JAEA-Data/Code
2021-004
DOI:10.11484/jaea-data-code-2021-004

Ocean Current Data Obtained by Acoustic Doppler Current Profiler across the Tsugaru Strait (Joint Research)

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May 2021
Japan Atomic Energy Agency
日本原子力研究開発機構

JAEA-Data/Code

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(Received January 20, 2021)

The Japan Atomic Energy Agency measured the ocean current across the Tsugaru Strait using an Acoustic Doppler Current Profiler attached on a ferryboat from October 1999 to January 2008. The characteristics of the ocean current in the Tsugaru Strait must be understood for predicting oceanic dispersion of radioactive materials released from nuclear facilities around the strait. Furthermore, it is critical to elucidate the mechanism of the Tsugaru Warm Current from an oceanography viewpoint. The dataset obtained in this investigation consists of daily ocean current data files that record the components of the current speed in the east-west and north-south directions from the surface layer to the bottom layer. The dataset stores 2,211 daily ocean current data files, despite some data periods missing from October 1999 to January 2008. In this study, information on the dataset is described for users to analyze the dataset properly for their purposes. Section 1 provides the background and purpose of the ocean current measurement, Section 2 explains the methodology of measurement using an Acoustic Doppler Current Profiler, and Section 3 explains the record format of the daily ocean current data files and data acquisition rate and presents analysis results. Finally, Section 4 concludes this study.

Keywords: Ocean Current Data, Acoustic Doppler Current Profiler, Tsugaru Strait, Tsugaru Warm Current, Ferryboat, Volume Transport

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This work has been performed in JAEA as a joint research with Research Institute for Applied Mechanics, Kyushu University and that with Japan Marine Science Foundation.

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JAEA-Data/Code 2021-004

超音波流速計で測定された津軽海峡の海流データ
（共同研究）

日本原子力研究開発機構
原子力科学研究部門　原子力科学研究所　原子力基礎工学研究センター
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（2021 年 1 月 20 日受理）

日本原子力研究開発機構は 1999 年 10 月から 2008 年 1 月の期間中、津軽海峡を航行するフェリーに設置した超音波流速計を使用して、当該海域における海流調査を実施した。津軽海峡における海流の特徴を把握することは、周辺に立地する原子力施設から放出される放射性物質の海洋拡散を予測する上で重要なことである。さらに、津軽暖流のメカニズムを解明することは、海洋学の観点からも非常に興味深いことである。本調査で整備した海流のデータセットは日毎のデータファイルから構成されており、各データファイルには表層から底層までの流速の東西･南北成分が記録されている。データが欠損している期間があるが、データセットには 1999 年 10 月から 2008 年 1 月まで合計 2,211 日分のデータファイルが格納されている。本報では、ユーザーが適切にデータセットを解析するために必要な情報を記載している。第 1 章では、海流調査の背景と目的を述べる。第 2 章では、超音波流速計を使用した調査方法について説明する。第 3 章では、データファイルのレコード形式とデータ取得率について説明するとともに、解析結果の一例を示す。最後に、第 4 章で本報の結論を述べる。

本研究は日本原子力研究開発機構と九州大学応用力学研究所との共同研究及び日本原子力研究開発機構と公益財団法人日本海洋科学振興財団との共同研究に基づいて実施したものである。
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1. Introduction

The Tsugaru Strait connects the Japan Sea and the North Pacific (Fig. 1.1). The strait is ~130 km long in the east-west direction, and the maximum bottom depth is ~450 m. An eastward strong current called the Tsugaru Warm Current (TWC) flows from the Japan Sea to the North Pacific across the strait throughout the year. TWC seasonally varies in the offshore ocean after it passes through the strait. TWC tends to generate a large anticyclonic eddy in the offshore ocean in summer, whereas it tends to flow southward along the coast in winter[1)]. TWC is critical to transport pollutants in the ocean around the strait.

Nuclear facilities such as a spent fuel reprocessing plant in Rokkasho village on the North Pacific coast exist around the Tsugaru Strait. In the operation of nuclear facilities, a small number of radioactive materials without influence on the marine environment are systematically released from nuclear facilities to the surrounding ocean. During an emergency at nuclear facilities, unplanned radioactive materials could be released from nuclear facilities to the surrounding ocean. Therefore, it is useful to understand the characteristics of the ocean circulation around the strait in advance to predict the oceanic dispersion of radioactive materials.

It is challenging to measure the ocean current directly. The Japan Atomic Energy Agency (JAEA) started to measure the ocean current across the Tsugaru Strait using an Acoustic Doppler Current Profiler (ADCP) attached on a ferryboat, M. V. Virgo, belonging to HIGASHINIHON-FERRY (present TSUGARUKAIKYO-FERRY) Co., Ltd. from October 1999 to clarify the variation of velocity and volume transport of TWC. This monitoring method using ADCP can obtain continuous ocean current data spatiotemporally. The sufficient cross-sectional ocean current data with high spatiotemporal resolution across the strait enable analyzing the variation of velocity and volume transport of TWC. The volume transport of TWC across the strait can be estimated by integrating the component of the current speed in the east-west direction over the transection. Ito et al. (2003)[2)] analyzed the variation of velocity and volume transport of TWC across the strait over the initial measurement period (November 1999–March 2000). They suggested that TWC predominantly flowed east in the central part of the strait, and the counter westward currents were often accompanied in the northern and southern parts of the strait over this period. Consequently, they quantitatively estimated that the eastward volume transport of TWC across the strait varied between 1.1 and 2.1 Sv (1 Sv = 10^6 m^3 s^{-1}) with a mean value of 1.5 Sv and standard deviation of 0.3 Sv. Studies have also suggested that the volume transport of TWC seasonally varied between 0.8 and 2.7 Sv, with a mean value of 1.5 Sv[3), 4), 5)], which corresponds to the estimate of Ito et al. (2003)[2)]. Ito et al. (2003)[2)] also found relatively good correlations between the volume transport of TWC and sea-level differences around the strait.

JAEA continued to measure the ocean current across the Tsugaru Strait using ADCP until January 2008, with the voluntary cooperation of HIGASHINIHON-FERRY Co., Ltd. A large amount of ocean current data measured in the strait was stored, despite some data missing periods from October 1999 to January 2008. The ocean current data should be useful for predicting the oceanic dispersion of pollutants in the surrounding ocean around the strait and elucidating the mechanism of TWC from an oceanography viewpoint. Therefore, we compiled the ocean current data from October 1999 to January 2008 to facilitate data processing.

In this study, information on the dataset consisting of daily ocean current data files is described. Section 2 explains the methodology of measurement using ADCP. Section 3 explains the record format of the daily ocean current data files and data acquisition rate and presents some analysis results. Section 4 concludes this study.

2. Methodology of measurement

A current monitoring system using ADCP was installed on a ferryboat, M. V. Virgo, (135 m and 6,706 ton) belonging to HIGASHINIHON-FERRY Co., Ltd. The monitoring system was based on the design suggested by Kaneko et al. (1998)[6]. ADCP can measure the ocean current continuously with high spatiotemporal resolution using the Doppler effect of acoustic waves.

ADCP is a 150 kHz broadband type manufactured by RD Instruments. Transducers of ADCP were set at a depth of ~5 m below the sea surface. The maximum depth along the ferryboat operation routes in the Tsugaru Strait is ~200 m (Fig. 1.1). This monitoring system measured the ocean current referring the sea bottom. The ocean current data were obtained from the first depth of ~17 m to the deepest depth near the sea bottom with a vertical resolution of ~4 m, which were recorded every 60 sec. The ocean current data were sent to and stored on personal computers on the ferryboat and regularly transferred to the port for data storage on land. The horizontal current speed was divided into the components in the east-west and north-south directions.

This monitoring system causes accuracy problems in the ocean current data near the sea surface and sea bottom. Therefore, the ocean current data measured below a depth of ~25 m should be used because the ocean current data measured near the body of the ferryboat are inaccurate. The ocean current data measured near the sea bottom are also inaccurate because of acoustic interference. Therefore, the ocean current data measured in the bottom layer deeper than ~75% of the sea bottom depth should be excluded. Ito et al. (2003)[2] used the ocean current data measured from a depth of 25 m to the 75% depth of the sea bottom depth to analyze the variation of velocity and volume transport of TWC. According to RD Instruments manual[7], the accuracy of the bottom-tracking measurement that was applied to this monitoring system is 0.2% of the measured current speed ± 0.2 cm s^{-1}.

The ferryboat alternately changed the operation routes of Aomori–Hakodate and Aomori–Muroran from October 1999 to January 2008. In the operation route period of Aomori–Hakodate, the ferryboat plied twice a day between Aomori and Hakodate (Fig. 1.1). However, the ferryboat plied once a day between Aomori and Muroran (Fig. 1.1) in the operation route period of Aomori–Muroran. Table 2.1 summarizes the periods and operation routes of the ferryboat operation recorded in the ocean current data. The longest continuous period is ~5 years from April 3, 2000–April 13, 2005, along the Aomori–Muroran ferryboat operation route. Figure 2.1 shows representative samples of data positions at a depth of 25–50 m along the ferryboat operation route in December 1999, May 2000, June 2005, November 2006, and October 2007. The ferryboat plied north-south in the Tsugaru Strait along the operation route between Aomori and Hakodate. However, it plied north-south in the strait, changing direction outside the strait along the operation route between Aomori and Muroran. The ocean current data were continuously measured with high spatiotemporal resolution along the ferryboat operation routes.

3. Results

3.1 Record format

The ocean current data are recorded in daily ocean current data files from October 1999 to January 2008. The daily ocean current data files are named YYYYMMDD.txt indicating year (YYYY), month (MM), and day (DD) of the measurement date to improve user-friendliness. Consequently, the 2,211 daily ocean current data files are stored in the dataset, despite some data missing periods from October 1999 to January 2008.

In the daily ocean current data files, the ocean current data provider is described in the first row. The second row describes the ocean current data format, which follows the Ocean Data View (ODV) spreadsheet. A software package ODV is freely available for noncommercial research, enabling interactive data analysis and visualization. Date files with formats following the ODV spreadsheet can be imported into ODV directly. The ODV spreadsheet is popular in oceanographical data.

The third row is the column header row describing the labels for each column. Below the column header row, the data rows contain 10 columns. The details of each column are set out as below.

- Cruise (column 1): Ferryboat operation route. A text string “VIRGO-AO-HA” indicates the ferryboat operation route between Aomori and Hakodate. A text string “VIRGO-AO-MU” indicates the ferryboat operation route between Aomori and Muroran.
- Station (column 2): Measurement station. A text string “000” is a dummy value.
- Type (column 3): Type of data. A character “B” indicates that the number of layers is less than 250. A character “C” indicates that the number of layers is more than 250.
- mon/day/yr (column 4): Measurement date (month/day/year, UTC).
- hh:mm (column 5): Measurement time (hour:minute, UTC).
- Lon(E) (column 6): Longitude (°E) of measurement position.
- Lat(N) (column 7): Latitude (°N) of measurement position.
- Bot.Depth[m] (column 8): Bottom depth (m) of measurement position. A character “0” indicates no data.
- Depth[m] (column 9): Depth (m) of measurement position.
- InstType (column 11): Instrument type of measurement. A text string “CA” indicates that the ocean current was measured using ADCP.
- Eastward current velocity[mm/s] (column 13): Component (mm s^{-1}) of the current speed in the east-west direction. The eastward direction is positive.
- Northward current velocity[mm/s] (column 15): Component (mm s^{-1}) of the current speed in the north-south direction. The northward direction is positive.
- QF (columns 10, 12, 14, and 16): Qualifying flag of each left column. The components of the current speed in the east-west and north-south directions are qualified with four flags (0: good, 1: unknown,

4: questionable, and 8: bad) in columns 14 and 16.

Table 3.1 summarizes the daily ocean current data files' format. Additionally, Figure 3.1 shows an example of the daily ocean current data files, which helps readers to understand the record format.

3.2 Data acquisition rate

Monitoring the ocean current using ADCP has the advantage of obtaining the continuous ocean current data spatiotemporally. However, the ocean current data were occasionally missed because of weather conditions and ferryboats in the dock. The current monitoring system using ADCP frequently failed to acquire the ocean current data in winter because of a decline in the back-scattering signal intensity.

Figure 3.2 illustrates the temporal variation of the data acquisition rate of each month from October 1999 to January 2008. The vertical axis indicates the number of the daily ocean current data files in each month, which is numerically expressed in Table 3.2. The data acquisition rate temporally differs over the above period. The ocean current data are available on all days in July and August over the above period, except July 2004, suggesting that the data acquisition was relatively stable in summer. Unfortunately, the ocean current data were hardly obtained along the ferryboat operation route between Aomori and Muroran from October 2001 to April 2002 and October 2003 to June 2004. However, the ocean current data were relatively well obtained from November 1999 to September 2001, May to September 2002, December 2002 to March 2003, and June to September 2003. Specifically, the data acquisition rate is considerably good after July 2004, except for December 2006 and January 2007.

3.3 Analysis of the ocean current data

It is considered that TWC is dominant throughout the year in the Tsugaru Strait. The ocean current data were analyzed to demonstrate the ocean circulation in the strait. Figures 3.3–3.17 show the ocean current at a depth of 25–50 m along the ferryboat operation route from October 1999 to January 2008. The ocean current is plotted as a stick from the measurement position, of which the length is proportional to the current speed. We thinned out the ocean current data in the region of 40.9–41.7 °N, with a current speed of less than 500 mm s^{-1}, and qualifying flags of 0 in columns 14 and 16 of the daily ocean current data files. Note that the ocean current in Figs. 3.3–3.17 is the representative distribution of the ocean current of each month over the above period. The structure of the ocean current in the strait is briefly analyzed below in each period (Table 2.1).

