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*SACLANT UNDERSEA
RESEARCH CENTRE*

MEMORANDUM



**Surface measurements made
from the R/V Alliance during
the Mediterranean Aircraft-Ship
Transmission Experiment
(MASTEX), June 1990**

P.J. Minnett

December 1992

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SACLANT Undersea Research Centre
Viale San Bartolomeo 400
19138 San Bartolomeo (SP), Italy

tel: 0187 540 111
fax: 0187 524 600
telex: 271148 SACENT I

NORTH ATLANTIC TREATY ORGANIZATION

SACLANTCEN SM-264

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H. Urban
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Executive Summary: High resolution images of sea surface temperature (SST) from satellites are a critical source of data for large area ocean modeling, results of which can be used as input for acoustic propagation models. The utility of the satellite images for such modeling is greatly enhanced when the images can be processed to give calibrated measurements. In order to retrieve calibrated SST measurements from satellite images, it is essential to account for the effects of the intervening atmosphere.

This report presents measurements of surface oceanographic and meteorological variables taken from NRV *Alliance* during its cruise in June 1990 in the area north of Crete and in the Ionian Sea as part of the Mediterranean Aircraft-Ship Transmission Experiment (MASTEX), a collaborative experiment with the UK Meteorological Office.

This data will be used to verify the numerical models which simulate the passage through the atmosphere of radiation detected by satellite radiometers. The data collected from NRV *Alliance*, along with similar data from participating aircraft, will be used for direct validation of satellite SST measurements.

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**Surface measurements made
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June 1990**

P.J. Minnett

Abstract: Measurements of sea-surface temperature, surface meteorology and atmospheric profiles taken during the June 1990 cruise of the R/V *Alliance* in the Aegean and Ionian Seas are presented in graphical form. True winds, net long-wave radiation and turbulent air-sea fluxes have been calculated and are also presented. The data reported form part of the 'MASTEX' (Mediterranean Aircraft-Ship Transmission Experiment) data set which includes airborne measurements from the C-130 of the UK Meteorological Research Flight.

Keywords: Aegean Sea ◦ air-sea interaction ◦ diurnal thermocline ◦
Ionian Sea ◦ meteorology ◦ sea-surface temperature

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1

Introduction

This data report presents measurements of surface oceanographic and meteorological variables and of atmospheric temperature and humidity profiles taken on board R/V *Alliance* during the cruise in the Sea of Crete and Ionian Sea during 1–12 June 1990 (Fig. 1).

The measurements taken on board the *Alliance* are presented as time series of calibrated variables, or as vertical profiles through the atmosphere. Some derived quantities relevant to the surface heat budget have been calculated and are also presented as time series.

1.1. BACKGROUND

Measurements of sea-surface variables from instruments on earth satellites are of increasing importance in oceanography, in climate change studies, and in monitoring the marine environment. In particular high resolution ($\sim 1 \text{ km}^2$) images of sea-surface temperature (SST) are an important source of information on the surface thermal structure. Such images are provided by the Advanced Very High Resolution Radiometer (AVHRR) on the polar orbiting satellites of the US NOAA series. While the uncalibrated images contain a wealth of information on the form and spatial distribution of oceanic thermal fronts, the utility of such measurements, especially when used in conjunction with upper ocean thermodynamic and hydrodynamic models, is greatly enhanced when the satellite measurements are processed to give calibrated measurements of the SST.

A critical step in the data processing to retrieve SST from the satellite measurements is in accounting for the effects of the intervening atmosphere. This is done by combining collocated measurements taken at different wavelength intervals (or channels) according to a simple algorithm. The precise form of the algorithm, or the coefficients used in an algorithm, can be determined by either comparing large sets of simultaneous satellite and *in situ* measurements or by numerical simulations of the passage through the atmosphere of the radiation detected by the satellite radiometer [Minnett, 1988; 1990]. Satellite measurements from which SST values can be derived are usually taken in the infrared part of the electromagnetic spectrum (although some measurements have been successfully made with those detecting microwave radiation), in spectral intervals where the atmosphere is relatively transparent. One such 'atmospheric window', at 10–12 μm wavelengths, roughly coincides with the peak of the Planck function at temperatures typical of the sea-surface,

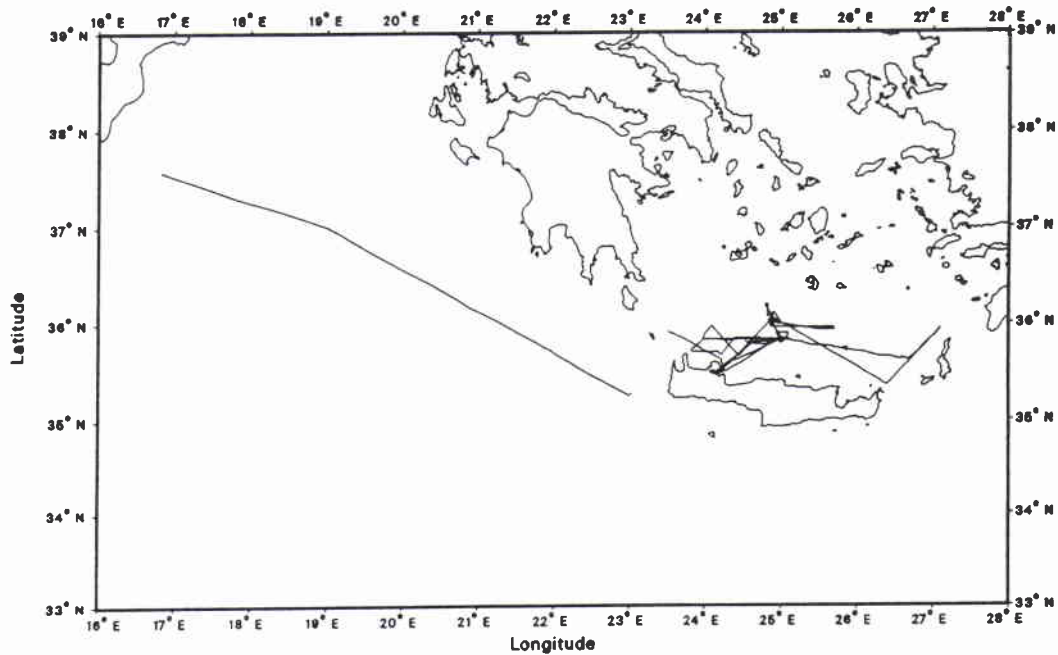


Figure 1 *A track plot of the position of the R/V Alliance for the period covered by this report. The ship was to the north of Crete for the period June 1 to June 10, and on the section from Crete towards Italy on June 11 and 12.*

and channels 4 and 5 of the AVHRR share this 'window'. The main component of atmospheric effects in this spectral interval is that due to water vapour, which exhibits so-called continuum absorption, and emission, and this has a wavelength dependence across the window, being more absorbing at longer wavelengths. To accurately simulate the satellite measurements, the effects of the atmosphere on the infrared radiation propagating through it must be well understood.

SACLANTCEN SM-264**1.2. OBJECTIVES**

In the numerical simulation of satellite measurements in the 10–12 μm interval, one of the main uncertainties is the description of the correct behaviour of the atmospheric water-vapour continuum [Grant, 1990]. Measurements designed to study these atmospheric effects were made during a cruise of the R/V *Alliance* in June 1990 in a collaborative experiment with the Meteorological Research Flight of the UK Meteorological Office, called the Mediterranean Aircraft-Ship Transmission Experiment (MASTEX). During this experiment radiometric SST measurements were made from the ship and an aircraft (a C-130 Hercules) which flew at various heights over the track of the ship (Kilsby *et al.* 1990). The ship-borne measurements also include *in situ* sea temperature, surface meteorology, and profiles of atmospheric temperature and humidity from balloon-borne instruments (radiosondes), while those from the aircraft included profiles of temperature, humidity, aerosols and broad-band radiation.

Those SST measurements from the ship and from the aircraft, when flying low, made at the time of satellite overpasses can be used for direct validation of the satellite SST measurements.

Furthermore the ship-borne measurements provide data for the study of the oceanic thermal skin effect [Robinson, Wells and Charnock, 1984], provide a record of the environmental conditions under which other activities on the ship were conducted, and contribute to the general body of knowledge of the oceanography and meteorology of the area.

2

Cruise details

The *Alliance* left Ancona at 13:00 UTC (15:00 local; all times given below are UTC) on May 29 1990 and sailed to Souda Bay, Crete, arriving at 05:00 on June 1. During this transit the instruments were reassembled and tested. The ship sailed from Souda Bay at 08:30, to an area to the north of Crete, returning to the port at 05:00 on June 2. In the course of this outing all of the instruments related to this project were brought on-line and routine data-logging began. The *Alliance* left Souda Bay at 09:00, June 2, and remained at sea, to the north of Crete, until returning to Souda Bay at 05:00 on June 10. The passage back to Italy began at 00:00 on June 11 and the ship docked at Civitavecchia on the morning of June 15. Daily ship tracks are presented in Appendix A.

Joint experiments with the C-130 aircraft were conducted on five days: June 7, 8, 9, 11 and 12. On each occasion the aircraft flew 'racetrack' flight patterns at a range of altitudes over the position of the ship. The alignment of the racetracks was along the ship's track so that the surface temperature measurements taken from the ship were repeated many times from the aircraft. The flight times were arranged so that the aircraft was taking measurements at the times of the overpasses of the NOAA-11 spacecraft. Full details of the aircraft operations are given by [Kilsby *et al.* 1990].

3

Instrumentation and Data Acquisition

The majority of measurements described in this report were obtained by the 'Satellite Validation System' [Minnett *et al.* 1991] of the R/V *Alliance*, often referred to as the ZAN¹ (ZENO¹ — *Alliance* — Network). This measures surface meteorological and oceanographic variables using instruments distributed about the ship (Fig. 2), the characteristics of which given in Table 1. The sensors are sampled by remote 'Intelligent Sensor Interfaces' (ISIs), where calibration coefficients are applied and where mean values of measurements are calculated and stored before being transmitted to a central computer on a fibre-optic Local Area Network. All of the sensors attached to the ZAN were sampled during this cruise at 1 Hz and a 1 min block average was generated at intervals of 1 min.

In addition to the computer-logged measurements the bridge officers take routine marine weather observations according to the WMO schedule, usually at 6-hour intervals.

3.1. NAVIGATION

Navigation information is available from the ship's PLNS (Precision Location and Navigation System). At intervals of about one minute, the ZAN obtains values of latitude, longitude, ship's speed, heading (gyrocompass reading) and course made good. The PLNS synthesizes an optimum ship's navigation status from a variety of navigation aids including the Global Positioning System, Satellite Navigation and Loran-C. Plots of the ship's track are given in Appendix A.

3.2. SURFACE METEOROLOGY

The wind speed and direction are measured by R. M. Young anemometers (propeller and wind vane type) mounted on the foremast, at a height of about 16 m above the waterline, and on a 7 m lattice-work mast at the stern of the ship, about 12 m above the water. The foremast carries two identical sensors to provide redundancy in case of failure and the three sets of sensors together ensure good measurements from all directions irrespective of the relative wind direction. Air temperature and humidity are also measured by precision thermistors and 'Rotronics hygrometer' sensors at the same locations as the wind sensors. Again there are two sets of sensors at the foremast and one at the stern. Also mounted on the foremast are two radiometers, manufactured by the Eppley Laboratory, one to measure the downwelling short-

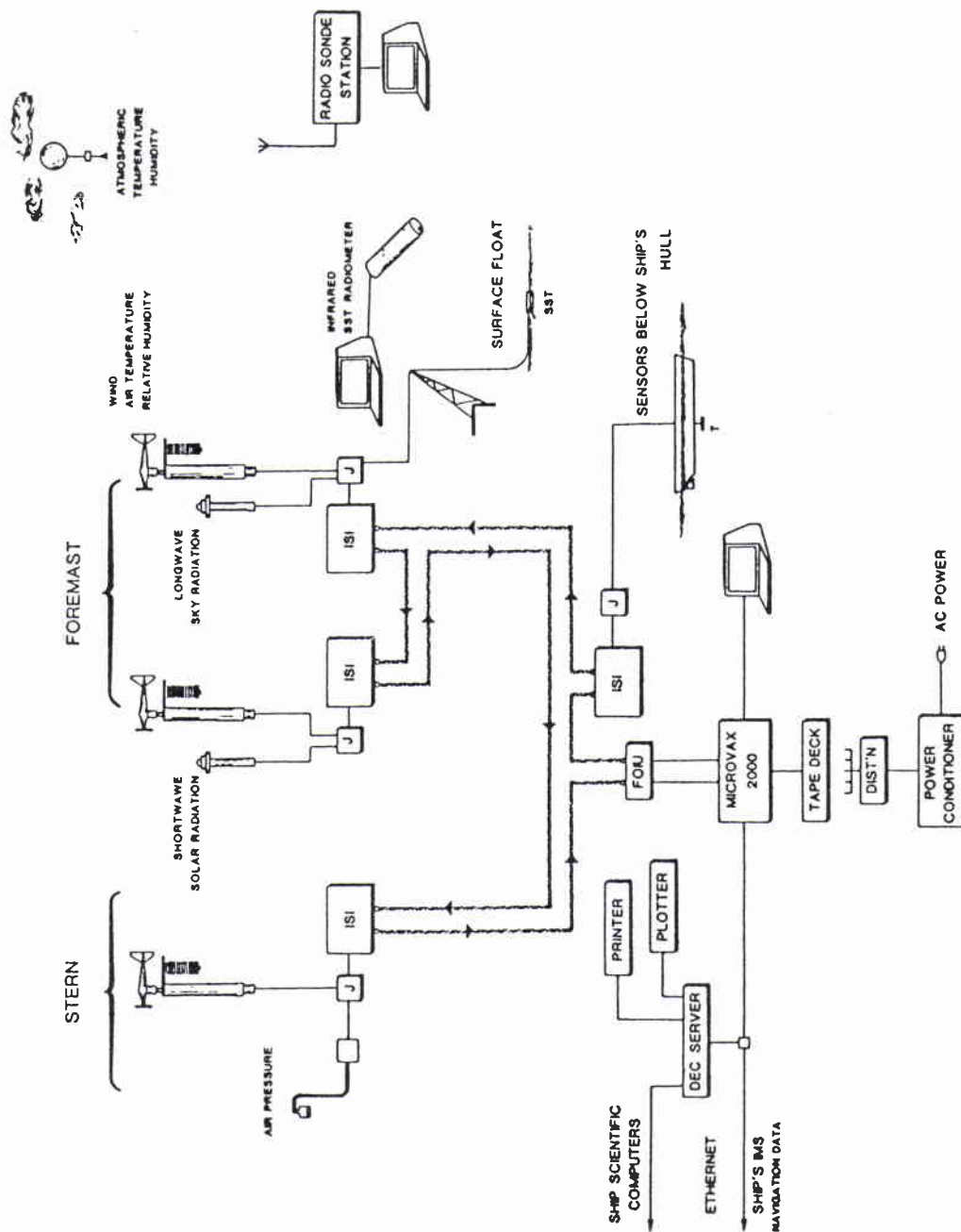


Figure 2 Schematic representation of the instruments of the ZAN (Zeno-Alliance Network) on the R/V Alliance. ISI stands for Intelligent Sensor Interface, FOIU is Fibre-Optics Interface Unit, J is Junction box, IMS is Information Management System, SST is Sea Surface Temperature, T is Temperature.

