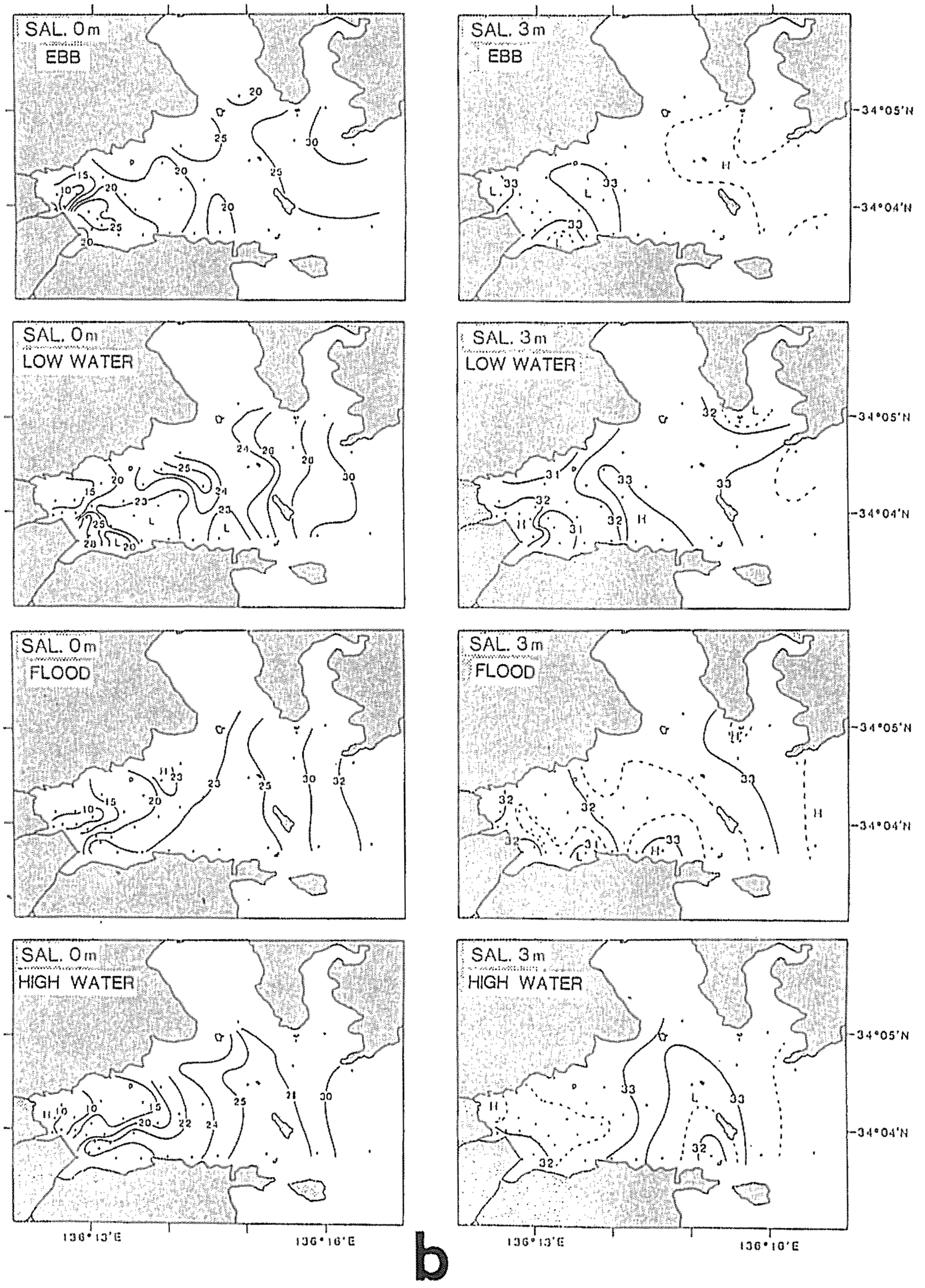
