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The Gulf Stream Dynamics Experiment: Inverted Echo Sounder Data Report for the July 1982 to April 1983 Deployment Period

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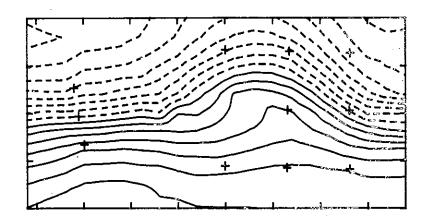
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THE GULF STREAM DYNAMICS EXPERIMENT:

Inverted Echo Sounder Data Report for the July 1982 to April 1983 Deployment Period



bу

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GSO Technical Report Number 86-5

October 1986

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THE GULF STREAM DYNAMICS EXPERIMENT: Inverted Echo Sounder Data Report for the July 1982 to April 1983 Deployment Period

GSO Technical Report No. 86-5

by

Amy I. Friedlander Karen L. Tracey and D. Randolph Watts

October, 1986

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ABSTRACT

The Gulf Stream Dynamics Experiment was conducted in the region just northeast of Cape Hatteras to study the propagation and growth characteristics of Gulf Stream meanders. This report documents the inverted echo sounder data collected during the July 1982 to April 1983 deployment period. Time series plots of the half-hourly travel time and low-pass filtered thermocline depth measurements are presented for eleven instruments. Basic statistics are given for all the data records shown. Maps of the thermocline depth field in a 200 km by 400 km region are presented at daily intervals.

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SECTION 1

Experiment Description and Data Processing

1.1 Introduction

This report documents data collected using inverted echo sounders (IESs) in the Gulf Stream northeast of Cape Hatteras from July 1982 to April 1983, as part of the Gulf Stream Dynamics Experiment. The measurements were made under the support of an NSF project entitled "The Dynamics of Gulf Stream Meanders". Other data collected as part of the program conducted by the University of Rhode Island (D. R. Watts, P. I.) included two current meter moorings with instruments at three levels (under ONR sponsorship) and closely spaced CTD casts along two transects. These other data have been documented by W. E. Johns (1984) and E. Johns (1984), respectively.

The principal objectives of the experiment were:

 determining the propagation and growth characteristics of Gulf Stream meanders and how these vary downstream,

2) determining the vertical structure of the current and temperature fluctuations associated with Gulf Stream meanders in the study area,

3) determining the potential vorticity distribution of the Gulf Stream, and

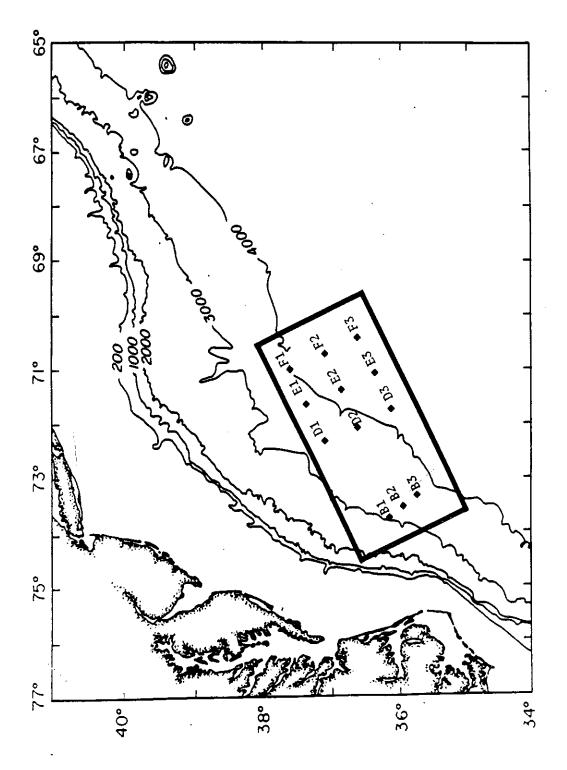
4) determining if the current is in geostrophic balance.

Additionally, these data are being used in cooperation with other investigations of the Gulf Stream in the same region. Collaboration with P. Cornillon's satellite imagery project (NSF supported) and H. T. Rossby's Pegasus project (ONR supported) is currently underway to obtain detailed descriptions of the meander characteristics.

To address these objectives, an array of inverted echo sounders was deployed in the Gulf Stream approximately 200 km downstream of Cape Hatteras. The study area, shown in Figure 1, was occupied from July 1982 to April 1983. The IESs were located on four lines in an approximately rectangular grid 130 km cross-stream by 300 km downstream. The instrument sites are shown in Figure 1 and listed in Table 1. Deployment of the twelve IESs took place from 5 to 25 July 1982 on a cruise aboard the R/V ENDEAVOR (ENO87). The three instruments along line B were recovered on a cruise aboard the R/V ENDEAVOR (ENO92) from 20 to 29 November 1982. The remaining recoveries took place from 16 to 27 April 1983 aboard the R/V COLUMEUS ISELIN (CI8304).

1.2 Site and Record Naming Conventions

In this report, each instrument site and the associated data record are referred to by both a line letter and a site number. The four cross-stream lines are designated from west to east by the letters B, D, E, and F. The IES sites along each line are numbered consecutively from 1 through 3, with site 1 located at the northwestern end of the line. This designator has a prefix of IES, indicating that the instrument is a standard type of inverted echo sounder (i.e., without any optional sensors). Additionally, a two-digit code, 83, indicates the reference year of the time base and (except for line B) the year in which the instruments were recovered. (The three instruments along line B were recovered in 1982.) For example, IES83E2, the second site from the northwestern end of line E, was recovered during 1983.



The box outlines the 200 km by IES sites (solid squares) along 400 km region (the combined areas 1 and 2 in the inset of Figure 5), which was lines B through F were occupied during 1982-1983. The Gulf Stream Dynamics Experiment Study Area. mapped by objective analysis (Figure 7). Figure l.

Table 1. In	nstrument a	Site	Locations	and	Data	Returns.
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SITE	LATITUDE (N)	LONGITUDE (W)	1982 1983 <u>JASONDJFMA</u>
IES83B1	36°10.48	73°43.80	XXXXX
IES83B2	35°57.18	73°32.23	XXXXX
IES83B3	35°44.07	73°19.97	XXXXX
IES83D1	37°08.03	72°19.40	XXXXXXXXXXX
IES83D2	36°38.14	72°04.32	
IES83D3	36°08.55	71°44.29	XXXXXXXXXXX
IES83E1	37°23.10	71°38.90	XXXXXXXXXXX
IES83E2	36°53.01	71°22.00	XXXXXXXXXXX
IES83E3	36°23.13	71°04.67	XXXXXXXXXXX
IES83F1	37°37.49	71°00.10	XXXXXXXXXXX
IES83F2	37°08.02	70°43.06	XXXXXXXXXXX
IES83F3	36°38.10	70°24.81	XXXXXXXXXXX

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1.3 Inverted Echo Sounder Description

A detailed description of the IES is presented in Chaplin and Watts (1984) and will not be repeated here. Briefly, the IES is an instrument which is moored one meter above the ocean floor and which monitors the depth of the main thermocline acoustically. A sample burst of acoustic pulses is transmitted every half hour and the round trip travel times to the surface and back are recorded on a digital cassette tape within the instrument. For the standard IES, a sample burst typically consists of twenty 10-kHz pings. Additionally, bottom pressure and temperature can be measured and recorded; however, during this deployment period, none of the instruments were equipped with these optional sensors.

<u>1.4 Data Processing</u>

The raw data are recorded within the IES on Sea Data model 610 recorders. The cassette tape contains the counts associated with travel time measurements as a series of integer words of varying lengths. All processing was done on a PRIME 750 computer, except for the initial dumping of the data from the cassette tapes onto a 9-track magnetic tape. This was performed on the Hewlett Packard 2000 series computer maintained by the URI Marine Technicians. The basic processing steps, which include transcription, editing, and conversion into scientific units, are illustrated by the flowchart in Figure 2. The data processing is accomplished by a series of routines specifically developed for the IES (Tracey and Watts, 1986a) and these are outlined below.

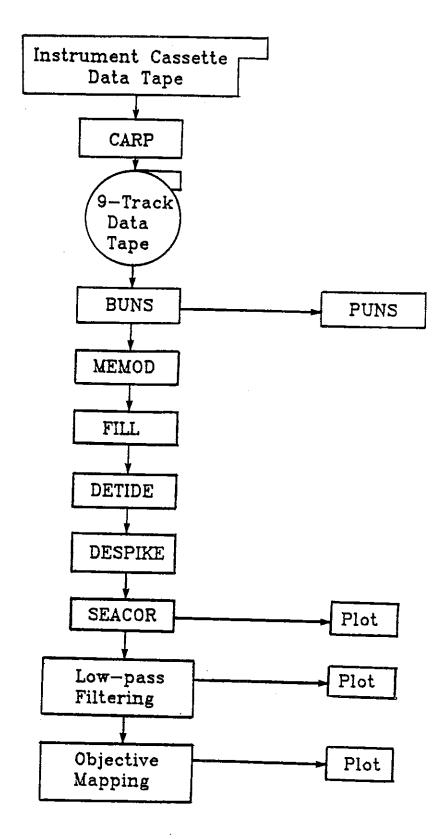


Figure 2. IES Data Processing Flowchart.

- CARP: Transfers the data from cassettes to 9-track magnetic tape for subsequent processing.
- BUNS: Converts the series of integer words of varying lengths into standard length 32-bit integer words.
- PUNS: Produces integer listings and histograms of the travel time sample bursts. Provides an initial look at data quality and travel time distributions. Used to determine the first (after launch) and last (before recovery) 'on bottom' samples.
- MEMOD: Establishes the time base. Determines either the median or modal value (at the user's option) of the travel time burst as the representative measurement. Converts all travel time counts into scientific units of seconds.
- FILL: Checks for proper incrementing of the time base. Missing data points are filled by inserting interpolated values.
- DETIDE: From user-supplied tidal constituents specific to each site, determines the tidal contribution to the travel times and removes it from the measured values.
- DESPIKE: Identifies and replaces travel time spikes with interpolated values.
- SEACOR: Removes the effects of seasonal warming and cooling of the surface layers from the travel times. Plots of the half-hourly travel times are generated.
- LOW-PASS FILTERING: Convolves the travel times with a 40-hour low-pass Lanczos filter. The smoothed series are subsampled at six-hour intervals and plotted.
- OBJECTIVE MAPPING: Produces daily maps of the depth of the 12°C isotherm.

The FESTSA time series analysis package (Brooks, 1976),

modified for the PRIME 750, was used to remove the higher frequency (tidal and inertial) motions from those with periods of several days or longer, which are the main focus of this project. The symmetric filter, with a Lanczos taper, was designed with the quarter-power point at 0.025 cph and the tidal cycle attenuated by 60 db. The half-hourly travel time data (plotted in Figures 3.1-11) were low-pass filtered and the smoothed output series (40 HRLP) had sampling intervals of six hours.

1.4.1 Travel Time Calibration

Variations in the travel times have been shown to be proportional to variations in the thermocline depth (Watts and Rossby, 1977; Watts and Wimbush, 1981). Calibration XBTs were taken at each IES site in order to convert the travel times (τ) into thermocline depths (ξ) according to the relation: $\xi = M\tau + B$, where M is a scale factor and the intercept B depends on the depth of the instrument. Regressions of τ versus ξ , performed for several instruments, show that the constant value, M = -19.0 m/sec, is appropriate for all these Gulf Stream sites. The values of B used for each instrument are listed in the tables in Section 2.

For practical purposes the main thermocline depth can be represented by the depth of an individual isotherm. For this work, we have chosen the 12°C isotherm since it is situated near the highest temperature gradient of the main thermocline and correlates well with τ (Rossby, 1969; Watts and Johns, 1982). The low-pass filtered travel time records were scaled to the thermocline depths (Z₁₂) and these records are shown in Figures 4.1-4. Since τ is resolved to 0.1 msec, the 40 HRLP Z₁₂ scaled values are therefore resolved to ± 2 m. However, there is a constant offset of ± 25 m for most records, which is the estimated accuracy of the intercept B. This is determined from the several calibration XBTs taken at each site.

1.4.2 Thermocline Depth Mapping

Objective maps of the thermocline (Z_{12}) field in the array region have been produced at daily intervals from these records. The boxed region in Figure 1, oriented 064°T, is the region which has been mapped.

The objective mapping techniques were developed by E. Carter (1983); special adaptations for their application to the Gulf Stream frontal zone are discussed in Watts and Tracey (1985). Two results presented in this latter work are of particular importance to the objective mapping performed here: 1) If the mean field is removed, the perturbations have essentially isotropic correlation fields. 2) The space-time correlation functions used for the objective analysis are shown.

The objective analysis is performed on the "perturbation fields", which are obtained by removing the mean field from the input data set and normalizing by the standard deviation. To represent the mean field, $\overline{Z_{12}}(x,y)$, a third order polynomial was fitted to the mean thermocline depth values observed during the July 1982 to April 1983 deployment period. The function form of the polynomial was:

$\overline{Z_{12}}(x,y) = B_0 + B_1 x + B_2 y + B_{11} x^2 + B_{12} x y + B_{22} y^2 + B_{111} x^3 + B_{112} x^2 y + B_{122} x y^2 + B_{222} y^3$

where (x,y) is the position in kilometers from the origin at $36^{\circ}00'N$, 73°30'W, B₀ is 4.555453E+02, B₁ is 7.737683E-01, B₂ is -4.613387E+00, B₁₁ is -2.845196E-03, B₁₂ is 1.188891E-03, B₂₂ is 2.173707E-03, B₁₁₁ is 4.411177E-06, B₁₁₂ is -2.999912E-06, B₁₂₂ is -3.097973E-05, and B₂₂₂ is 1.408226E-04. The standard deviation field, $\sigma(x,y)$, was defined as a function of the mean field depth, from a Gaussian form representative of all IES records:

$$\sigma(\mathbf{x},\mathbf{y}) = \mathbf{A} + \mathbf{B} \exp \left[\frac{\overline{\mathbf{Z}_{12}}(\mathbf{x},\mathbf{y}) - \mathbf{Z}_{0}}{\mathbf{C}}\right]^{2}$$

where A is 50 m, B is (200 m - A), C is 200 m, Z₀ is 470 m, and $\overline{Z_{12}}(x,y)$ is the mean thermocline depth at that (x,y) location. Figure 5 shows both the mean and standard deviation fields in plan view.

For each output grid point, the objective mapping technique selects, from all the input data within a specified maximum time lag (T) and radial distance (R), the number of points (N) which have the highest correlations. The output fields in Figures 6 and 7 result from specifying N = 8, T = ± 4 days, and R = 120 km, and using the idealized correlation function (Watts and Tracey, 1985) with an assumed noise level E = 0.05.

The output of the objective mapping is the perturbation field (Figure 7) on a full grid of points, with 20-km grid spacing, within the mapped region. The thermocline depth maps (also shown in Figure 7) are obtained by renormalizing the perturbation field by the standard deviation and restoring the mean. In this report, two different sizes of regions are mapped, depending on the locations of the instrument sites (see inset of Figure 5). These are: 1) For the period from July to November 1982, the region mapped is 200 km cross-stream by 400 km downstream. 2) From November 1982 to April 1983, it is 200 km by 240 km. The accuracy of these output fields can be obtained from the estimated error fields, which are shown in Figure 6. A detailed discussion of the accuracy is given in Watts and Tracey (1986).

1.4.3 Time Base

The date and time were assigned to each sampling period. The tables in Section 2 report the hour, minutes, and seconds associated with the first and last sampling period as a six-digit number. All times are given as Greenwich Mean Time (GMT). For processing convenience, the times were converted into yearhours. Table 2 lists the yearhour which corresponds to 0000 GMT of each day for non-leap years. (For leap years, the yearhours can be determined by adding 24 to each day after February 28.) There are a total of 8760 hours in a standard (non-leap) year and 8784 hours in a leap year. The yearhours given in this report are referenced to 0000 GMT on January 1, 1983, with measurements occurring between January and April 1983 assigned positive yearhours. Negative values correspond to sampling periods occurring during July through December 1982.

