Fol. 41B

International Council for the
Exploration of the Sea

Fish Capture Committee
C.M. 1995/B:12, Ref. H

Diurnal variations in acoustic density measurements of wintering Norwegian spring spawning herring

by

Ingvar Huse and Rolf Korneliussen
Institute of Marine Research
P. O. Box 1870, N-5024 Bergen, Norway

ABSTRACT

Survey data from six herring assesment cruises in the wintering areas for spring spawning Norwegian herring were analysed with regard to variation in abundance and depth with time of day. The data were quite consistant between cruises, showing a downwards vertical migration at *in situ* dawn and an upwards migration at dusk, with a subsequent descent of parts of the herring through the dark period. This behaviour was attributed to schooling and predator avoidance during the day, and energy conservation and swimbladder refilling during the night. There were significantly high average S_A values during the short winter day compared to very low values at dawn and dusk, and also quite low values at night. This variation was mainly attributed to articulate angular distribution of the herring during dusk and dawn, and also during the night time swim/sink/glide energy conservation exercise. The implications on assesment surveying is discussed.

INTRODUCTION

The entire adult stock of spring spawning Norwegian herring has been hibernating during fall and winter in Tysfjord and Ofotfjord in Northern Norway over the last few years. The herring enter the fjords in September/October, and stay until January/February when the spawning migration commences. The herring barely feed during this period, and consequently concentrate on avoiding predation and conserve energy. In order to avoid predation, the herring school when and where illumination is above the schooling threshold. They also generally stay deep during the daylight hours to avoid the predominantly visual predators in the fjord, mainly cod, saithe and killer whales. In order to concerve energy, a strategy of alternating upward swimming and downward gliding is adapted (Huse et al. 1994).

The location of the entire adult fraction as well as some of the juveniles of this large herring stock in these two fjords creates a very good situation for acoustic abundance estimates, which is taken advantage of both for routine measurements and for methods development including studies of behaviour with consequences for the acoustic abundance estimation methodology (Røttingen et al. 1994). Huse et al. (1994) showed that as a consequence of its energy conservation strategy, the herring exhibited a variety of body tilt angles for different depths and times of day. This might be expected to affect acoustic density measurements as it is well known that acoustic target strength is a function of body tilt angle for herring (Olsen and Nakken 1978; Foote and Nakken 1978). As the herring is a physostomous fish, with no known gas production capasities, it is also likely that depth will influence their acoustic back scattering properties. Consequently, as the wintering herring exhibit substantial vertical migration day and night, and also have adapted a depth maintenance strategy which at times will cause substantial body tilt angles, it is of interest to investigate if this will induce noticable diurnal effects on acoustic density measurements. The present study therefore includes the six latest assessment surveys carried out in the area, from November/December 1992 to January 1995. All acoustic measurements made during these surveys are included, and they are grouped by depth and time of day in order to find if there is systematic variation in acoustic density measurements of herring with these parameters.

MATERIALS AND METHODS

The materials for this investigation were collected during six survey cruises with R/V "Johan Hjort" and R/V "G.O. Sars" in December and January from December 1992 to January 1995. Surveys were carried out on a 24 hour basis. Between 2 and 4 million tons of herring were present in the survey area during the cruises. All S_A values were collected at 38kHz with Simrad EK500 sounder and were post-processed with the Bergen Echo Integrator software. All data used were stored with a resolution of 0.1 nautical mile horizontally and 10 m vertically. All scrutinized data from these surveys were used without any form of selection. Data were corrected for density dependent extinction according to the methods described by Foote et al. (1992) and Foote (1994). A more detailed description of the survey methodology is given by e. g. Røttingen et al. (1994). Files of scrutinized data were extracted from the acoustic database and transformed into tables with S_A values for each 10 m depth channel down to either 320 or 400 m, and all data were grouped into hourly values by generating the means of all values recorded within one hour. Also 0-values were included in the means. On this basis, isoplethe diagrams with average S_A values against depth and time of day were produced. All times used in diagrams are UTC, which is about two hours less than geographical time for the survey area. Times of day are given as the starting point of the hour, meaning that the hour 12:00 to 13:00 is given as 12. Also, depth channels are given as the starting depth, meaning that e. g. 210-220 m is given as 210 m. The standard error bars of Fig. 7 are generated from the mean hourly value for each of the six cruises, and they represent +/- 1 SE.

RESULTS

Figures 1 to 6 are isoplethe diagrams of S_A values plotted against depth and time of day for each of the six cruises. Generally they all tell the same story, with a consentration of herring from 2-300 m between 10 and 12, and a subsequent vertical migration to 50-150 m from where the herring seem to disperse vertically as the night progresses. Looking at the spring (Fig. 7) and fall (Fig. 8) surveys together they show the same general picture, but in spring (January) the herring tend to have a more pronounced vertical distribution with more of the fish deeper than in the fall (December) at all times of day. Figure 9 shows all cruises together and can of course only explanation is that in the daytime the herring probably are schooling even at depths down to 2-300 m. Schooling herring generally swim horizontally. The tilt angle with the horizontal plane is small, and consequently maximal energy is reflected back towards the transducer (Foote and Nakken 1978). In the dark period, however, the upward swim/sink/glide strategy (Huse et al. 1994) will result in an articulated angular distribution of the herring with the horizontal plane. This can lead to a substantial decrease in backscattering from the herring shoals which could explain the lower values for the hours outside of day. The difference may even be larger than indicated by the figure, as the largest herring concentrations tend to have a deeper distribution during the day than at night, which could be expected to cause the shallower values to be overestimated compared to the deeper ones due to swim bladder volume variation with depth.

Dawn and dusk values were minimal. This can illustrate the importance of tilt angle, as it probably is related to the tilt angles the herring maintain under vertical migration at dawn and dusk.

So what are the possible implications of these results on the abundance estimation situation? Obviously there is a significant diurnal variation in expected acoustically measured herring density, at least from dusk and dawn values to daytime values, but probably also from night values to day values. As long as surveys are supposed to produce relative indices and are carried out exactly the same way from year to year, it may perhaps be acceptable. The horizontal distribution of the herring may, however, vary, and consequently one may not encounter the largest concentrations at the same times of day from survey to survey. Also, the intellectual challenge of acoustic abundance methodology development is to have good absolute estimates. It is therefore adviceable to design a survey strategy which takes these conditions into account, either by stratification, by surveying at selected hours, or by generating a time and depth dynamicTS function from a herring behaviour model.

AKNOWLEDGEMENT

The help from Bjørn Totland in transforming the data material is gratefully aknowledged.

corraborate and enhance the impression from each of the cruises. Figure 10 shows mean diurnal S_A values for all cruises. High values are in the middle of the day, and the lowest values seem to be connected with the establishment and dispersal of the daytime concentration. Night time values are generally lower than day time values.