SACLANTCEN SM-264**Table 1** *Characteristics of the measurement sensors*¹

Variable	Sensor type	Units	Resol.	Accur.
Air temp.	Prec. therm.	°C	0.1	0.2
Sea surf. temp. ²	Prec. therm.	°C	0.1	0.1
Rel. humidity	Capacitance	%	1.0	2.0
Wind speed	Prop. anemom.	ms ⁻¹	0.1	0.5
Wind direction	Vane	°	1.0	2.0
SW radiation	Pyranometer	Wm ⁻²	0.1	~ 3%
LW radiation	Pyrgeometer	Wm ⁻²	0.1	~ 3%

¹ Sensors mounted on the foremast are at a height of 16 m above the water line, and those at the stern 12 m.

² Data from a nominal depth of 10 cm.

wave insolation, defined by the spectral response of the glass dome over the sensing element to the interval between 0.28 to 2.8 μm , and the second to measure the downwelling long-wave radiation, in the range from about 4.5–50 μm . Atmospheric pressure measurements are provided by a digital barometer (Paroscientific) mounted at the stern.

3.3. SEA-SURFACE TEMPERATURE

Sea-surface temperature was measured by three independent instruments: an infrared radiometer detected the electromagnetic emission from the surface, a towed thermistor measured the *in situ* temperature with an accuracy of $\sim 0.01\text{K}$ at an approximate depth of 0.1 m, and a high-precision thermometer (Sea-Bird) was mounted through the hull at a depth of about 3 m. Data from the two *in situ* thermometers are presented here, and the radiometer measurements will be the subject of a separate report.

3.3.1. Bulk surface temperature at ~ 0.1 m

As in previous cruises [Minnett, 1991] the *in situ* sea-surface temperature was measured at a nominal depth of 0.1 m by a thermistor mounted in a surface-following device towed on an electromechanical cable from the forward crane, or from a boom extended sideways from the forward working-deck. This device is called the ‘cappello’ and was logged by the ZAN system. The towing speed of the cappello can be limited in high sea-states, but this problem was not encountered during this cruise. Nevertheless it was sometimes necessary to bring the cappello inboard for certain ship’s manoeuvres.

Table 2 *Radiosonde Launches*

Date	Time	Position	Min.P. μ Pa	Satellite overpass
3	11 : 30	36°01.1'N, 24°53.3'E	67	NOAA-11, rev 8703 at 11 : 41
4	10 : 45	36°00.6'N, 24°52.8'E	61	NOAA-11, rev 8717 at 11 : 37
5	11 : 13	35°57.2'N, 25°10.9'E	81	NOAA-11, rev 8731 at 11 : 27
6	10 : 50	36°01.0'N, 24°58.9'E	57	NOAA-11, rev 8745 at 11 : 16
7	6 : 40	35°49.3'N, 26°57.4'E	56	NOAA-10, rev 19319 at 05 : 53
7	11 : 15	35°40.6'N, 26°45.9'E	70	NOAA-11, rev 8759 at 10 : 56
8	06 : 48	35°50.1'N, 24°43.2'E	72	NOAA-10, rev 19333 at 05 : 01
8	12 : 30	35°50.7'N, 24°40.2'E	43	NOAA-11, rev 8774 at 12 : 28
9	06 : 50	35°48.3'N, 24°48.5'E	65	NOAA-10, rev 19348 at 06 : 19
9	12 : 30	35°48.6'N, 24°48.7'E	54	NOAA-11, rev 8788 at 12 : 17
11	06 : 27	35°20.7'N, 22°46.8'E	58	NOAA-10, rev 19376 at 05 : 33
11	11 : 40	35°35.7'N, 22°12.7'E	50	NOAA-11, rev 8816 at 11 : 55
12	06 : 23	36°23.1'N, 20°00.7'E	84	NOAA-10, rev 19390 at 05 : 10
12	11 : 45	36°50.7'N, 19°22.1'E	68	NOAA-11, rev 8830 at 11 : 44

3.3.2. Bulk temperature at 3 m

The bulk sea temperature was measured continually by a Sea-Bird sensor mounted on a ram that extends it through the hull at a depth of about 3 m. The sensing element is beyond the boundary layer flow of the hull, on the forward port side about 25 m behind the bow, just forward of the level of the bridge. This is connected to the ZAN by an ISI and its sampling is not restricted by sea-state nor ship's speed.

3.4. ATMOSPHERIC PROFILES

Atmospheric profiles of temperature and humidity were made using disposable radiosondes carried aloft on helium balloons, and the measurements were transmitted to a receiving station (a Vaisala RAWIN system) on the ship. The radiosondes were launched so their ascents coincided with satellite overpasses (Table 2). All radiosonde profiles reached into the stratosphere and therefore beyond practically all of the atmospheric water vapour. Appendix G contains plots of the atmospheric profiles.

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3.5. SATELLITE IMAGES.

During the cruise the sky was mostly cloud-free and conditions for remote sensing of the sea-surface temperature using satellite-borne infrared radiometers, such as AVHRR, were very good. The direct broadcast APT (Automatic Picture Transmission) signals from the NOAA-10 and NOAA-11 polar-orbiting spacecraft were received on-board and images from the AVHRR data were generated in near real-time. These revealed some of the surface temperature structure and the presence and types of those clouds that were in the area. Full resolution AVHRR data for the days of the cruise have been purchased from ground stations for proper analysis.

3.6. SEA-STATE PHOTOGRAPHS.

The C-130 aircraft also carried an experimental microwave radiometer, the measurements of which are dependent on sea-surface temperature and sea-state. As an aid to the interpretation of the microwave measurements, colour photographs of the sea surface were taken from the bridge at hourly intervals, and at the time of the aircraft low-level overflights, on the days of the joint experiments.

3.7. INSTRUMENT PERFORMANCE

The only problem encountered with the ZAN system was with the long-wave pyrgeometer. On June 1 the signal was badly contaminated by noise caused by a poor contact at the instrument output, and this was corrected *en route* only to reveal a malfunction of the preamplifier between the long-wave pyrgeometer on the foremast and the ISI. This unit, a replacement from the manufacturer, had been installed prior to the cruise but due to a construction fault its input impedance was much too low with the result that it 'pulled down' the instrument output. The preamplifier was replaced at sea on June 4 at about 06:30. Subsequent bench tests showed that the effect was to reduce the effective gain of the preamplifier by a factor of 2.1, and the contaminated data have been appropriately corrected.

Because of other activities at the stern of the ship it was not possible to mount the mast supporting the stern instruments until the afternoon of June 6; and the data were first logged at 08:15. Prior to this there are no winds, air temperatures, nor humidities from the stern sensors.

4

Data processing

During the cruise the measurements from the ZAN were archived on disk in a FOCUS database from which derived variables and plots were generated in near-real time. Periodic inspection of the sensors took place throughout the cruise and the domes of the radiometers were cleaned at intervals of a few days. In the very calm weather and clean air conditions experienced during the cruise there was no evidence of dirt or salt deposition on the radiometer domes. The anemometers were inspected during and after the cruise and no evidence was found to suggest that the bearings were becoming worn thereby invalidating the calibration.

4.1. CALIBRATION

The thermometers and relative humidity sensors were calibrated by the Ocean Engineering Department (OED) before and after the cruise and these calibrations have been applied to the data presented in this report. There was no significant change in the calibration characteristics during the cruise; in particular the calibration drift of the Sea-Bird sensor was found to be less than 0.005 K at the 16 and 20°C calibration points. The calibration algorithms are given in Table 3.

The thermistor used in the cappello was calibrated by OED against a laboratory standard before and after the cruise, giving the following linear expression relating SST to the digital counts N produced by the ISI

$$SST = 58.1 - 0.021N. \quad (1)$$

The non-linearity of the thermistor output, not properly matched in the ZAN interface, lead to a temperature dependent error in the cappello temperatures. This had not been apparent in the measurements of earlier cruises as it only became significant for temperatures greater than $\sim 18^\circ\text{C}$. By comparing the cappello output with a digital thermometer when both were immersed in a water bath on the deck of the ship, a correction applicable to the temperatures derived from Eq. (1) was determined:

$$SST^* = 1.066SST - 1.107, \quad \text{for } SST > 16.6^\circ\text{C}. \quad (2)$$

After the cruise the long-wave pyrgeometer was compared at the UK Meteorological Office with a transfer standard instrument traceable to a reference at the UK National Physical Laboratory (Grimmer, 1991), and a temperature dependence of the

gain of the device was revealed to be:

$$g = xT_{\text{sink}} + y, \quad (3)$$

where T_{sink} is the instrument's sink temperature, $x = 0.1219$ and $y = 1.993$ (Fig. 3). The gain given by the manufacturer is a constant with the value $4.16 \mu\text{V}/(\text{Wm}^{-2})$. The data were corrected using Eq. (3) with the measurement of air temperature being used as an estimate of T_{sink} . With an air temperature of 20°C , this changes the measurement of $\text{LW}\downarrow$ by 6.6%.

4.2. DATA SELECTION

The selection of the best exposed wind sensor was made by examining the relative wind direction. The upwind sensors were selected according to the angles given in Table 4, which were determined by examining the differences between wind speed and direction measured by each combination of pairs of instruments as a function of relative wind direction (Fig. 4).

Discrepancies between the wind speed and direction from the pair of sensors on the foremast were small being generally less than 1 ms^{-1} and 5° . With the wind coming from ahead, the differences are $\sim 0 \text{ ms}^{-1}$ and $\sim 2^\circ$. On a few occasions when the ship was sailing sections on reciprocal headings, the wind speed measured from the stern with a following wind was observed to be lower, by a few meters per second, than that measured by the foremast sensors with a headwind. This is not believed to be entirely the result of the different heights of the sensors above the waterline, which could be corrected, but rather to be due to the relatively poor exposure of the stern sensors. There are insufficient sets of cases where the wind was steady and the ship turned from a headwind to a tailwind to permit the determination of the transfer function to convert the stern measurement to a good relative wind speed measurement, as this would be dependent both on the wind speed and the relative direction. Instead the fluctuations in the measured wind speed measured by the stern sensor when it provided the best exposure were presumed to be accurate and the absolute level was adjusted by linear interpolation to give a smooth transition with the measurements from the foremast sensors at the start and end of each data segment where the stern sensor data were selected. For the period before the erection of the stern mast during which there are no stern wind measurements, wind speed values are derived by linear interpolation between the values from the foremast sensors at the start and ends of the intervals when the foremast sensors are not well exposed.

Comparison between the air temperature measurements from the sensors at the foremast showed a mean discrepancy of 0.35°C (e.g. Fig. 5) after the application of the post-cruise calibration corrections. This difference could not be resolved by comparison with the standard bridge observations of air temperature as these displayed a larger scatter when compared with each of the foremast sensors than is found

Table 3 Calibration algorithms for ZAN temperature and humidities, MASTEX 1990¹

Location	Calibration algorithm
<i>1. Air temperature</i>	
Foremast port	$T = 1.013 \cdot T_m - 0.211$
Foremast starboard	$T = 1.027 \cdot T_m - 0.406$
Stern port	$T = 1.025 \cdot T_m - 0.325$
<i>2. Relative humidity</i>	
Foremast port	$R = 1.087 \cdot R_m - 9.67$
Foremast starboard	$R = R_m$
Stern port	$R = 1.109 \cdot R_m - 11.03$

¹ T_m is measured air temperature, T is the calibrated air temperature, R_m is measured relative humidity and R is the calibrated relative humidity.