<u>1.5 Data Recovery</u>

Table 1 summarizes the data returns from each of the inverted echo sounders. Of the twelve instruments deployed, all but one, IES83D2, were recovered, giving an instrument recovery rate of 92%. The travel time detectors on the eleven recovered instruments performed successfully, resulting in a 92% data return rate.

Table 2.	Yearhour Calendar for Non-Leap Years.	Only the yearhour corresponding
	to 0000 GMT is listed for each day.	

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SECTION 2

Individual Site and Record Information Tables

The following tables provide information about the location, dates, and basic statistics of the data records. Each table documents a single instrument site.

General site information, such as position, bottom depth, and launch and recovery times, are given first. Subsequently, details about the travel time and thermocline depth records plotted in Sections 3 and 4 are tabulated. For each plot, the times associated with the first and last data point are supplied. All yearhours are referenced to 0000 GMT on January 1, 1983 as indicated by the two-digit number, 83, of the site name. Measurements made during the calendar year prior to the reference date are given as negative yearhours.

The first order statistics (minimum, maximum, mean, and standard deviation) were calculated for the half-hourly travel time and the 40 HRLP Z_{12} records. These are also presented in the following tables.

Table 3. Site and Record Information for IES83B1

Serial Number: 023		
Type of Travel Time	Detector:	TTB
Number of Pings per	Sampling:	20
Additional Sensors:	None	

Position:	36°10.48 N	Depth:	3055 m
	73°43.80 W	-	

	DATE	GMT	CRUISE
LAUNCH:	Jul 16, 1982	0550	ENO87
RECOVERY:	Nov 24, 1982	1110	EN092

TRAVEL TIME RECORDS (Fig. 3.1)

	<u> </u>	<u> </u>	YEARHOUR
lst DATA POINT:	Jul 16, 1982	070626	-4048.8929
LAST DATA POINT:	Nov 24, 1982	110323	-900.9436

Number of Points: 6297 Sampling Interval: 0.49999195 hrs

Minimum $ au$ = 4.06140 s	Mean = 4.07042 s
Maximum $ au$ = 4.07756 s	Standard deviation = 0.00303 s

40 HRLP THERMOCLINE DEPTH RECORDS (Fig. 4.1)

 Z_{12} Conversion equation: $Z_{12} = (-19000 \text{ms}^{-1}) (\tau_d) + B$ where B = 77598.82 m $\tau_d = \text{Travel Time (sec) with tide removed}$

 DATE
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 1st DATA POINT:
 Jul 17, 1982
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 -4014.00

 LAST DATA POINT:
 Nov 23, 1982
 000000
 -936.00

Number of Points: 514 Sampling Interval: 6.00 hrs

Minimum $Z_{i2} = 160.63$ m	Mean = 260.81 m
Maximum $Z_{12} = 419.01$ m	Standard Deviation = 55.79 m

Table 4. Site and Record Information for IES83B2

Serial Number: 017 Type of Travel Time Detector: TTB Number of Pings per Sampling: 20 Additional Sensors: None

Position: 35°57.18 N Depth: 3380 m 73°32.23 W

	DA	TE	GMT	CRUISE
LAUNCH	Jul 18	, 1982	0057	ENO87
RECOVERY:	Nov 24	, 1982	0800	ENO92

TRAVEL TIME RECORDS (Fig. 3.2)

	DATE	<u> </u>	YEARHOUR
lst DATA POINT:	Jul 18, 1982	015626	-4006.0594
LAST DATA POINT:	Nov 24, 1982	075626	-904.0594

Number of Points: 6205 Sampling Interval: 0.50 hrs

Minimum τ = 4.51400 s	Mean= 4.52148 s
Maximum τ = 4.53285 s	Standard Deviation = 0.00317 s

40 HRLP THERMOCLINE DEPTH RECORDS (Fig. 4.1)

 Z_{12} Conversion equation: $Z_{12} = (-19000 \text{ms}^{-1}) (\tau_d) + B$ where B = 86375.86 m $\tau_d = \text{Travel Time (sec) with tide removed}$

	DATE	<u> </u>	<u>YEARHOUR</u>
lst DATA POINT:	Jul 19, 1982	120000	-3972.00
LAST DATA POINT:	Nov 23, 1982	000000	-936.00

Number of Points: 507 Sampling Interval: 6.00 hrs

 Minimum $Z_{12} = 292.42 \text{ m}$ Mean = 466.81 m

 Maximum $Z_{12} = 595.13 \text{ m}$ Standard Deviation = 59.16 m

Table 5. Site and Record Information for IES83B3

Serial Number: 014	I.	
Type of Travel Time	Detector:	TTB
Number of Pings per	Sampling:	20
Additional Sensors:	None	

Position:	35°44.07 N	Depth:	3695 m
	73°19.97 W	-	

	<u>DATE</u>	_GMT	CRUISE
LAUNCH:	Jul 17, 1982	2238	ENO87
RECOVERY:	Nov 24, 1982	0456	EN092

TRAVEL TIME RECORDS (Fig. 3.3)

	DATE	<u> </u>	<u>YEARHOUR</u>
Ist DATA POINT:	Jul 17, 1982	232122	-4008.6440
LAST DATA POINT:	Nov 24, 1982	045122	-907.1440

Number of Points: 6204 Sampling Interval: 0.50 hrs

Minimum τ = 4.93478 s	Mean	= 4 9	3817 s	
Maximum $= -4.04447$				-
Maximum τ = 4.94447 s	Standard Deviation	= 0.0	0145 s	3

40 HRLP THERMOCLINE DEPTH RECORDS (Fig. 4.1)

 Z_{12} Conversion equation: $Z_{12} = (-19000 \text{ms}^{-1}) (\tau_{d}) + B$ where B = 94483.66 m $\boldsymbol{\tau}_{_{cl}}$ = Travel Time (sec) with tide removed

DATE GMT **YEARHOUR** 1st DATA POINT: Jul 19, 1982 060000 -3978.00 LAST DATA POINT: Nov 22, 1982 180000 -942.00

> Number of Points: 507 Sampling Interval: 6.00 hrs

Minimum $Z_{12} = 570.52 \text{ m}$ Mean = 658.03 mMaximum $Z_{12} = 712.43$ m Standard Deviation = 26.49 m

Table 6. Site and Record Information for IES83D1

Serial Number: 022 Type of Travel Time Detector: TTB Number of Pings per Sampling: 20 Additional Sensors: None

Position: 37°08.03 N Depth: 3350 m 72°19.40 W

		DATI	<u> </u>	<u> </u>	CRUISE
LAUNCH:	Jul	13,	1982	1528	ENO87
RECOVERY:	Apr	19,	1983	0530	CI8304

TRAVEL TIME RECORDS (Fig. 3.4)

	DATE	<u> </u>	YEARHOUR
lst DATA POINT:	Jul 13, 1982	162352	-4111.6022
LAST DATA POINT:	Apr 19, 1983	052352	2597.3978

Number of Points: 13419 Sampling Interval: 0.50 hrs

Minimum τ = 4.44954 s Mean = 4.46807 s Standard Deviation = 0.00687 s

Maximum $\tau = 4.47715 \, s$

40 HRLP THERMOCLINE DEPTH RECORDS (Fig. 4.2)

 Z_{12} Conversion equation: $Z_{12} = (-19000 \text{ms}^{-1}) (\tau_{d}) + B$ where B = 85165.29 m $\tau_{\rm d}$ = Travel Time (sec) with tide removed

	DATE	GMT	<u>YEARHOUR</u>
lst DATA POINT:	Jul 15, 1982	000000	-4080.00
LAST DATA POINT:	Apr 18, 1983	000000	2568.00

Number of Points: 1109 Sampling Interval: 6.00 hrs

Mean = 272.47 mStandard Deviation = 129.77 m

Minimum $Z_{12} = 124.42$ m Maximum $Z_{12} = 606.17$ m

Table 7. Site and Record Information for IES83D3

Serial Number: 020		
Type of Travel Time	Detector:	TTB
Number of Pings per	Sampling:	20
Additional Sensors:	None	

Position:	36°08.55 N 71°44.29 W	Depth:	4120 m
	/⊥ 44.29 W		

	<u> </u>	GMT	CRUISE
LAUNCH:	Jul 13, 1982		EN087
RECOVERY:	Apr 18, 1983	1618	CI8304

TRAVEL TIME RECORDS (Fig. 3.5)

	DATE	<u> </u>	YEARHOUR
1st DATA POINT:	Jul 13, 1982	074559	-4120.2336
LAST DATA POINT:	Apr 18, 1983	161559	2584.2664

Number of Points: 13410 Sampling Interval: 0.50 hrs

			5.47855	
Maximum	τ	=	5.51288	s

s Standard Deviation = 0.00456 s

Mean = $5.48876 \, s$

40 HRLP THERMOCLINE DEPTH RECORDS (Fig. 4.2)

 Z_{12} Conversion equation: $Z_{12} = (-19000 \text{ms}^{-1}) (\tau_d) + B$ where B = 105002.78 m $\tau_d = \text{Travel Time (sec) with tide removed}$

	DATE	<u> </u>	<u>YEARHOUR</u>
1st DATA POINT:	Jul 14, 1982	180000	-4086.00
LAST DATA POINT:	Apr 17, 1988	060000	2550.00

Number of Points: 1107 Sampling Interval: 6.00 hrs

 Minimum $Z_{12} = 274.22 \text{ m}$ Mean = 717.38 m

 Maximum $Z_{12} = 892.29 \text{ m}$ Standard Deviation = 84.10 m

Table 8. Site and Record Information for IES83E1

Serial Number: 019 Type of Travel Time Detector: TTB Number of Pings per Sampling: 20 Additional Sensors: None

Position: 37°23.10 N Depth: 3580 m 71°38.90 W

	DA1	<u>'E</u>	GMT	_CRUISE
LAUNCH:	Jul 7,		0745	ENO87
RECOVERY:	Apr 23,	1983	0051	CI8304

TRAVEL TIME RECORDS (Fig. 3.6)

 DATE
 GMT
 YEARHOUR

 1st DATA POINT:
 Jul 7, 1982
 084254
 -4263.2850

 LAST DATA POINT:
 Apr 23, 1983
 004254
 2688.7150

Number of Points: 13905 Sampling Interval: 0.50 hrs

 Minimum τ = 4.75087 s
 Mean = 4.76790 s

 Maximum τ = 4.77657 s
 Standard Deviation = 0.00598 s

40 HRLP THERMOCLINE DEPTH RECORDS (Fig. 4.3)

Z₁₂ Conversion equation: $Z_{12} = (-19000 \text{ms}^{-1}) (\tau_d) + B$ where B = 90855.44 m $\tau_d = \text{Travel Time (sec) with tide removed}$

•	DATE	GMT	YEARHOUR `
lst DATA POINT:	Jul 8, 1982	180000	-4230.00
LAST DATA POINT:	Apr 21, 1983	180000	2658.00

Number of Points: 1149 Sampling Interval: 6.00 hrs

 Mean
 265.93 m

 m
 Standard Deviation = 112.34 m

Minimum $Z_{12} = 117.29$ m Maximum $Z_{12} = 575.92$ m

Table 9. Site and Record Information for IES83E2

Serial Number: 016		
Type of Travel Time	Detector:	TTB
Number of Pings per		20
Additional Sensors:	None	

Position:	36°53.01 N	Depth:	4105 m
	71°22.00 W	-	

	DATE		_GMT	CRUISE
LAUNCH:	Ju1	7, 1982	0344	ENO87
RECOVERY:	Apr 2	2, 1983	1824	CI8304

TRAVEL TIME RECORDS (Fig. 3.7)

	DATE	<u> </u>	<u>YEARHOUR</u>
lst DATA POINT:	Jul 7, 19	82 044123	-4267.3103
LAST DATA POINT:	Apr 22, 19	83 181123	2682.1897

Number of Points: 13900 Sampling Interval: 0.50 hrs

Minimum τ = 5.44679 s	s Mean	 5.45876	s
Maximum τ = 5.48201 s			-

40 HRLP THERMOCLINE DEPTH RECORDS (Fig. 4.3)

 Z_{12} Conversion equation: $Z_{12} = (-19000 \text{ms}^{-1}) (\tau_d) + B$ where B = 104257.16 m τ_{d} = Travel Time (sec) with tide removed

	DATE	<u> </u>	<u>YEARHOUR</u>
lst DATA POINT:	Jul 8, 1982	120000	-4236.00
LAST DATA POINT:	Apr 21, 1983	120000	2652.00

Number of Points: 1149 Sampling Interval: 6.00 hrs

Minimum $Z_{12} = 119.75 \text{ m}$	•	Mean = 542.99 m
Maximum $Z_{12} = 752.99$ m	Sta	ndard Deviation = 187.89 m

_ _ _

Table 10. Site and Record Information for IES83E3

Serial Number: 015 Type of Travel Time Detector: TTB Number of Pings per Sampling: 20 Additional Sensors: None

Position: 36°23.13 N Depth: 4315 m 71°04.67 W

		DATI	Ξ	<u>_GMT</u>	CRUISE
LAUNCH:	Ju1	6,	1982	2349	ENO87
RECOVERY:	Apr	22,	1983	1139	CI8304

TRAVEL TIME RECORDS (Fig. 3.8)

 DATE
 GMT
 YEARHOUR

 1st DATA POINT:
 Jul 6, 1982
 003643
 -4271.3881

 LAST DATA POINT:
 Apr 22, 1983
 113643
 2675.6119

Number of Points: 13895 Sampling Interval: 0.50 hrs

Minimum $\tau = 5.69466$ sMean = 5.70510 sMaximum $\tau = 5.73179$ sStandard Deviation = 0.00692 s

40 HRLP THERMOCLINE DEPTH RECORDS (Fig. 4.3)

	DATE	GMT	<u>YEARHOUR</u>
lst DATA POINT:	Jul 8, 1982	060000	-4242.00
LAST DATA POINT:	Apr 21, 1983	060000	2646.00

Number of Points: 1149 Sampling Interval: 6.00 hrs

 Minimum $Z_{12} = 237.74 \text{ m}$ Mean = 736.82 m

 Maximum $Z_{12} = 918.35 \text{ m}$ Standard Deviation = 129.19 m

Table 11. Site and Record Information for IES83F1

Serial Number: 005 Type of Travel Time Detector: TTB Number of Pings per Sampling: 20 Additional Sensors: None

Position: 37°37.49 N Depth: 3970 m 71°00.10 W

		DAT	<u>E</u>	<u>GMT</u>	CRUISE
LAUNCH:	Ju1	6,	1982	0817	ENO87
RECOVERY:	Apr	21,	1983	1258	CI8304

TRAVEL TIME RECORDS (Fig. 3.9)

	<u> </u>	<u> </u>	<u>YEARHOUR</u>
lst DATA POINT:	Jul 6, 1982	092612	-4286.5633
LAST DATA POINT:	Apr 21, 1983	122612	2652.4367

Number of Points: 13879 Sampling Interval: 0.50 hrs

Minimum = E 0.7EEA =	
Minimum τ = 5.27554 s	Mean = 5.29418 s
Maximum $ au$ = 5.30192 s	Standard Deviation = 0.00548 s

40 HRLP THERMOCLINE DEPTH RECORDS (Fig. 4.4)

 Z_{12} Conversion equation: $Z_{12} = (-19000 \text{ms}^{-1}) (\tau_d) + B$ where B = 100840.10 m $\tau_d = \text{Travel Time (sec) with tide removed}$

	DATE	GMT	YEARHOUR
lst DATA POINT:	Jul 7, 1982	180000	-4254.00
LAST DATA POINT:	Apr 20, 1983	060000	2622.00

Number of Points: 1147 Sampling Interval: 6.00 hrs

.73 m Mean = 250.88 m .26 m Standard Deviation = 102.89 m

Minimum $Z_{12} = 127.73$ m Maximum $Z_{12} = 583.26$ m

Table 12. Site and Record Information for IES83F2

Serial Number: 011 Type of Travel Time Detector: TTB Number of Pings per Sampling: 20 Additional Sensors: None

Position: 37°08.02 N Depth: 4220 m 70°43.06 W

	 DAT	<u> </u>	<u>GMT</u>	CRUISE
LAUNCH: RECOVERY:		1982 1983	1236 2054	EN087 CI8304

TRAVEL TIME RECORDS (Fig. 3.10)

