GCP/RAF/271/FIN-TD/20 (En) June 1994

Hydrological modelling on Lake Tanganyika

by
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FINNISH INTERNATIONAL DEVELOPMENT AGENCY

FOOD AND AGRICULTURE ORGANIZATION
OF THE UNITED NATIONS

Bujumbura, June 1994

PREFACE

The Research for the Management of the Fisheries on Lake Tanganyika project (LTR) 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 Development Agency (FINNIDA).

LTR's objective is 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 are 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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GCP/RAF/271/FIN PUBLICATIONS

Publications of the project are issued in two series:

a series of **technical documents (GCP/RAF/271/FIN-TD)** related to meetings, missions and research organized by the project; and

* a series of **manuals and field guides (GCP/RAF/271/FIN-FM)** related to training and field work activities conducted in the framework of the project.

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).**

For bibliographic purposes this document should be cited as follows:

Huttula, T. and V. Podsetchine, Hydrological modelling on
1994 Lake Tanganyika. FAO/FINNIDA Research for the Management of the Fisheries on Lake Tanganyika. **GCP/RAF/271/FIN-TD/20 (En):** 13p.

ABSTRACT

Studies of wind conditions and water temperature regime in Lake Tanganyika during the dry season of 1993 are presented and discussed. Data were collected during hydrophysical surveys and with automatic instruments moored in the lake. Water temperature time series from the station near the south end of the lake were used for estimation of vertical thermal diffusivity. Results of numerical experiments with two-dimensional vertical hydrodynamic model revealed the importance of accurate estimation of the wind field over the lake and coefficient of vertical mixing.

ACKNOWLEDGEMENTS

The authors express their gratitude to Prof. Ossi V. Lindqvist and Dr. Hannu Mölsä, respectively the Scientific Coordinator and Deputy Scientific Coordinator of LTR, for their help. Dr. George Hanek, LTR Coordinator, and his field staff in Bujumbura, Kigoma and Mpulungu have made it possible to deploy our instruments and obtain the necessary data. Mr. Pekka Kotilainen, APO-Fisheries biologist, has been responsible for the maintenance and control of the instruments.

TABLE OF CONTENTS

1. INTRODUCTION

The aim of the hydrophysical study on Lake Tanganyika is to get detailed information on the thermal hydrodynamic regime of the lake and the main factors influencing it. It is known, that during the 4-month long dry season (May-August) southerly wind causes upwelling of the thermocline at the southern end of the lake. Recent satellite images indicate secondary upwelling in several areas of the lake. Appearance of deep anoxic waters (about 70 % of lake water is anoxic) and mixing of hydrogen sulphide into littoral waters have caused occasionally fish kills.

The intention is to understand the mixing and transport processes in the lake. This information is needed for studies of the biological production in the lake and to assess the influence of thermo- and hydrodynamical features on activity and productivity of the biological communities. A numerical model is now under development. The model together with continuous meteorological and hydrodynamic data will make it possible to predict the occurrence and extension of the upwelling during various weather conditions.

The development of the hydrological model of the Lake Tanganyika has begun by Dr. Victor Podsetchine in collaboration with Drs. Timo Huttula and Anu Peltonen of the Tampere Water and Environment District and the colleagues of the University of Kuopio. The preliminary field data of lake temperature, water level changes, and meteorological parameters collected with automatic recorders and meteorological stations at the lake have been analyzed and their application to the model itself has been initiated.

Data on wind conditions, such as wind direction, speed and gust, were collected during the first half of 1993 on the landbased meteorological station at Bujumbura harbour and with the weather sensors on a lake buoy outside Mpulungu. complementary wind measurements were made in Kigoma and onboard during the sampling cruises and shorter trips.

The effect of wind pattern on the thermal stratification of water column have been measured with the thermistor string outside Mpulungu, the southern end of the lake, where the upwelling phenomena are assumed to be most pronounced.

2. RESULTS

2.1 Weather conditions and thermal regime of Lake Tanganyika

Lake Tanganyika region has two main weather seasons. The wet season, usually from September through May, is characterized by weak winds over the lake, higher humidity, considerable precipitation and frequent thunderstorms. Heating of the lake takes place mainly during the beginning of this season in SeptemberNovember (Coulter *et al*., 1991) . As a result, thermal stratif ication establishes all over the lake with temperature difference between surface and bottom layers within a 4°C. In the south part of the lake, thermocline occupies position from approximately 40 to the 60 meters. The bathymetric map of the Lake Tanganyika is given in Figure 1.

The dry season, usually from May through the end of August, is characterized by dry weather with strong regular southerly winds. The lake loses heat by evaporation caused by strong winds (Coulter *et al*., 1991). This cooling is strongest in the southern basin. Regular southerly winds during four months period are the result of large-scale atmospheric processes. During this period the global wind convergence zone is located in the region, occupied by the lake.

The new observations made at three automatic weather stations (Bujumbura, north part of the lake; Kigoma, 150 km to the south and the lake weather station near Mpulungu, south end of the lake) revealed that winds have a strong periodical structure within a 24 h period, even during the dry season. This periodicity has not been reported earlier.

The influence of topographical effects, the channelling effect of the lake, and land breeze system all make the wind field over the whole lake very complicated. Estimation of these factors is important for correct approximation of the wind field.