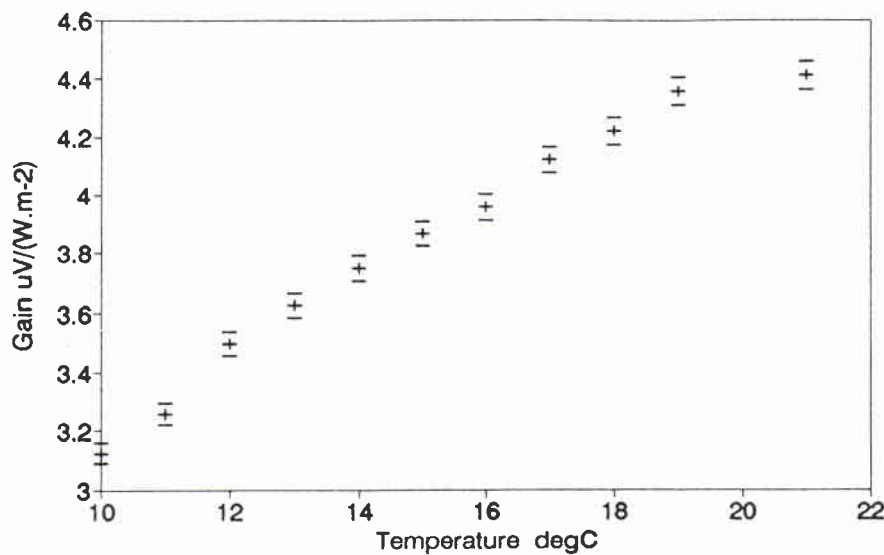
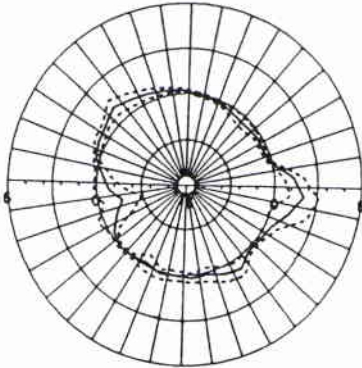


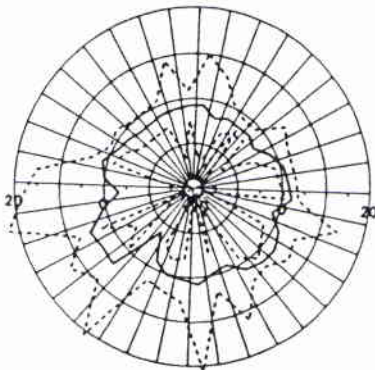
Figure 3 Temperature dependence of the gain of the pyrgeometer measuring downwelling long-wave radiation at the foremast. The values were determined experimentally by Grimmer, 1991. The error bars show the expected range of uncertainty due to the experimental method. The 21°C data point appears suspect and was not used in least-squares determination of a correction algorithm applied to the data.

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Wind speed difference [ms^{-2}]
5285 samples



Wind direction difference [$^{\circ}$]



Distribution of samples

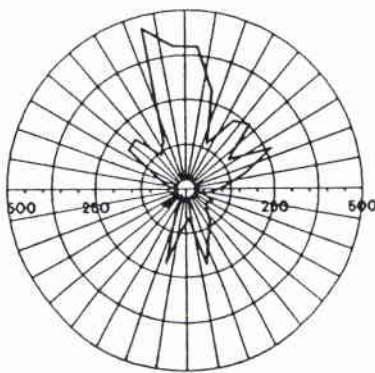
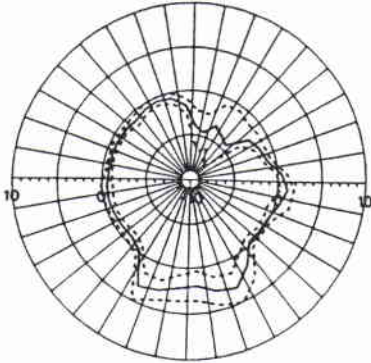
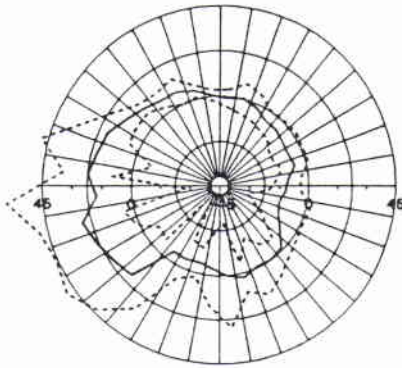


Figure 4a Angular distribution of differences in the wind speed and direction measured by the two foremost sensors. Phase 2 refers to the period between the port calls on June 2 and 10. The measurements were partitioned into 10° segments according to the measured wind direction measured at by the foremost port sensor. The mean $\pm$ standard deviation for the data in each segment are plotted in polar form, with the small arrow (top) showing the direction of the ship's head. The scales of the wind speed difference plots are $\pm 5 \text{ ms}^{-1}$ and for wind direction is $\pm 20^{\circ}$. The lowest plots of each group show the angular distribution of the sample.

Wind speed difference [ms^{-2}]
5285 samples



Wind direction difference [$^{\circ}$]



Distribution of samples

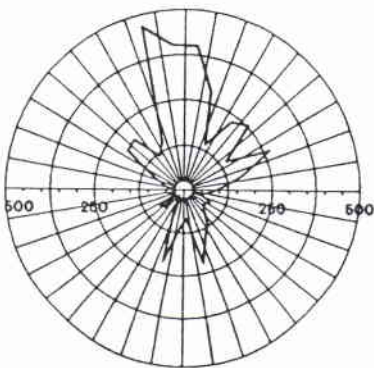


Figure 4b Angular distribution of differences in the wind speed and direction measured between the two port sensors, stern and foremast. Phase 2 refers to the period between the port calls on June 2 and 10. The measurements were partitioned into 10° segments according to the measured wind direction measured at by the foremast port sensor. The mean $\pm$ standard deviation for the data in each segment are plotted in polar form, with the small arrow (top) showing the direction of the ship's head. The scales of the wind speed difference plots are $\pm 5 \text{ ms}^{-1}$ and for wind direction is $\pm 20^{\circ}$. The lowest plots of each group show the angular distribution of the sample.

SACLANTCEN SM-264**Table 4** *Angles used to select the upwind wind sensors*

Upwind sensor	Relative wind direction range*
Foremast Port	205–15°
Foremast Starboard	15–145°
Stern Port	145–205°

* The ship's bow defines 0° relative.

Air temperature difference [°C]
1294 samples

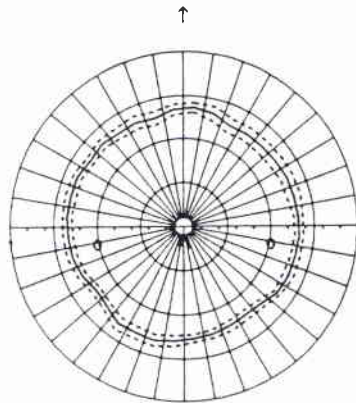


Figure 5 *Angular distribution of differences in the air temperature measured by the two foremast sensors. The data from June 5 are shown. The measurements were partitioned into 10° segments according to the measured wind direction measured at by the foremast port sensor. The mean $\pm$ standard deviation for the data in each segment are plotted in polar form, with the small arrow (top) showing the direction of the ship's head. The scale is $\pm 1^\circ$.*

between the foremast sensors themselves. This may be due to the relatively poor exposure of the meteorological instruments on the bridge wings and the large 'heat island' effect of the superstructure of the ship in the conditions of high insolation encountered during the cruise. However, there is no diurnal modulation to the scatter. An additional, and possibly dominant, contribution to the scatter arises from the lack of precise time-keeping for the WMO observations. The foremast air temperatures show fluctuations of several tenths of a degree in the permissible 10–15 min interval either side of the nominal time of the WMO measurements. Comparisons of the contemporaneous near-surface measurements from the radiosondes at launch and foremast air temperatures show better agreement with those from the foremast port thermometer (Fig. 6). At air temperatures above 22°C the scatter between the foremast temperatures and the near-surface radiosonde measurements increases, with the radiosonde temperature being higher. This may be due to the 'heat island' effect of the ship influencing the radiosonde data at launch from the boat deck, in which case the differences are spurious, or to the difference in measurement height (~ 8 m) on hot days when strong stratification was observed in the atmosphere (see the profiles in Appendix G), in which case the differences are real.

There is a mean discrepancy of about 2% between the pairs of foremast humidity measurements (Fig. 7), and like the air temperature measurements this could be

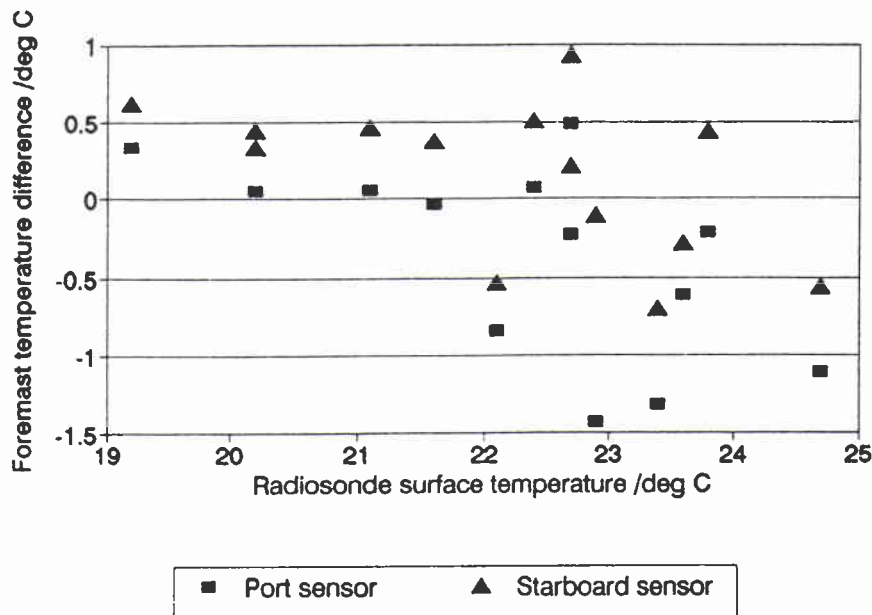


Figure 6 Comparison between the air temperatures measured by radiosondes, at launch, and the contemporaneous values from the two foremast thermometers.

Relative humidity difference [%]
1294 samples

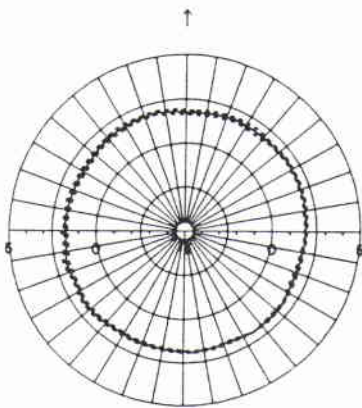


Figure 7 Angular distribution of differences in the relative humidity measured by the two foremast sensors. The data from June 5 are shown. The measurements were partitioned into 10° segments according to the measured wind direction measured at by the foremast port sensor. The mean $\pm$ standard deviation for the data in each segment are plotted in polar form, with the small arrow (top) showing the direction of the ship's head. The scale is $\pm 5\%$.

resolved not by comparison with the bridge measurements, but also neither by comparison with the near-surface radiosonde measurements (Fig. 8). There is a lot of scatter between the foremast and radiosonde near-surface humidity measurements, with the radiosonde measurements being too low. This is likely to be caused by the radiosonde sensor being inadequately aspirated, and too hot, just after launch. In the cases where the scatter is smallest, the more reliable sensor is that at the port foremast. This is endorsed by the fact that the starboard foremast sensor gave maximum relative humidity measurements of $\sim 103\%$, which, while not impossible, are

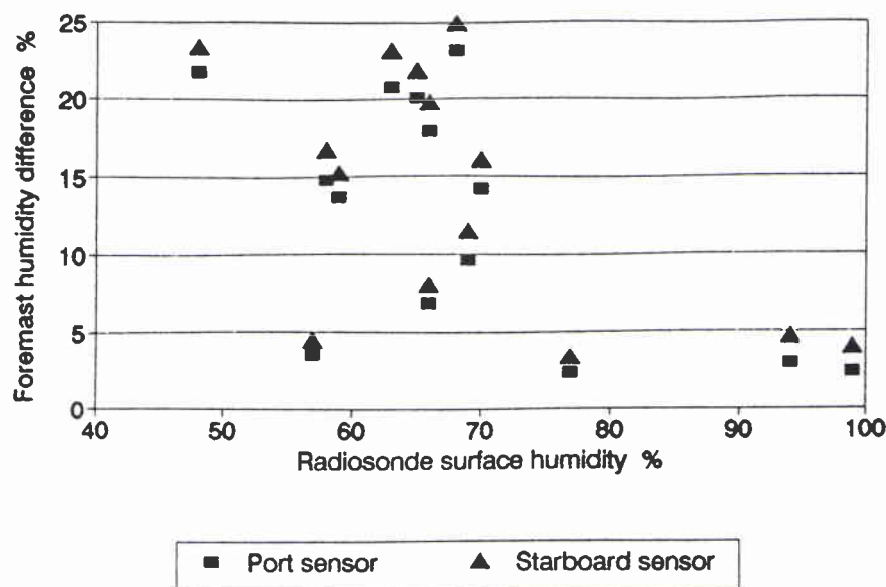
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Figure 8 Comparison between the relative humidities measured by radiosondes, at launch, and the contemporaneous values from the two foremast sensors.

very unlikely. The maximum relative humidity measurements from the port sensor are $\sim 101\%$.

4.3. GENERATION OF DERIVED VARIABLES

From the measured data it is possible to calculate a number of derived variables. These are the true wind speed, the net long-wave radiation at the sea surface and the turbulent fluxes of latent heat and sensible heat.

Although the sensors are all sampled at 1 Hz and 1-minute averages are built up, the times appropriate to the average values are not exactly synchronous for all sensors. So before calculating derived variables it was necessary to resample the various time series at a common time base. For those calculations requiring the use of sea-surface temperature, all of the data streams from the individual instruments were resampled to the time-base of the port foremast sensors.

The true wind speed and direction were calculated from the relative wind measurements by the removal of the ship's speed and heading, which were resampled to the times of the wind measurements.

The net long-wave radiation is the difference between the measured incoming long-wave radiation and that emitted by the sea surface at the measured sea surface temperature. An emissivity ϵ of 0.98 was used in the Stephan-Boltzmann equation:

$$LW\uparrow = \epsilon\sigma T^4, \quad (4)$$

where σ is the Stephan-Boltzmann constant ($5.67 \times 10^{-8} \text{ Wm}^{-2}\text{K}^{-4}$) and T is the sea-surface temperature in Kelvin. No attempt was made to model the effect of the thermal skin layer on the emitted radiation [Robinson *et al.* 1984].

The net short-wave radiation at the sea-surface has been calculated by

$$SW_{\text{net}} = SW \downarrow (1 - \alpha), \quad (5)$$

where $SW \downarrow$ is the measured incident short-wave radiation and α is the sea-surface albedo which for the present purposes has been taken as a constant with a value of 0.06 (Payne, 1972).