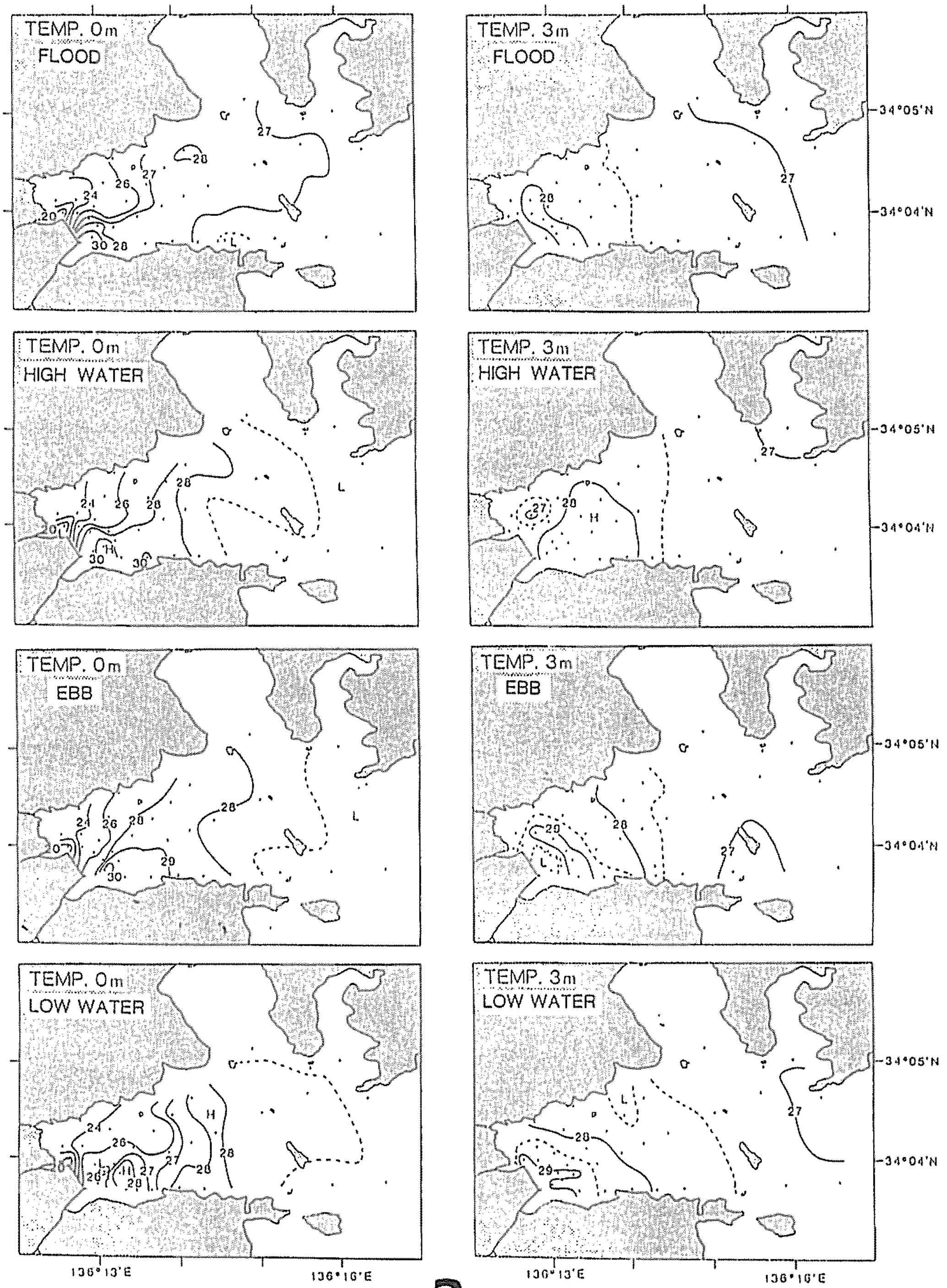