Strong surface shear stresses cause intensive mixing of upper layer, deepening of the thermocline in the northern part of the lake, destruction of stratif ication, and upwelling of deep anoxic waters in the southern part of the lake (Coulter *et al*., 1991). These phenomena influence considerably the oxygen and nutrient regime in the lake, especially in its southern part. To get representative information about wind dynamics at least two more additional weather stations, evenly distributed over the lake, are required. Recording wind speed and direction as well as numerical modelling of the near surface wind field will provide reliable information to feed the numerical hydrodynamic model of the lake.

2.2 Estimation of vertical eddy diffusivity

Water temperature series of the thermistor chain, installed in the southern part of the lake, were used for estimation of vertical eddy dif fusivity in the epilimnion. Flux-gradient method gives estimation of vertical eddy diffusivity coefficient from water temperature and short wave radiation heat flux time series at different depths. Vertical water movements are supposed to be small enough and are neglected (Henderson-Sellers, 1984; Hondzo *et al*., 1991). Calculations of eddy diffusivity were based on one hour mean water temperature values in six layers (at 1, 5 , 30, 50 , 70 and 90 meters) for the period of 35 days (10.06 14.07.93). The data are shown in the Figure 2. The mean value for vertical eddy diffusivity was 0.04 m^2/s at 5 m depth. Since short wave radiation flux was not taken into account, the calculated mean value overestimates the real value. It is known that numerical differentiation has a tendency to increase measurement errors. Error analysis of these calculations is currently in process. The proximity of the calculated value to the value of near surface eddy diffusivity = 0.0325 m^2/s, suggested by Witten and Thomas (1976), is encouraging.

2.3 Numerical experiments

To evaluate the role of different forces acting on the lake, several numerical tests were made with two-dimensional vertical flow and temperature model. The model calculates horizontal and vertical components of flow velocity (X,Z components), water temperature and density (Wang and Kahavita, 1983). The main features of the model are:

(1) lateral effects are neglected, i. e. lake is considered homogeneous in lateral (Y) direction;

(2) buossinesq (density variations are considered to be important only in the Archimedian bouyancy force) and hydrostatic (linear changes of pressure with depth) assumptions;

(3) quadratic dependence of water density on water temperature;

(4) vertical eddy diffusivity is a function of local Richardson number (the ratio of vertical density gradient to squared vertical gradient of the horizontal velocity, serves as a measure for the stability of a shear flow); and

(5) fully implicit in time, control volume scheme on staggered computational grid.

Lake transect along main axis was schematically represented with rectangular domain (Figure 3). only the uppermost 200 m are included in the model. Temperature distribution, used as initial condition, was two-layered: the ' first surface layer, 50 m thick with temperature 26.5°C and underlying laver, 150 m thick with temperature 23.5°C. Computational grid had 60 sections in horizontal and 25 layers in vertical, time step was 600 s. This schematization is rather coarse, but it gives possibility to study the role of different forcing factors on the lake scale.

First, numerical experiments for the case of constant wind both in time and space were conducted. Heat fluxes on the air-water interface were neglected. No-flux boundary condition was used on the bottom. Calculated temperature distributions after 5 days with wind speed 5,10 and 15 m/s are shown in the Figures 4-6. Surface eddy diffusivity coefficient had a value of 0.001 M^2/S. In all cases mixing and upwelling in the lake model is observed. Their intensity depends strongly on wind speed. For the wind

5 m/s, the upwelling zone occupies only small area at the south end of the lake, while for the wind speed 15 m/s practically the whole lake is mixed.

The second set of experiments was made with real weather data from Bujumbura meteorological station for the period 10.06 14.07.93. Heat flux components were calculated using formulae that

have been developed earlier and applied for lakes in temperate zone (Sahlberg, 1983; Huttula *et al.*, 1992). Calculated short wave radiation fluxes match the true observations rather well (Figure 7). First, vertical eddy diffusivity coefficient was calibrated against surface temperature measurements. With the value of 0.005 m2/s, the calculated surface temperature had about the same order of fluctuations (0.5°C) as the observed ones. Calculated temperature isolines after simulation of 30 days are depicted in the Figure 8. As it was expected, intensity of mixing is not as strong as in the case of steady-state wind, and similarly, the upwelling zone is not as clearly distinguished like in steady-state calculations. Picture becomes much more complicated than in the previous case. It shows sensitivity of the model to vertical mixing coefficient. This difference is possibly explained by nonlinear character of interaction between temperature and flow fields when surface air-water heat flux components are taken into account.

3. CONCLUSIONS

The main conclusion of the water temperature and meteorological data analysis together with the results of preliminary experiments with two-dimensional vertical model is that the computation of thermal regime dynamics of such a large tropical lake, like Lake Tanganyika, depends on accurate estimation of wind induced shear stresses over the lake and on correct identification of vertical turbulent diffusivity which controls the processes of vertical mixing.

In the next phase the model will be expanded into three dimensions and the effects of wind fields will be studied in more details. The three-dimensional model will enable calculation of the wind driven current field on lake wide scale, upwelling and the exchange of waters between littoral and pelagic zones.