The turbulent fluxes were calculated using the standard bulk aerodynamic formulae which relate latent and sensible heat exchanges to the standard surface meteorological measurements:

$$H = \rho c_p C_H U (T - SST), \quad (6)$$

$$E = \rho L C_E U (q - q_0), \quad (7)$$

where H and E are the turbulent fluxes of sensible and latent heats to the ocean, ρ is air density, c_p is the specific heat of air, and L is the latent heat of evaporation; U , T and q are wind speed, air temperature and specific humidity measured at a given height above the sea-surface, SST is the sea-surface temperature and q_0 is the specific humidity at the surface, assumed to be close to saturation (98% to allow for the effects of salinity) at the SST. The bulk transfer coefficients C_H and C_E are dependent on the sensor height, on wind speed and on atmospheric stability. The coefficients used in this study were derived using the algorithms of [Smith, 1988] using an air temperature of 20°C and a sensor height of 16 m above the waterline, and have explicit dependence on the sensor height, wind speed and the stability of the atmospheric boundary layer.

For the purposes of this report, the turbulent fluxes, and the upwelling long-wave radiation, have been derived using the sea-temperatures measured by the Sea-Bird sensor at a depth of about 3 m. This gives better sampling and continuity than would be the case using the near-surface cappello measurements, but are less accurate when there are significant near-surface vertical temperature gradients in the water (see Appendix D).

5

Data presentation

A plot of the ship's position derived from the PLNS is shown in Fig. 1 for the whole period covered by this report. Daily ship tracks are given in Appendix A, where, apart from June 3 and 4, the positions of the ship at three-hourly intervals are marked.

Time series plots of true wind speed and direction, air temperature, relative humidity, and surface pressure are presented in Appendix B. Each plot covers a one-day period of the cruise, and data are plotted with full temporal resolution. The spikes in the true wind direction and, to a lesser degree, speed result from the imperfect compensation for the ship's motion when the vessel was making rapid manoeuvres; the relative winds being averages over one-minute intervals while the ship's navigation data are spot samples within those intervals. The large excursions in surface pressure on June 6 are associated with the erection of the stern instrument mast on which the barometer vent is mounted. Unphysical spikes in the pressure trace before this date are caused by deficient exposure of the barometer vent which was susceptible to spurious effects caused by wind.

Time series of the radiative terms of the surface heat budget are shown in Appendix C. These are the measured hemispheric downwelling short-wave radiation (insolation), and hemispheric downwelling long-wave radiation. Also shown are the calculated upwelling long-wave radiation, net long-wave radiation, and net surface radiation. Near-surface temperature time-series are given in Appendix D, with the smooth trace being the Sea-Bird measurements taken at a depth of about 3 m and resolved to 0.01°C and the discontinuous trace being the cappello measurement from about 10 cm depth and resolved to 0.1°C.

The air and sea temperatures, and their differences, are shown in Appendix E. The sea temperature is that measured at a depth of about 3 m by the Sea-Bird sensor.

The derived variables shown in Appendix F include the total turbulent air-sea heat exchange and the latent and sensible component fluxes. The Bowen ratio is the ratio between the sensible and latent heat exchanges, and the surface energy budget is the sum of the turbulent and radiative fluxes.

The atmospheric profiles are presented in Appendix G against a vertical axis of atmospheric pressure. Each profile is identified by the time and location of the radiosonde launch. The measured variables are temperature and humidity and the absolute humidity and wet bulb depression were calculated using standard meteo-

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rological algorithms. The absolute humidity trace is shown magnified by a factor of ten as a dashed line for humidities below 1 g m^{-3} .

6

Discussion

The daily statistics of the measured and derived variables are given in Table 5, and the daily mean values of selected variables are shown in Figs. 9, 10 and 11. Data from June 10 are omitted because of the short data record for that day.

The winds experienced during the cruise were variable, with a minimum in the daily mean values during the middle portion of the experimental interval. On most days a peak in excess of 10 ms^{-2} was experienced and winds $> 15 \text{ ms}^{-1}$ occurred on June 1 and June 8. On most days the minimum measured wind was $< 1 \text{ ms}^{-1}$. The air temperatures were high, as is expected given the location and season, with a maximum mean value on June 7. The maximum mean sea-surface temperature (at 3 m depth) was also measured for June 7, and the greatest daily standard deviations were found on June 7 and 8 when the diurnal ranges were $> 1.5^\circ\text{C}$. The mean air-sea temperature differences generally increased throughout the period, being negative at the start, and with a maximum value on June 7. For June 1 and 2 the differences were always negative, and became consistently positive on June 7, 9, 11 and 12. The relative humidity was very variable with daily mean values ranging from 62% to 96%, with the lower values being found earlier in the cruise.

The vertical structure in the atmosphere was very marked, with a pronounced layer of warm, low humidity air overlying the very shallow marine boundary layer.

The measured insolation was high as cloud cover was generally sparse. Indeed some of the measured diurnal insolation cycles show no influence of cloud effects at all. The daily mean values were about 300 Wm^{-2} , with noon values peaking at 1 kWm^{-2} . This is compared to a value of 1280 Wm^{-2} calculated for the incident radiation at the top of the atmosphere at noon on June 5 at a latitude of 36°N (Beer, 1990). The maximum mean noon atmospheric transmission is therefore 0.80. The daily means of the measured downwelling long-wave radiation have values similar to those of the insolation, but with very small diurnal modulation. The infrared radiation emitted by the sea exceeded that arriving at the surface, giving a net long-wave radiative heat loss by the sea of $100\text{--}125 \text{ Wm}^{-2}$. The net surface radiation budget has daily mean values of 200 to -300 Wm^{-2} and shows a strong diurnal cycle caused by the dominant insolation, with noon peaks of 900 Wm^{-2} and night-time values of about -100 to -150 Wm^{-2} . On days with low wind speed these conditions are favourable for the development of a diurnal thermocline in the surface layer of the ocean. This near-surface temperature gradient is in evidence in the sea temperature differences between 10 cm and 3 m measurement depths (Appendix D), which show maximum values of over 1°C .

Table 5 *Daily statistics of measured variables and components of the surface heat budget*

Date* (June)	N [†]	Mean	Stand. dev.	Min.	Max.
<i>Wind speed at 16 m ms⁻¹</i>					
1	1001	8.710	3.313	0.350	16.710
2	1420	4.991	2.102	0.210	11.110
3	1394	7.155	1.952	2.190	13.390
4	1295	3.228	1.632	0.170	13.240
5	1294	5.059	1.227	2.180	12.990
6	1416	4.062	1.086	0.890	7.390
7	1430	2.956	1.303	0.150	6.560
8	1412	6.609	3.334	0.000	17.950
9	1394	8.795	2.594	0.880	14.480
11	1160	6.813	1.287	3.790	10.950
12	1433	5.292	1.549	1.190	8.340
<i>Air pressure μPa</i>					
1	1001	1014.634	1.071	1012.820	1016.500
2	1420	1015.881	0.776	1014.370	1018.010
3	1394	1014.678	0.613	1012.970	1016.800
4	1295	1015.188	0.774	1013.240	1017.640
5	1294	1017.318	0.965	1013.430	1019.770
6	1416	1015.407	1.147	1013.560	1019.510
7	1430	1012.939	1.184	1010.040	1014.840
8	1412	1010.051	0.443	1009.150	1011.400
9	1394	1010.769	0.543	1009.470	1011.760
11	1160	1013.737	0.798	1012.010	1015.190
12	1433	1014.450	1.560	1011.180	1016.870
<i>Air temperature $^{\circ}\text{C}$</i>					
1	1001	17.427	0.621	16.300	18.430
2	1420	18.089	0.855	15.790	19.440
3	1394	19.896	0.409	19.040	20.960
4	1295	20.590	0.552	19.340	21.670
5	1294	20.187	0.152	19.750	20.560
6	1416	20.563	1.121	18.530	22.480
7	1430	22.796	0.805	21.470	25.110
8	1412	22.341	0.910	20.760	24.200
9	1394	21.466	0.483	20.560	22.680
11	1160	22.657	0.397	21.670	23.290
12	1433	21.940	0.442	21.370	23.800

* Because of the small number of samples taken, statistics for June 10 are not included.

† N is the number of 1 min averages used to compute the statistics.

SACLANTCEN SM-264**Table 5** (Cont'd)

Date* (June)	N [†]	Mean	Stand. dev.	Min.	Max.
<i>Sea surface temperature at 3 m depth °C</i>					
1	1001	19.684	0.281	19.300	20.820
2	1420	19.652	0.289	19.230	20.460
3	1394	19.566	0.121	19.370	19.760
4	1295	19.896	0.198	19.550	20.250
5	1294	19.919	0.126	19.680	20.200
6	1416	20.283	0.290	19.860	20.940
7	1430	21.310	0.445	20.450	21.950
8	1412	21.273	0.481	20.440	22.210
9	1394	20.464	0.179	19.930	20.830
11	1160	21.399	0.300	20.880	21.760
12	1433	21.370	0.314	20.820	22.020
<i>Air-sea temperature difference °C</i>					
1	1001	-2.257	0.444	-3.130	-1.330
2	1420	-1.562	0.891	-3.860	-0.030
3	1394	0.329	0.325	-0.440	1.420
4	1295	0.694	0.499	-0.270	1.980
5	1294	0.268	0.119	-0.100	0.610
6	1416	0.280	0.893	-1.540	1.710
7	1430	1.485	0.588	0.550	3.320
8	1412	1.067	0.673	-0.050	2.810
9	1394	1.003	0.427	0.200	2.260
11	1160	1.258	0.544	0.260	2.300
12	1433	0.570	0.297	0.150	2.050
<i>Relative humidity %</i>					
1	1001	64.773	3.278	58.050	73.270
2	1420	62.363	4.304	51.750	79.460
3	1394	72.349	3.390	61.310	79.680
4	1295	70.105	8.088	57.510	84.900
5	1294	96.021	2.570	82.400	99.680
6	1416	94.500	5.587	82.400	101.530
7	1430	85.392	8.154	68.380	98.270
8	1412	87.692	7.000	67.940	98.810
9	1394	86.475	3.677	74.570	94.140
11	1160	82.630	7.212	66.960	96.200
12	1433	77.053	10.038	60.120	96.310

* Because of the small number of samples taken, statistics for June 10 are not included.

† *N* is the number of 1 min averages used to compute the statistics.

Table 5 (Cont'd)

Date* (June)	N†	Mean	Stand. dev.	Min.	Max.
<i>Specific humidity at sea surface</i> 10^{-3}					
1	1001	13.896	0.257	13.544	14.925
2	1420	13.851	0.245	13.493	14.553
3	1394	13.791	0.110	12.618	13.969
4	1295	14.072	0.172	13.772	14.393
5	1294	14.062	0.110	13.833	14.314
6	1416	14.415	0.274	14.029	15.039
7	1430	15.405	0.431	14.594	16.032
8	1412	15.414	0.463	14.613	16.326
9	1394	14.644	0.162	14.163	14.980
11	1160	15.474	0.283	14.995	15.833
12	1433	15.436	0.297	14.962	16.077
<i>Specific humidity at 16 m height</i> 10^{-3}					
1	1001	7.976	0.604	6.758	9.367
2	1420	7.988	0.591	6.860	9.464
3	1394	10.394	0.505	8.402	11.422
4	1295	10.487	0.993	8.828	12.561
5	1294	14.010	0.377	12.091	14.433
6	1416	14.124	0.577	12.953	15.517
7	1430	14.687	1.246	11.744	16.556
8	1412	14.701	0.872	12.082	16.302
9	1394	13.747	0.537	12.620	14.702
11	1160	14.100	1.269	10.742	16.021
12	1433	12.574	1.678	10.013	15.669
<i>Insolation</i> Wm^{-2}					
2	963	332.338	366.419	-1.000	1016.300
3	1394	321.317	363.165	-1.000	965.000
4	1295	326.768	349.070	-12.800	1023.100
5	1294	357.823	363.575	0.000	1025.600
6	1416	310.102	346.196	-1.500	966.800
7	1430	346.096	374.176	0.000	970.300
8	1412	318.671	354.685	0.000	944.700
9	1394	337.571	367.298	-6.000	963.800
11	1160	419.705	374.249	0.000	959.500
12	1433	306.125	342.165	0.000	922.300

* Because of the small number of samples taken, statistics for June 10 are not included.

† N is the number of 1 min averages used to compute the statistics.

SACLANTCEN SM-264**Table 5** (Cont'd)

Date* (June)	N†	Mean	Stand. dev.	Min.	Max.
<i>Down welling long-wave radiation Wm^{-2}</i>					
2	963	279.660	17.646	260.260	334.430
3	1394	280.086	14.034	258.710	313.970
4	1295	297.204	14.748	277.680	344.140
5	1294	306.024	12.982	285.060	343.220
6	1416	308.346	27.271	278.000	374.310
7	1430	289.703	12.885	261.770	325.150
8	1412	299.960	11.390	277.100	352.220
9	1394	303.415	12.273	284.360	332.370
11	1160	293.909	9.670	279.080	316.230
12	1433	303.540	13.472	285.210	338.250
<i>Emitted long-wave radiation Wm^{-2}</i>					
1	1001	408.655	1.571	406.510	415.030
2	1420	408.476	1.612	406.120	413.000
3	1394	407.997	0.673	406.900	409.080
4	1295	409.836	1.106	407.910	411.820
5	1294	409.965	0.705	408.630	411.540
6	1416	412.012	1.630	409.640	415.710
7	1430	417.812	2.523	412.950	421.450
8	1412	417.602	2.731	412.890	422.940
9	1394	413.024	1.005	410.030	415.090
11	1160	418.312	1.704	415.370	420.360
12	1433	418.150	1.784	415.030	421.850
<i>Net long-wave radiation Wm^{-2}</i>					
2	963	-128.803	16.317	-147.420	-76.660
3	1394	-127.910	14.139	-149.640	-93.990
4	1295	-112.633	15.271	-133.640	-64.100
5	1294	-103.942	12.771	-124.630	-65.910
6	1416	-103.664	28.257	-136.750	-36.170
7	1430	-128.109	13.125	-158.820	-92.650
8	1412	-117.642	10.940	-137.370	-61.340
9	1394	-109.608	11.990	-128.970	-81.590
11	1160	-124.402	10.294	-139.900	-100.950
12	1433	-114.610	12.317	-132.370	-83.600

* Because of the small number of samples taken, statistics for June 10 are not included.