	DATE	GMT	YEARHOUR
lst DATA POINT:	Jul 6, 1982	130050	-4281.9861
LAST DATA POINT:	Apr 21, 1983	203050	2660.5139

Number of Points: 13886 Sampling Interval: 0.50 hrs

 .				
Minimum $\tau = 5.58430$	S	Moan		_
Mandaura	-		= 5.59733	
Maximum τ = 5.61933 s	s Standard	Deviation	= 0.00984	S

40 HRLP THERMOCLINE DEPTH RECORDS (Fig. 4.4)

	DATE	<u> </u>	YEARHOUR
lst DATA POINT:	Jul 8, 1982	000000	-4248.00
LAST DATA POINT:	Apr 20, 1983	120000	2628.00

Number of Points: 1147 Sampling Interval: 6.00 hrs

 Minimum $Z_{12} = 134.69$ m
 Mean = 536.83 m

 Maximum $Z_{12} = 769.85$ m
 Standard Deviation = 185.82 m

Table 13. Site and Record Information for IES83F3

Serial Number: 012 Type of Travel Time Detector: TTB Number of Pings per Sampling: 20 Additional Sensors: None

Position: 36°38.10 N Depth: 4380 m 70°24.81 W

		DAT	<u>E</u>	<u>GMT</u>	CRUISE
LAUNCH:	Jul	6,	1982	1826	ENO87
RECOVERY:	Apr	22,	1983	0408	CI8304

TRAVEL TIME RECORDS (Fig. 3.11)

	DATE	<u> </u>	YEARHOUR
lst DATA POINT:	Jul 6, 1982	193331	-4276.4414
LAST DATA POINT:	Apr 22, 1983	040331	2668.0586

Number of Points: 13890 Sampling Interval: 0.50 hrs

Minimum $\tau = 5.83357$ sMean = 5.84270 sMaximum $\tau = 5.86739$ sStandard Deviation = 0.00562 s

40 HRLP THERMOCLINE DEPTH RECORDS (Fig. 4.4)

 Z_{12} Conversion equation: $Z_{12} = (-19000 \text{ms}^{-1}) (\tau_d) + B$ where B = 111763.74 m $\tau_d = \text{Travel Time (sec)}$ with tide removed

 DATE
 GMT
 YEARHOUR

 1st DATA POINT:
 Jul 8, 1982
 060000
 -4242.00

 LAST DATA POINT:
 Apr 20, 1983
 180000
 2634.00

Number of Points: 1147 Sampling Interval: 6.00 hrs

 Minimum $Z_{12} = 329.05 \text{ m}$ Mean = 752.75 m

 Maximum $Z_{12} = 916.64 \text{ m}$ Standard Deviation = 105.80 m

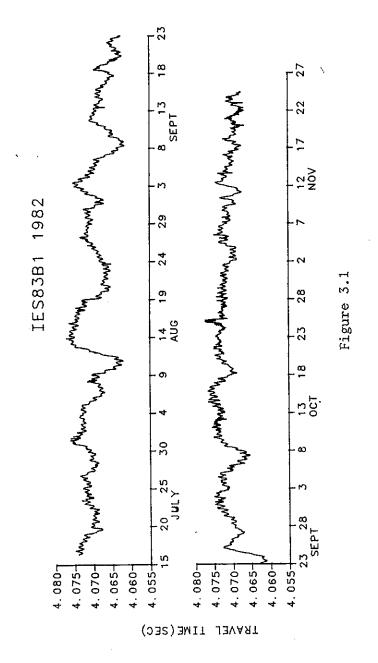
SECTION 3

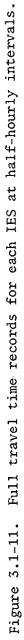
Half-hourly Travel Time Data For Each Instrument

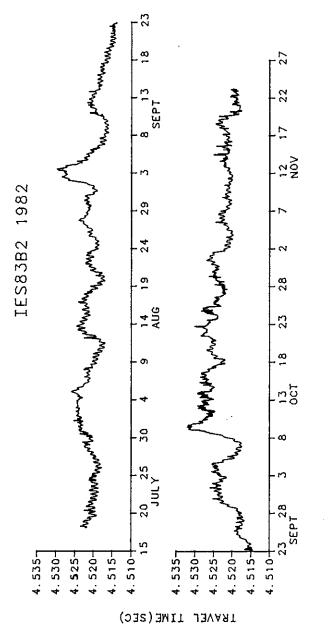
Plots of the travel time records from each instrument are presented. The time scale is the same for all plots, with each increment corresponding to 5 days. The axis begins on 0000 GMT of the first date labelled.

The vertical scale is consistent between instruments, with each increment corresponding to 5 msec for the travel time records.

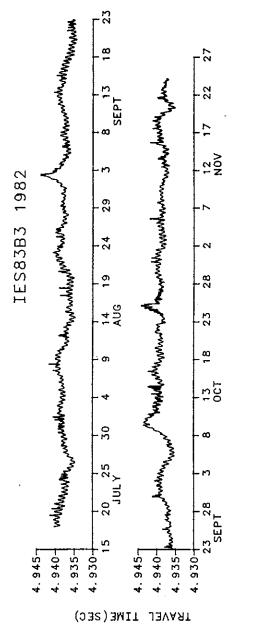
The sampling interval is nominally 0.5 hours; the actual interval for each instrument is given in the tables of Section 2. The length and the start and end times of the data records are also given in these tables.













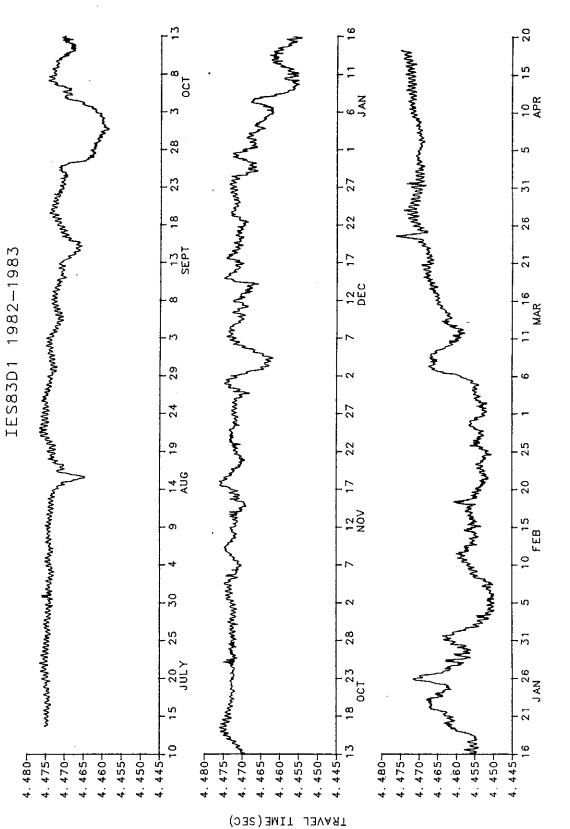


Figure 3.4

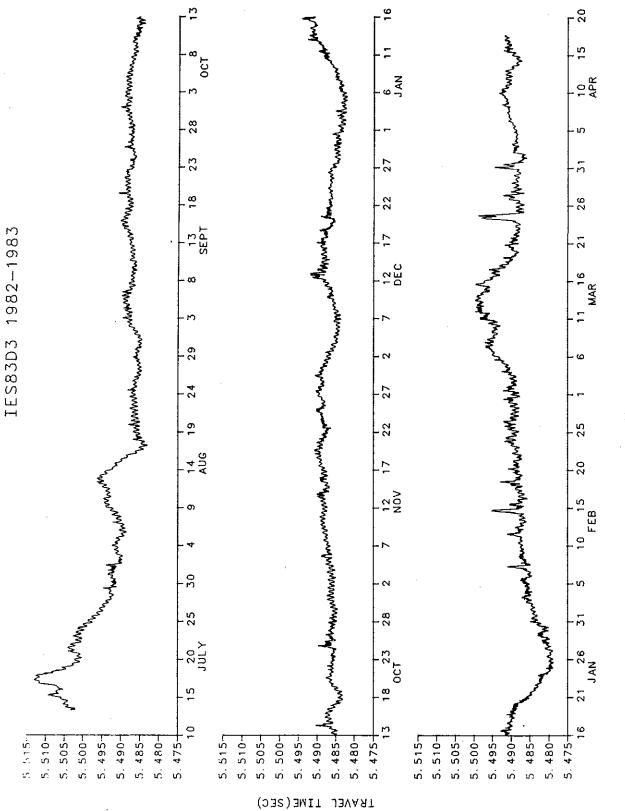
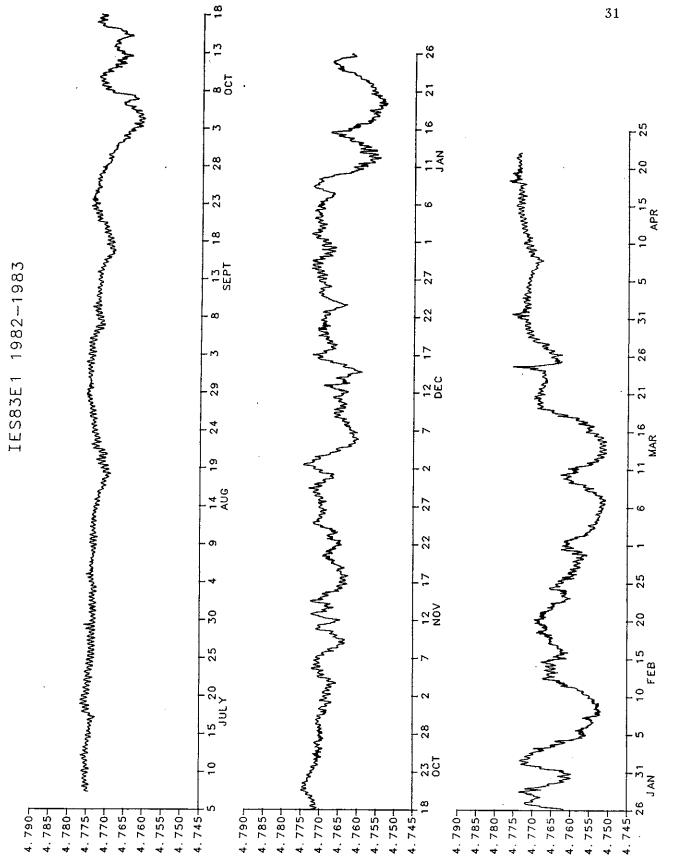
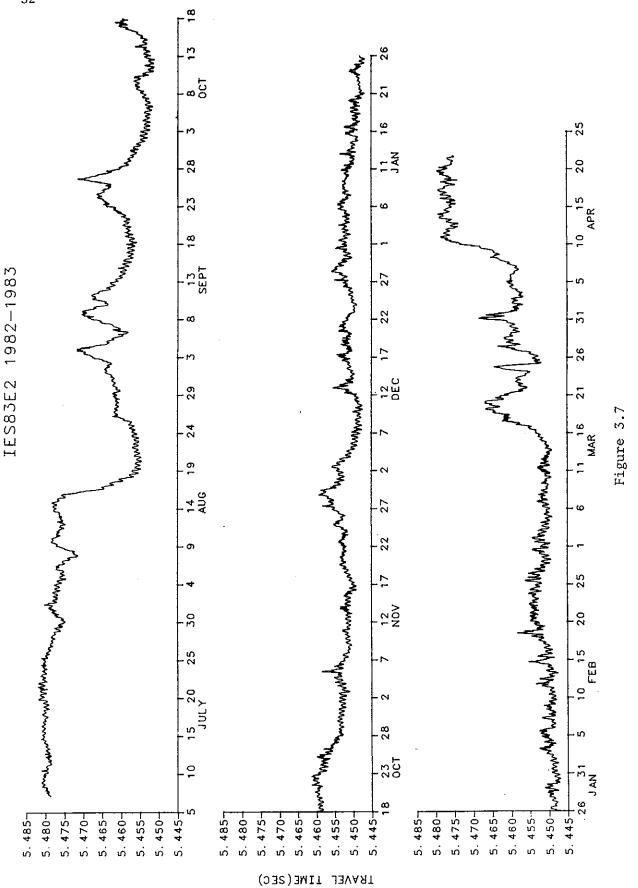


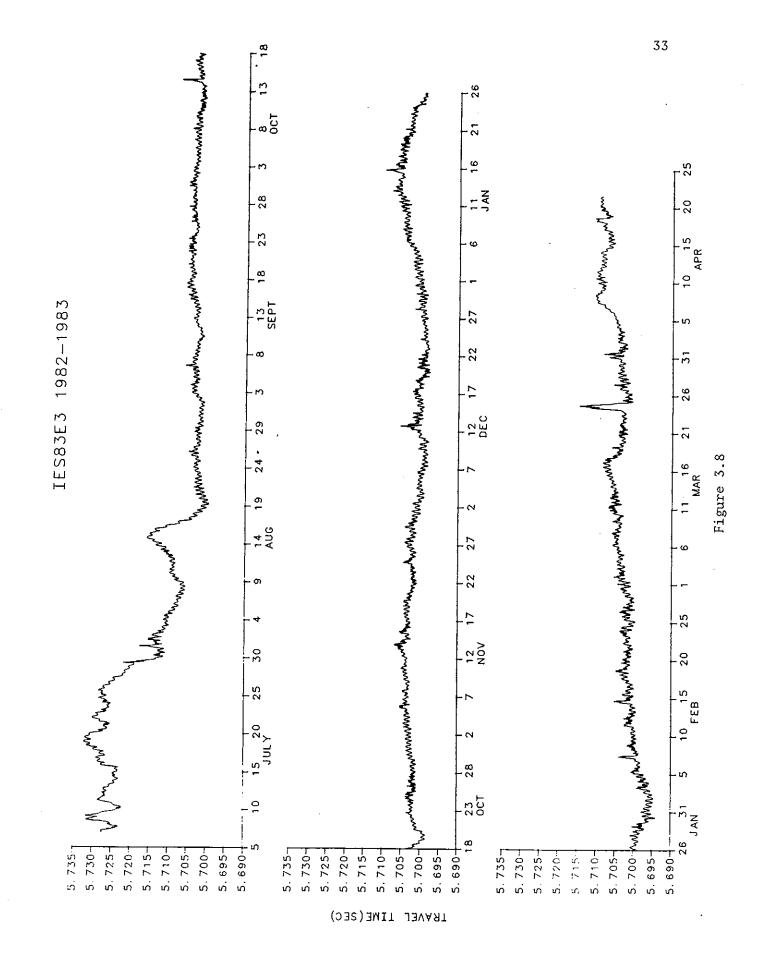
Figure 3.5



TRAVEL TIME (SEC)

