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HYDROLOGICAL MODELLING: ACTIVITY REPORT FOR THE PERIODS OF 01.04–31. 05.1995 and 01.09–30.09.1995

by

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FOOD AND AGRICULTURE ORGANIZATION
OF THE UNITED NATIONS

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PREFACE

The Research for the Management of the Fisheries on Lake Tanganyika Project (Lake Tanganyika Research) became fully operational in January 1992. It is executed by the Food and Agriculture organization of the United Nations (FAO) and funded by the Finnish International Developmental Agency (FINNIDA) and the Arab Gulf Programme for United Nations Development Organizations (AGFUND).

This project aims at the determination of the biological basis for fish production on Lake Tanganyika, in order to permit the formulation of a coherent lake–wide fisheries management policy for the four riparian States (Burundi, Tanzania, Zaïre and Zambia).

Particular attention will be also given to the reinforcement of the skills and physical facilities of the fisheries research units in all four beneficiary countries as well as to the build-up of effective coordination mechanisms to ensure full collaboration between the Governments concerned.

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For both series, reference is further made to the document number **(01)**, and the language in which the document is issued: English **(En)** and/or French **(Fr)**.

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Dr. Podsetchine and **Dr. Huttula** are members of the LTR Scientific team.

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ABSTRACT

Results of numerical model refinement by including more realistic wind–induced shear stresses are presented. The diurnal cycle of near–surface winds over Lake Tanganyika for an average day in the dry season was calculated with a mesoscale meteorological model at the Meteorological Department of Helsinki University. An interface between meteorological and circulation models for interpolation and transfer of wind data is described in detail. Results of spectral analysis of water temperature time series are in good agreement with theoretical estimates of internal waves periods in Lake Tanganyika. Horizontal transport in Lake Tanganyika, at steady state conditions, was studied using a particle tracking technique. A special post-processing and flow visualisation program for PC/Windows was developed. A description of the installation procedure and user's instructions complete the report.

List of Figures

1. INTRODUCTION

The field data and simulation results of the hydrophysical regime of Lake Tanganyika both support the conclusion that the major part of energy from the boundary meteorological layer comes into the lake during the dry season, from the end of May to early September (Coulter *et al.,* 1991, Huttula *et al*., 1994). Therefore our recent study was focused on a more accurate description of the lake hydrodynamics of this particular season.

The lake circulation model was combined with a mesoscale meteorological model. The meteorological model simulates diurnal dynamics of near–surface winds due to a variation of temperature contrast between land and lake. This provides an opportunity to study peculiarities of lake–wide circulation of an average day during the dry season. Thermal effects apparently play a significant role in generating a wind circulation pattern over the Lake Tanganyika region.

As another output of the numerical circulation model, we introduce results of buoyant particle trajectory calculations under various wind conditions. These results may have implications in the biological and limnological studies on the lake, particularly in estimations of floating and migration of small particles such as algae, zooplankton, and even fish eggs and larvae.

Software was developed to visualize the calculated surface and depth–averaged currents in Lake Tanganyika as well as particle trajectories. A description of a PC installation and user’s guide is also given.

2. RESULTS

2.1 DIURNAL CYCLE OF WINDS OVER LAKE TANGANYIKA ON AN AVERAGE JULY DAY

In order to get a detailed description of wind field variations over Lake Tanganyika, a mesoscale meteorological model (see Savijärvi, 1993) was applied for the calculations of thermal winds on an average day in July. The computations were undertaken by Professor Hannu Savijärvi at the Meteorological Department of Helsinki University, Finland. The results of near–surface wind calculations were used as a forcing for a lake circulation model.

During the dry season, also known as the period of trade winds (Ashani, 1990), the position of the Inter Tropical Convergence Zone (ITCZ) is found to be at its northernmost and its distance from Lake Tanganyika at its greatest. The land-lake breeze air circulation’s are diurnal mesoscale flow patterns caused by temperature differences between lake and land. Circulation’s are quasi–regular and strong in tropics. They are also intensified by trade winds during the dry season. The thermodynamic effect (i.e. convergence of mesoscale vertical heat and moisture heat fluxes) is significant in the Lake Tanganyika region. It tends to cool and dry the coastal zone near the surface, and, on the other hand, to warm and moisten air higher up in the boundary layer during daytime (Savijärvi, 1993).

The calculated vector plots of thermal winds combined with background south-easterly trade wind speed 2.5 ms^{-1} are shown in Figures 1-24. During the daytime, they are combined lake and upslope winds, whereas at night–time, they are mainly downslope winds. At night–time, the convergence zone is located over the central part of the lake, but during daytime, it is replaced by a divergence zone. The maximum calculated wind speed is about 7 ms^{-1} at 13:00 when the temperature contrast is at its highest. The calculations are in good agreement with the average diurnal cycle (Ashnani, 1990). The results for certain days may show different patterns and higher lake and slope winds may be observed (Fig. 25).

2.2 INTERFACE BETWEEN METEOROLOGICAL AND CIRCULATION MODELS: TRANSFER AND INTERPOLATION OF DATA

The mesoscale meteorological model has a space resolution 2 km along the X–axis (transverse to the main lake axis direction) and 55.5 km (0.5^0) along the Y-axis (along the main lake axis). The calculated near–surface wind data for each hour (24 time slices) were transferred via a computer network and interpolated on an irregular triangular grid of the lake circulation model, consisting of 1619 nodes and 2920 linear elements. A commercial software Argus MeshMaker Pro[1] (version 2.0) was used. The program

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[1] Argus MeshMaker Pro is trademark of Argus Holdings Ltd. and is mentioned here for reference only.

uses an inverse distance weighted interpolation algorithm. Interpolated X and Y components of near– surface wind vectors were exported and stored in a data base. These interpolated wind data were used as an input for the lake circulation model.

2.3 VARIATIONS OF FLOW FIELDS DURING AN AVERAGE JULY DAY

Simulated surface currents with 1 hour intervals are shown in Figures 26–49. The structure of currents is more complicated than in the case of spatially and temporally constant winds (Figures 62-85). The surface currents mainly follow wind direction, particularly in moderately shallow regions of the lake in the north. In other areas, such as the vicinity of the River Ifumi estuary on the east coast, they directed toward north–west during the whole day, independently of changes in wind direction. Currents vary more, both in direction and magnitude, over the deep central basins of the lake.

In Figures 50-53, a dynamically changing picture of depth-averaged flow can be seen. Due to the variations of wind shear stresses, the anticyclonic gyre in the central part of the lake during morning hours (06:00 a.m.) is replaced by a cyclonic one in the evening (18:00 p.m.). The anti-cyclonic gyre in the southeastern bay of the lake, by contrast, is more or less stable during the whole day. The water level oscillates around equilibrium state, its amplitude changes from 1 to 3.5 cm (Figs. 54–57). As in previous numerical experiments, no regularity was found in the vertical velocity distribution. The maps in Figs. 58-61 show a mosaic, patchy structure of upwelling and downwelling zones.

2.4 INTERNAL WAVES IN LAKE TANGANYIKA

The great depth (mean value 572 m) and regular forcing of the winds during the dry season result in a long and persistent internal wave motion in Lake Tanganyika. The importance of internal waves and their role in lake ecology has been underlined by Coulter (1991) and Plisnier *et al*. (1995). In the current project, internal waves have been recorded with automatic devices for the first time.

The periods of the internal fluctuations were studied by spectral analysis. Daily mean water temperature data from the Mpulungu buoy station on 20.05.-14.09.93 (dry season), 15.09.–31.12.93 (wet season) and from Kigoma on 5.03.-31.05.1993 were used.

Spectral analysis revealed a strong period of 23.4 days in temperature fluctuations during the dry season in Mpulungu at the depths of 50, 150, 200 and 300 m. The same period was also found at the depths of 70, 90, 110 m, but with less significance. This period was not found near to the surface due to the noise and short term fluctuations. The internal waves are spread in all water layers, but the small density gradient in the upper layers and also the intensive vertical mixing make it possible for noisy fluctuations to penetrate downwards. The thermocline, however, prevents their penetration. Below the thermocline, this outer (noisy) component decreases and internal waves become clearer.

The period of internal waves during the dry season is equal to 23.4 days and 34.8 days during the wet season. The frequency of the waves confirms the assumption that they are internal Kelvin waves. The shorter cycle in the dry season is a consequence of the periodic forcing of winds.

In Kigoma, where the major part of the data from year 1994, March–May, represent the dry season, the period of internal waves is 26.3 days. This period reinforces the statement that wind forcing determines a shorter period of internal waves during the dry season.

During the latter part of the rainy season in Mpulungu, from 15.12.93 to 05.05.94, strong temperature oscillations with a period of 24 days were observed at the depths of 30 and 50 m (Fig. 86)

This peak can be seen both in the frequency domain and on the plot of autocorrelation function (Fig. 87). The reason for the exceptionally short period if compared with the first part of the wet season (15.9.-31.12.93) remains unclear. It is possible that intensification of thermal local winds has caused this phenomena.

3. VISUALIZATION AND PARTICLE TRACKING PROGRAM - PURPOSE, HARDWARE REQUIREMENTS AND INSTALLATION

Purpose

The purpose of TANGPT is to visualize flow fields calculated with a 3D numerical circulation model of Lake Tanganyika and to perform particle tracking calculations, i.e. particle trajectories under steady–state flow conditions. At present, the flow fields database on the setup diskette includes 24 surface flow fields and 4 depth-averaged flow fields under the main wind directions and at three wind speeds: 2, 5 and 8 ms^{-1}.

Hardware requirements

It is a PC/Windows based application, which uses a graphical interface for displaying vector fields and organizing a dialogue with a user. The program is written in Visual Basic, Version 3.0. This is a preliminary beta–version of the program. The author would be very grateful if potential users could inform him about any problems with this program, and would also be glad to hear any suggestions concerning improvements and its further development.

Installation procedure

TANGPT requires a PC AT (386 processor or higher) computer with Windows version 3.0 or later. For better performance, a numerical coprocessor is recommended. To install a program, insert a distribution diskette (3.5”-2HD, 1.44 Mb) into drive A: or B:. In Windows, choose Run from the File menu, type a:setup and click OK, or double-click setup.exe from the File Manager. The setup program asks for the directory where you want the program to be installed, expands packed files and copies them on to the destination drive. It is possible that some of the files, such as VBRUN300.DLL, COMNDLG.DLL are already installed in your Windows\System subdirectory. In this case, setup will cancel the installation procedure. It is recommended that these files be removed to another subdirectory and that the installation be repeated.

4. CONCLUSIONS

As a part of LTR hydrodynamic studies, the lake circulation model was combined with a mesoscale meteorological model. The simulation results for an average day in July showed considerable diurnal variation of different hydrophysical characteristics: flow currents, water levels, vertical velocities. As expected, the surface flows mainly followed the wind direction. The results of the model showed high variation of currents, both in direction and magnitude, in deep parts of the lake.

Internal waves were studied by applying a spectral analysis technique. The 23.4 days periodic fluctuations for the dry season and 34.8 days for the wet season are in good agreement with previous studies and theoretical predictions. Further analysis of correlations between local winds and water temperature is required to explain the exceptionally short period of waves (24 days) observed during the late wet season in Mpulungu.

Software tools were developed for the visualization of calculated velocities and particle trajectories under different wind loadings. The results may be used in estimating the passive drifting of particles or small organisms in the pelagic zone, and also in assessing the migrations patterns of algae, zooplankton and fish life stages.

5. REFERENCES

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ANNEX

TANGPT - USER'S INSTRUCTIONS

When TANGPT starts, it displays the window as shown in Fig. 88 with a menu bar at the top and Lake Tanganyika boundary in the rectangular grid at the center of the window. Numbers along the vertical and horizontal axes show X and Y coordinates in km in relative rectangular coordinate system. The menu bar includes the next Menu titles: Run, View, Exit and About. When a menu title Run or View is clicked, a menu containing a list of menu items drops down. A tree of menu dialogue has the following structure:

Run - ***File Open,***
— ***Enter Parameter Values,***
- ***Start Simulation, View — ZoomIn,***
— ***ZoomOut, Exit,***
About.

A detailed description of each menu item is given below.

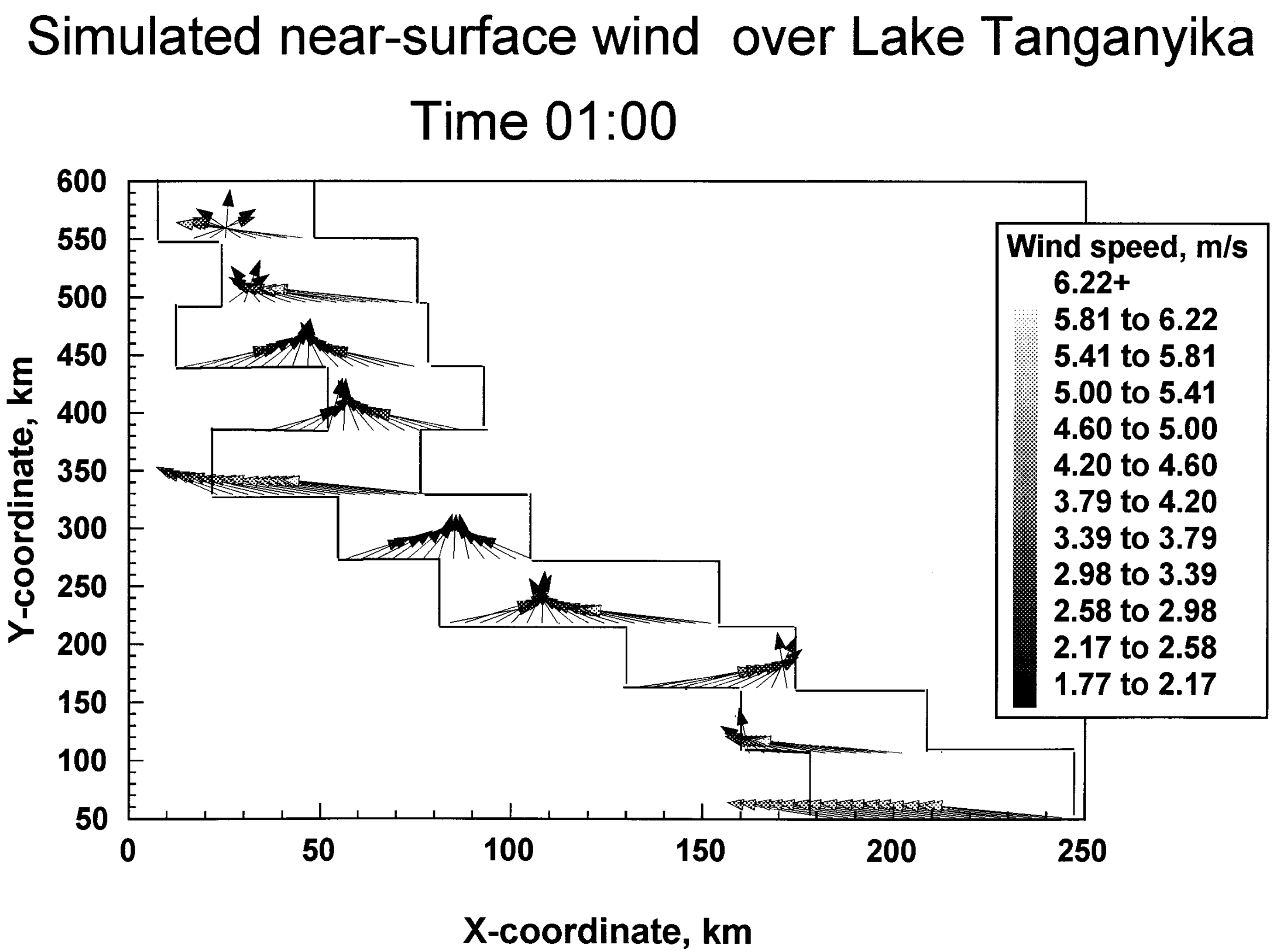
When the ***Run*** is clicked for the first time only the ***File Open*** item is enabled, the other two are dimmed and cannot be executed. After the ***File Open*** menu item is clicked, a standard file open dialogue box appears, giving the user the possibility of selecting a flow field data file from the existing data base. The next file naming conventions were used for this data base: all flow fields files have the extension "dat". The first four letters portray whether it is a surface flow field - "surf" or depth-averaged - "davr". The next two letters denote wind direction: "nn" — northerly wind, "ne" — north—easterly, "ee" — easterly, "se" — south—easterly, "ss" — southerly, "sw" — south-westerly, "ww" — westerly and "nw" — north—westerly. A digit at the end of a file name means a wind speed in ins

After the file selection is done, an open dialogue closes and the ***File Open*** item is disabled, a selected flow field is drawn over the Lake Tanganyika map. The next menu item ***Enter Parameter Values*** becomes enabled. When clicked it displays several Dialog Boxes, one after another, asking for keyboard input of several parameters: Number of Particles , Simulation Time Step in seconds, Simulation Time in Hours, Dispersion Coefficient ms^{-1} and X-,Y—coordinates (km) of Release Point. Then by clicking the ***Start Simulation*** menu item, a simulation starts. The program calculates particle trajectories step by step and displays them on the screen after calculations are performed.

Please remember, if the number of particles is large enough, the simulation time step is small and the simulation period is long, then computational time can be very long.

Figure 89 shows the results of particle tracking simulation under a steady south—easterly wind 8 ms^{-1}. The total simulation period equals 50 days. Under these conditions, a particle can travel a distance of more than 100 km. The ***View*** menu title gives the user the option to ***Zoom In*** on or ***Zoom Out*** of the whole figure. The magnification factor always equals 2. This means that after clicking the ***Zoom In*** item, for example, 3 times, the whole figure is magnified 8 times, if compared with the original one. When the figure is magnified, only a part of the lake can be viewed in the window. Then for navigating over the map, horizontal and vertical scroll bars should be used. The fastest way is to catch a scroll box by pressing the left mouse button over it and dragging it to the desired location. Both the ***Zoom In*** and ***Zoom Out*** items can be activated anytime, except when the program is performing calculations. The ***Exit*** menu title cancels the program execution and returns the controls to Windows. By clicking the ***About*** menu title a short information window about this program is displayed.

During the testing of the program on different computers, some problems were found. These problems and their possible solutions are briefly described here. After the number is entered from the keyboard, you receive the message "Type mismatch", and program execution is terminated. The reason is that your computer Windows uses a comma "," as decimal separator, while the TANGPT by default uses a dot "." as a decimal separator. One solution is to use a comma as decimal separator for numbers, such as the Dispersion Coefficient or Scale Factor, or to change the decimal separator to the dot **(".")** in Windows Control Panel/International/Number Format/Decimal Separator.



Simulated near-surface wind over Lake Tanganyika
Time 01:00
600
550
500
450
400
350
300
250
200
150
100
50
0
50
100
150
200
250
Y-coordinate, km
X-coordinate, km
Wind speed, m/s
6.22+
5.81 to 6.22
5.41 to 5.81
5.00 to 5.41
4.60 to 5.00
4.20 to 4.60
3.79 to 4.20
3.39 to 3.79
2.98 to 3.39
2.58 to 2.98
2.17 to 2.58
1.77 to 2.17

Fig.1

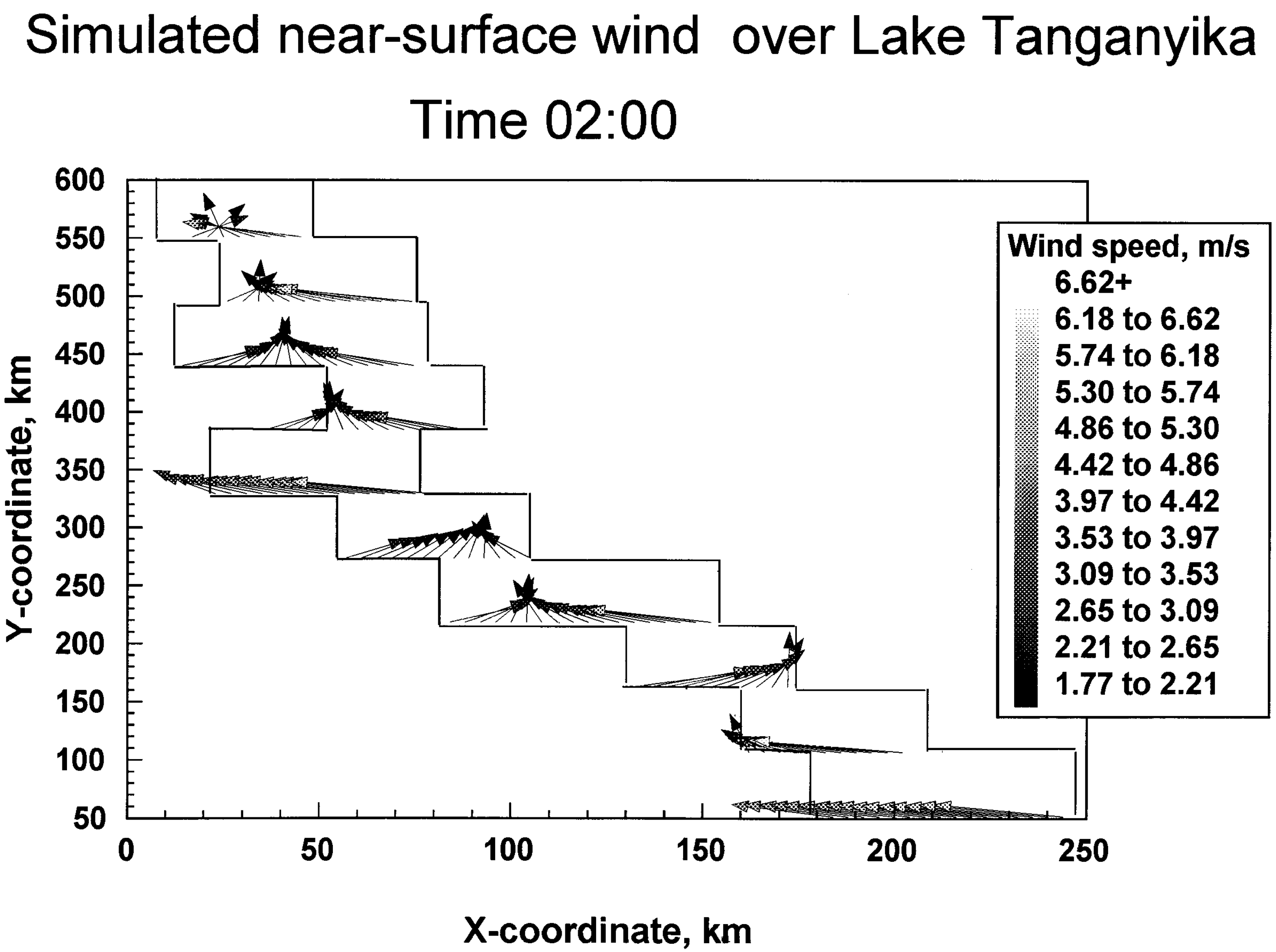

Simulated near-surface wind over Lake Tanganyika
Time 02:00
Wind speed, m/s
6.62+
6.18 to 6.62
5.74 to 6.18
5.30 to 5.74
4.86 to 5.30
4.42 to 4.86
3.97 to 4.42
3.53 to 3.97
3.09 to 3.53
2.65 to 3.09
2.21 to 2.65
1.77 to 2.21
Y-coordinate, km
X-coordinate, km
600
550
500
450
400
350
300
250
200
150
100
50
0
50
100
150
200
250

Fig.2

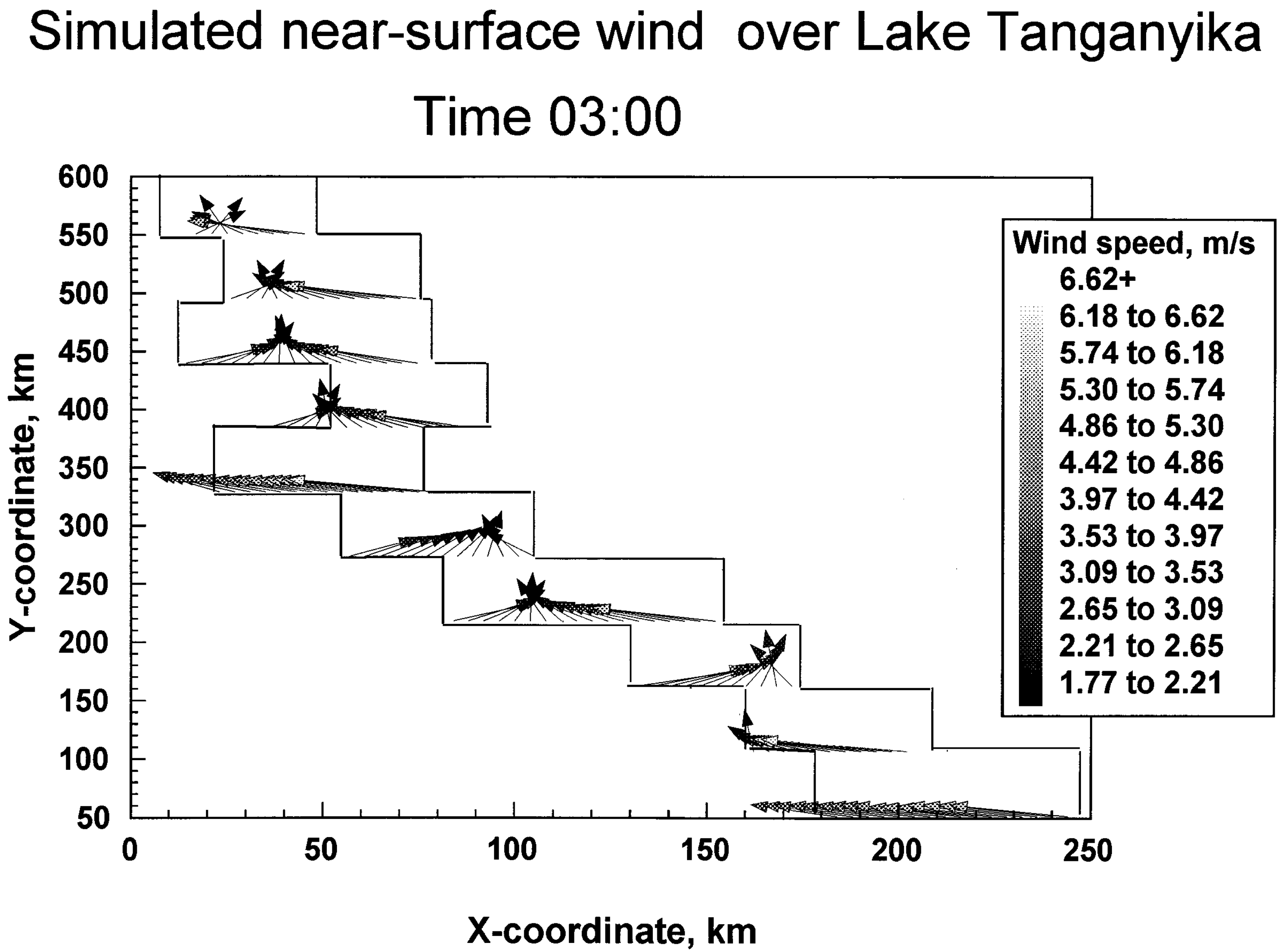
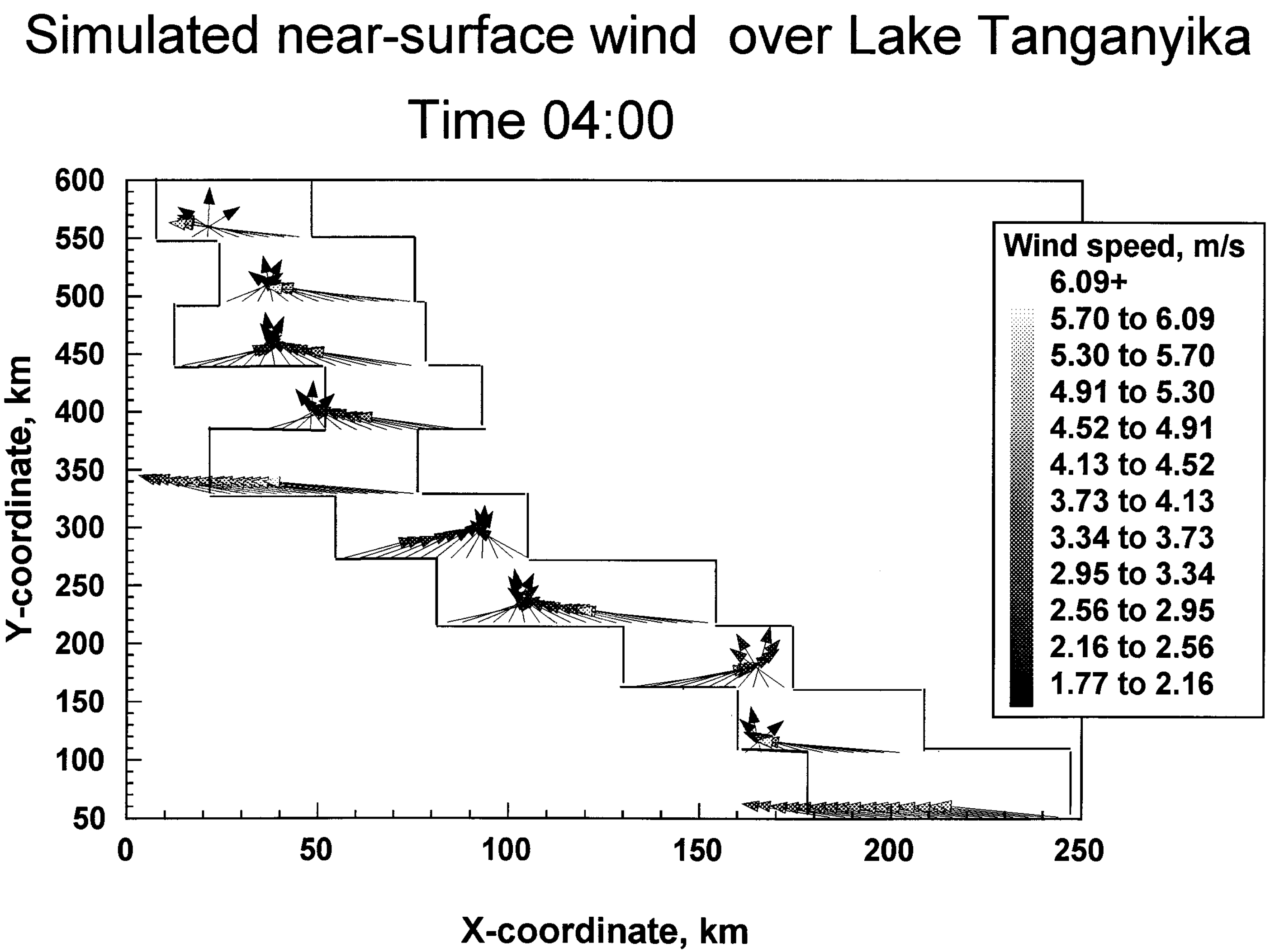

Simulated near-surface wind over Lake Tanganyika
Time 03:00
Wind speed, m/s
6.62+
6.18 to 6.62
5.74 to 6.18
5.30 to 5.74
4.86 to 5.30
4.42 to 4.86
3.97 to 4.42
3.53 to 3.97
3.09 to 3.53
2.65 to 3.09
2.21 to 2.65
1.77 to 2.21
Y-coordinate, km
600
550
500
450
400
350
300
250
200
150
100
50
0
50
100
150
200
250
X-coordinate, km

Fig3.



Simulated near-surface wind over Lake Tanganyika
Time 04:00
Wind speed, m/s
6.09+
5.70 to 6.09
5.30 to 5.70
4.91 to 5.30
4.52 to 4.91
4.13 to 4.52
3.73 to 4.13
3.34 to 3.73
2.95 to 3.34
2.56 to 2.95
2.16 to 2.56
1.77 to 2.16
Y-coordinate, km
X-coordinate, km
600
550
500
450
400
350
300
250
200
150
100
50
0
50
100
150
200
250

Fig4.

Simulated near-surface wind over Lake Tanganyika

Time 05:00

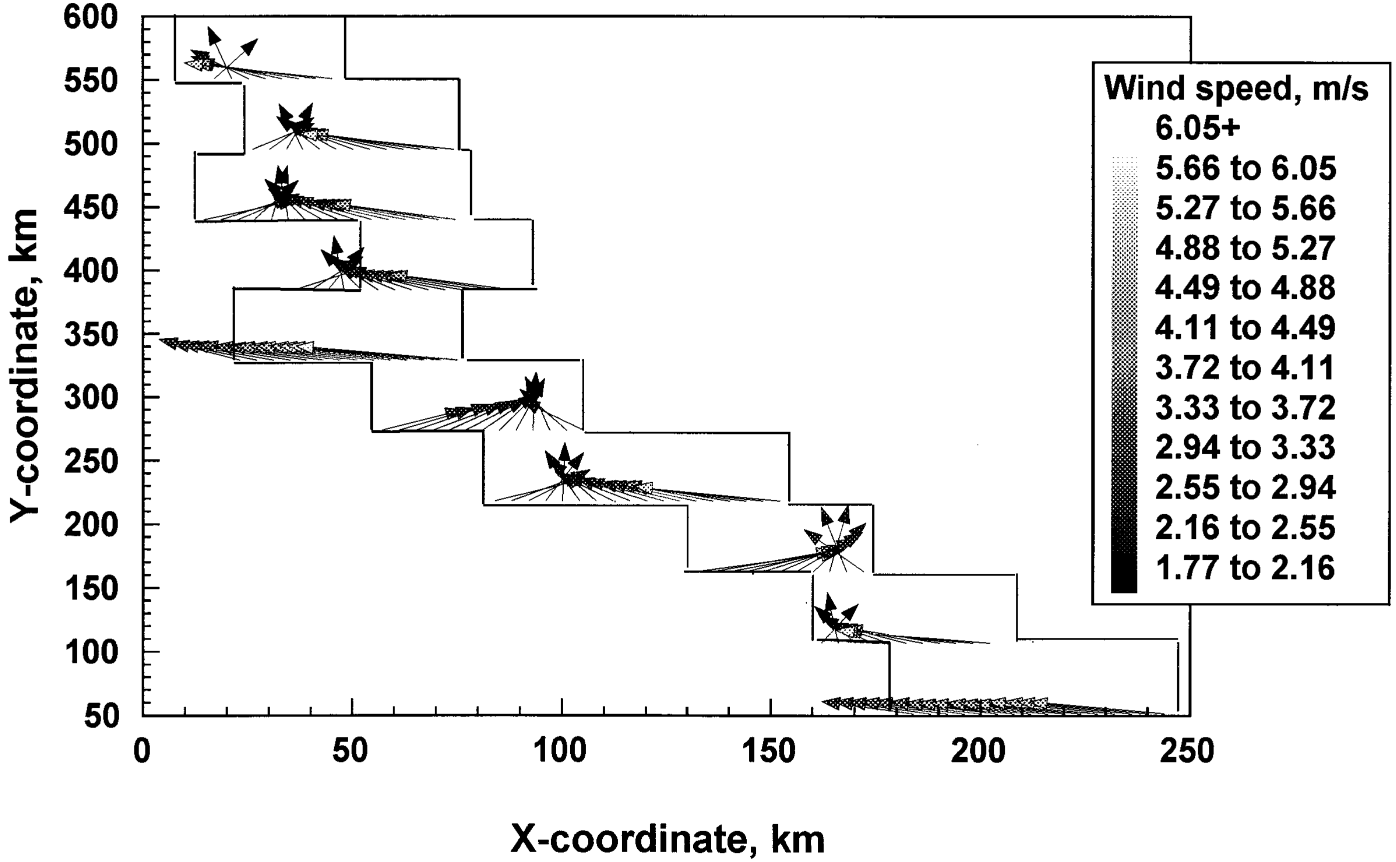


Fig5.

Simulated near-surface wind over Lake Tanganyika

Time 06:00

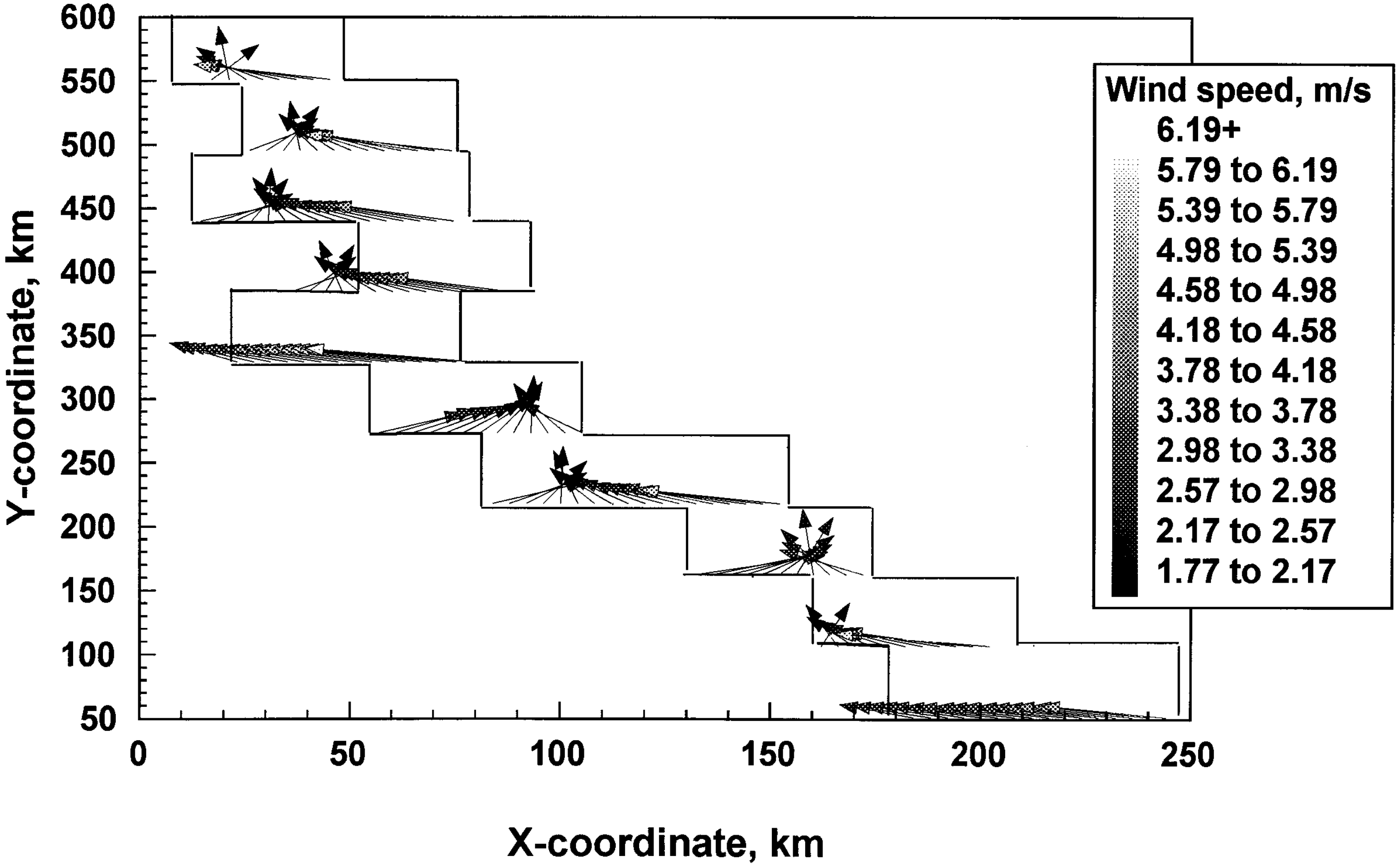


Fig6.

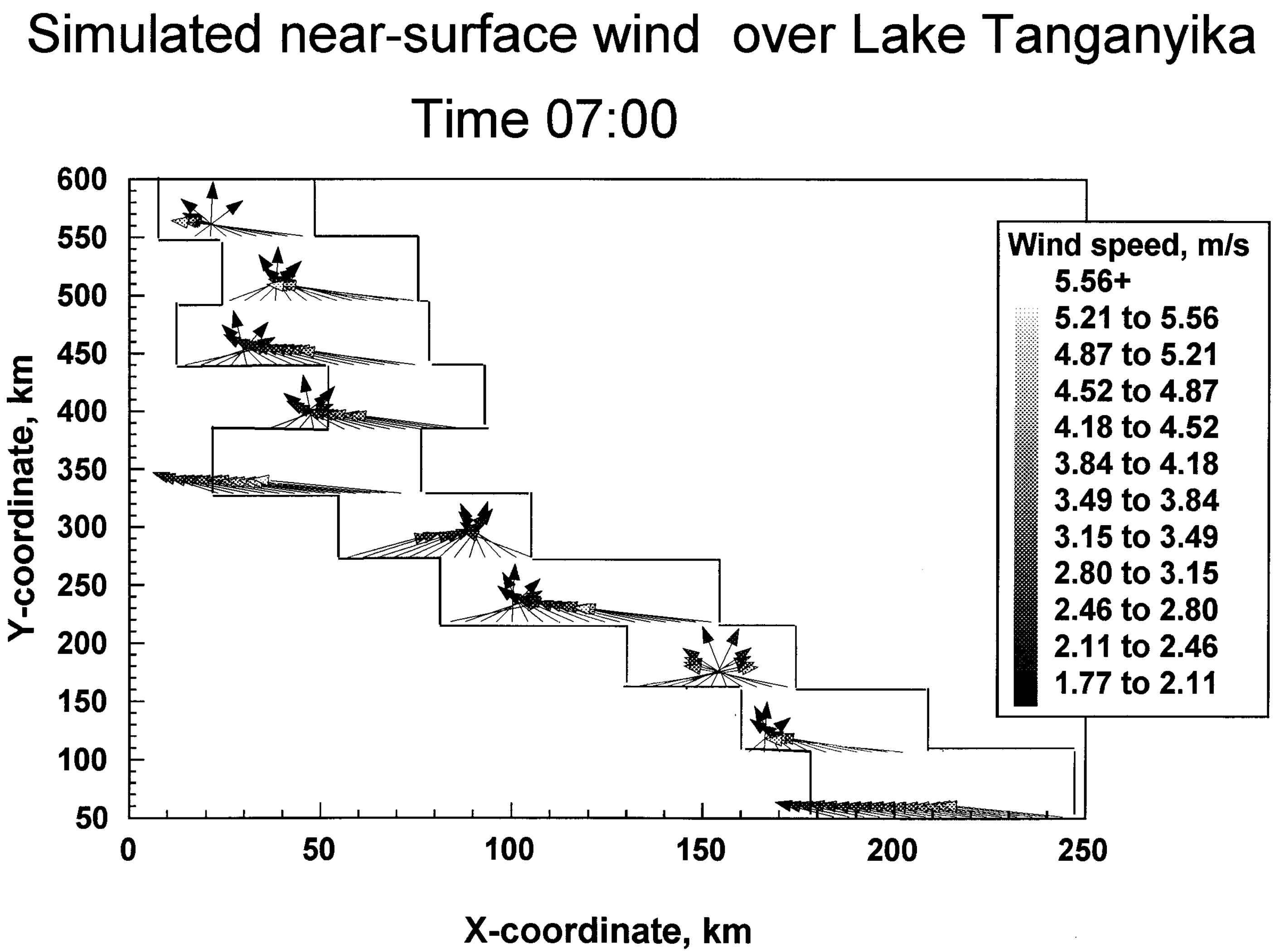

Simulated near-surface wind over Lake Tanganyika
Time 07:00
Y-coordinate, km
X-coordinate, km
600
550
500
450
400
350
300
250
200
150
100
50
0
50
100
150
200
250
Wind speed, m/s
5.56+
5.21 to 5.56
4.87 to 5.21
4.52 to 4.87
4.18 to 4.52
3.84 to 4.18
3.49 to 3.84
3.15 to 3.49
2.80 to 3.15
2.46 to 2.80
2.11 to 2.46
1.77 to 2.11

Fig7.