The ocean current data used in Fig. 3.3 were measured along the ferryboat operation route between Aomori and Hakodate from October 1999 to March 2000, which is almost the same as those reported by Ito et al. (2003)[2]. The ferryboat plied twice a day between Aomori and Hakodate over this period. The ocean current along the ferryboat operation route was relatively strong on November 15 and December 15 in 1999, and January 15 and March 14 in 2000. It is slightly difficult to detect the structure of TWC because the ocean current data are nearly raw data that include unreliable data, despite the qualifying flags of 0 in columns 14 and 16 of the daily ocean current data files. Additionally, the ocean current data probably include the relatively strong tidal current in the Tsugaru Strait, which was suggested by previous studies[8), 9)]. If users want to analyze TWC using the ocean current data, it is helpful to refer to Ito et al. (2003)[2)]. They used the ocean current data to estimate the variation of velocity and volume transport of TWC as discussed below. They used only the component of the current speed in the east-west direction because TWC generally flows east-west through the strait. They used the ocean current data below a depth of 25 m because the ocean current data measured near the body of the ferryboat are inaccurate. They excluded the ocean current data measured in the bottom layer deeper than the 75% depth of the sea bottom depth. They assumed discrete stations along the ferryboat operation route, of which the latitudinal interval was ~2′, and spatially averaged the ocean current data within a 2′ in latitude × 2′ in longitude grid. Finally, they temporally applied a running mean low-pass filter to remove the component of the tidal current. It is useful to average the ocean current data spatiotemporally for extracting the component of TWC.

Figures 3.4–3.11 show the ocean current at a depth of 25–50 m along the ferryboat operation route between Aomori and Muroran from April 2000 to March 2005. The ferryboat plied once a day between Aomori and Muroran over this period. The relatively strong eastward ocean current corresponding to the core of TWC appeared between 41.5 °N and 41.7 °N near the outlet of the Tsugaru Strait. However, the westward ocean current was frequently found south of 41.5 °N and west of the Shimokita Peninsula. This must be the return flow of TWC after it reached the west coast of the Shimokita Peninsula. It was suggested that TWC is dominant in the central part of the strait, accompanying the return flow frequently in the northern and southern parts of the strait. For example, this characteristic structure of ocean current in the strait was remarkable on September 15, 2003, when the eastward ocean current flowed between 41.4 °N and 41.7 °N near the outlet of the strait, and the westward ocean current flowed south of 41.4 °N and west of the Shimokita Peninsula (Fig. 3.9).

Figures 3.12–3.14 show the ocean current at a depth of 25–50 m along the ferryboat operation route between Aomori and Hakodate from April 2005 to September 2006. The ferryboat plied twice a day between Aomori and Hakodate over this period. The characteristic structure of ocean current in the Tsugaru Strait was found from April 2005 to February 2006. However, the westward ocean current was relatively dominant in the central part of the strait between 41.3 °N and 41.7 °N from May to September 2006. Moreover, the ocean current direction was inverse during two round trips in the central part of the strait between 41.2 °N and 41.5 °N on April 15, 2006, probably because the surface ocean current in the strait is variable because of the tidal current and sea surface wind.

Figures 3.15 and 3.16 show the ocean current at a depth of 25–50 m along the ferryboat operation route between Aomori and Muroran from October 2006 to August 2007. The ferryboat plied once a day between Aomori and Muroran over this period. The westward ocean current continued to be dominant in the central part of the Tsugaru Strait between 41.3 °N and 41.7 °N from October to December 2006. Afterward, the characteristic structure of TWC accompanied by the eastward ocean current in the central part of the strait was found from February to August 2007, except July 2007.

Figure 3.17 shows the ocean current at a depth of 25–50 m along the ferryboat operation route between Aomori and Hakodate from September 2007 to January 2008. The ferryboat plied twice a day between

Aomori and Hakodate over this period. The characteristic structure of TWC accompanied by the eastward ocean current in the central part of the Tsugaru Strait was relatively dominant over this period. However, the westward ocean current corresponding to the return flow of TWC was detectable south of 41.4 °N and west of the Shimokita Peninsula.

TWC has a characteristic vertical structure in the Tsugaru Strait, suggesting that the ocean current is stronger in the surface layer than the deeper layer. Moreover, the counter current was occasionally observed near the sea bottom. Figures 3.18–3.22 show the ocean current at a depth of 5–150 m along the ferryboat operation route in December 1999, May 2000, June 2005, November 2006, and October 2007. The ocean current is plotted as a stick using the ocean current data with qualifying flags of 0 for the components of the current speed in the east-west and north-south directions. Overall, the ocean current in Figs. 3.18–3.22 demonstrates the characteristic vertical structure of TWC, where the speed of the ocean current decreases with depth. Note that the ocean current data at a depth of 5–25 m probably include unreliable data, as shown in the ocean current on December 1, 1999 (Fig. 3.18), even though the qualifying flags for the components of the current speed in the east-west and north-south directions are 0. This must be because the ocean current data measured near the body of the ferryboat are inaccurate. Additionally, note that the ocean current data near the sea bottom probably include unreliable data, as shown in the ocean current on December 1, 1999 (Fig. 3.18), June 1, 2005 (Fig. 3.20), November 1, 2006 (Fig. 3.21), and October 1, 2007 (Fig. 3.22). This must be because the ocean current data measured near the sea bottom are inaccurate because of acoustic interference. Note that users should be careful of the ocean current data measured in the surface and bottom layers. For example, Ito et al. (2003)[2] excluded the ocean current data measured in the surface layer shallower than 25 m and the bottom layer deeper than 75% of the sea bottom depth.

4. Conclusions

JAEA measured the ocean current across the Tsugaru Strait using ADCP attached on the ferryboat from October 1999 to January 2008. We compiled the enormous ocean current data and constructed the dataset consisting of 2,211 daily ocean current data files, despite some data missing periods. The daily ocean current data files record the components of the current speed in the east-west and north-south directions from the surface layer to the bottom layer. The ocean current data format follows the ODV spreadsheet that is popular in oceanographical data.

We analyzed the ocean current data to understand the ocean circulation in the Tsugaru Strait, demonstrating that TWC predominantly flowed in the central part of the strait accompanying the return flow frequently in the northern and southern parts of the strait. The ocean current data include unreliable data, especially in the surface and bottom layers. Note that users should be careful of analyzing the ocean current data because of being nearly raw data.

This study describes information on the dataset for users to analyze the dataset properly for their purposes. The dataset should be a useful tool for understanding the characteristics of ocean current in the Tsugaru Strait. It is of great interest to analyze the dataset to elucidate the mechanism of TWC. The dataset can also be used to validate oceanic dispersion simulations around the strait.

Acknowledgement
We express our thanks to HIGASHINIHON-FERRY Co., Ltd. We are grateful to the captain and crew of a ferryboat, M. V. Virgo, for their voluntary cooperation in the current monitoring.

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Table 2.1 Ferryboat operation routes from October 1999 to January 2008

Period	Operation route
October 29, 1999–April 2, 2000	Aomori–Hakodate
April 3, 2000–April 13, 2005	Aomori–Muroran
April 14, 2005–September 30, 2006	Aomori–Hakodate
October 1, 2006–August 31, 2007	Aomori–Muroran
September 1, 2007–January 9, 2008	Aomori–Hakodate

Table 3.1 Record format of the daily ocean current data files

Column number	Item	Unit	Format	Remarks
1	Cruise	—	Character	
2	Station	—	Integer	
3	Type	—	Character	
4	mon/day/yr	month/day/year	—	
5	hh:mm	hour:minute	—	
6	Lon	°E	Real	
7	Lat	°N	Real	
8	Bot.Depth	m	Integer	
9	Depth	m	Real	
10	QF	—	Integer	Qualifying flag of depth
11	InstType	—	Character	
12	QF	—	Integer	Qualifying flag of InstType
13	Eastward current velocity	mm s^{-1}	Integer	
14	QF	—	Integer	Qualifying flag of eastward current velocity
15	Northward current velocity	mm s^{-1}	Integer	
16	QF	—	Integer	Qualifying flag of northward current velocity

Table 3.2 Number of the daily ocean current data files in each month

	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
Jan.	—	23	31	0	30	0	24	26	9	9
Feb.	—	25	28	4	28	0	28	28	28	—
Mar.	—	25	31	0	31	0	31	31	31	—
Apr.	—	23	30	7	14	0	30	30	30	—
May	—	23	29	31	0	0	31	31	31	—
Jun.	—	13	30	30	20	0	30	30	30	—
Jul.	—	31	31	31	31	19	31	31	31	—
Aug.	—	31	31	31	31	31	31	31	31	—
Sep.	—	26	19	19	20	30	30	30	30	—
Oct.	3	25	0	0	0	21	31	31	31	—
Nov.	26	21	0	12	4	30	30	28	30	—
Dec.	26	23	0	31	0	31	31	3	31	—

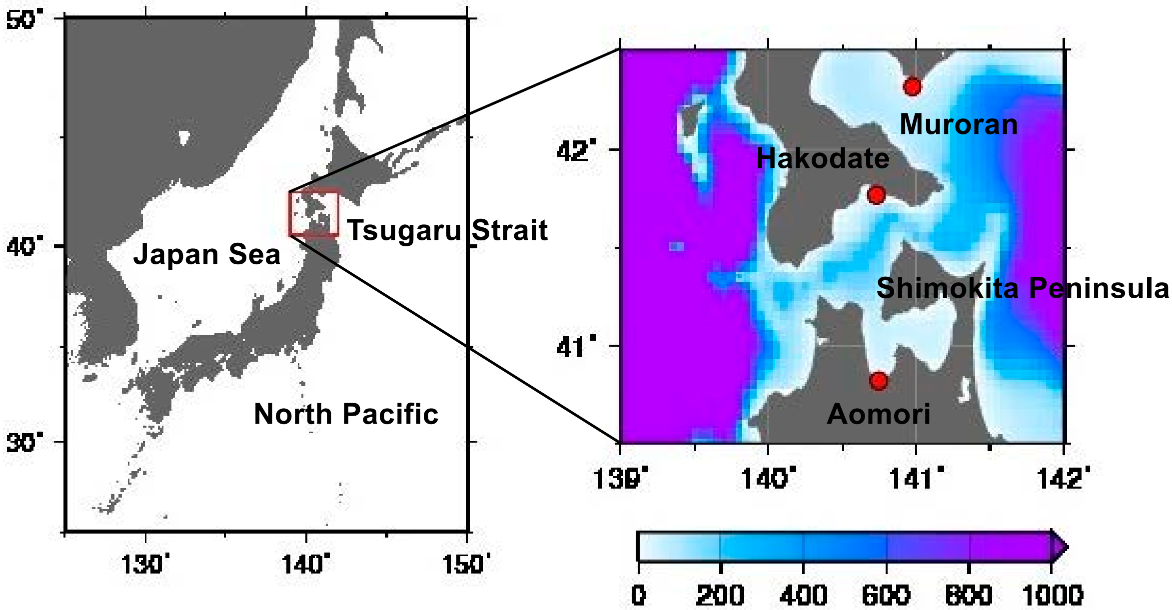

Fig.1.1 Bottom topography in the Tsugaru Strait (m)

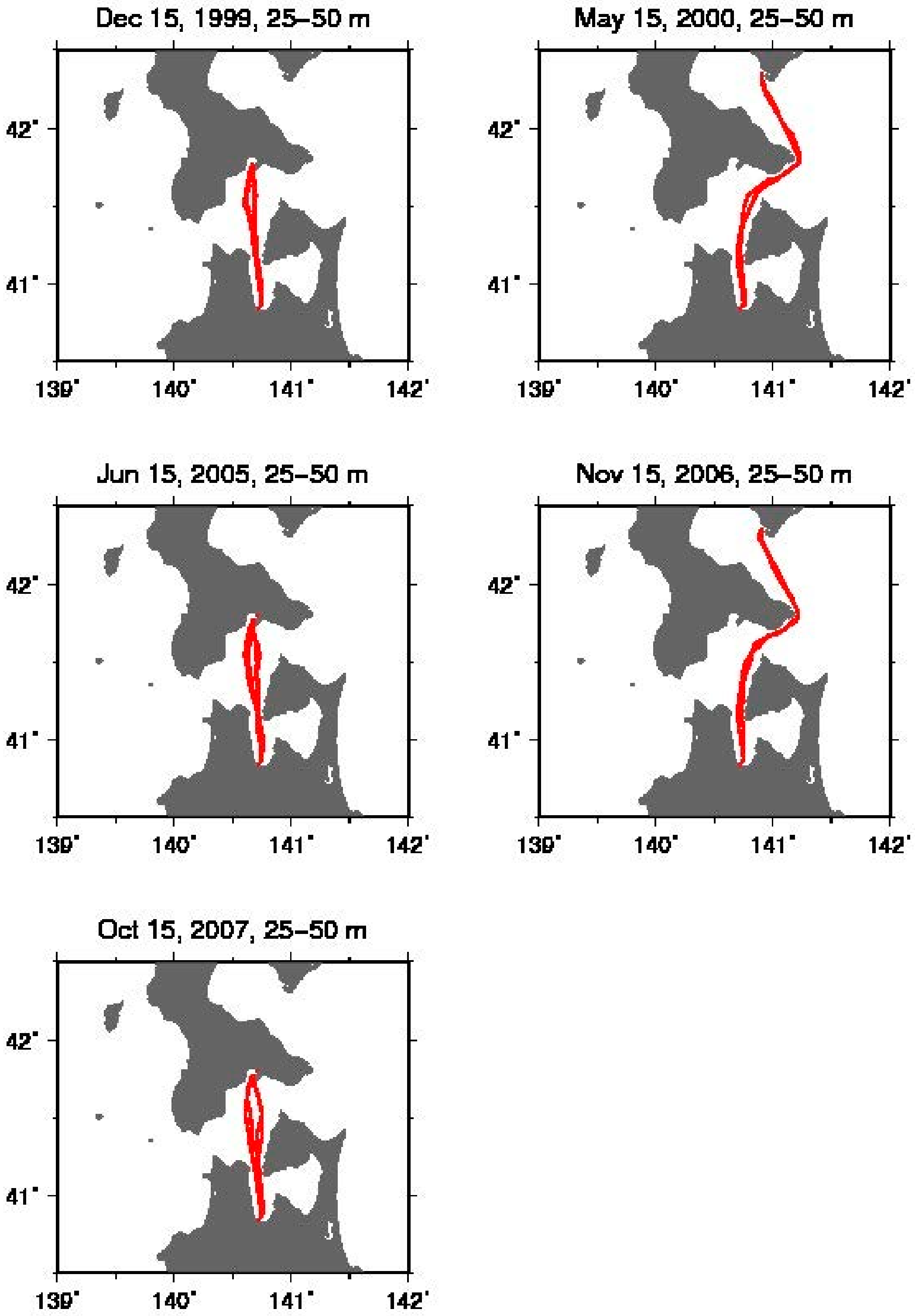

Fig.2.1 Data positions at a depth of 25–50 m along the ferryboat operation route in December 1999, May 2000, June 2005, November 2006, and October 2007