Figure 3.6





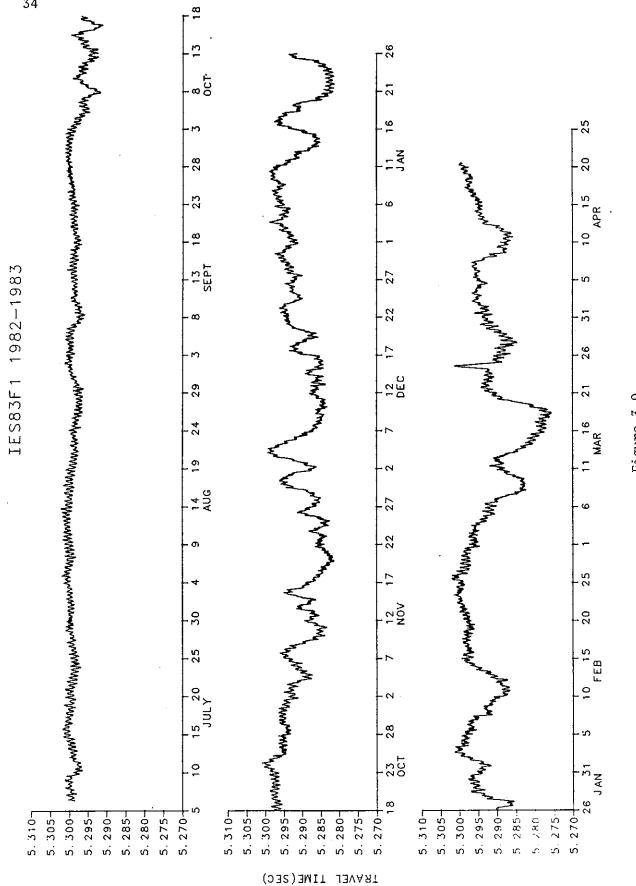
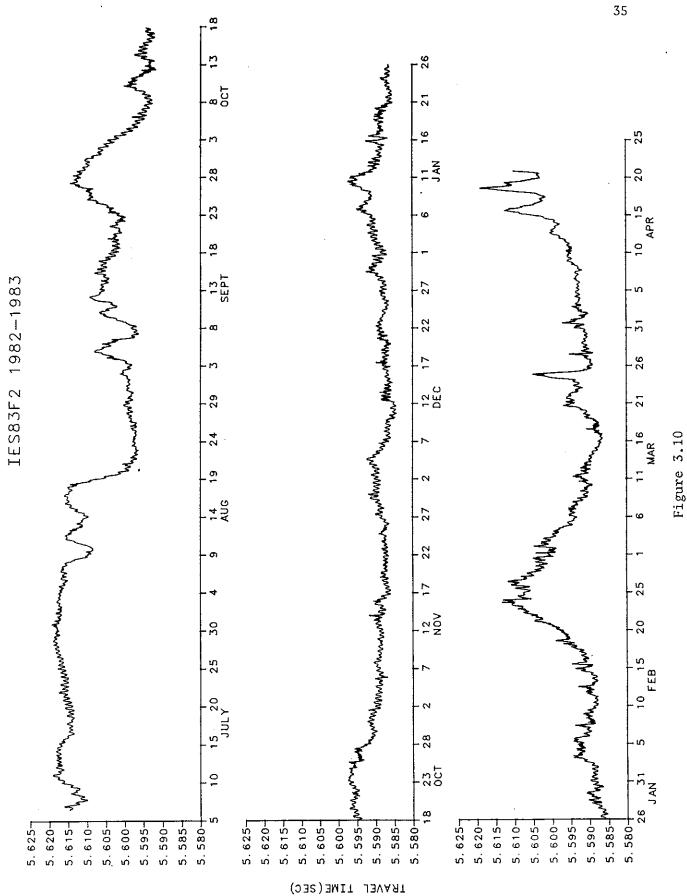
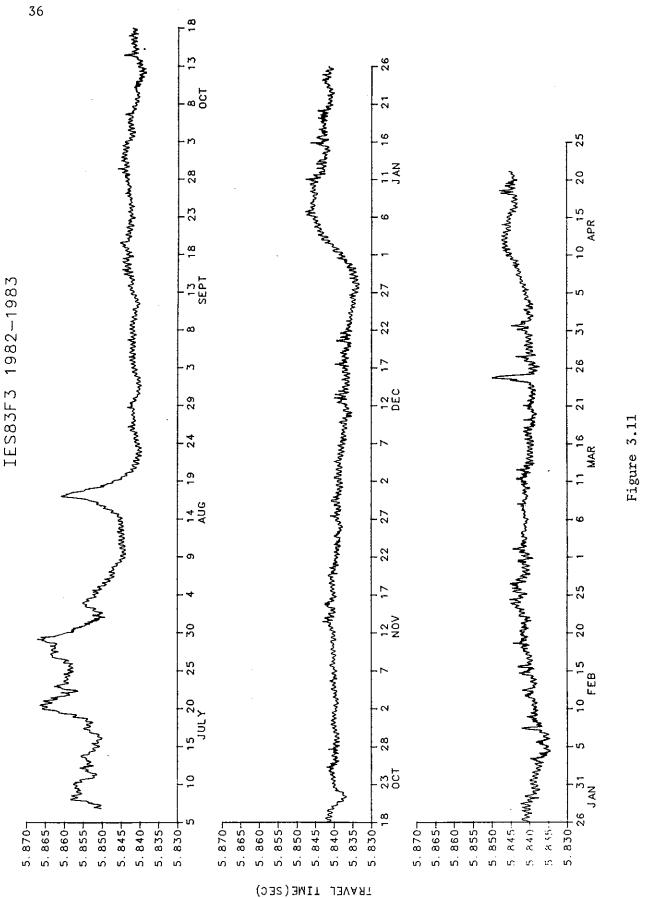


Figure 3.9





SECTION 4

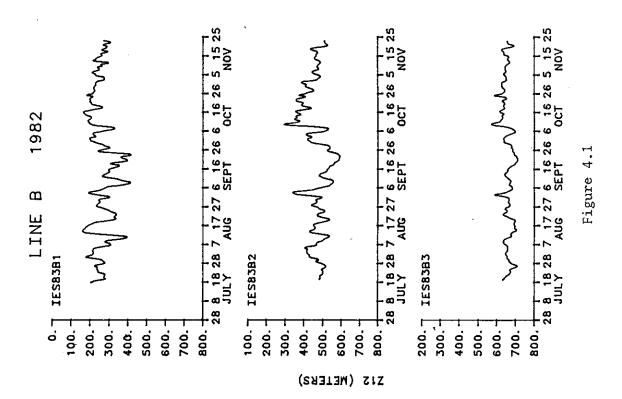
40 HRLP Thermocline Depth Data For Each Cross-Stream Line

The 40 HRLP thermocline depths (Z_{12}) are plotted for each instrument. These are grouped by cross-stream line, with the northwesternmost IES on each line plotted at the top of the figure. Each plot is labelled with the instrument name in the upper or lower left corner.

The time scale is the same for all plots, with each increment corresponding to 10 days. The axis begins on 0000 GMT of the first date labelled.

Vertical scale for the Z_{12} records is consistent for all the plots; each increment corresponds to 100 m.

The sampling interval is 6 hours. The length and the start and end times of the data records are tabulated in Section 2.



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Figure 4.1-4 40 HRLP thermocline depth data along lines B to F.

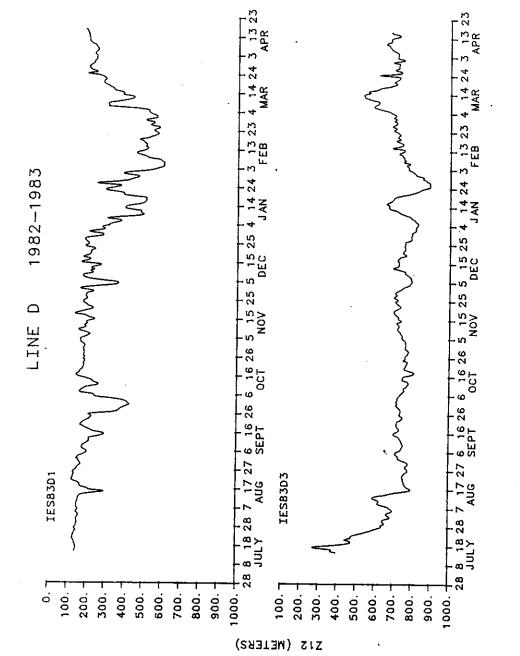


Figure 4.2

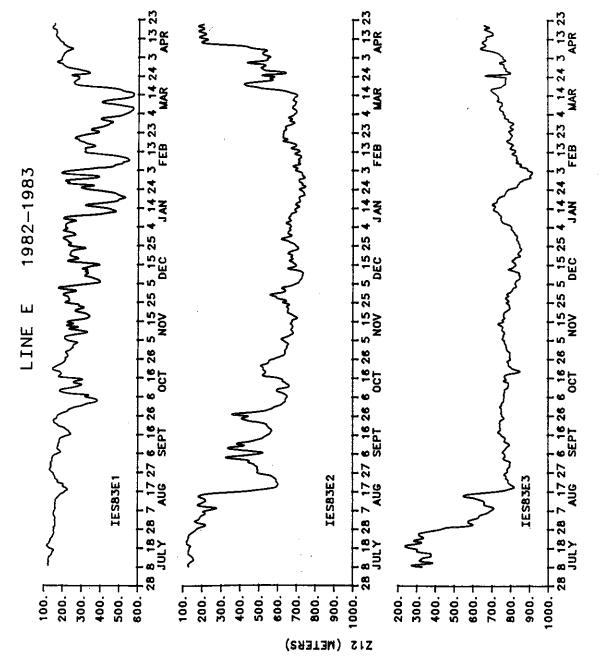


Figure 4.3

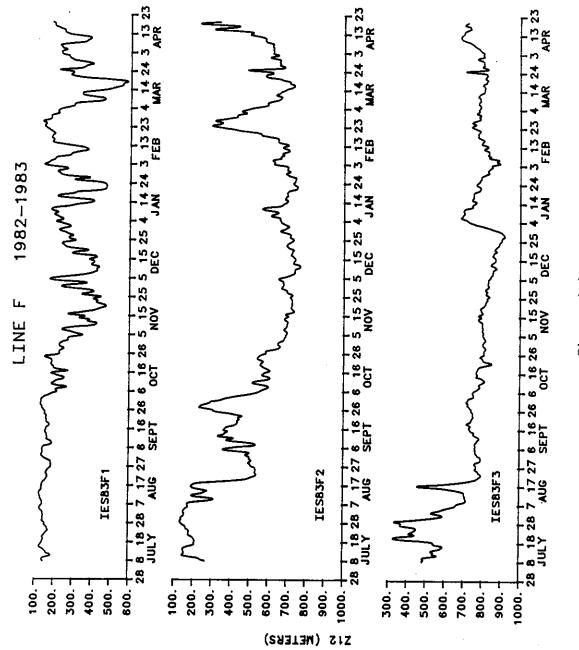


Figure 4.4

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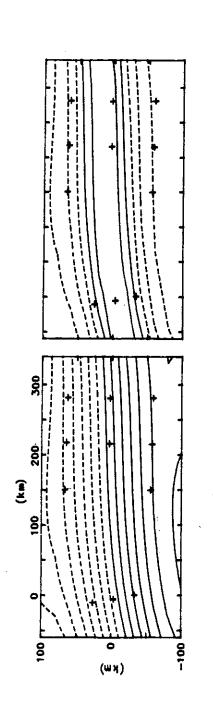
SECTION 5

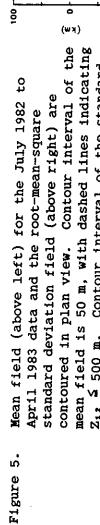
Thermocline Depth Maps: Mean and Standard Deviation Fields, Error Fields, and Daily Thermocline Depth and Perturbation Fields

Contour plots of the mean thermocline depth and standard deviation fields, the error fields, the thermocline depth (Z_{12}) fields, and the perturbation fields are presented.

Two different sizes of regions are mapped, depending on the number and location of the instrumented sites. These are: a) From July to November 1982, the region is 200 km cross-stream by 400 km downstream. b) From November 1982 to April 1983, it is 200 km by 240 km. The inset in Figure 5 shows the relationship of these regions to each other; the upper right-hand corner of both regions corresponds to the same location. In Figures 5-7, each of the contoured frames corresponds to either the full boxed region in Figure 1 (areas 1 and 2 in the inset of Figure 5) or a portion of it (area 2 in Figure 5). The boxed region is oriented 064°T, and north is indicated by the arrow in Figure 5. The horizontal scales in Figure 5 apply also to the frames in Figures 6 and 7.

Each frame consists of a grid of points at 20 km spacing. The actual IES sites are indicated by the + marks and the positions are listed in Table 1. During April 1983, most of the IESs documented in this report were recovered and redeployed at the same locations. Thus for 17-27 April 1983, the most accurate Z_{12} maps were obtained by combining the data records from this deployment period and the next one. The positions of the instruments and their data records from the April 1983 to June 1984 deployment are presented in Tracey and Watts (1986b).





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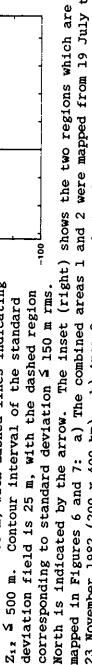
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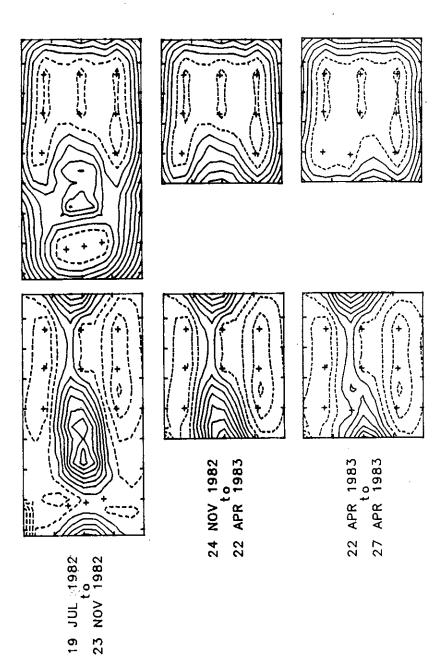
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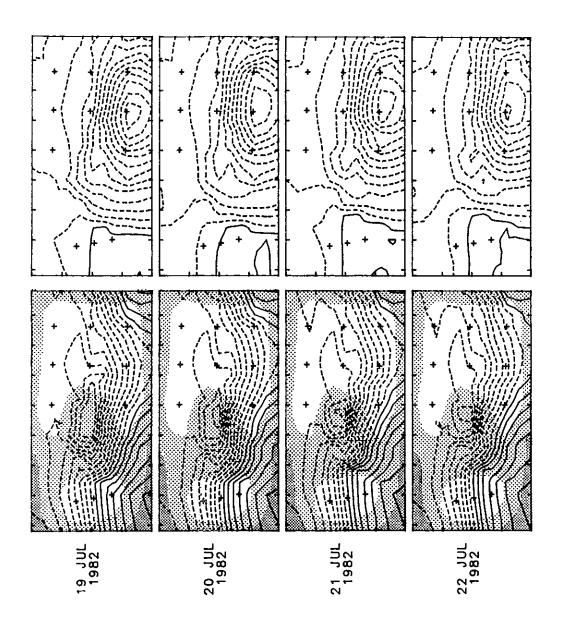
mapped in Figures 6 and 7: a) The combined areas 1 and 2 were mapped from 19 July to 23 November 1982 (200 x 400 km). b) Area 2 corresponds to the region mapped from 24 November 1982 to 27 April 1983 (200 x 240 km).



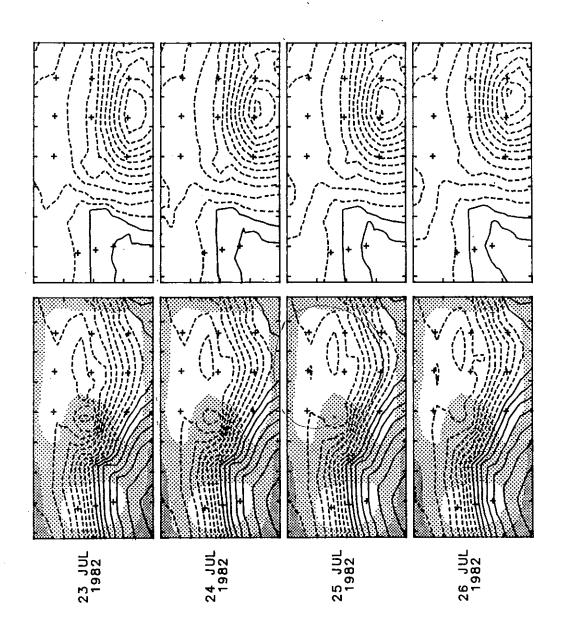
fields in Figure 7 for the dates shown. The horizontal scales are the same as those 5°% fields (left) have a contour interval of 10 m and the dashed region corresponds to labelled in Figure 5, with the upper right-hand corner of all frames corresponding The error (percent standard deviation) fields, shown at right, are contoured at The three sets of error maps apply to the $Z_{1,2}$ and perturbation The error-bar intervals, with the dashed region corresponding to < 15% error. to the same location. errors < 50 m. Figure 6.