DISCUSSION

The overall picture of the vertical distribution pattern of hibernating herring conforms well with the kind of survival/energy conservation strategy proposed by Huse et al. (1994). The herring stay deep, probably scooling during the day. A large part of the population then migrates vertically to upper water layers when dusk sets in and the risk of predation from visual predators is decreased. The ascent could be undertaken in order to reduce energy expenditure during swimming due to higher buoyancy from a more inflated swim bladder closer to the surface. Also, there might be a need in parts of the stock to refill the swim bladder at the surface. It could also be that herring maintain their well established diurnal vertical migration also during this non-feeding hibernation period in order to keep contact with potential navigational cues at the surface. As night progresses, parts of the herring are dispersing downwords. Probably they are sinking while being immobile or swimming very slowly (Radakov and Solovjev 1959) and subsequently adapting the alternating upward swim and sink or downward glide suggested by Huse et al. (1994) in order to maintain depth at some level, either to school at *in situ* dawn for schooling, or at least not to sink out of their chosen range which seems to extend downwards to about 400 m.

Although very similar, the vertical distribution during spring cruises tended to be deeper than in the fall. This could be related to the onset of the spawning migration which starts in mid January and normally takes place in deeper water masses, at least in the early stages. It could also possibly be related to a decrease in lipid reserves through the hibernation period (Røttingen et al. 1994) with a consequent increase in density.

The high average S_A values during the short North Norwegian winter day compared with the lower values during the other hours can be related to several factors. The most obvious

REFERENCES

Foote, K.G. 1994. Extinction cross section of herring: new measurements and speculations. ICES C.M. 1994/(B+D+G+H):2. 10 pp.

Foote, K.G., Ona, E. and Toresen, R. 1992. Determining the extinction cross section of aggregating fish. J. Acoustic. Soc. Am., 90: 37-47.

Foote, K. and Nakken, O. 1978. Dorsal aspect target strength functions of six fishes at two ultrasonic frequencies. Fisken og havet Ser.B. 1978(3).

Huse, I., Foote, K., Ona, E. and Røttingen, I. 1994. Angular distribution of overwintering Norwegian spring spawning herring. ICES C.M. 1994/B:19, Ref. H. 14 pp.

Nakken, O. and Olsen, K. 1977. Target strength measurements of fish. Rapp. P.-v. Réun. Cons. int. Explor. Mer, 170: 52-69.

Røttingen, I., Foote, K.G., Huse, I. and Ona, E. 1994. Acoustic abundance estimation of wintering Norwegian spring spawning herring, with emphasis on methodological aspects. ICES C.M. 1994/(B+D+G+H):1. 34 pp.

Radakov, P.V. and Solovjev, B.S. 1959. The first experiments with the use of a submarine for observation of the behaviour of herring. Rybnoe chozjajstvo, 7: 16-21. [In Russian]

Figure legends:

Figure 1. Isopleths of S_A values with depth and time of day. Fall 1992.

Figure 2. Isopleths of S_A values with depth and time of day. Spring 1993.

Figure 3. Isopleths of S_A values with depth and time of day. Fall 1993.

Figure 4. Isopleths of S_A values with depth and time of day. Spring 1994.

Figure 5. Isopleths of S_A values with depth and time of day. Fall 1994.

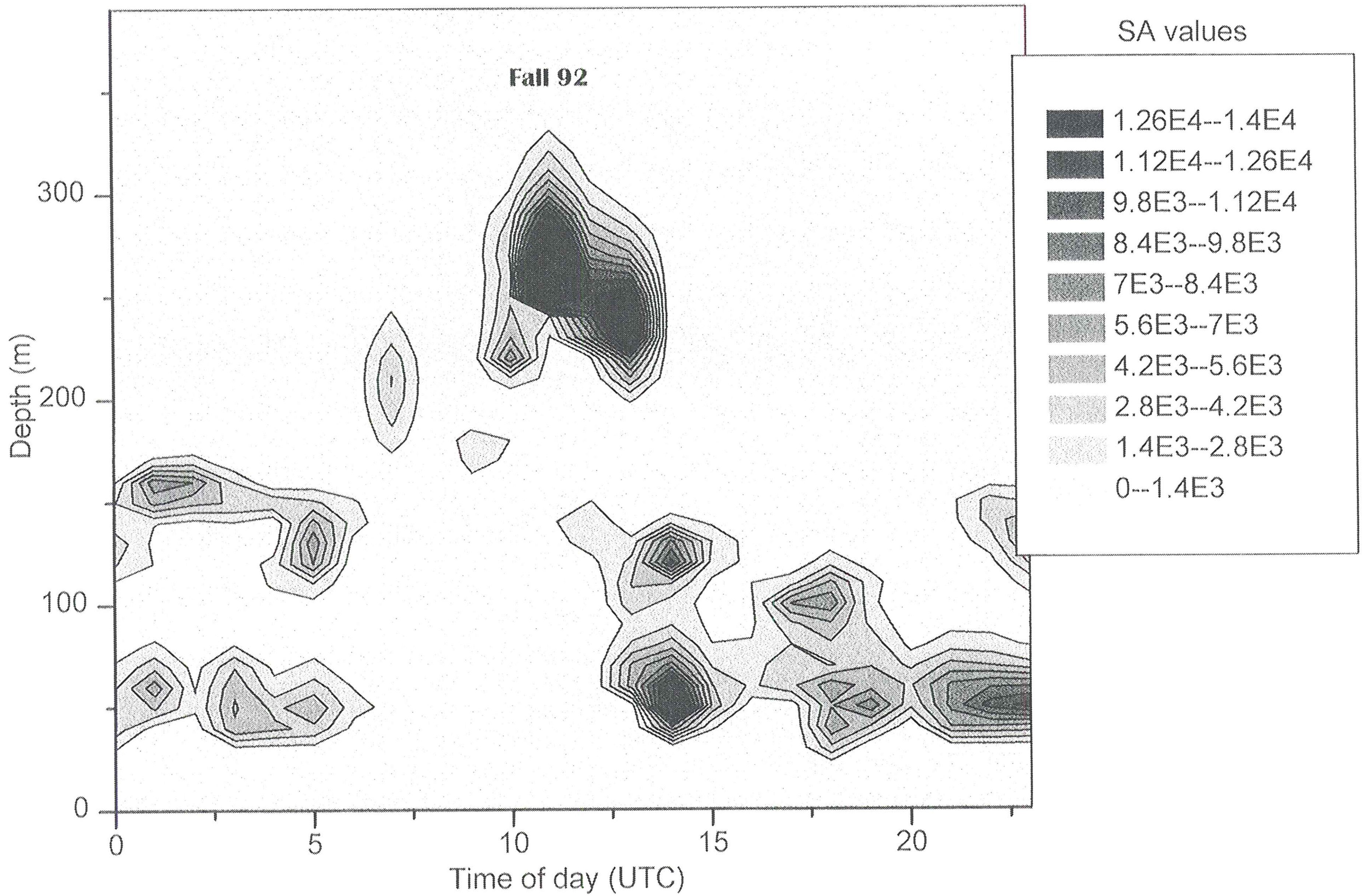
Figure 6. Isopleths of S_A values with depth and time of day. Spring 1995.