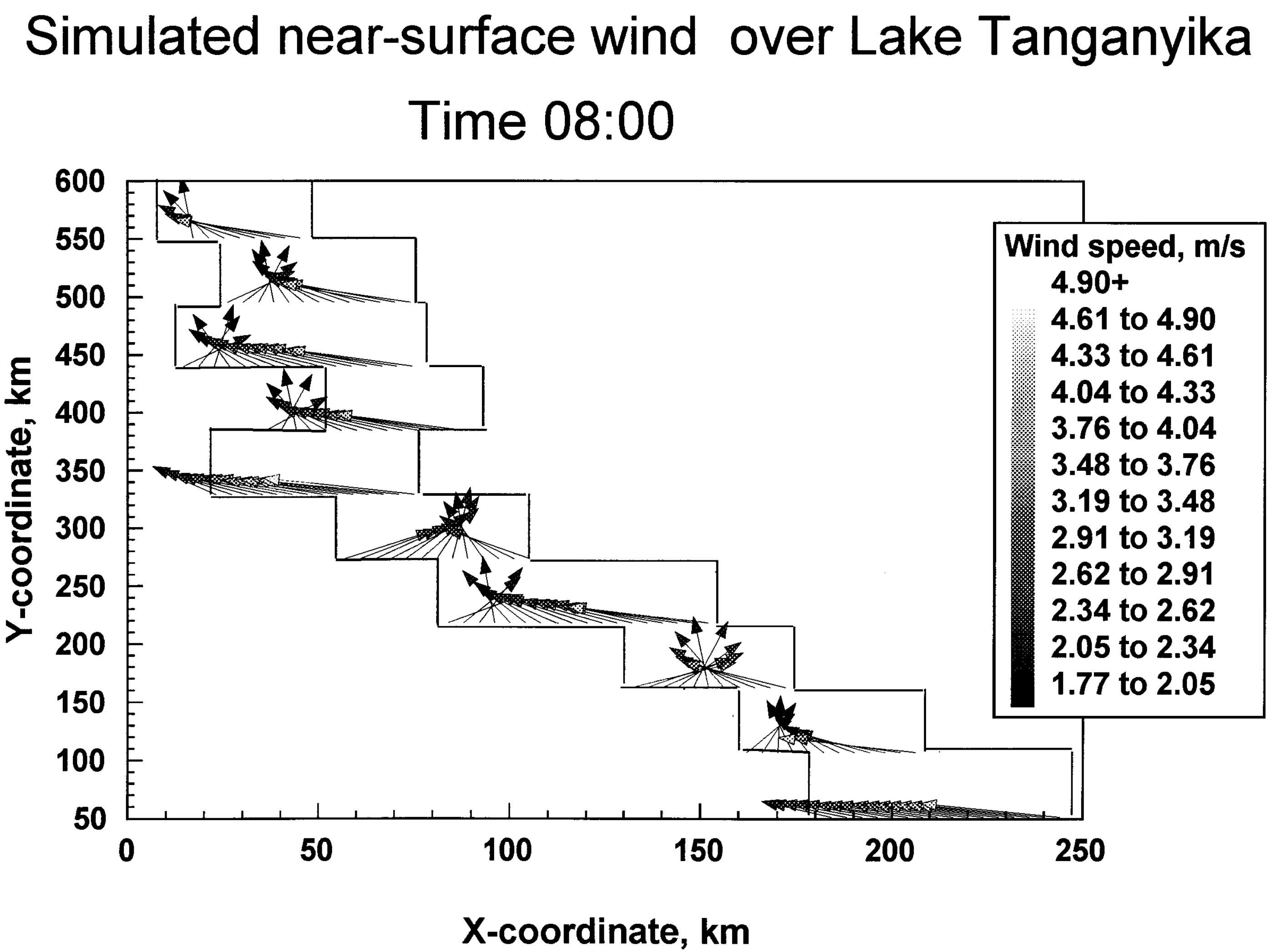

Simulated near-surface wind over Lake Tanganyika
Time 08:00
Y-coordinate, km
600
550
500
450
400
350
300
250
200
150
100
50
0
50
100
150
200
250
X-coordinate, km
Wind speed, m/s
4.90+
4.61 to 4.90
4.33 to 4.61
4.04 to 4.33
3.76 to 4.04
3.48 to 3.76
3.19 to 3.48
2.91 to 3.19
2.62 to 2.91
2.34 to 2.62
2.05 to 2.34
1.77 to 2.05

Fig8.

Simulated near-surface wind over Lake Tanganyika

Time 09:00

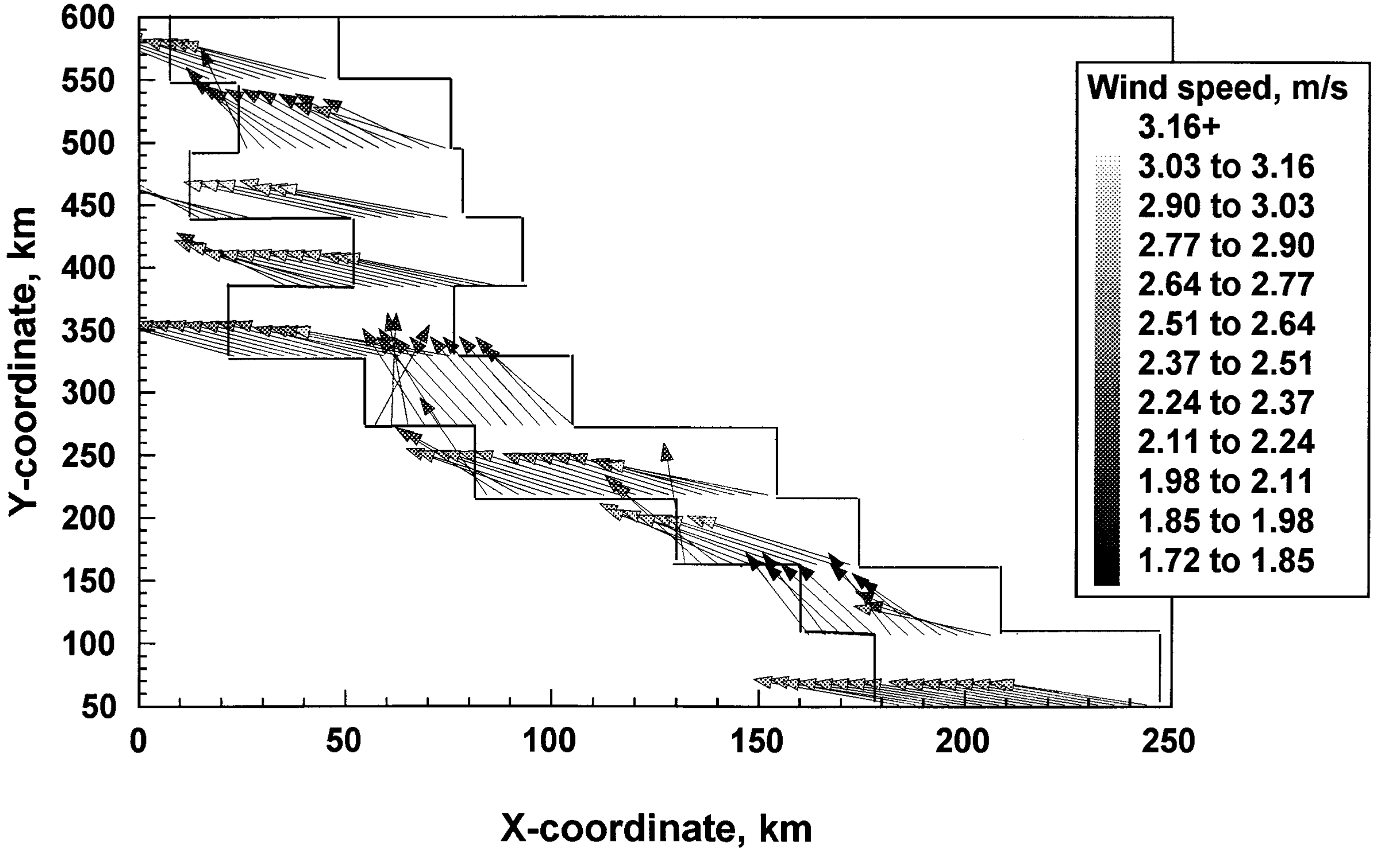


Fig9.

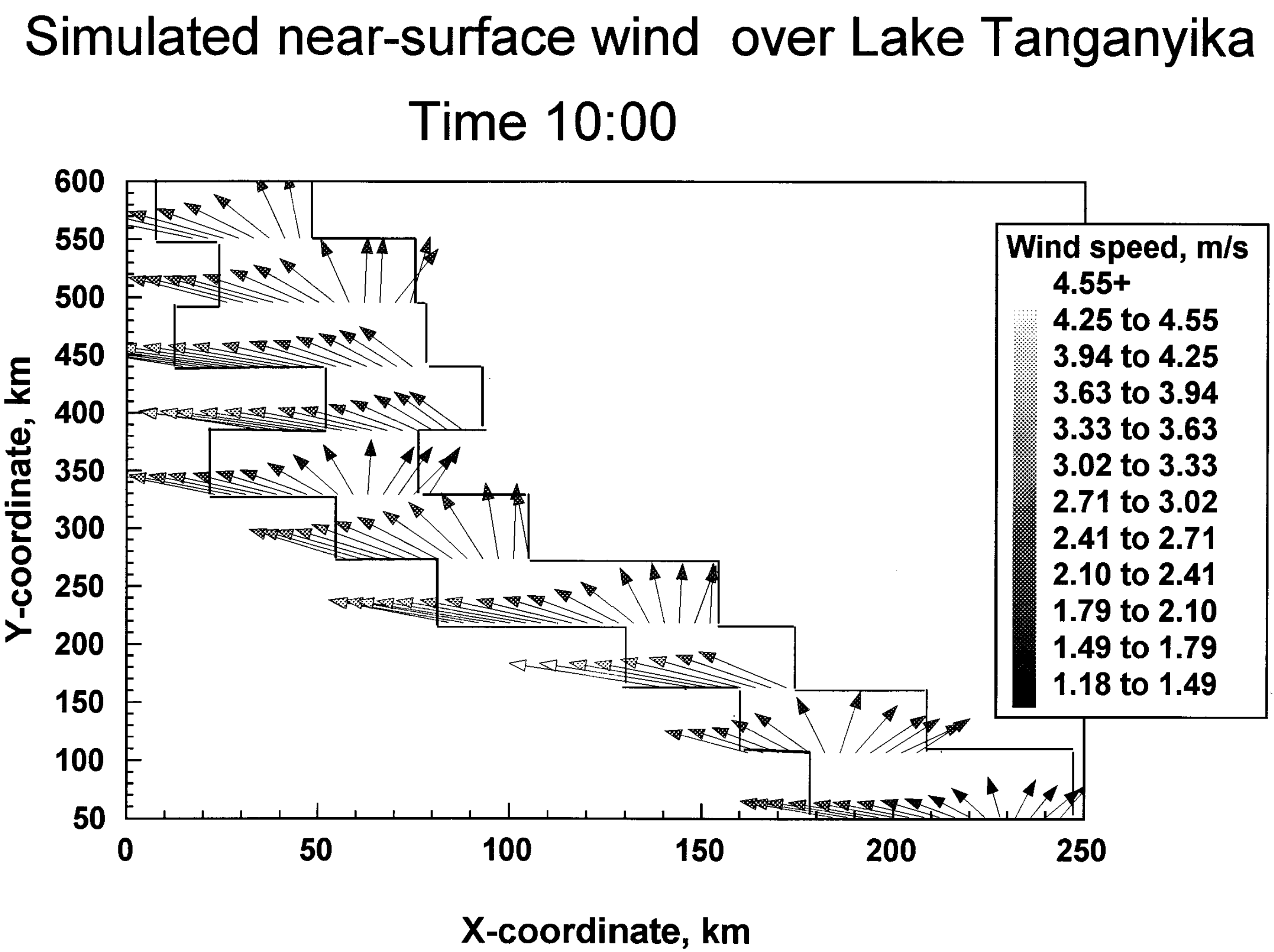

Simulated near-surface wind over Lake Tanganyika
Time 10:00
Wind speed, m/s
4.55+
4.25 to 4.55
3.94 to 4.25
3.63 to 3.94
3.33 to 3.63
3.02 to 3.33
2.71 to 3.02
2.41 to 2.71
2.10 to 2.41
1.79 to 2.10
1.49 to 1.79
1.18 to 1.49
Y-coordinate, km
600
550
500
450
400
350
300
250
200
150
100
50
0
50
100
150
200
250
X-coordinate, km

Fig10.

Simulated near-surface wind over Lake Tanganyika

Time 11:00

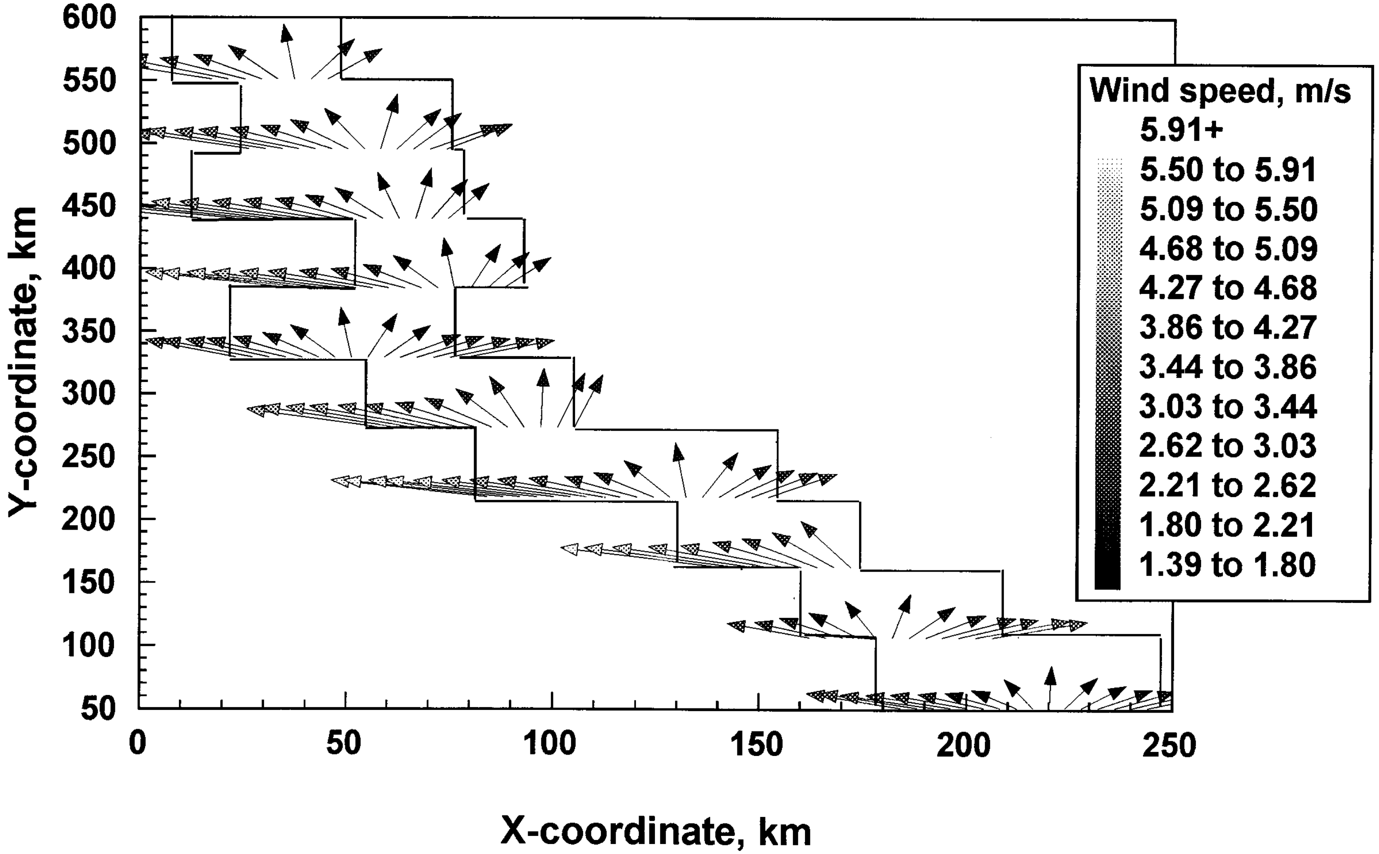


Fig.11

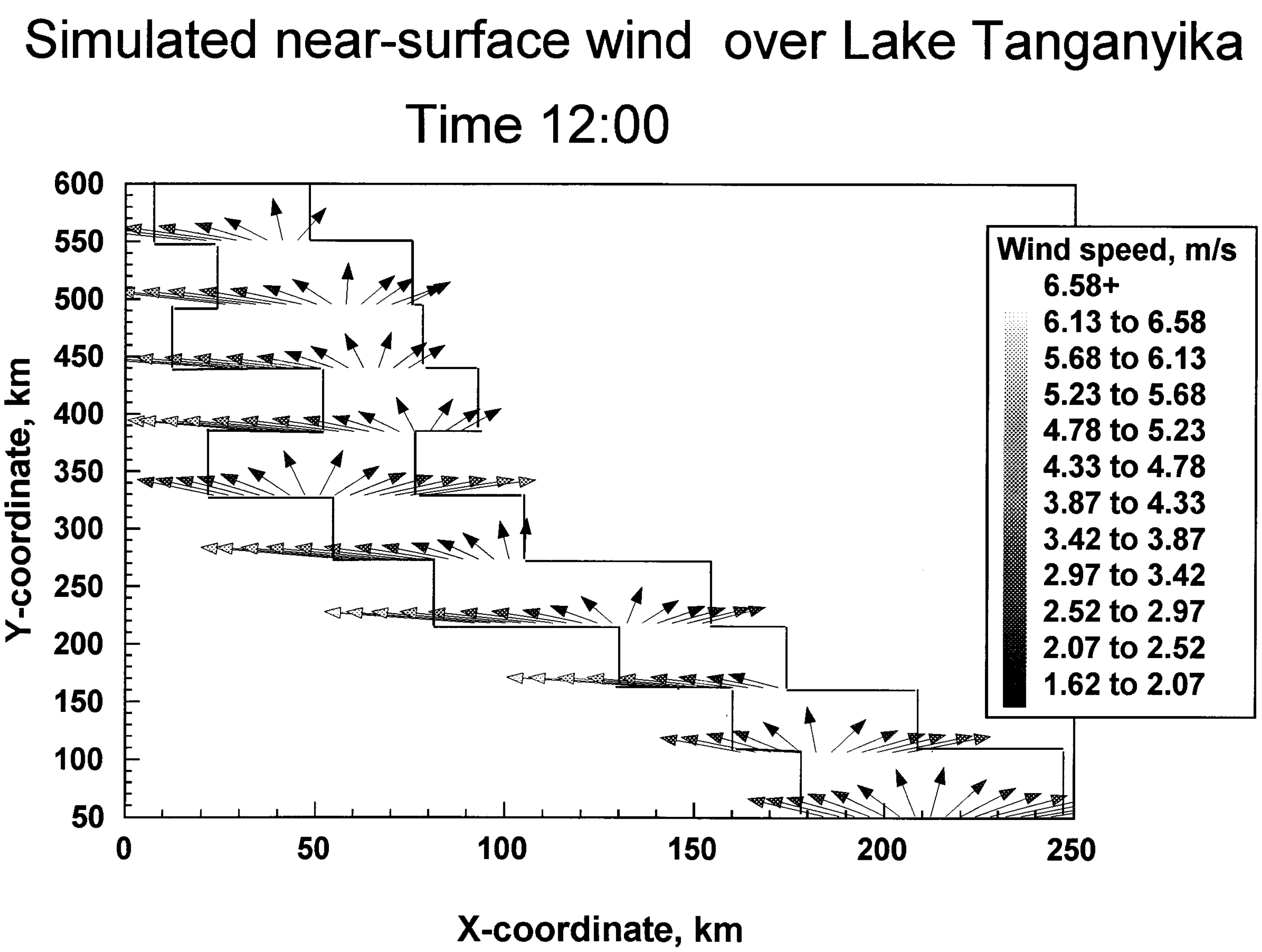

Simulated near-surface wind over Lake Tanganyika
Time 12:00
Y-coordinate, km
X-coordinate, km
600
550
500
450
400
350
300
250
200
150
100
50
0
50
100
150
200
250
Wind speed, m/s
6.58+
6.13 to 6.58
5.68 to 6.13
5.23 to 5.68
4.78 to 5.23
4.33 to 4.78
3.87 to 4.33
3.42 to 3.87
2.97 to 3.42
2.52 to 2.97
2.07 to 2.52
1.62 to 2.07

Fig.12

Simulated near-surface wind over Lake Tanganyika

Time 13:00

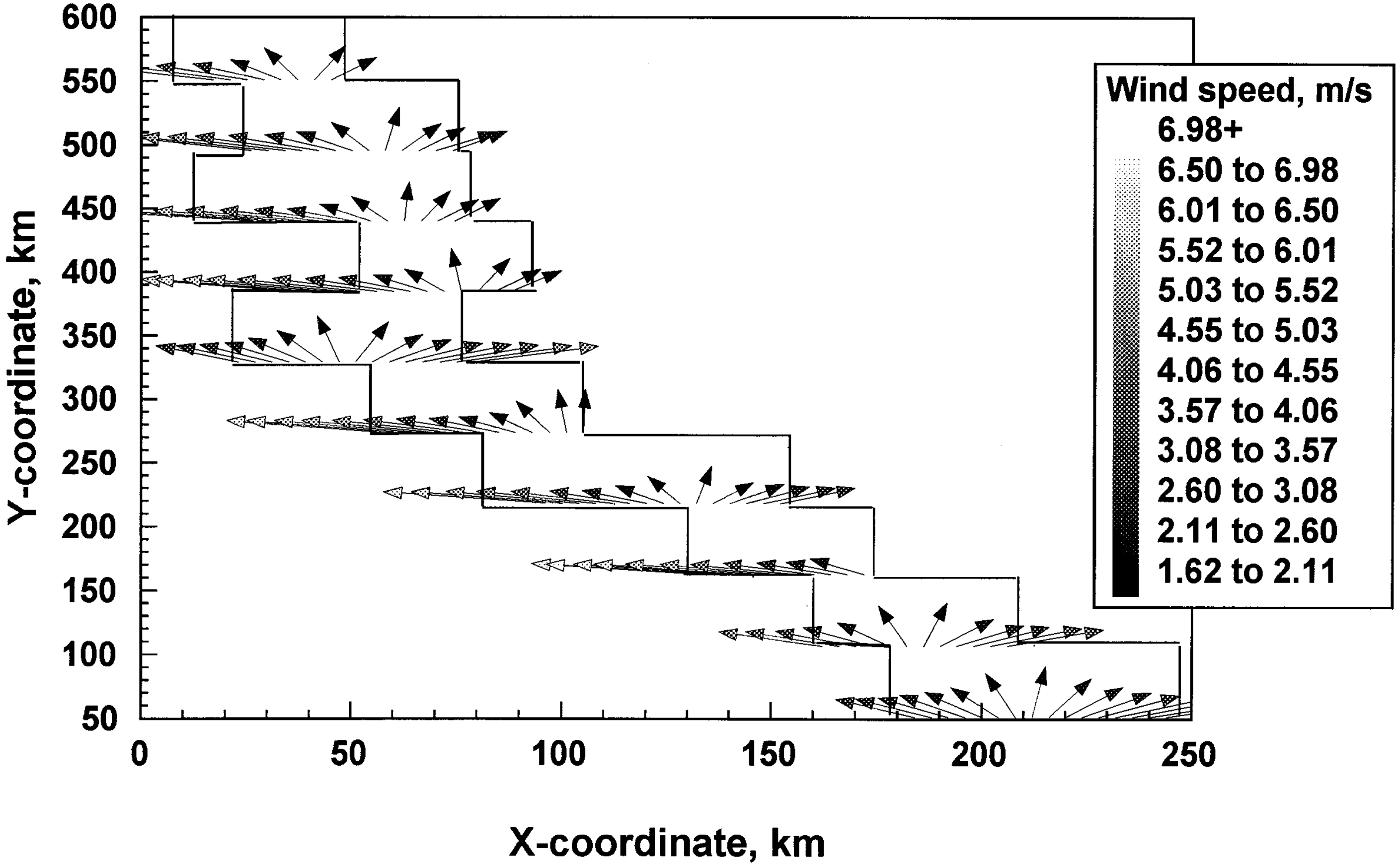


Fig.13

Simulated near-surface wind over Lake Tanganyika

Time 14:00

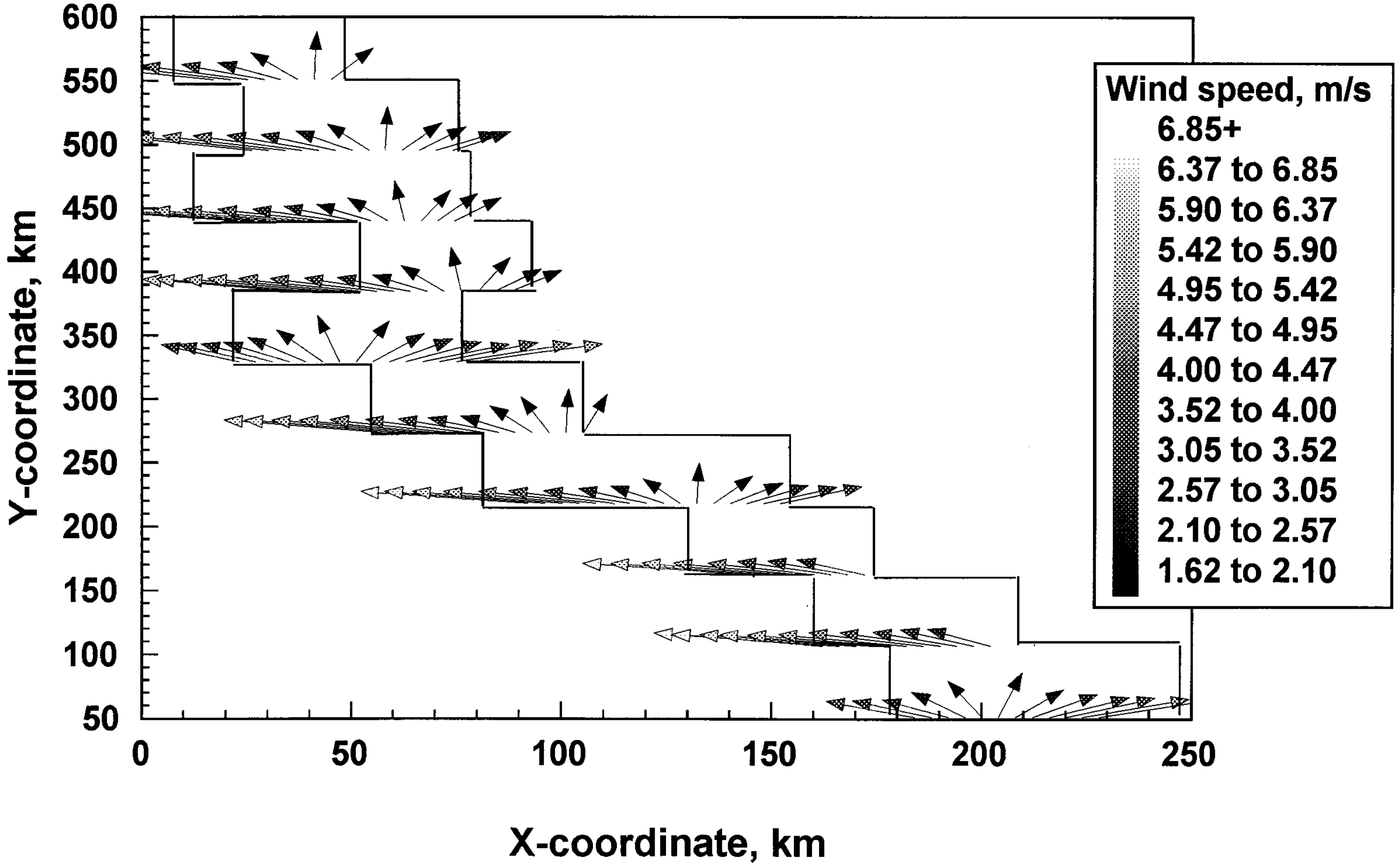


Fig.14

Simulated near-surface wind over Lake Tanganyika

Time 15:00

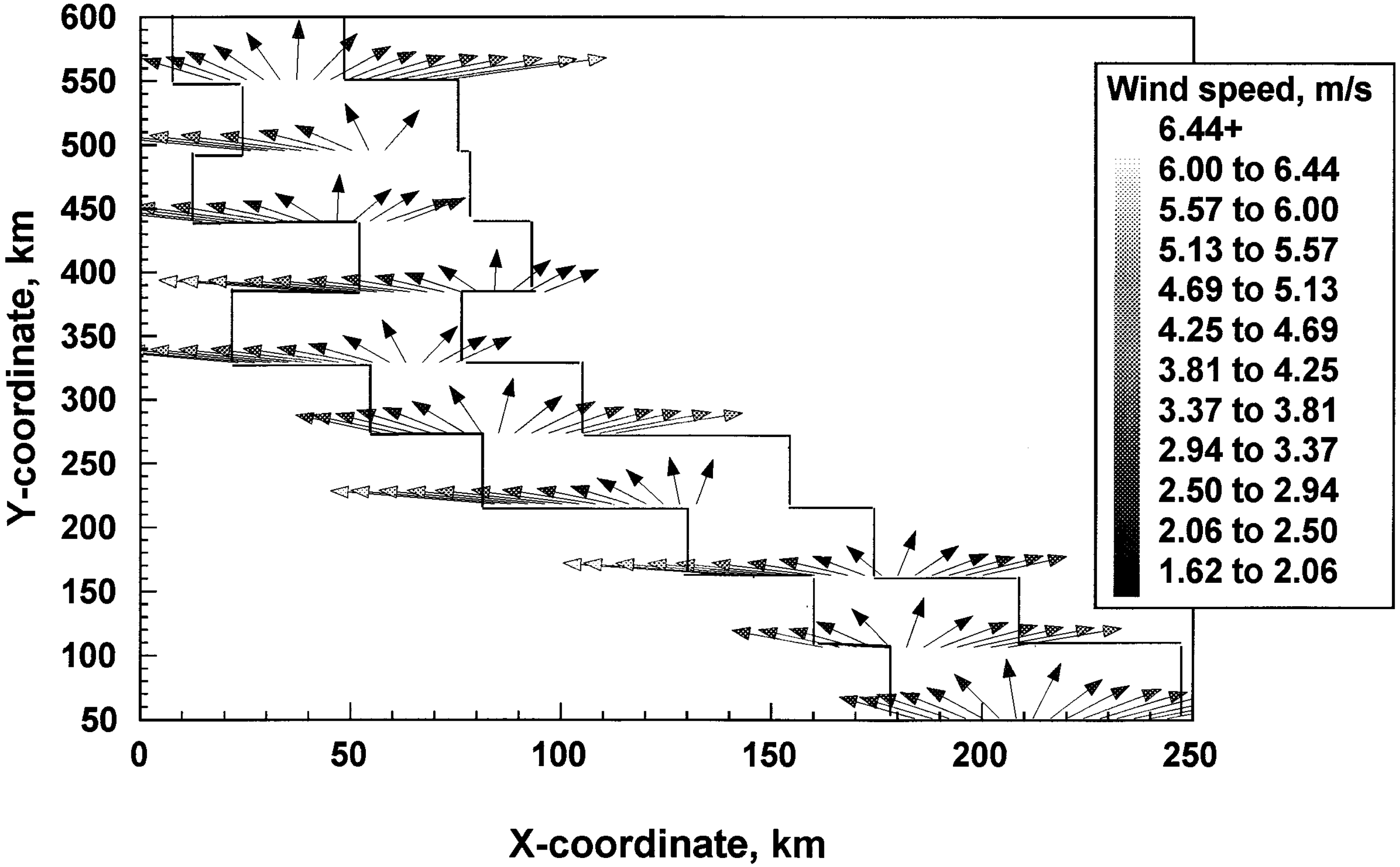


Fig.15

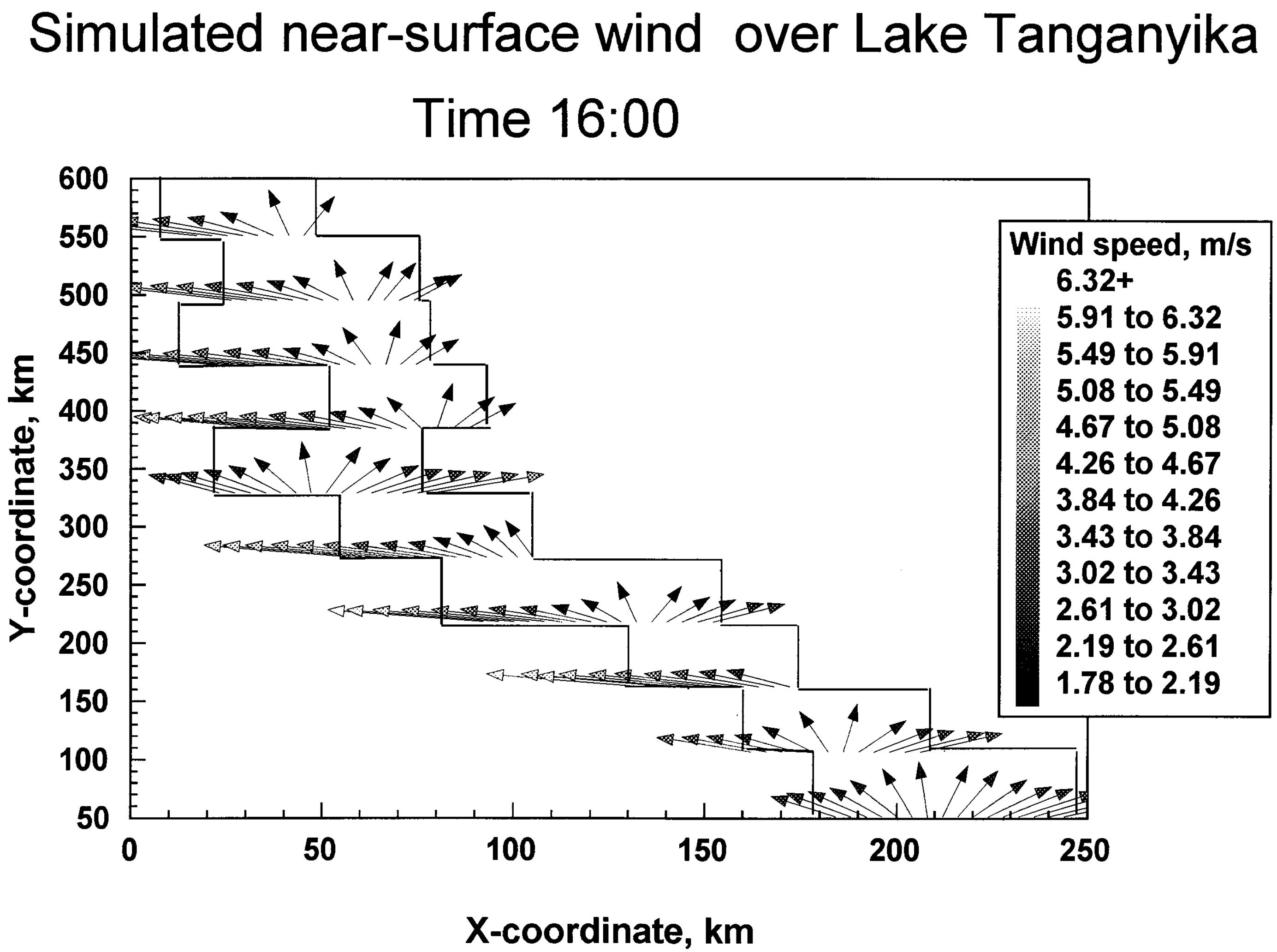

Simulated near-surface wind over Lake Tanganyika
Time 16:00
Wind speed, m/s
6.32+
5.91 to 6.32
5.49 to 5.91
5.08 to 5.49
4.67 to 5.08
4.26 to 4.67
3.84 to 4.26
3.43 to 3.84
3.02 to 3.43
2.61 to 3.02
2.19 to 2.61
1.78 to 2.19
Y-coordinate, km
600
550
500
450
400
350
300
250
200
150
100
50
0
50
100
150
200
250
X-coordinate, km

Fig.16

Simulated near-surface wind over Lake Tanganyika

Time 17:00

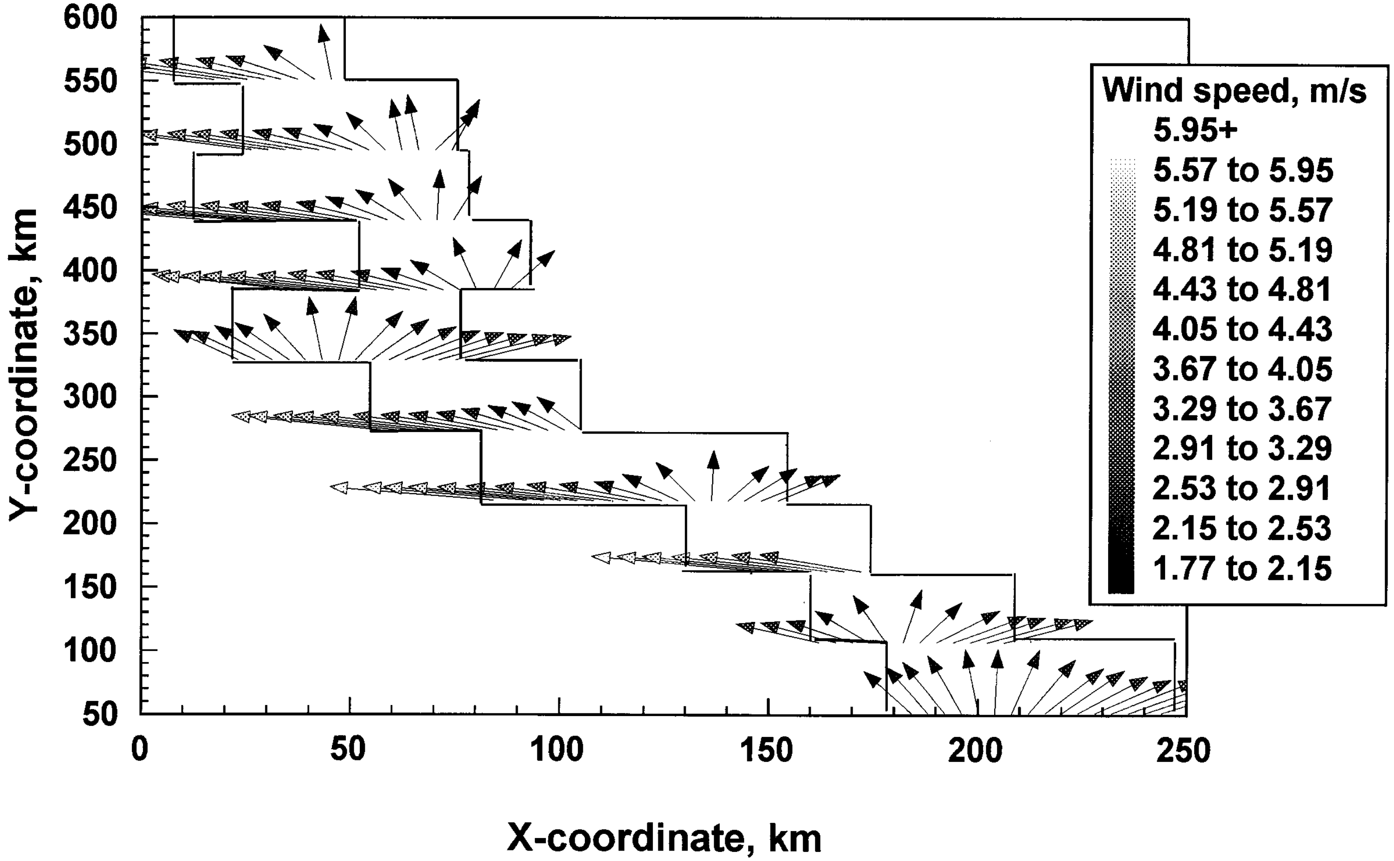


Fig.17

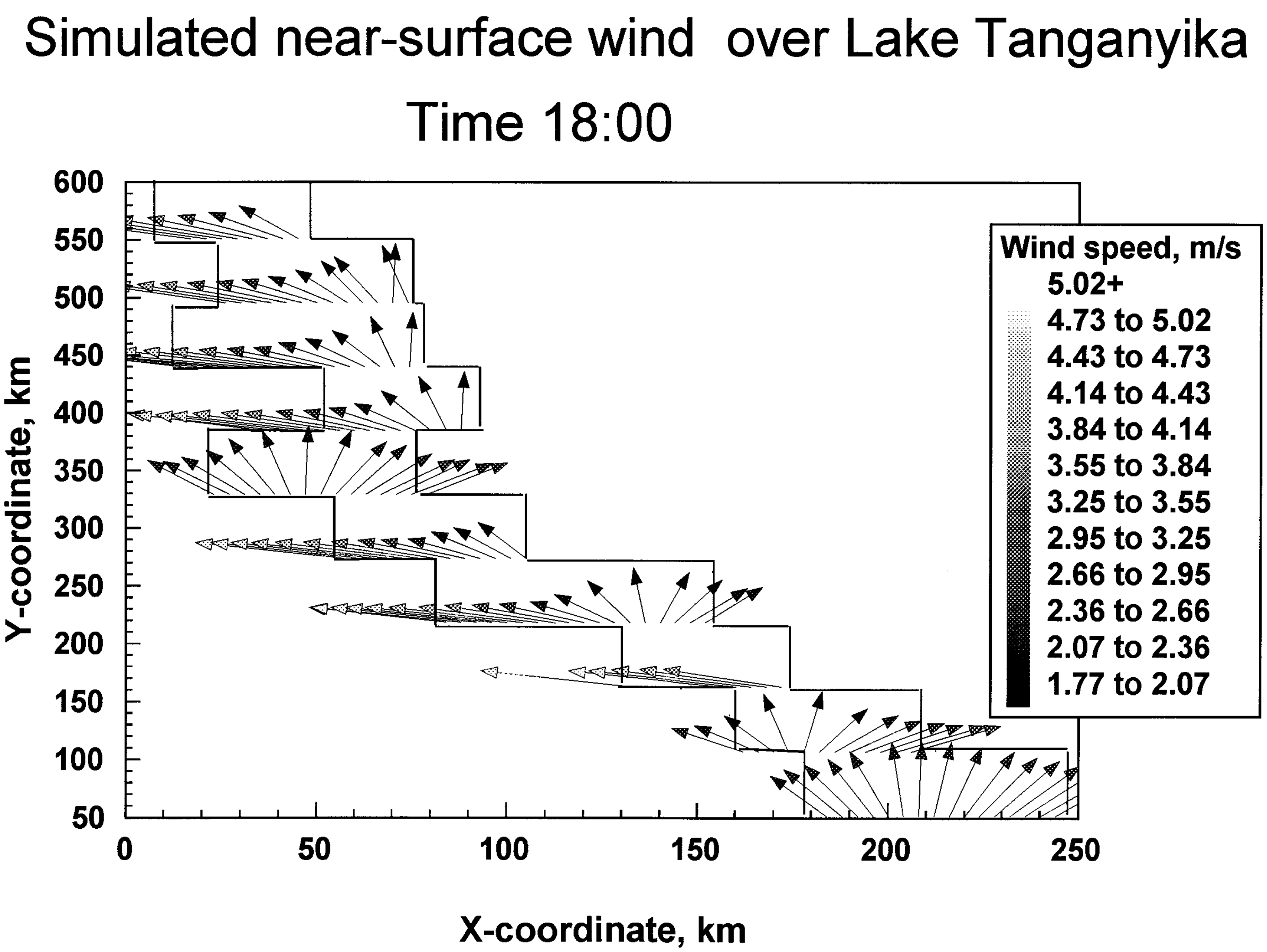

Simulated near-surface wind over Lake Tanganyika
Time 18:00
Wind speed, m/s
5.02+
4.73 to 5.02
4.43 to 4.73
4.14 to 4.43
3.84 to 4.14
3.55 to 3.84
3.25 to 3.55
2.95 to 3.25
2.66 to 2.95
2.36 to 2.66
2.07 to 2.36
1.77 to 2.07
Y-coordinate, km
600
550
500
450
400
350
300
250
200
150
100
50
0
50
100
150
200
250
X-coordinate, km