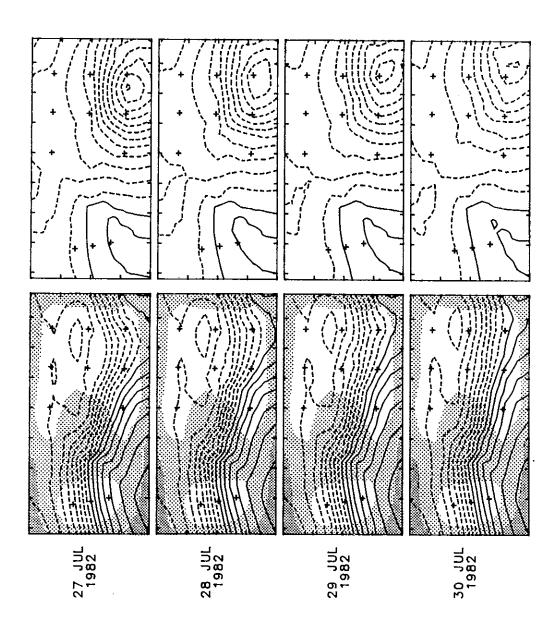
Figure 7. The 12°C isotherm depth (Z_{12}) field (left) and the perturbation field (right) are shown at daily intervals from 19 July 1982 to 27 April 1983. The maps are shown for 1200 GMT on the date indicated at the left. Contour interval of the perturbation field is 0.5 with the dashed region corresponding to negative values. The Z_{12} field is contoured at 50 m intervals and depths shallower than 500 m are dashed. The lighter shaded area corresponds to regions of $\geq 15\%$ estimated error and the darker shading to errors of $\geq 35\%$, as shown in the error maps in Figure 6.

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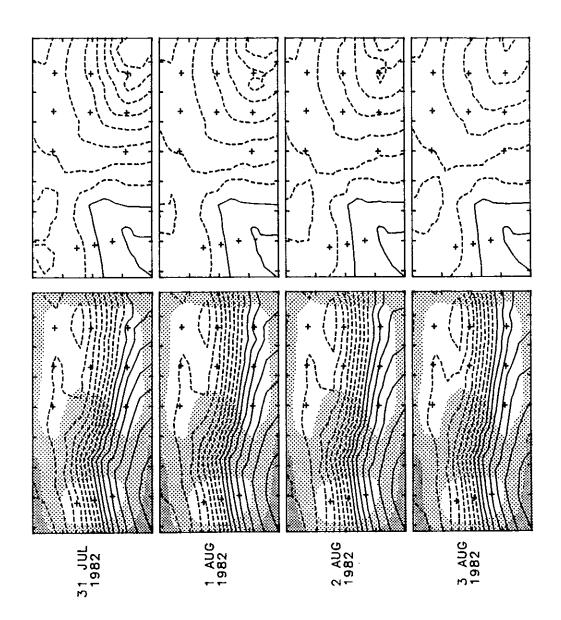


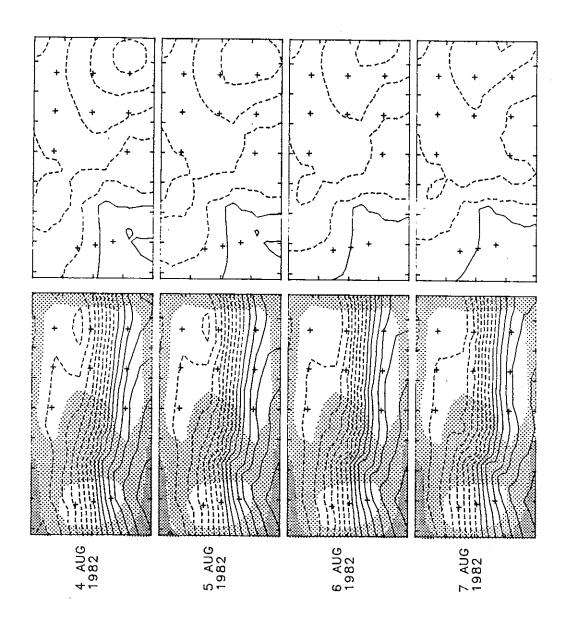
J.

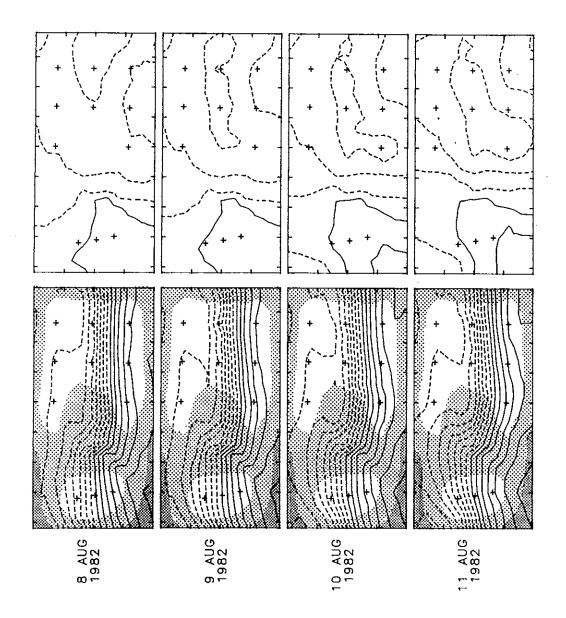


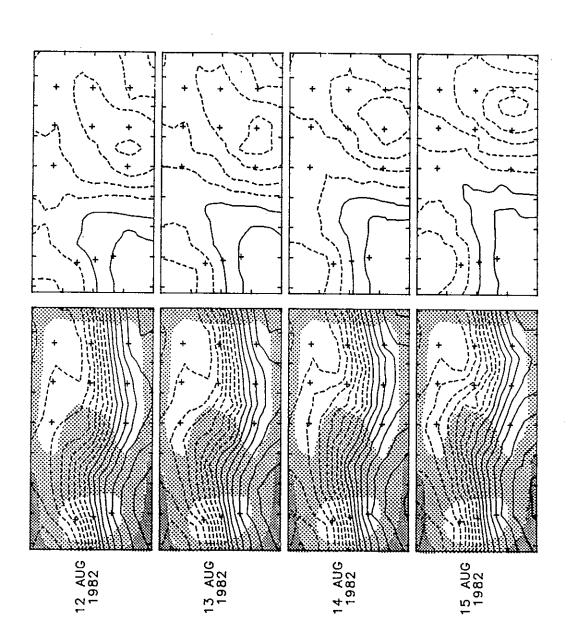


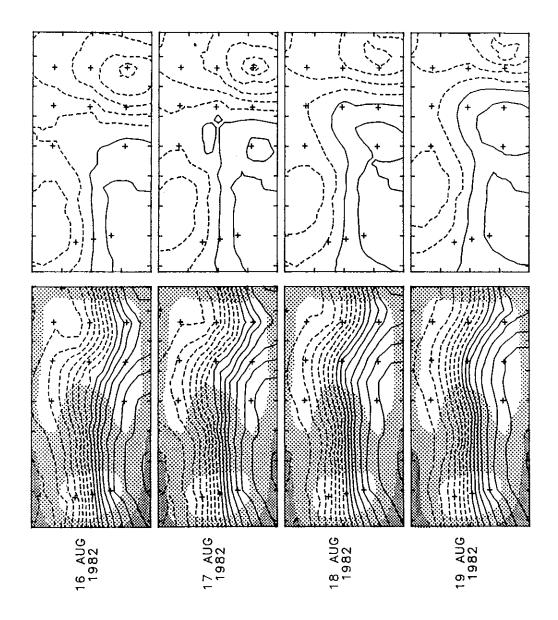
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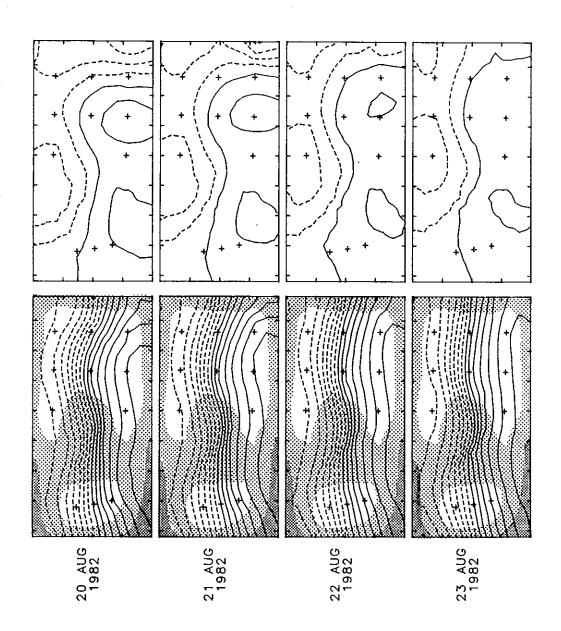


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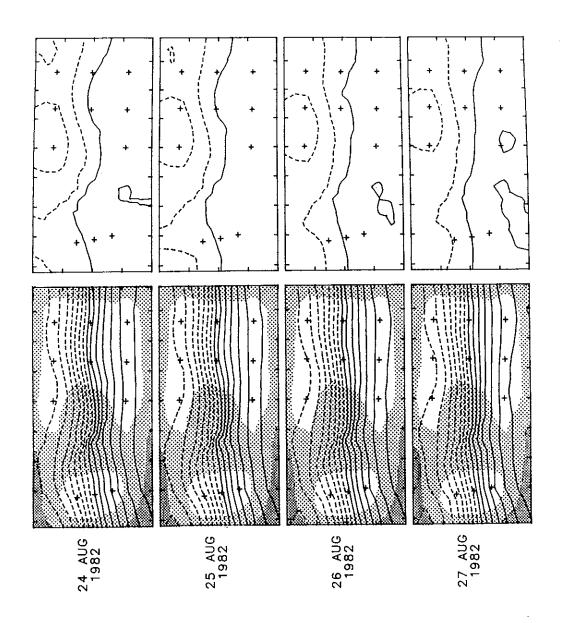
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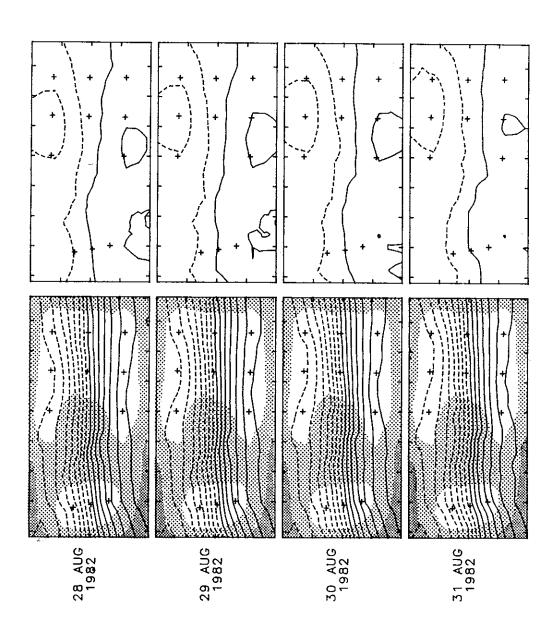
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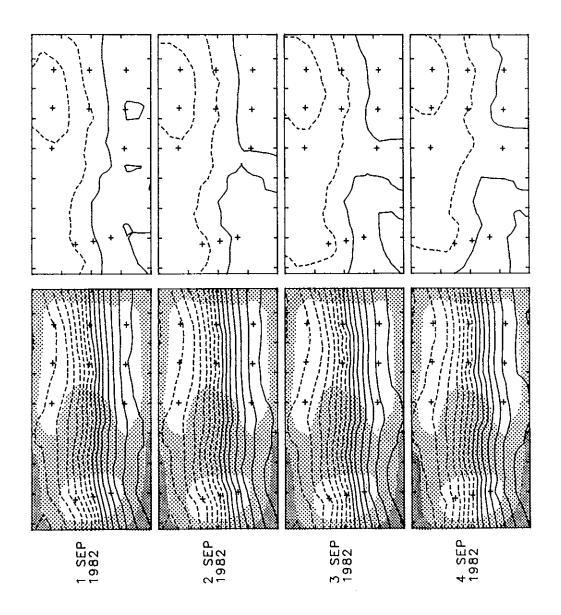


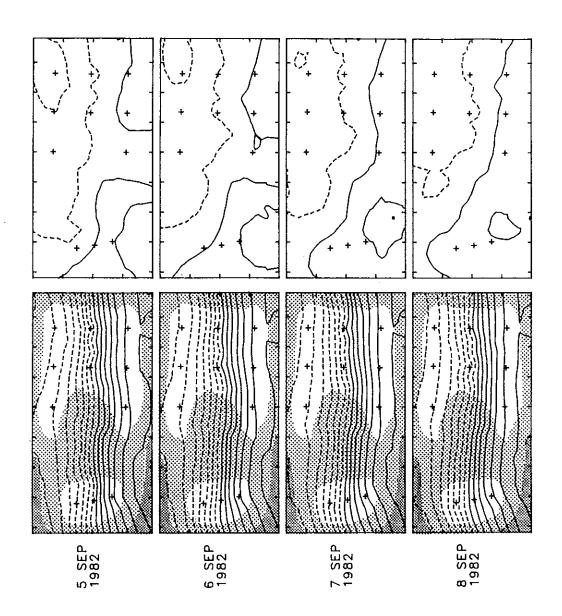
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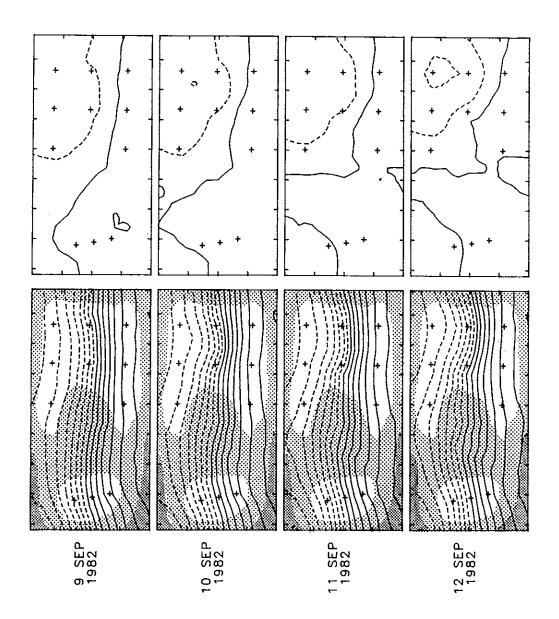


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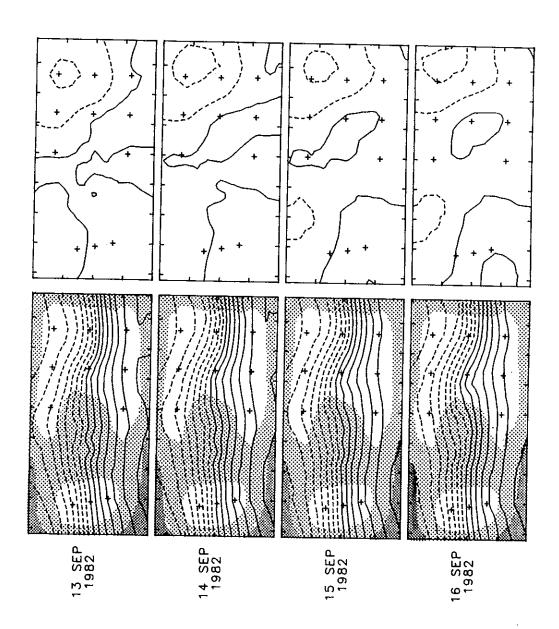