Testing of the model requires regular acquisition of temperature and meteorological data on the lake and shore areas. To obtain good picture of wind field over the lake, two lake meteostations are required in addition to the existing one outside Mpulungu. In March 1994 one was instaleed outside

Kigoma. Besides this meteorological station on R/V Tanganyika Explorer gives an opportunity to study the spatial differences of wind field. This far momentary current measurements are done weekly near each research station. The results will be used to calibrate the new 3D model. In the future, the current measurements with recording instruments will become essential part of hydrodymanical programme and will provide more data for calibration and verification of the lake model. It is thus suggested that LTR purchases nine such instruments to be employed near LTR research stations.

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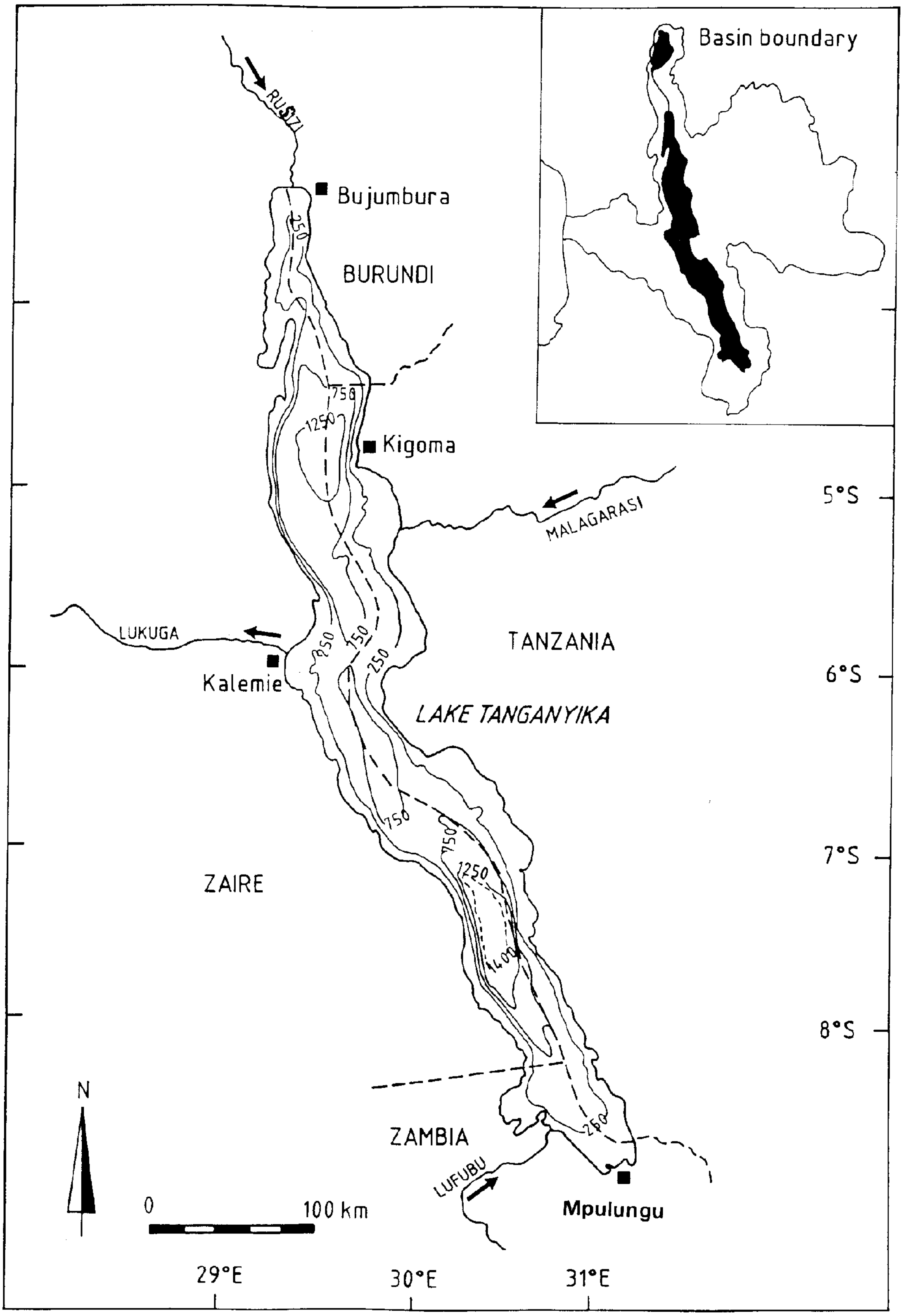
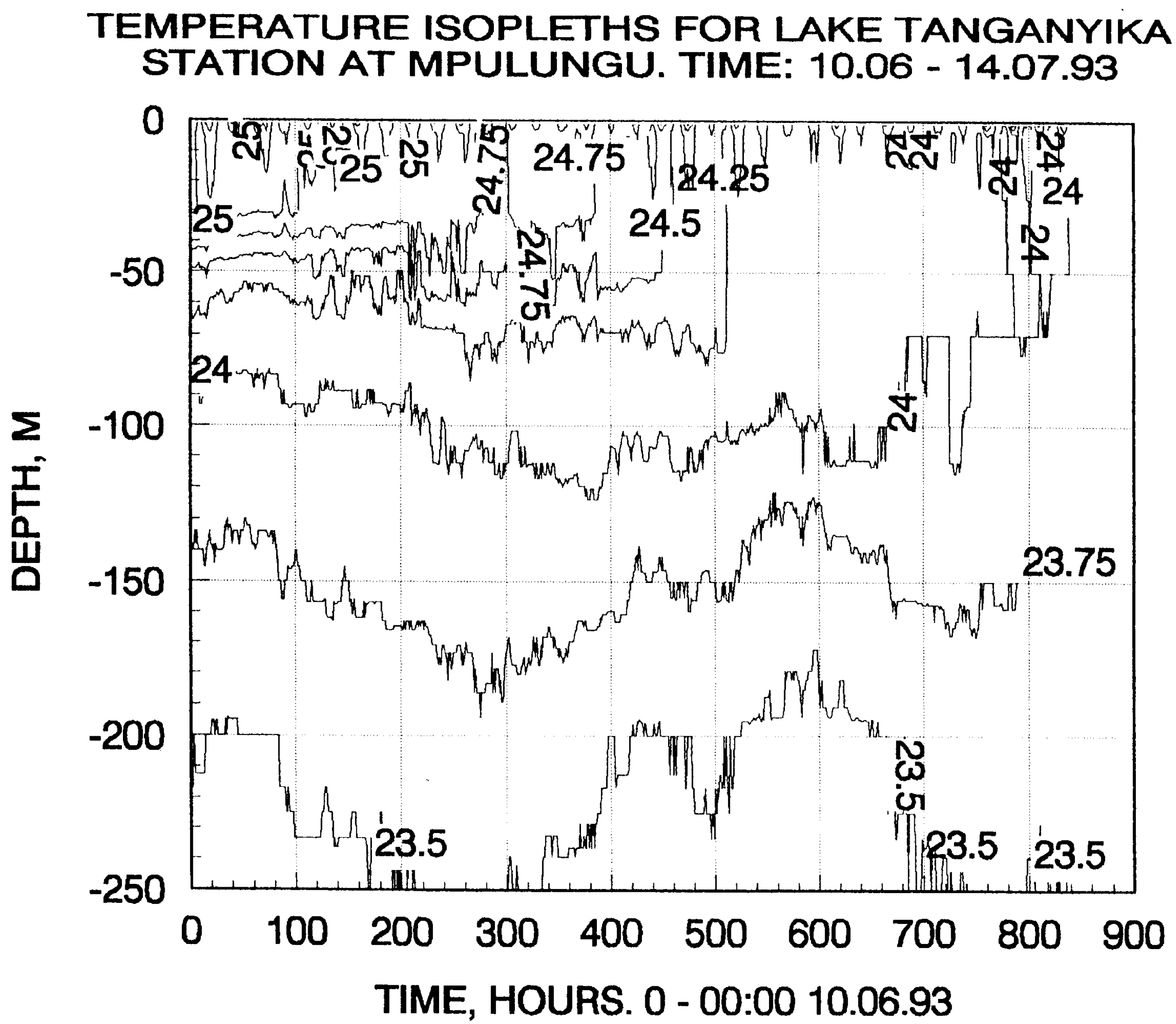
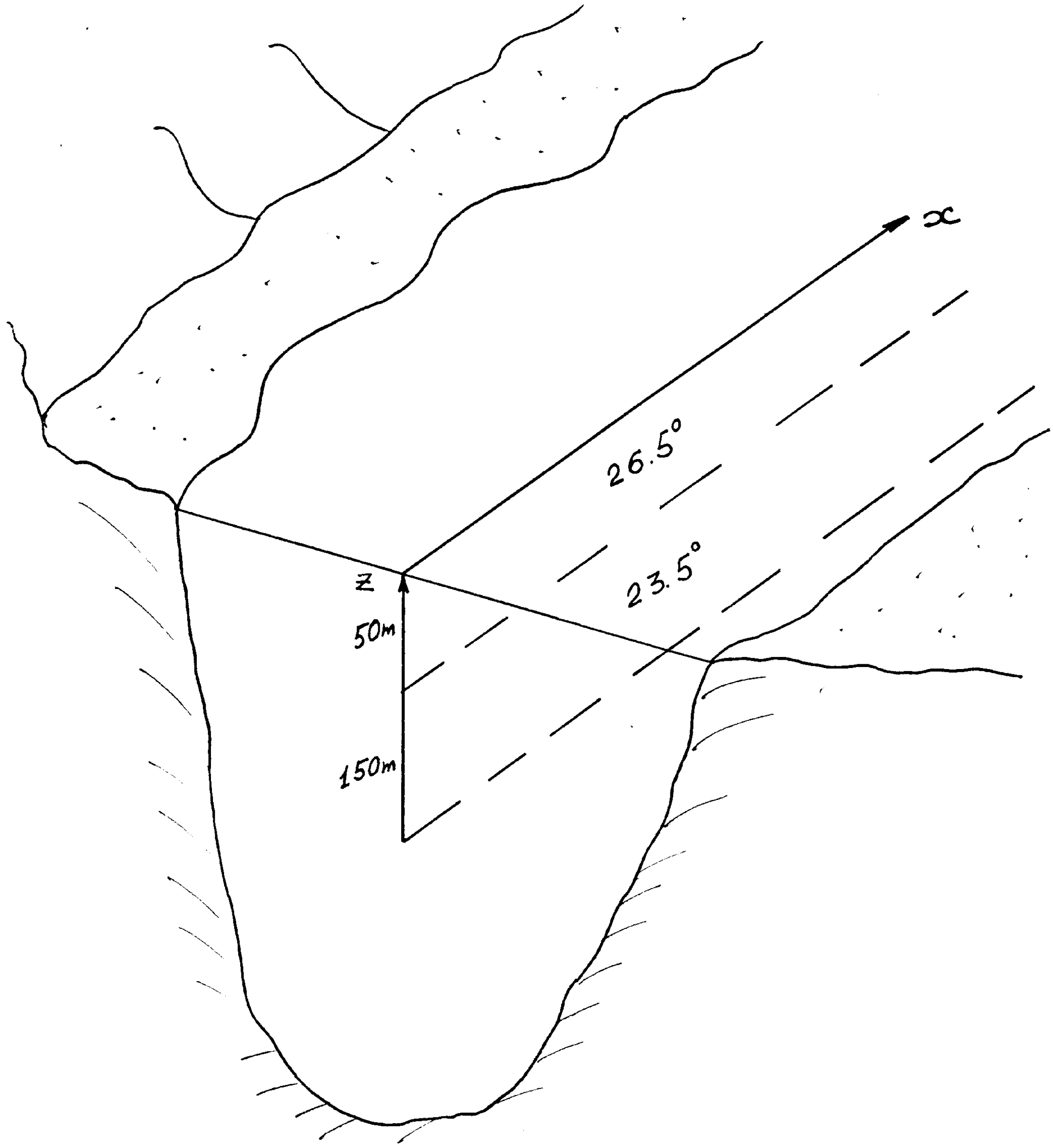
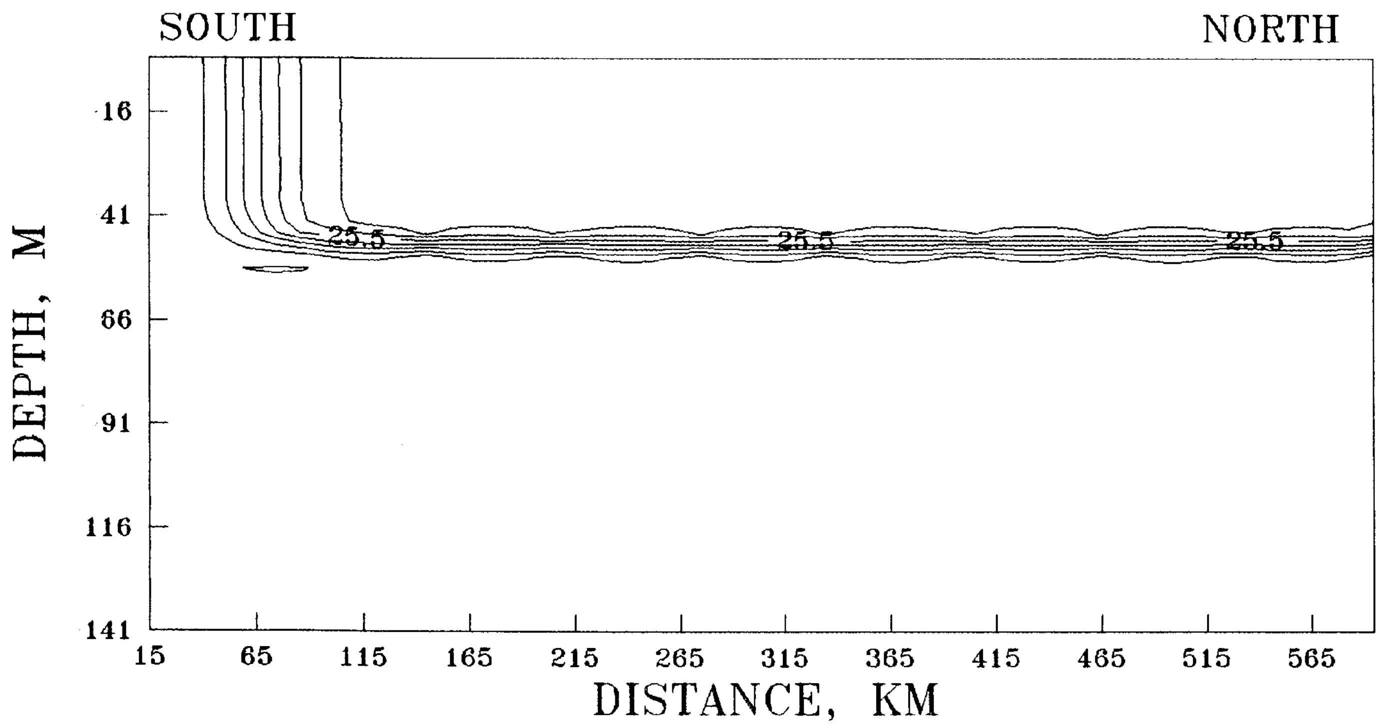
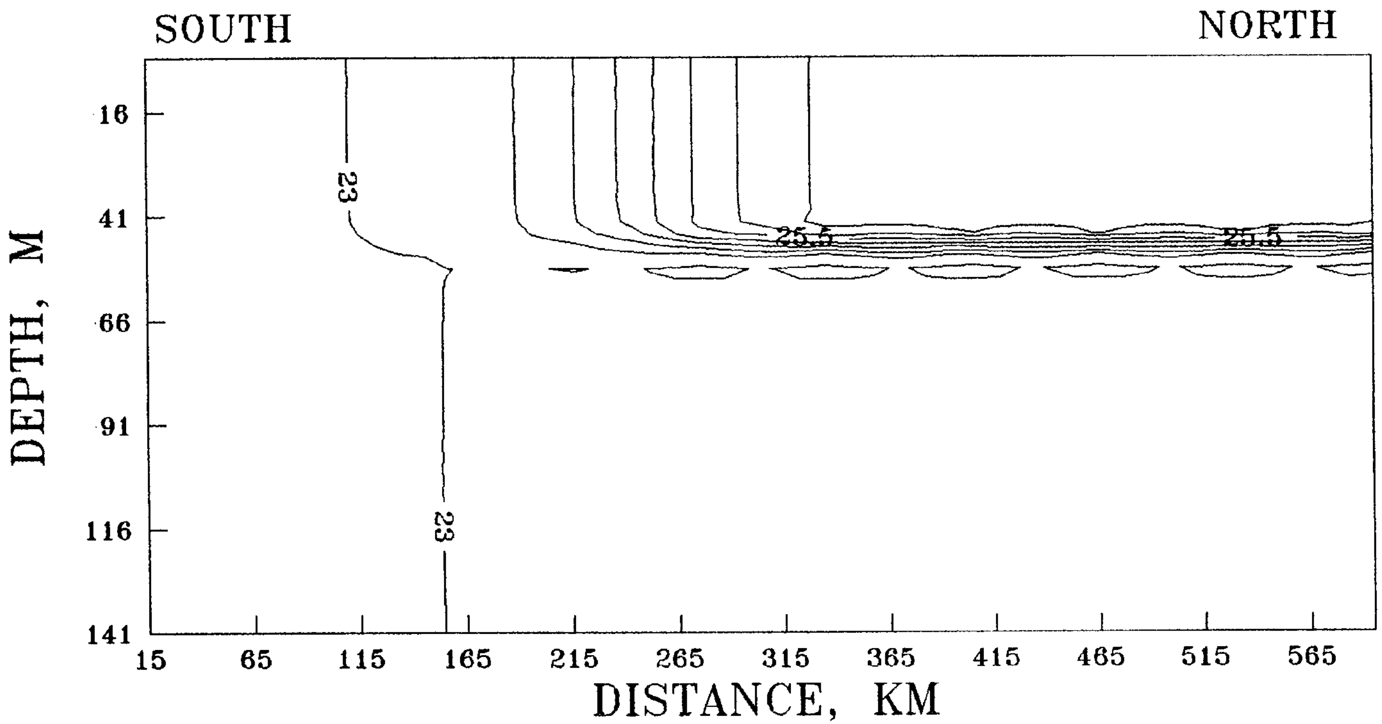