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//Provider: Japan Atomic Energy Agency
//Format: ODV Spreadsheet
Cruise  Station Type    mon/day/yr      hh:mm   Lon(E)  Lat(N)  Bot.Depth[m]    Depth[m]        QF      InstType        QF      Eastward current velocity[mm/s] QF
Northward current velocoty[mm/s]        QF
VIRGO-AO-HA     000     B       10/29/1999      11:29   140.6883        41.7992 0       17.4    0       CA      0       -7      0       -7      0
VIRGO-AO-HA     000     B       10/29/1999      11:29   140.6871        41.7985 0       17.4    0       CA      0       -13     0       -10     0
VIRGO-AO-HA     000     B       10/29/1999      11:29   140.6860        41.7977 0       17.4    0       CA      0       5       0       -10     0
VIRGO-AO-HA     000     B       10/29/1999      11:30   140.6848        41.7970 0       17.4    0       CA      0       1       0       5       0
VIRGO-AO-HA     000     B       10/29/1999      11:30   140.6837        41.7962 0       17.4    0       CA      0       -12     0       -10     0
VIRGO-AO-HA     000     B       10/29/1999      11:30   140.6824        41.7954 0       17.4    0       CA      0       -1      0       -6      0
VIRGO-AO-HA     000     B       10/29/1999      11:30   140.6812        41.7947 0       17.4    0       CA      0       2       0       7       0
VIRGO-AO-HA     000     B       10/29/1999      11:31   140.6800        41.7939 0       17.4    0       CA      0       1       0       11      0
VIRGO-AO-HA     000     B       10/29/1999      11:31   140.6788        41.7931 0       17.4    0       CA      0       1       0       -2      0
VIRGO-AO-HA     000     B       10/29/1999      11:31   140.6777        41.7922 0       17.4    0       CA      0       -8      0       3       0
VIRGO-AO-HA     000     B       10/29/1999      11:31   140.6769        41.7912 0       17.4    0       CA      0       3       0       11      0
VIRGO-AO-HA     000     B       10/29/1999      11:32   140.6764        41.7901 0       17.4    0       CA      0       17      0       -6      0
VIRGO-AO-HA     000     B       10/29/1999      11:32   140.6759        41.7890 0       17.4    0       CA      0       -3      4       -30     4
VIRGO-AO-HA     000     B       10/29/1999      11:32   140.6754        41.7878 0       17.4    0       CA      0       -27     0       10      0
VIRGO-AO-HA     000     B       10/29/1999      11:32   140.6749        41.7867 0       17.4    0       CA      0       29      0       -33     0
VIRGO-AO-HA     000     B       10/29/1999      11:32   140.6749        41.7867 0       21.4    0       CA      0       -5      0       -18     0
VIRGO-AO-HA     000     B       10/29/1999      11:33   140.6744        41.7856 0       17.4    0       CA      0       17      4       9       4
VIRGO-AO-HA     000     B       10/29/1999      11:33   140.6744        41.7856 0       21.4    0       CA      0       -10     0       -16     0
VIRGO-AO-HA     000     B       10/29/1999      11:33   140.6738        41.7845 0       17.4    0       CA      0       -11     0       26      0
VIRGO-AO-HA     000     B       10/29/1999      11:33   140.6738        41.7845 0       21.4    0       CA      0       -12     0       -18     0
VIRGO-AO-HA     000     B       10/29/1999      11:33   140.6732        41.7833 0       17.4    0       CA      0       27      0       9       0
VIRGO-AO-HA     000     B       10/29/1999      11:33   140.6732        41.7833 0       21.4    0       CA      0       8       0       -11     0
VIRGO-AO-HA     000     B       10/29/1999      11:33   140.6727        41.7822 0       17.4    0       CA      0       -18     0       1       0
VIRGO-AO-HA     000     B       10/29/1999      11:33   140.6727        41.7822 0       21.4    0       CA      0       -28     0       5       0
VIRGO-AO-HA     000     B       10/29/1999      11:33   140.6722        41.7810 0       17.4    0       CA      0       -61     4       -89     4
VIRGO-AO-HA     000     B       10/29/1999      11:33   140.6722        41.7810 0       21.4    0       CA      0       -12     0       -36     0
VIRGO-AO-HA     000     B       10/29/1999      11:34   140.6717        41.7798 0       17.4    0       CA      0       -8      4       -28     4
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Fig.3.1 Example of the daily ocean current data files indicating the first part of 19991029.txt. Note that the column header row divided in the third and fourth rows in this figure is recorded in the third row in the daily ocean current data files

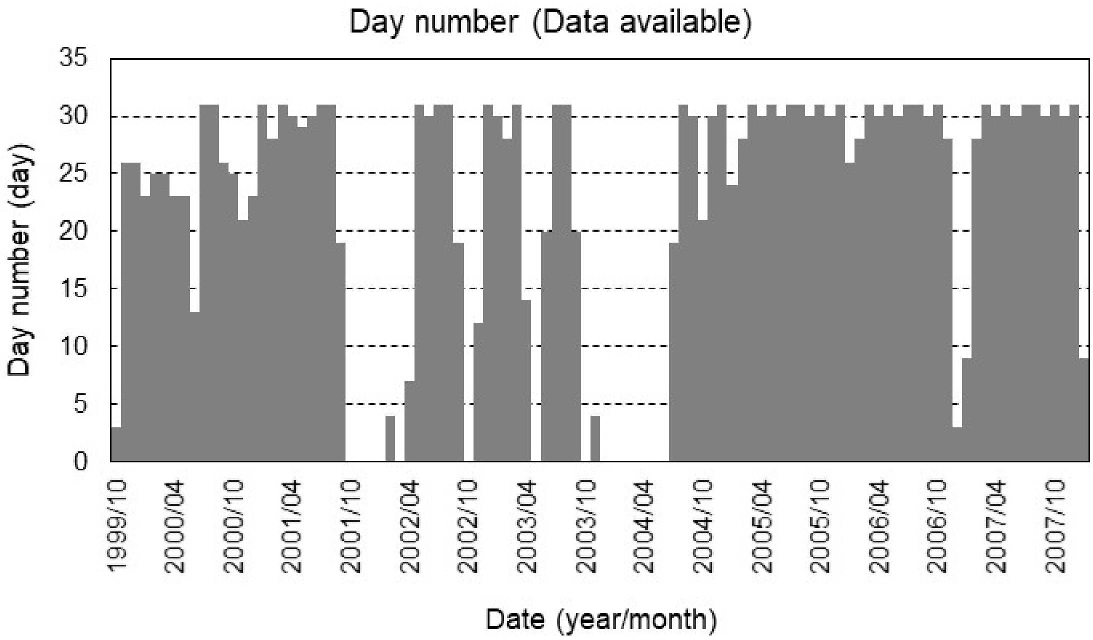

Fig.3.2 Histogram of the number of the daily ocean current data files in each month from October 1999 to January 2008

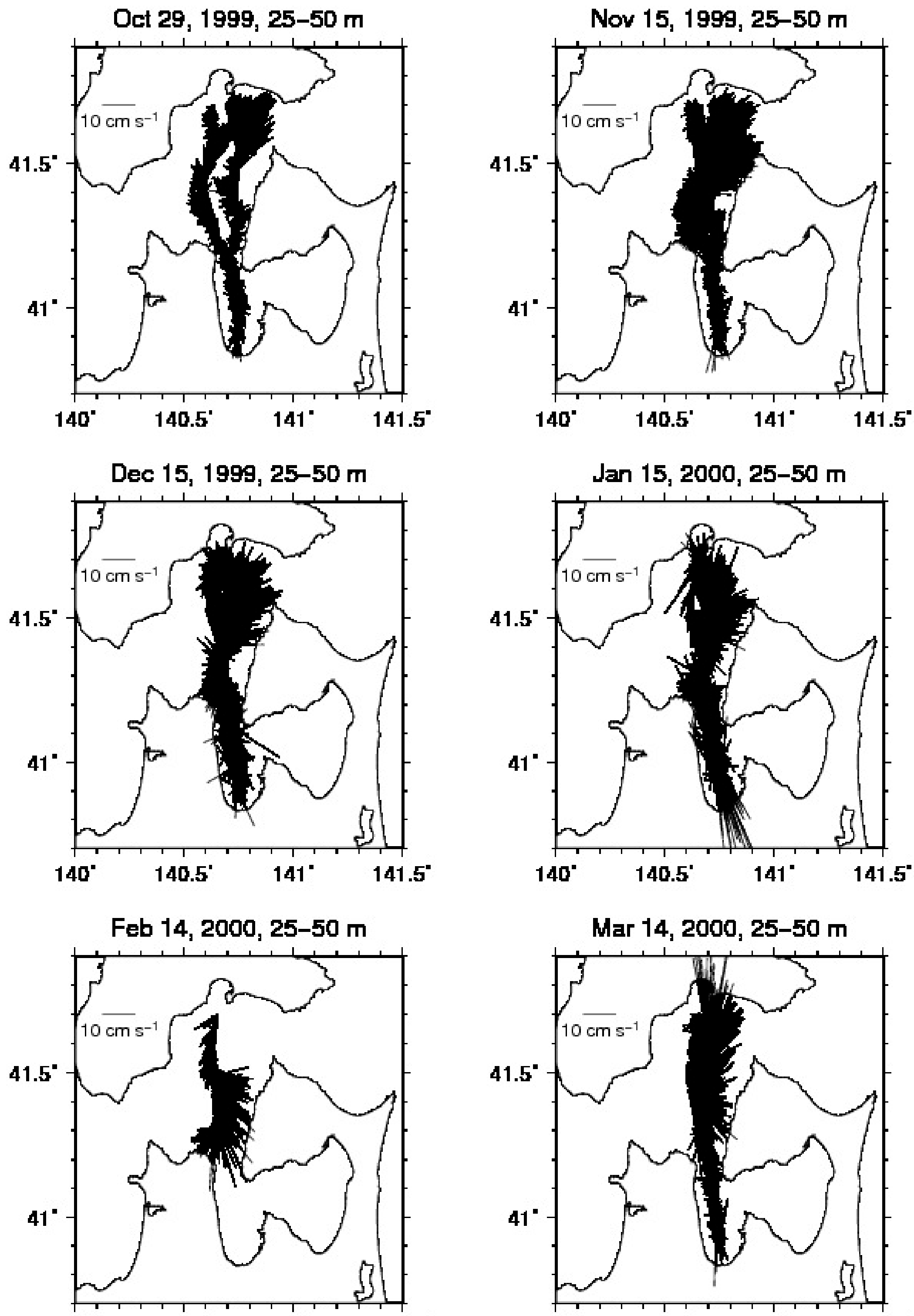

Fig.3.3 Ocean current at a depth of 25–50 m along the ferryboat operation route from October 1999 to March 2000