Figure 7. Isopleths of S_A values with depth and time of day. Spring surveys.

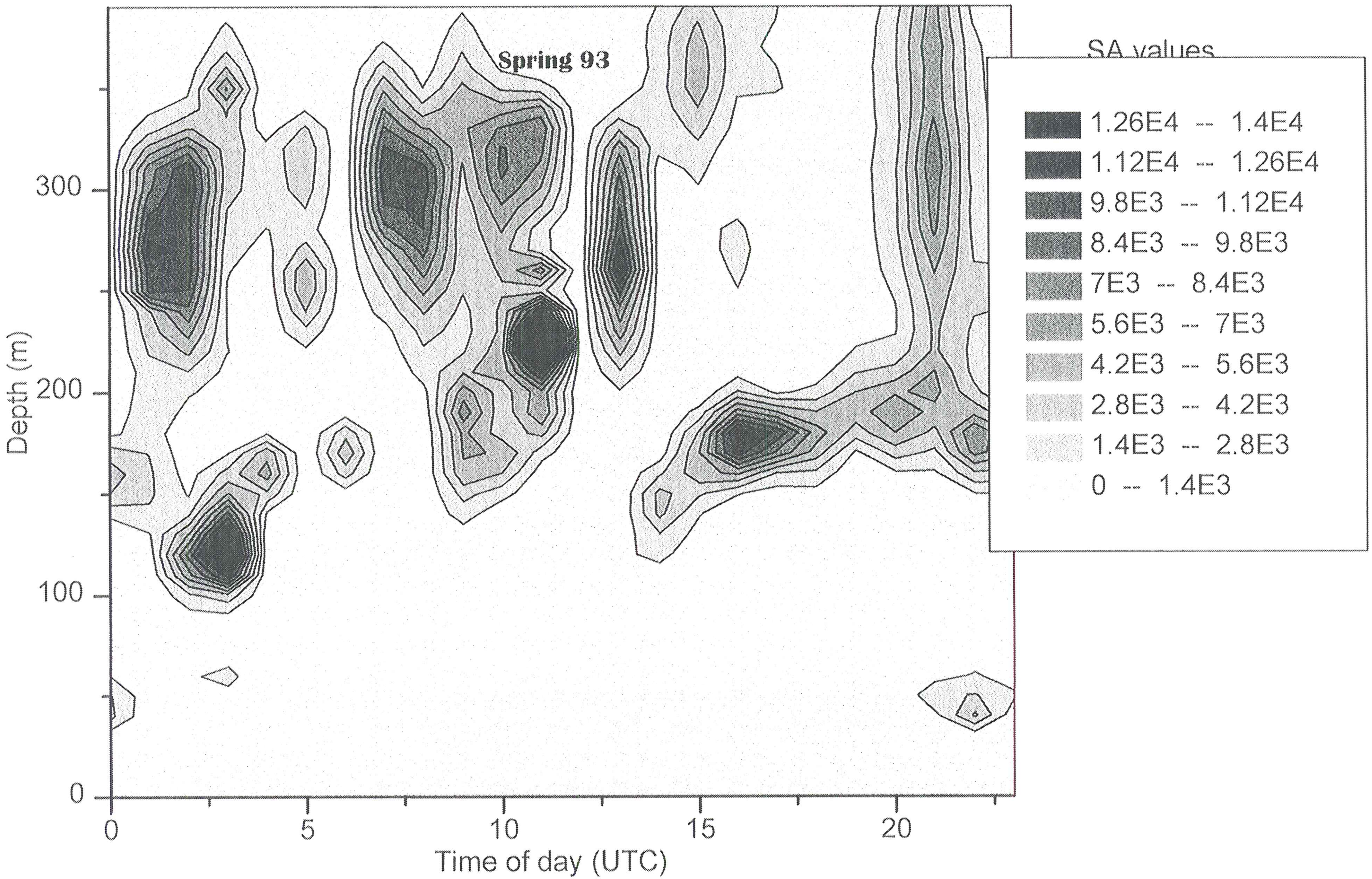
Figure 8. Isopleths of S_A values with depth and time of day. Fall surveys.

Figure 9. Isopleths of S_A values with depth and time of day. All surveys.