† N is the number of 1 min averages used to compute the statistics.

Table 5 (Cont'd)

Date* (June)	N [†]	Mean	Stand. dev.	Min.	Max.
<i>Net surface radiation Wm⁻²</i>					
2	963	212.522	382.841	-148.200	921.810
3	1394	193.408	370.133	-148.420	866.380
4	1295	214.135	359.079	-137.260	941.830
5	1294	253.881	374.748	-124.130	950.640
6	1416	206.439	364.729	-136.750	893.130
7	1430	217.988	384.773	-143.380	869.570
8	1412	201.032	358.924	-137.370	844.710
9	1394	227.964	378.187	-126.010	879.140
11	1160	295.303	383.608	-139.900	858.550
12	1433	191.514	352.910	-132.370	824.560
<i>Latent heat flux Wm⁻²</i>					
1	1001	-183.527	66.110	-11.920	-373.536
2	1420	-106.144	37.015	-8.630	-209.623
3	1394	-76.417	25.289	-20.512	-156.762
4	1295	-23.526	15.027	-0.149	-98.404
5	1294	-1.316	6.221	6.409	-31.730
6	1416	-4.591	7.172	8.329	-24.438
7	1430	-2.540	4.173	8.508	-17.029
8	1412	-15.160	15.923	28.364	-72.887
9	1394	-21.752	16.541	22.952	-72.262
11	1160	-26.577	24.249	5.652	-100.749
12	1433	-39.575	30.414	6.585	-130.040
<i>Sensible heat flux</i>					
1	1001	-23.759	9.458	-1.643	-54.296
2	1420	-10.025	7.666	-0.228	-34.128
3	1394	2.826	2.530	11.964	-3.008
4	1295	1.169	0.817	4.574	-0.729
5	1294	1.391	0.617	3.090	-0.442
6	1416	0.399	4.098	7.663	-12.034
7	1430	1.970	1.810	7.307	-0.002
8	1412	4.894	4.294	29.051	-0.606
9	1394	9.489	5.553	29.486	-2.216
11	1160	8.282	4.625	21.171	1.466
12	1433	2.887	1.708	8.686	0.066

* Because of the small number of samples taken, statistics for June 10 are not included.

† N is the number of 1 min averages used to compute the statistics.

SACLANTCEN SM-264**Table 5** (Cont'd)

Date* (June)	N†	Mean	Stand. dev.	Min.	Max.
<i>Turbulent heat flux</i>					
1	1001	-207.286	74.656	-13.562	-427.831
2	1420	-116.169	43.024	-9.180	-242.385
3	1394	-73.590	23.858	-18.068	-148.296
4	1295	-22.357	14.627	-0.138	-97.950
5	1294	0.075	6.330	8.005	-29.538
6	1416	-4.192	9.124	13.647	-36.472
7	1430	-0.570	3.242	13.327	-10.740
8	1412	-10.266	14.185	40.706	-50.927
9	1394	-12.263	16.314	33.555	-53.443
11	1160	-18.295	24.407	10.116	-97.668
12	1433	-36.688	30.963	11.128	-125.695
<i>Bowen ratio</i>					
1	1001	0.130	0.022	0.080	0.182
2	1420	0.089	0.048	0.002	0.259
3	1394	-0.035	0.034	-0.271	0.035
4	1295	-0.062	0.038	-0.179	0.030
5	1294	0.279	2.615	-16.108	68.860
6	1416	0.259	6.616	-129.987	109.768
7	1430	-1.967	45.244	-1586.695	105.006
8	1412	-0.426	9.318	-345.632	25.650
9	1394	-0.438	1.474	-17.972	26.351
11	1160	-0.247	10.358	-255.603	83.109
12	1433	-0.318	8.108	-291.594	42.859
<i>Surface energy flux</i>					
2	963	95.689	374.063	-305.830	785.240
3	1394	119.818	369.902	-287.750	813.750
4	1295	191.779	369.520	-204.250	932.600
5	1294	253.956	375.141	-153.060	953.690
6	1416	202.247	359.276	-135.610	875.840
7	1430	217.417	383.184	-142.870	869.390
8	1412	190.765	360.347	-180.780	844.140
9	1394	215.701	379.573	-157.510	881.640
11	1160	277.008	395.360	-228.710	857.560
12	1433	154.826	350.724	-214.420	815.380

* Because of the small number of samples taken, statistics for June 10 are not included.

† *N* is the number of 1 min averages used to compute the statistics.

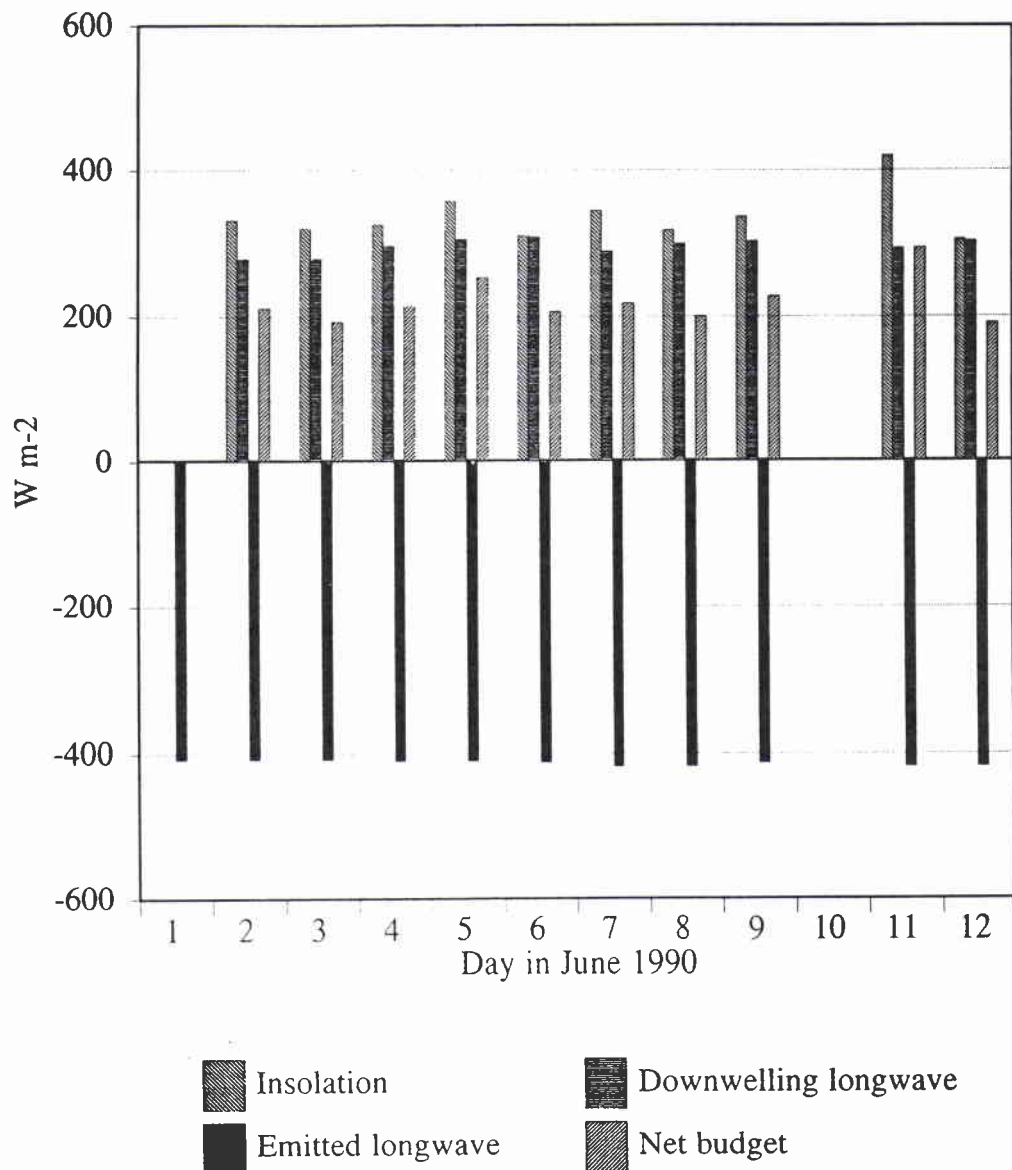


Figure 9 Bar chart of the daily mean components of the surface radiation budget. With the exception of June 1, for which there are no radiation measurements and only the mean emitted long-wave radiation calculated from the measured sea-surface temperatures is shown, the three components (measured insolation, measured downwelling long-wave and calculated emitted long-wave) are shown together with the net radiation budget.

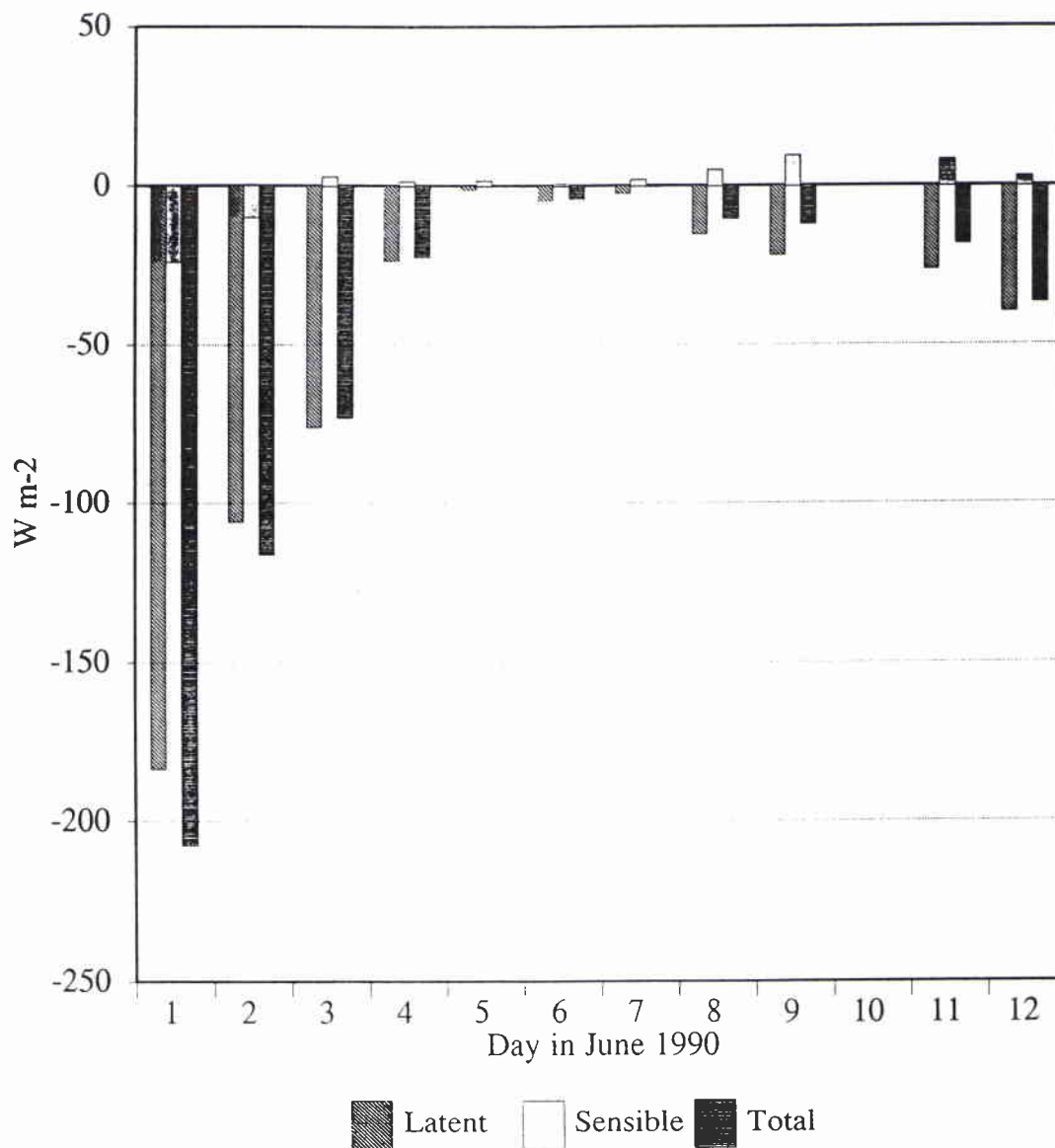
SACLANTCEN SM-264

Figure 10 Bar chart of the daily mean values of latent, sensible and total turbulent air-sea heat fluxes. Negative values indicate a heat loss from the ocean to the atmosphere.