Fig. 13. Same as Fig. 4 but for 31 August in 1989.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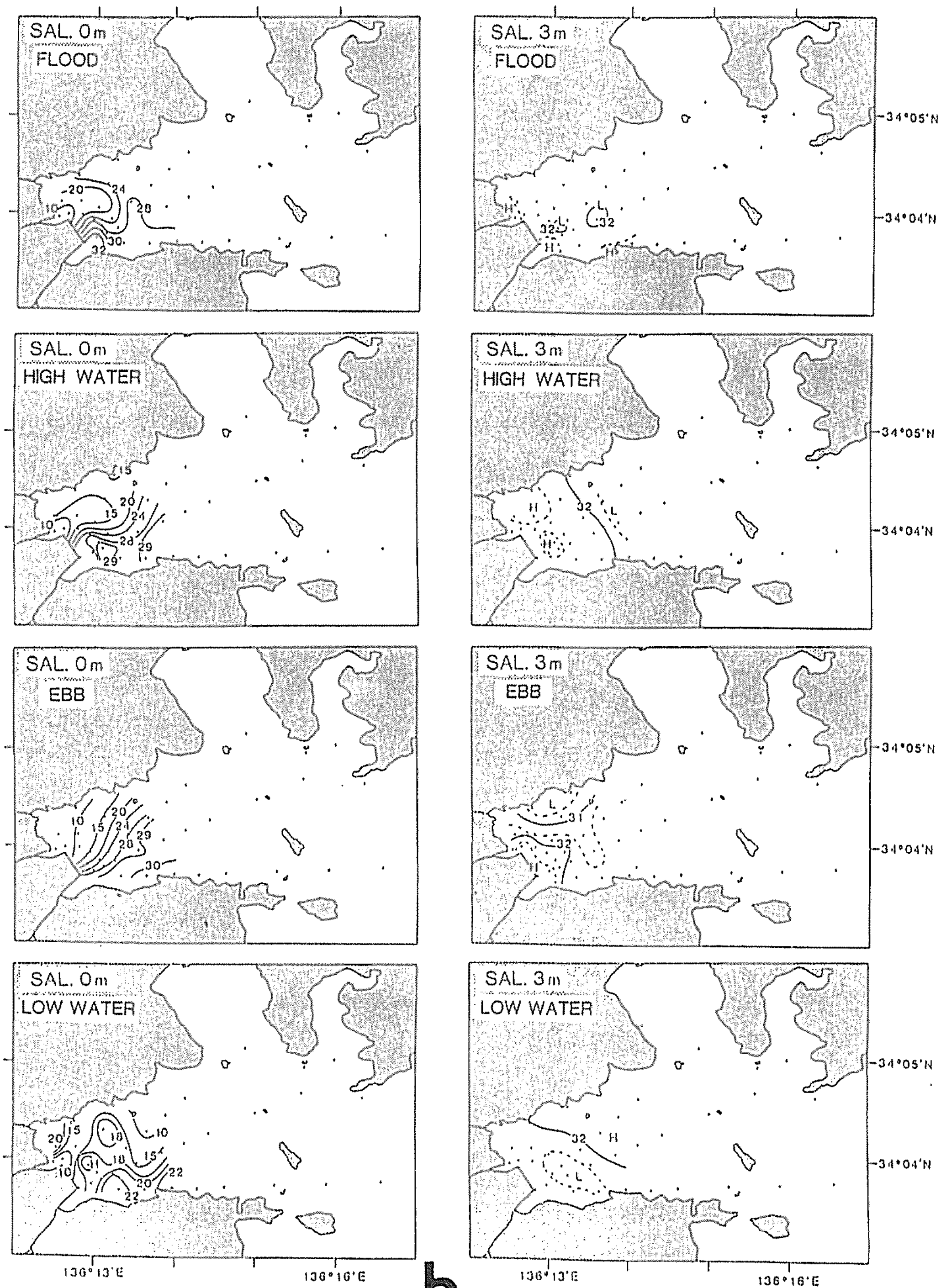