Fig.18

Simulated near-surface wind over Lake Tanganyika

Time 19:00

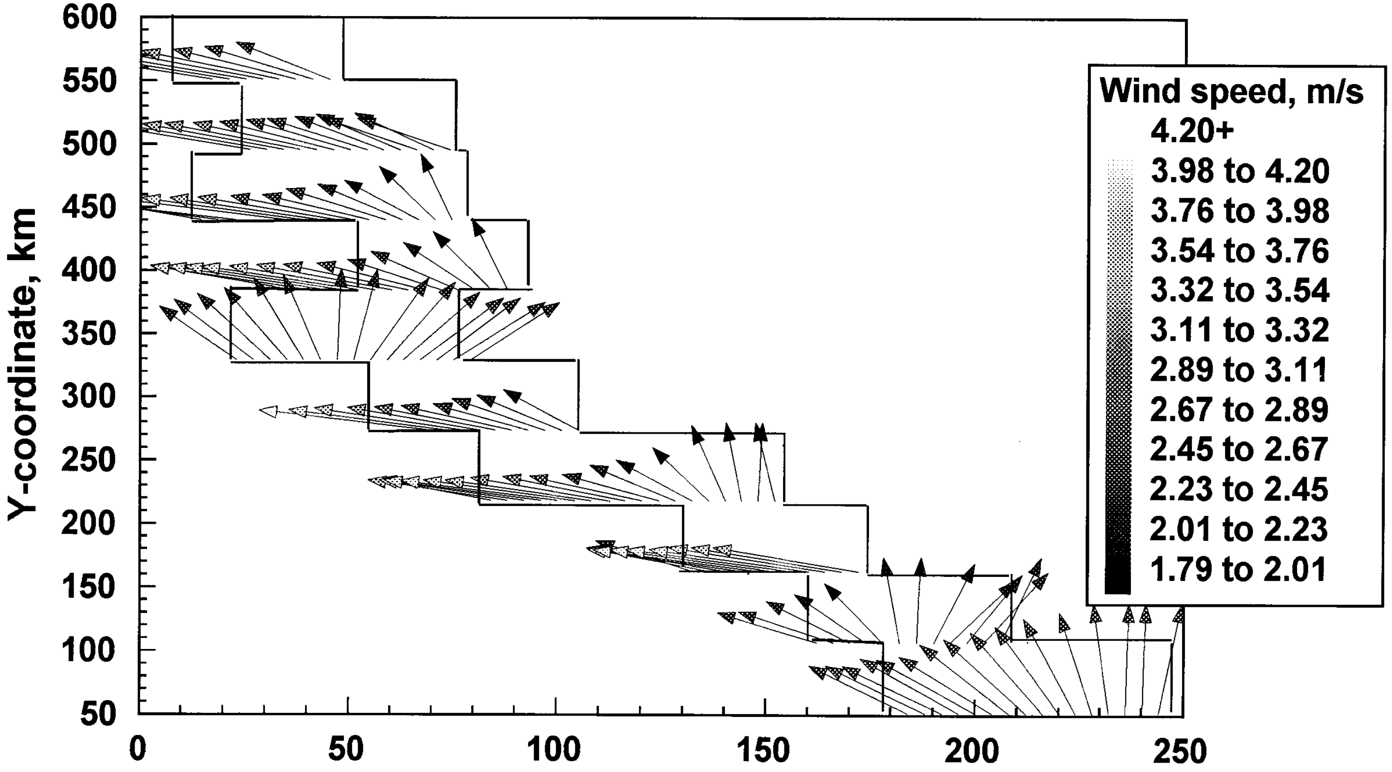


Fig.19

Simulated near-surface wind over Lake Tanganyika

Time 20:00

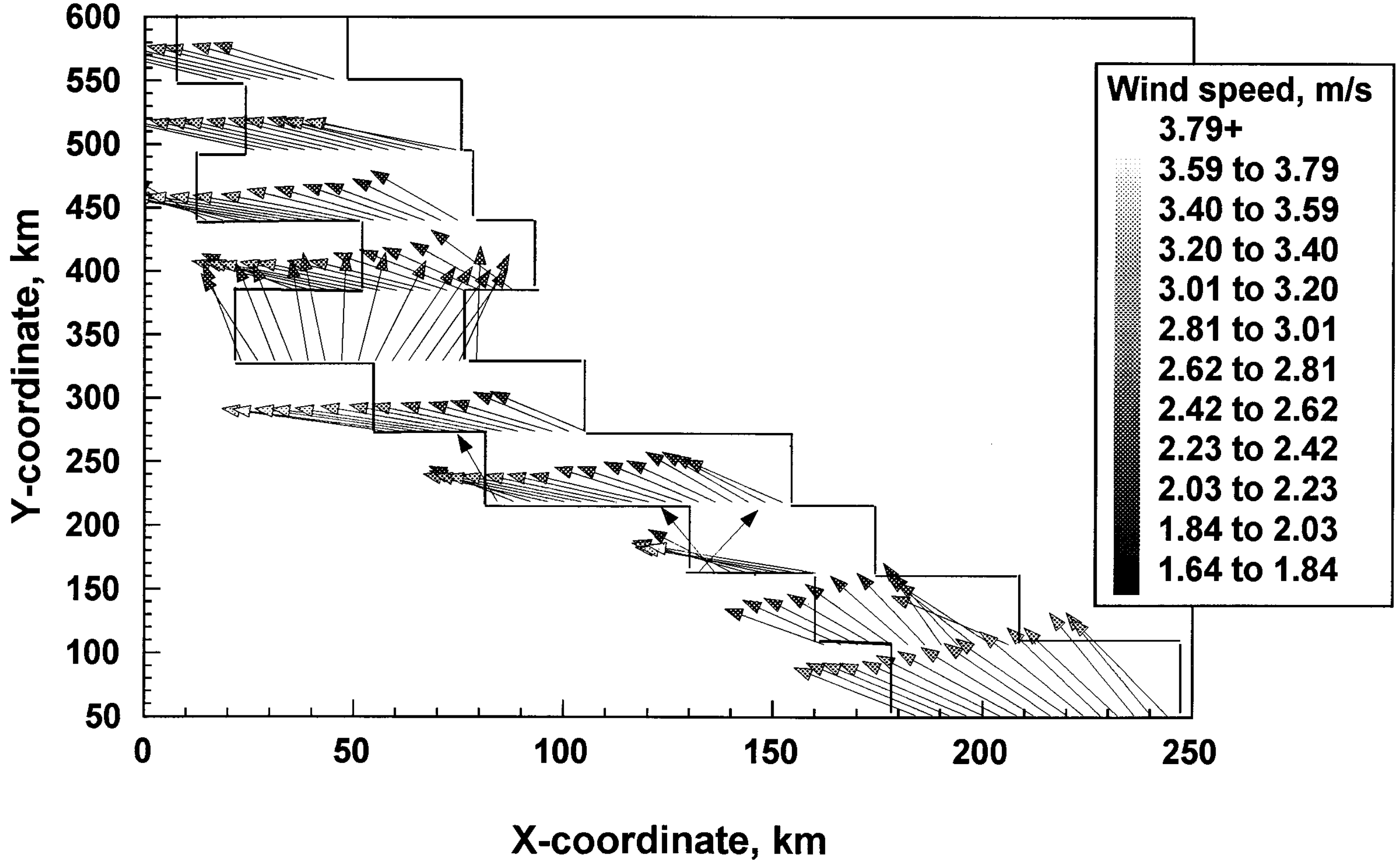


Fig.20

Simulated near-surface wind over Lake Tanganyika

Time 21:00

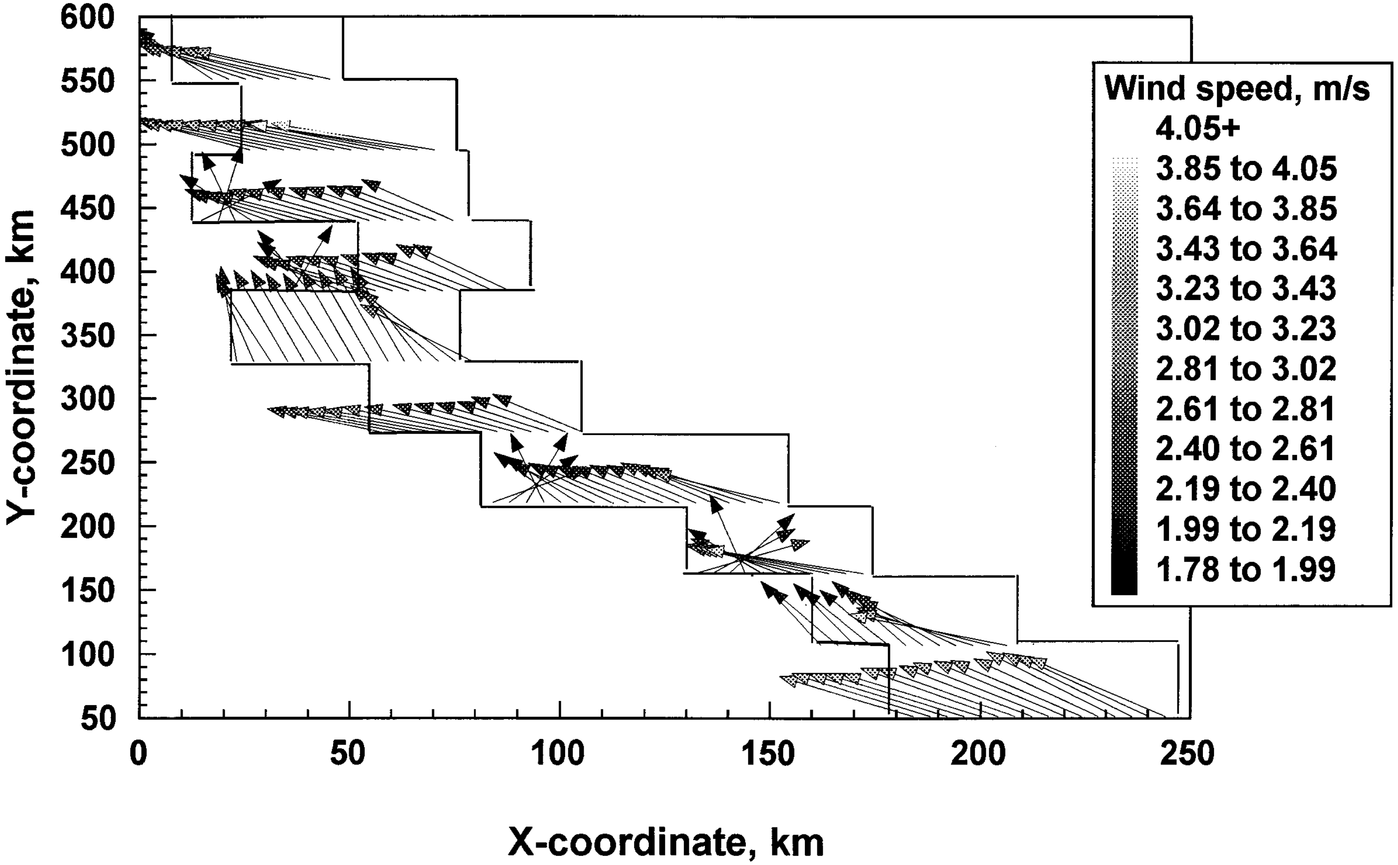
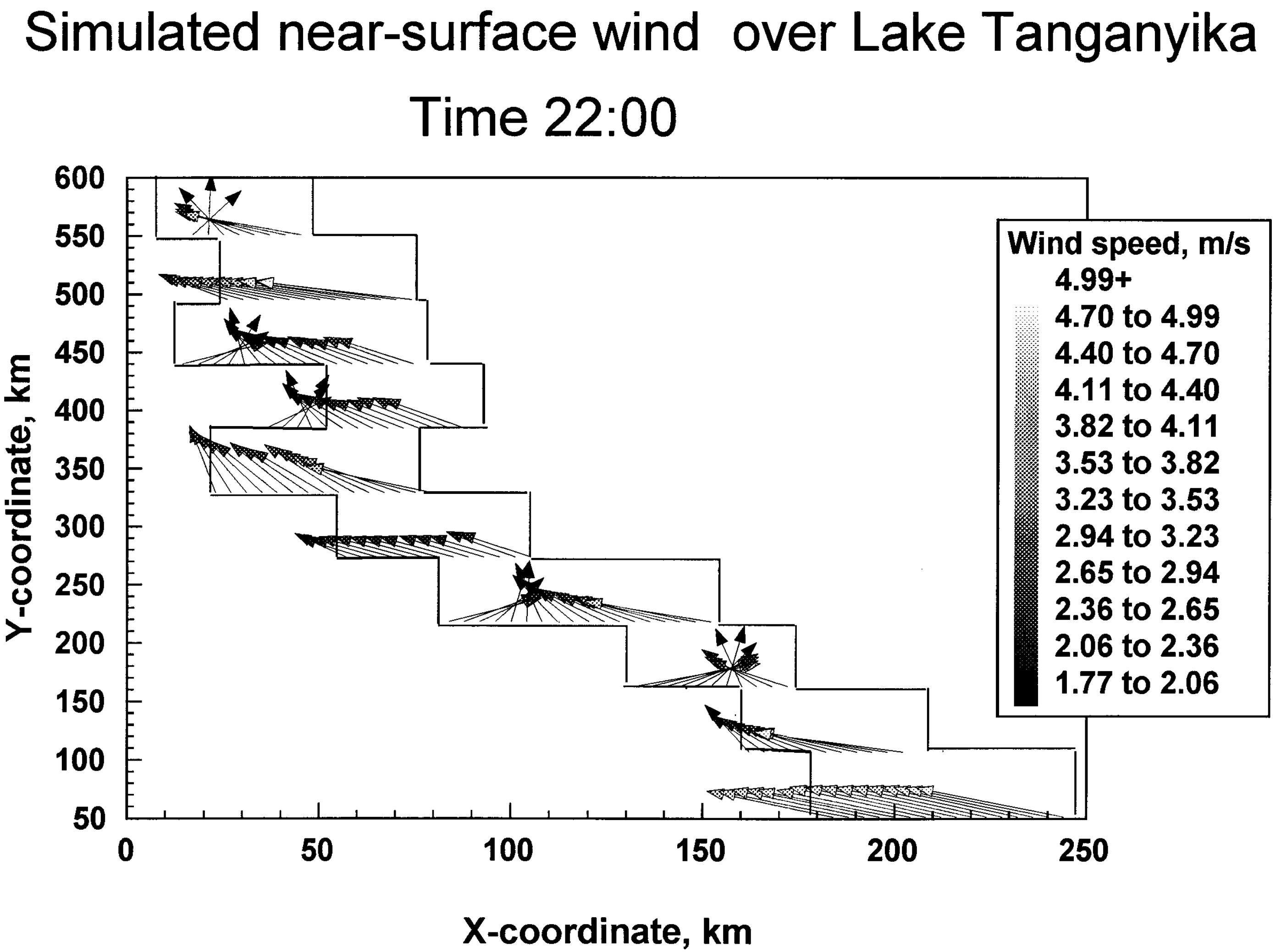


Fig.21



Simulated near-surface wind over Lake Tanganyika
Time 22:00
Wind speed, m/s
4.99+
4.70 to 4.99
4.40 to 4.70
4.11 to 4.40
3.82 to 4.11
3.53 to 3.82
3.23 to 3.53
2.94 to 3.23
2.65 to 2.94
2.36 to 2.65
2.06 to 2.36
1.77 to 2.06
Y-coordinate, km
600
550
500
450
400
350
300
250
200
150
100
50
0
50
100
150
200
250
X-coordinate, km

Fig.22

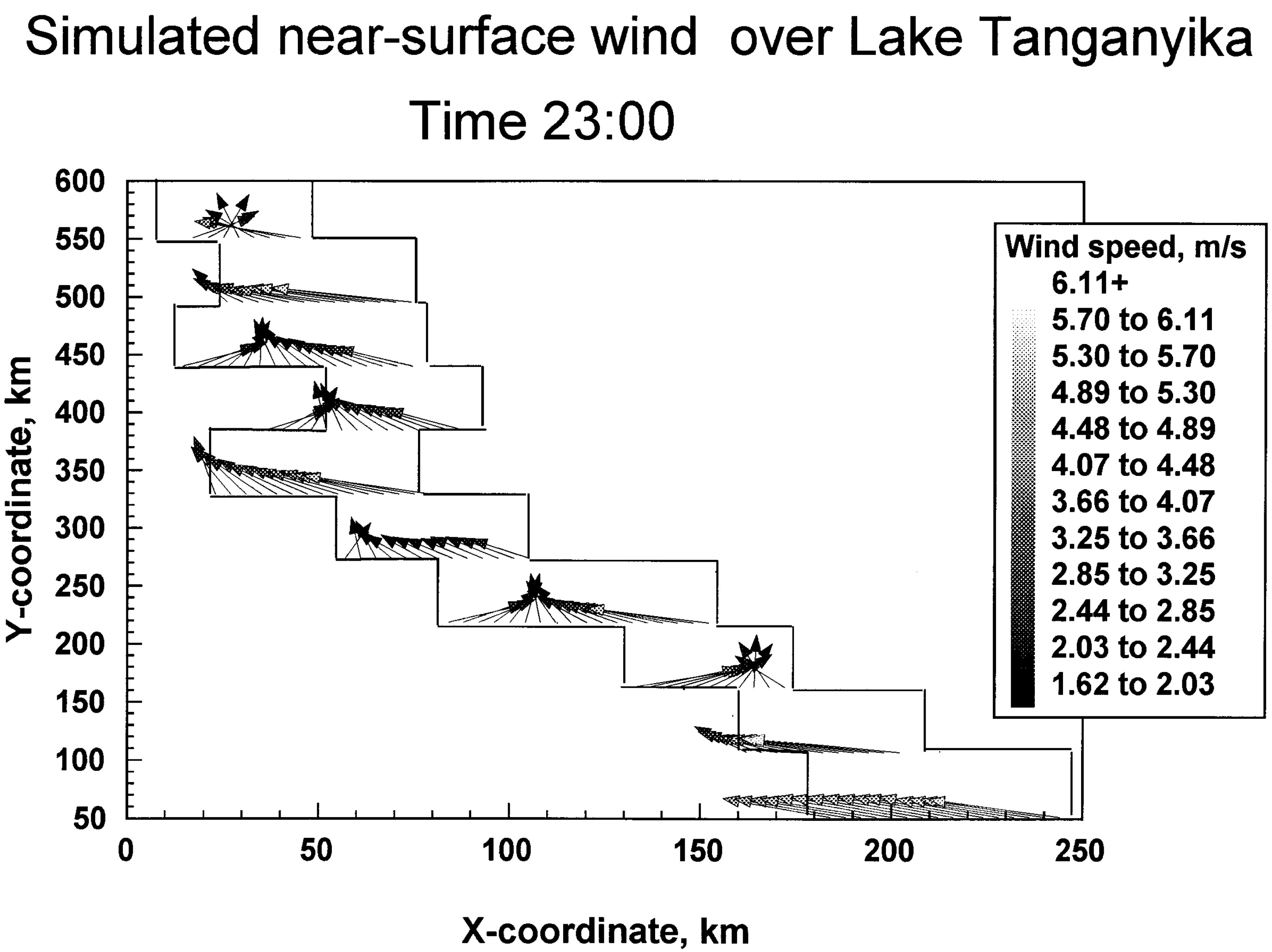

Simulated near-surface wind over Lake Tanganyika
Time 23:00
Y-coordinate, km
600
550
500
450
400
350
300
250
200
150
100
50
0
50
100
150
200
250
X-coordinate, km
Wind speed, m/s
6.11+
5.70 to 6.11
5.30 to 5.70
4.89 to 5.30
4.48 to 4.89
4.07 to 4.48
3.66 to 4.07
3.25 to 3.66
2.85 to 3.25
2.44 to 2.85
2.03 to 2.44
1.62 to 2.03

Fig.23

Simulated near-surface wind over Lake Tanganyika

Time 24:00

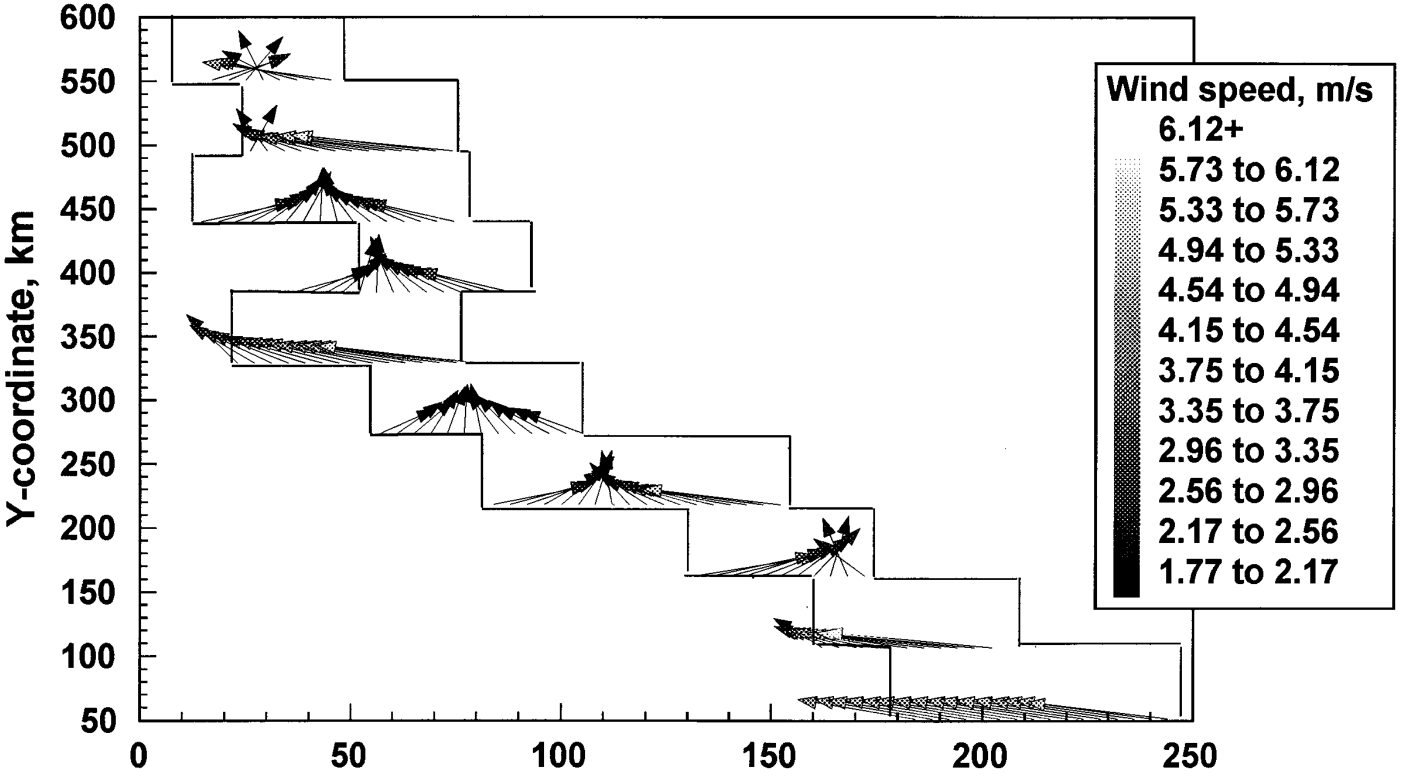


Fig.24

WIND SPEED AT KIGOMA WEATHER STATION

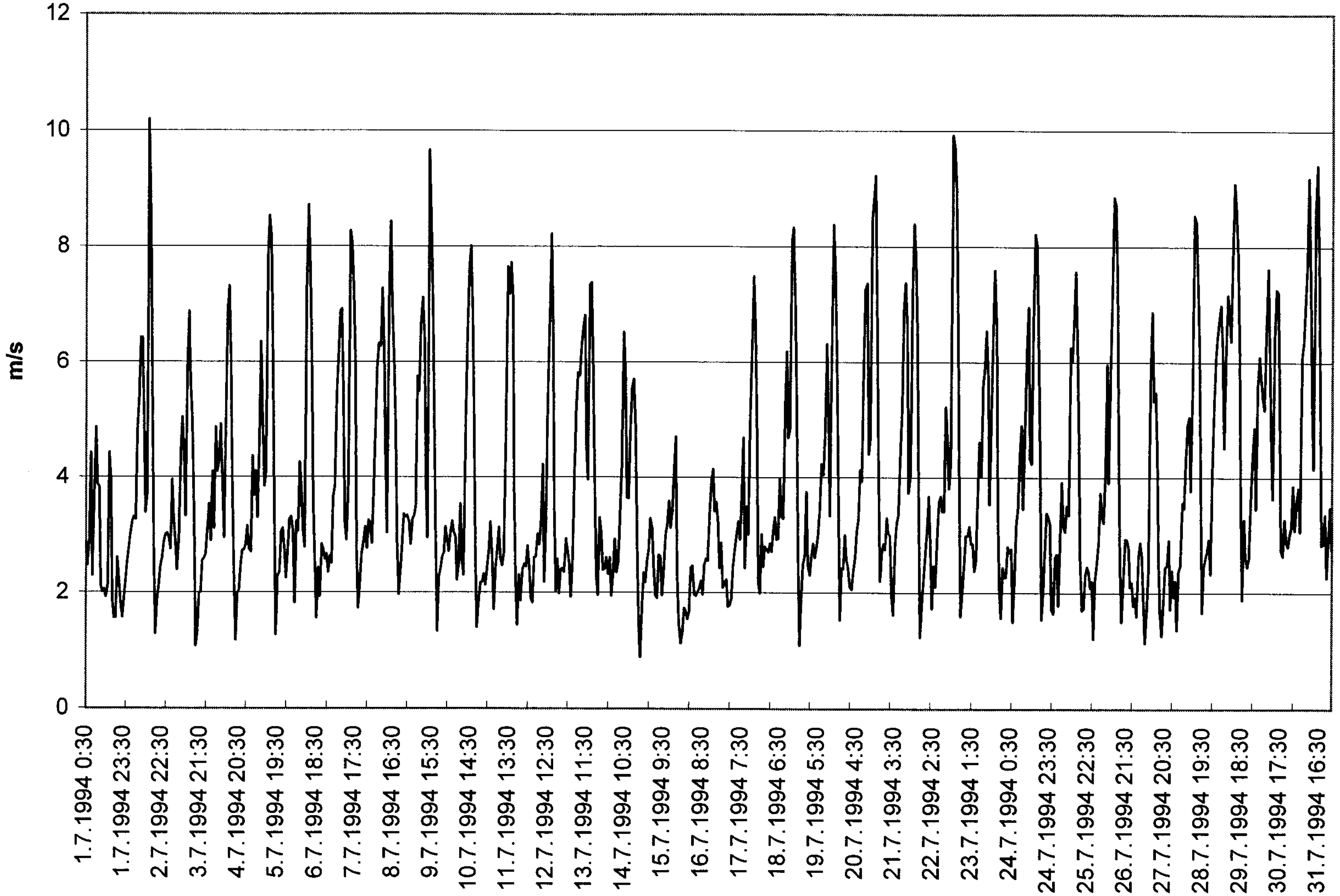
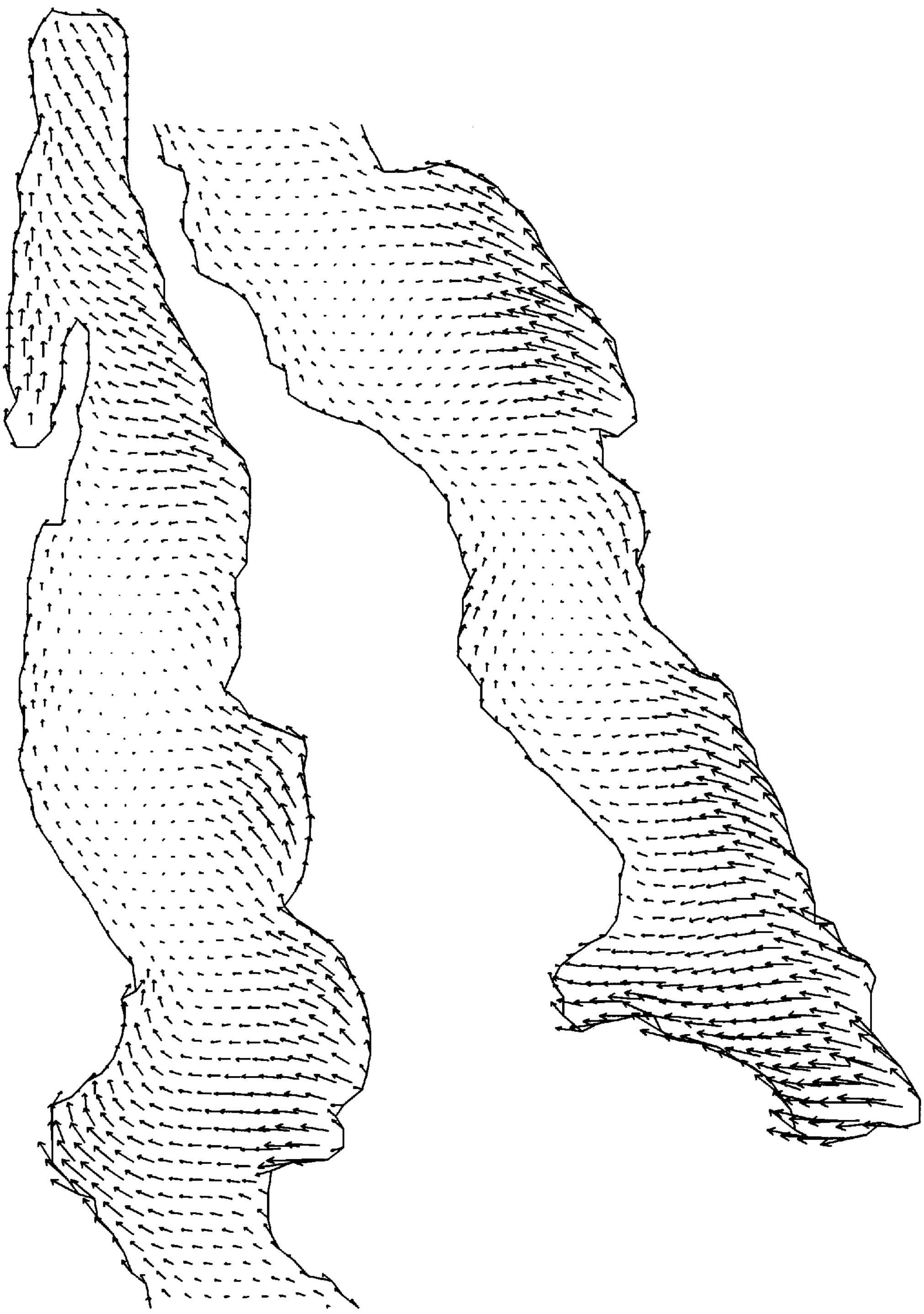


Fig.25

LAKE TANGANYIKA.SURFACE FLOW.SIMULATED WIND.TIME 01:00.



VELOCITY SCALE : 10 CM/S
MAXIMUM VALUE - 4.64CM/S

Fig.26

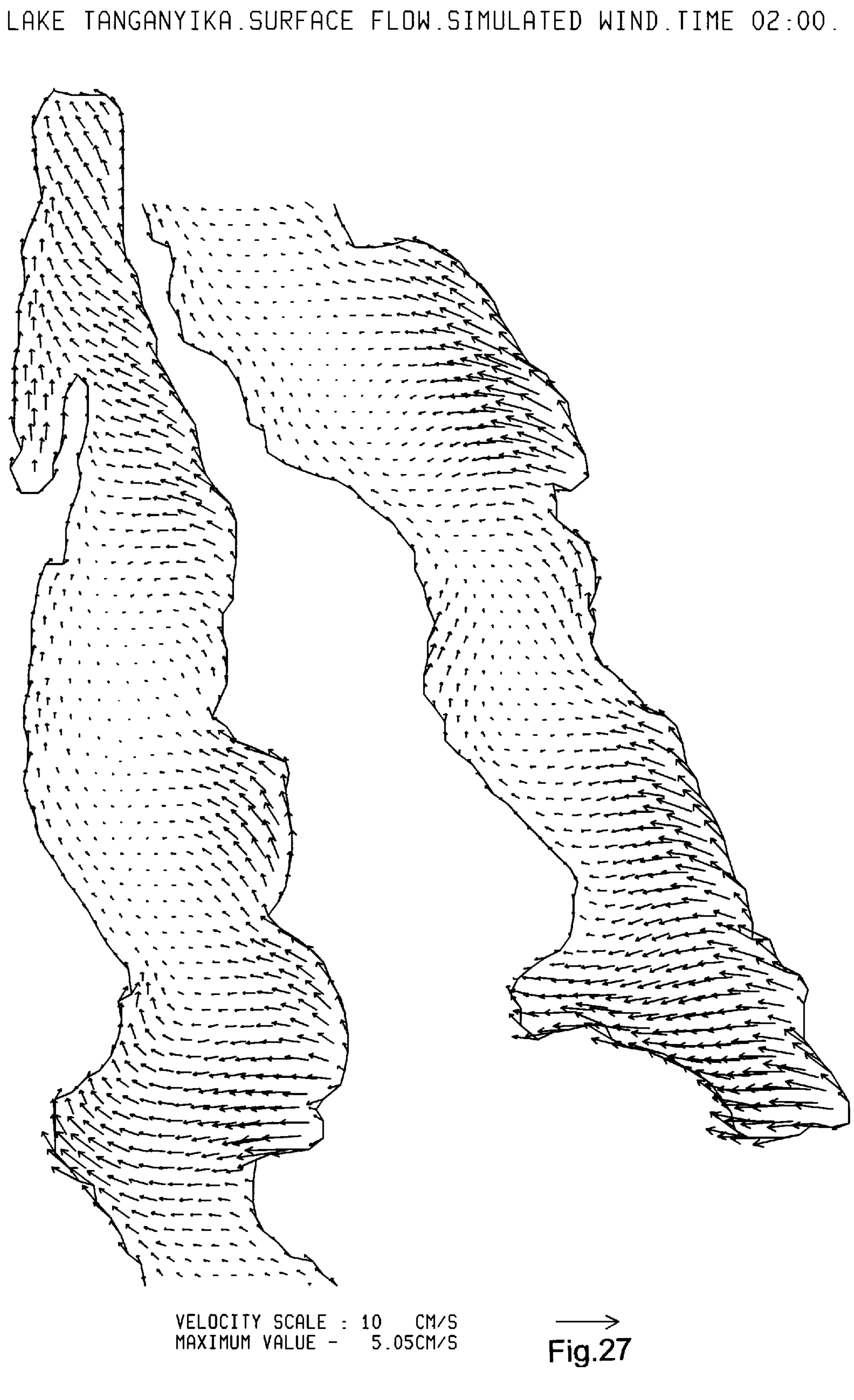
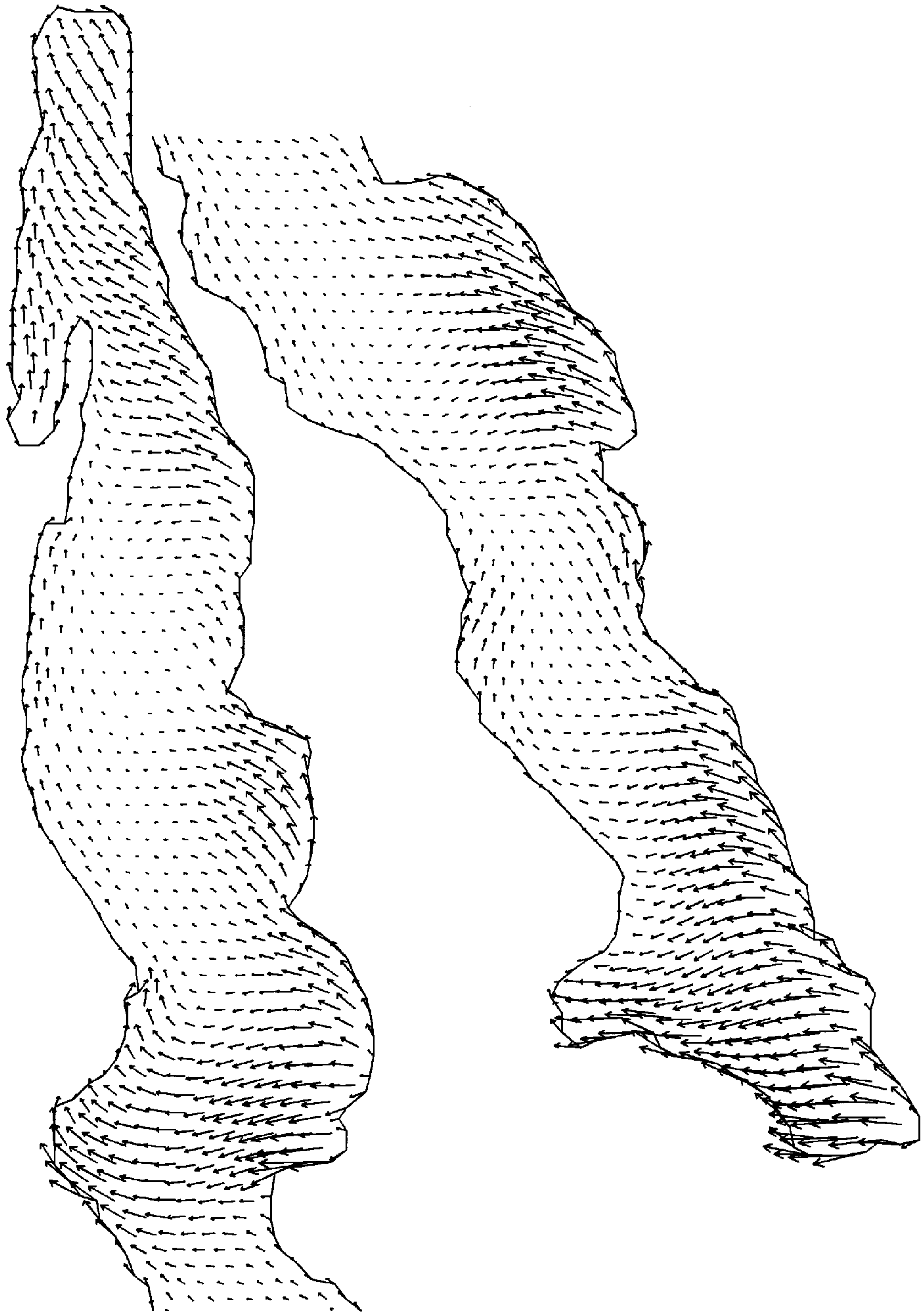

LAKE TANGANYIKA.SURFACE FLOW.SIMULATED WIND.TIME 02:00.
VELOCITY SCALE : 10 CM/S
MAXIMUM VALUE - 5.05CM/S

Fig.27

LAKE TANGANYIKA. SURFACE FLOW. SIMULATED WIND. TIME 03:00.



VELOCITY SCALE : 10 CM/S
MAXIMUM VALUE - 5.24CM/S

Fig.28

LAKE TANGNAYIKA.SURFACE FLOW.SIMULATED WIND.TIME 04:00.

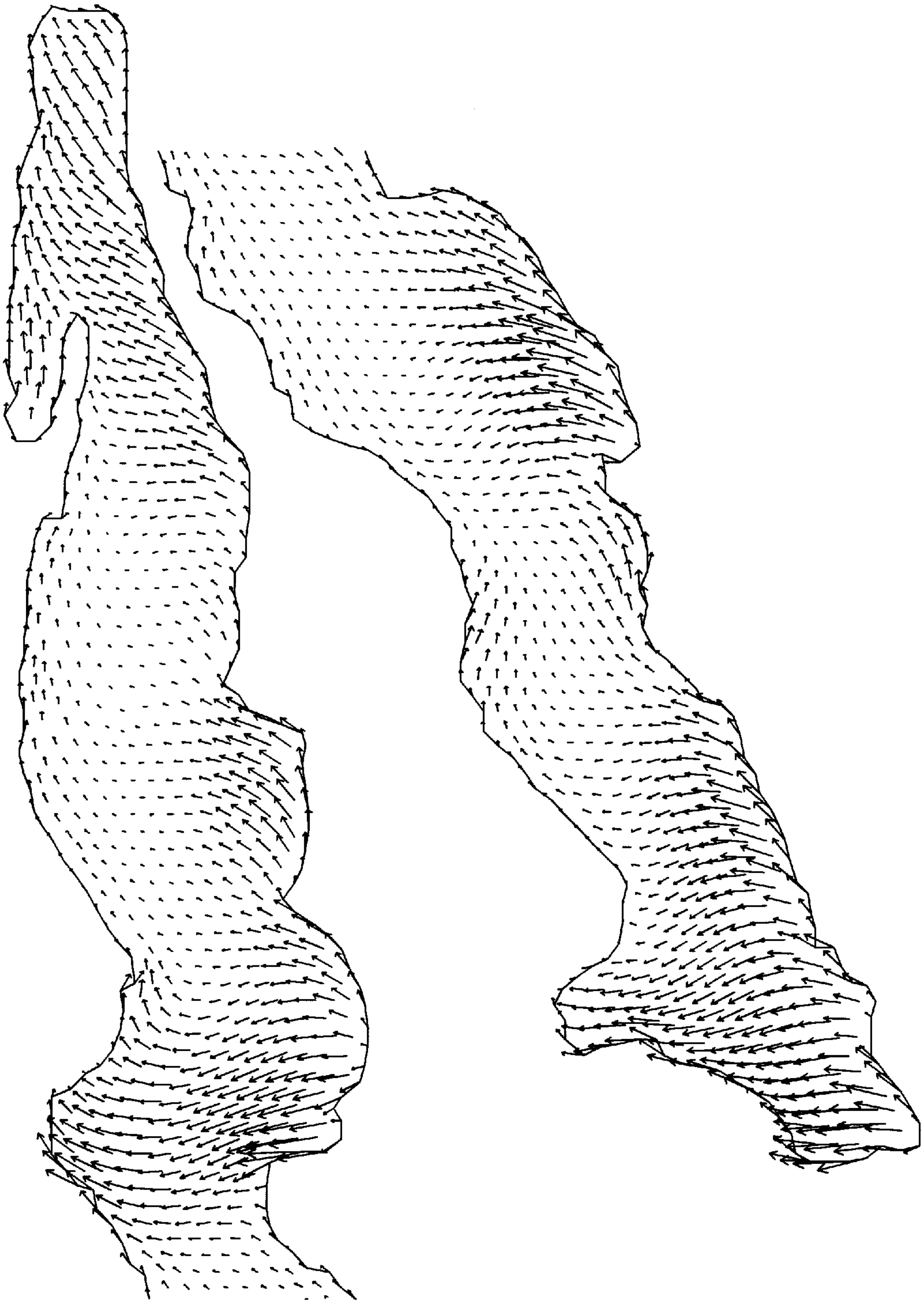
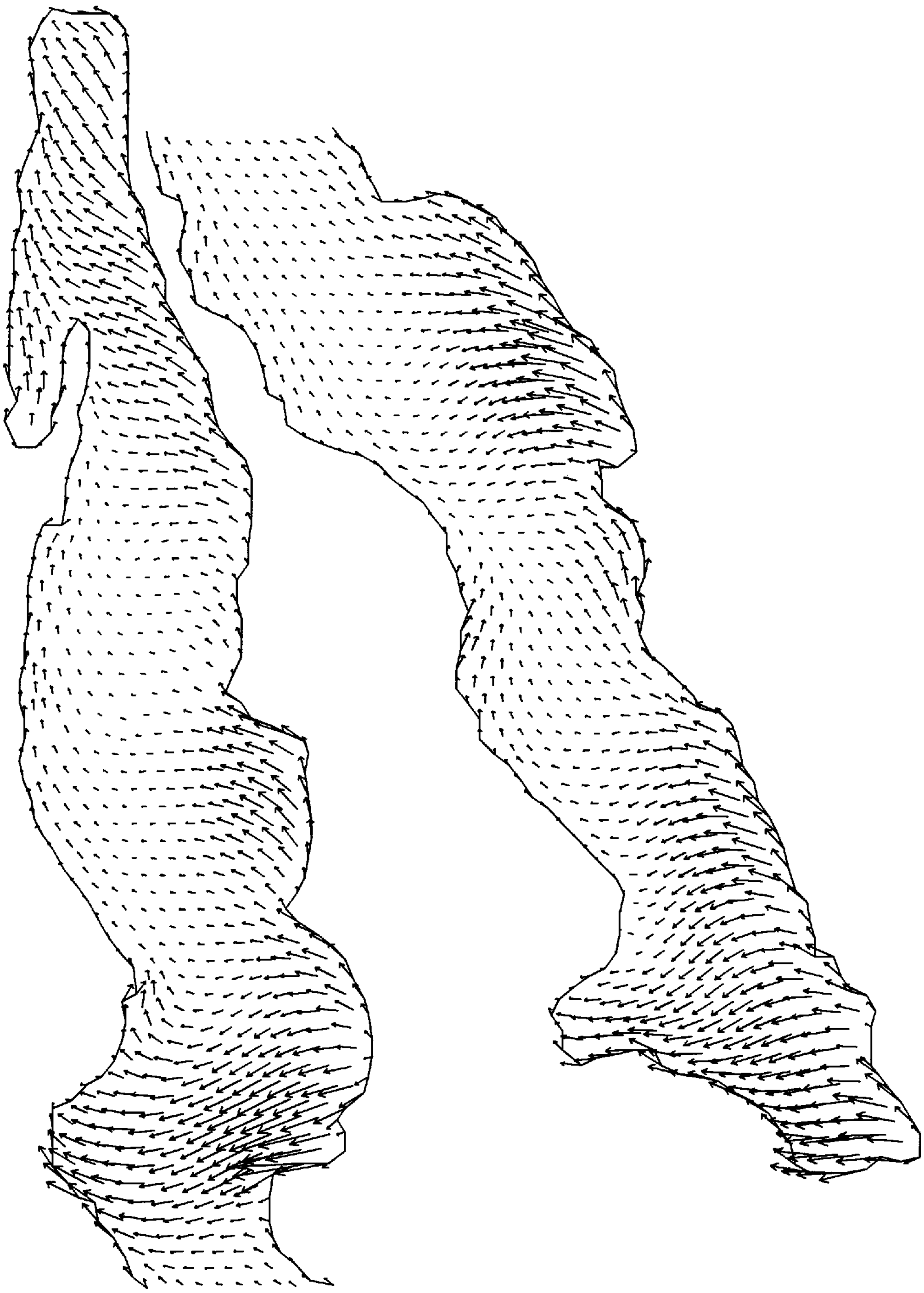


Fig.29

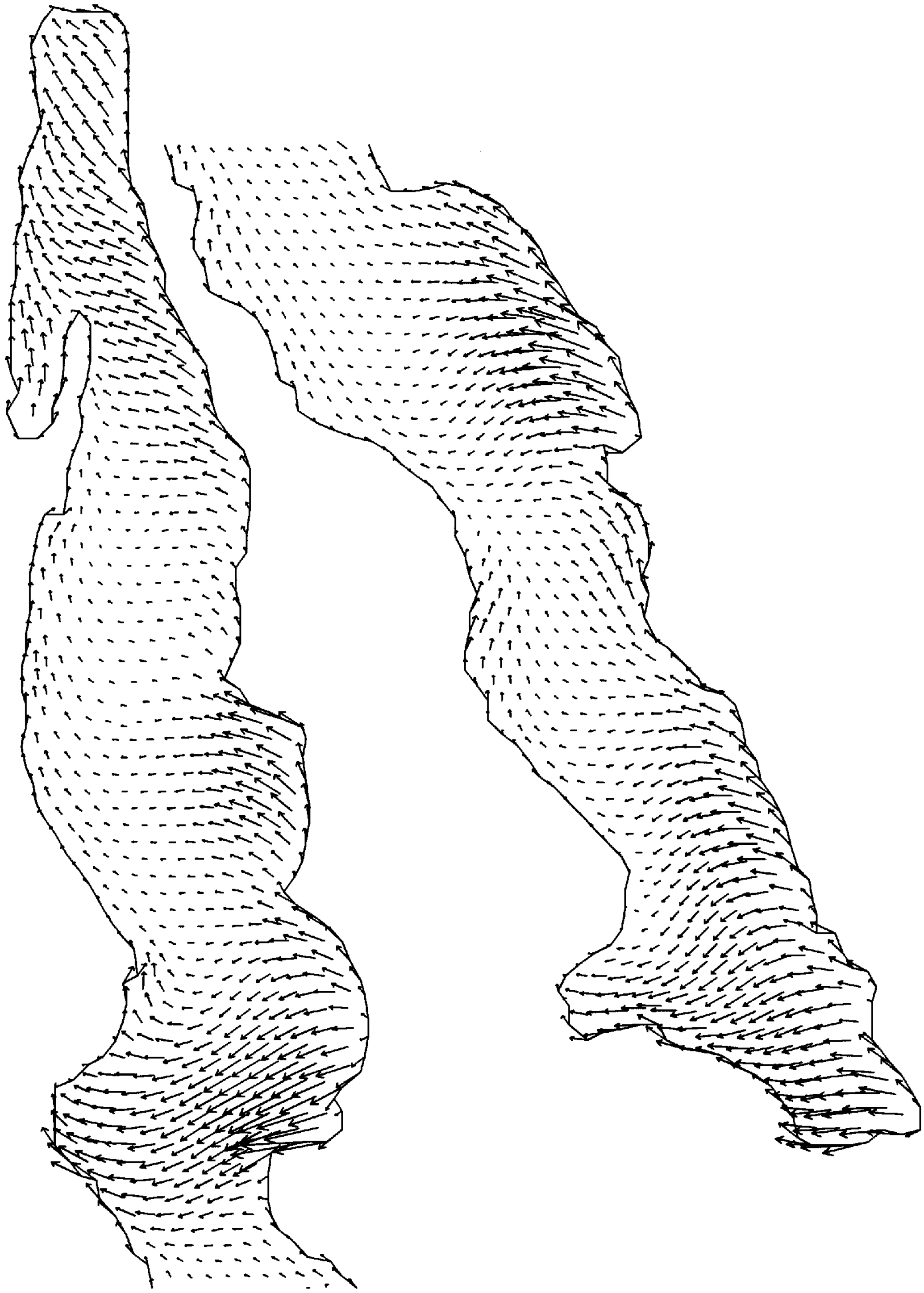
LAKE TANGANYIKA.SURFACE FLOW.SIMULATED WIND.TIME 05:00.