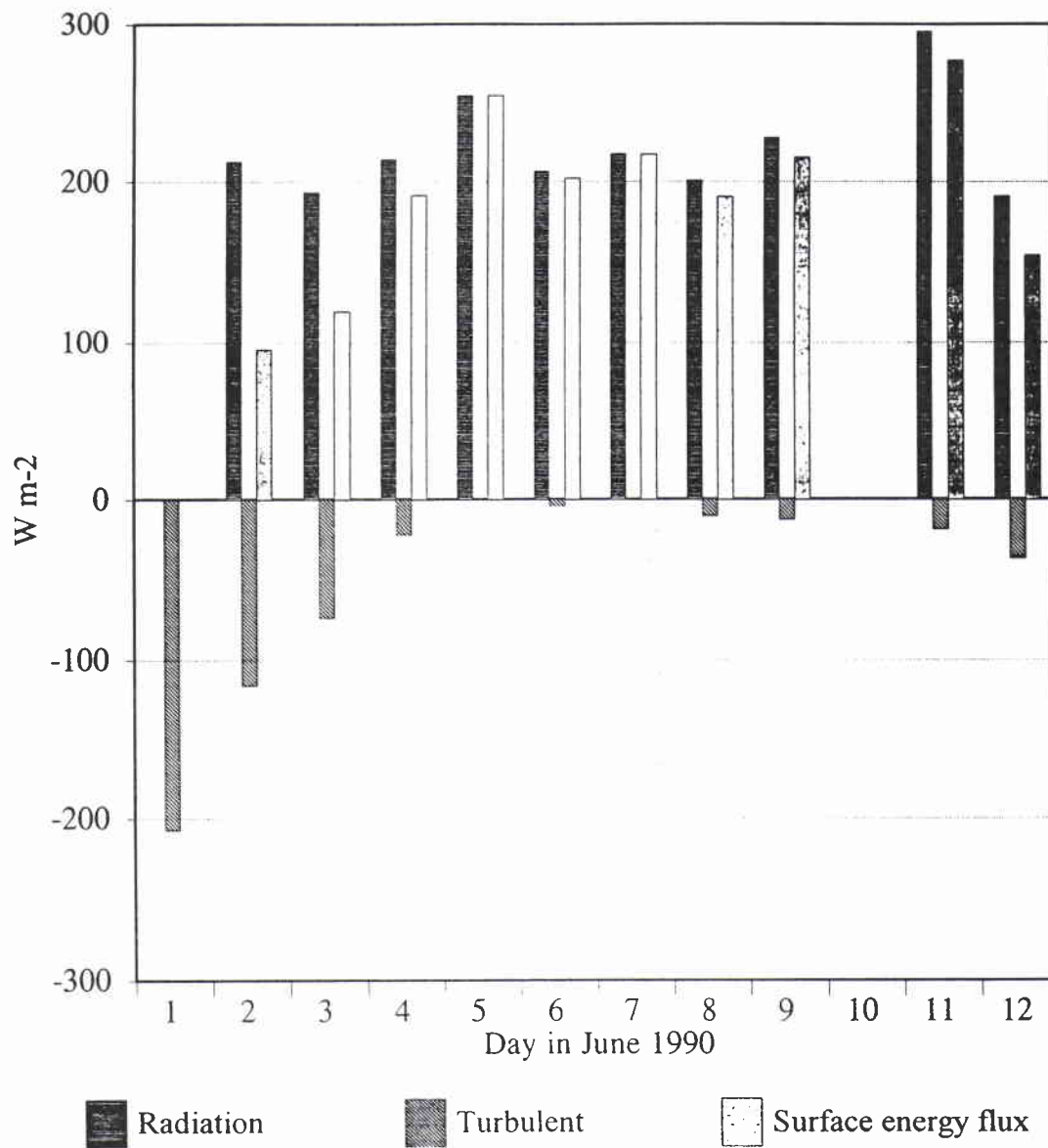


Figure 11 Bar charts of the radiative and turbulent components of the surface energy flux, together with the net mean value. For June 1 there are no radiation measurements, and only the mean value for the turbulent component is shown.

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The turbulent fluxes (Fig. 10) were variable, reflecting the fluctuations in the wind, air-sea temperature differences, and surface humidity. The latent heat flux was small during the middle part of the cruise, but had mean values 10 Wm^{-2} on June 1 and 2, in response to the moderate winds and dry surface air. The sensible heat flux was small throughout, and changed sign in response to the changing sign of the air-sea temperature difference. The total turbulent fluxes were thus generally small after June 3, being close to zero on June 5, 6 and 7, and $< 20 \text{ Wm}^{-2}$ on June 8, 9 and 11.

The daily mean values of the net surface energy budget (Fig. 11) show a gain by the ocean of $\sim 200 \text{ Wm}^{-2}$. The signal has a strong diurnal component resulting from the dominance of the surface insolation, with peak values of $\sim 950 \text{ W}^{-2}$.

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Appendix A

Ship tracks

Daily ship tracks derived from the ship's Precision Location and Navigation System are shown in Figs. A1–A12. Apart from June 3 and 4, the positions of the ship at three-hourly intervals are marked.

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R/V Alliance 1 June 1990 MASTEX