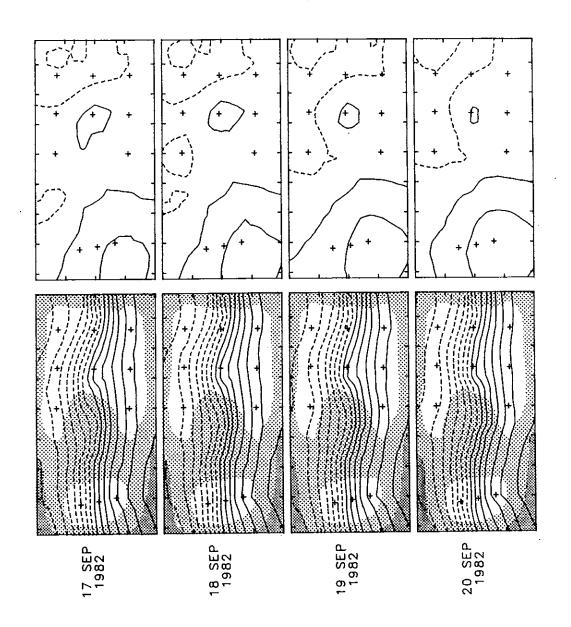


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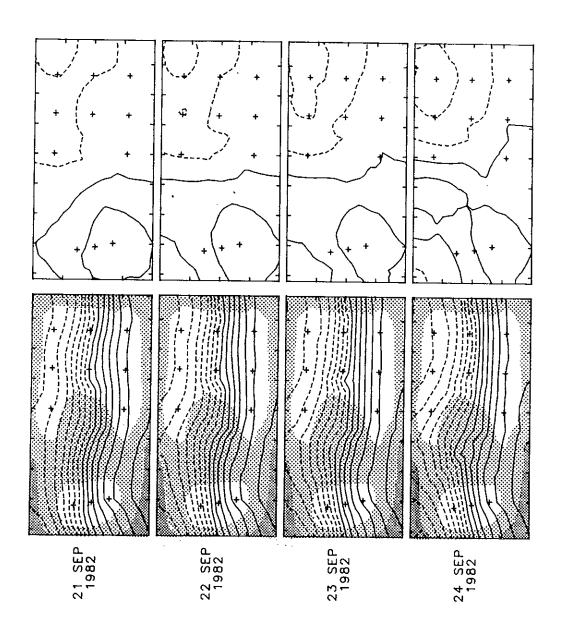


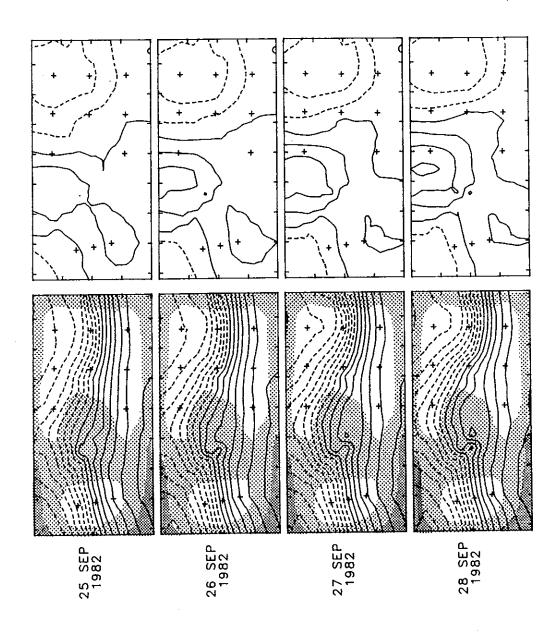
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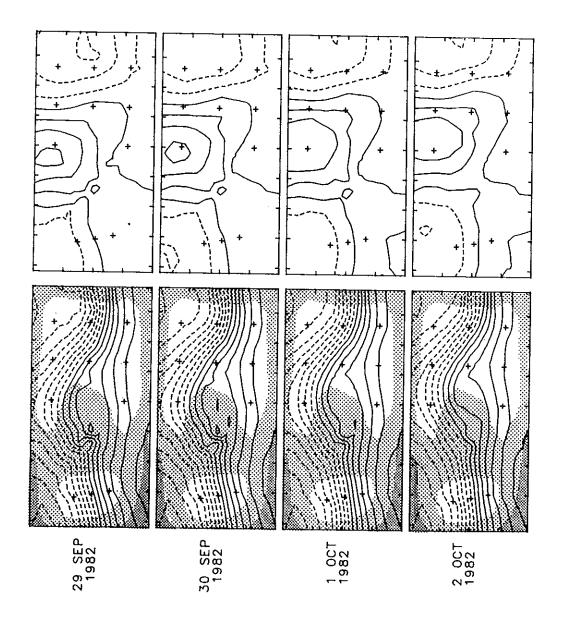


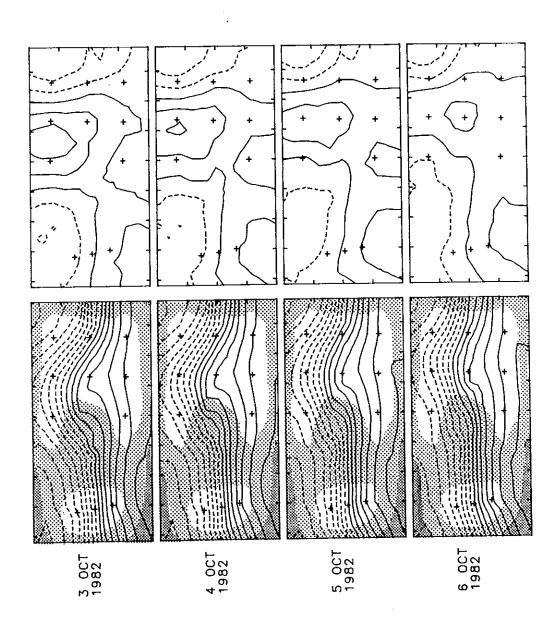


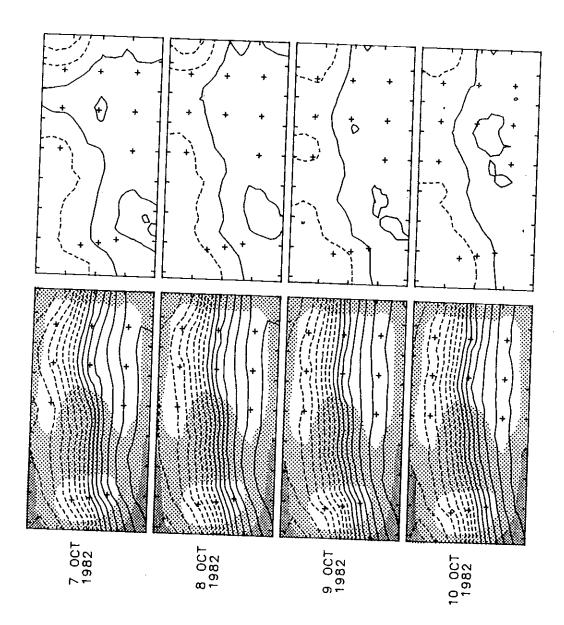
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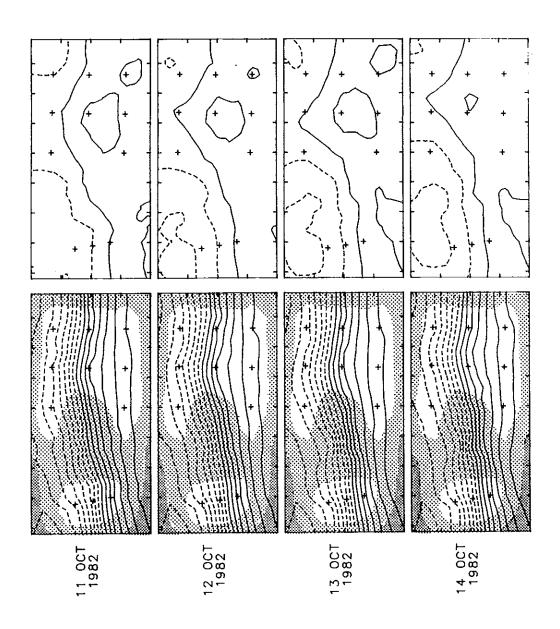