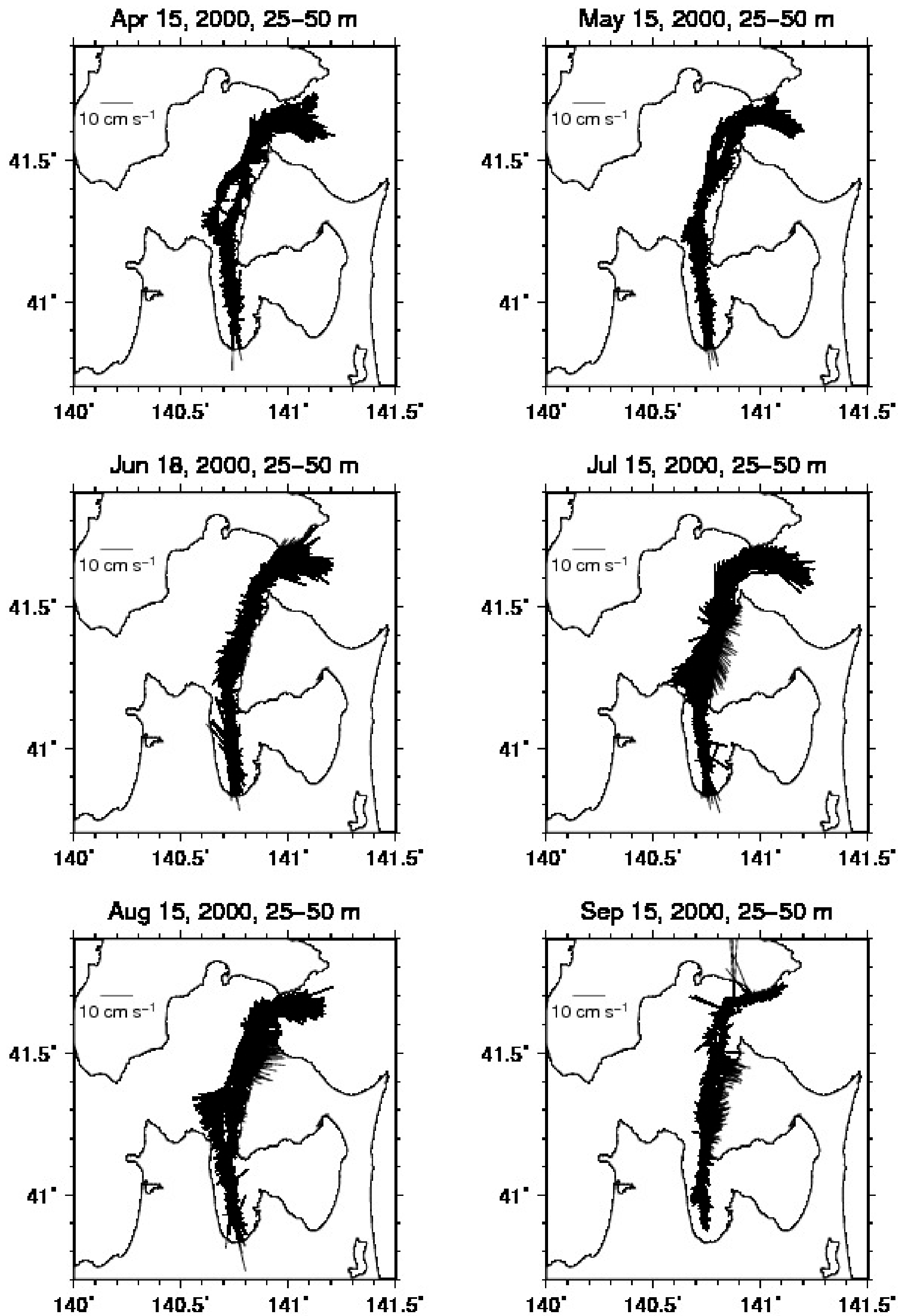

Fig.3.4 Same as Fig. 3.3, except for the period of April to September 2000

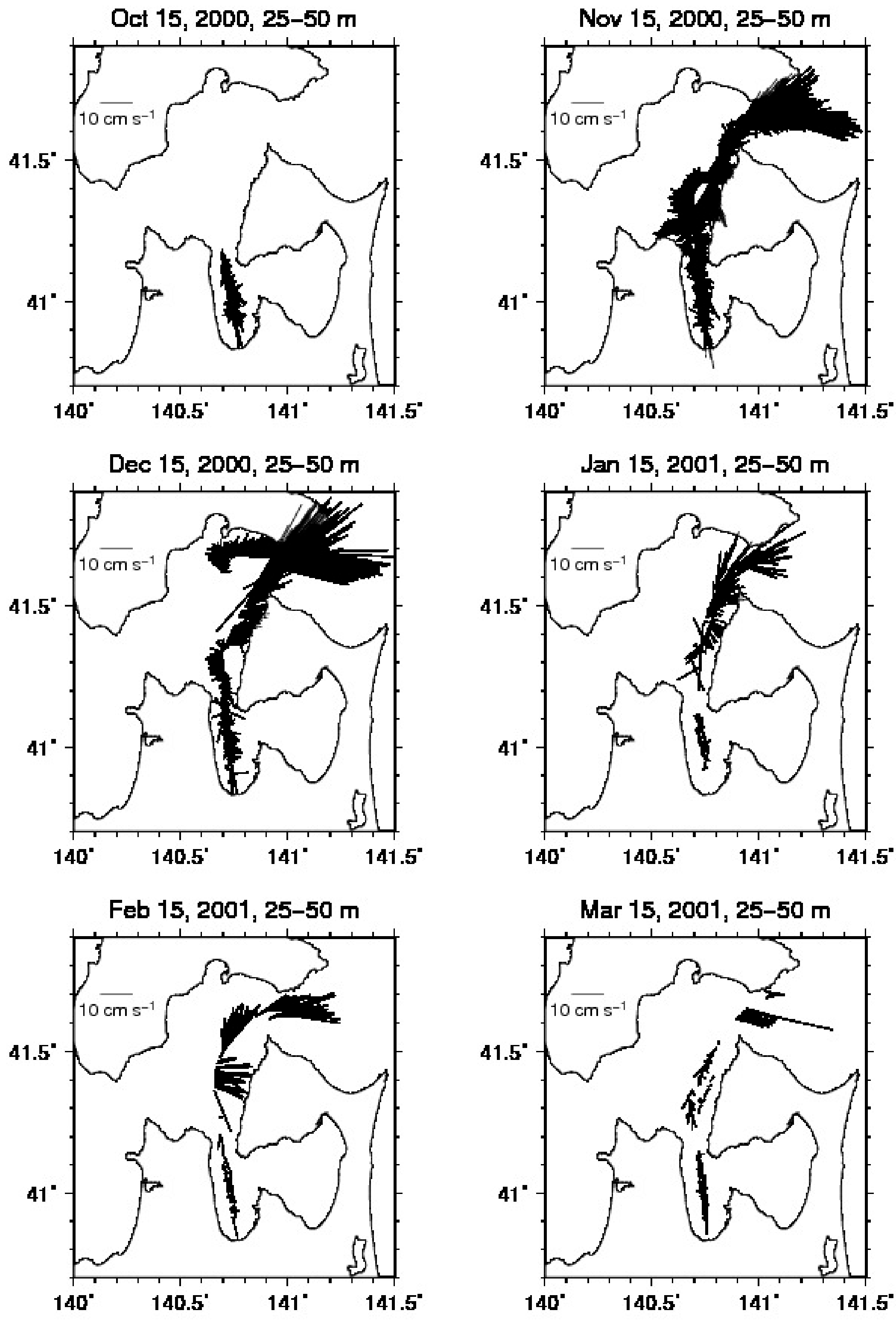

Fig.3.5　Same as Fig. 3.3, except for the period of October 2000 to March 2001

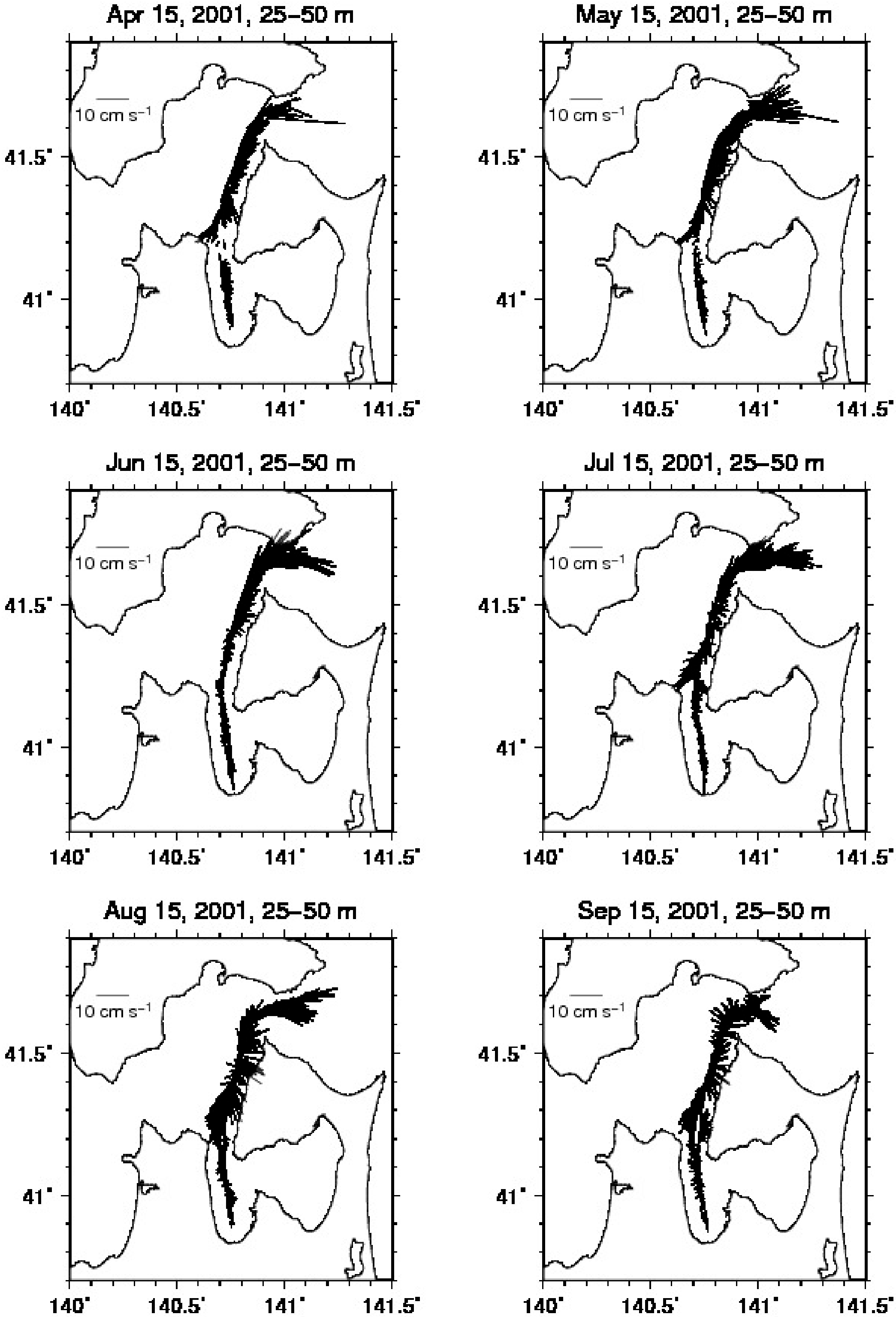

Fig.3.6 Same as Fig. 3.3, except for the period of April to September 2001

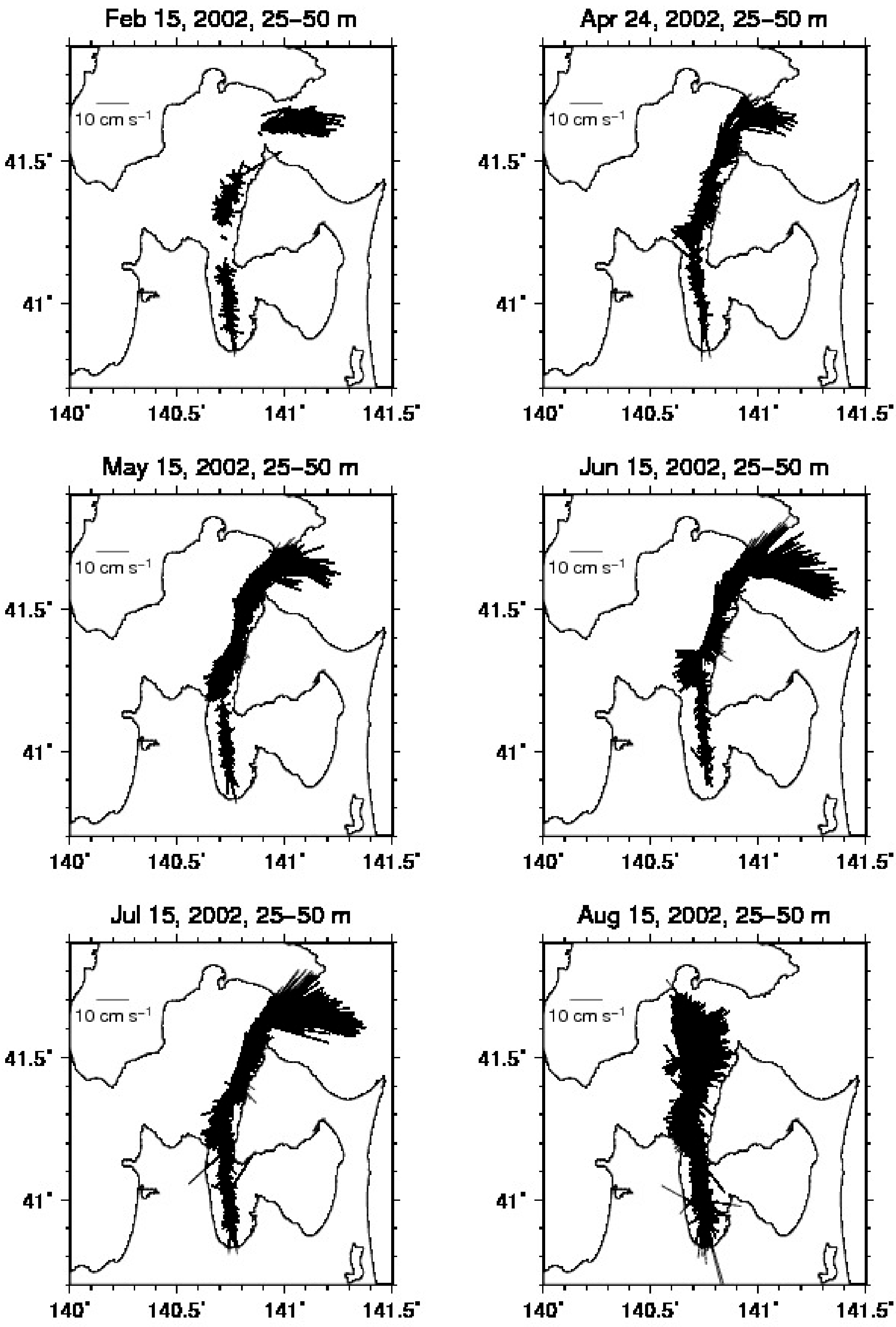

Fig.3.7 Same as Fig. 3.3, except for the period of February to August 2002