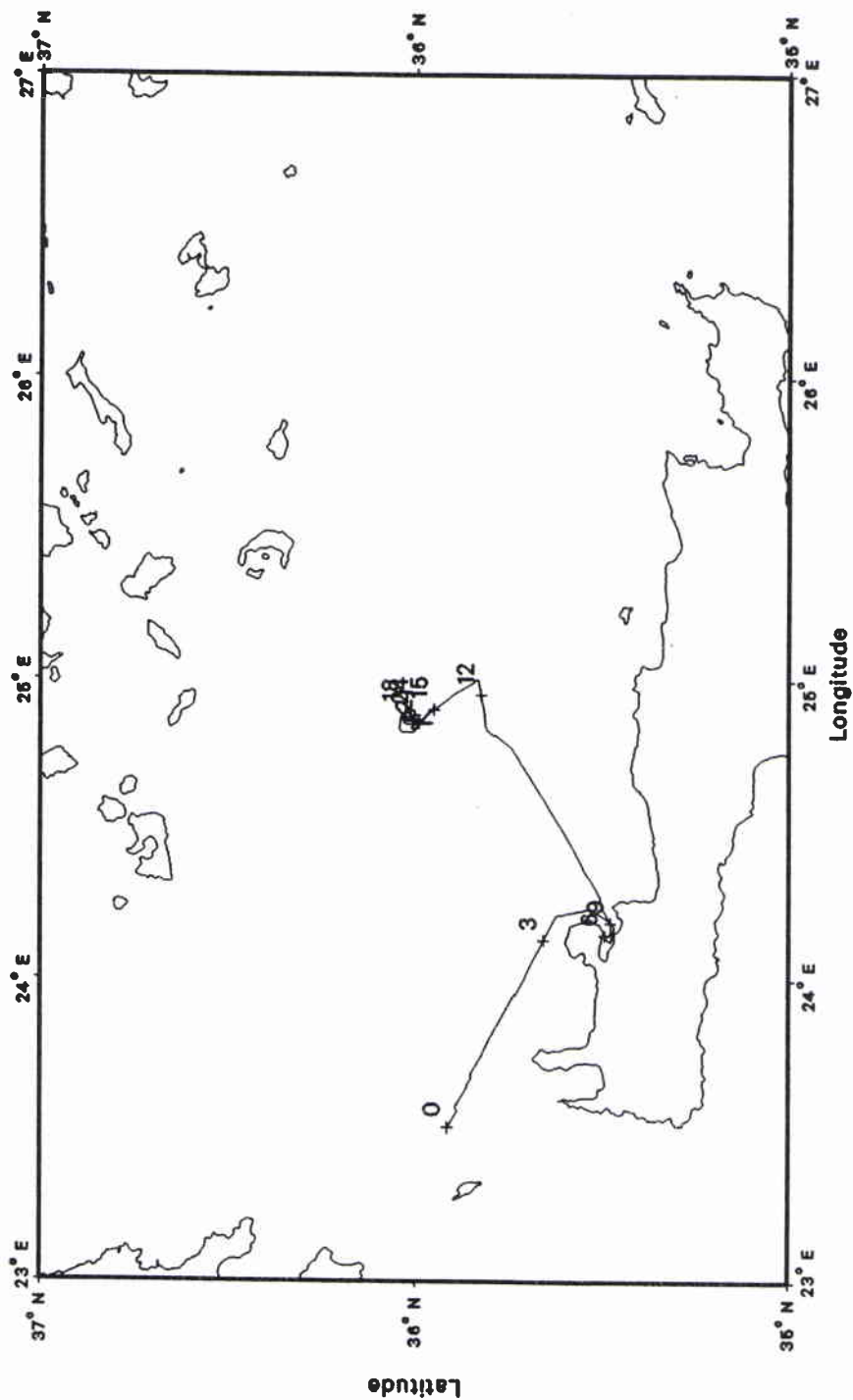


Figure A1

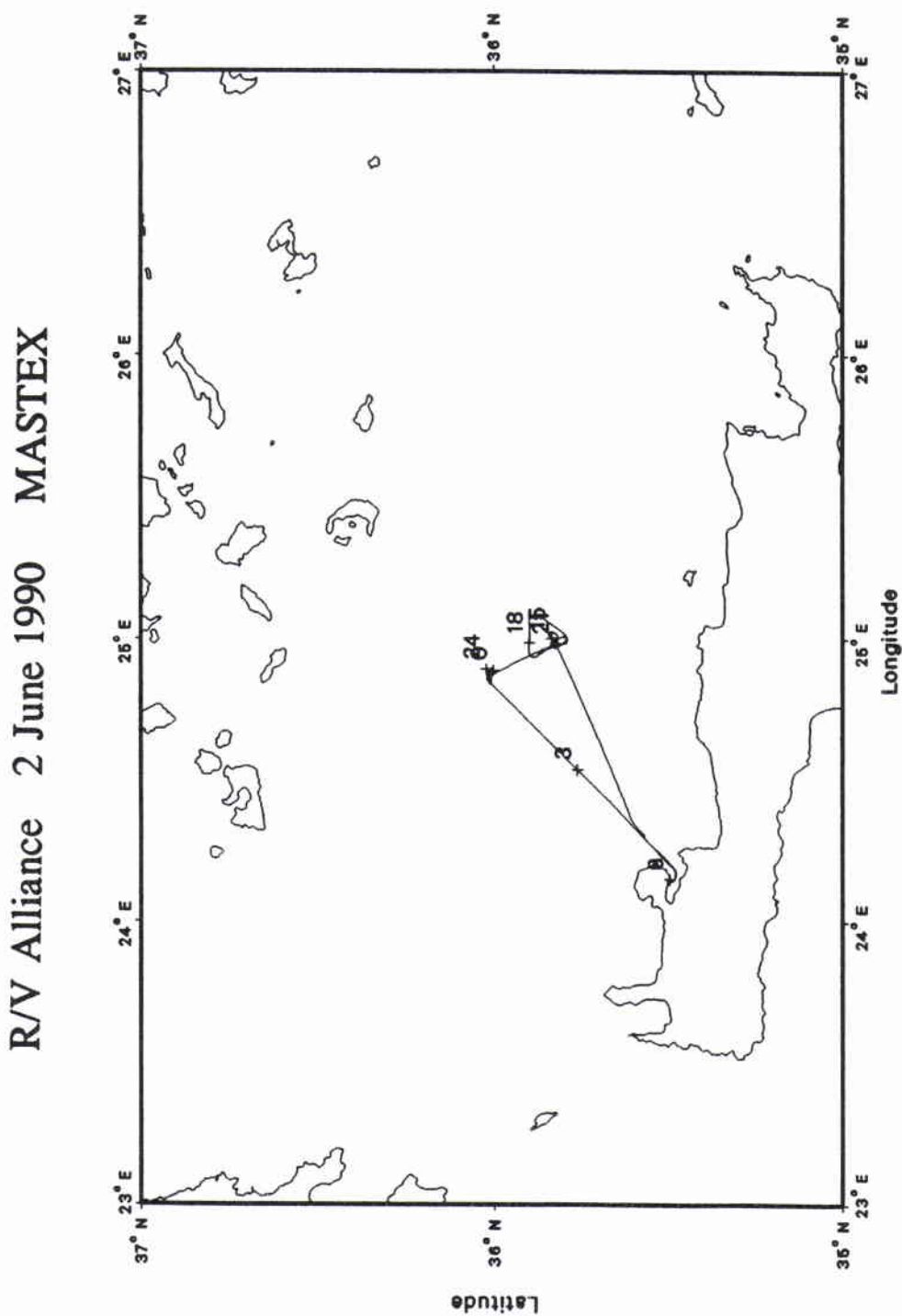


Figure A2

SACLANTCEN SM-264

R/V Alliance 3 June 1990 MASTEX

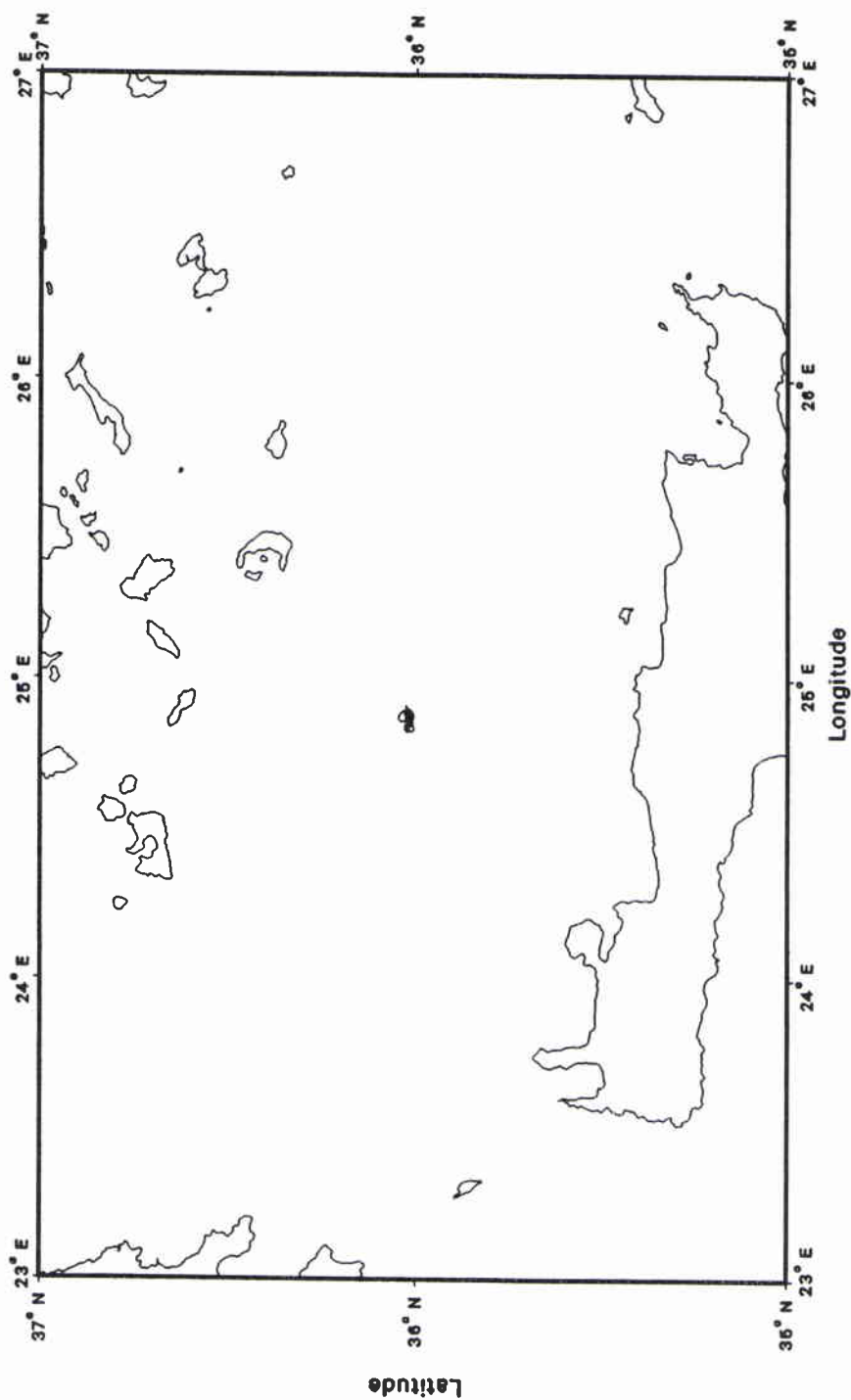


Figure A3

R/V Alliance 4 June 1990 MASTEX

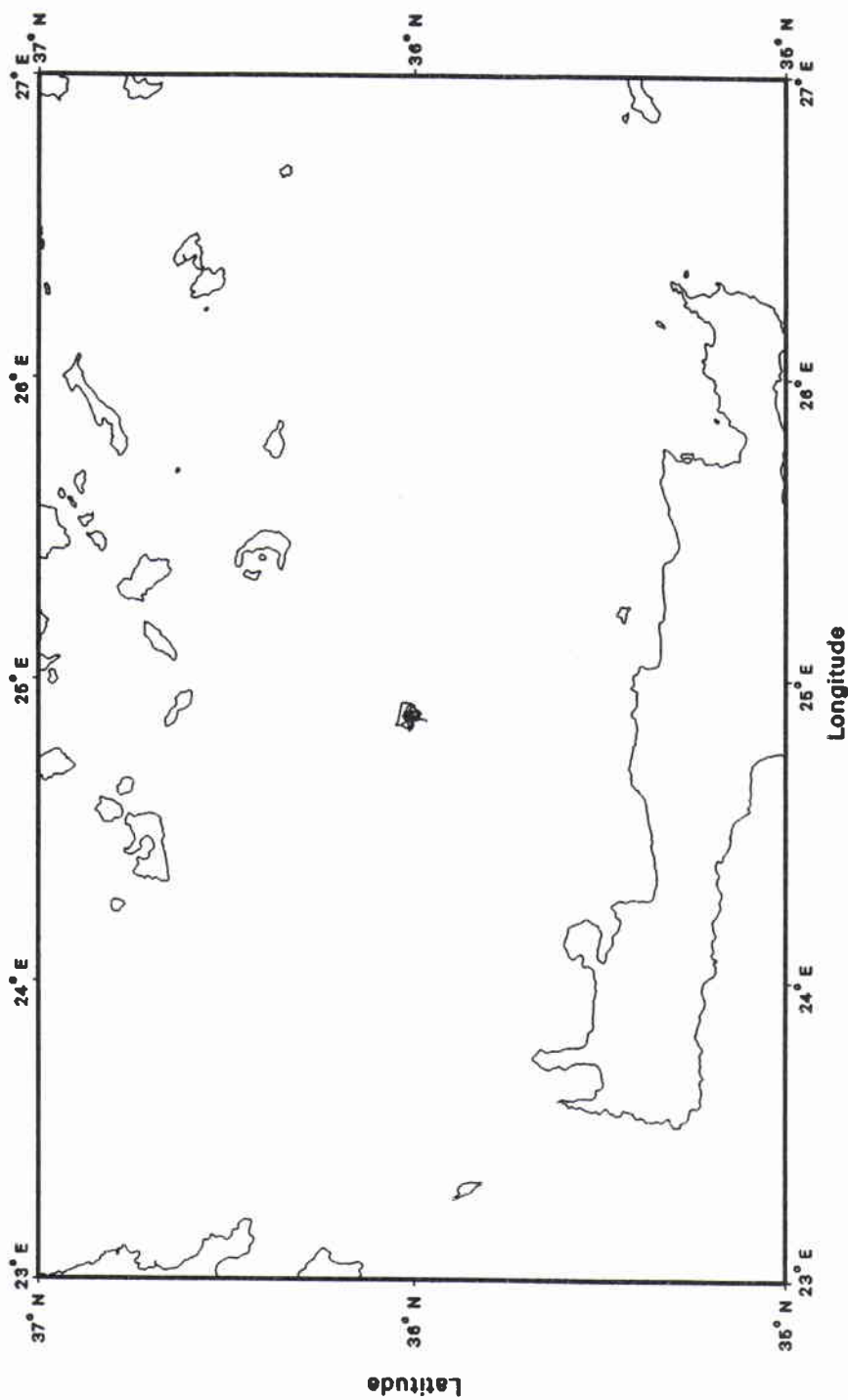


Figure A4

SACLANTCEN SM-264

R/V Alliance 5 June 1990 MASTEX

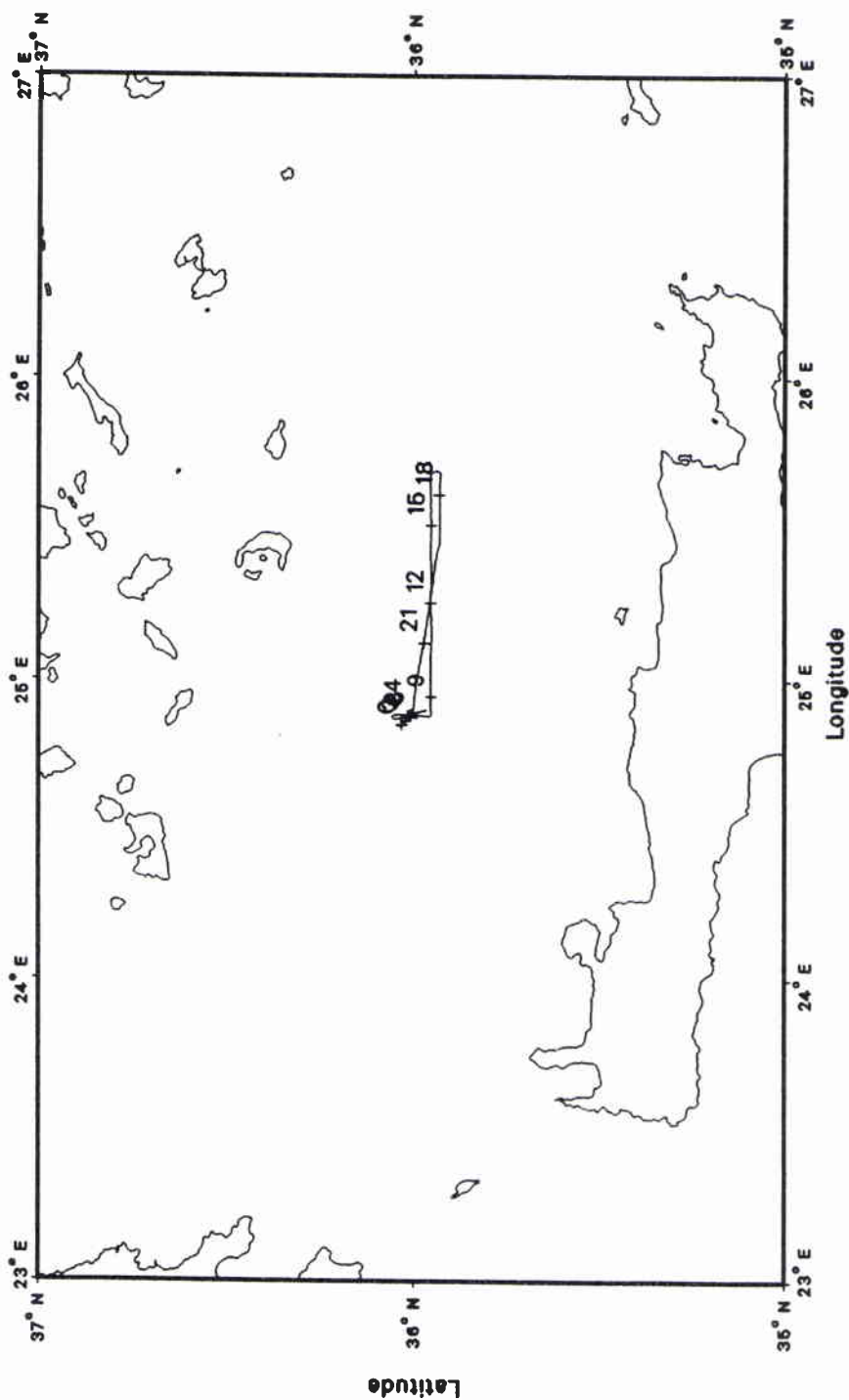


Figure A5

R/V Alliance 6 June 1990 MASTEX

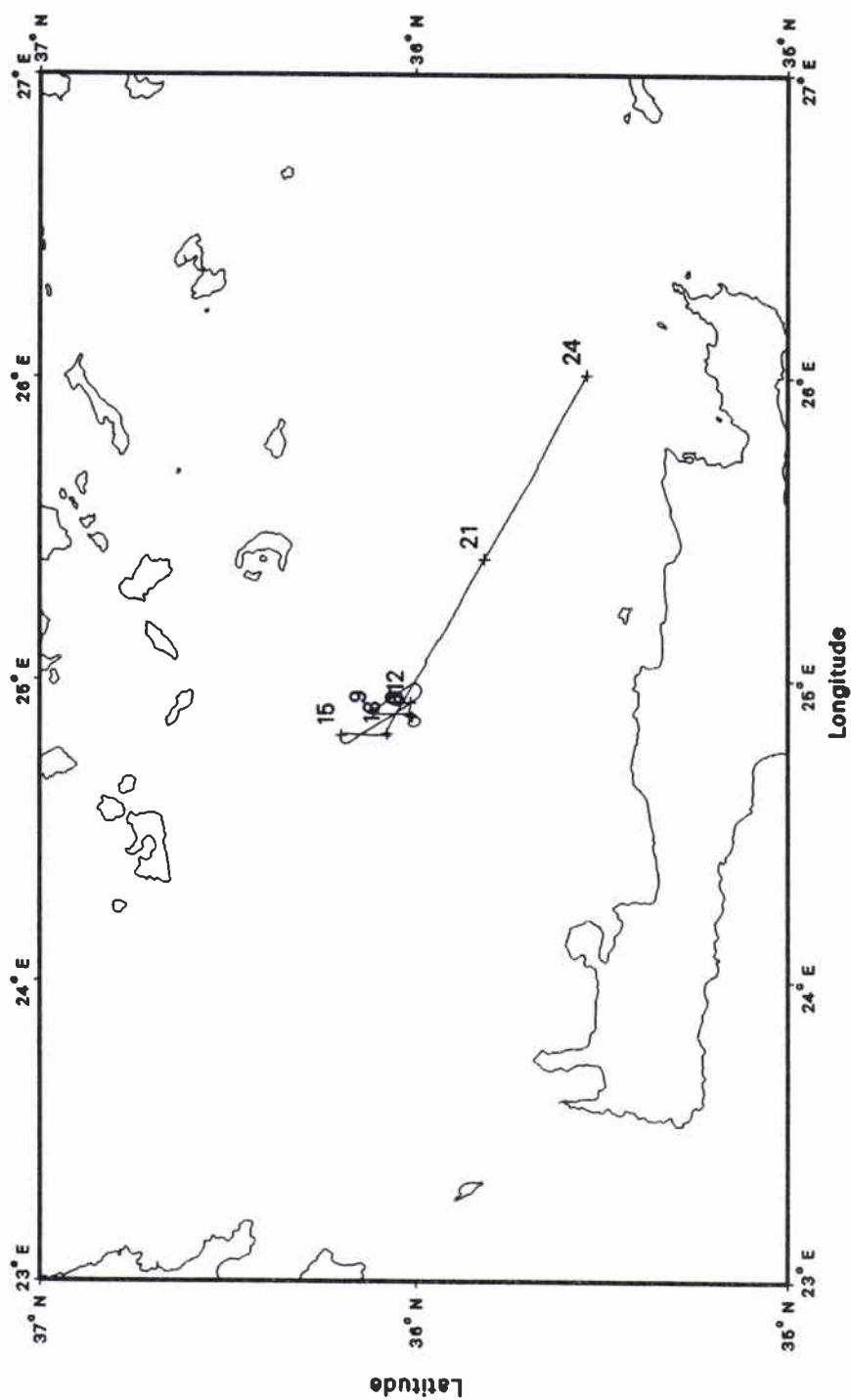