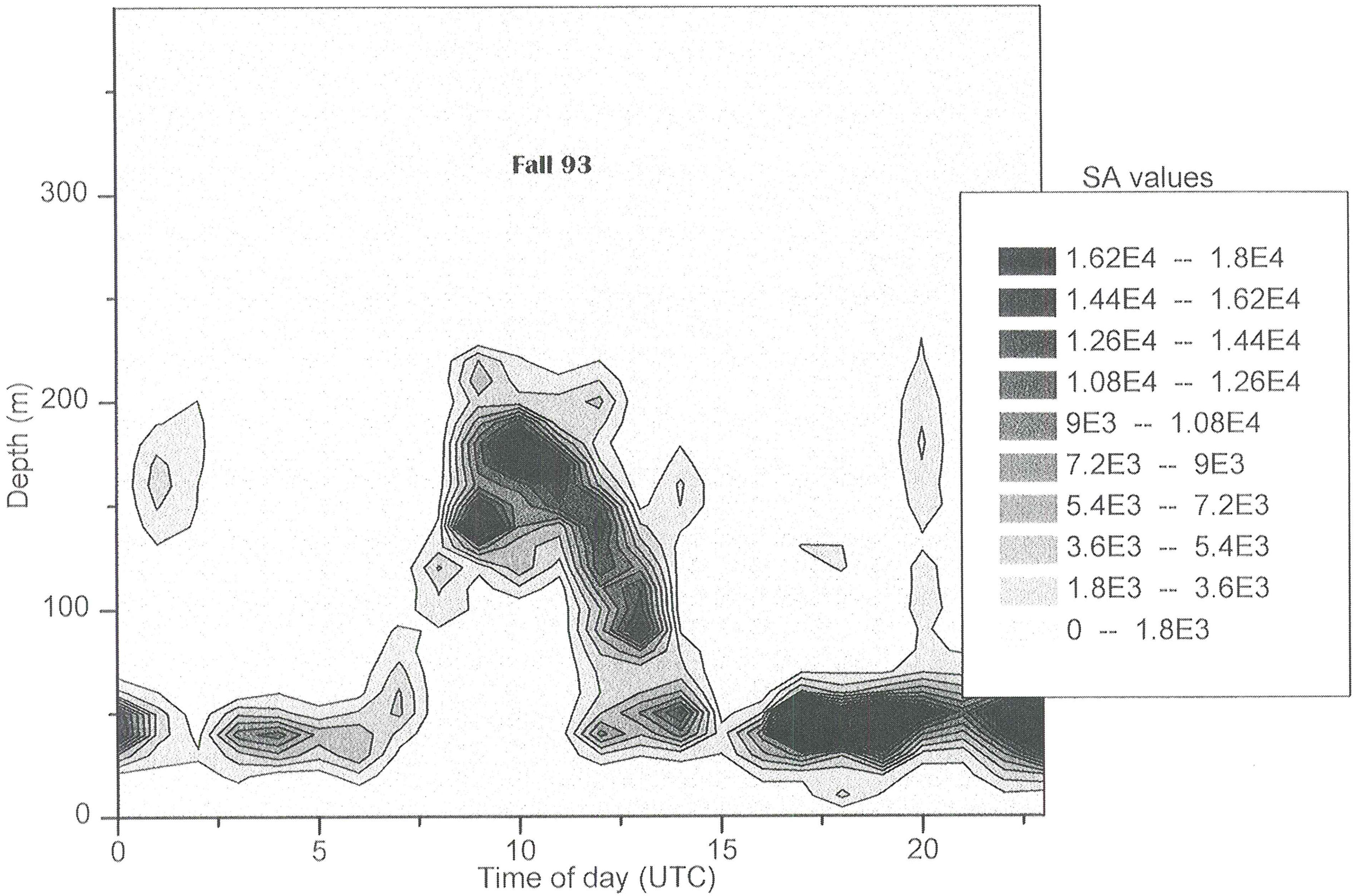
Figure 10. Mean diurnal S_A values per hour for all surveys.

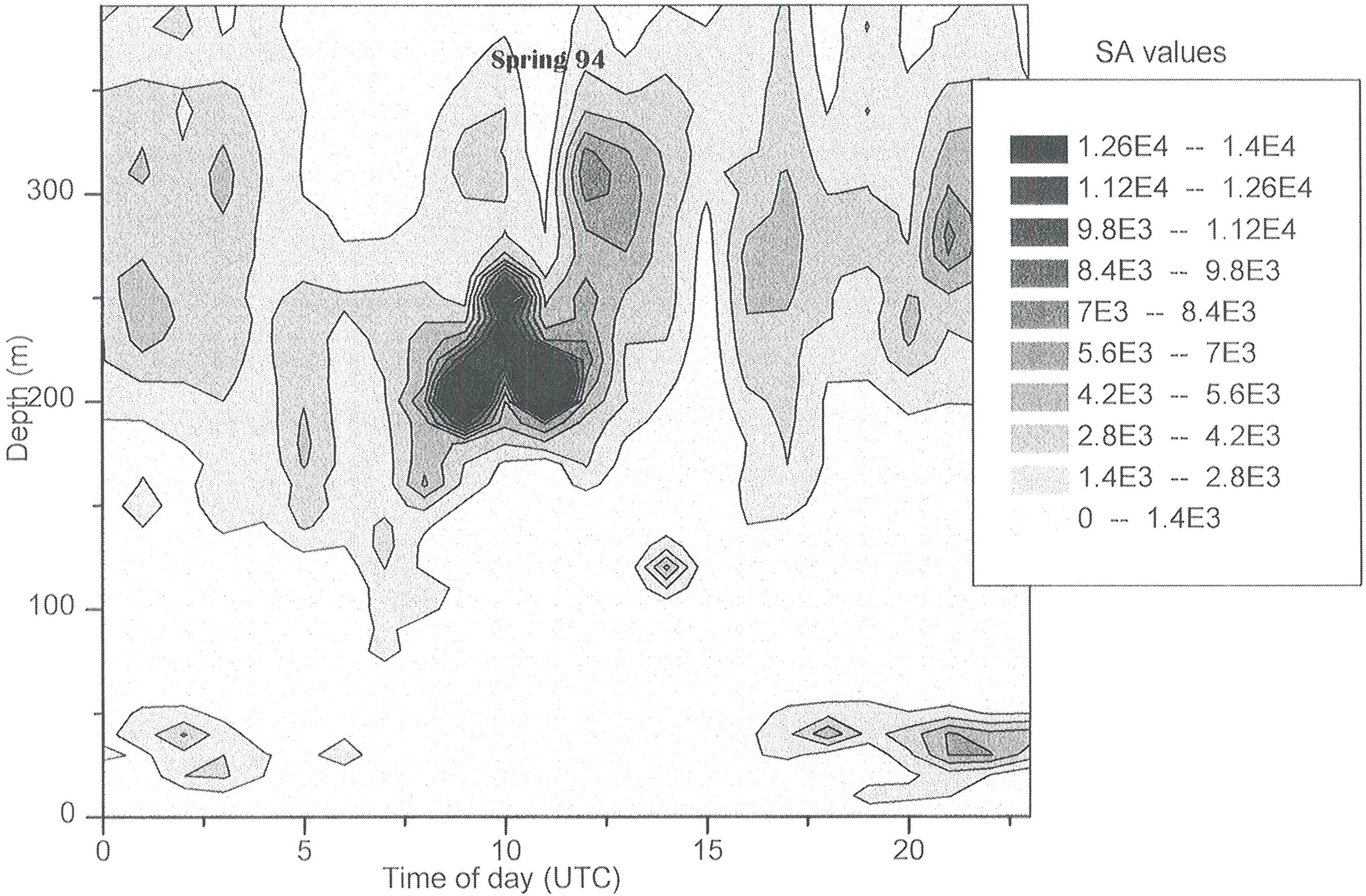


Fall 92
SA values
1.26E4--1.4E4
1.12E4--1.26E4
9.8E3--1.12E4
8.4E3--9.8E3
7E3--8.4E3
5.6E3--7E3
4.2E3--5.6E3
2.8E3--4.2E3
1.4E3--2.8E3
0--1.4E3
Depth (m)
0
100
200
300
Time of day (UTC)
0
5
10
15
20