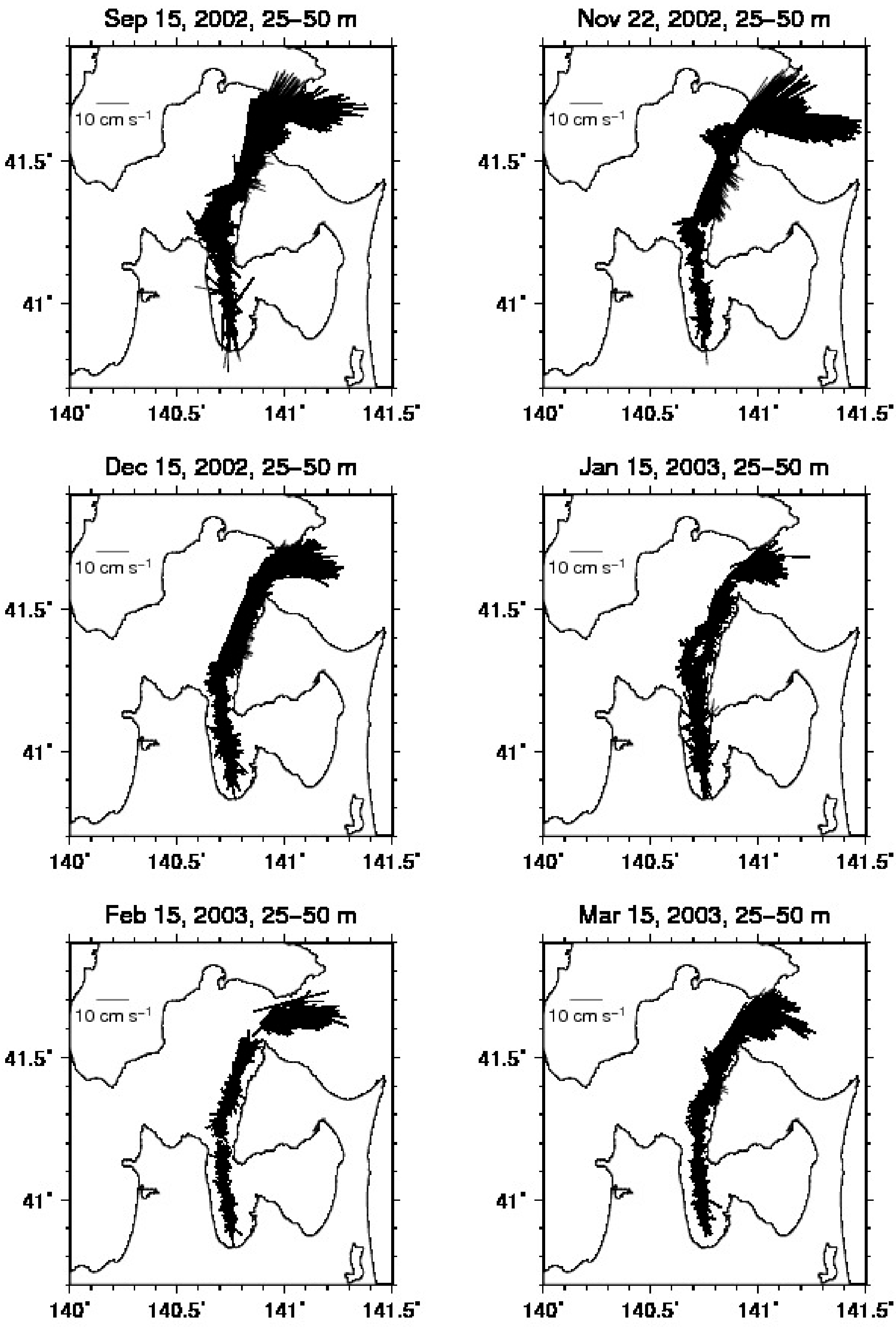

Fig.3.8 Same as Fig. 3.3, except for the period of September 2002 to March 2003

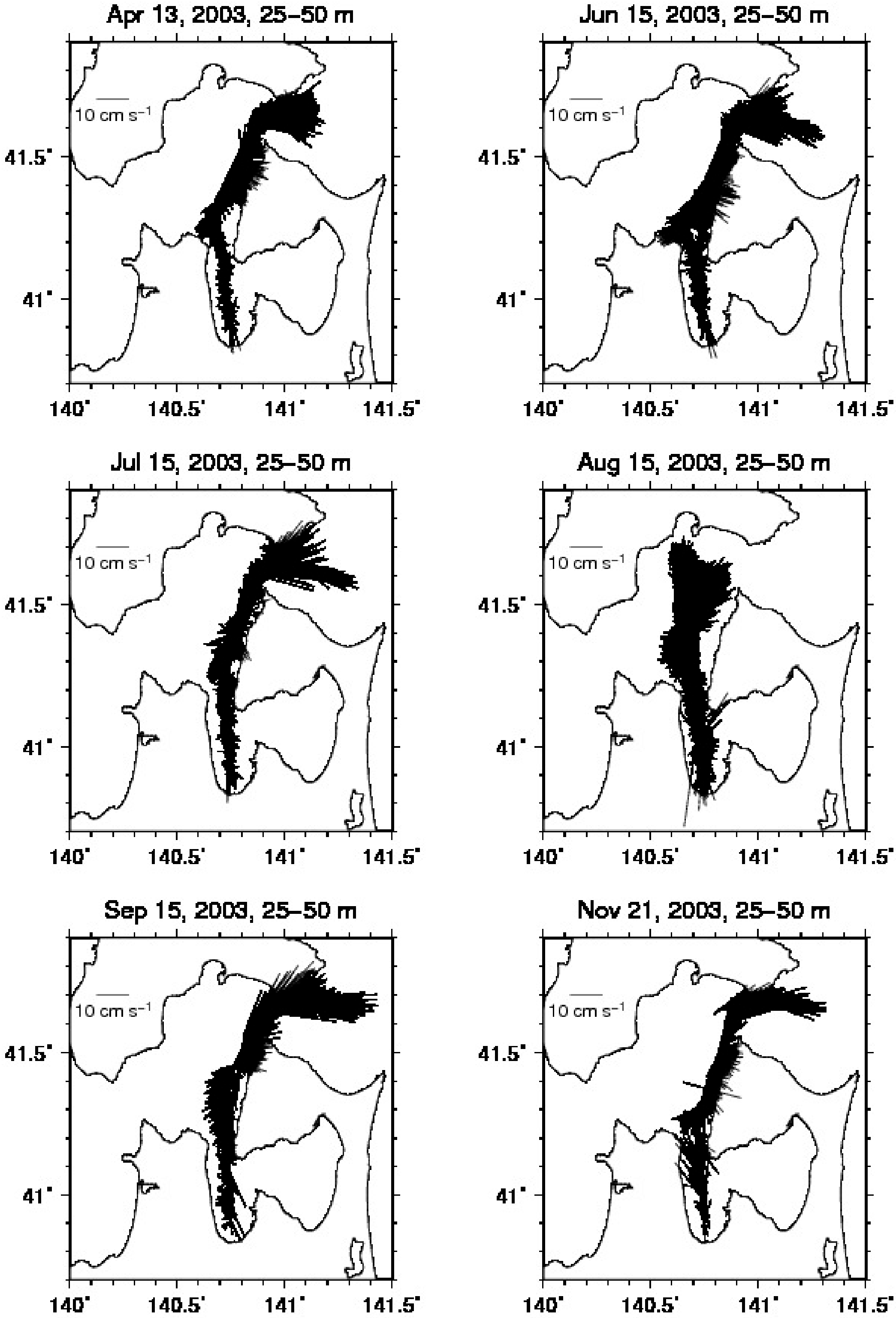

Fig.3.9 Same as Fig. 3.3, except for the period of April to November 2003

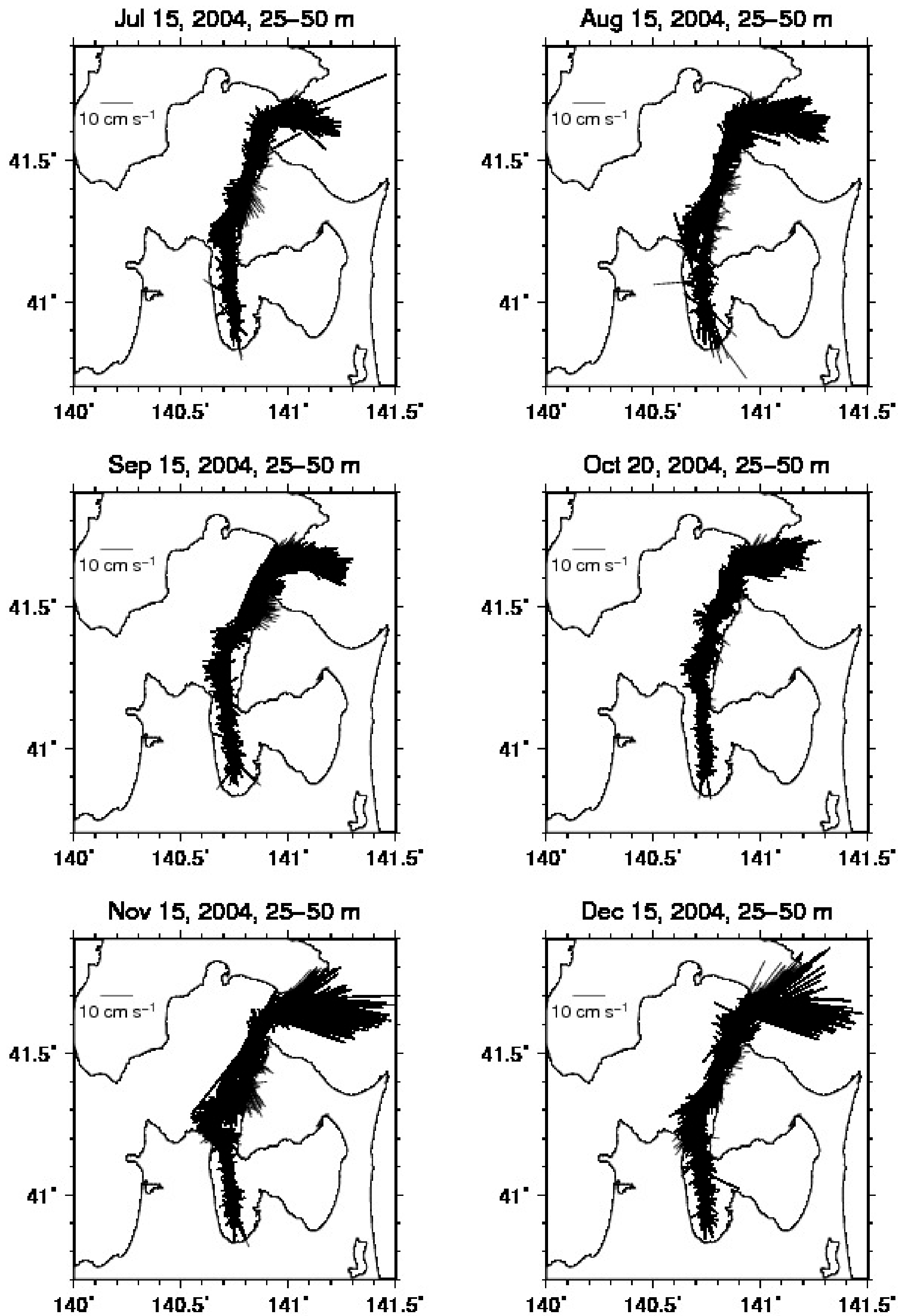

Fig.3.10　Same as Fig. 3.3, except for the period of July to December 2004

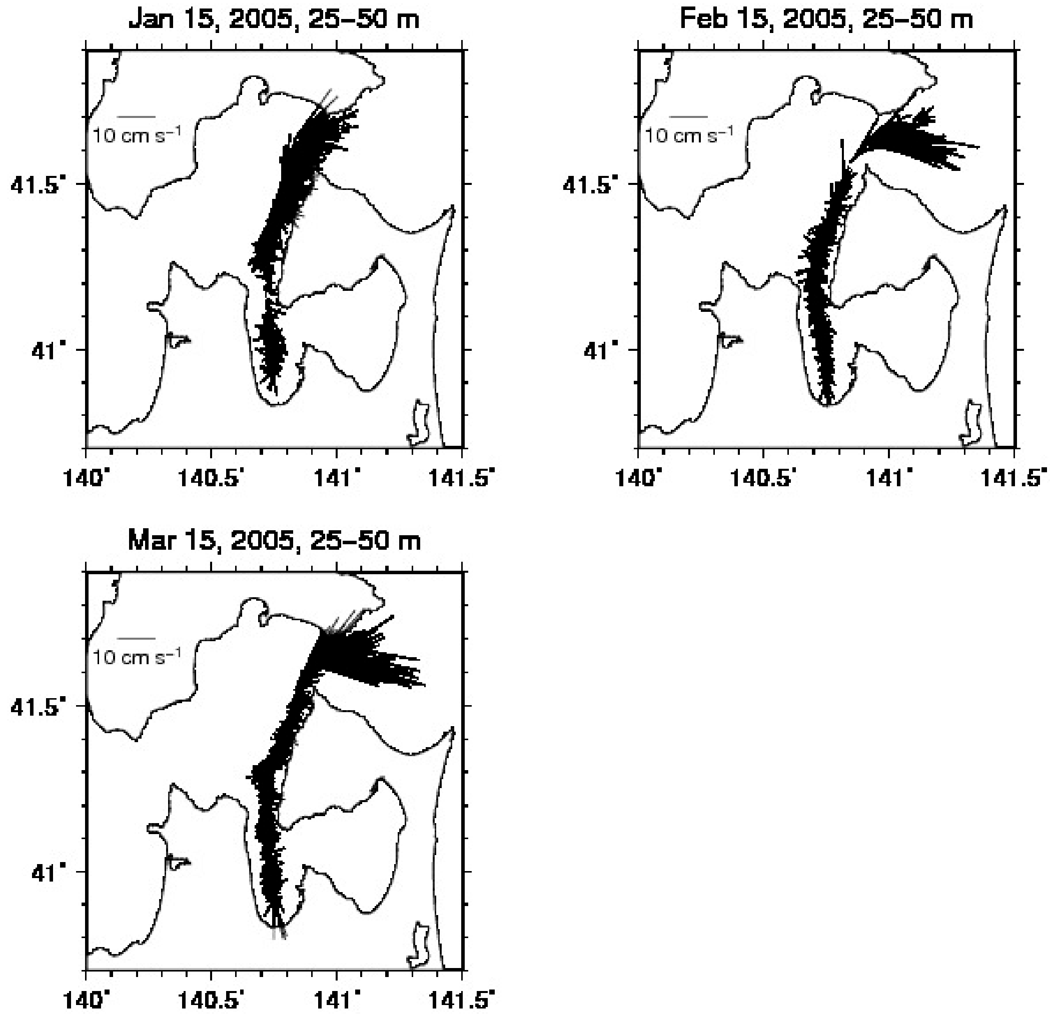

Fig.3.11　Same as Fig. 3.3, except for the period of January to March 2005