VELOCITY SCALE : 10 CM/S
MAXIMUM VALUE - 5.61CM/S

Fig.30

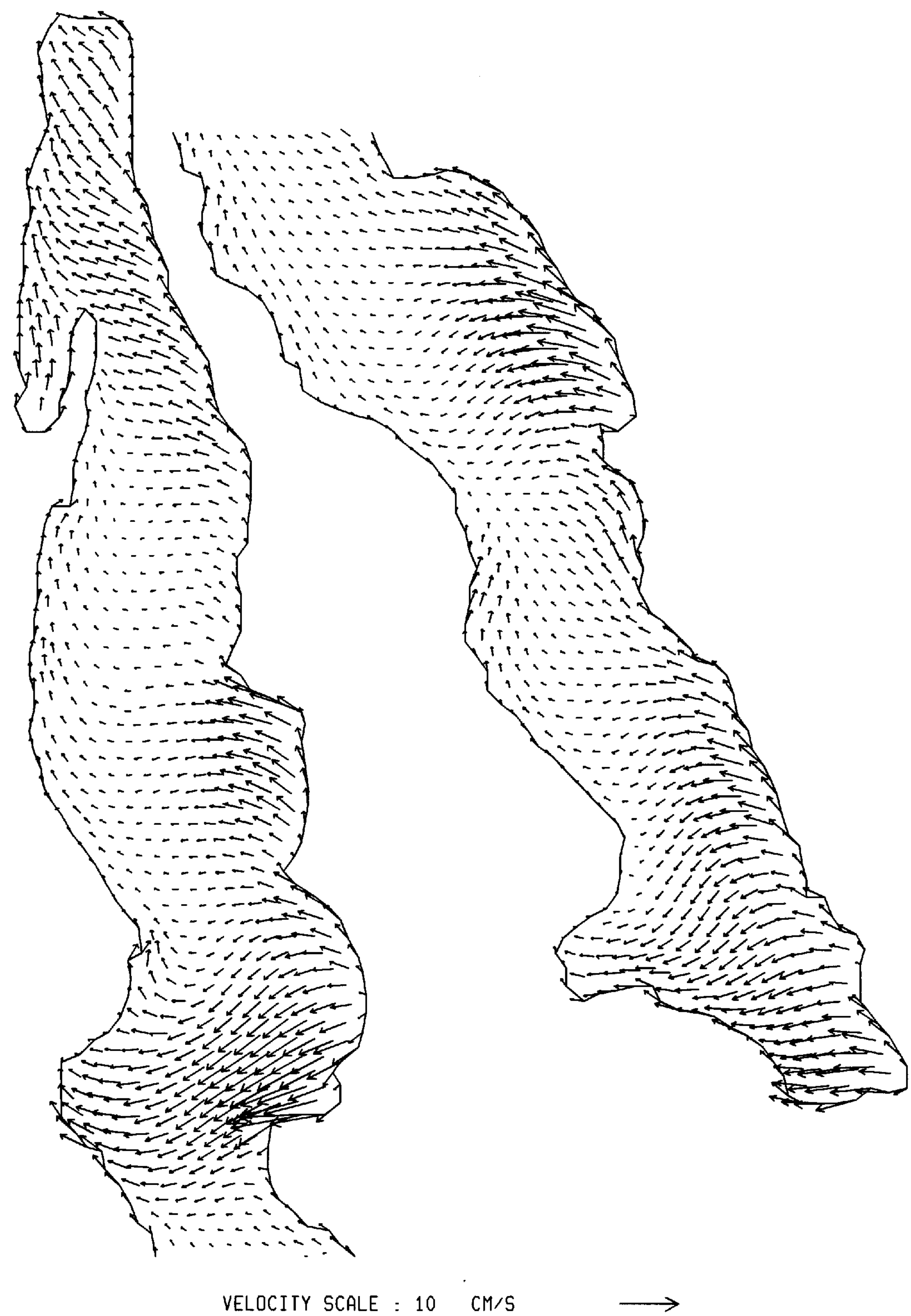
LAKE TANGANYIKA.SURFACE FLOW.SIMULATED WIND.TIME 06:00.



VELOCITY SCALE : 10 CM/S
MAXIMUM VALUE - 5.53CM/S

Fig.31

LAKE TANGANYIKA.SURFACE FLOW.SIMULATED WIND.TIME 07:00.



VELOCITY SCALE : 10 CM/S
MAXIMUM VALUE - 5.54CM/S

Fig.32

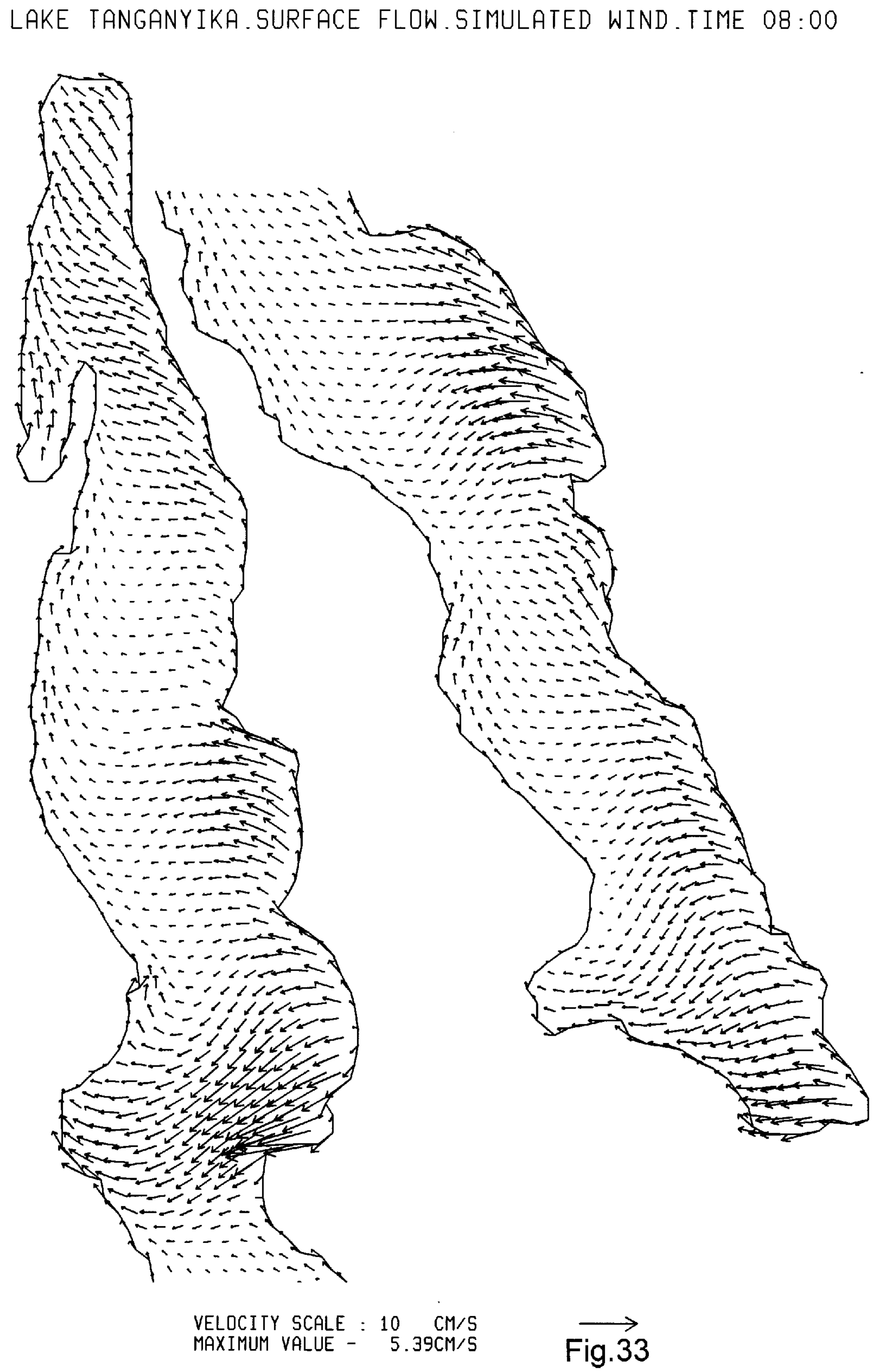
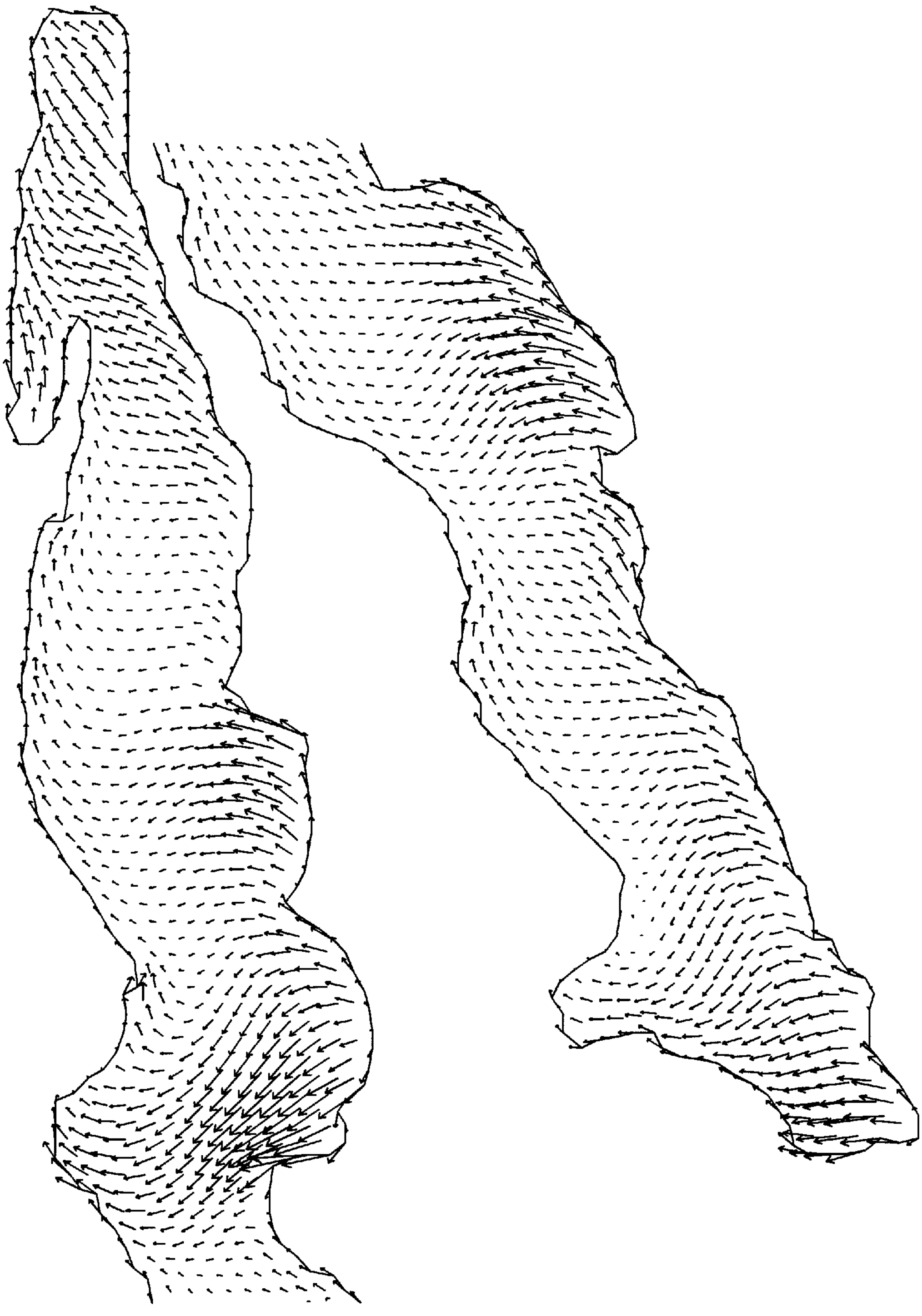

LAKE TANGANYIKA.SURFACE FLOW.SIMULATED WIND.TIME 08:00
VELOCITY SCALE : 10 CM/S
MAXIMUM VALUE - 5.39CM/S

Fig.33

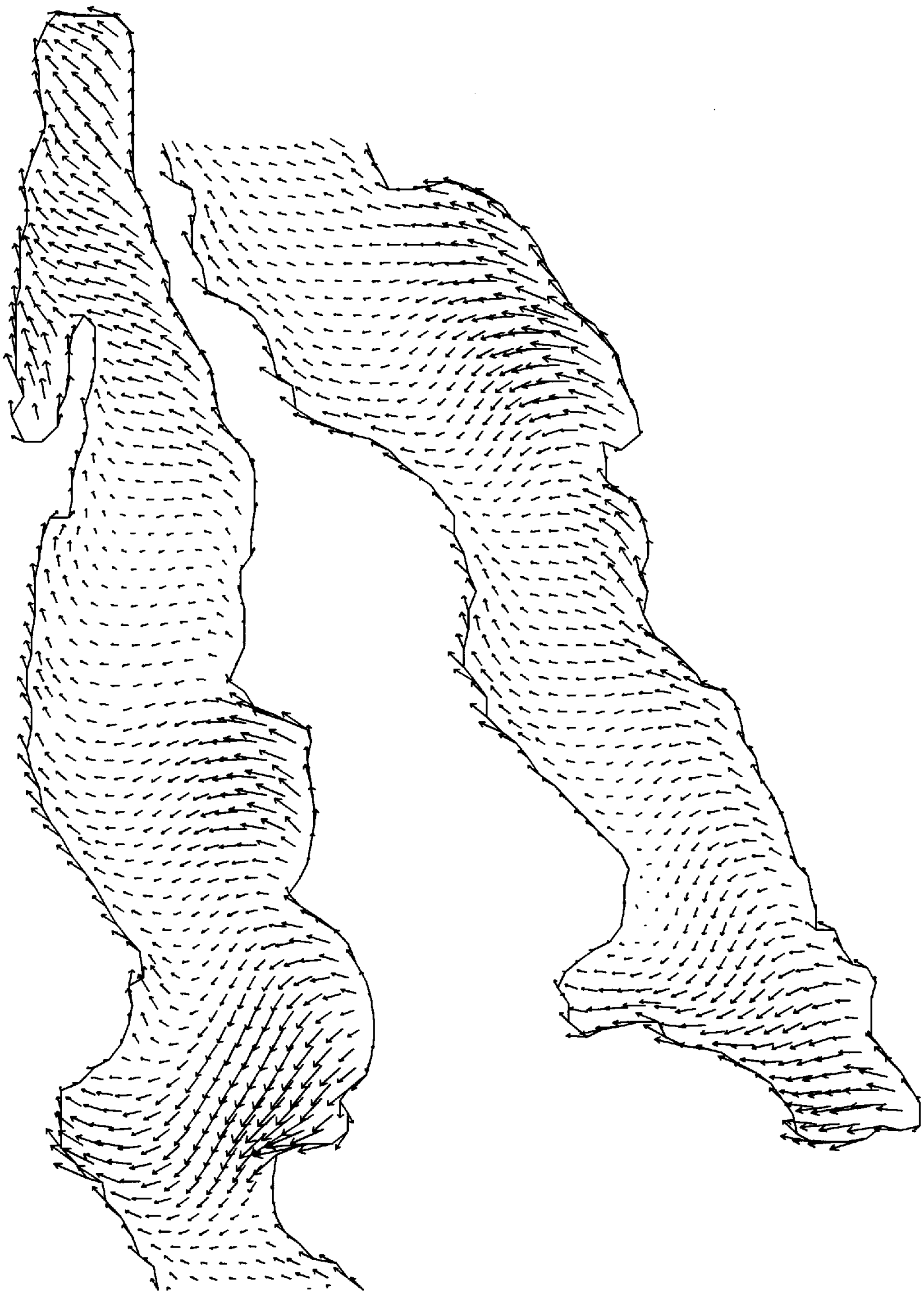
LAKE TANGANYIKA.SURFACE FLOW.SIMULATED WIND.TIME 09:00.



VELOCITY SCALE : 10 CM/S
MAXIMUM VALUE - 4.18CM/S

Fig.34

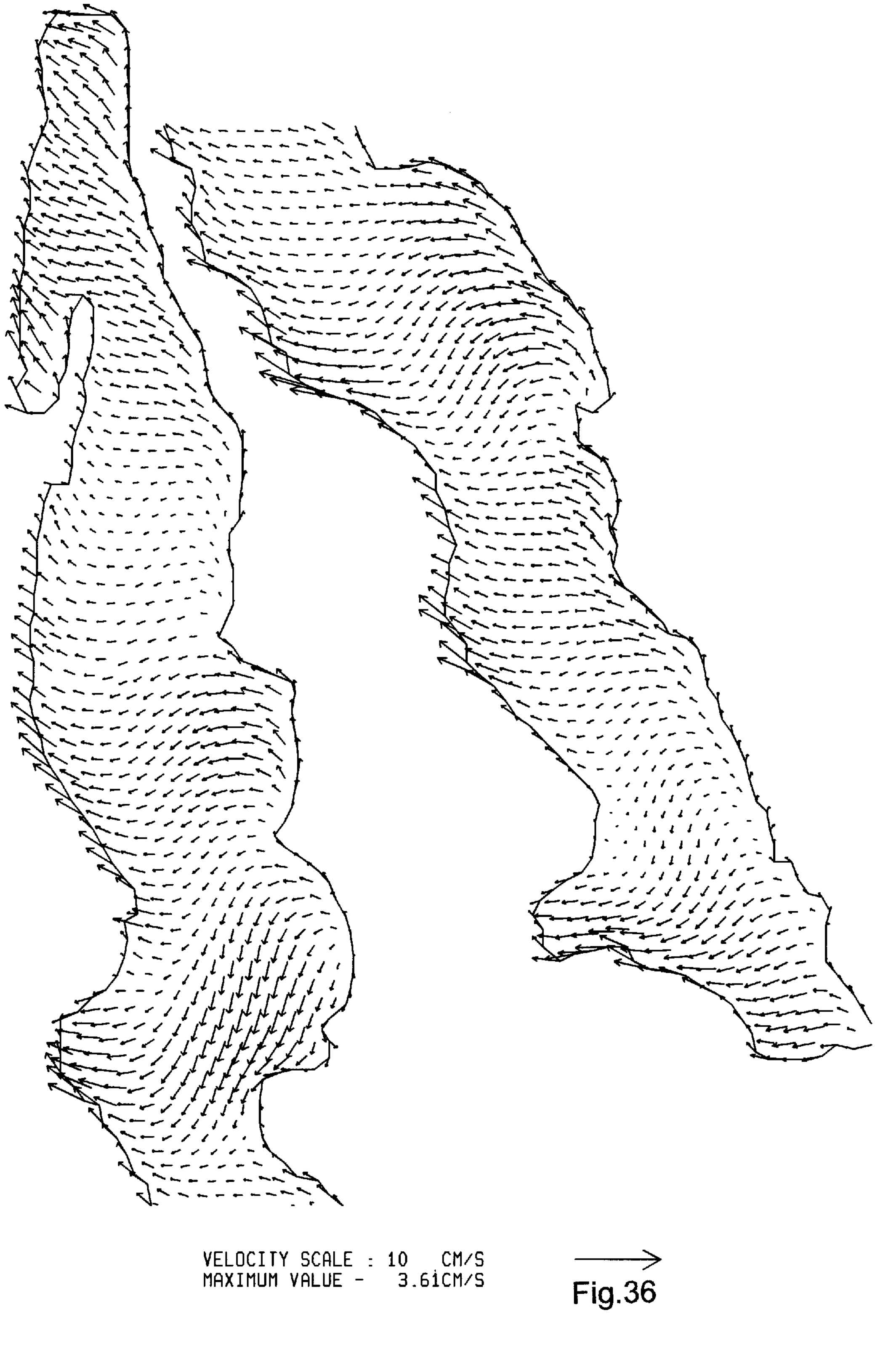
LAKE TANGANYIKA.SURFACE FLOW.SIMULATED WIND.TIME 10:00.



VELOCITY SCALE : 10 CM/S
MAXIMUM VALUE - 2.91CM/S

Fig.35

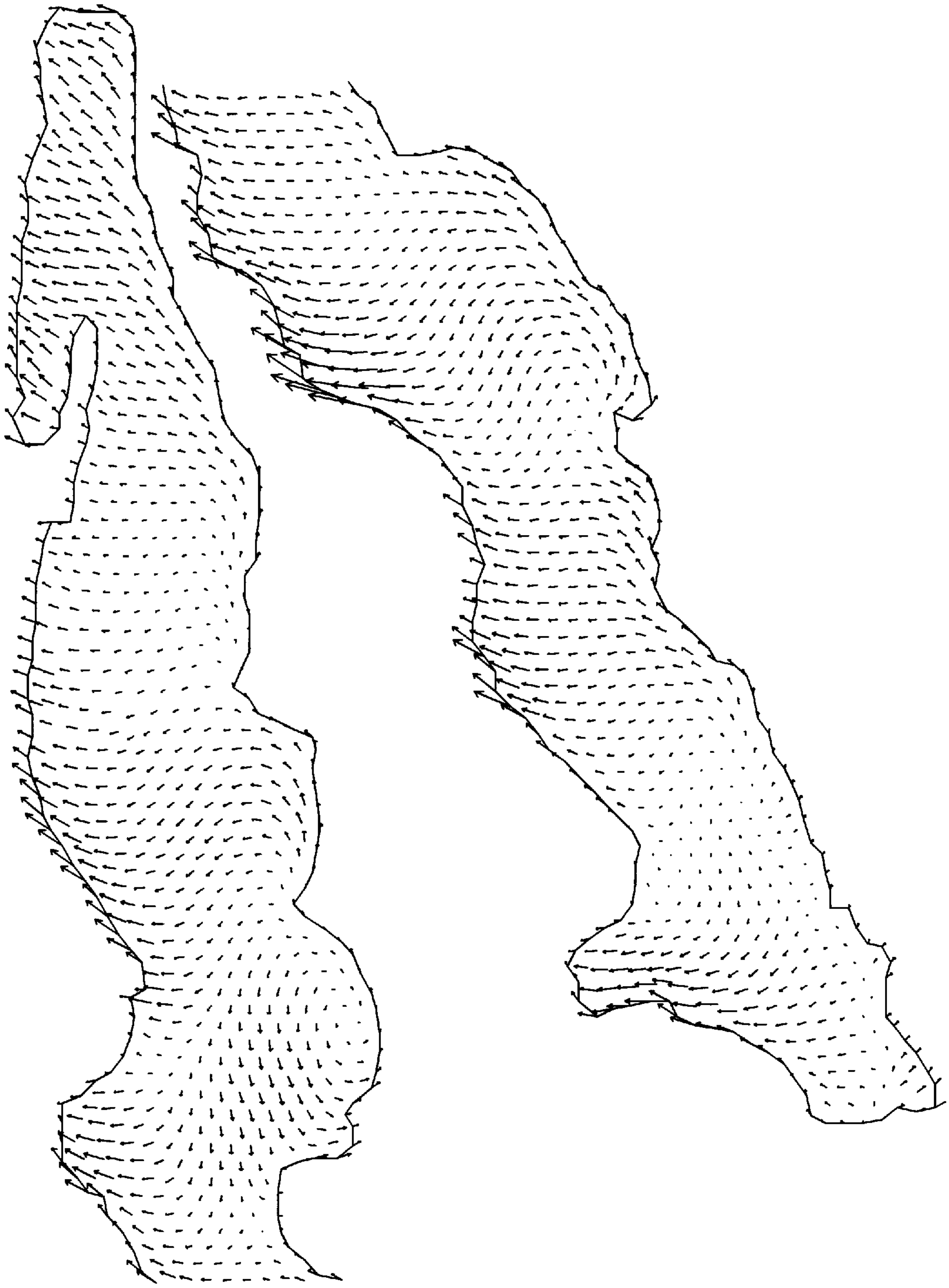
LAKE TANGANYIKA.SURFACE FLOW.SIMULATED WIND.TIME 11:00.



VELOCITY SCALE : 10 CM/S
MAXIMUM VALUE - 3.61CM/S

Fig.36

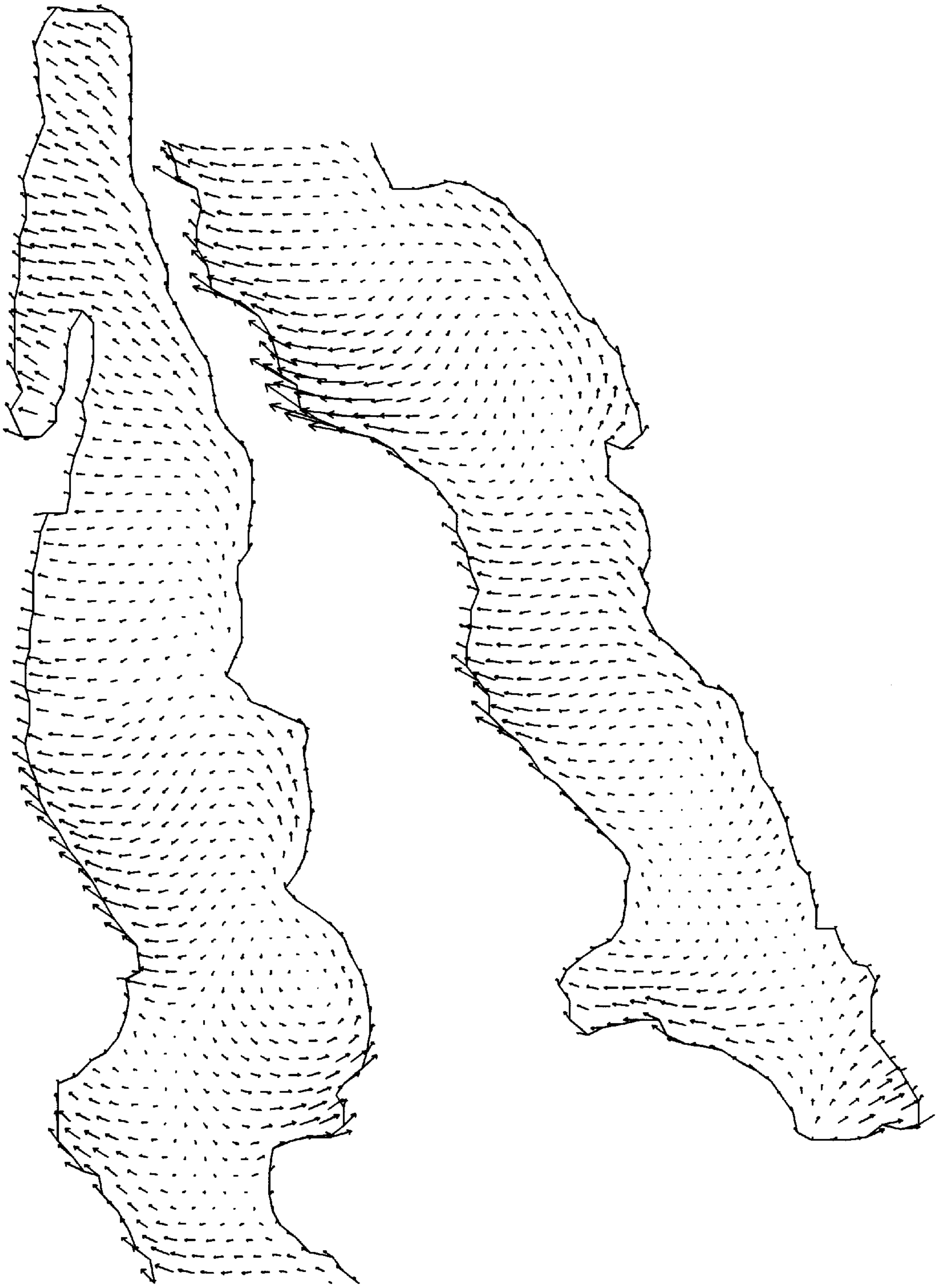
LAKE TANGANYIKA.SURFACE FLOW.SIMULATED WIND.TIME 12:00.



VELOCITY SCALE : 10 CM/S
MAXIMUM VALUE - 5.11CM/S

Fig.37

LAKE TANGANYIKA.SURFACE FLOW.SIMULATED WIND.TIME 13:00.



VELOCITY SCALE : 10 CM/S
MAXIMUM VALUE - 5.61CM/S

Fig.38

LAKE TANGANYIKA.SURFACE FLOW.SIMULATED WIND.TIME 14:00.

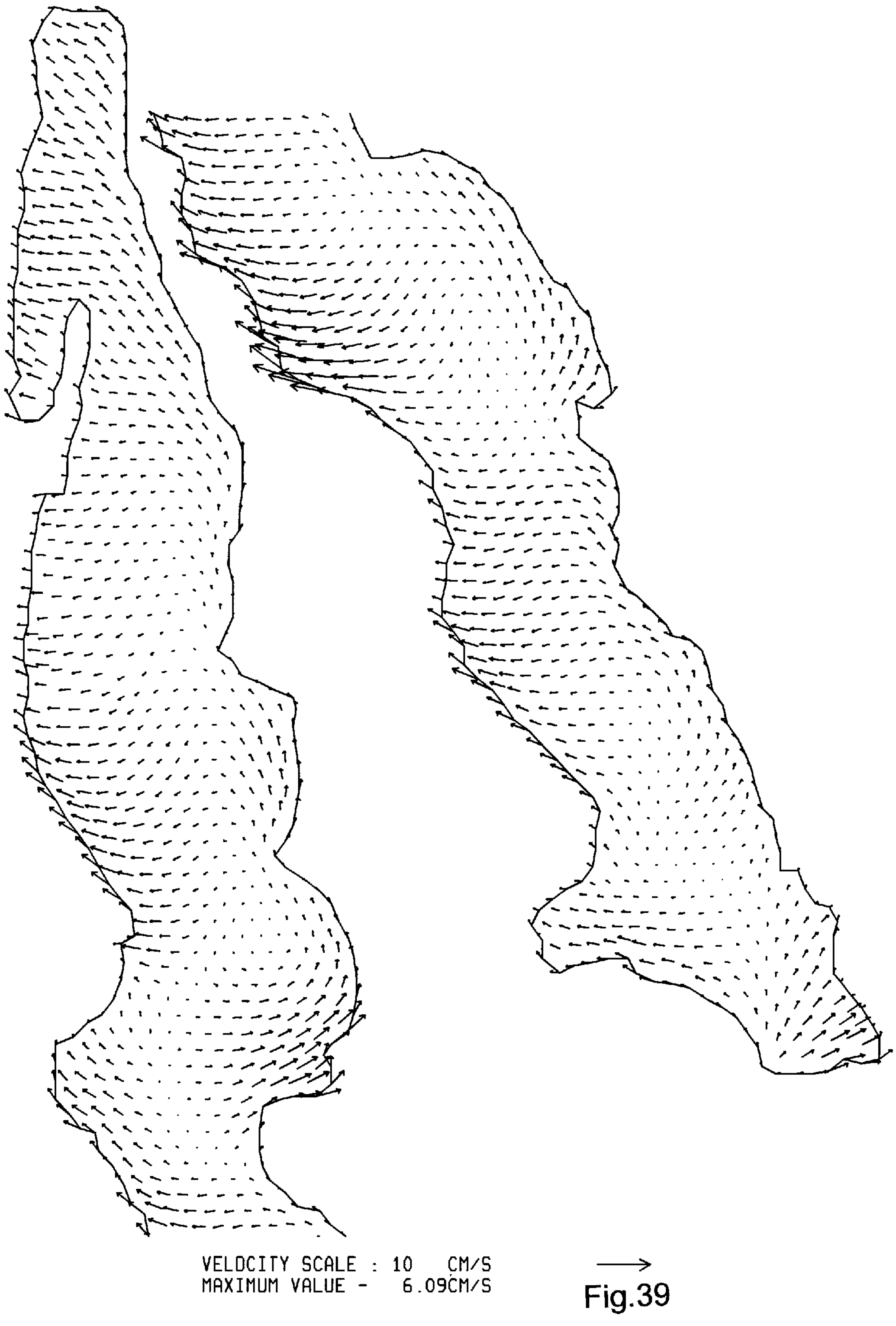


Fig.39

LAKE TANGANYIKA.SURFACE FLOW.SIMULATED WIND.TIME 15:00.

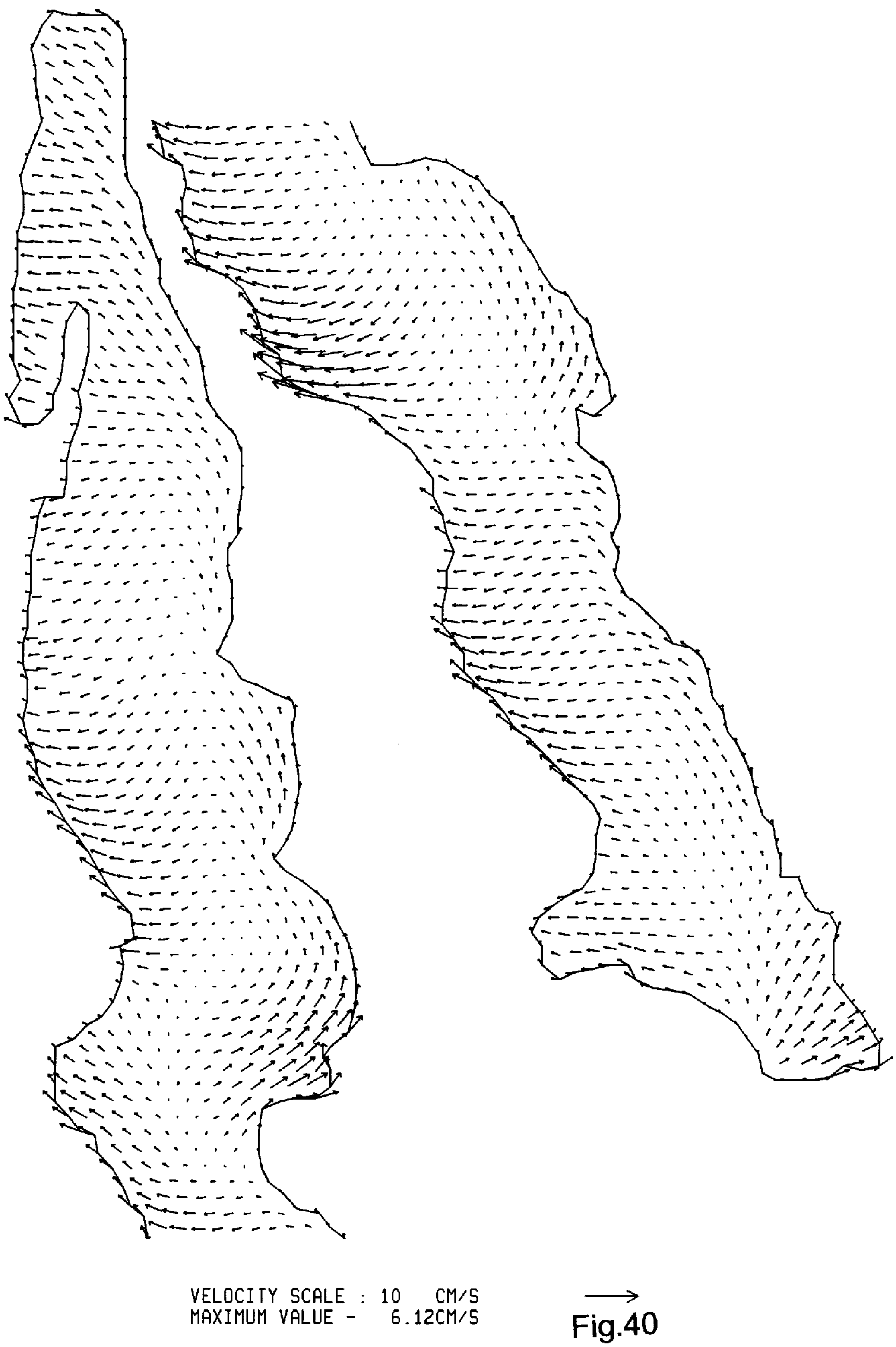


Fig.40

LAKE TANGANYIKA.SURFACE FLOW.SIMULATED WIND.TIME 16:00.

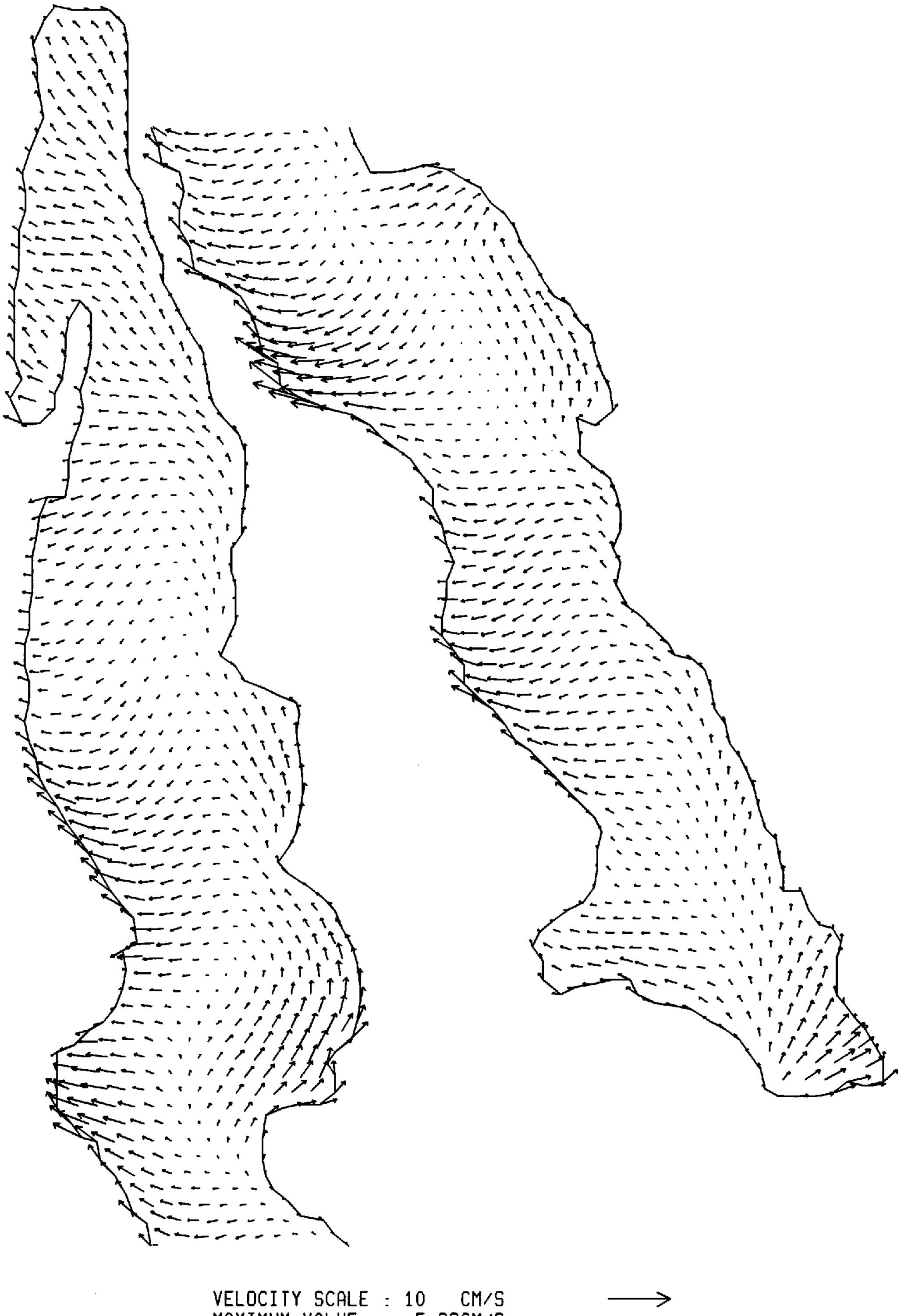
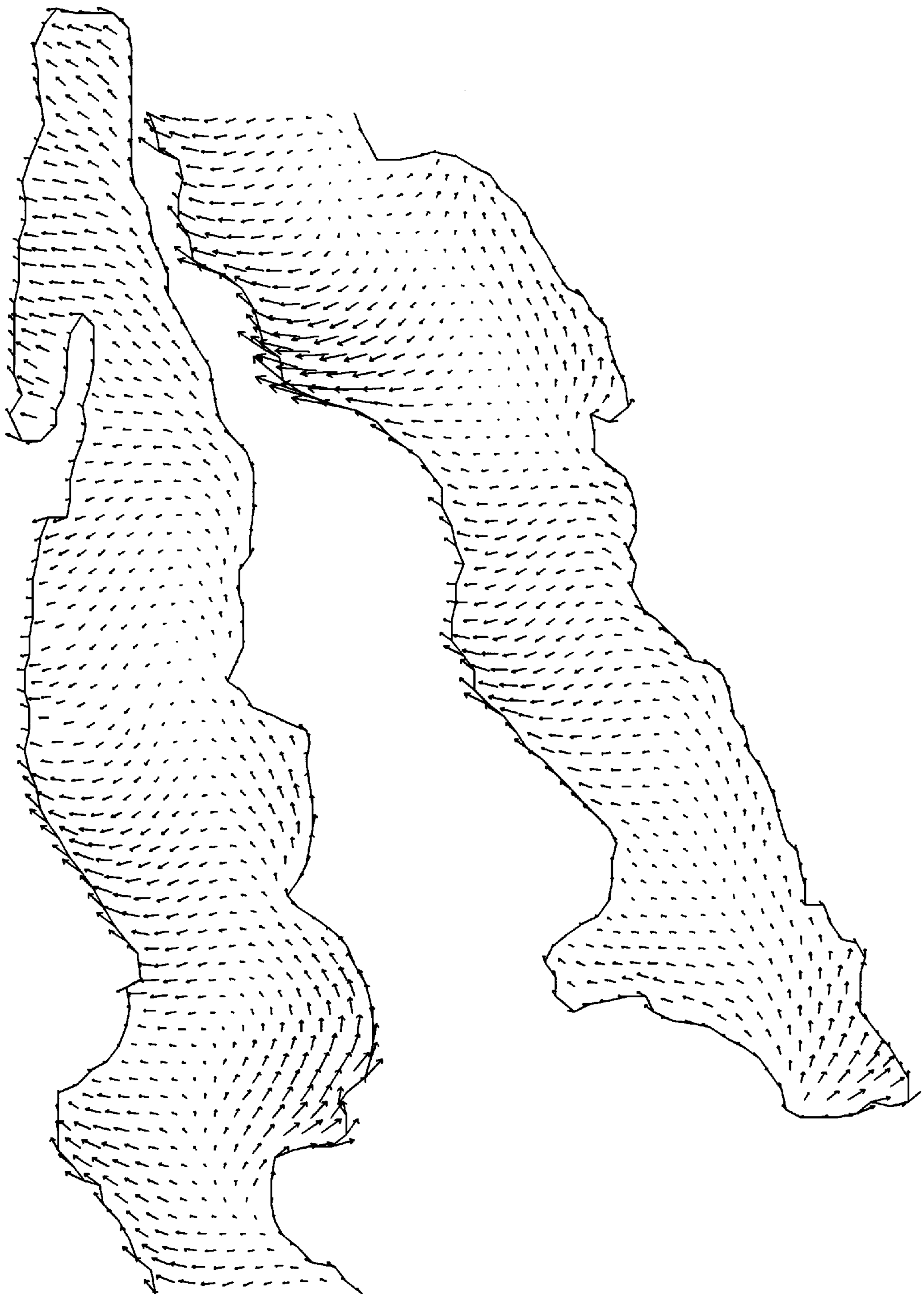


Fig.41

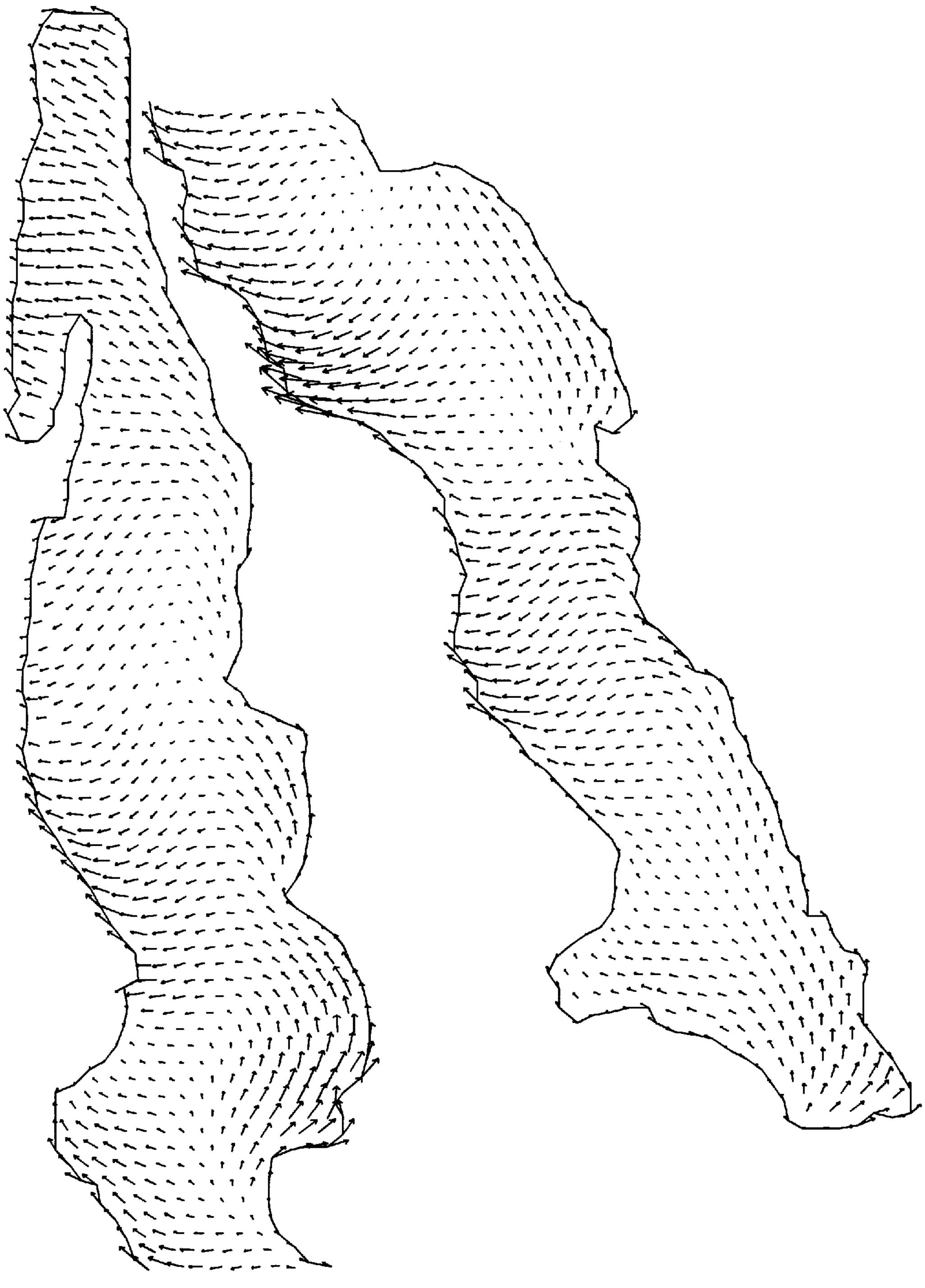
LAKE TANGANYIKA.SURFACE FLOW.SIMULATED WIND.TIME 17:00.