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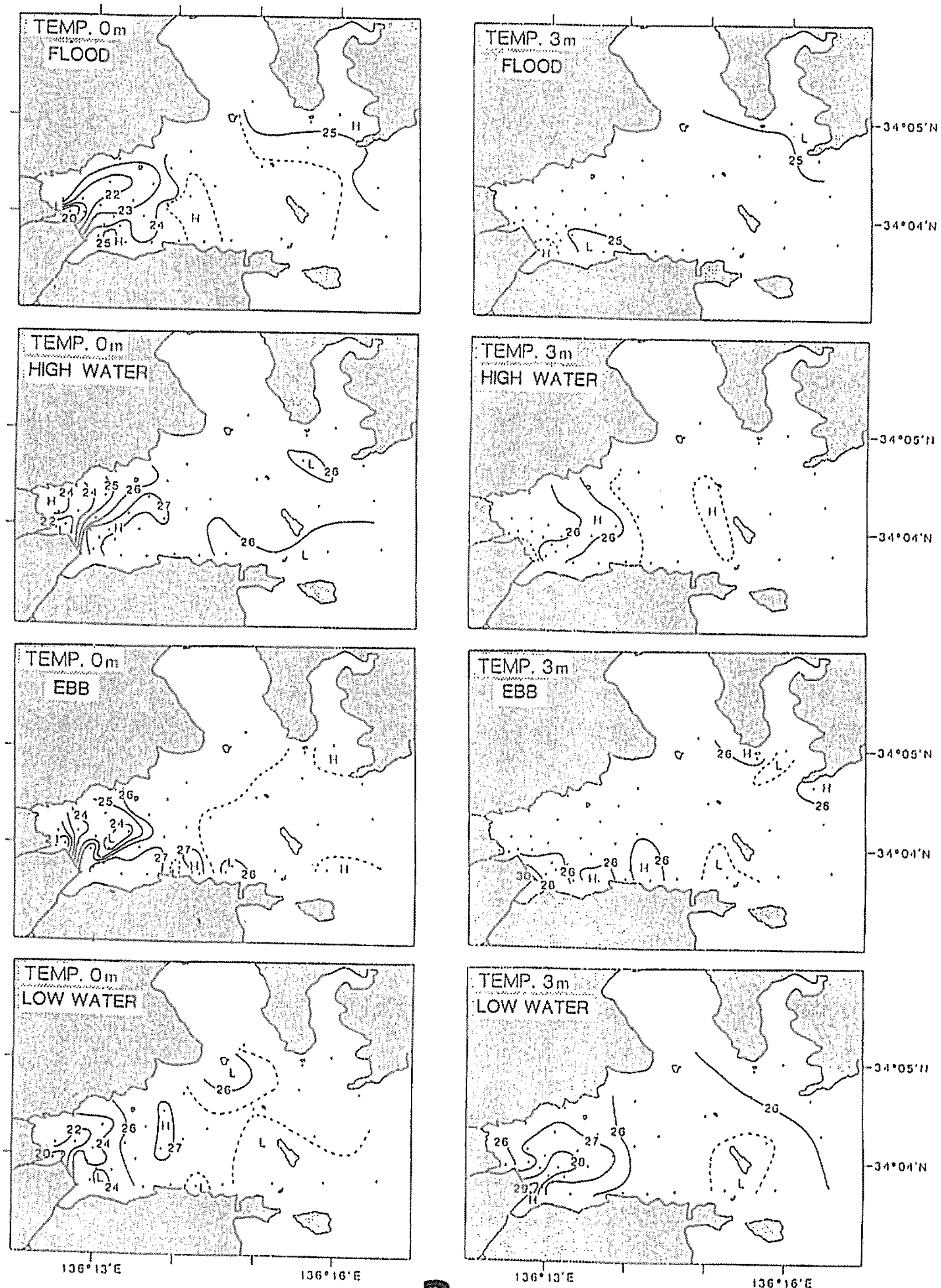
Fig. 14. Same as Fig. 4 