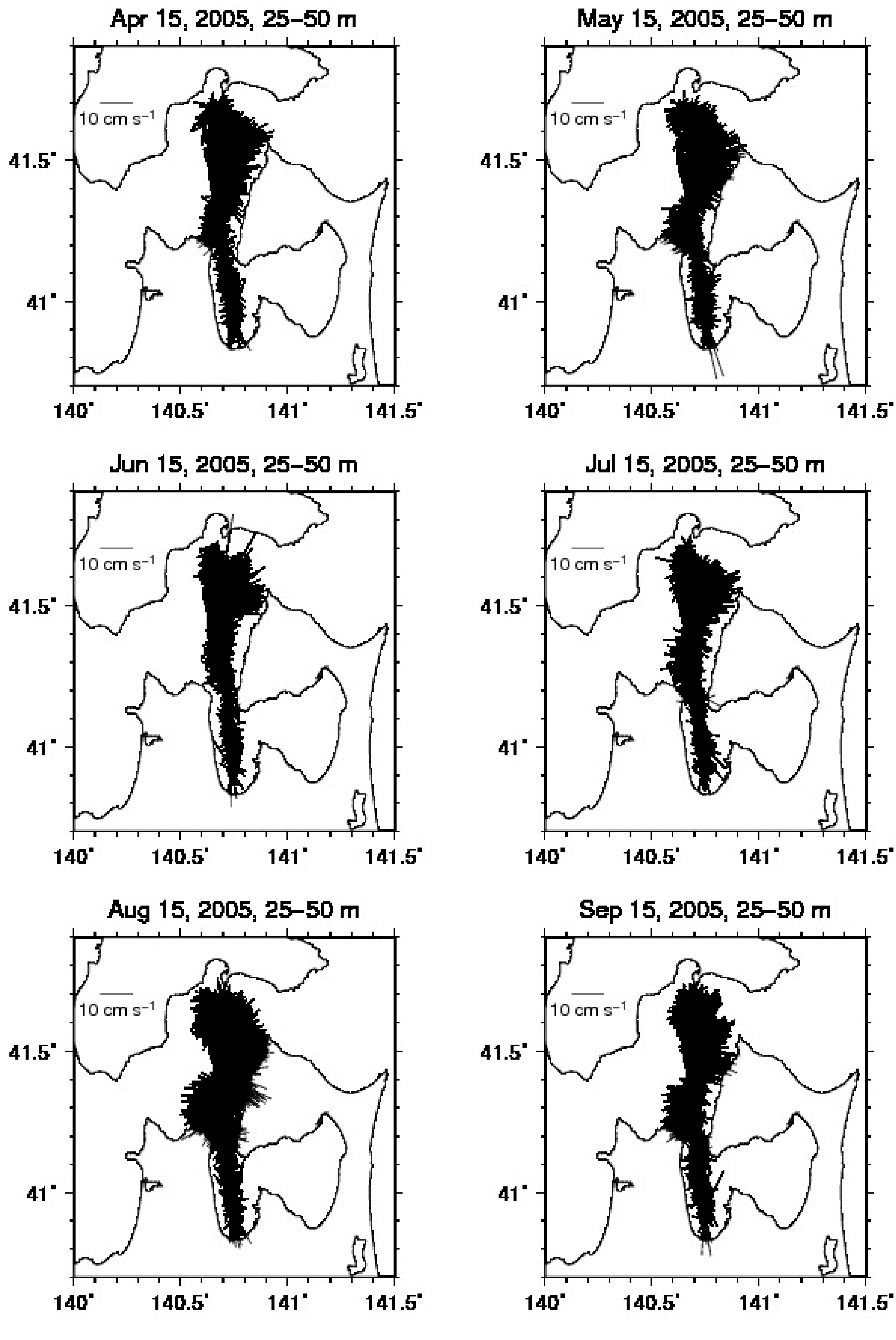

Fig.3.12 Same as Fig. 3.3, except for the period of April to September 2005

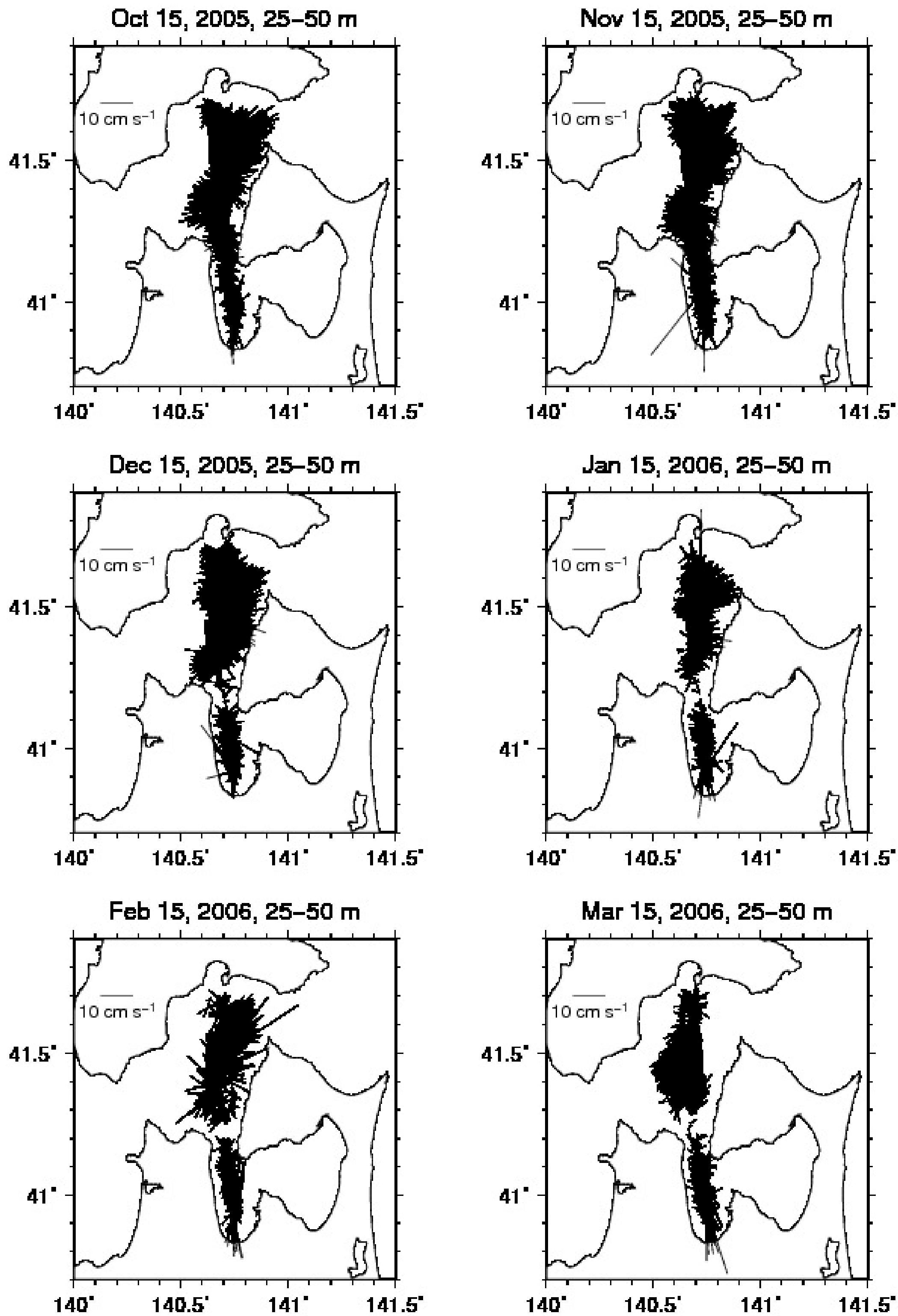

Fig.3.13 Same as Fig. 3.3, except for the period of October 2005 to March 2006

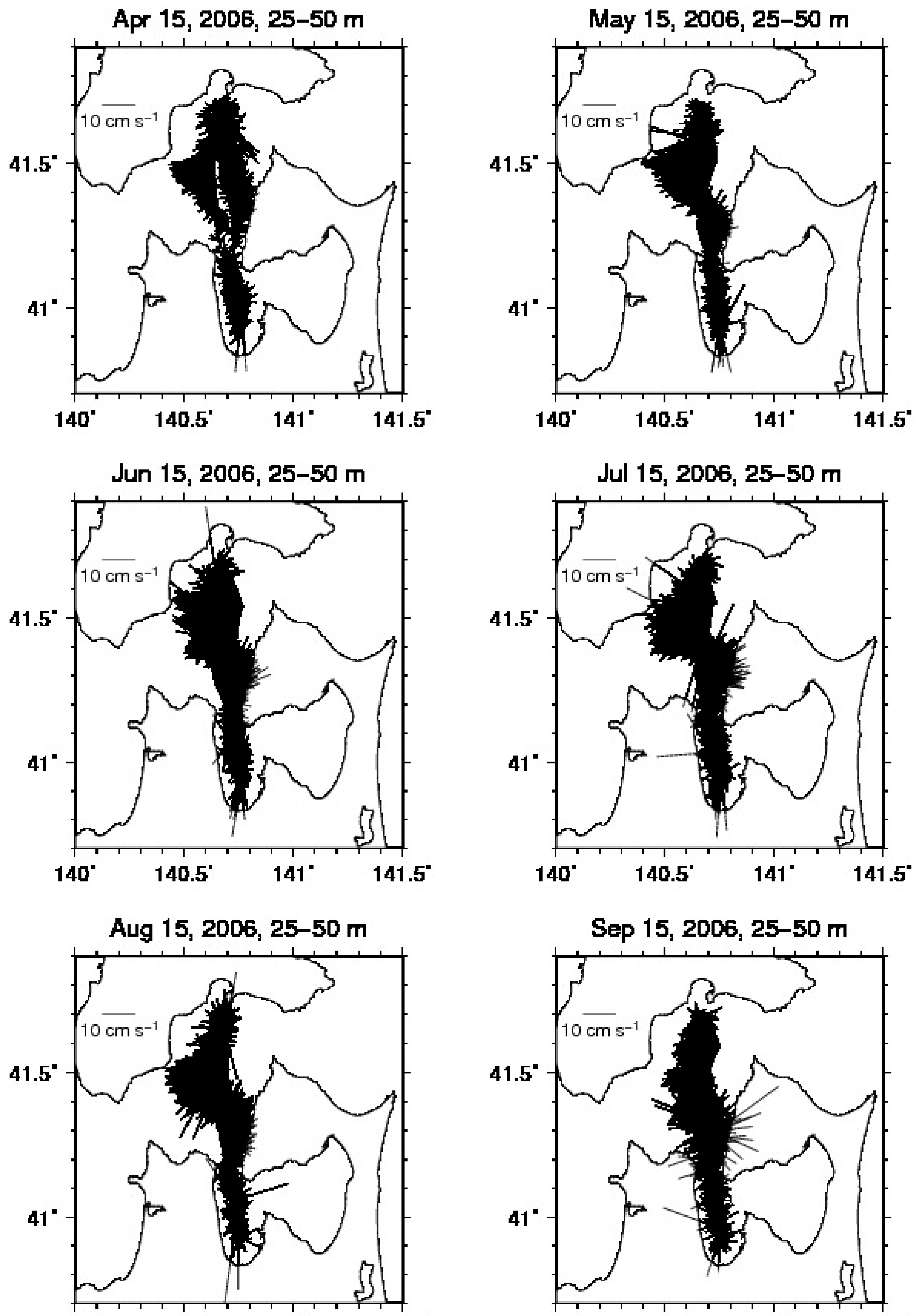

Fig.3.14 Same as Fig. 3.3, except for the period of April to September 2006

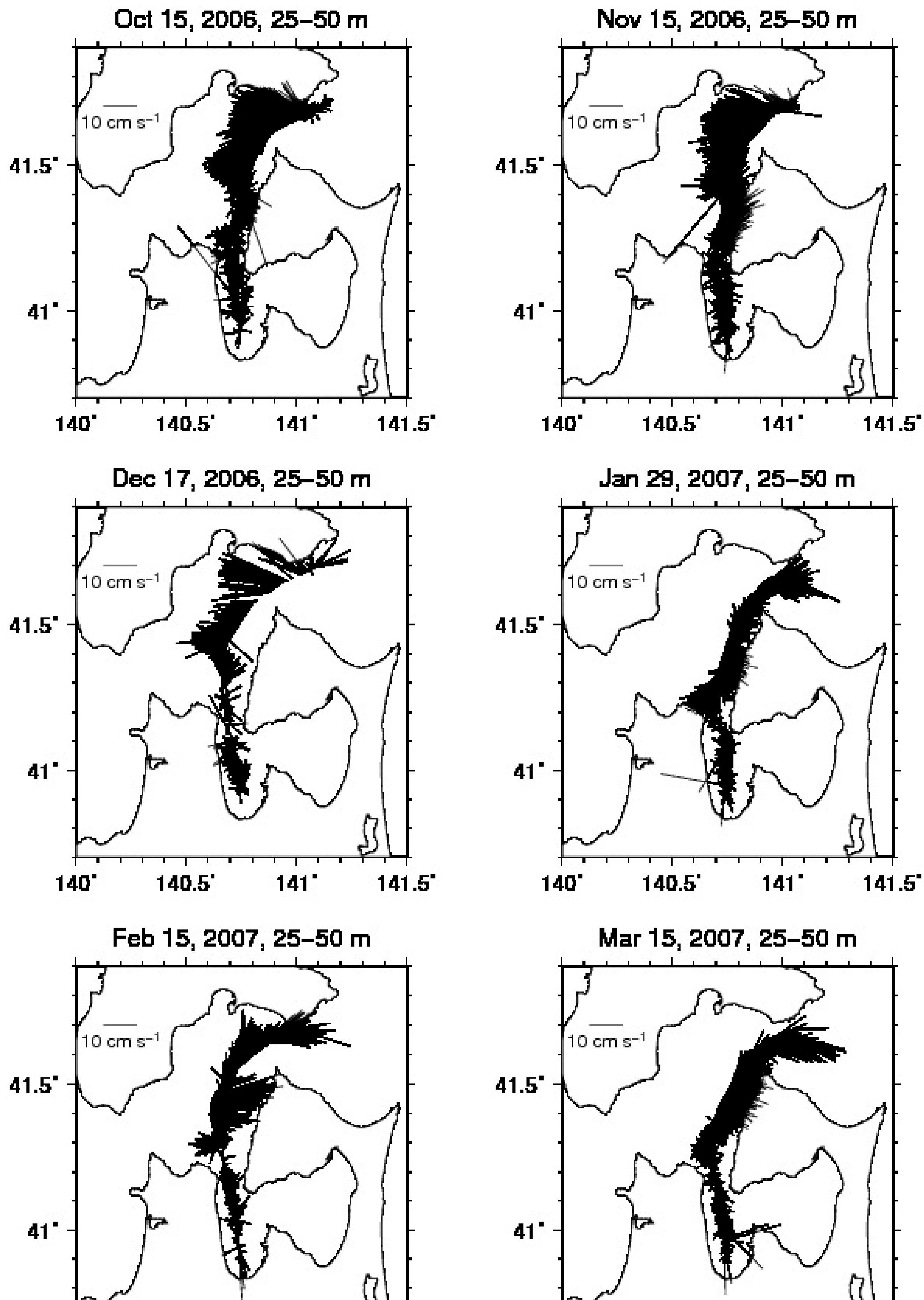

Fig.3.15 Same as Fig. 3.3, except for the period of October 2006 to March 2007