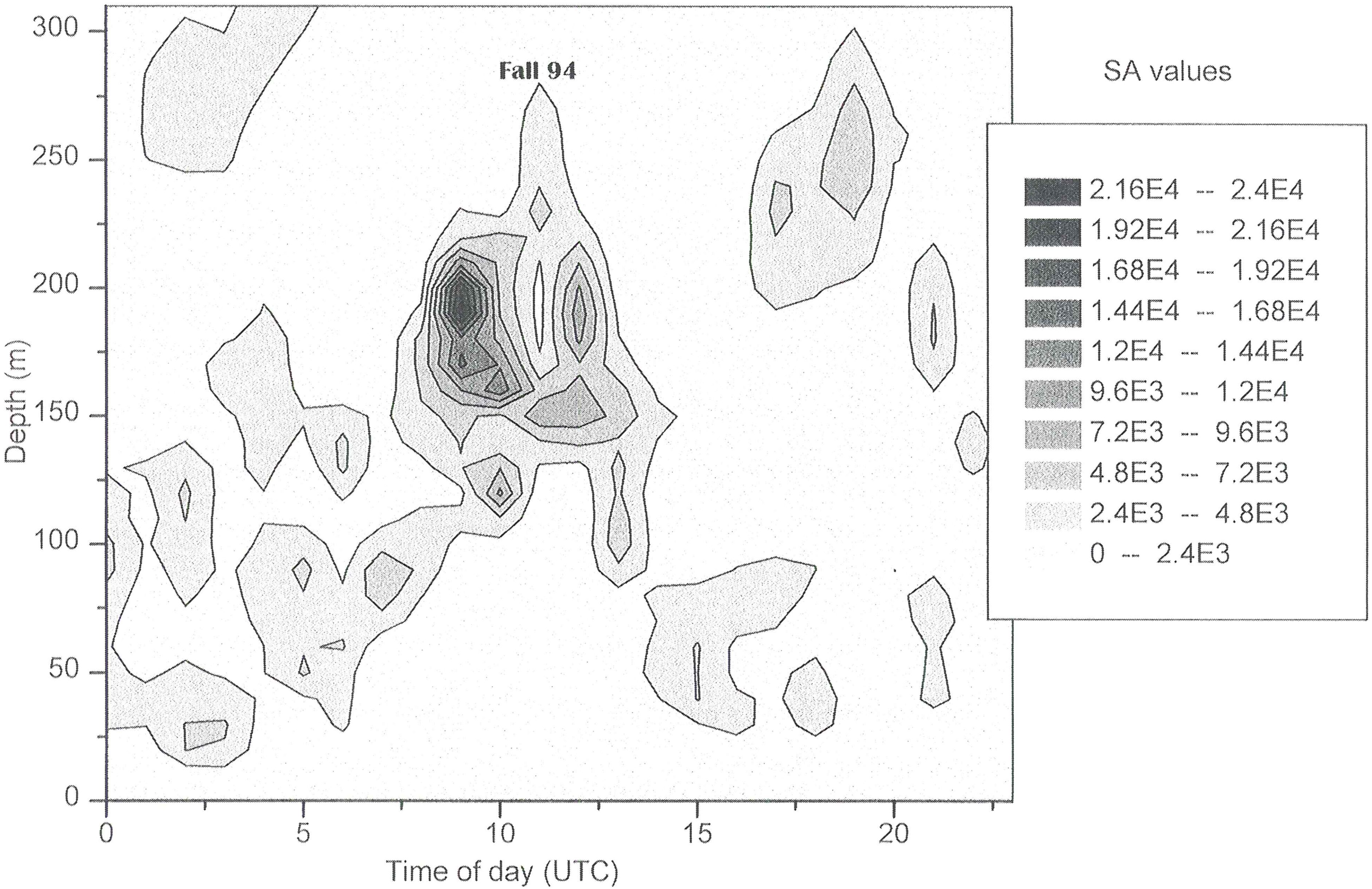


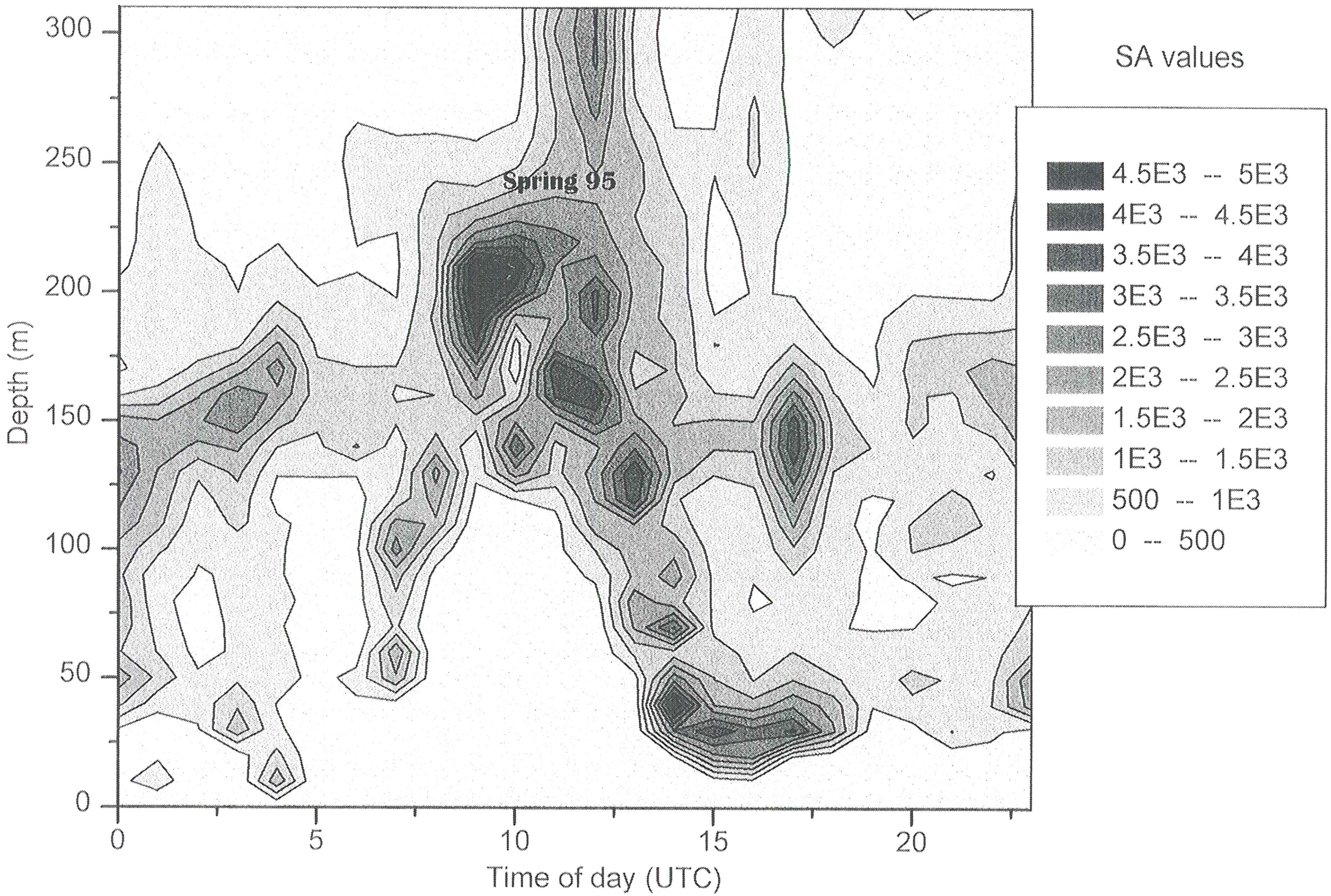
Spring 93
SA values
1.26E4 -- 1.4E4
1.12E4 -- 1.26E4
9.8E3 -- 1.12E4
8.4E3 -- 9.8E3
7E3 -- 8.4E3
5.6E3 -- 7E3
4.2E3 -- 5.6E3
2.8E3 -- 4.2E3
1.4E3 -- 2.8E3
0 -- 1.4E3
Depth (m)
300
200
100
0
0
5
10
15
20
Time of day (UTC)