VELOCITY SCALE : 10 CM/S
MAXIMUM VALUE - 5.62CM/S

Fig.42

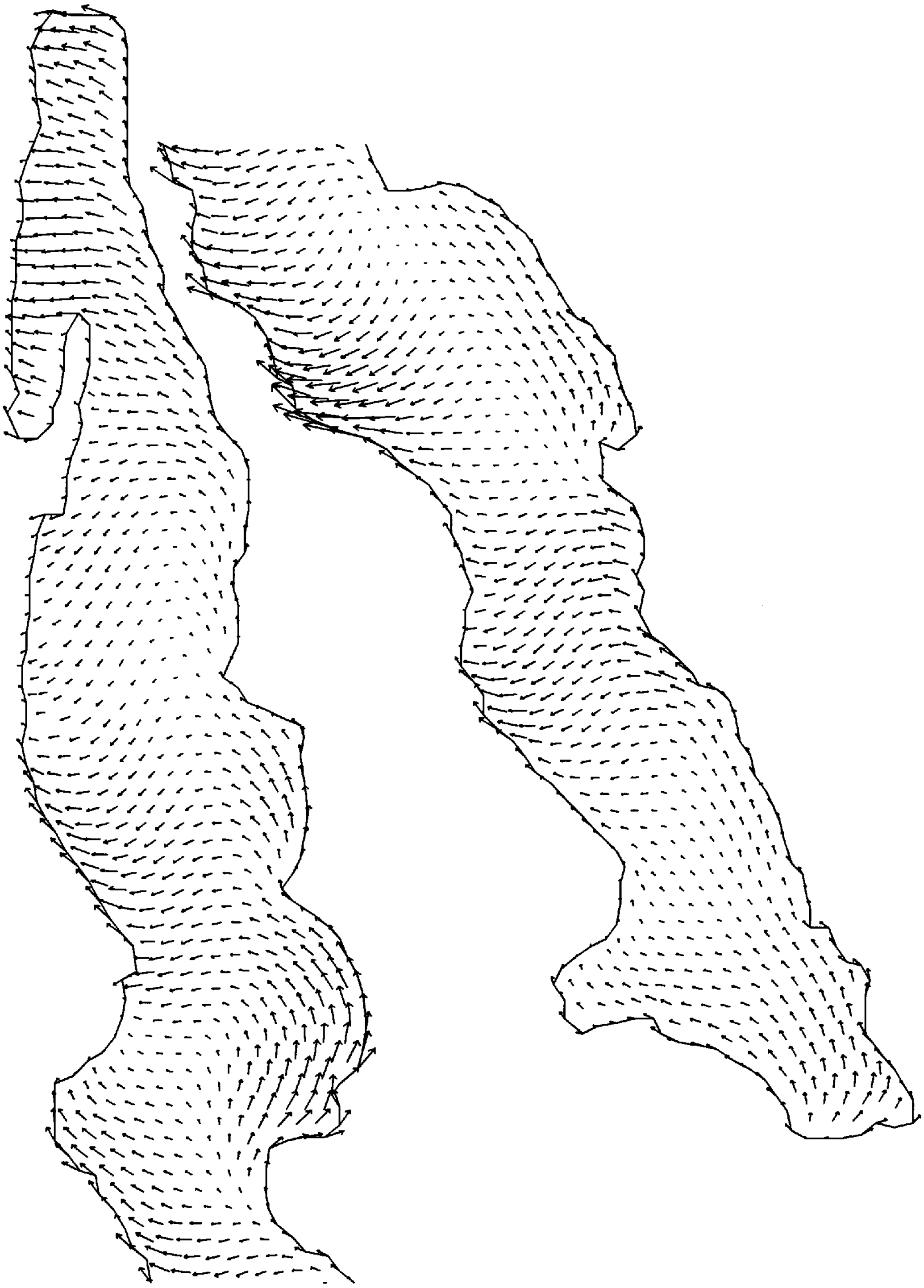
LAKE TANGANYIKA.SURFACE FLOW.SIMULATED WIND.TIME 18:00.



VELOCITY SCALE : 10 CM/S
MAXIMUM VALUE - 5.18CM/S

Fig.43

LAKE TANGANYIKA.SIRFACE FLOW.SIMULATED WIND.TIME 19:00.



VELOCITY SCALE : 10 CM/S
MAXIMUM VALUE - 4.36CM/S

Fig.44

LAKE TANGANYIKA.SURFACE FLOW.SIMULATED WIND.TIME 20:00.

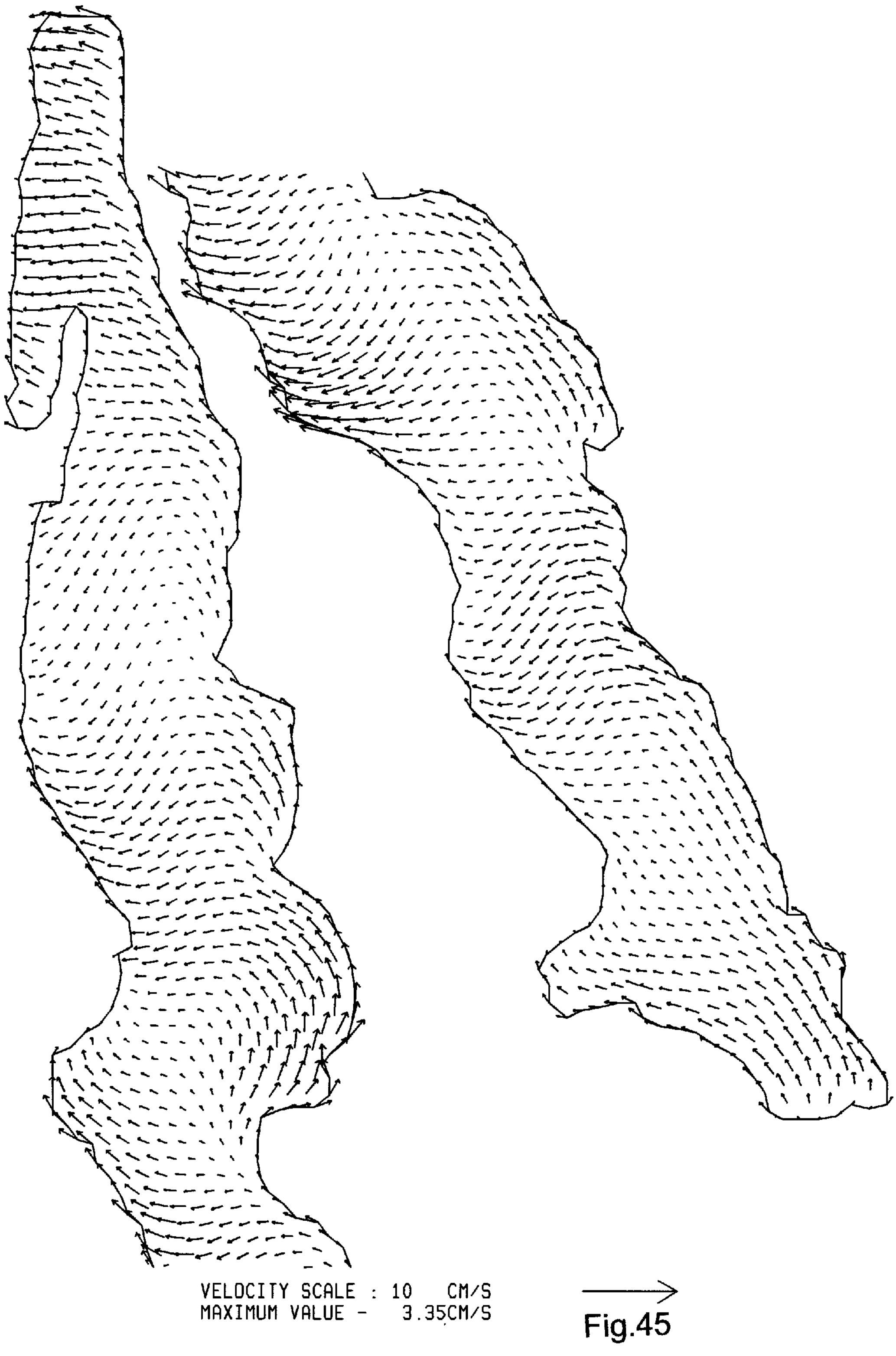


Fig.45

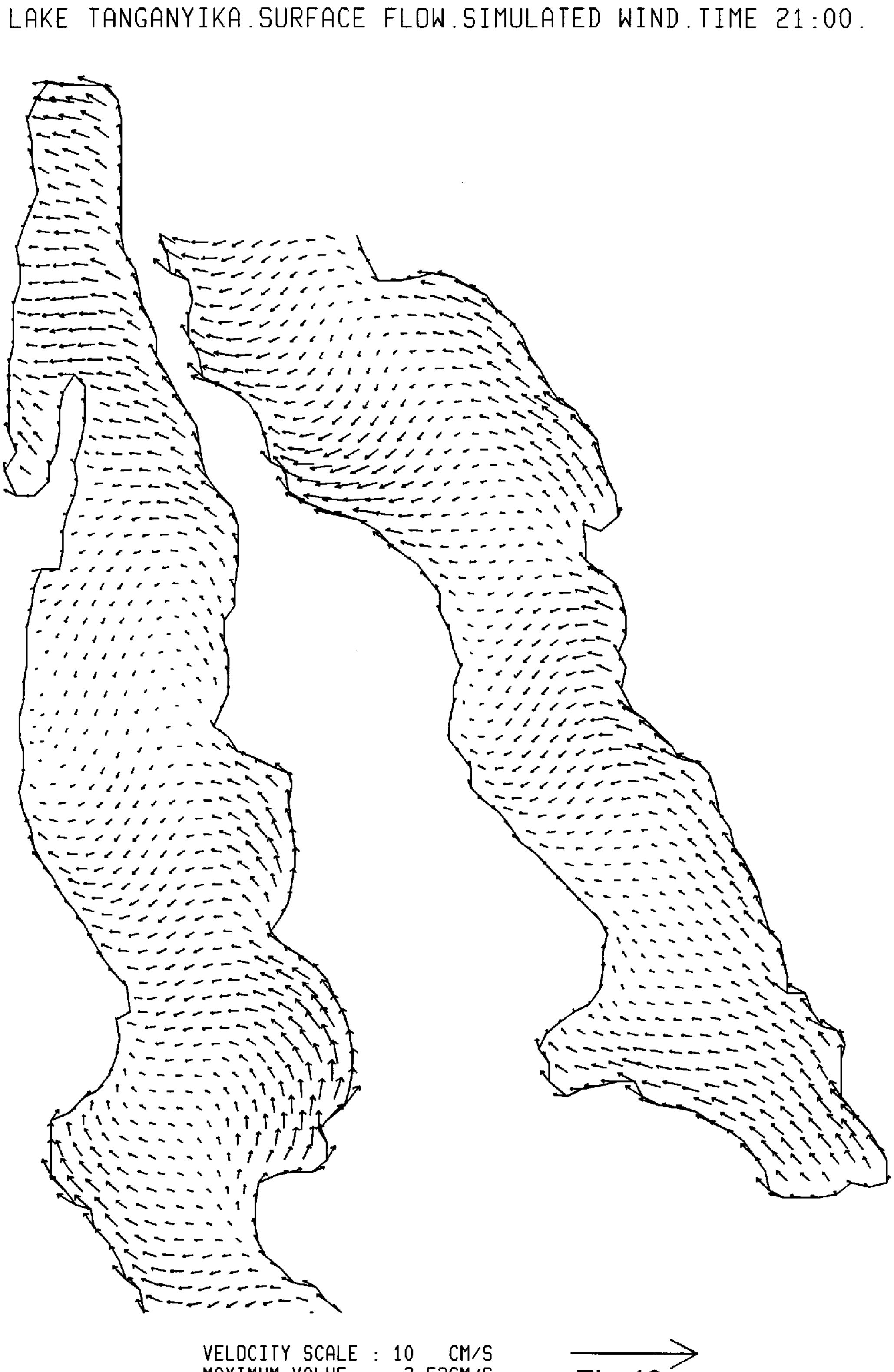

LAKE TANGANYIKA.SURFACE FLOW.SIMULATED WIND.TIME 21:00.
VELOCITY SCALE : 10 CM/S
MAXIMUM VALUE - 2.53CM/S

Fig.46

LAKE TANGANYIKA.SURFACE FLOW.SIMULATED WIND.TIME 22:00.

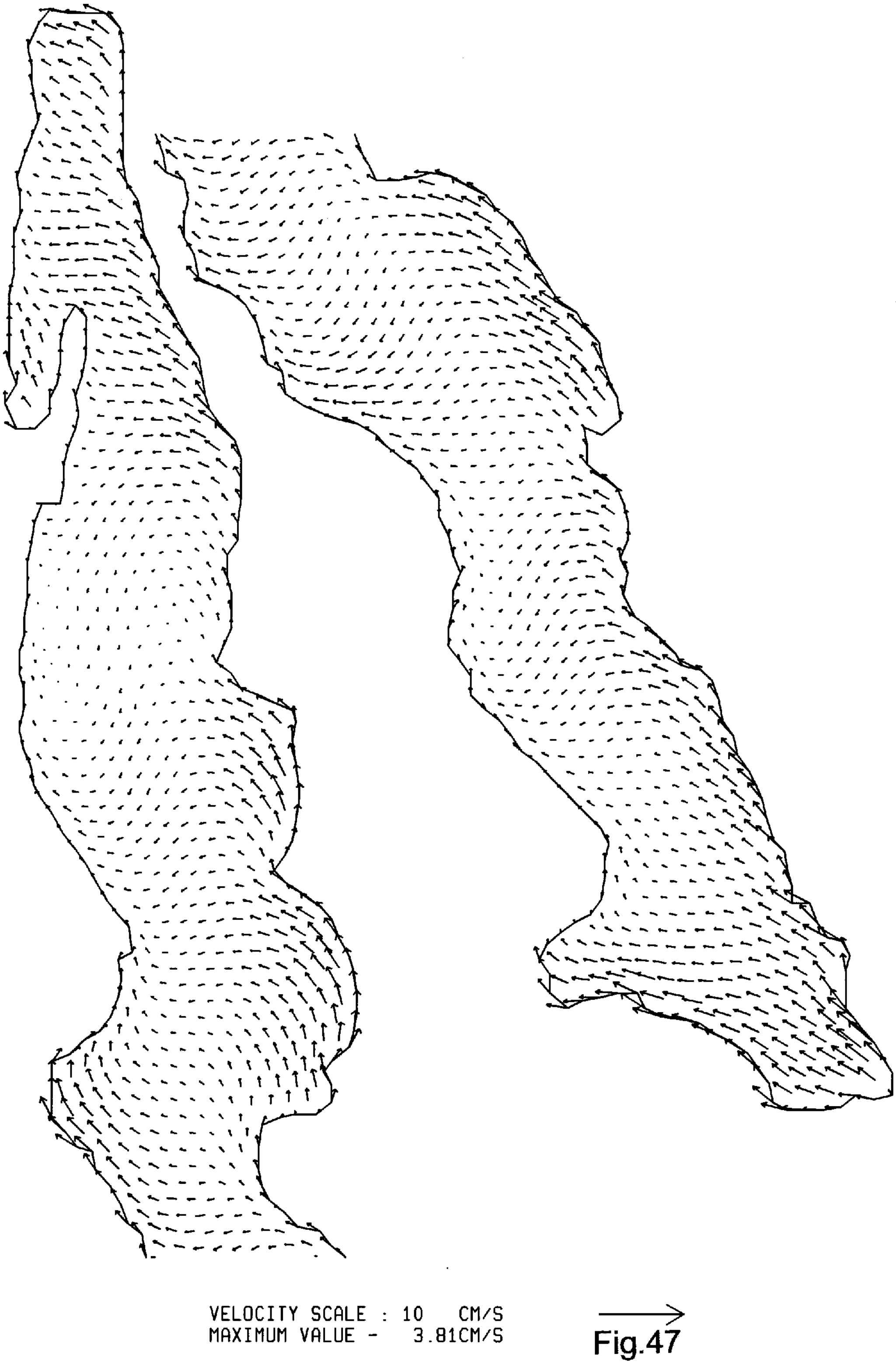
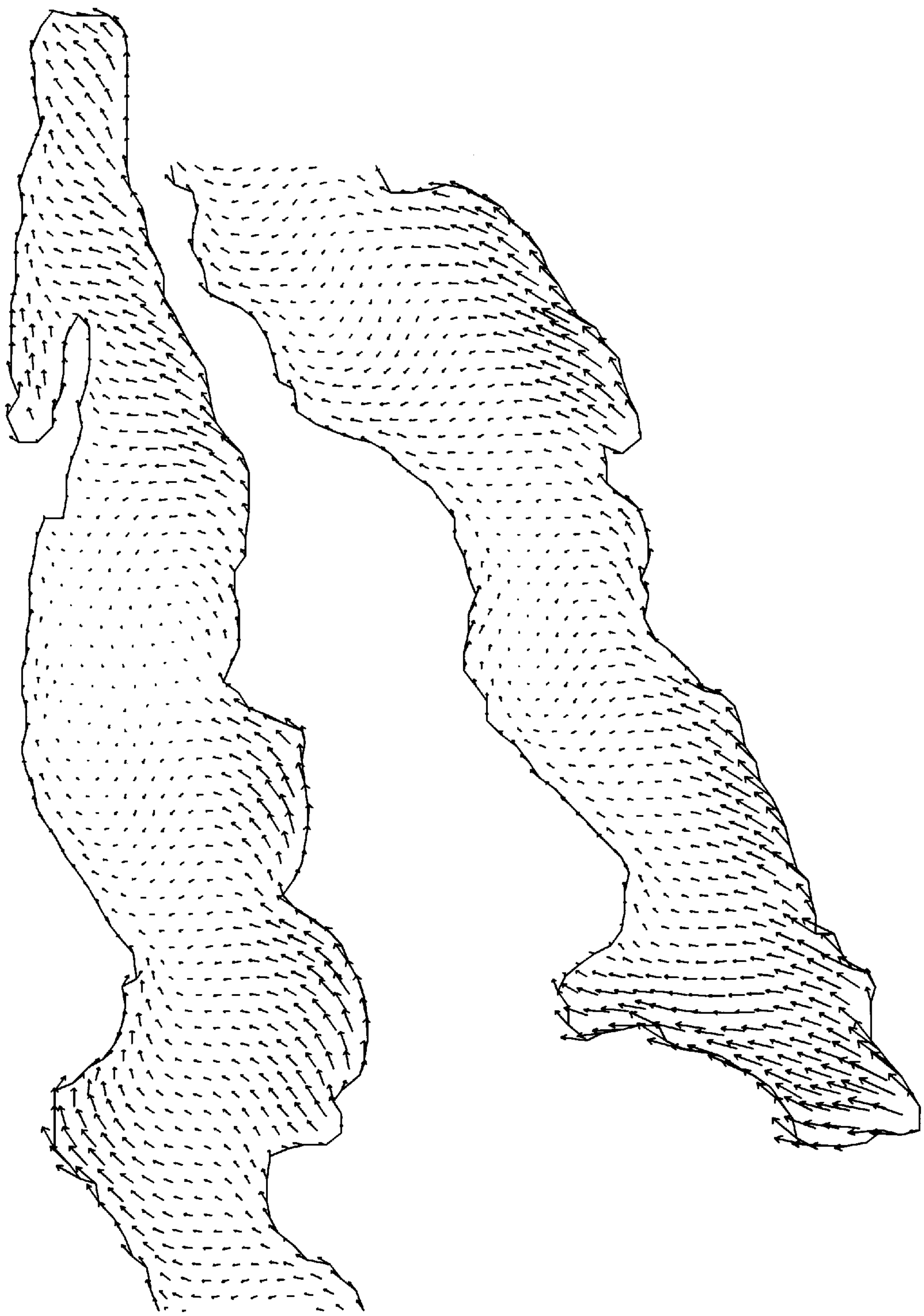


Fig.47

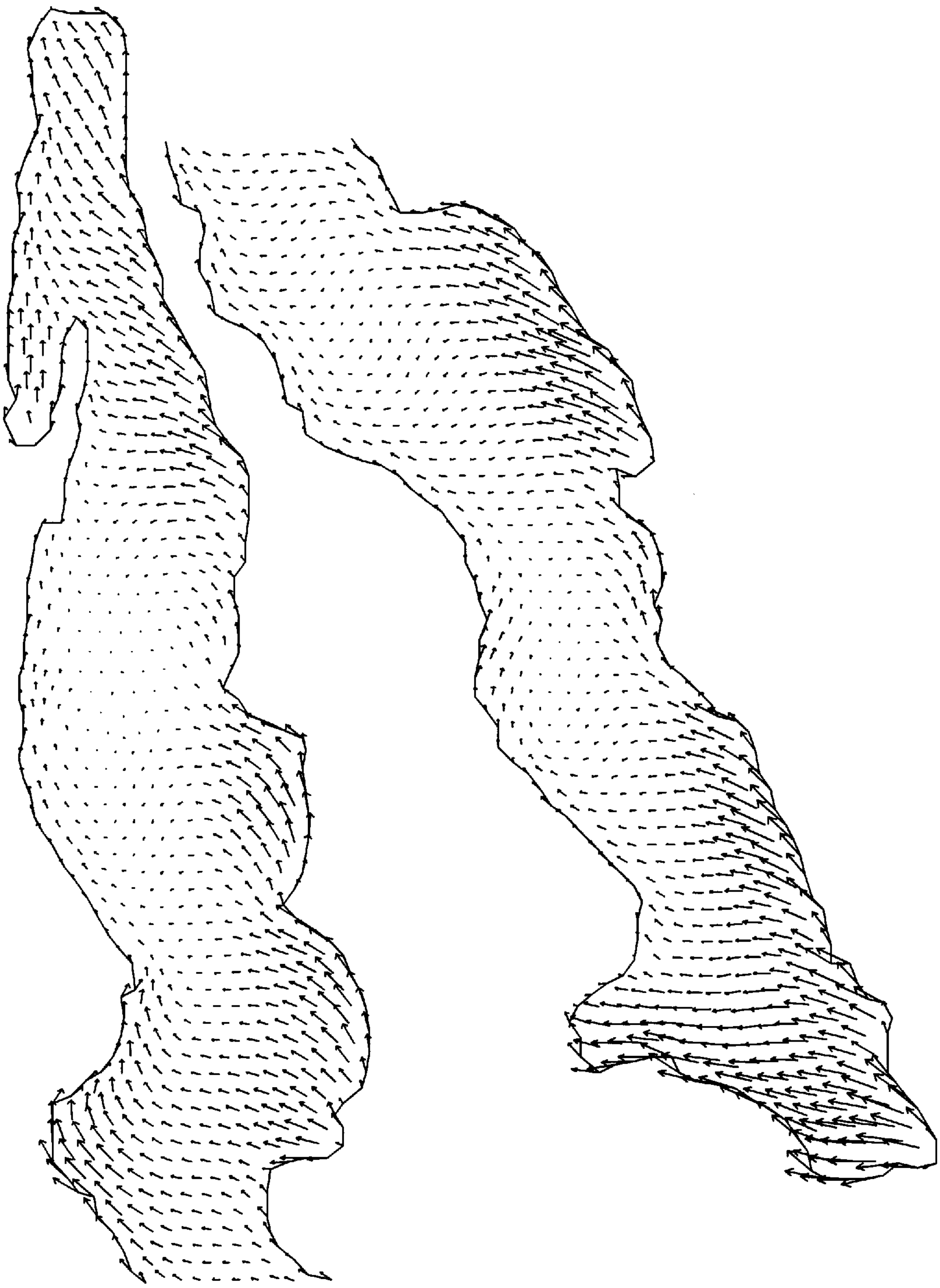
LAKE TANGANYIKA.SURFACE FLOW.SIMULATED WIND.TIME 23:00.



VELOCITY SCALE : 10 CM/S
MAXIMUM VALUE - 4.28CM/S

Fig.48

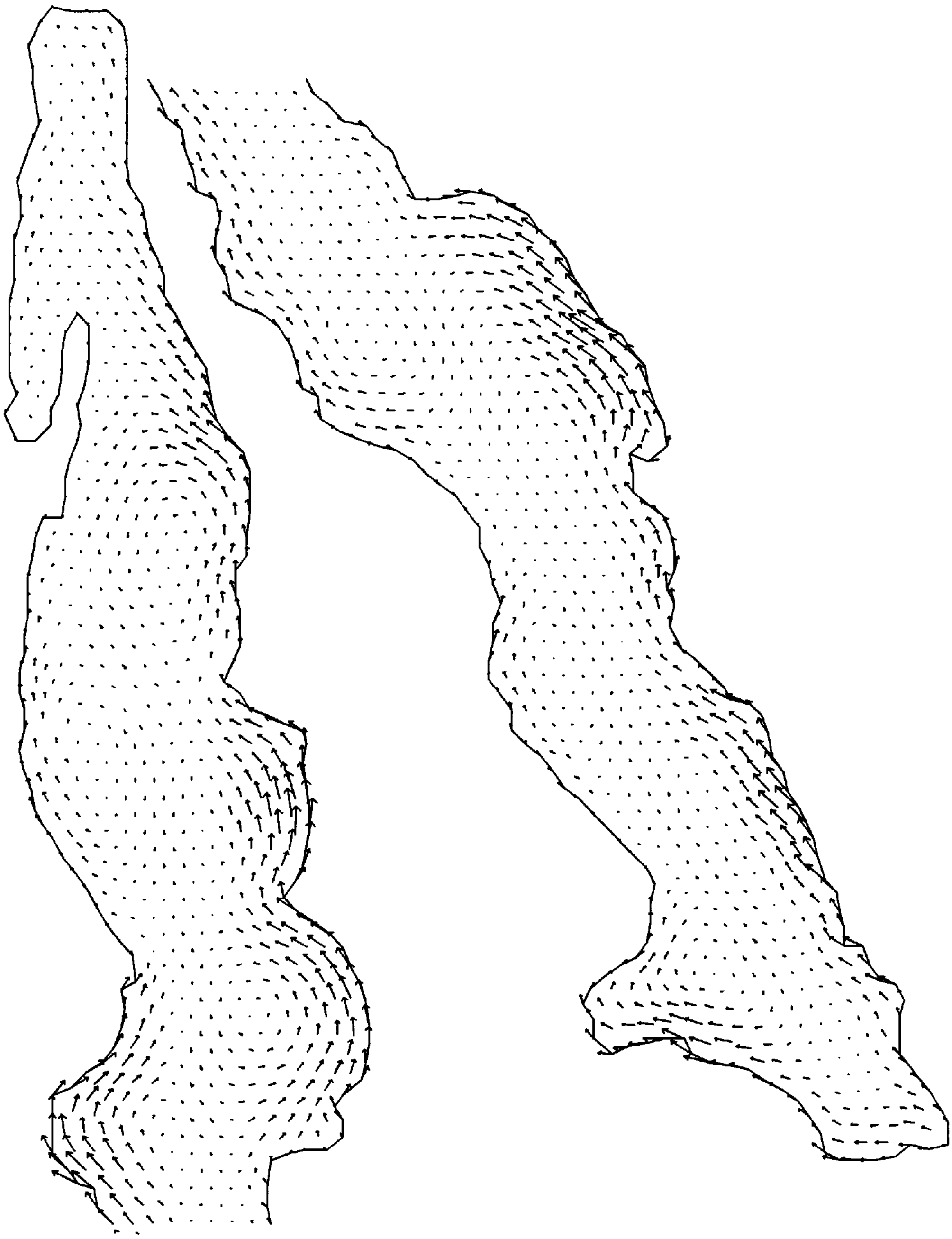
LAKE TANGANYIKA.SURFACE FLOW.SIMULATED WIND.TIME 24:00.



VELOCITY SCALE : 10 . CM/S
MAXIMUM VALUE - 4.31CM/S

Fig.49

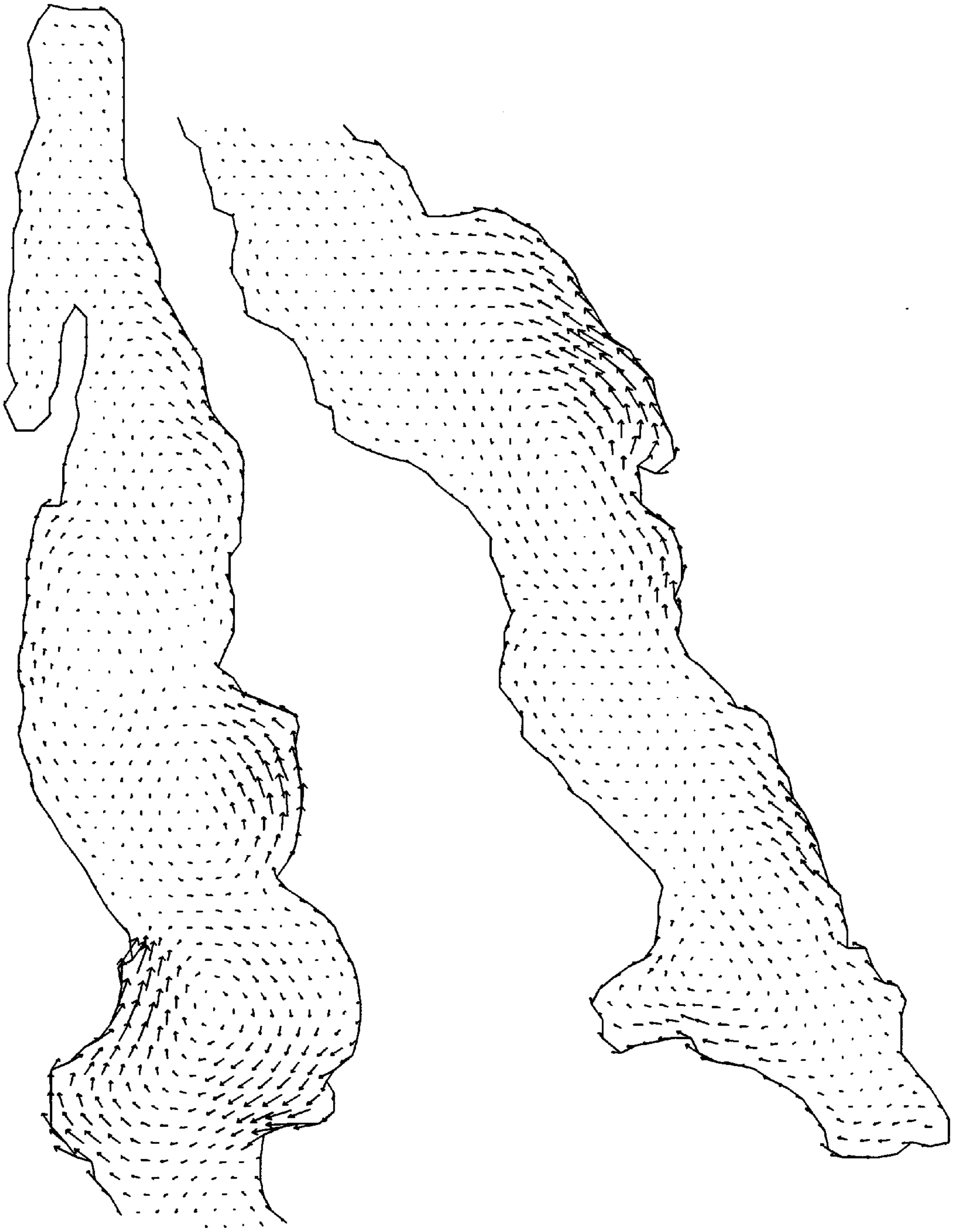
DEPTH-AVERAGED FLOW.SIMULATED WIND.TIME 00:00.



VELOCITY SCALE : 1 CM/S ⟶
MAXIMUM VALUE - 0.82CM/S

Fig.50

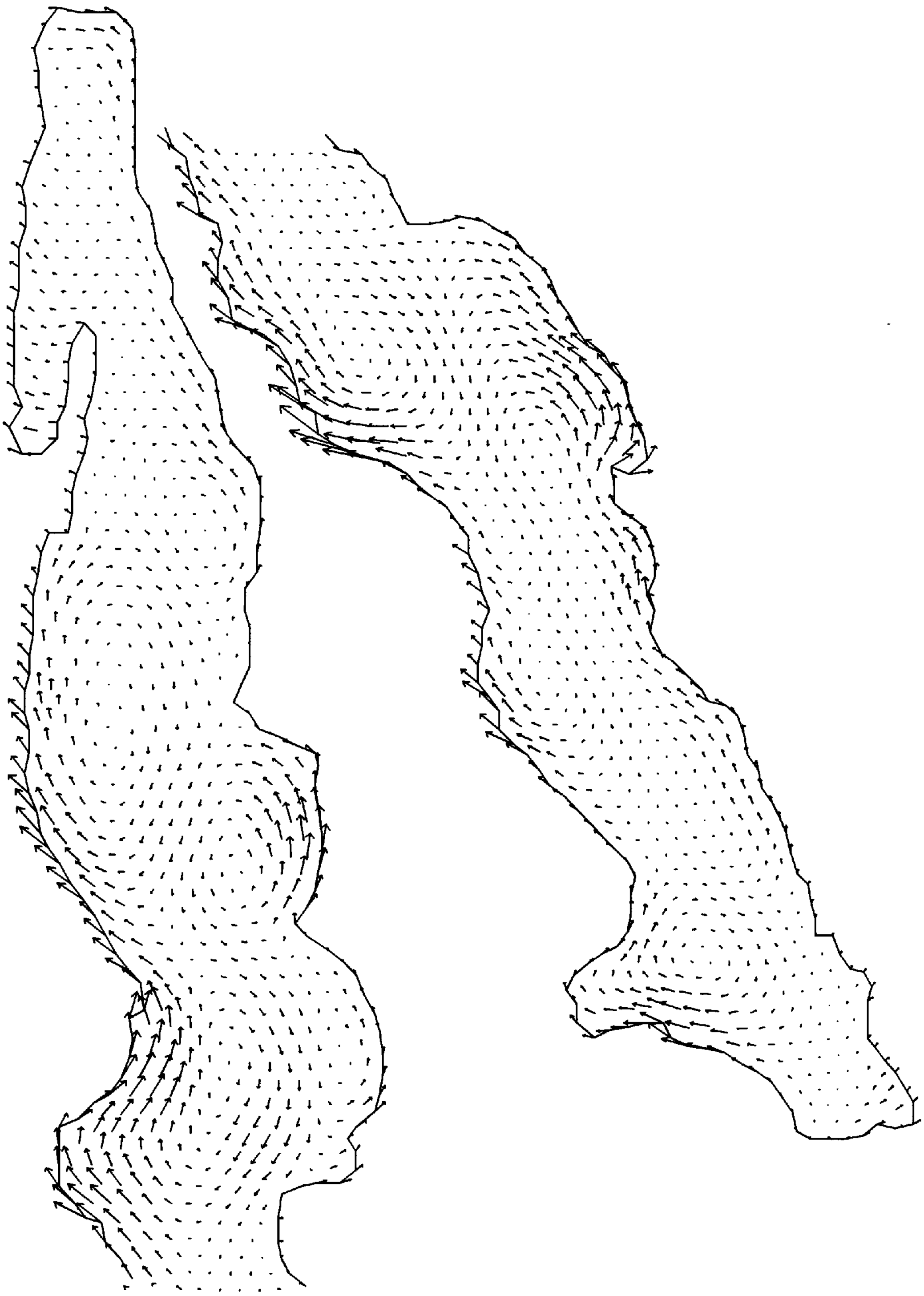
DEPTH-AVERAGED FLOW.SIMULATED WIND.TIME 06:00



VELOCITY SCALE : 10 CM/S
MAXIMUM VALUE - 1.06CM/S

Fig.51

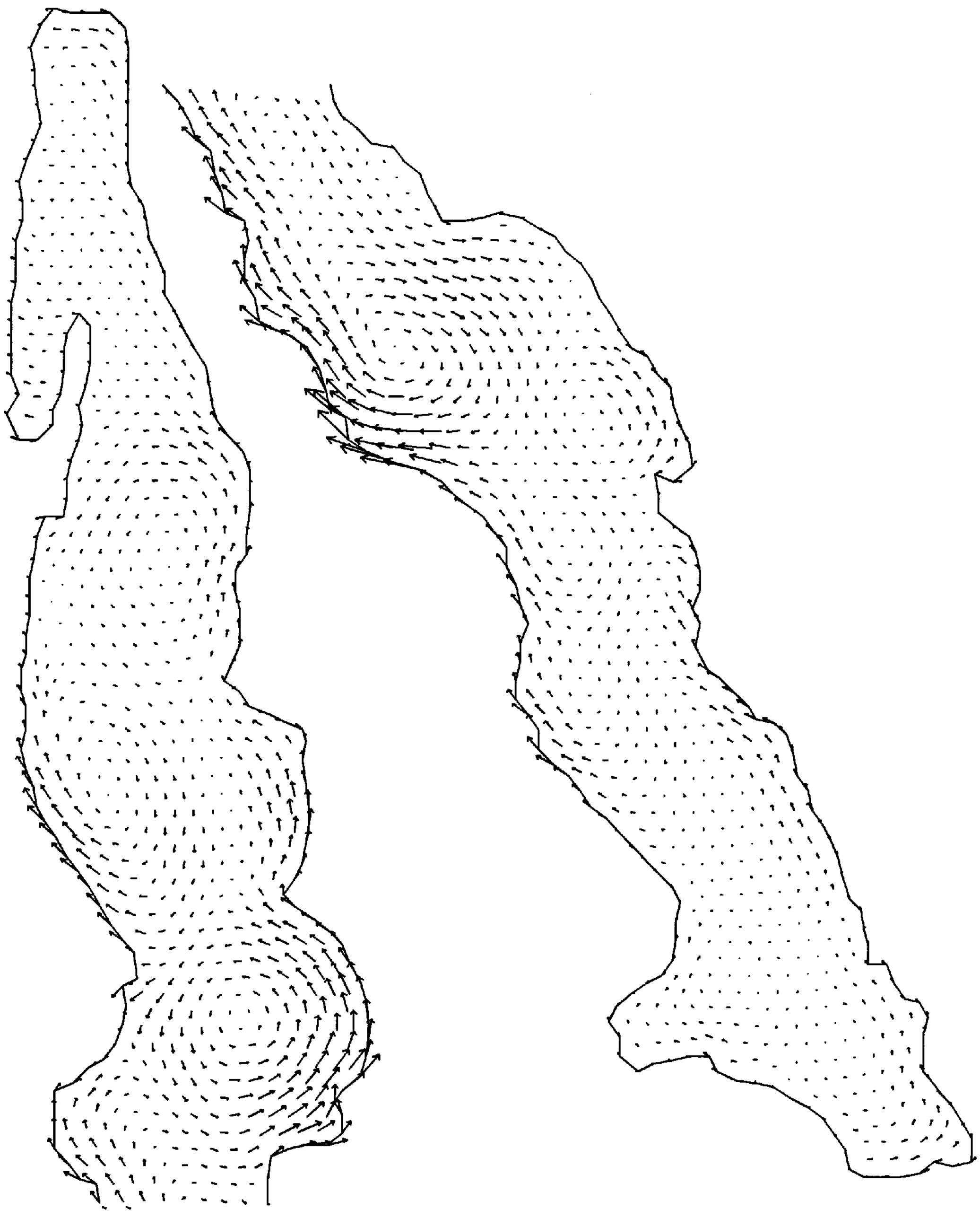
DEPTH-AVERAGED FLOW.SIMULATED WIND.TIME12:00.



VELOCITY SCALE : 1 CM/S ⟶
MAXIMUM VALUE - 0.74CM/S

Fig.52

DEPTH-AVERAGED FLOW.SIMULATED WIND.TIME 18:00.



VELOCITY SCALE : 10 CM/S
MAXIMUM VALUE - 1.08CM/S

Fig.53

WATER SURFACE IZOLINES.SIMULATED WIND.TIME 00:00.