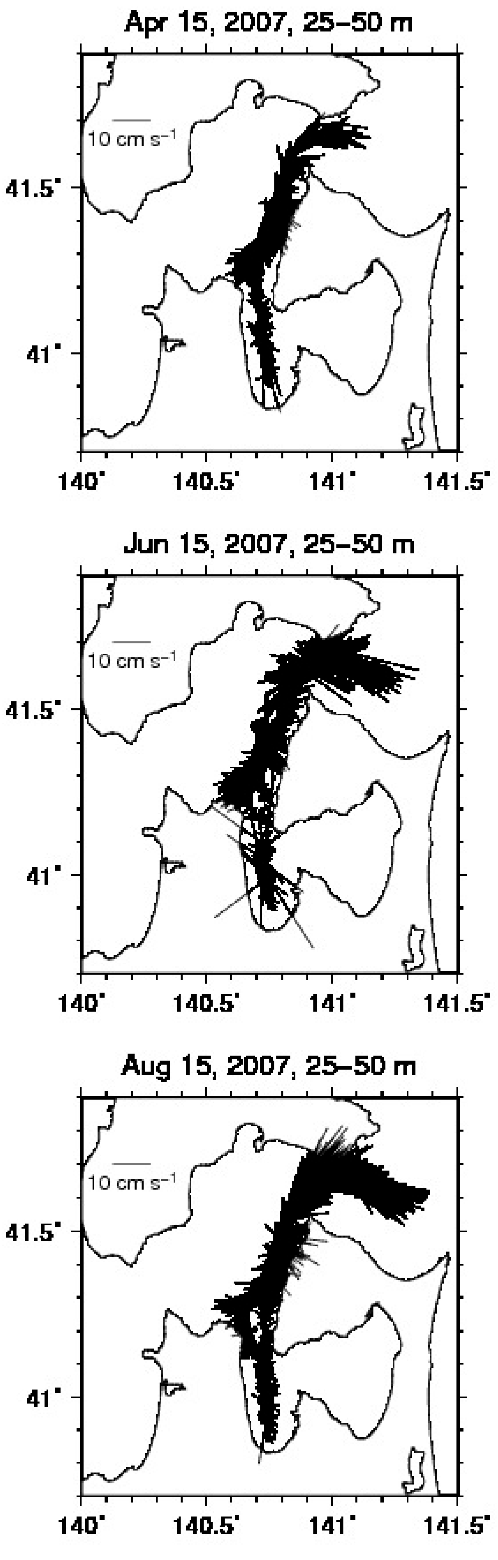

Fig.3.16 Same as Fig. 3.3, except for the period of April to August 2007

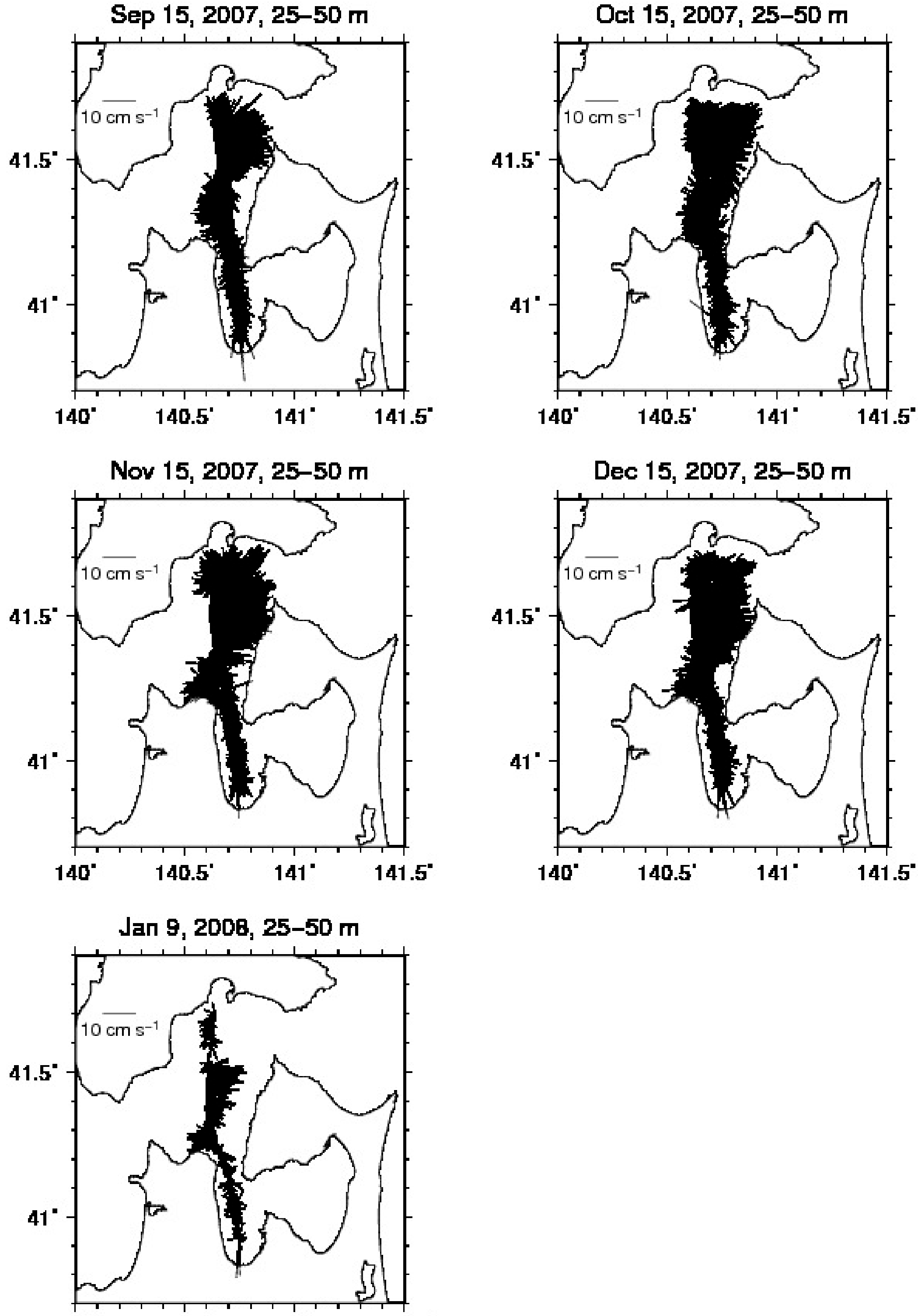

Fig.3.17 Same as Fig. 3.3, except for the period of September 2007 to January 2008

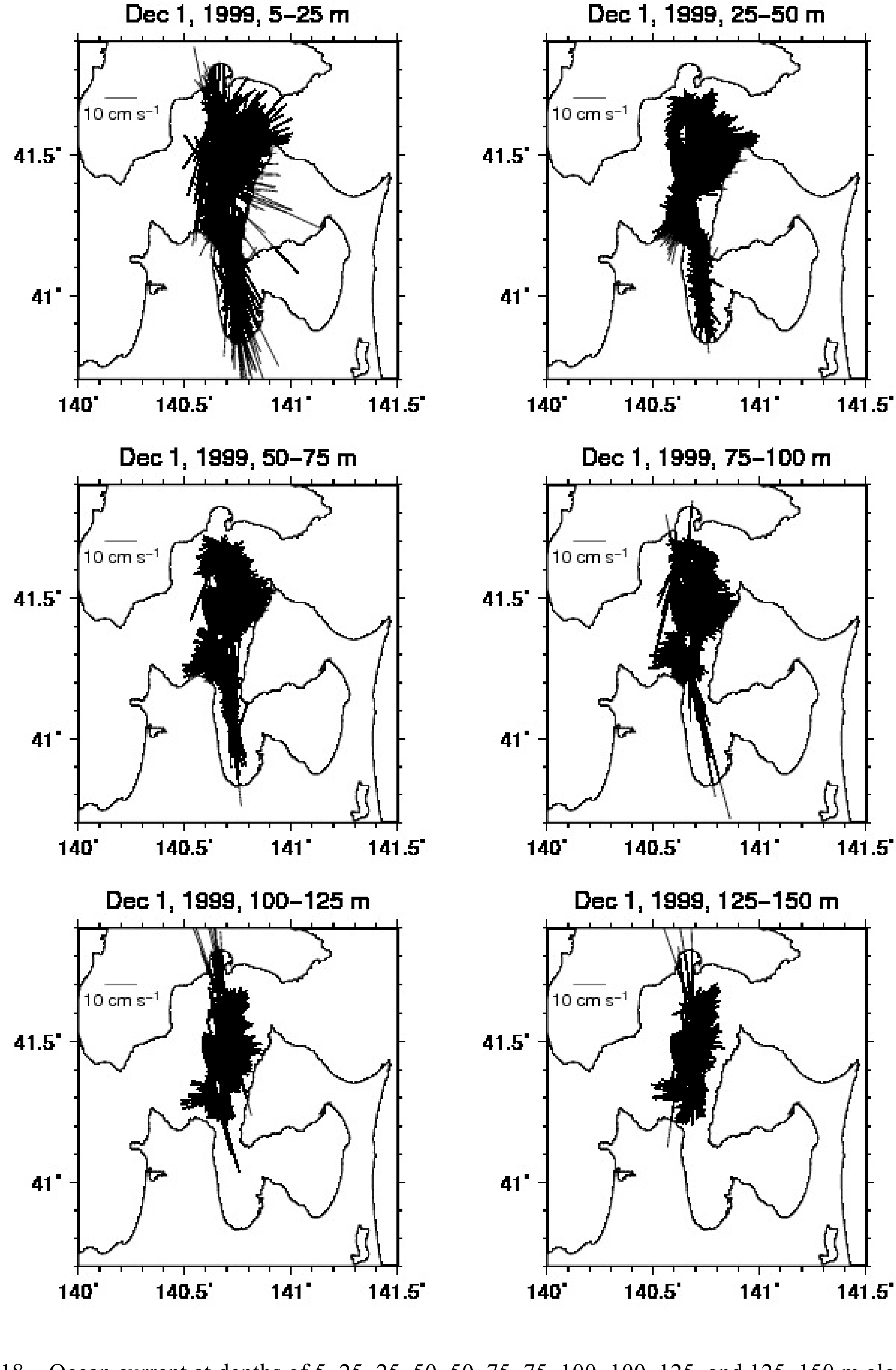

Fig.3.18 Ocean current at depths of 5–25, 25–50, 50–75, 75–100, 100–125, and 125–150 m along the ferryboat operation route in December 1999