Basin boundary
RUSIZI
Bujumbura
BURUNDI
Kigoma
MALAGARASI
LUKUGA
Kalemie
TANZANIA
LAKE TANGANYIKA
ZAIRE
ZAMBIA
LUFUBU
Mpulungu
N
0
100 km
5°S
6°S
7°S
8°S
29°E
30°E
31°E
250
750
1250
1400


TEMPERATURE ISOPLETHS FOR LAKE TANGANYIKA
STATION AT MPULUNGU. TIME: 10.06 - 14.07.93
DEPTH, M
TIME, HOURS. 0 - 00:00 10.06.93
0
-50
-100
-150
-200
-250
0
100
200
300
400
500
600
700
800
900
25
24.75
24.5
24.25
24
23.75
23.5


x
26.5°
23.5°
z
50m
150m


SOUTH
NORTH
DEPTH, M
16
41
66
91
116
141
25.5
25.5
25.5
15
65
115
165
215
265
315
365
415
465
515
565
DISTANCE, KM


SOUTH
NORTH
DEPTH, M
16
41
66
91
116
141
23
25.5
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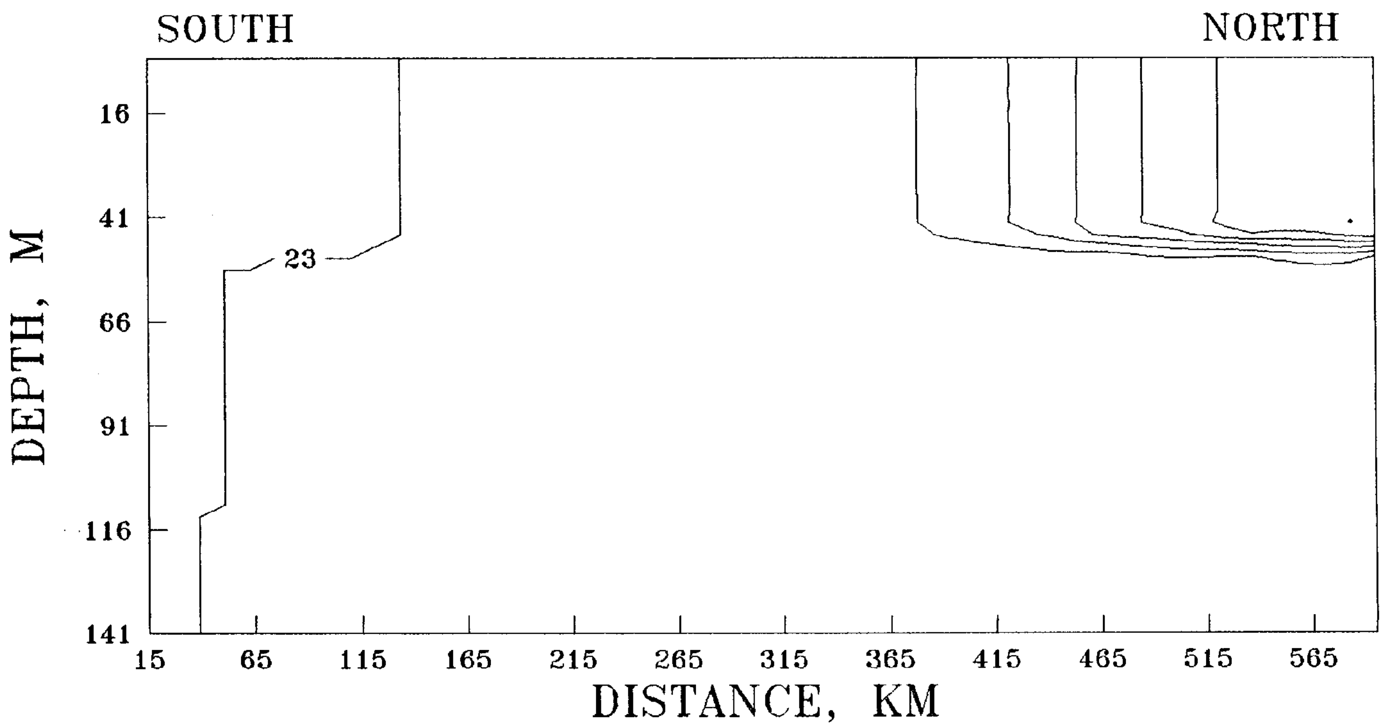
115
165
215
265
315
365
415
465
515
565
DISTANCE, KM