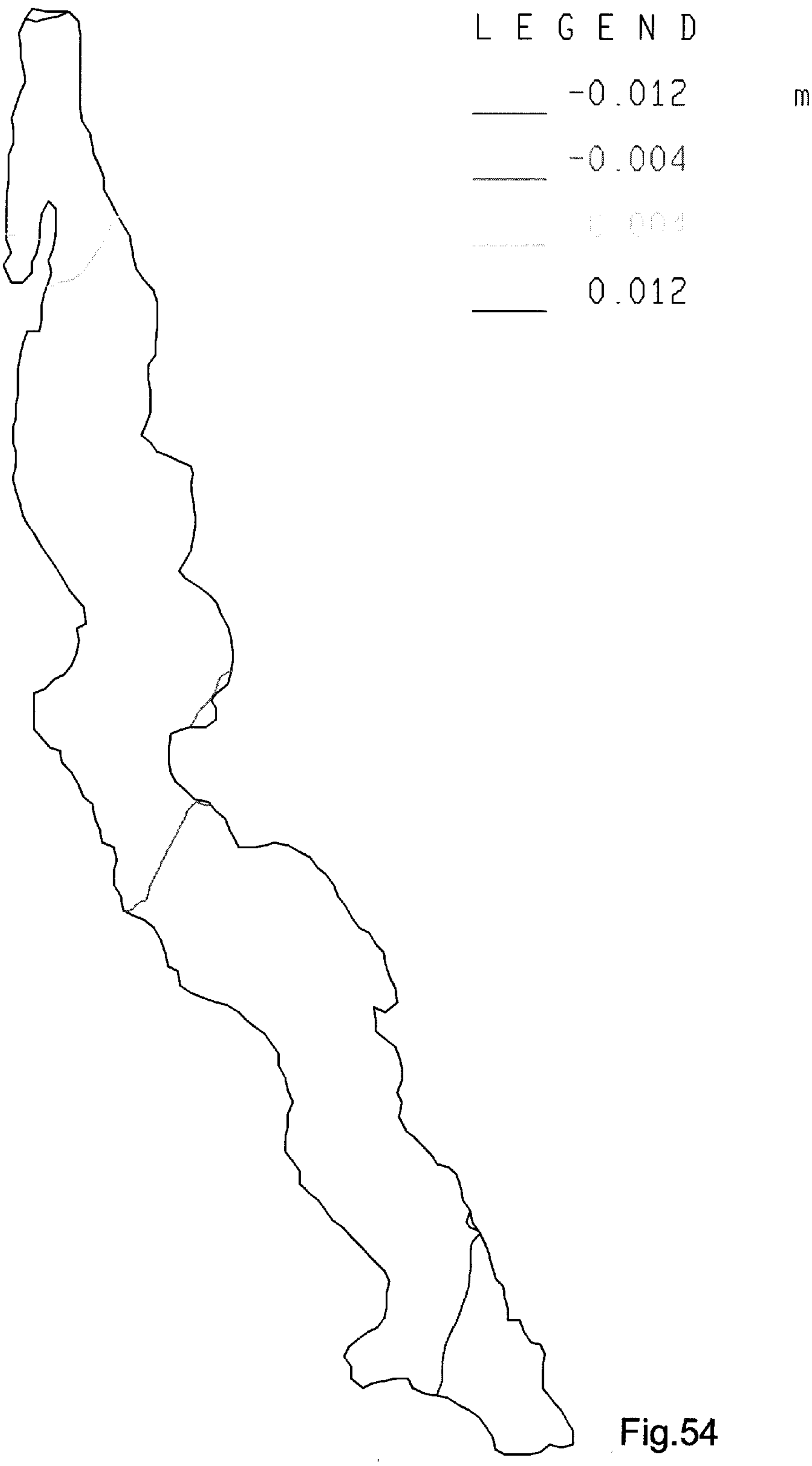


Fig.54

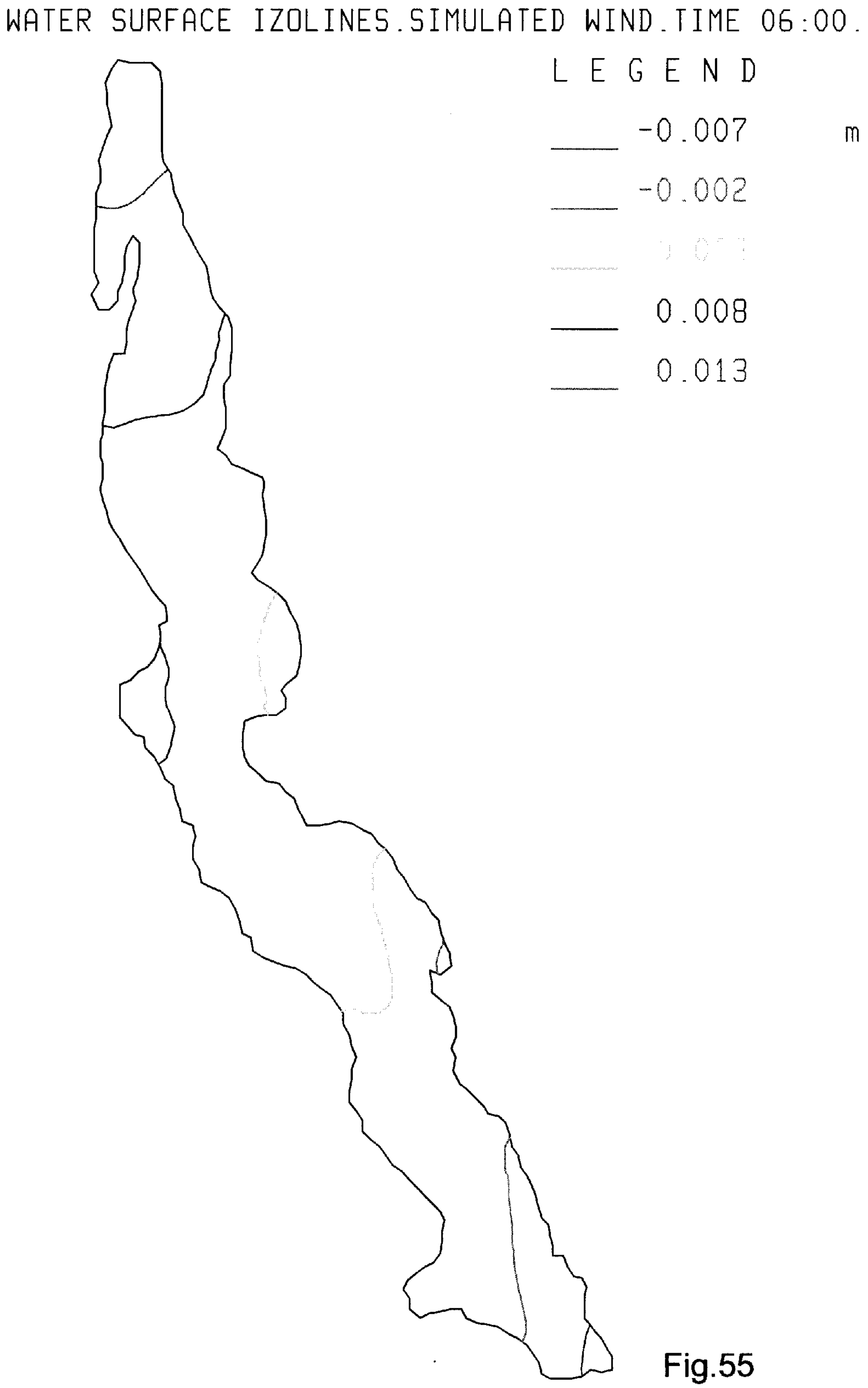

WATER SURFACE IZOLINES.SIMULATED WIND.TIME 06:00.
L E G E N D
-0.007 m
-0.002
0.008
0.013

Fig.55

WATER SURFACE IZOLINES.SIMULATED WIND.TIME 12:00.

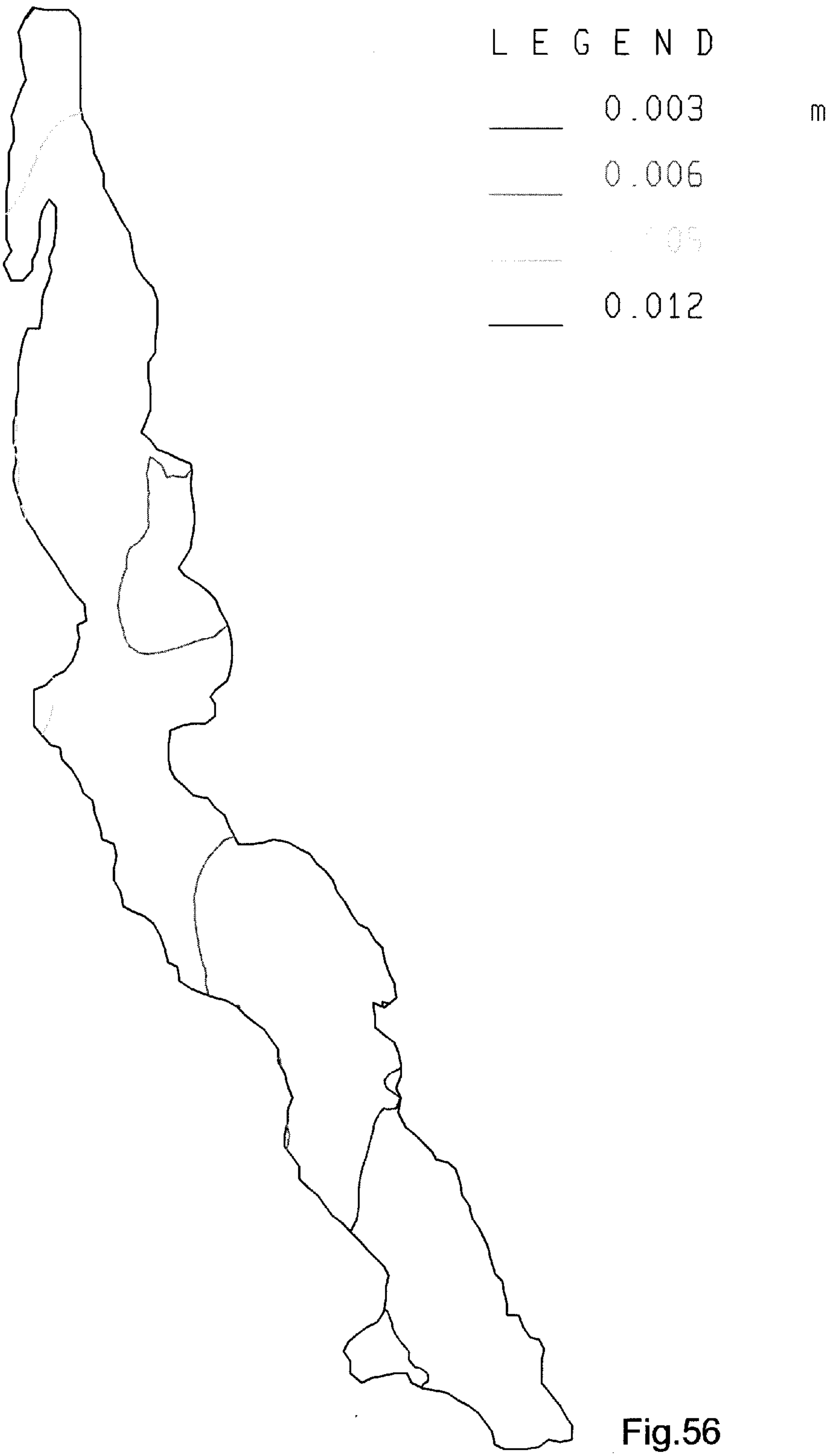


Fig.56

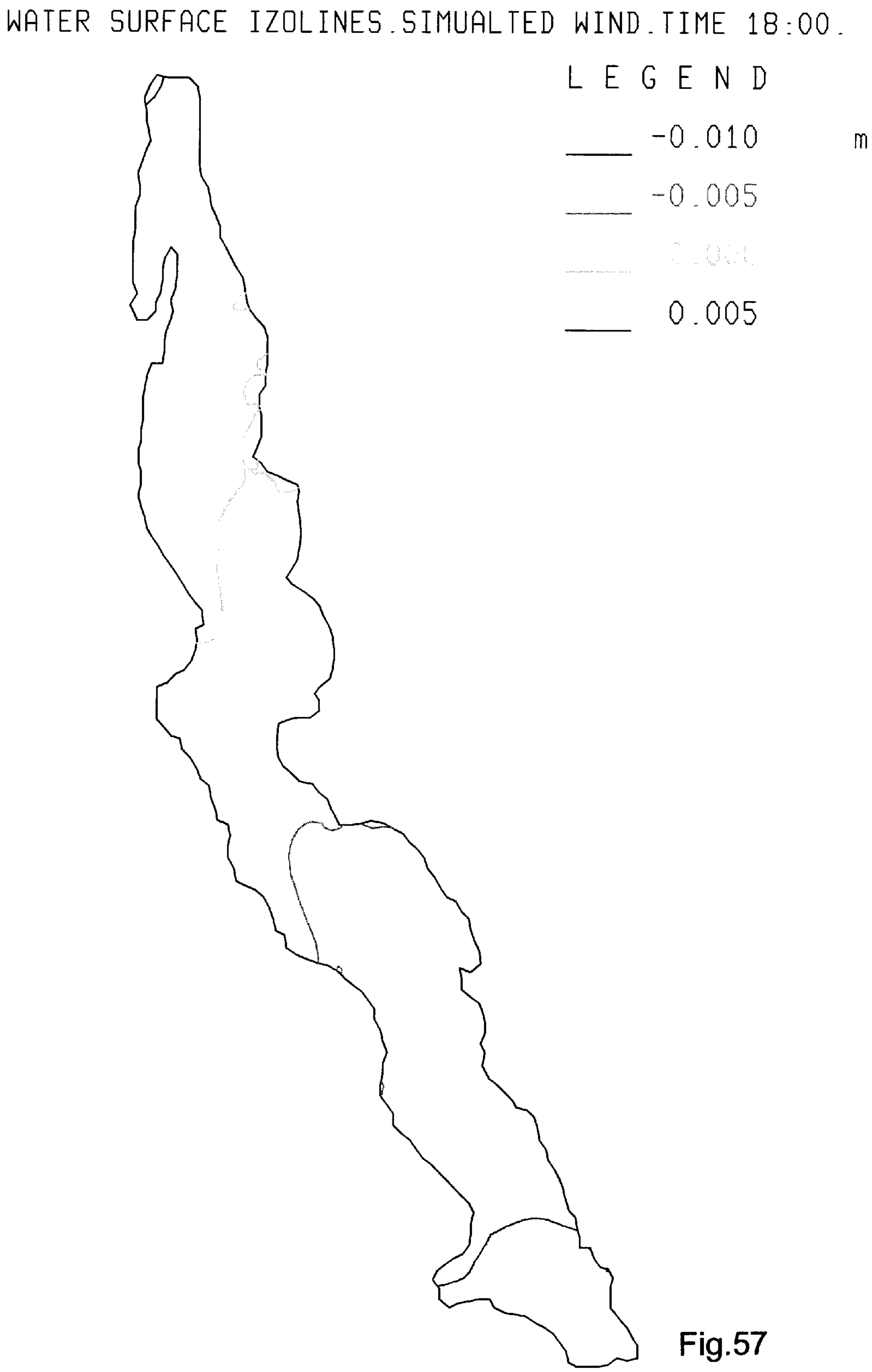

WATER SURFACE IZOLINES.SIMUALTED WIND.TIME 18:00.
L E G E N D
-0.010 m
-0.005
0.005

Fig.57

COLOUR MAP OF NEAR-SURFACE VERTICAL VELOCITY
TIME 00:00

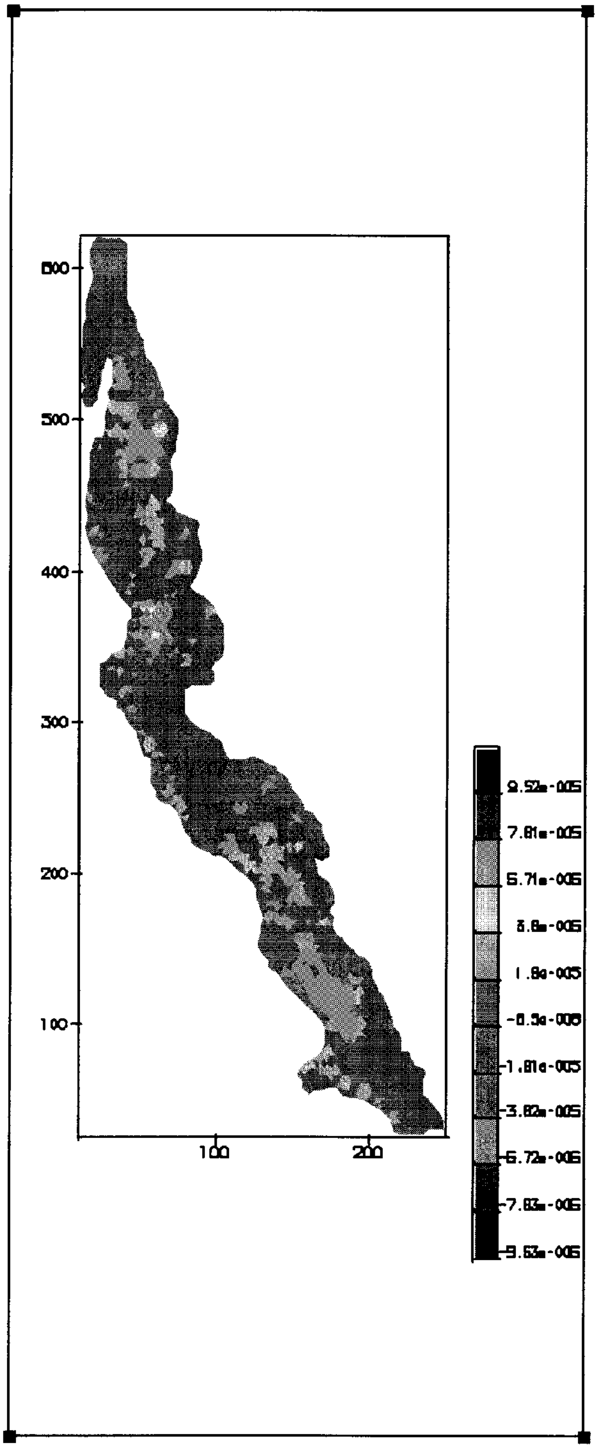


Fig.58

COLOUR MAP OF NEAR-SURFACE VERTICAL VELOCITY
TIME 06:00

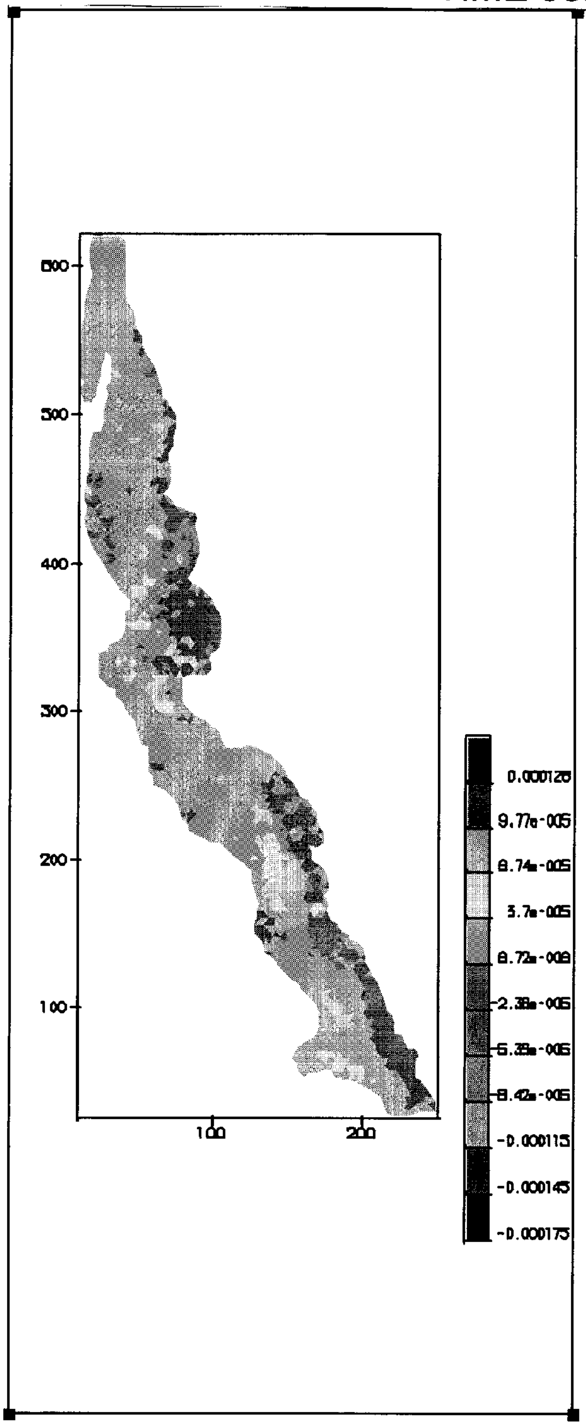


Fig.59

COLOUR MAP OF NEAR-SURFACE VERTICAL VELOCITY
TIME 12:00

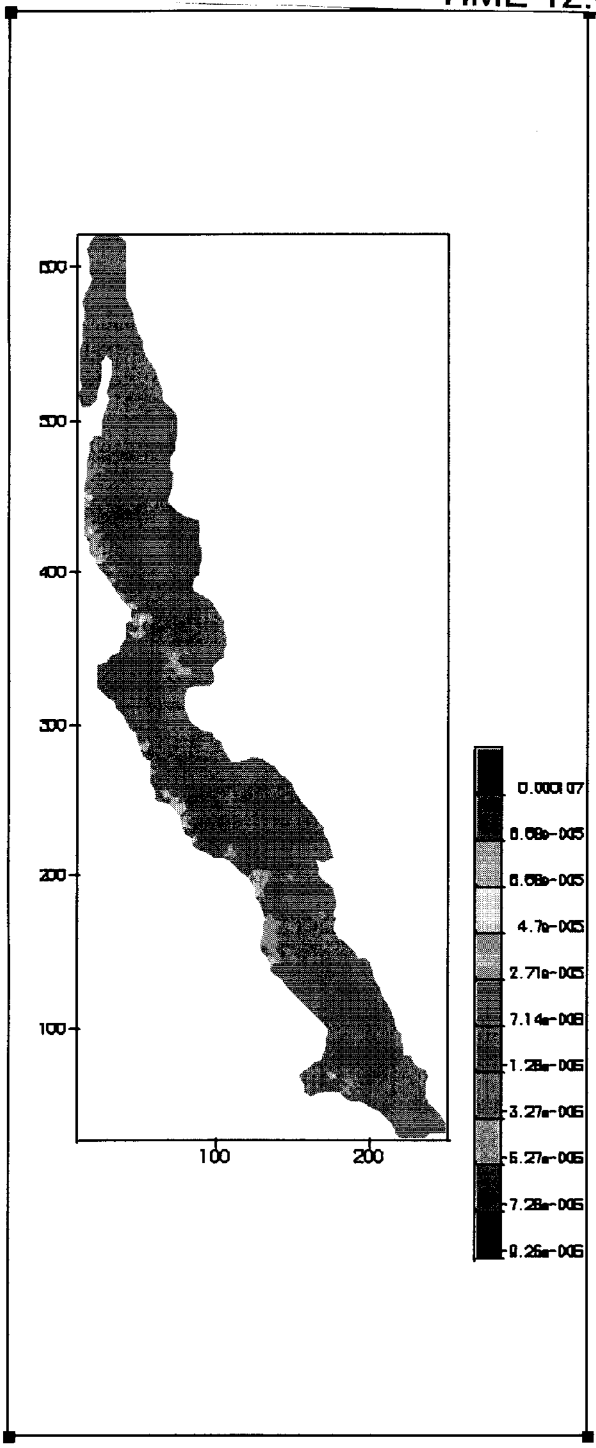


Fig.60

COLOUR MAP OF NEAR-SURFACE VERTICAL VELOCITY
TIME 18:00

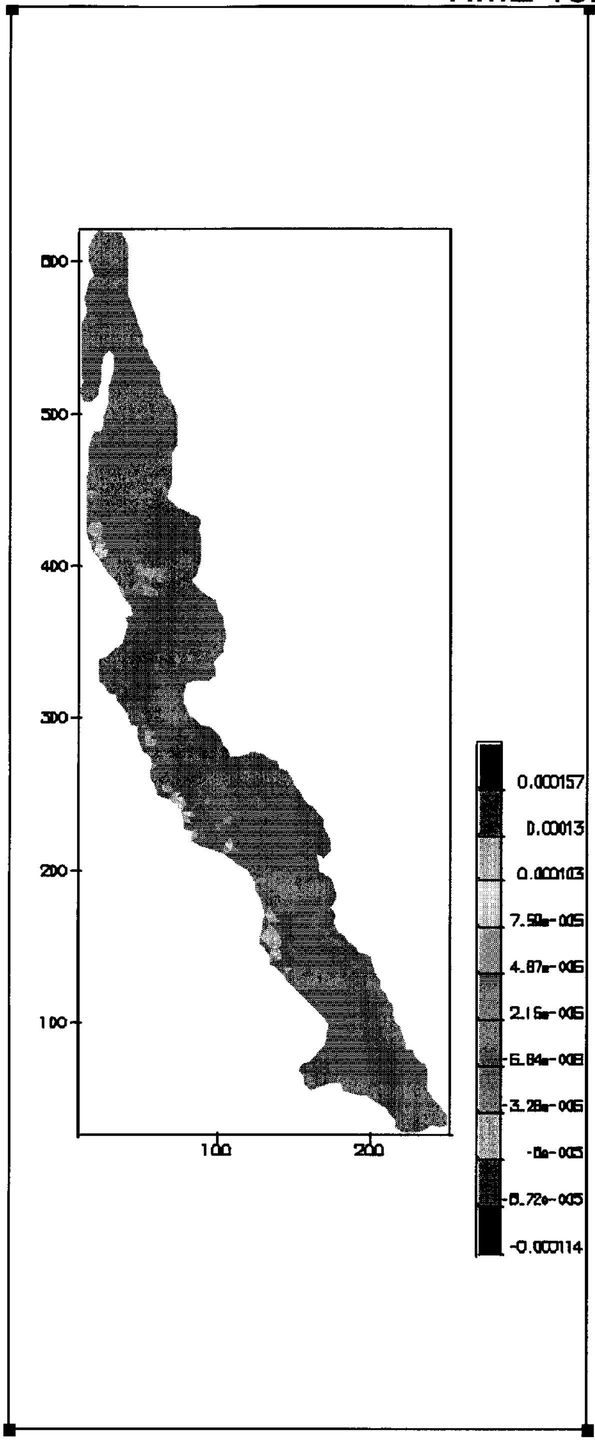


Fig.61

LAKE TANGANYIKA.SURFACE FLOW.NORTHERLY WIND 2 M/S.

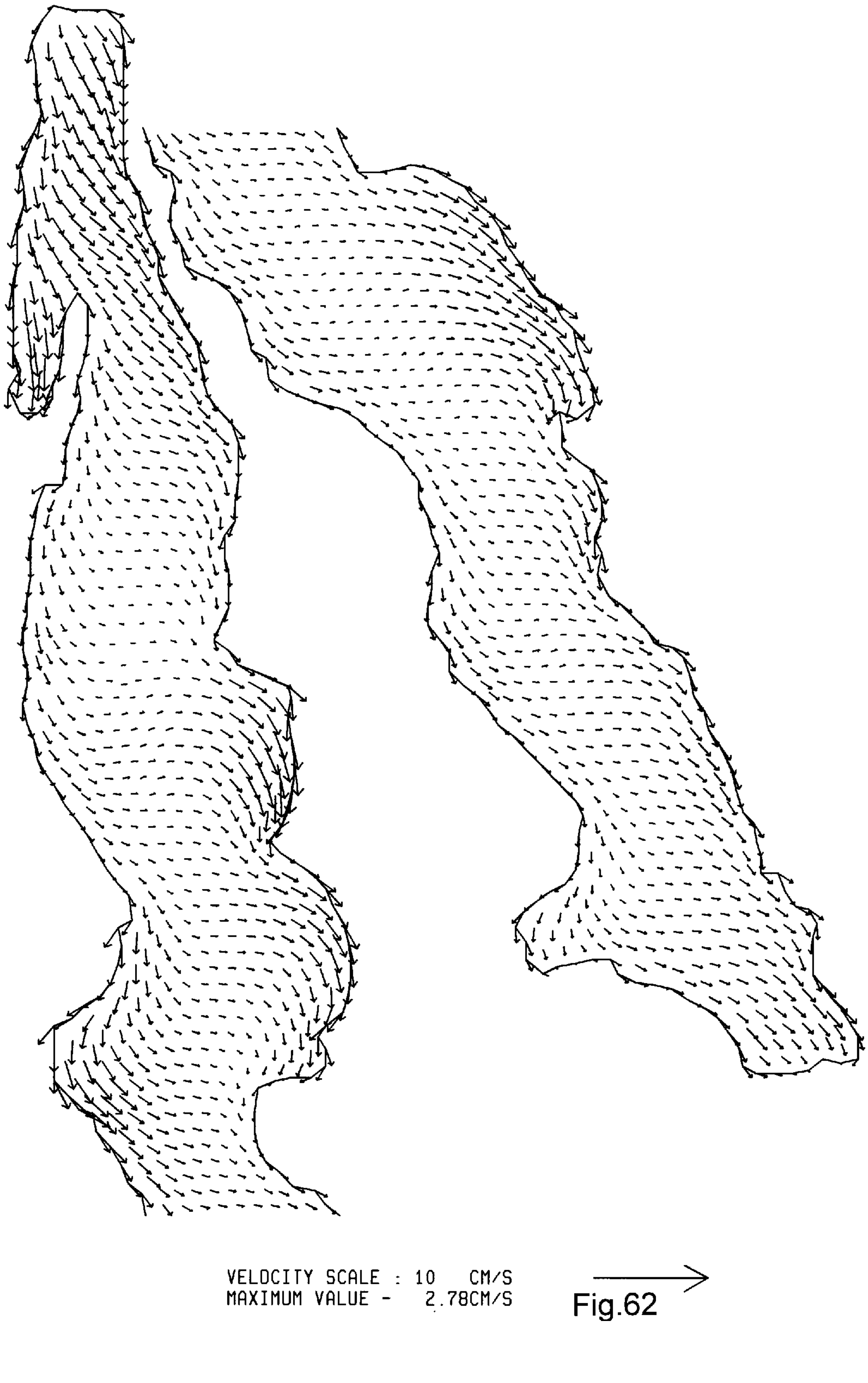


Fig.62

LAKE TANGANYIKA.SURFACE FLOW.NORTHERLY WIND 5 M/S.

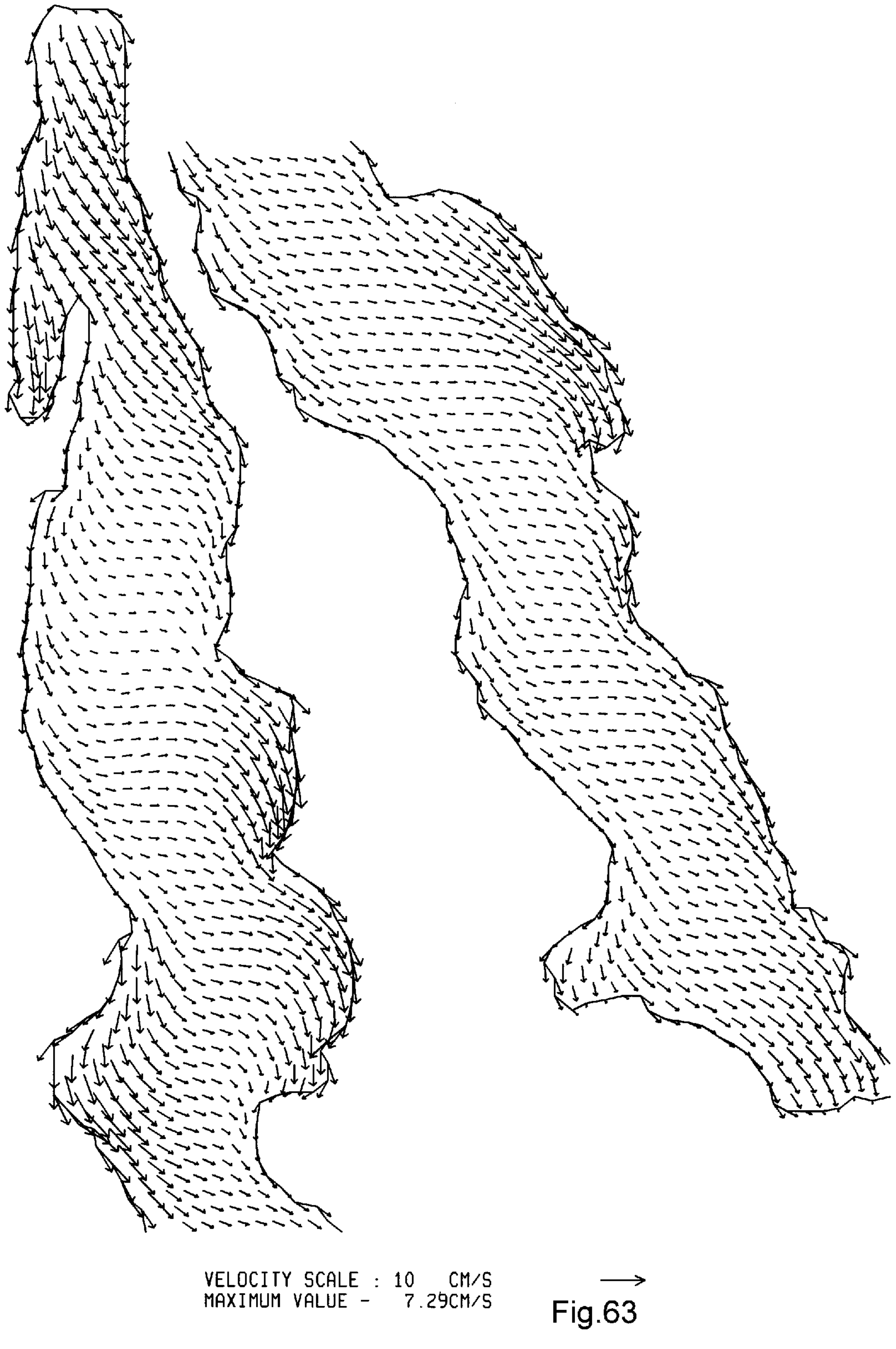


Fig.63

LAKE TANGANYIKA.SURFACE FLOW.NORTHERLY WIND 8 M/S.

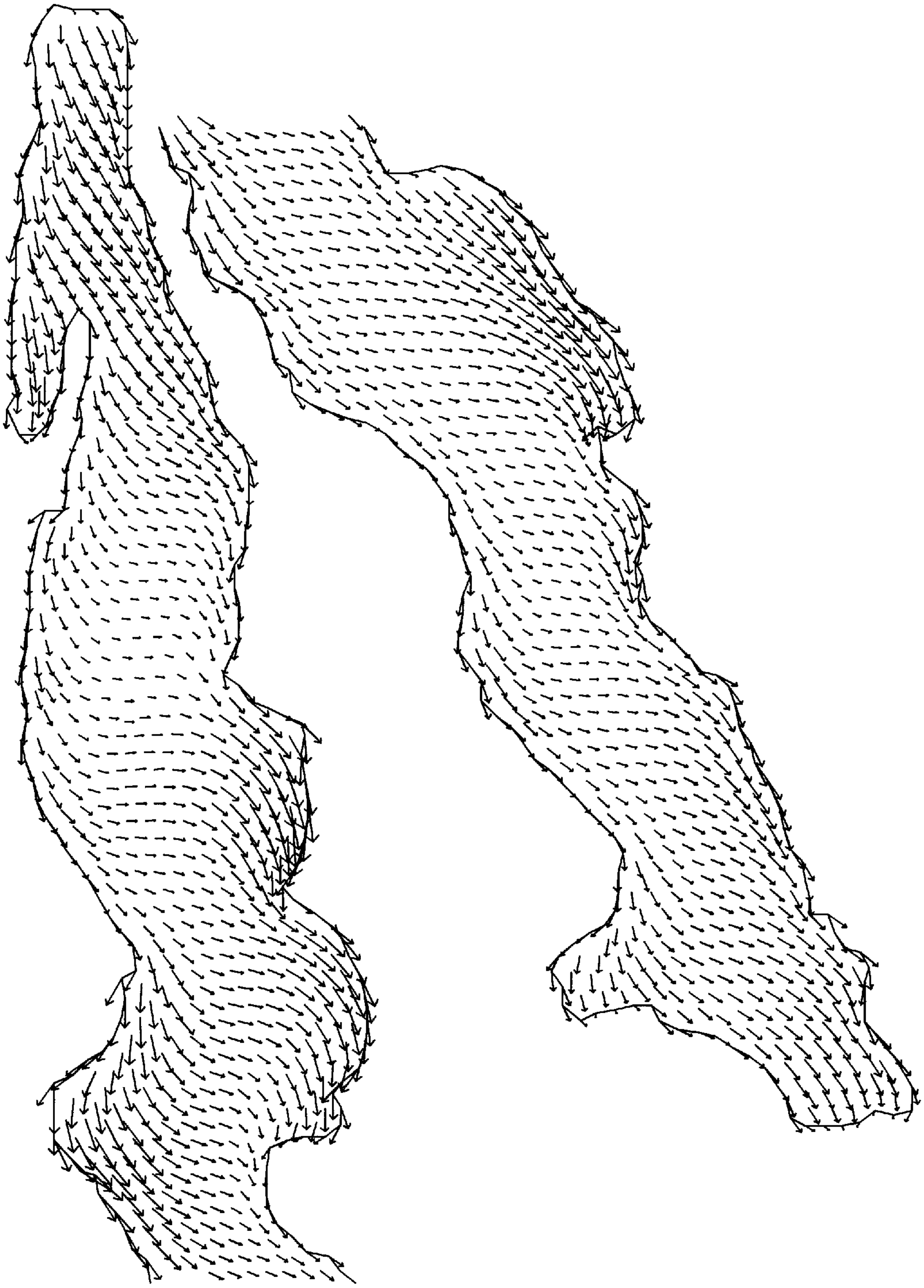


Fig.64

LAKE TANGANYIKA.SURFACE FLOW.NORTH-EASTERLY WIND 2 M/S.

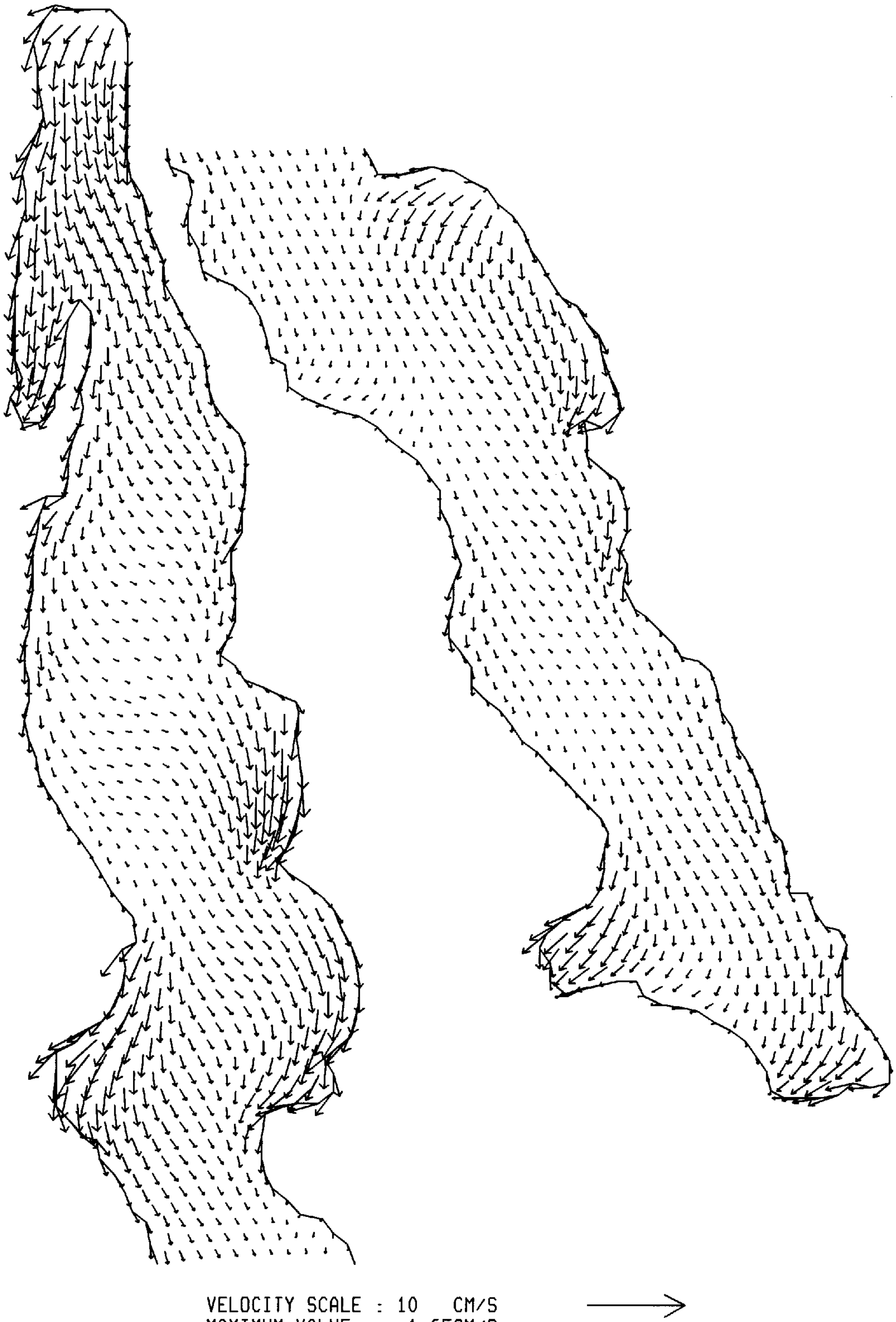
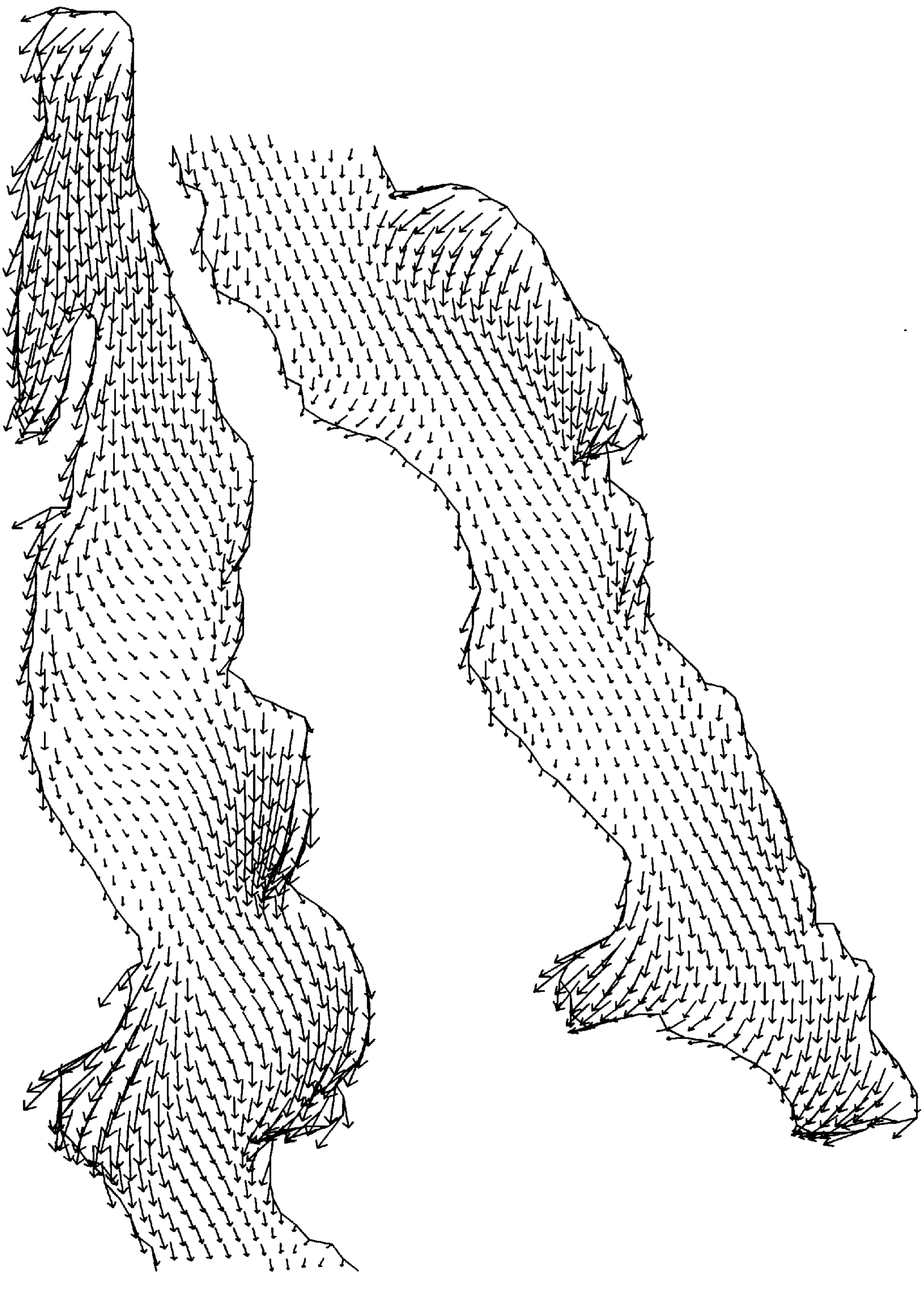


Fig.65

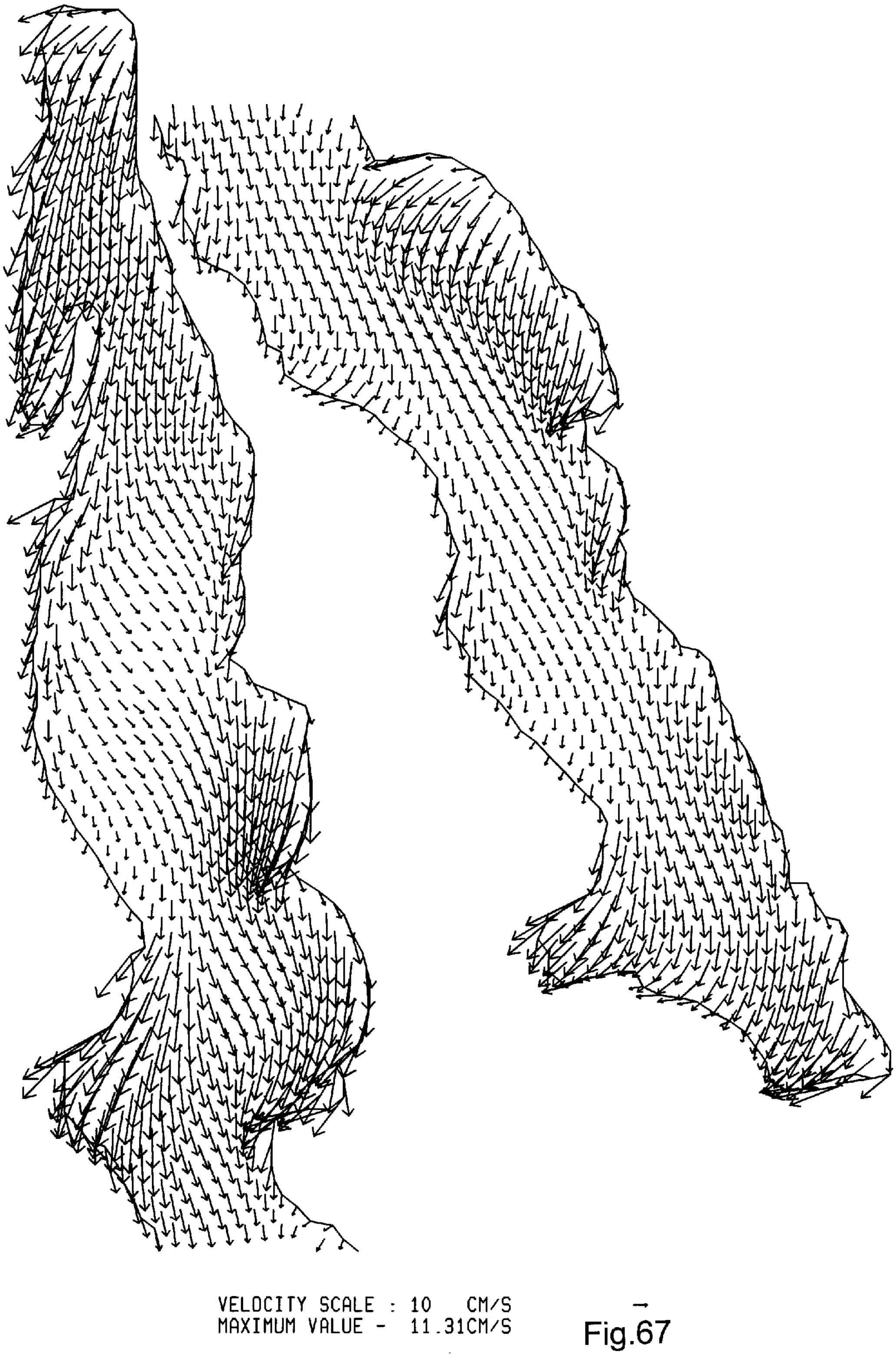
LAKE TANGANYIKA.SURFACE FLOW.NORTH-EASTERLY WIND 5 M/S



VELOCITY SCALE : 10 CM/S
MAXIMUM VALUE - 5.80CM/S

Fig.66

LAKE TANGANYIKA.SURFACE FLOW.NORTH-EASTERLY WIND 8 M/S.