but for 28 August in 1990.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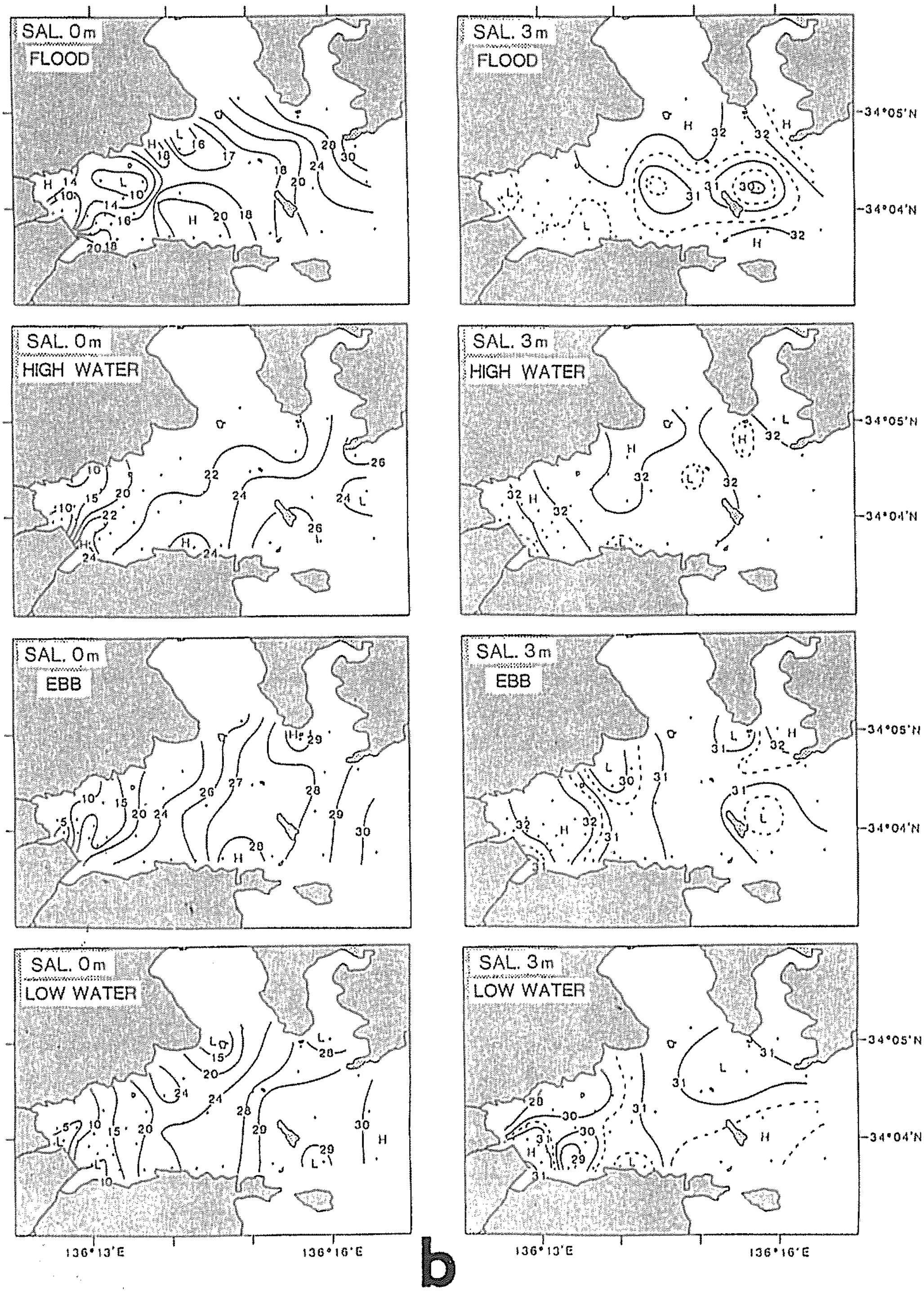