Fall 93
SA values
1.62E4 -- 1.8E4
1.44E4 -- 1.62E4
1.26E4 -- 1.44E4
1.08E4 -- 1.26E4
9E3 -- 1.08E4
7.2E3 -- 9E3
5.4E3 -- 7.2E3
3.6E3 -- 5.4E3
1.8E3 -- 3.6E3
0 -- 1.8E3
Depth (m)
300
200
100
0
0
5
10
15
20
Time of day (UTC)

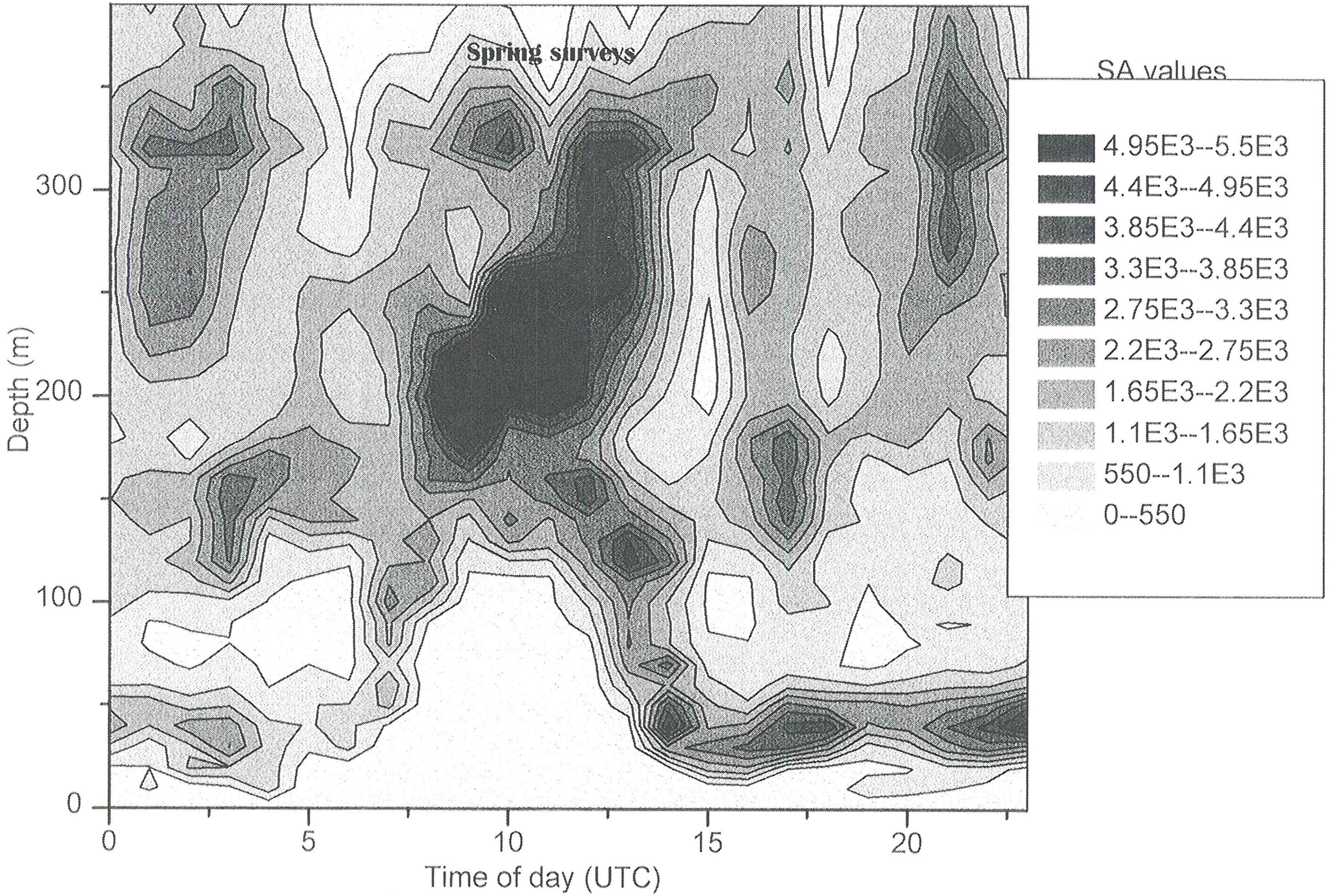


Spring 94
SA values
1.26E4 -- 1.4E4
1.12E4 -- 1.26E4
9.8E3 -- 1.12E4
8.4E3 -- 9.8E3
7E3 -- 8.4E3
5.6E3 -- 7E3
4.2E3 -- 5.6E3
2.8E3 -- 4.2E3
1.4E3 -- 2.8E3
0 -- 1.4E3
Depth (m)
0
100
200
300
0
5
10
15
20
Time of day (UTC)