VELOCITY SCALE : 10 CM/S
MAXIMUM VALUE - 11.31CM/S

Fig.67

LAKE TANGANYIKA.SURFACE FLOW.EASTERLY WIND 2 M/S.

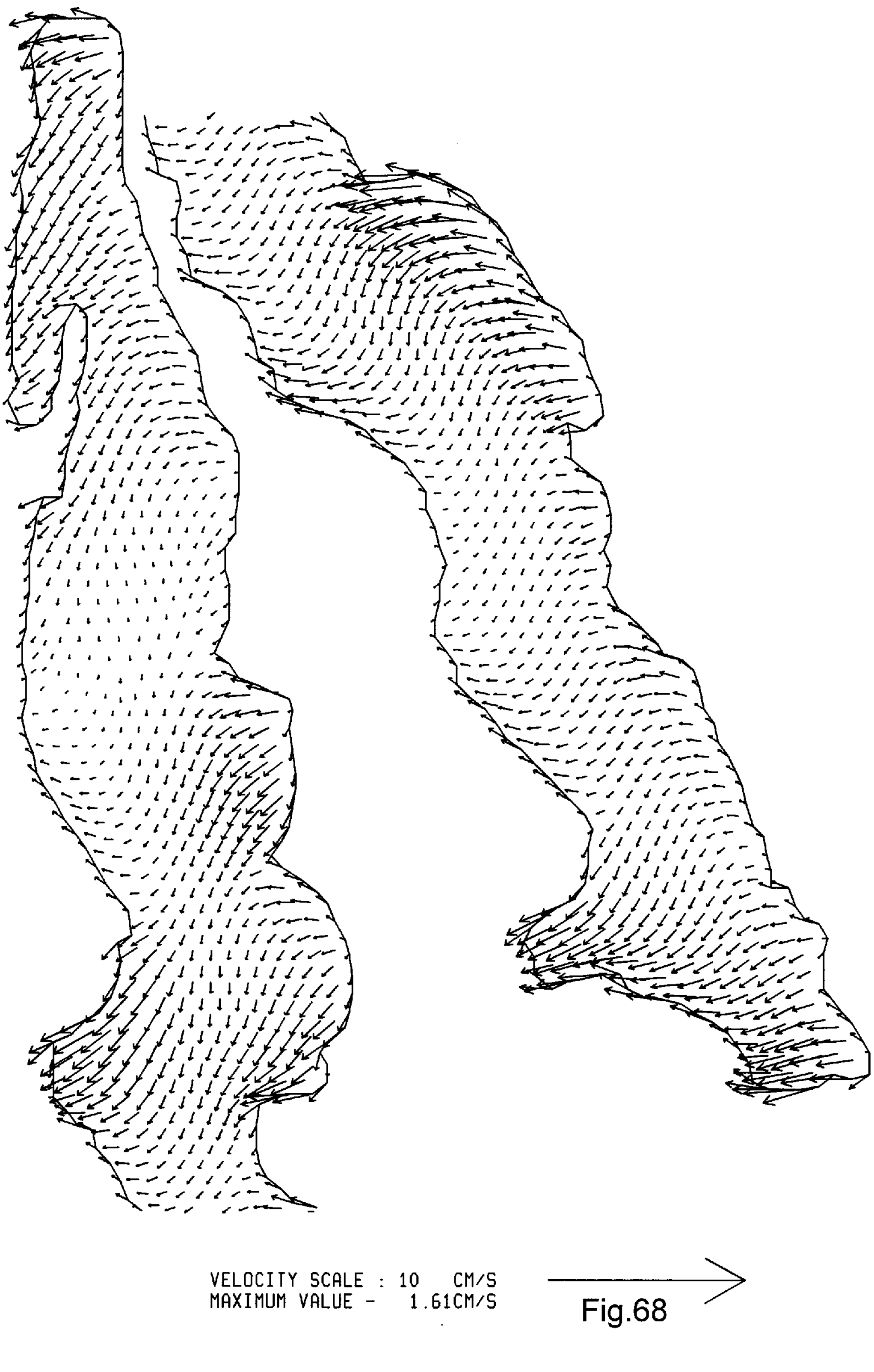
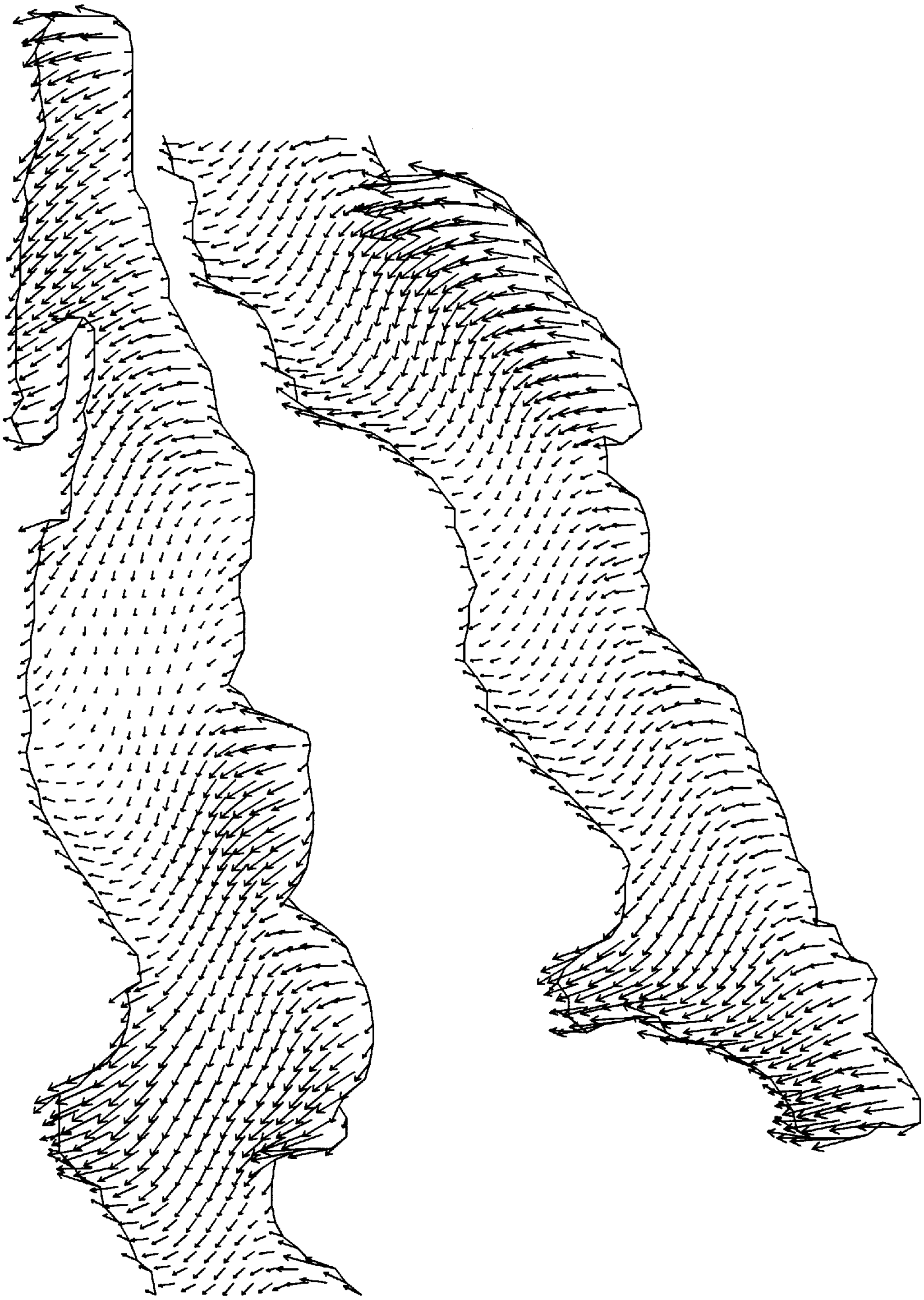


Fig.68

LAKE TANGANYIKA.SURFACE FLOW.EASTERLY WIND 5 M/S.



VELOCITY SCALE : 10 CM/S
MAXIMUM VALUE - 5.42CM/S

Fig.69

LAKE TANGANYIKA.SURFACE FLOW.EASTERLY WIND 8 M/S.

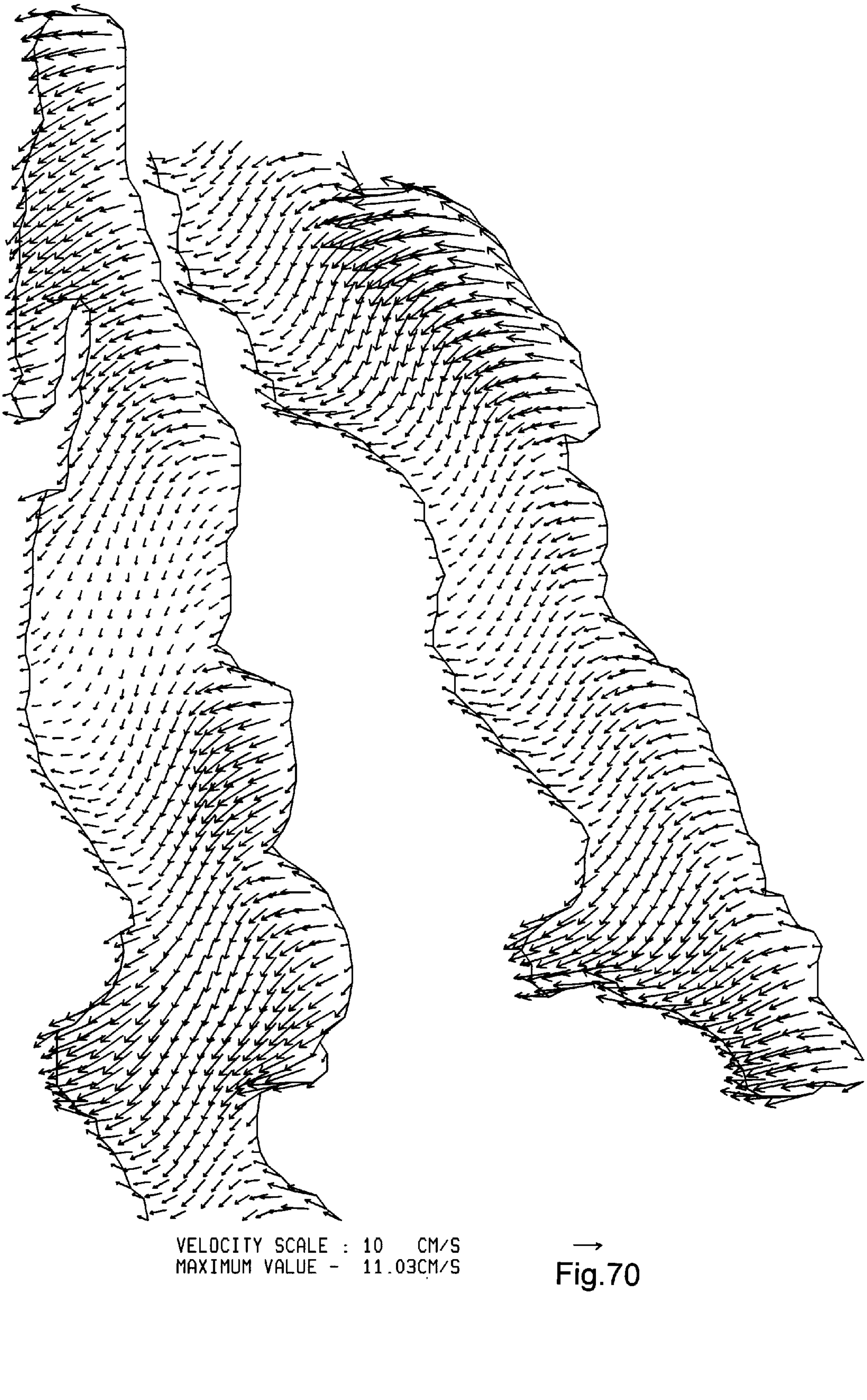
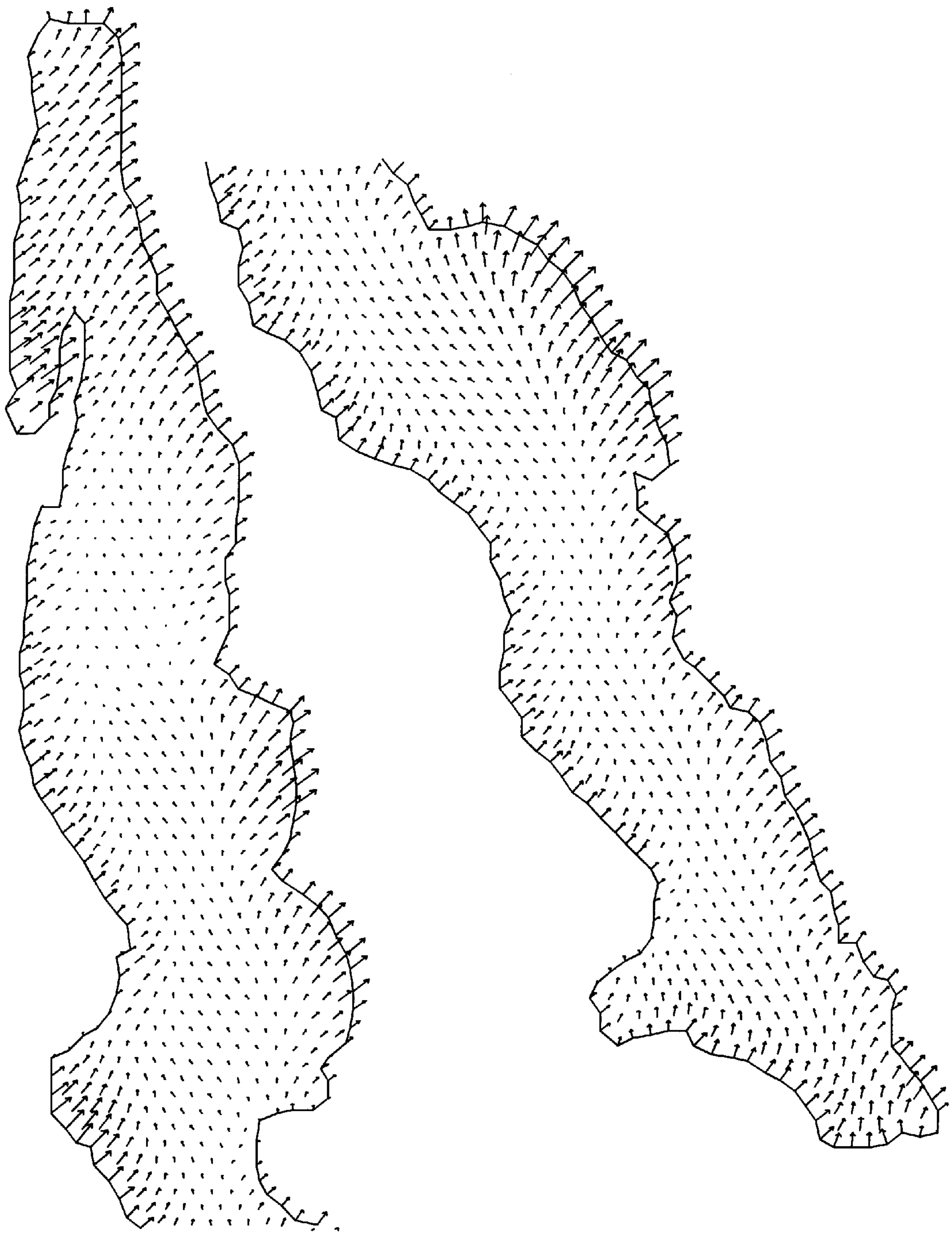


Fig.70

LAKE TANGANYIKA.SURFACE FLOW.SOUTH-EASTERLY WIND 2 M/S.



·VELOCITY SCALE : 10 CM/S
MAXIMUM VALUE - 2 93CM/S

Fig.71

LAKE TANGANYIKA.SURFACE FLOW.SOUTH-EASTERLY WIND 5 M/S.

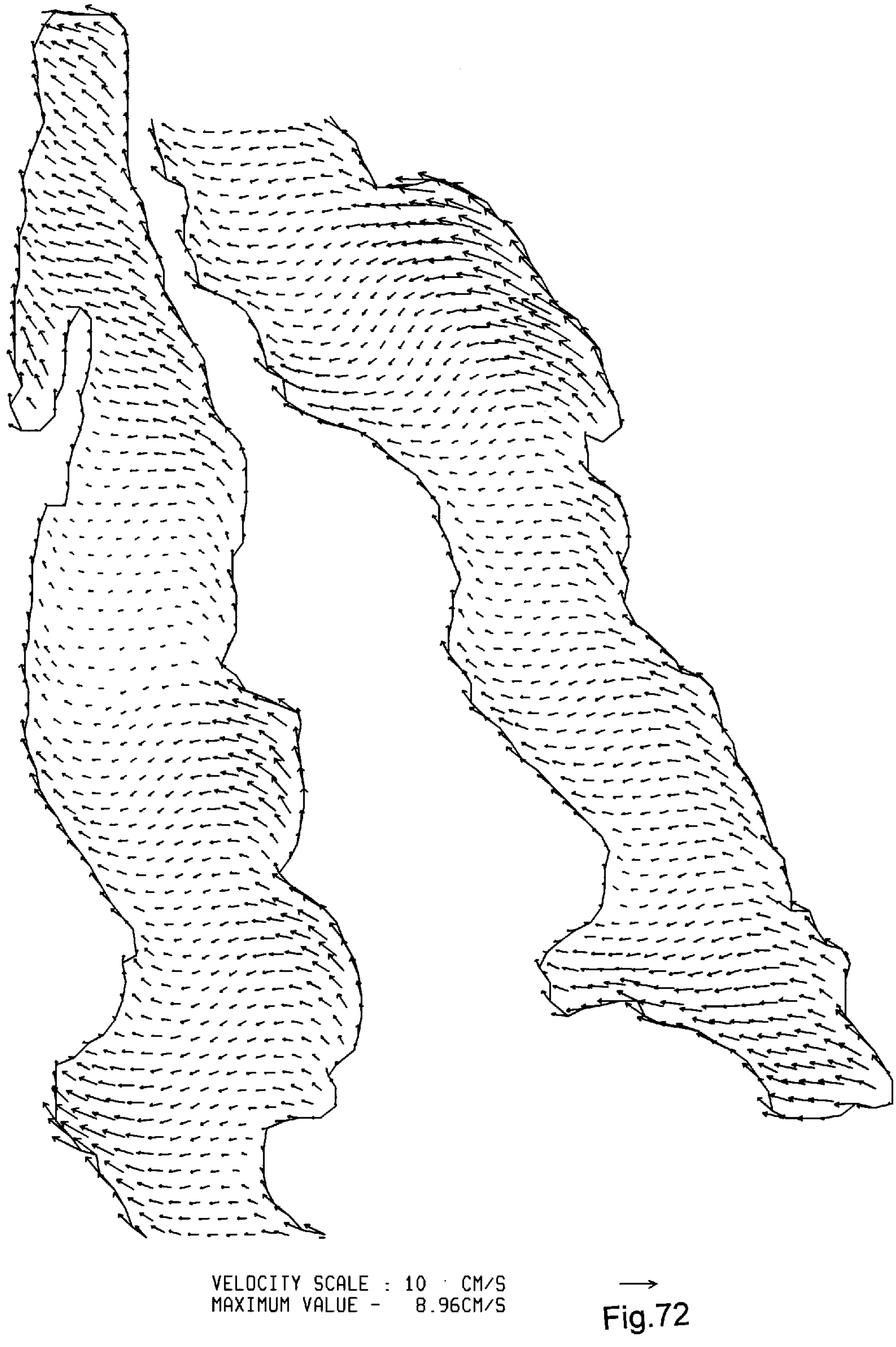
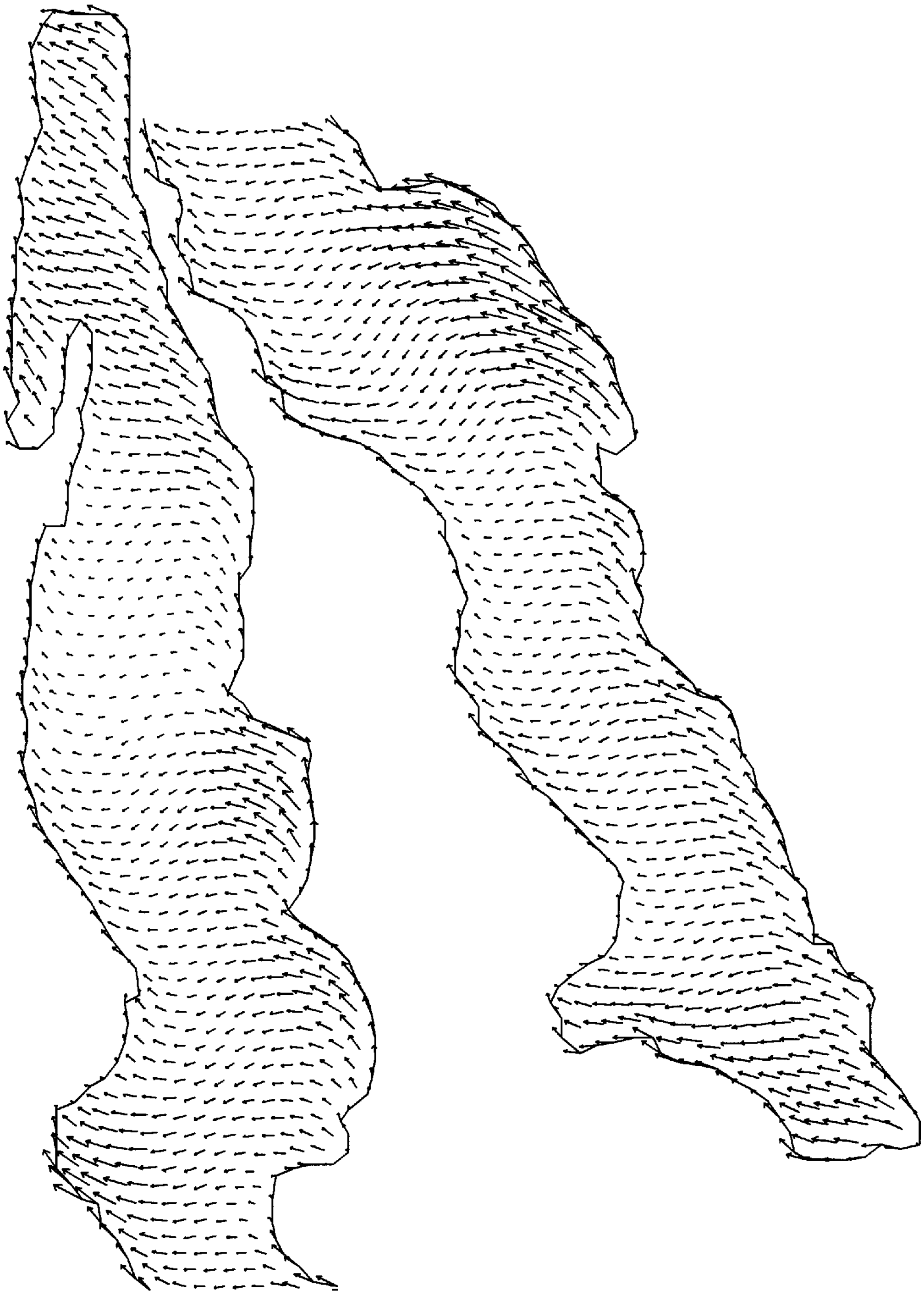


Fig.72

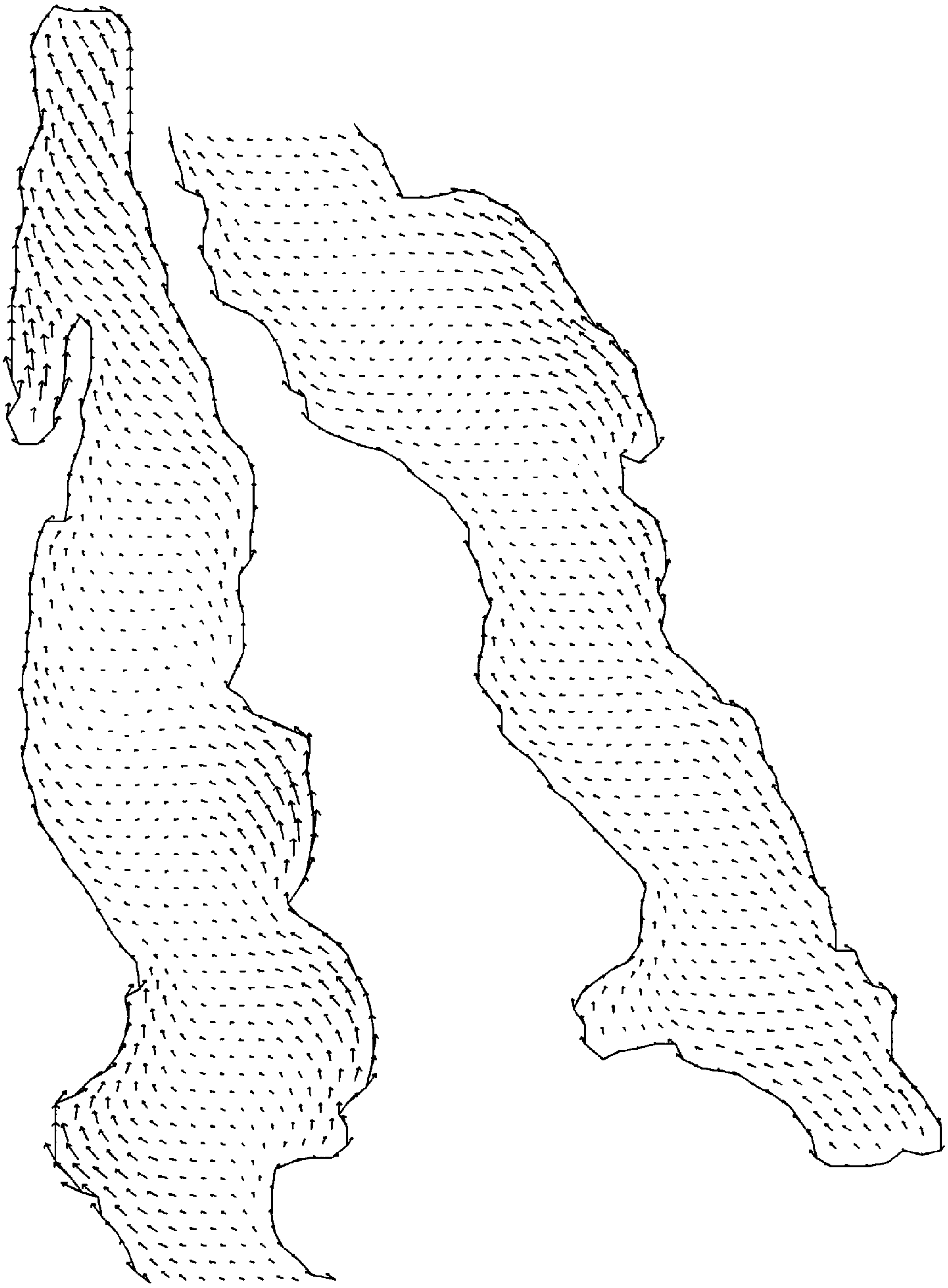
LAKE TANGANYIKA.SURFACE FLOW.SOUTH-EASTERLY WIND 8 M/S.



VELOCITY SCALE : 10 CM/S →
MAXIMUM VALUE - 16.93CM/S

Fig.73

LAKE TANGANYIKA.SURFACE FLOW.SOUTHERLY WIND 2 M/S.



VELOCITY SCALE : 10 CM/S
MAXIMUM VALUE - 2.81CM/S

Fig.74

LAKE TANGANYIKA.SURFACE FLOW.SOUTHERLY WIND 5 M/S.

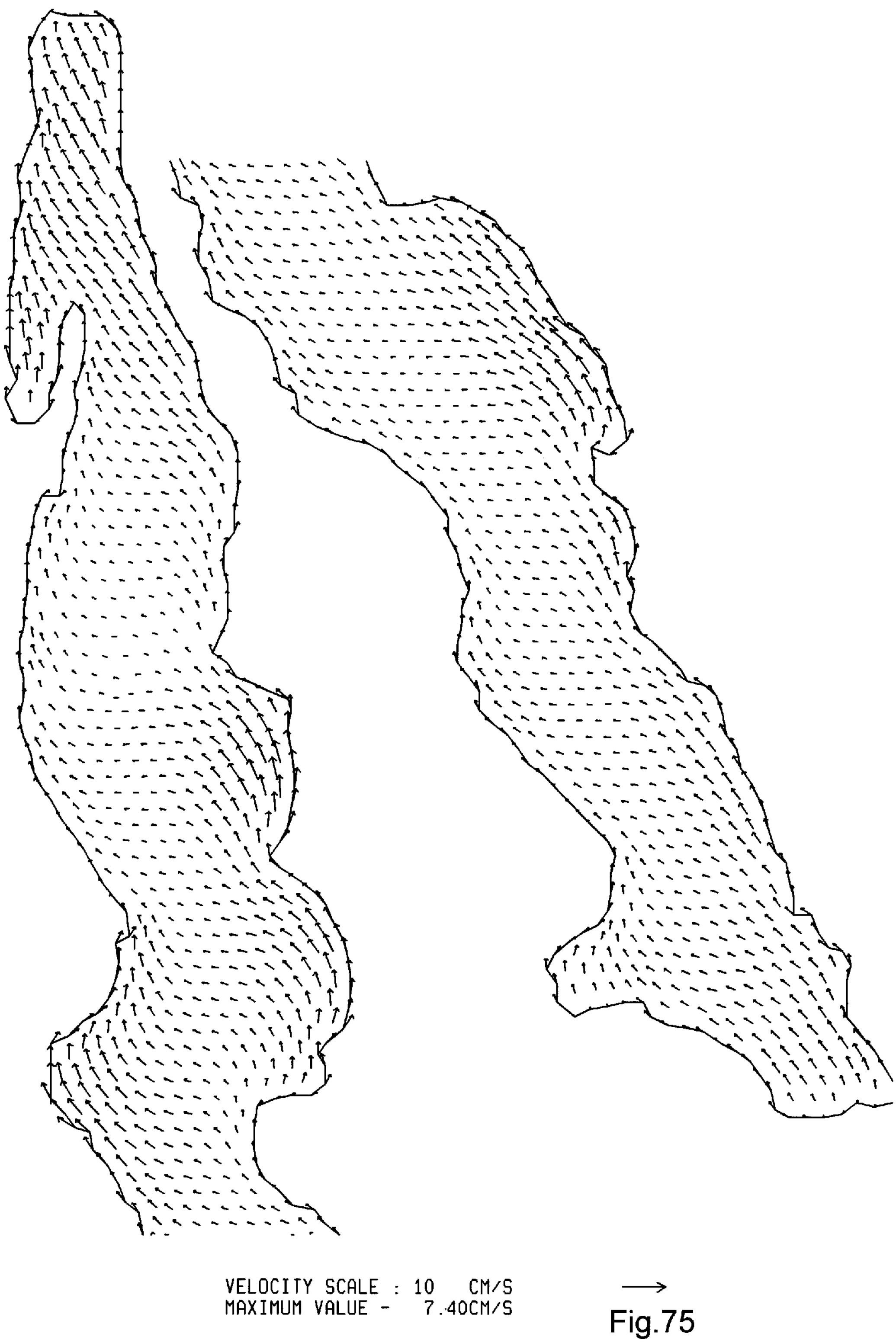
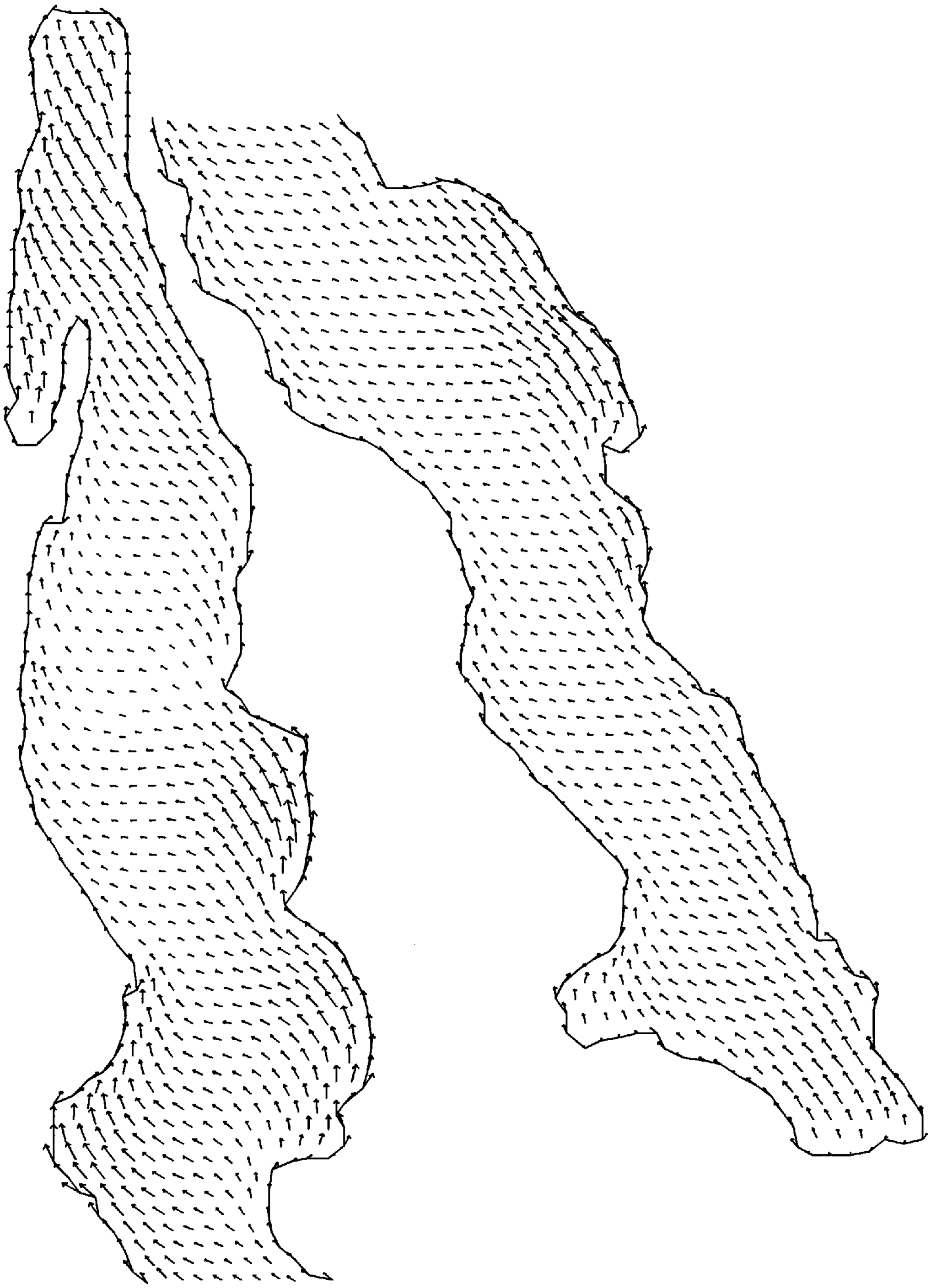


Fig.75

LAKE TANGANYIKA.SURFACE FLOW.SOUTHERLY WIND 8 M/S.



VELOCITY SCALE : 10 CM/S →
MAXIMUM VALUE - 14.63CM/S

Fig.76

LAKE TANGANYIKA.SURFACE FLOW.SOUTH-WESTERLY WIND 2 M/S.

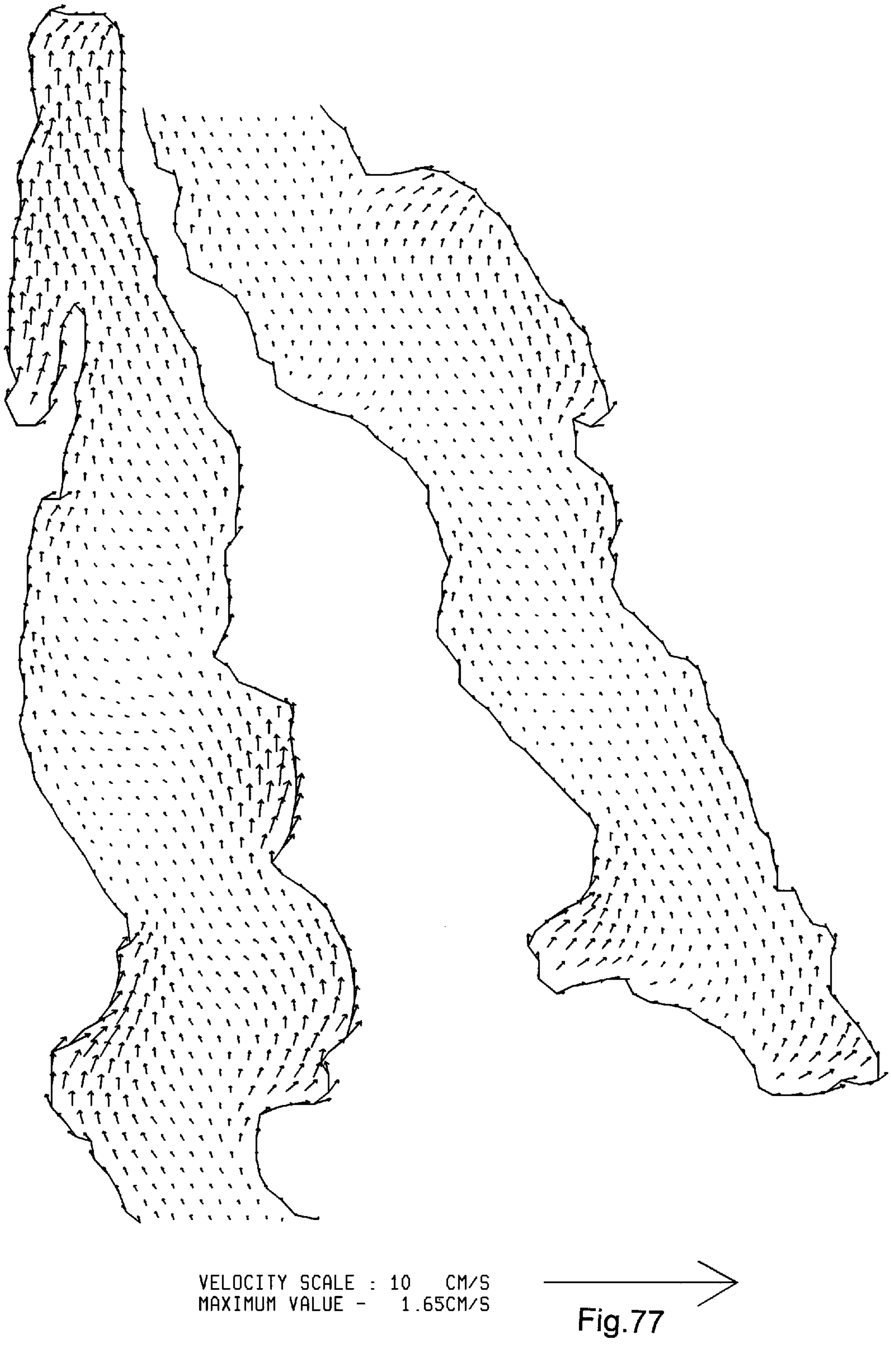


Fig.77

LAKE TANGANYIKA.SURFACE FLOW.SOUTH-WESTERLY WIND 5 M/S.