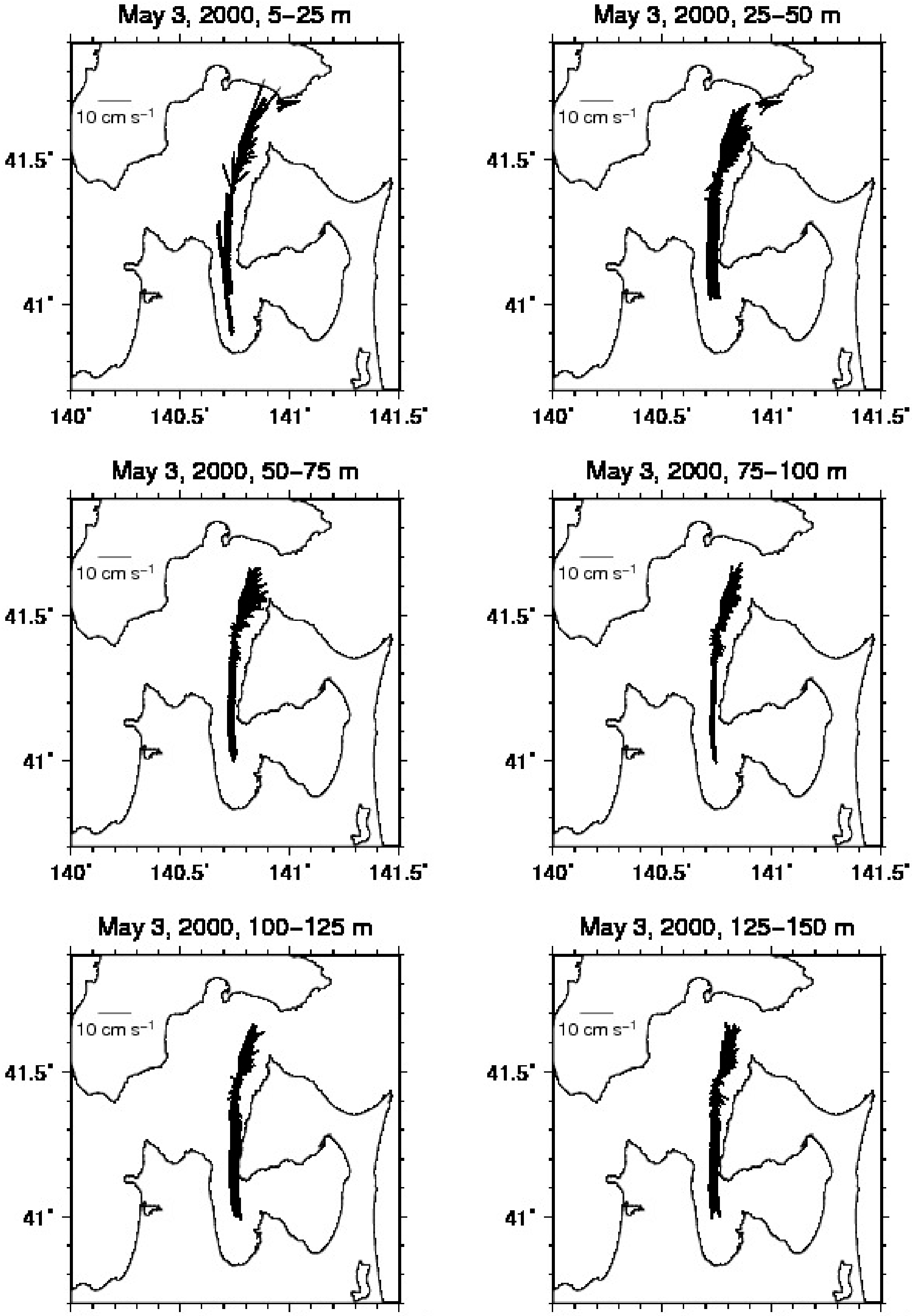

Fig.3.19　Same as Fig. 3.18, except for May 2000

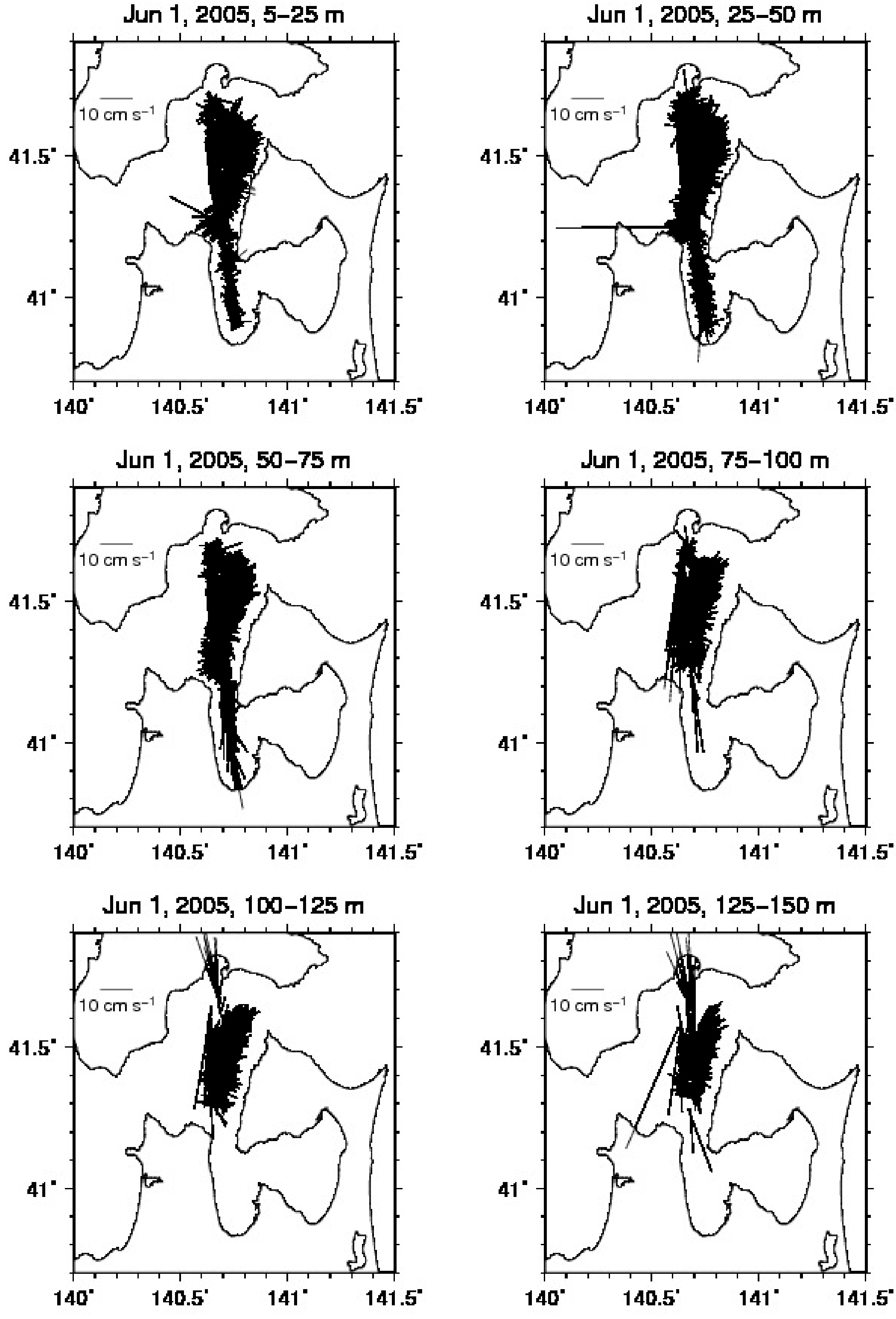

Fig.3.20　Same as Fig. 3.18, except for June 2005

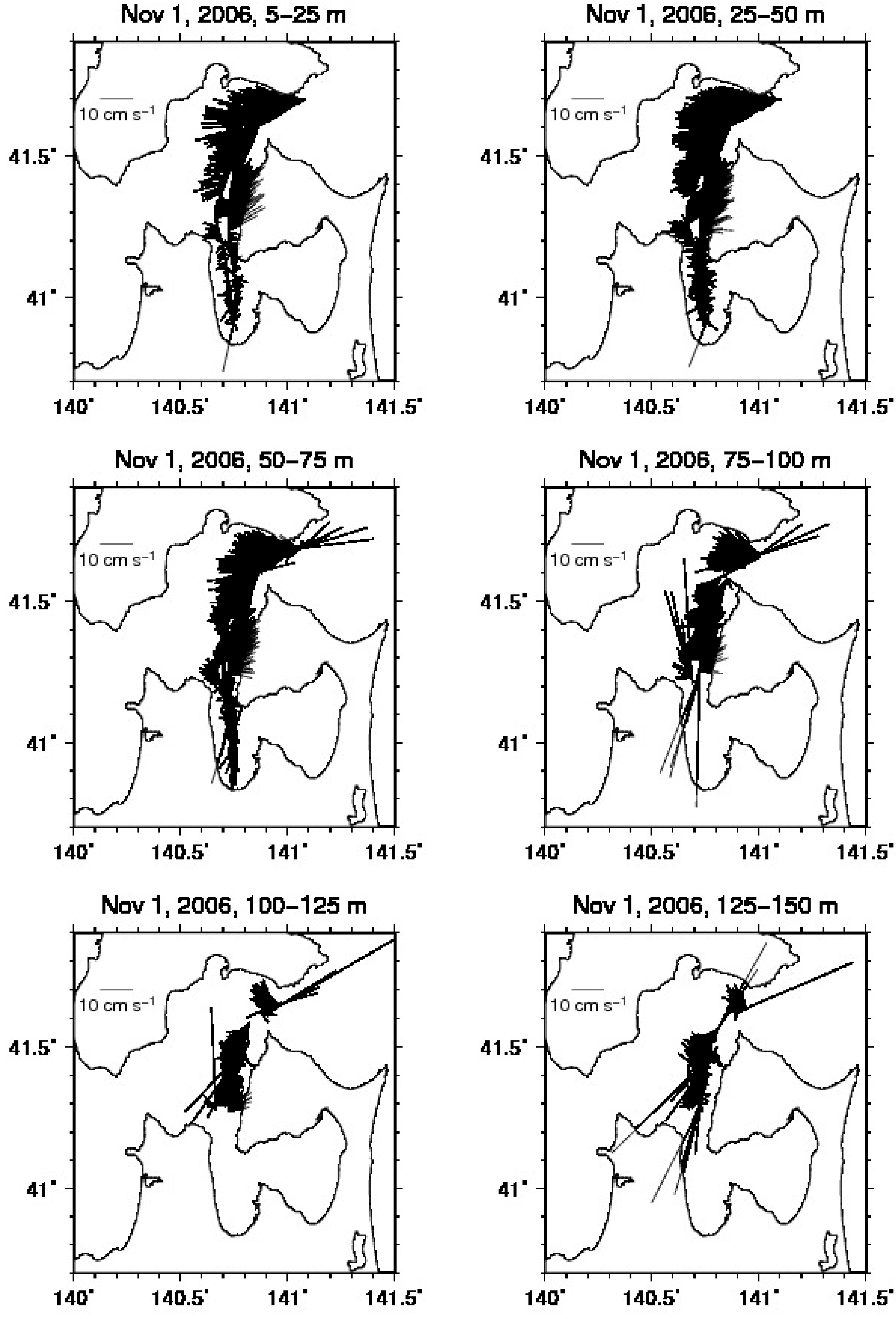

Fig.3.21 Same as Fig. 3.18, except for November 2006

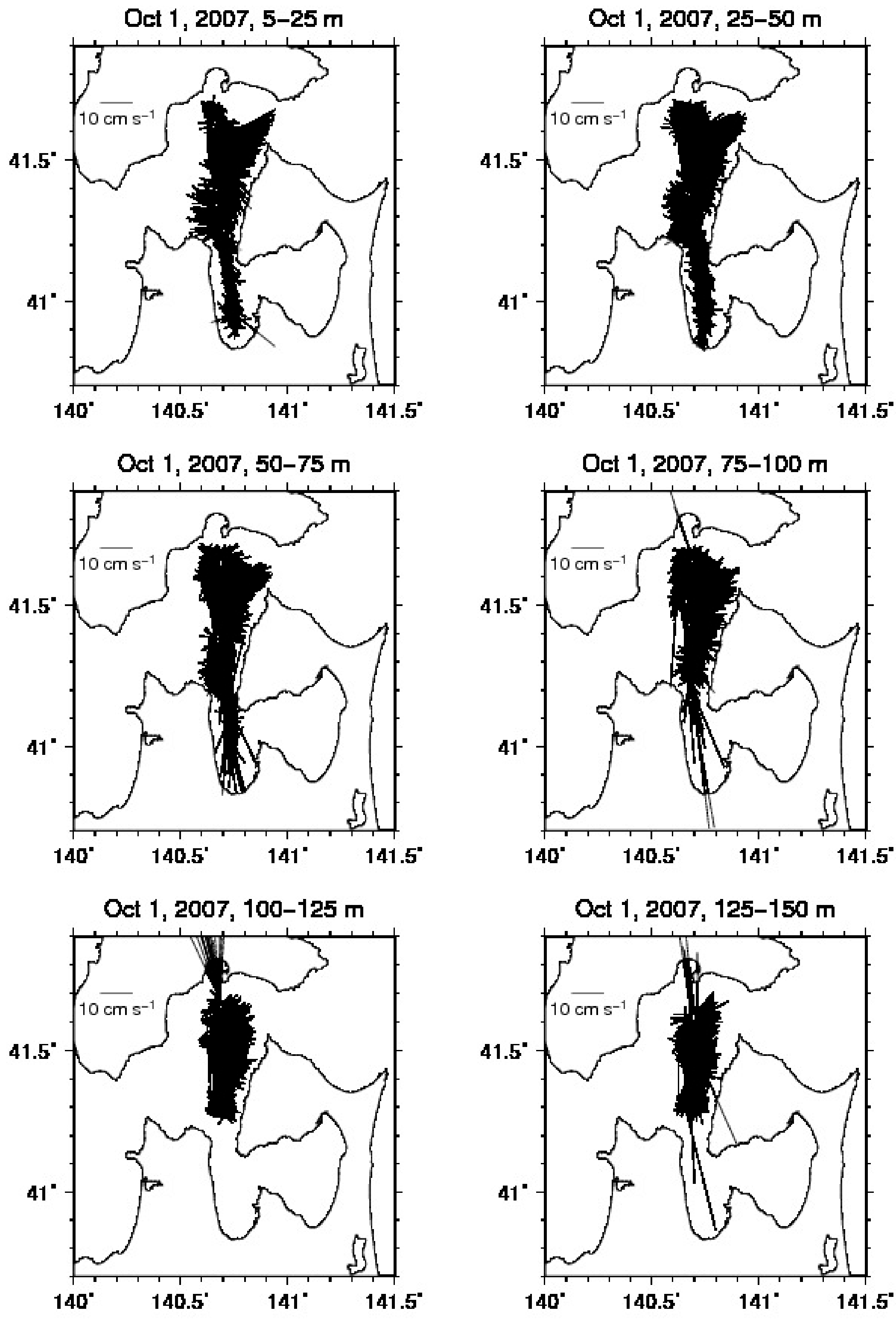

Fig.3.22 Same as Fig. 3.18, except for October 2007