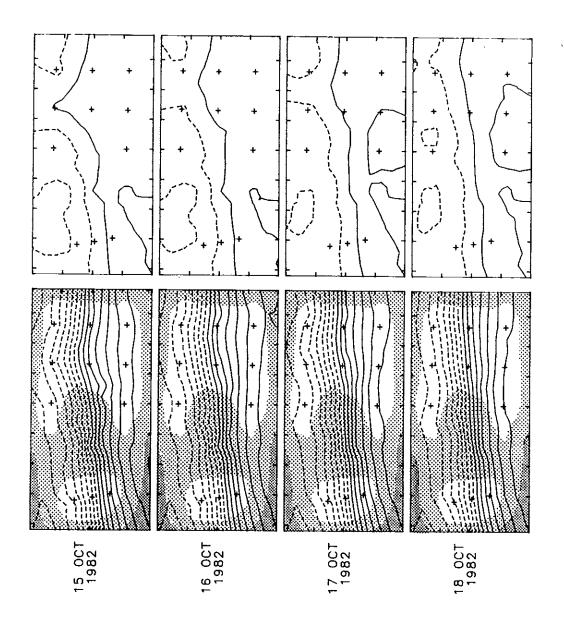


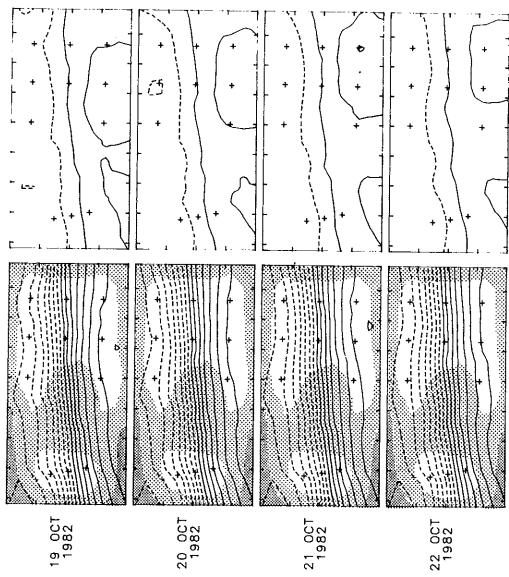


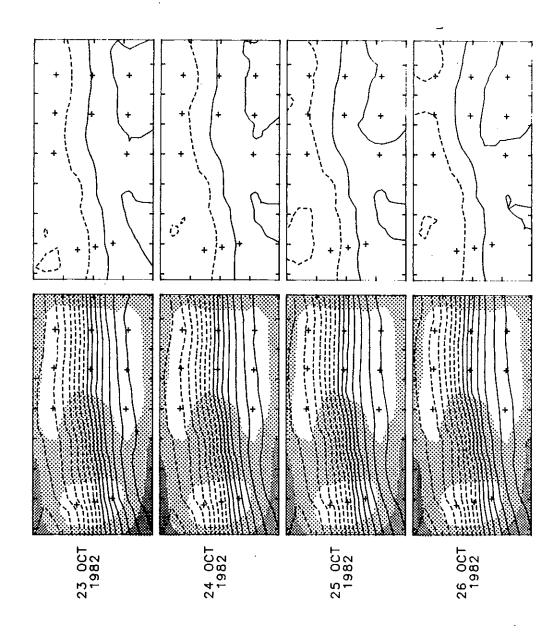




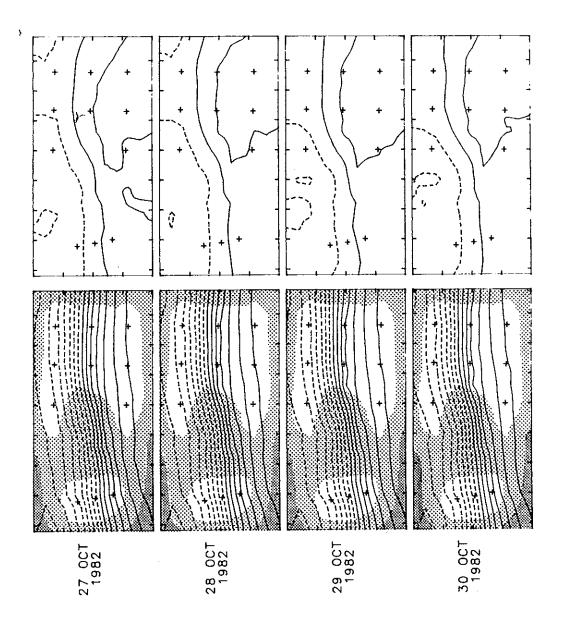


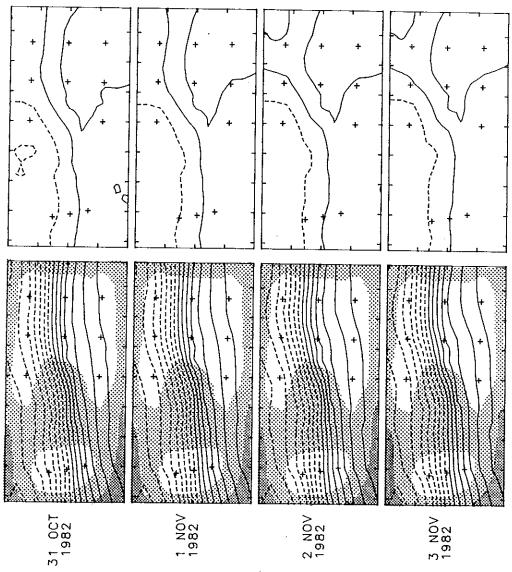




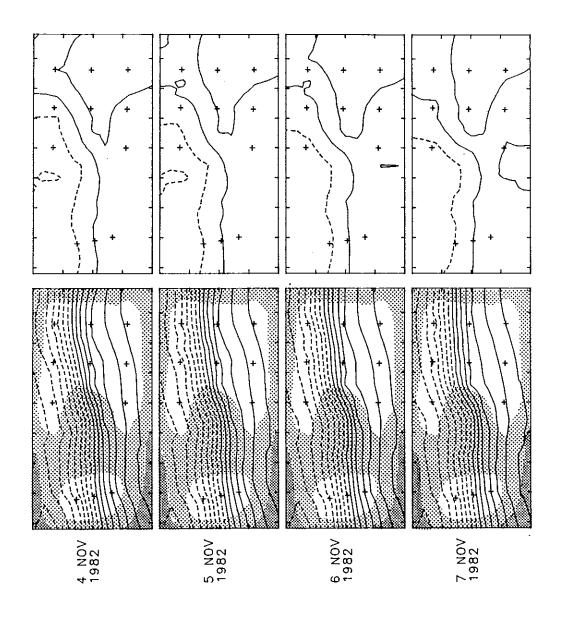


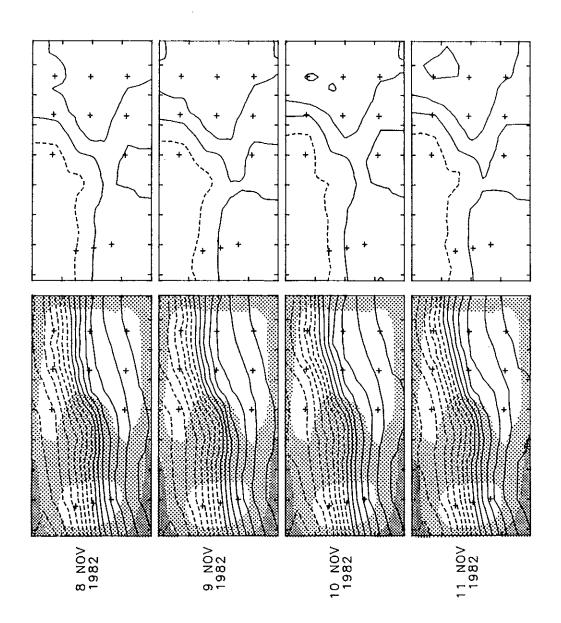
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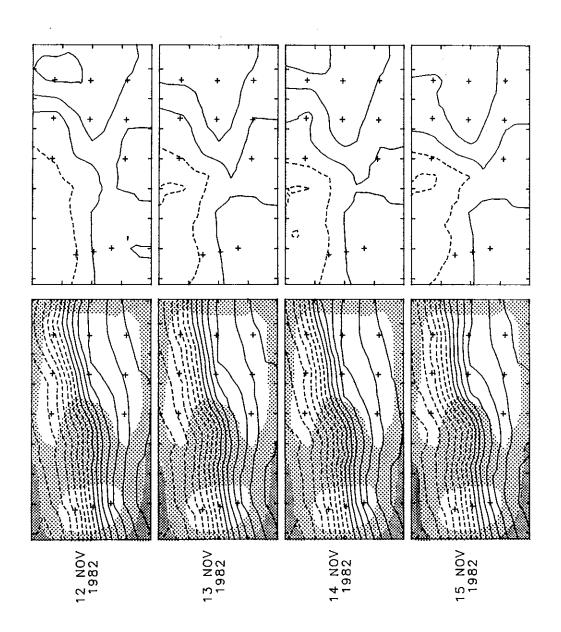
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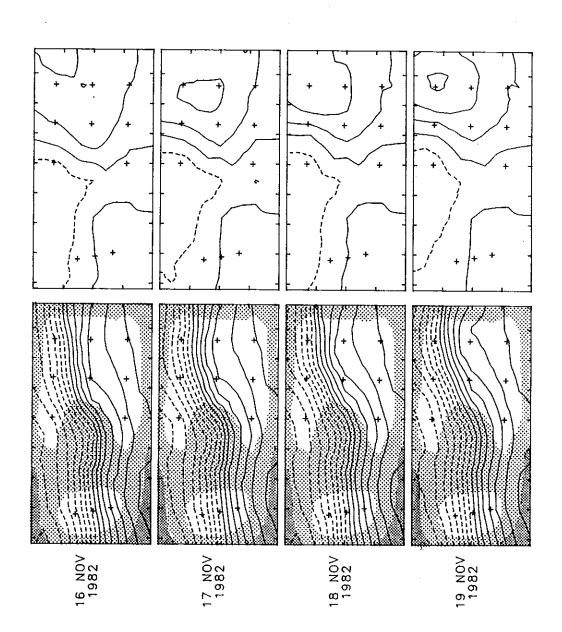
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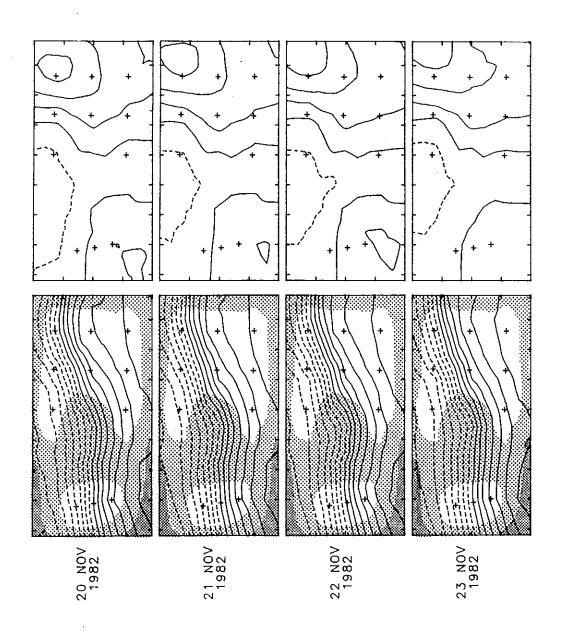


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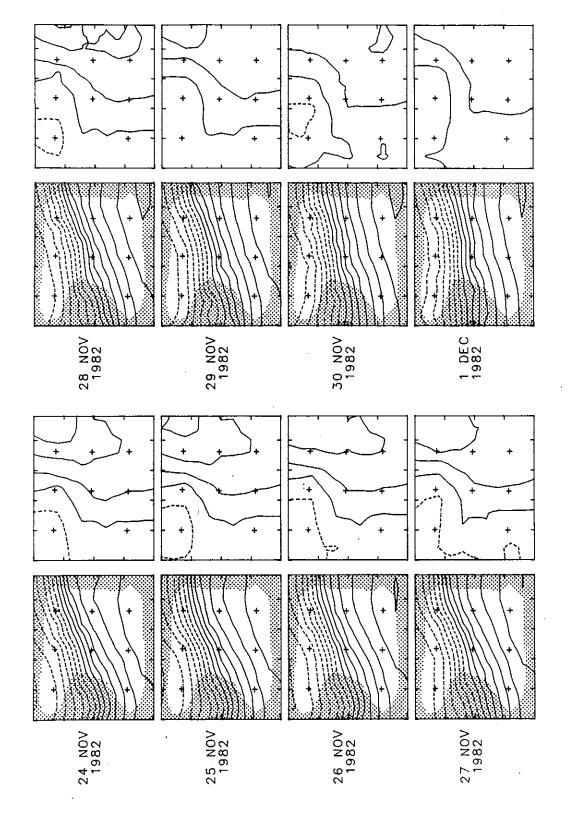
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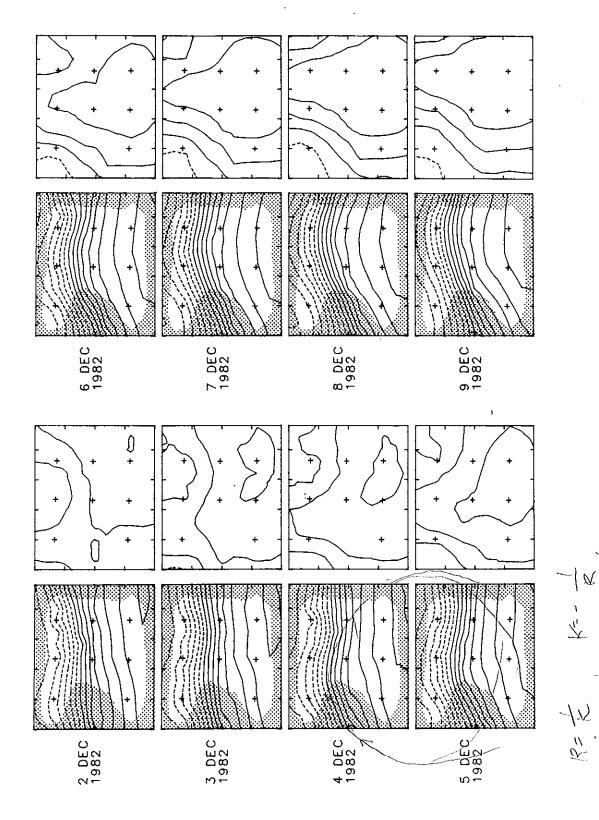


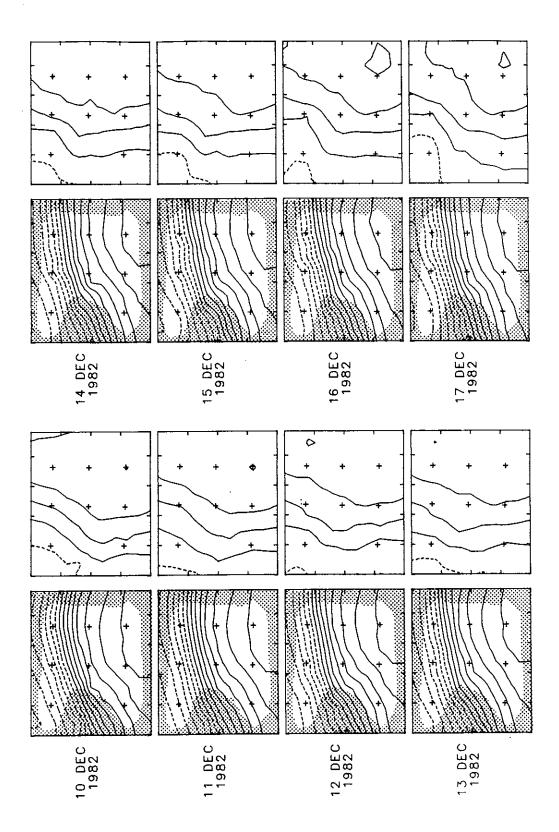
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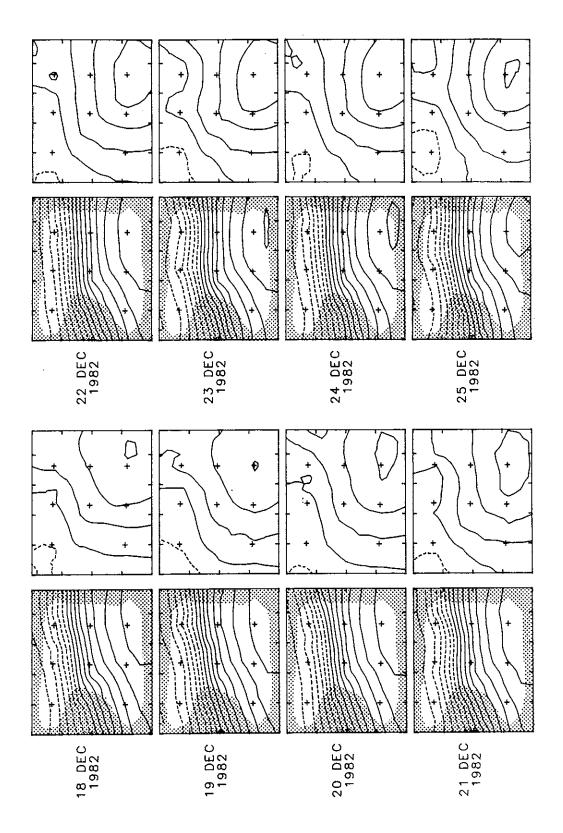


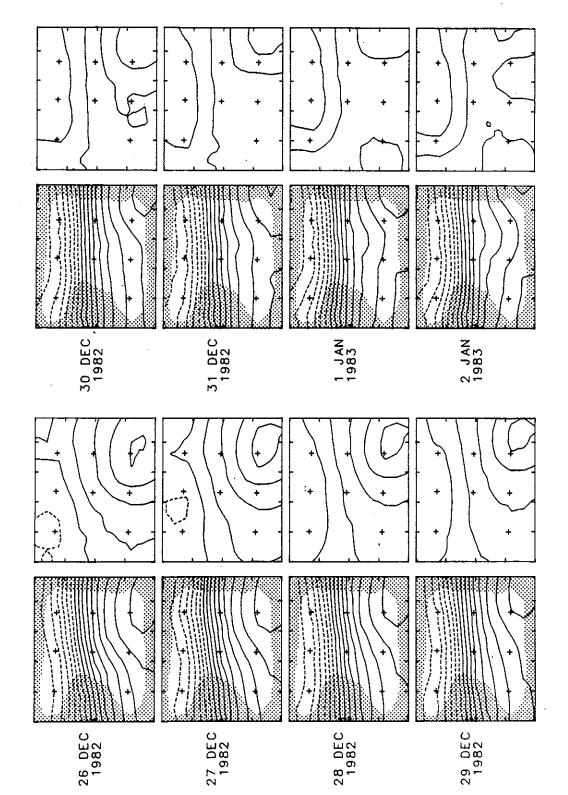
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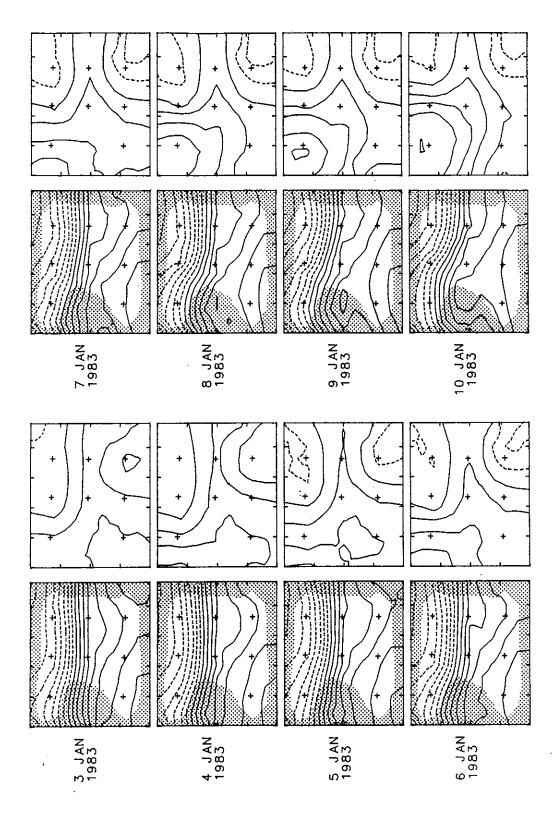




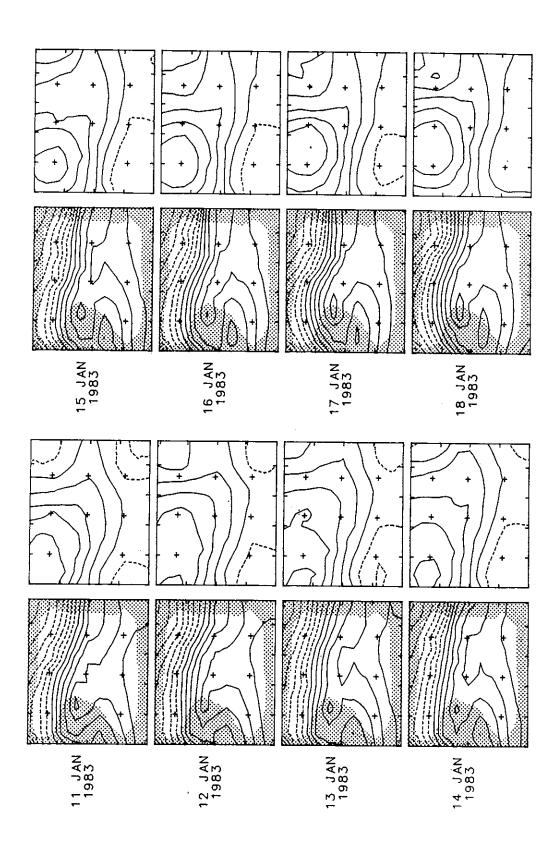


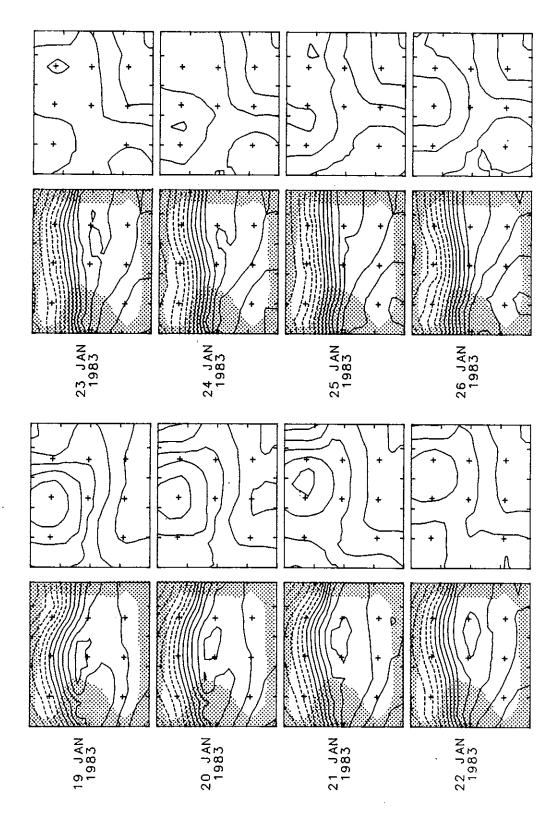


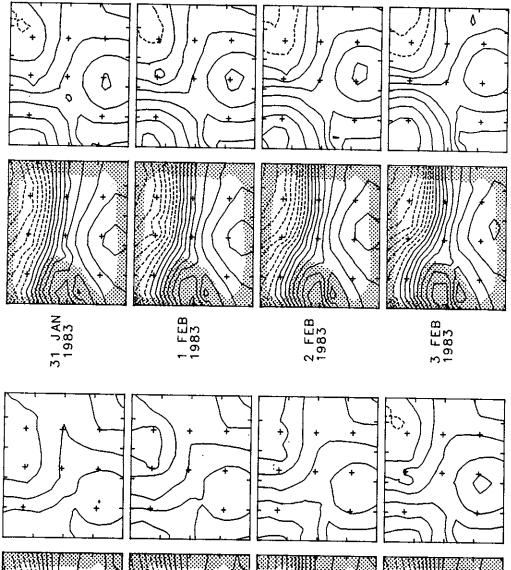
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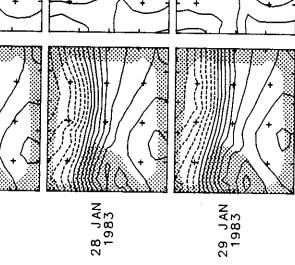