Fig. 15. Same as Fig. 4 but for 2 September in 1991.

Table 2. Classification of observation in view of water effluence

Group	Observational season	Water effluence		Corresponding observation (Figures)	
		Warm water	Fresh water		
I	Spring	—	—	86API-IV	(Fig. 3)
				89API-IV	(Fig. 4)
II	Summer	Small	Variable	86JLI-IV	(Fig. 5)
				86AGI-IV	(Fig. 6)
				87AGI-IV	(Fig. 7)
III	Summer	Large	Variable	87AGV-VIII	(Fig. 8)
				90AGI-IV	(Fig. 9)
IV	Summer	Large	Const.	88AGI-IV	(Fig. 10)
				88SPI-IV	(Fig. 11)
				89AGI-IV	(Fig. 12)
				89AGV-VIII	(Fig. 13)
				90AGV-VIII	(Fig. 14)
				91SPI-IV	(Fig. 15)

main characteristic features revealed by the observations are described as for the four Groups in Table 2.

As for the Group (I), a cold sea surface temperature (SST) less than 16°C intrudes northeastward in periods of ebb on 25 April 1986 (Fig. 3). Since no cold water less than 16°C is found at a depth of 3 m, thickness of effluence of fresh water is less than 3 m. As no effluent of fresh water was made in three hours before the observation in period of flood (Table 1), cold water less than 16°C is not detected. SST warmer than 21°C is found in periods of flood and high water. The warm water also exists at a depth of 3 m.

Almost similar characteristics to 25 April in 1986 (Fig. 3) are seen on 13 April in 1989 (Fig. 4a). A warm SST is detected in a southern area of the bay. Because of the increment of effluent of cold fresh water, cold water expands to eastward in period of low water. At a depth of 3 m, no significant spatial changes in temperature are found. There exist a warmer water under the area with warm SST, which is common to Fig. 3. Horizontal distribution of salinity (Fib. 4b) has a similar pattern to that of temperature: fresher water less than 30 psu occupied in west of 136°13′ in ebb period and it spreads significantly eastward in periods of low water.

During the observation of Group (II) in summer, volume of effluent of fresh water is changed, but that of warm water is constant (Tables 1 and 2). The horizontal distribution of temperature and salinity of Group (II) are shown in Figs. 5, 6 and 7. On the whole, it is shown that less saline water originated from effluent of fresh water has a tendency to extend more eastward in periods of ebb and low water: at a surface, less saline water less than 20 psu occupies western half of the bay in low water periods on 29 July in 1986 (Fig. 5), in which volume of effluent of fresh water before three hours of observation is 8.1 $m^3 sec^{-1}$ (Table 1). Conversely, even though large fresh water effluence of 24.2 $m^3 sec^{-1}$ are made in flood periods on 8 August in 1986 (Fig. 6) and 11 August in 1987 (Fig. 7), less saline water less than 20 psu occupies relatively small area in innermost of the bay. Here, although observations on 11 Aug. 1987 was carried out after the increase of the thermal electric plant in June 1987, the full power generation was not made in the observational period. So, this observation is classified into Group II.

Because effluent of fresh water of Group (III) is almost same to Group (II) (Tables 1 and 2), the influence of increment of effluent of warm water should be focused in the results of Group (III). On 19 August in 1987 (Fig. 8), a warm water more than 27°C occupies wider area for all the observational periods. It is noted that a cold saline water less than 25°C and more than 33 psu appears suddenly in periods of low water. Because this water mass has no relationship to those of other observations, details of the warm saline water is unknown.

On 20 August in 1990 (Fig. 9), a warm water more than 28°C occupies wider area in the bay west to 136°15′ and significant warm water more than 30°C appears in all the tidal periods. Warming is also found at a depth of 3 m: mean temperature of Fig. 8 over four times of observations is 25.9 ± 0.5°C, but that of Fig. 9 is 27.5 ± 0.1°C. On the whole, there exists a different characteristics between the results of two observations of Group (III). Because the increase of total volume of warm water effluence before the observation of Fig. 8 is very small (Table 1), the influence of large warm effluent is suggested to be weak. Conversely, sufficient time with large effluent has passed for the case of 20 August in 1990 and the influence of large effluent is relatively large.