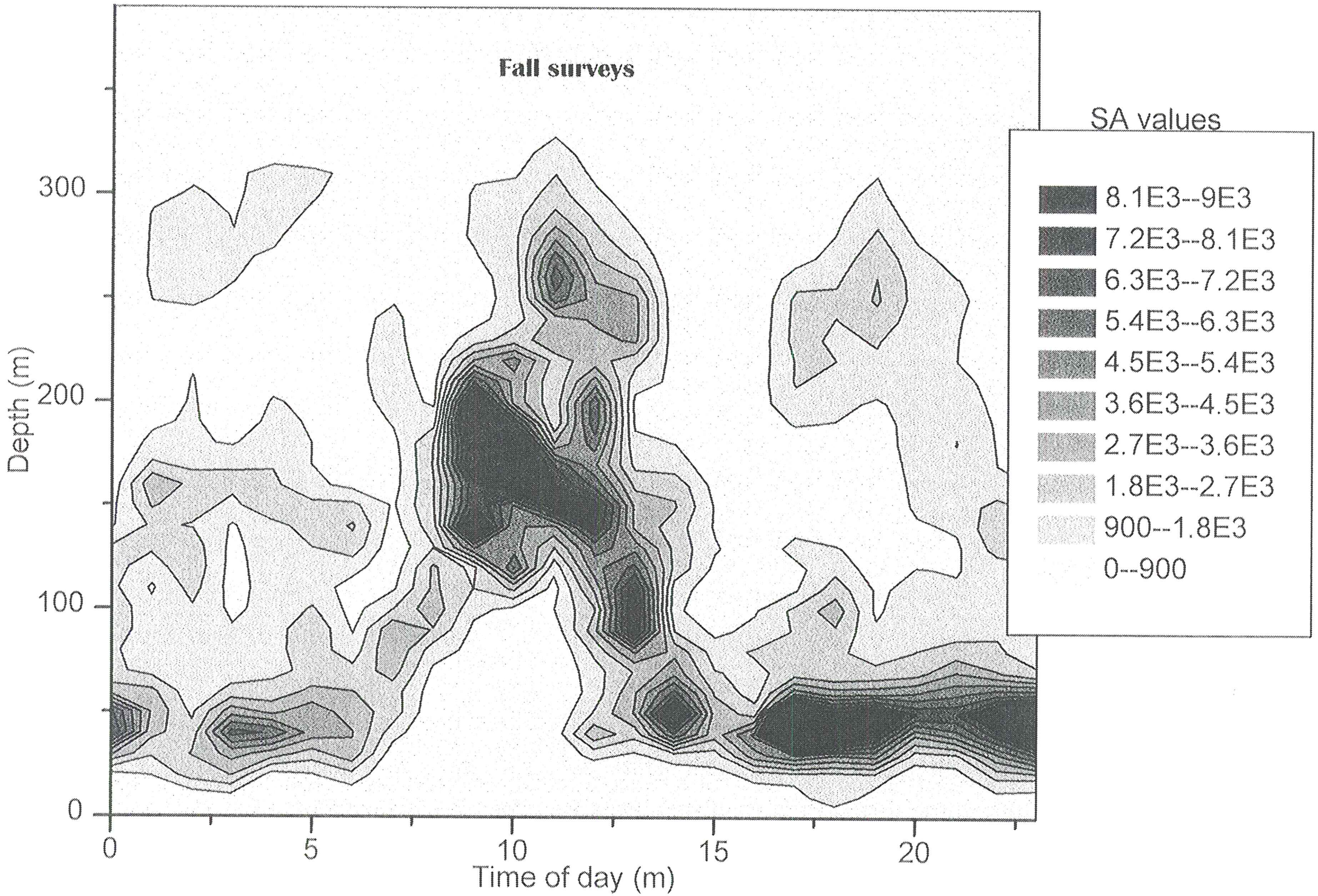

Fall 94
SA values
2.16E4 -- 2.4E4
1.92E4 -- 2.16E4
1.68E4 -- 1.92E4
1.44E4 -- 1.68E4
1.2E4 -- 1.44E4
9.6E3 -- 1.2E4
7.2E3 -- 9.6E3
4.8E3 -- 7.2E3
2.4E3 -- 4.8E3
0 -- 2.4E3
Depth (m)
300
250
200
150
100
50
0
0
5
10
15
20
Time of day (UTC)



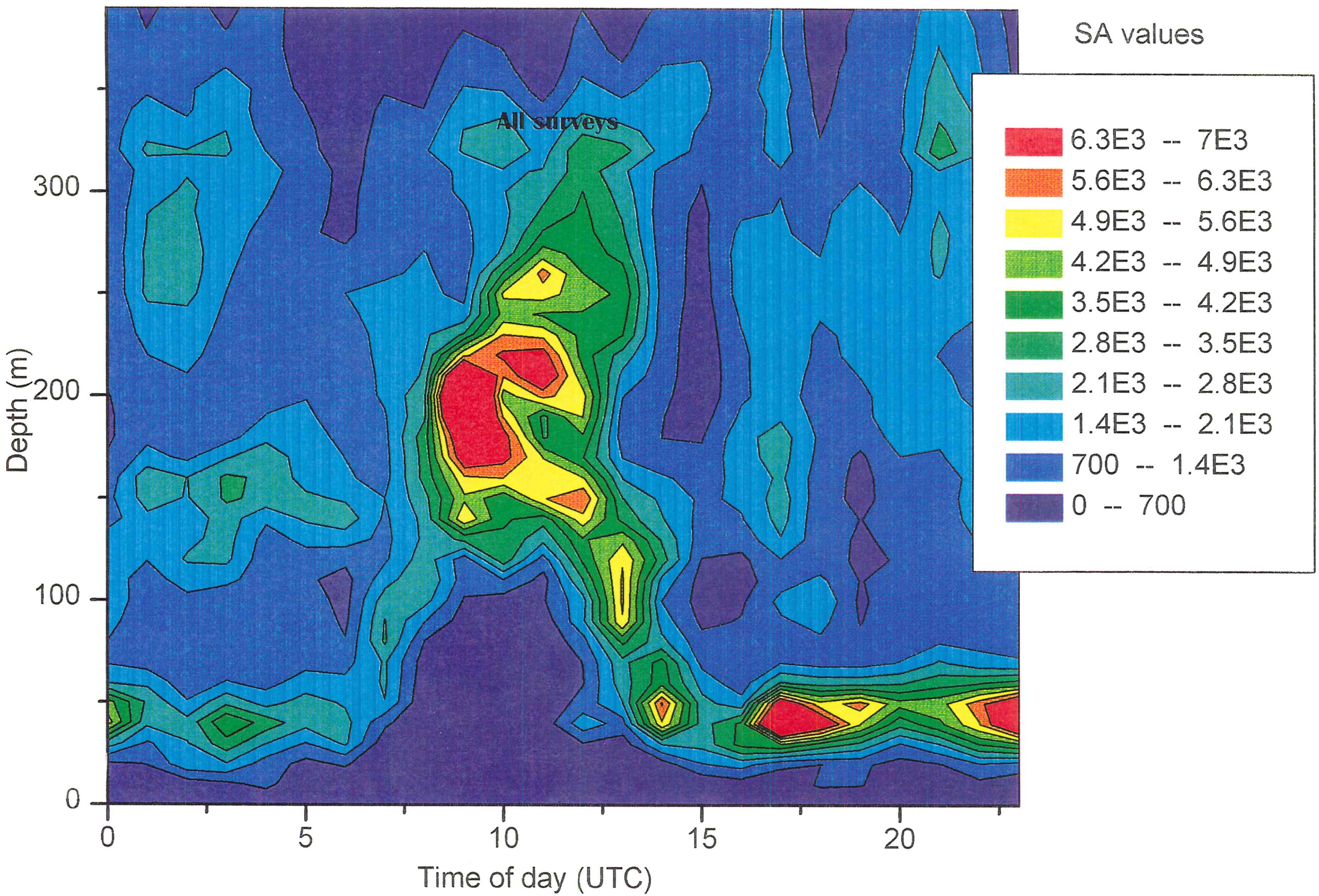
SA values
4.5E3 -- 5E3
4E3 -- 4.5E3
3.5E3 -- 4E3
3E3 -- 3.5E3
2.5E3 -- 3E3
2E3 -- 2.5E3
1.5E3 -- 2E3
1E3 -- 1.5E3
500 -- 1E3
0 -- 500
Spring 95
Depth (m)
300
250
200
150
100
50
0
0
5
10
15
20
Time of day (UTC)