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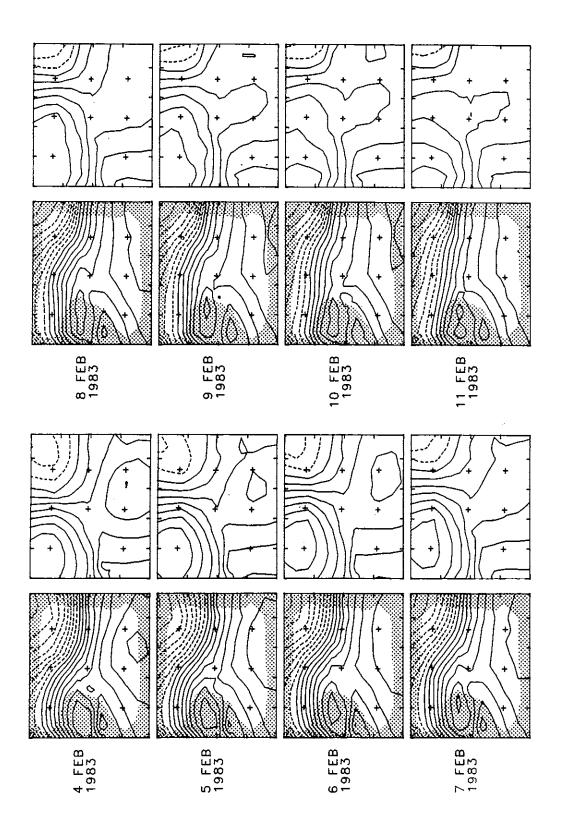


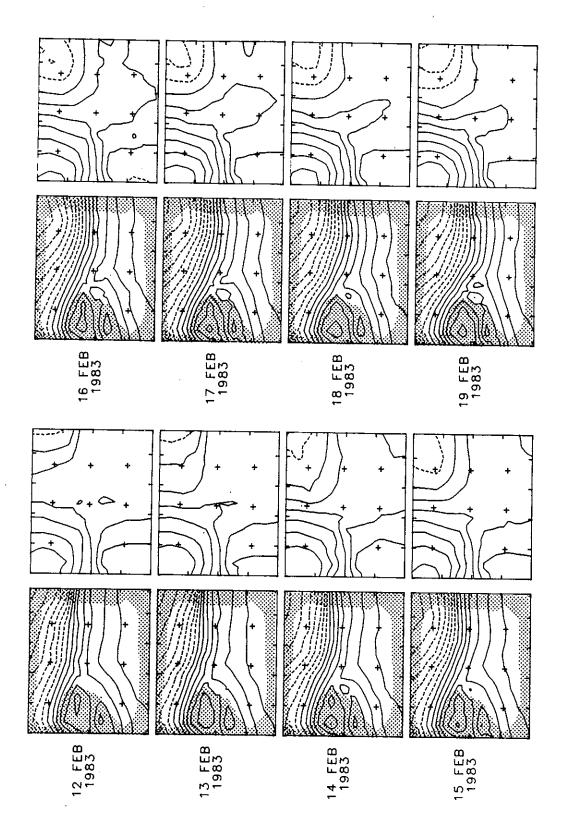


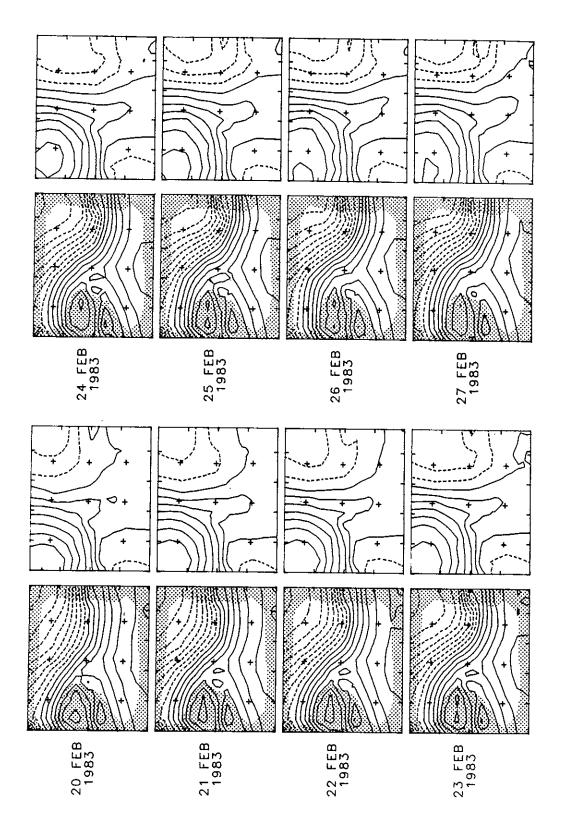
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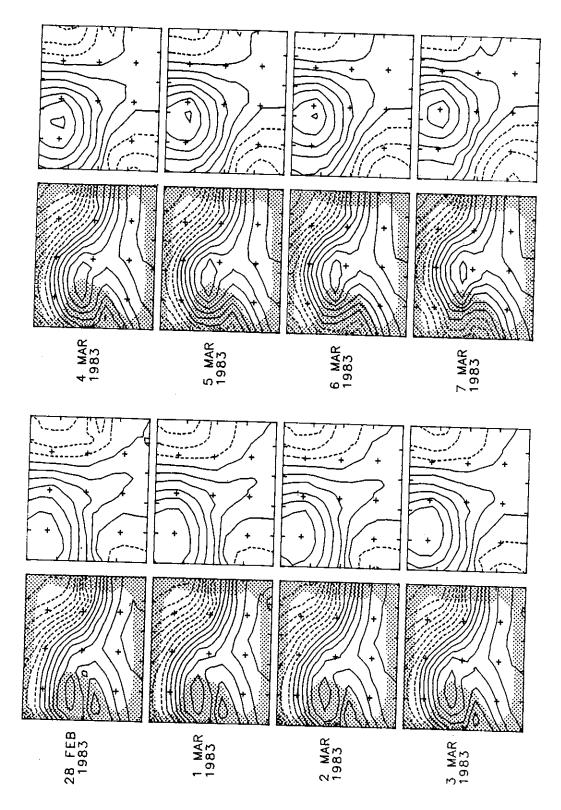
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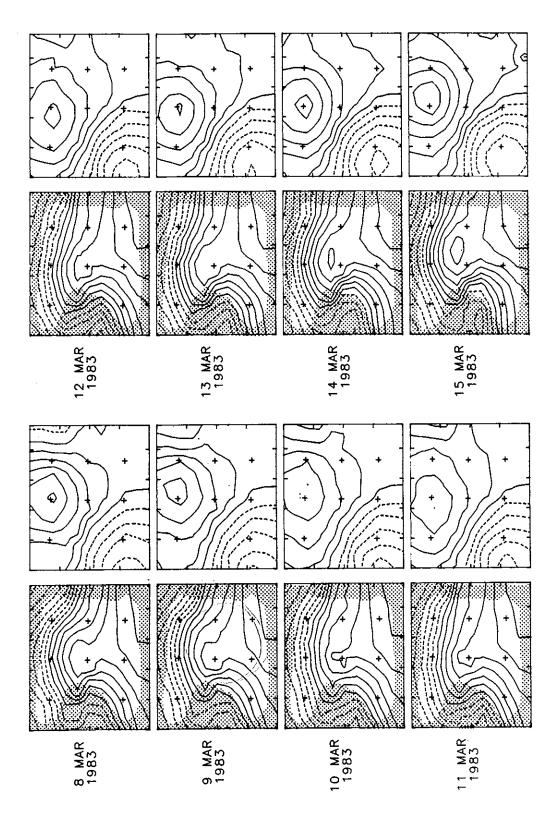
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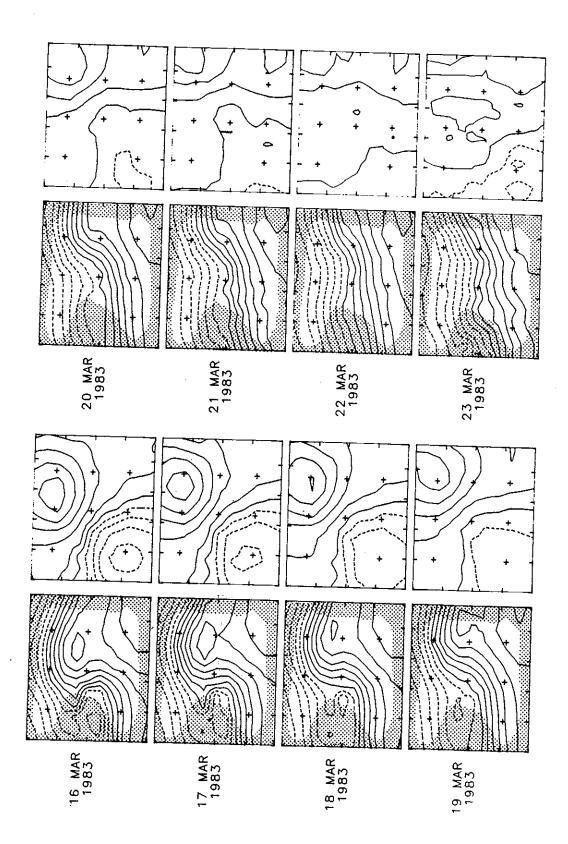


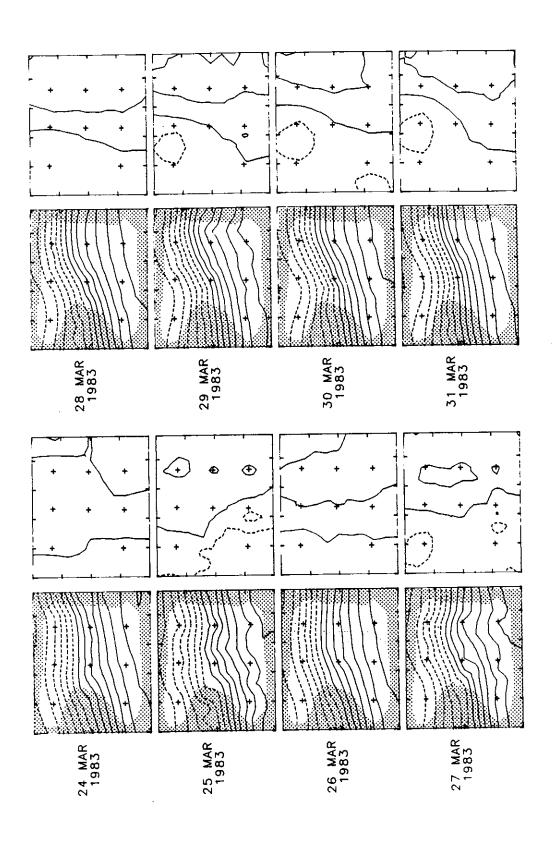


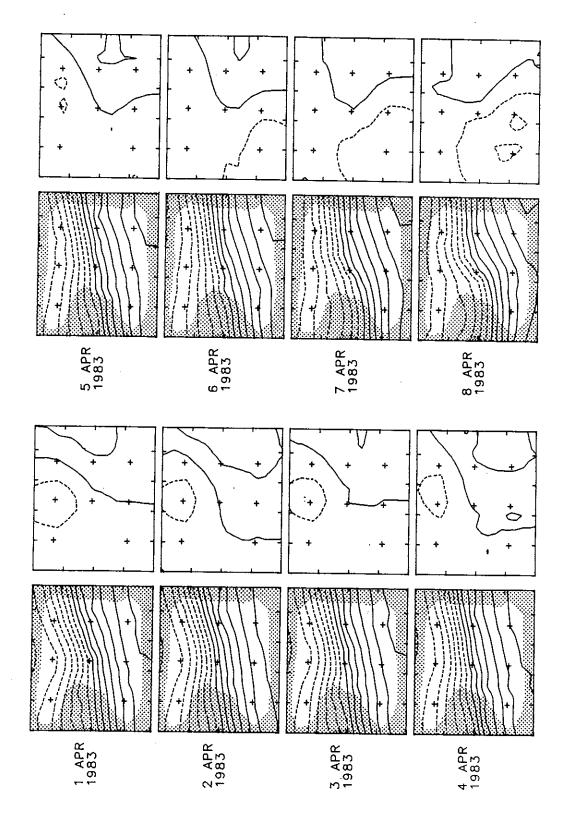


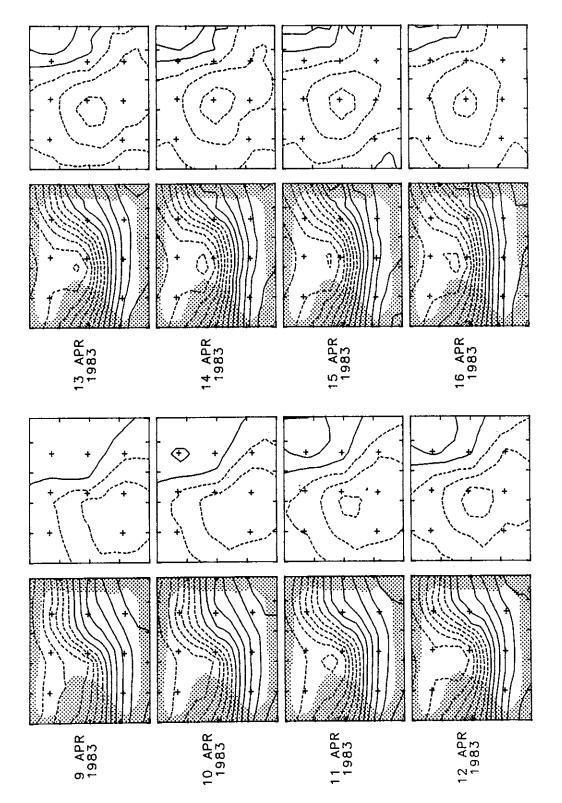


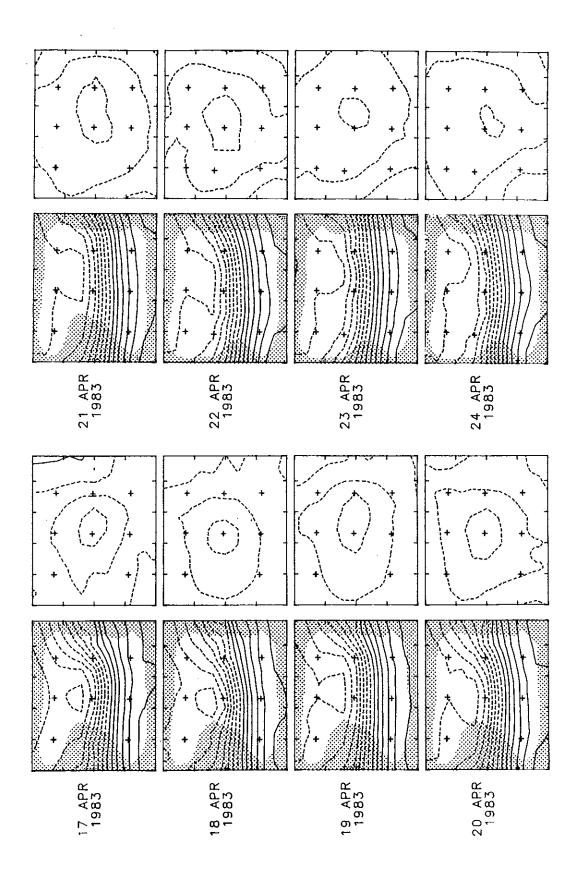


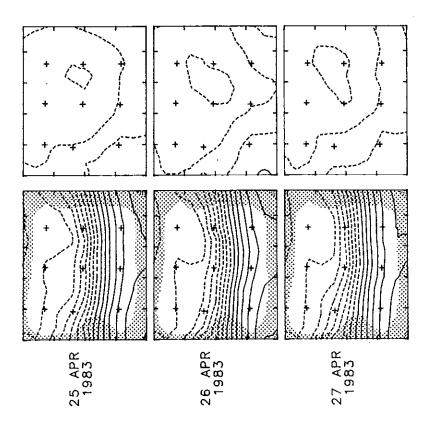












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