Main characteristics of the Group (IV) is a large constant effluent of fresh water about 24 m^3 sec^{-1} (Table 1), which is 43% of the constant effluent of warm water. On 26 August in 1988, cold water less than 25°C expands in relatively large area in periods of ebb and high water (Fig. 10a). In contrast to this, the cold water area in period of low water is confined to innermost of the bay and its area is relatively small. This contradicts the results denoted above. However, a large cold area less than 26°C is detected at northwest of Sabaru-Jima (Sabal Island) (Fig. 1) in period of low water. It is recognized from sea surface salinity (SSS) fields (Fig. 10b) that in periods from ebb and to low water, less saline water than 20 psu spread eastward and isolated less saline water are formed. The less saline water is advected westward in periods of flood and a wider area of less saline water at innermost of the bay is formed in high water period. This results in the wider area of cold water less that 25°C in period of high water (Fig. 10a). These process agree with the previous results of the present study. On the whole, large changes of oceanic condition depending on the tidal periods are concluded.

On 2 September in 1988 (Fig. 11), similar change in tidal cycle are detected. A warmer SST than 28°C at innermost of the bay is small, it spreads gradually in periods of ebb and low water. A saline water than 28 psu, which is confined to innermost shows similar tidal change (Fig. 11b). In particular, westward advection in period of flood is significant, which is more clearly seen by isohalines of 29–30 psu. Clear difference in tidal periods are also observed on 25 August in 1989 (Fig. 12). A cold and less saline water occupying northern area of the bay intrudes eastward in period of low water. Similar prominent intrusion is found in ebb period on 31 August in 1989 (Fig. 13a), which is also indicated by less saline water extension less than 20 psu shown in Fig. 13b. These intrusions are confined to a surface layer, the intrusion is not suggested from the temperature and salinity fields at a depth of 3 m. Details of the results on 28 August in 1990 and 2 September in 1991 (Figs. 14 and 15) may not be discussed due to the lack of salinity observation and to no data of warm water effluence, respectively.

4 Summary and discussion

As an initial phase of the coastal oceanographical study on Owase Bay, the results of observations have been presented. On the whole, a significant tidal change of oceanic condition in the surface layer shallower than 3 m have been detected. In period of constant effluent of fresh water, cold and less saline water from water power generation expands in relatively large area in ebb and low water periods and it has a tendency to be confined to innermost of the bay in flood and high water periods. This suggests that advection of tidal current is important for the diffusion of thermal and fresh water effluent. However, in period of time change in fresh water effluent, expansion of the cold and less saline water depends on the volume transport of discharged water. Here, interactions between the magnitude of volume trasport and tidal period change are also suggested. It is thus concluded that the volume transport of thermal and fresh water effiuent and tidal effect are important on the hydrographic conditions of the Owase Bay.

Vertical distributions of temperature and salinity will be discussed in a succeeding paper. Basing on these basic observational data, some quantitative study by use of numerical model will be possible. However, it is suggested from the significant tidal period change that detailed observations at eastern open (artificial) boundary of modeling of Owase Bay is strongly needed so as to give the adequate boundary condition in the numerical model. These observations will be also carried out in near future.

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尾鷲湾内部の水温・塩分の水平分布

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尾鷲湾は日本中部の紀伊半島に位置し，その海況は火力発電による温排水と水力発電による淡水の放出による。1986年4月より1991年9月にかけて13回の水温・塩分の観測を行った。観測結果の最初の報告として，水温と塩分の水平分布を示した。淡水の放出による低塩分低温度の水の張り出しが落潮時と干潮時に観測され，顕著な潮時ごとの海況の変化が認められた。これらの変化は海面近くに集中し，3m層では認められない。