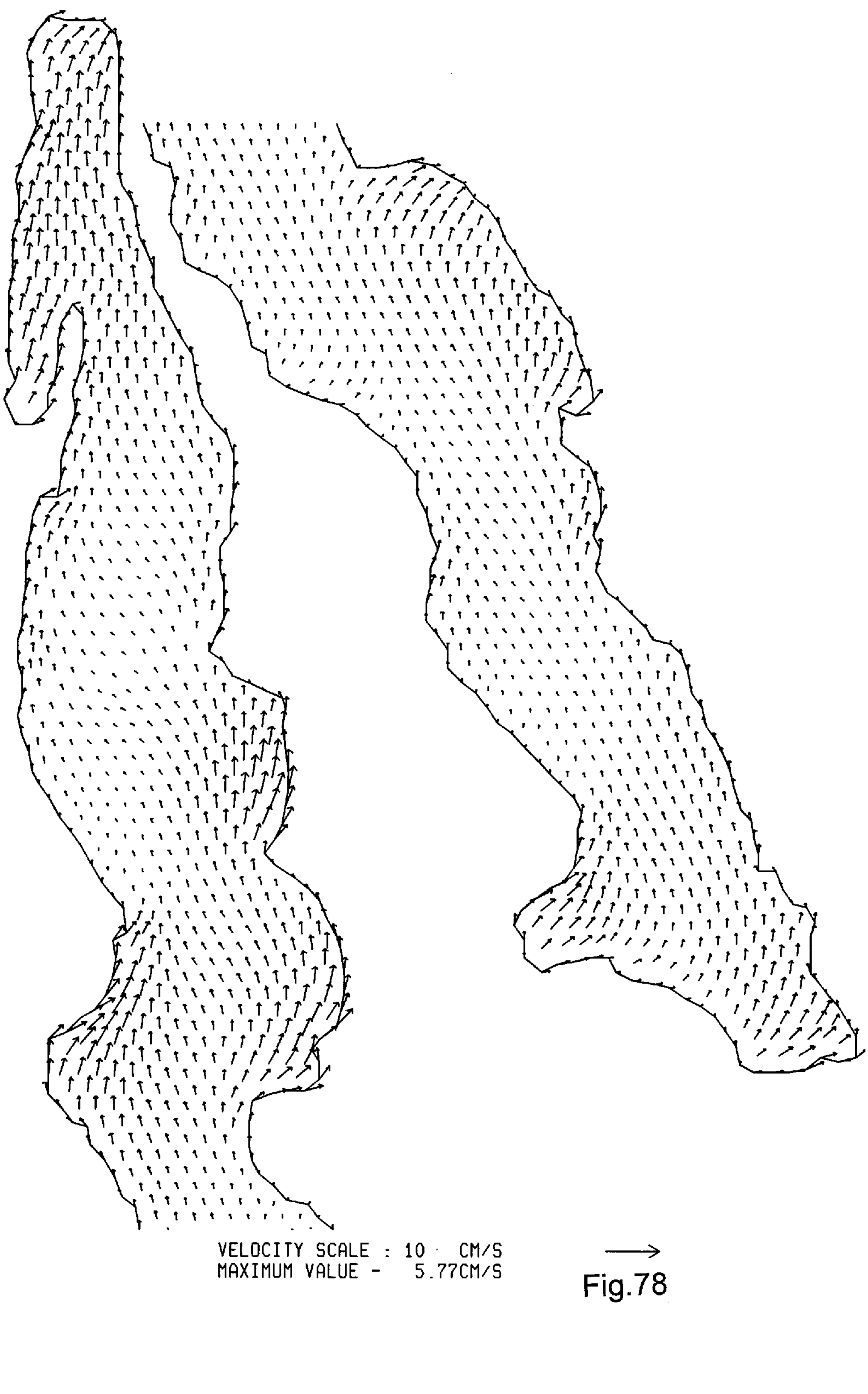


Fig.78

LAKE TANGANYIKA.SURFACE FLOW.SOUTH-WESTERLY WIND 8 M/S.

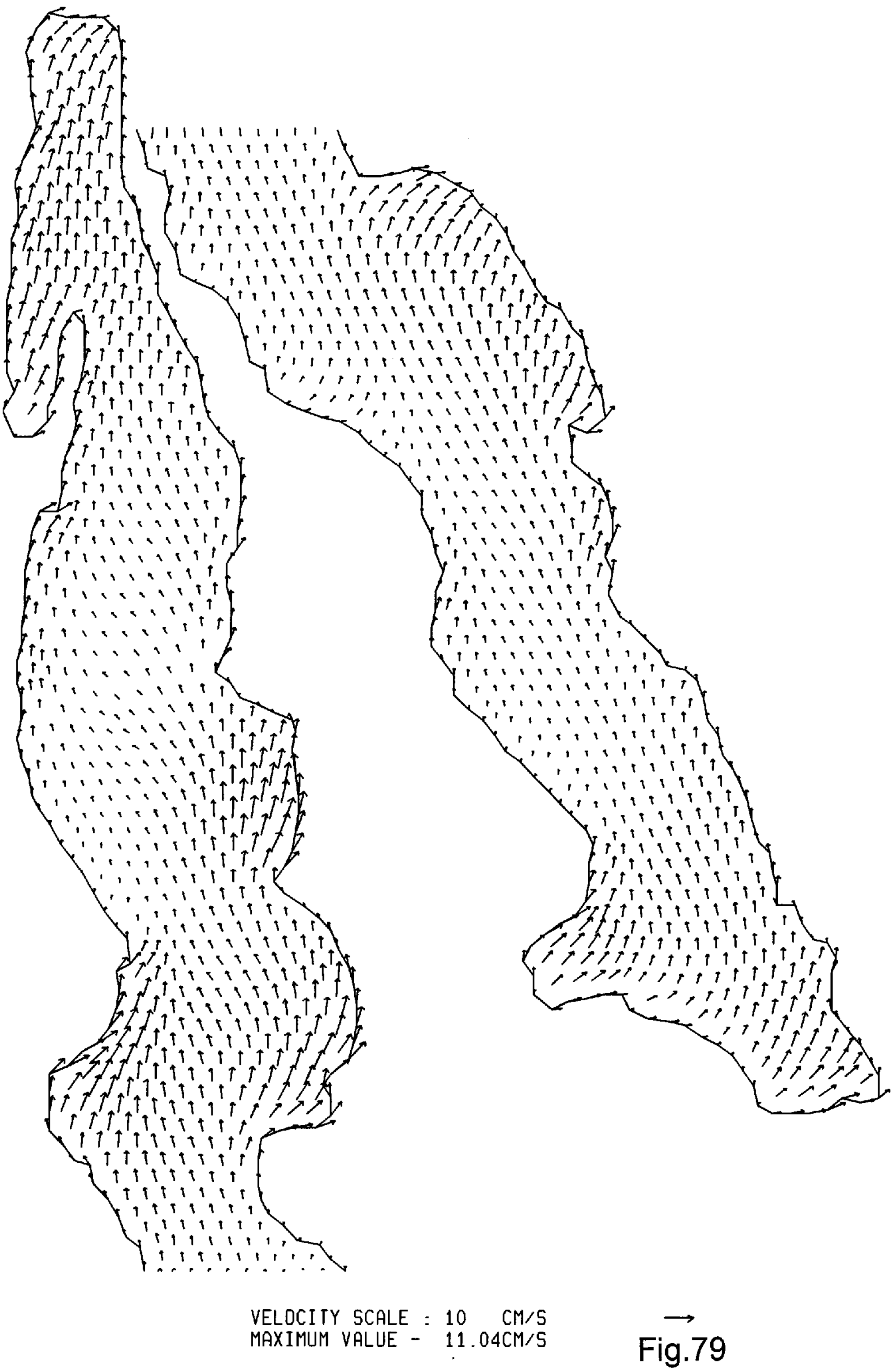


Fig.79

LAKE TANGANYIKA.SURFACE FLOW.WESTERLY WIND 2 M/S.

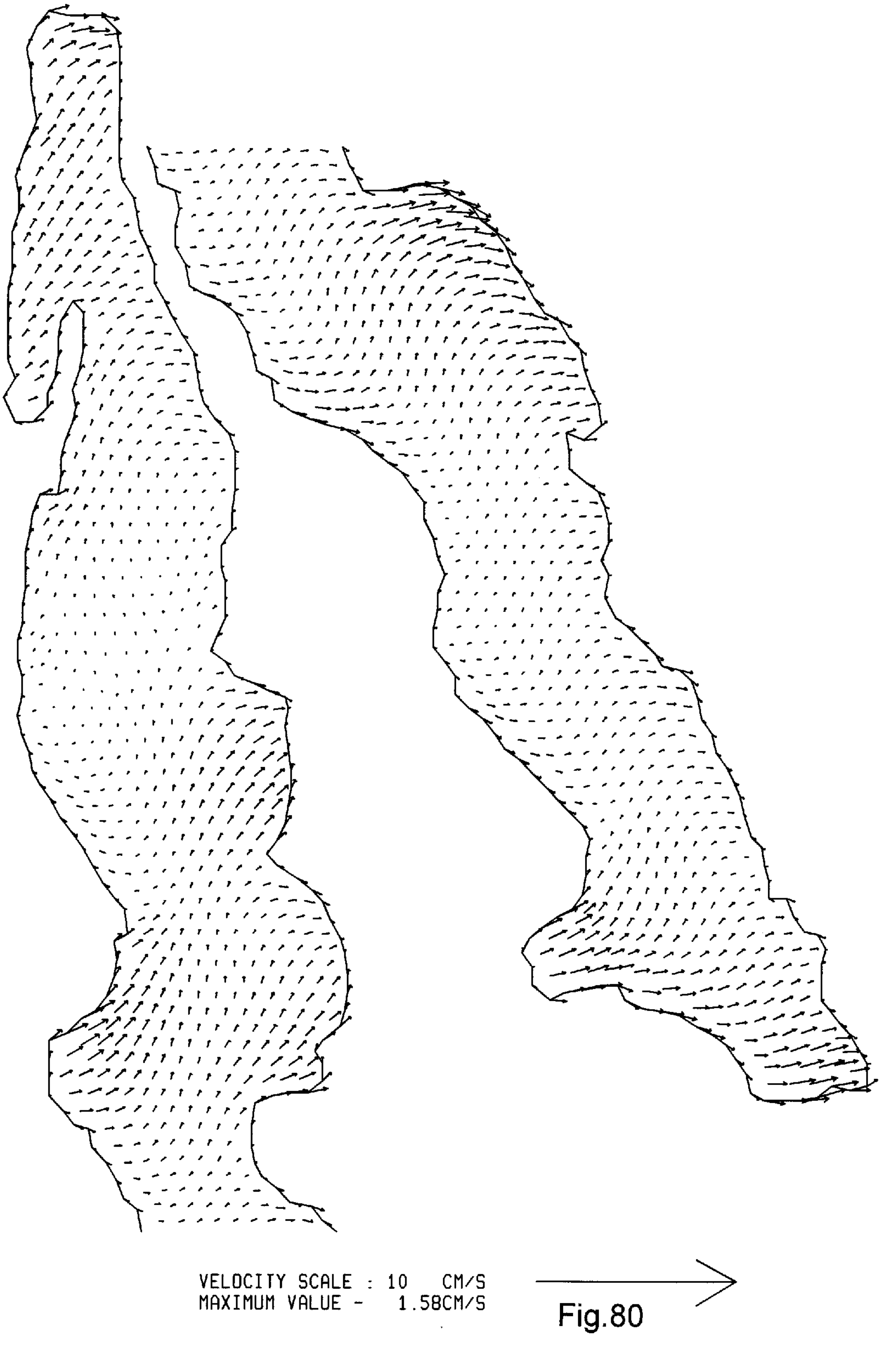
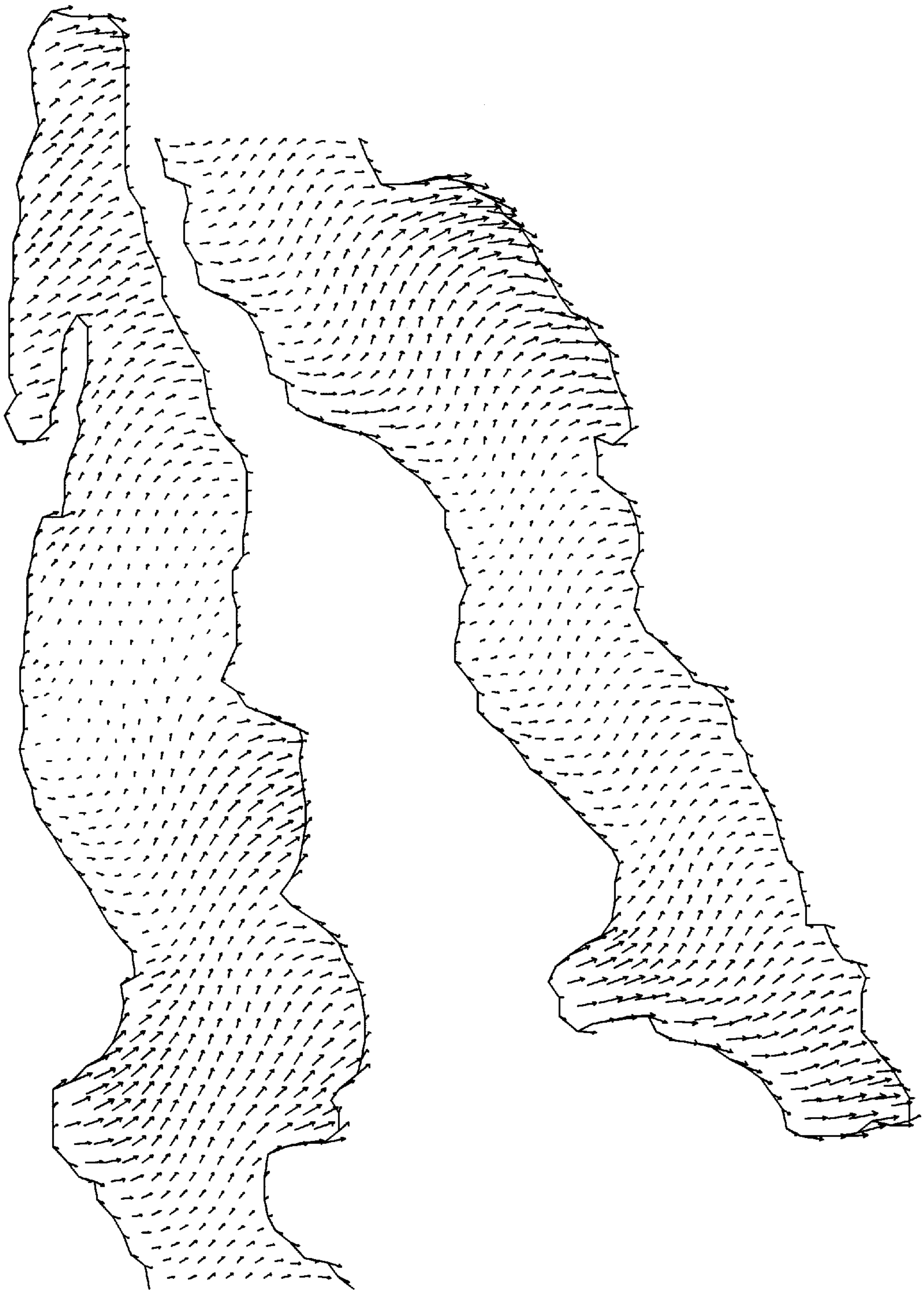


Fig.80

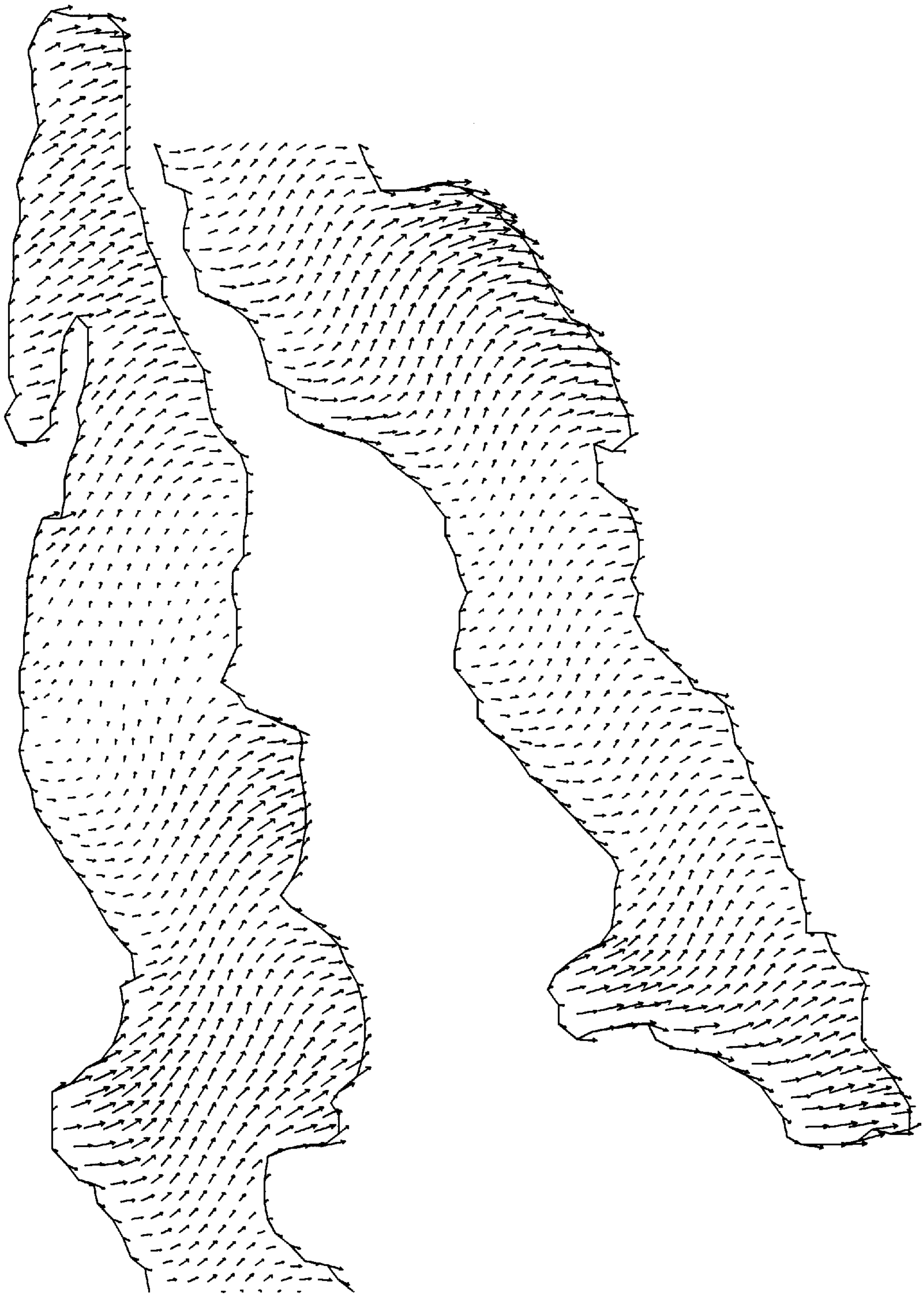
LAKE TANGANYIKA.SURFACE FLOW.WESTERLY WIND 5 M/S.



VELOCITY SCALE : 10 CM/S
MAXIMUM VALUE - 5.28CM/S

Fig.81

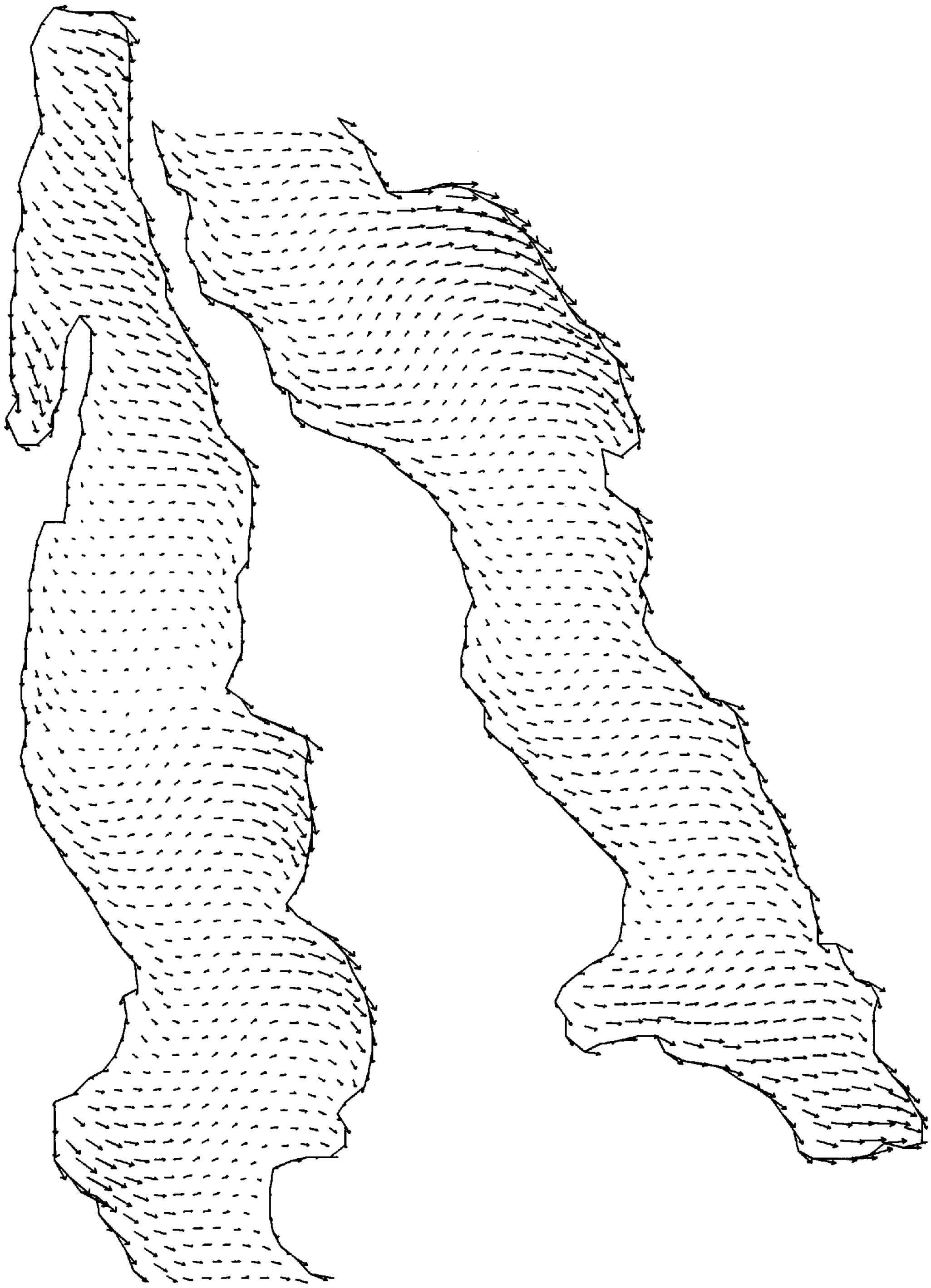
LAKE TANGANYIKA.SURFACE FLOW.WESTERLY WIND 8 M/S.



VELOCITY SCALE : 10 CM/S
MAXIMUM VALUE - 10.29CM/S

Fig.82

LAKE TANGANYIKA.NORTH-WESTERLY WIND 2 M/S.



VELOCITY SCALE : 10 CM/S
MAXIMUM VALUE - 2.35CM/S

Fig.83

LAKE TANGANYIKA.SURFACE FLOW.NORTH-WESTERLY WIND 5 M/S.

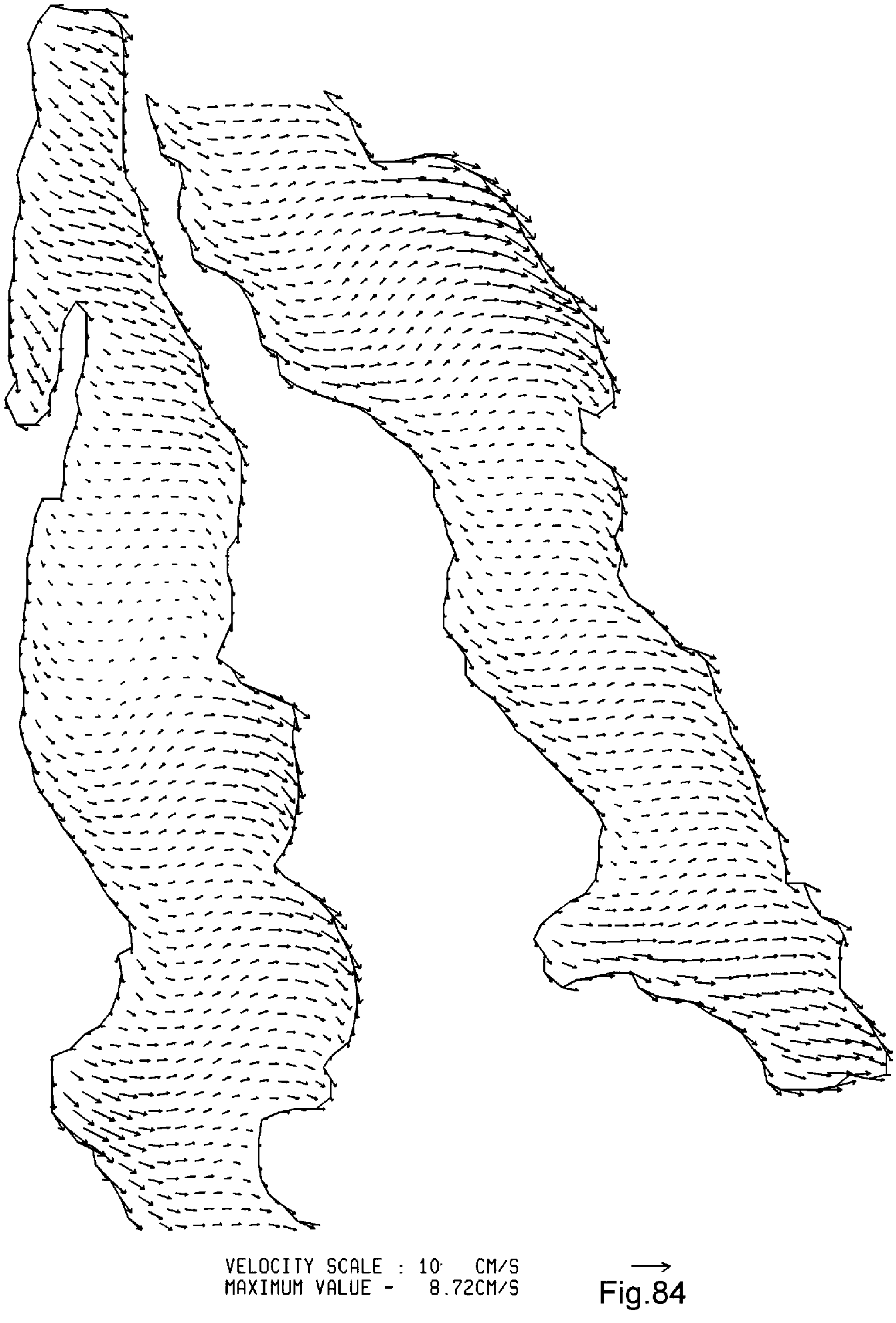


Fig.84

LAKE TANGANYIKA.SURFACE FLOW.NORTH-WESTERLY WIND 8 M/S

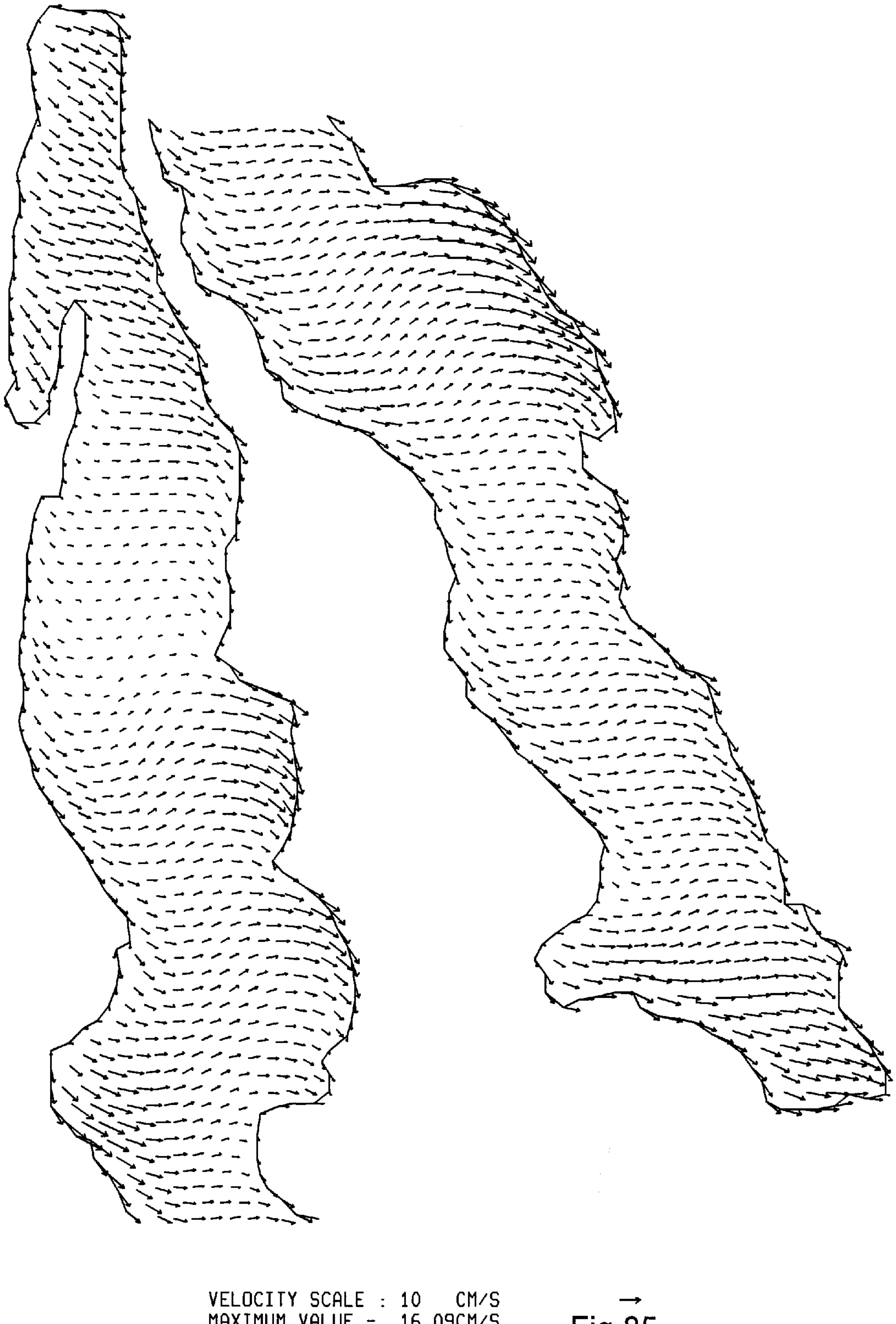


Fig.85

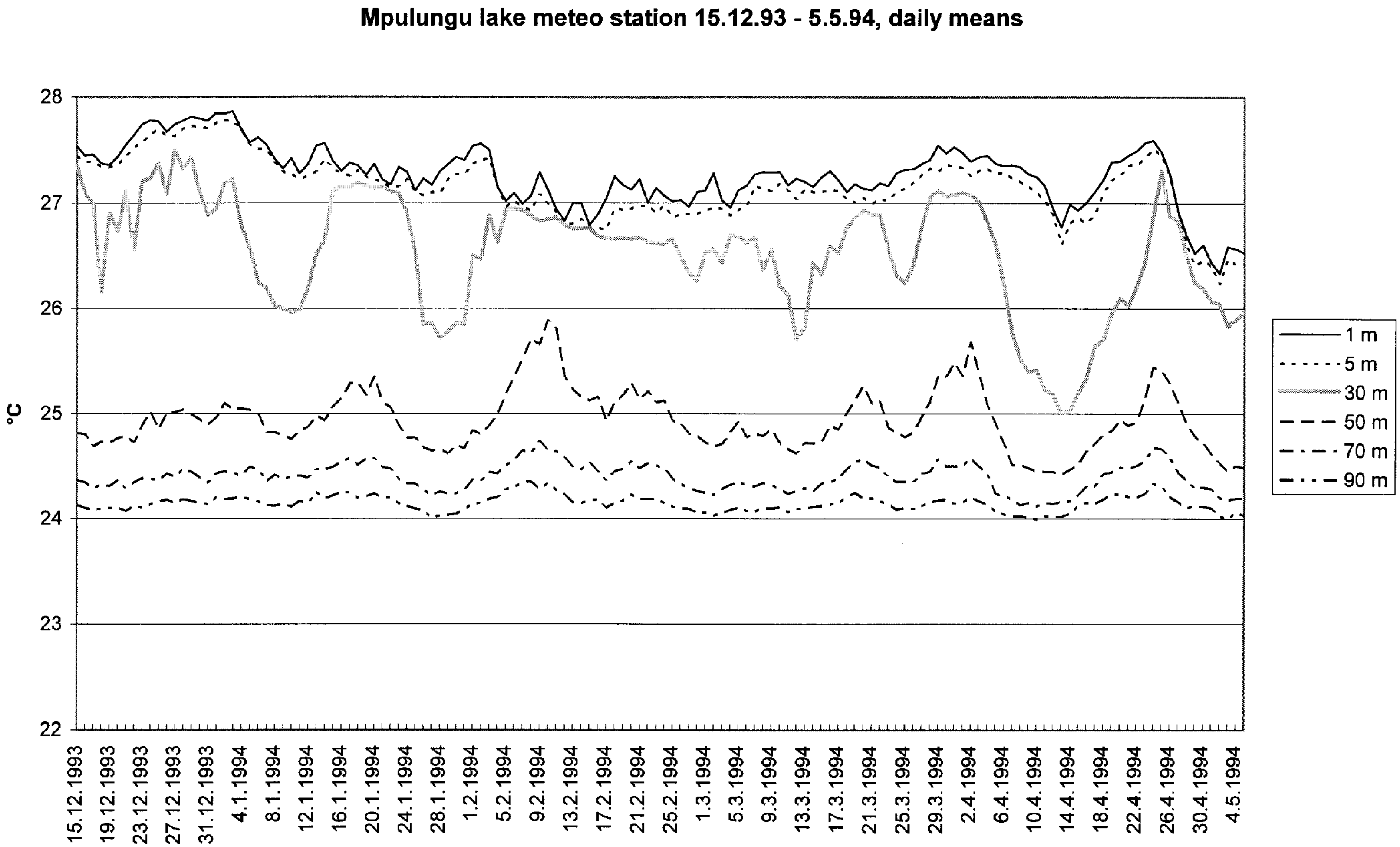
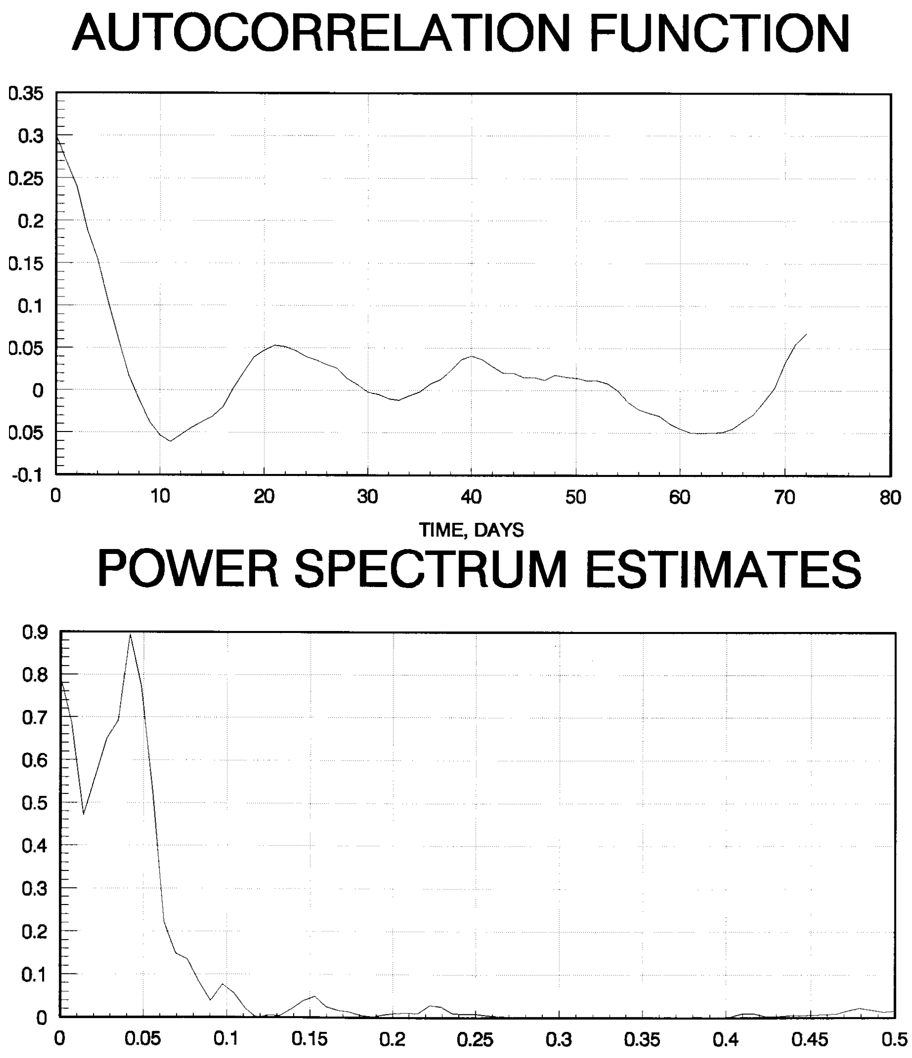

Mpulungu lake meteo station 15.12.93 - 5.5.94, daily means
°C
28
27
26
25
24
23
22
15.12.1993
19.12.1993
23.12.1993
27.12.1993
31.12.1993
4.1.1994
8.1.1994
12.1.1994
16.1.1994
20.1.1994
24.1.1994
28.1.1994
1.2.1994
5.2.1994
9.2.1994
13.2.1994
17.2.1994
21.2.1994
25.2.1994
1.3.1994
5.3.1994
9.3.1994
13.3.1994
17.3.1994
21.3.1994
25.3.1994
29.3.1994
2.4.1994
6.4.1994
10.4.1994
14.4.1994
18.4.1994
22.4.1994
26.4.1994
30.4.1994
4.5.1994
1 m
5 m
30 m
50 m
70 m
90 m

Fig.86



AUTOCORRELATION FUNCTION
TIME, DAYS
POWER SPECTRUM ESTIMATES
FREQUENCY

Fig.87

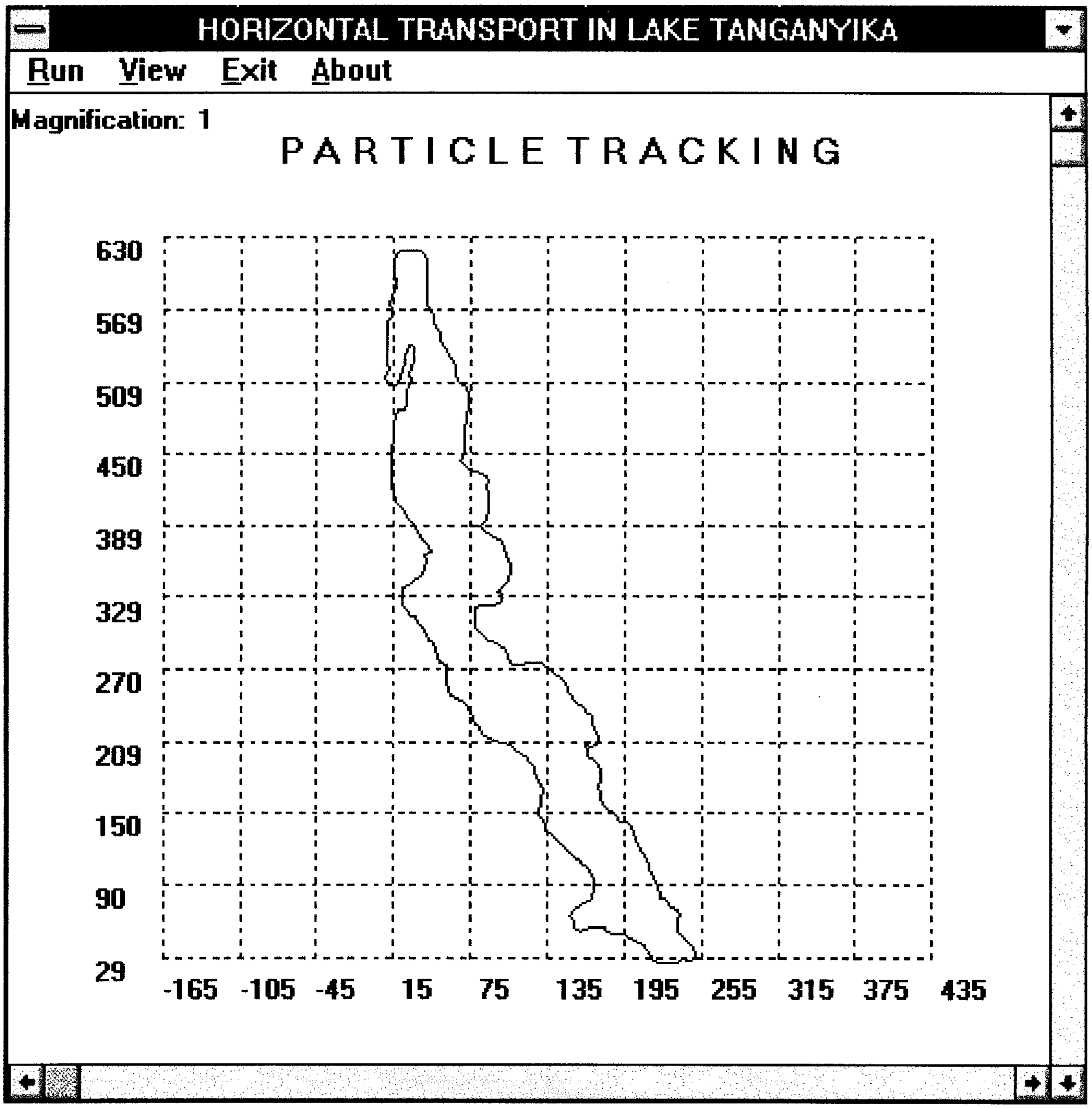

HORIZONTAL TRANSPORT IN LAKE TANGANYIKA
Run View Exit About
Magnification: 1
PARTICLE TRACKING
630
569
509
450
389
329
270
209
150
90
29
-165 -105 -45 15 75 135 195 255 315 375 435

Fig.88

RESULTS OF PARTICLE TRACKING SIMULATIONS
AFTER 50 DAYS
RELEASE POINT:KIIPILI
DISPERSION COEFFICENT 0.5 SQ.M/S

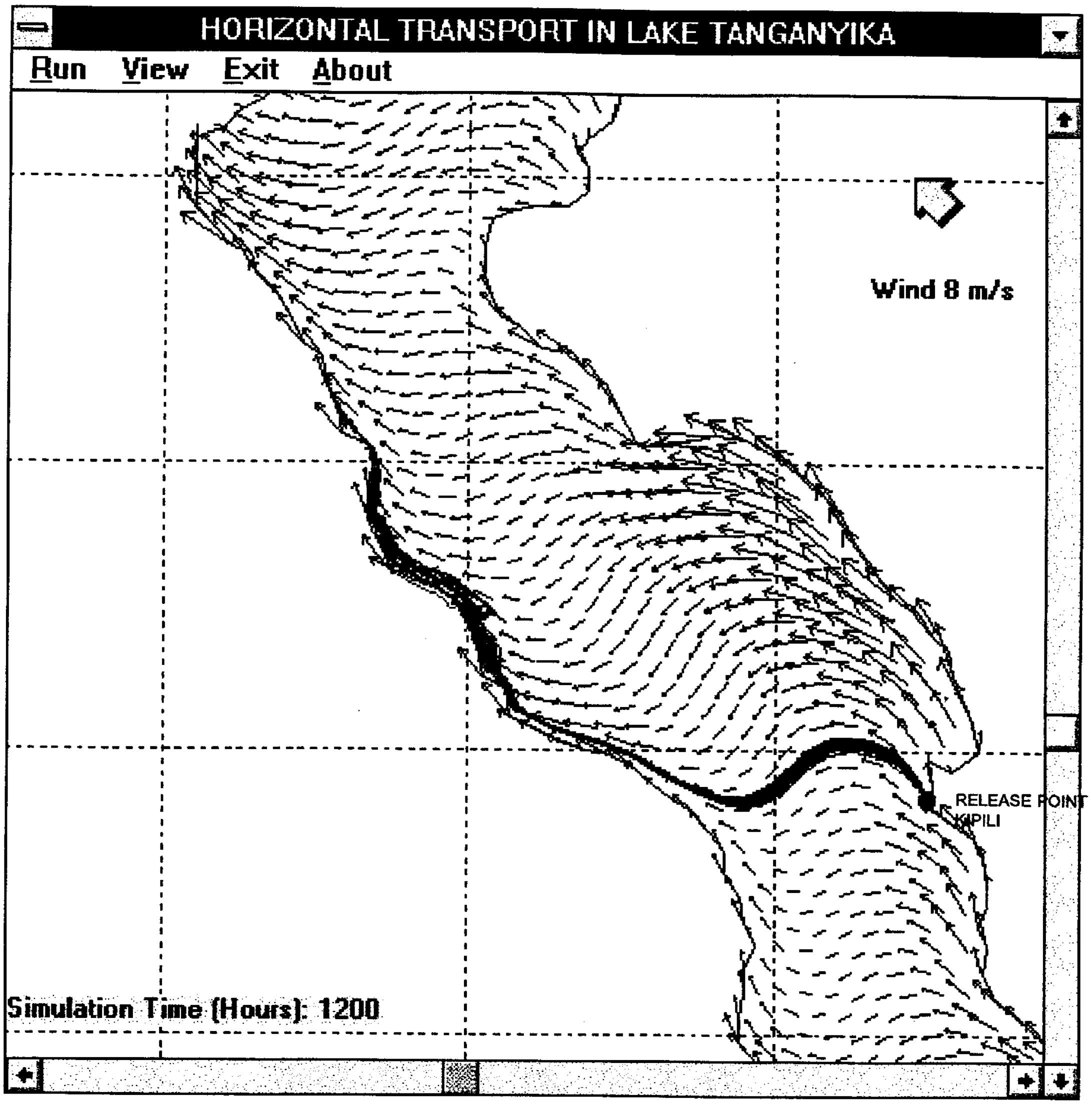


Fig.89.