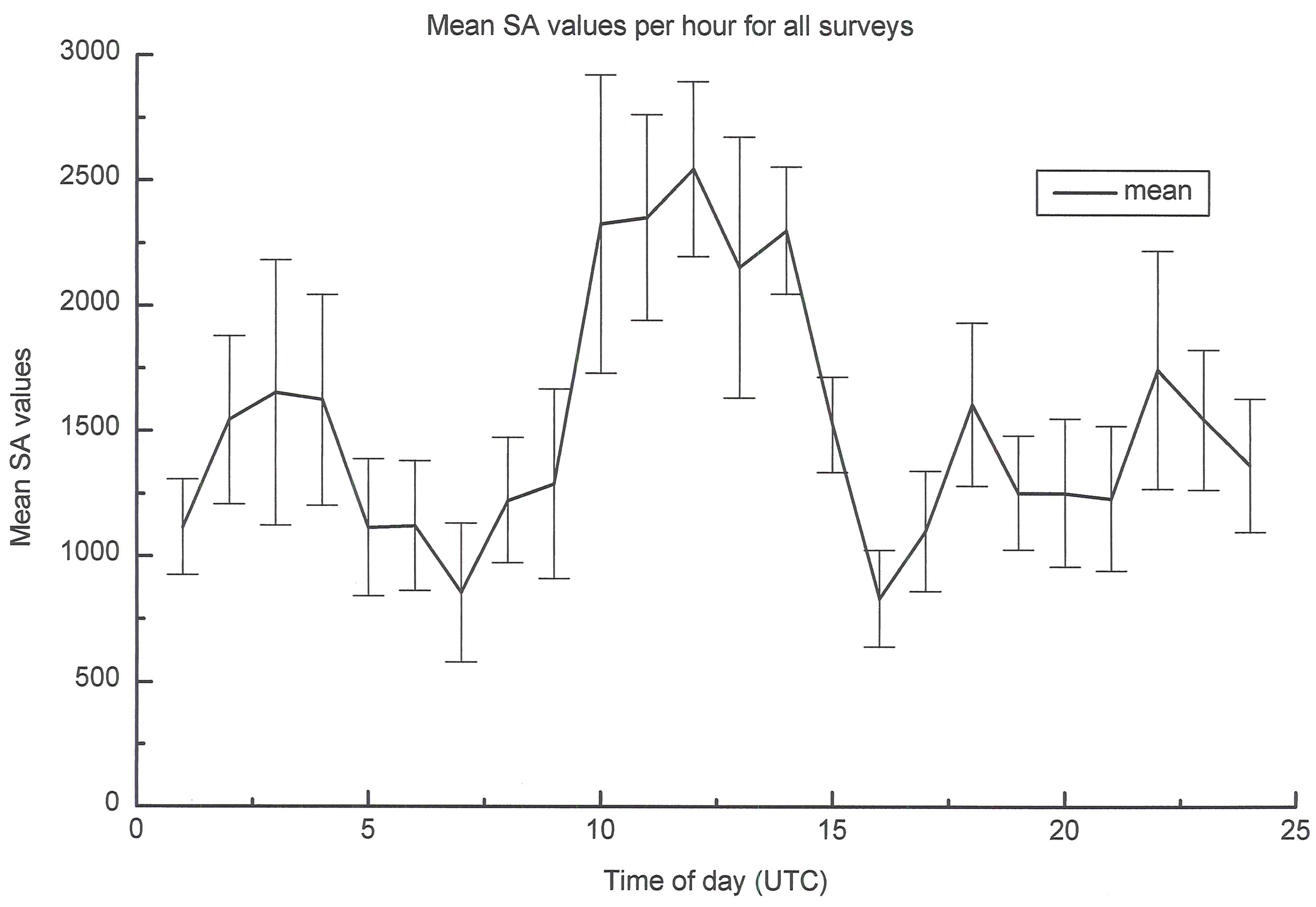
Spring surveys
SA values
4.95E3--5.5E3
4.4E3--4.95E3
3.85E3--4.4E3
3.3E3--3.85E3
2.75E3--3.3E3
2.2E3--2.75E3
1.65E3--2.2E3
1.1E3--1.65E3
550--1.1E3
0--550
Depth (m)
300
200
100
0
0
5
10
15
20
Time of day (UTC)



Fall surveys
SA values
8.1E3--9E3
7.2E3--8.1E3
6.3E3--7.2E3
5.4E3--6.3E3
4.5E3--5.4E3
3.6E3--4.5E3
2.7E3--3.6E3
1.8E3--2.7E3
900--1.8E3
0--900
Depth (m)
300
200
100
0
0
5
10
15
20
Time of day (m)



All surveys
SA values
6.3E3 -- 7E3
5.6E3 -- 6.3E3
4.9E3 -- 5.6E3
4.2E3 -- 4.9E3
3.5E3 -- 4.2E3
2.8E3 -- 3.5E3
2.1E3 -- 2.8E3
1.4E3 -- 2.1E3
700 -- 1.4E3
0 -- 700
Depth (m)
300
200
100
0
0
5
10
15
20
Time of day (UTC)


Mean SA values per hour for all surveys
Mean SA values
Time of day (UTC)
mean
0
500
1000
1500
2000
2500
3000
0
5
10
15
20
25