SOUTH
NORTH
DEPTH, M
16
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116
141
23
15
65
115
165
215
265
315
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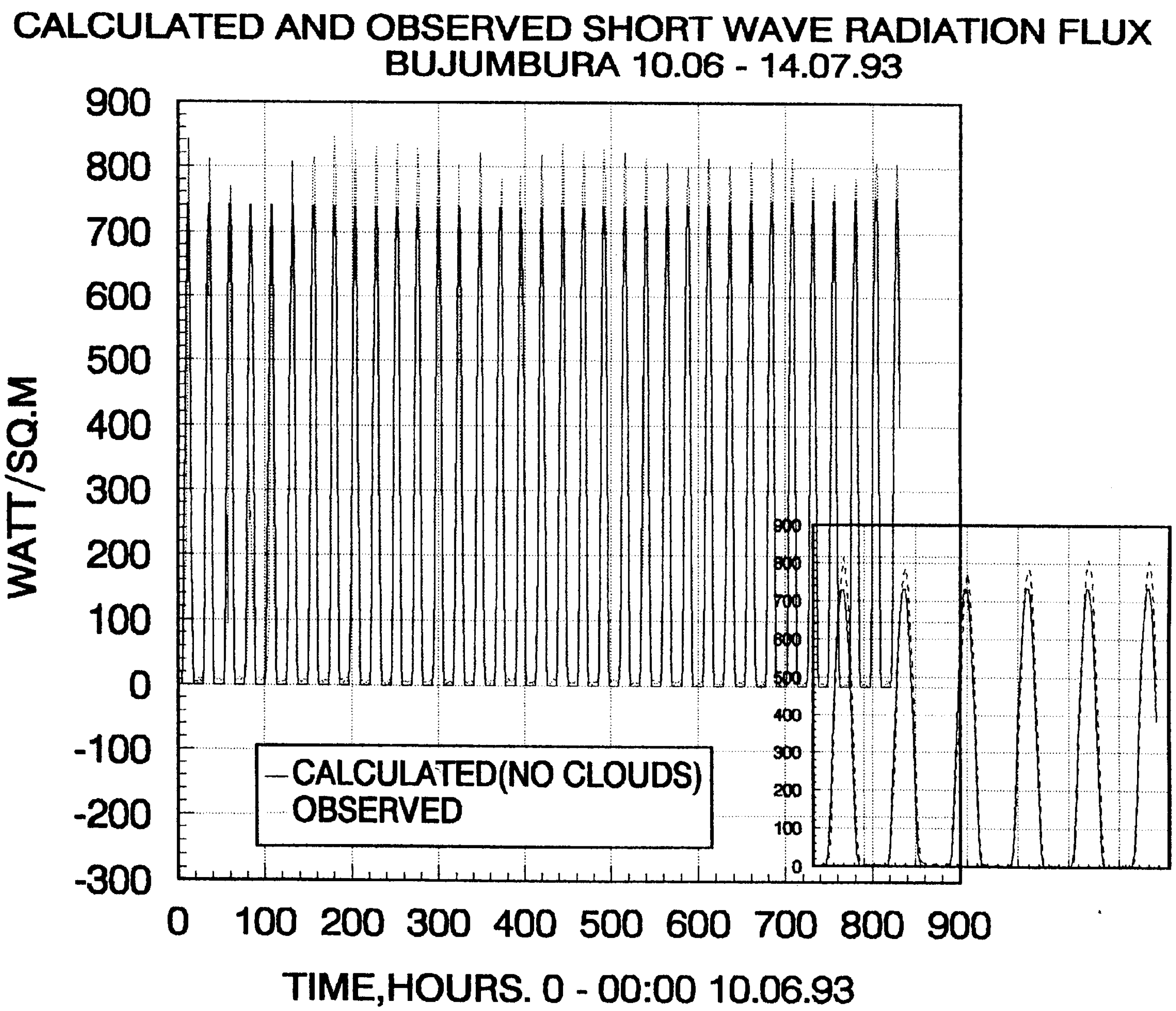
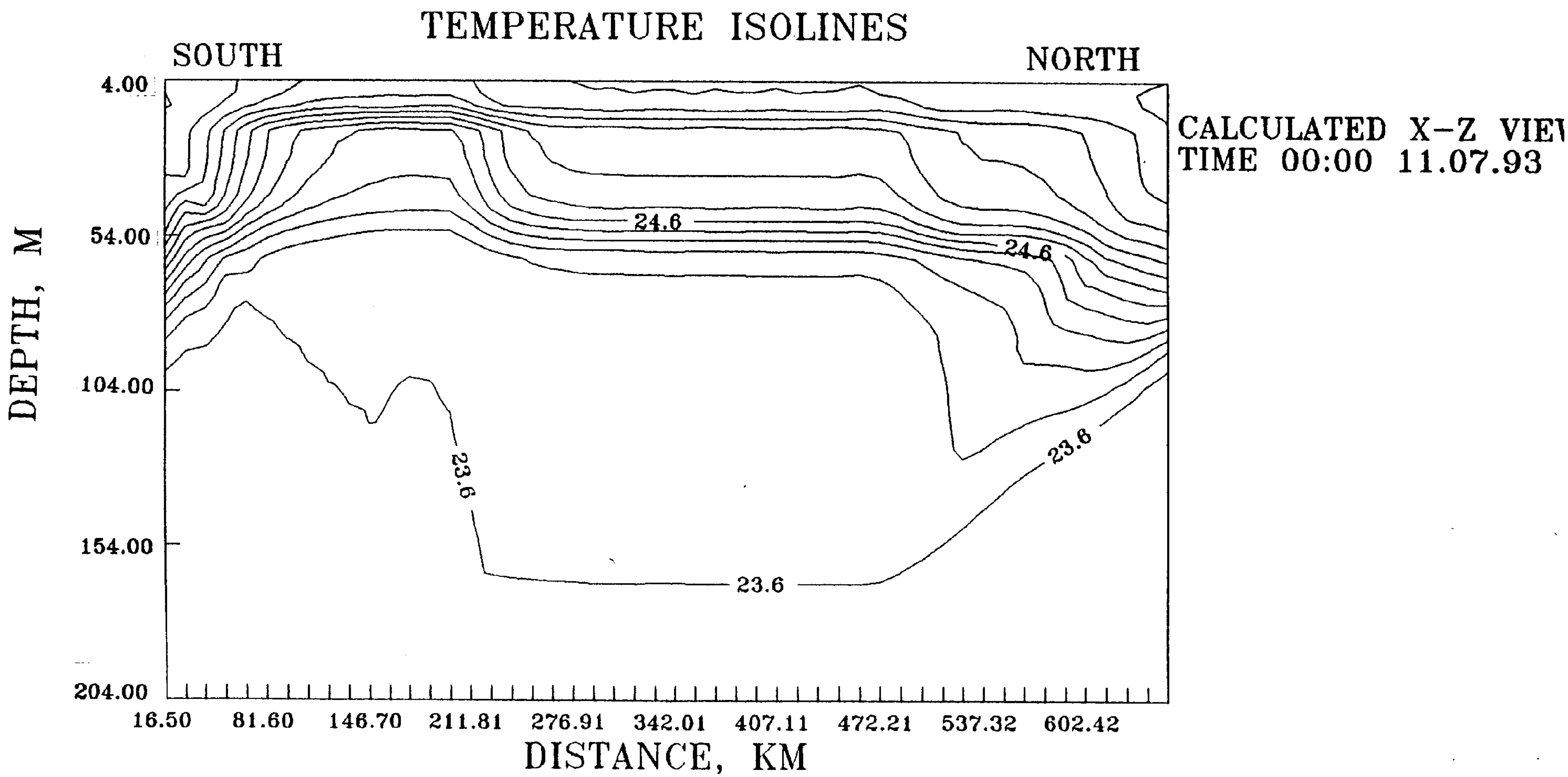
465
515
565
DISTANCE, KM


CALCULATED AND OBSERVED SHORT WAVE RADIATION FLUX
BUJUMBURA 10.06 - 14.07.93
WATT/SQ.M
900
800
700
600
500
400
300
200
100
0
-100
-200
-300
0 100 200 300 400 500 600 700 800 900
TIME,HOURS. 0 - 00:00 10.06.93
CALCULATED(NO CLOUDS)
OBSERVED


TEMPERATURE ISOLINES
SOUTH
NORTH
CALCULATED X-Z VIEW
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154.00
204.00
24.6
24.6
23.6
23.6
23.6
16.50
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146.70
211.81
276.91
342.01
407.11
472.21
537.32
602.42
DISTANCE, KM