Figure A6

SACLANTCEN SM-264

R/V Alliance 7 June 1990 MASTEX

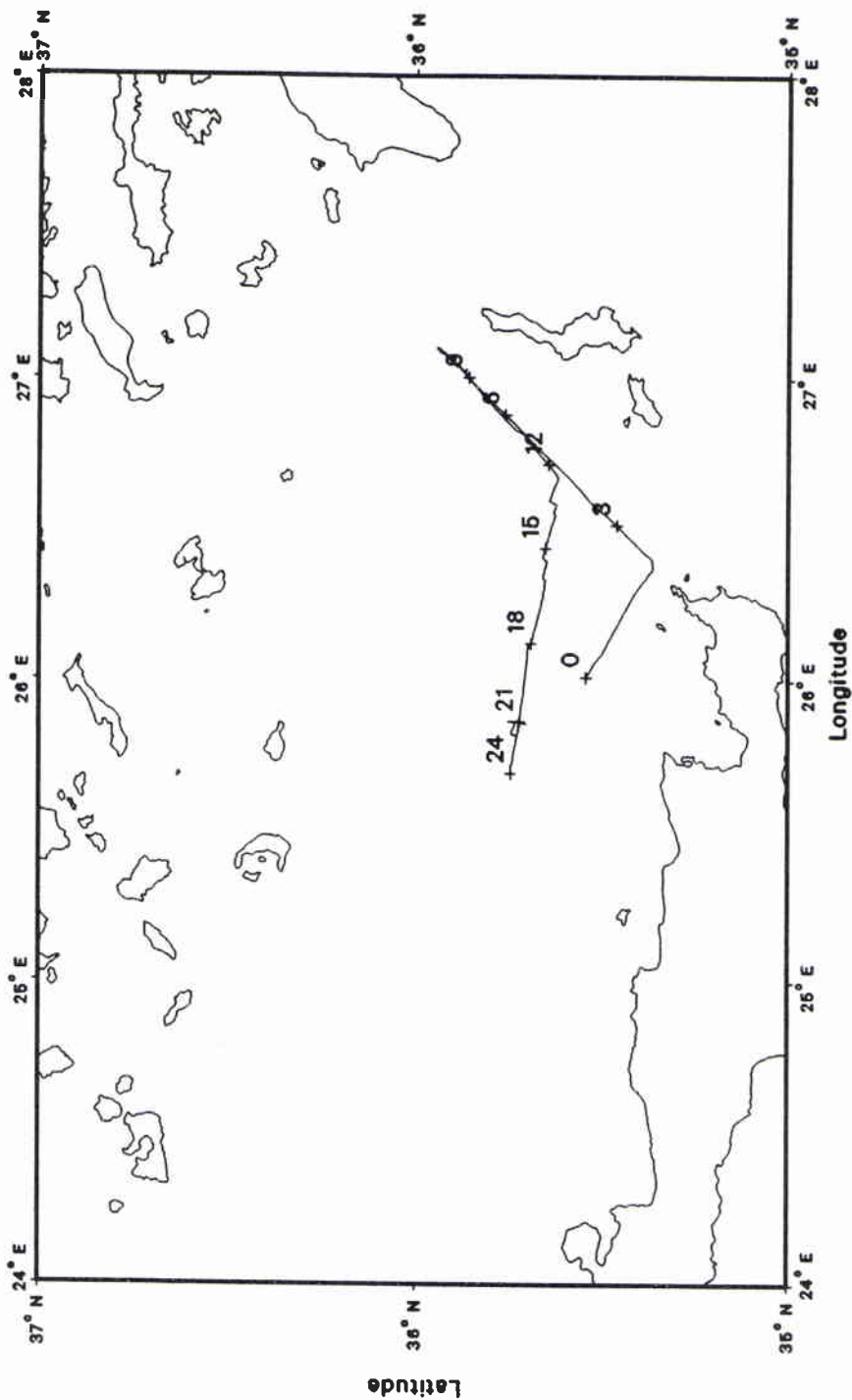


Figure A7

R/V Alliance 8 June 1990 MASTEX

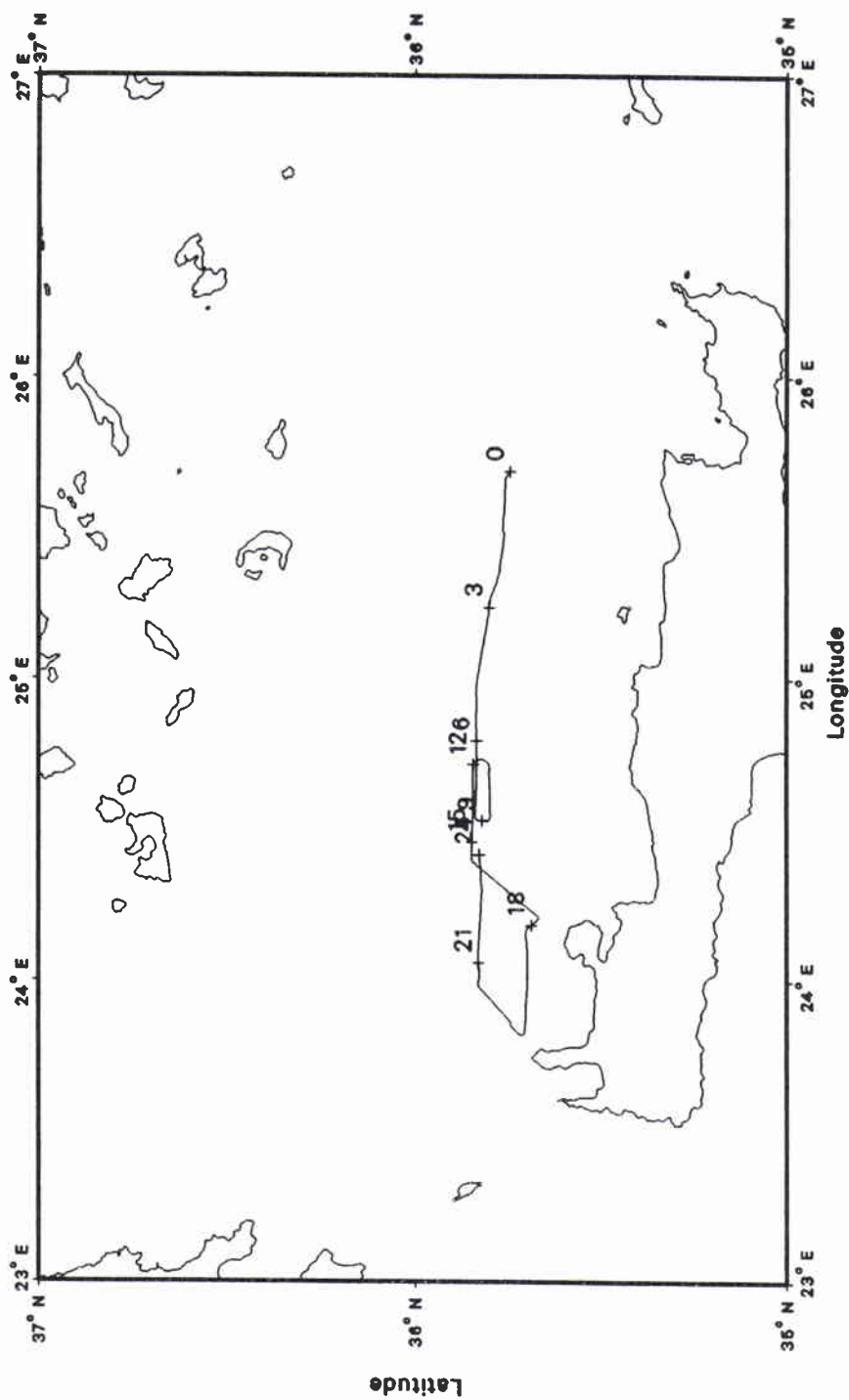


Figure A8

SACLANTCEN SM-264

R/V Alliance 9 June 1990 MASTEX

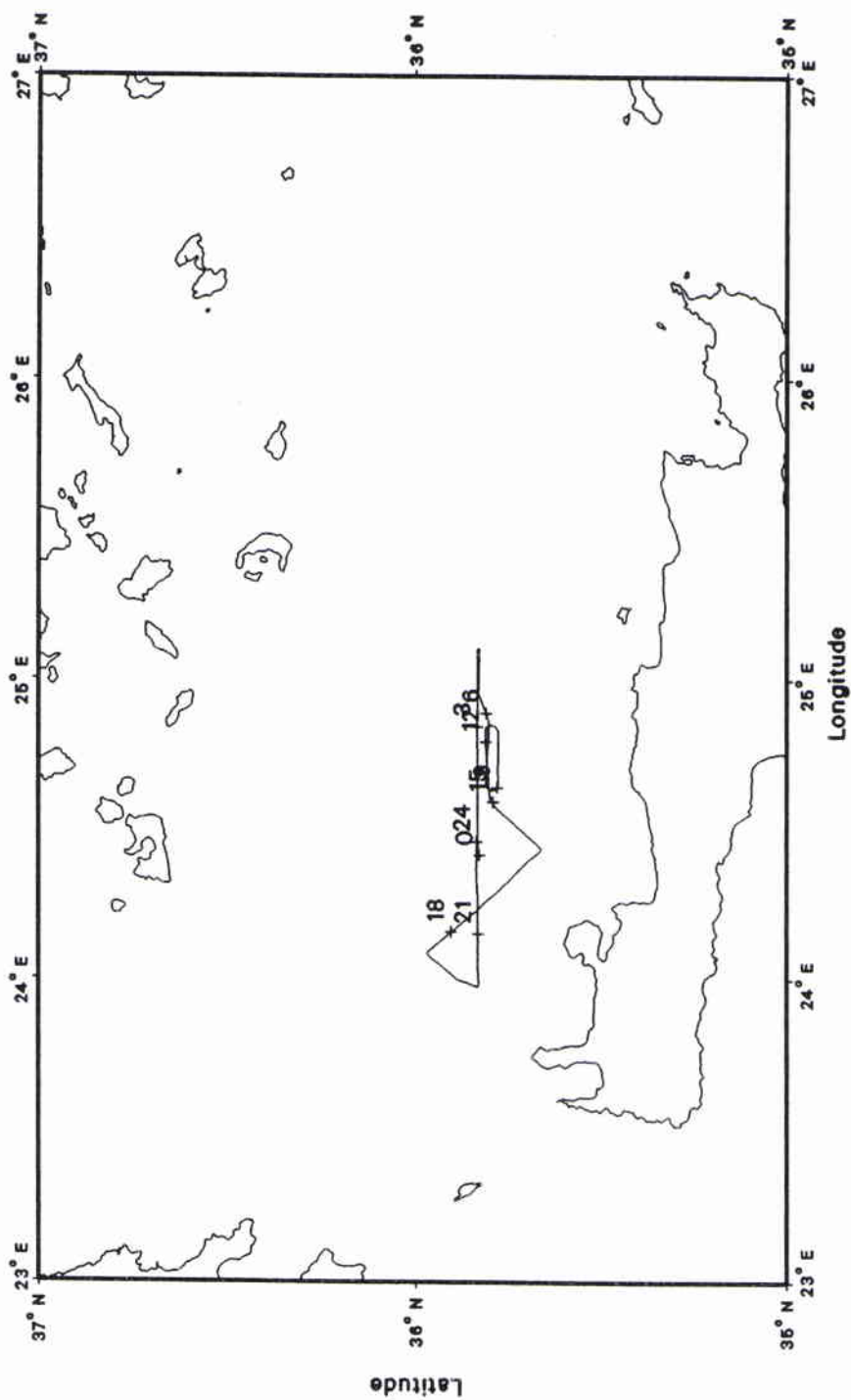


Figure A9

R/V Alliance 10 June 1990 MASTEX

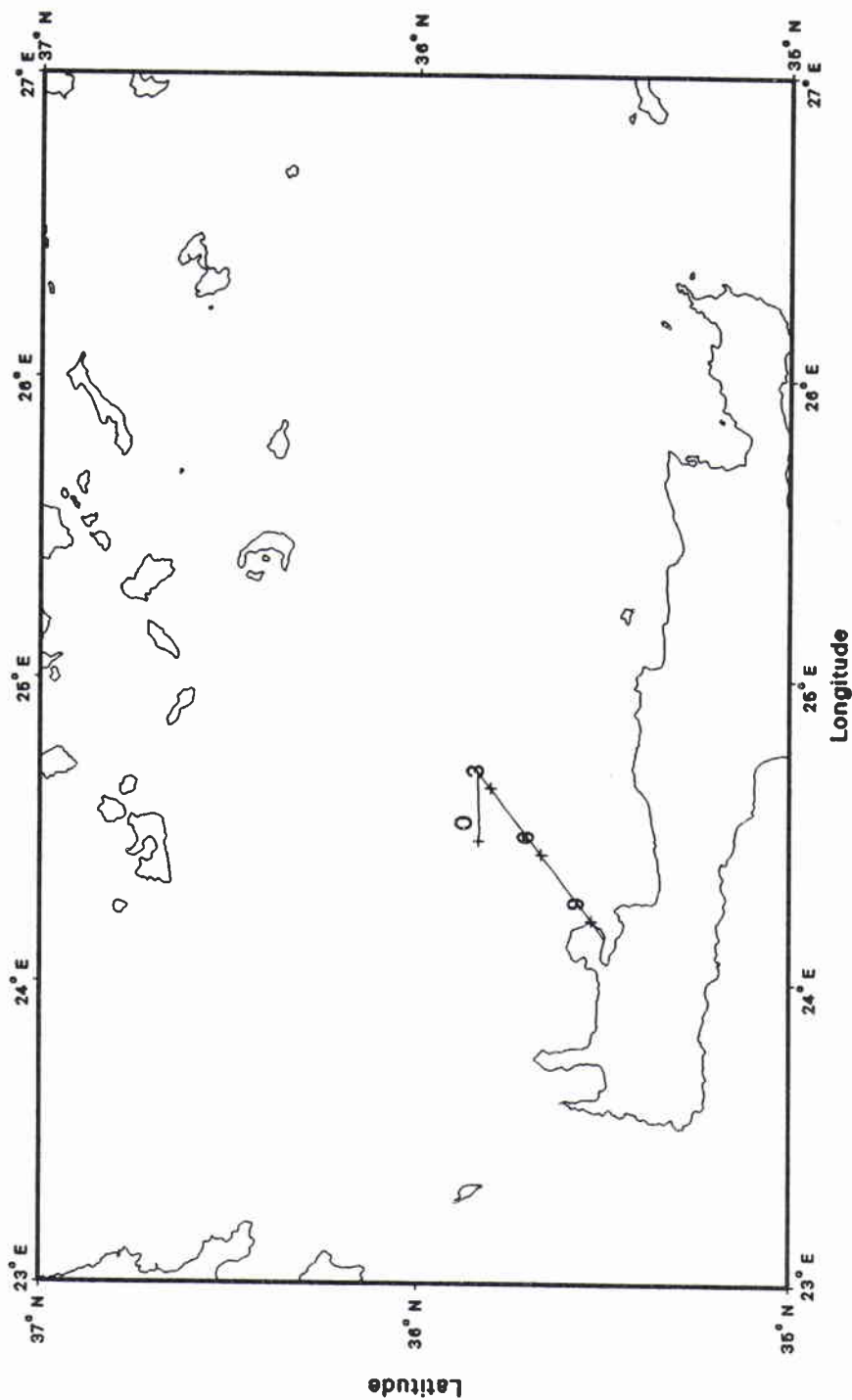


Figure A10

SACLANTCEN SM-264

R/V Alliance 11 June 1990 MASTEX

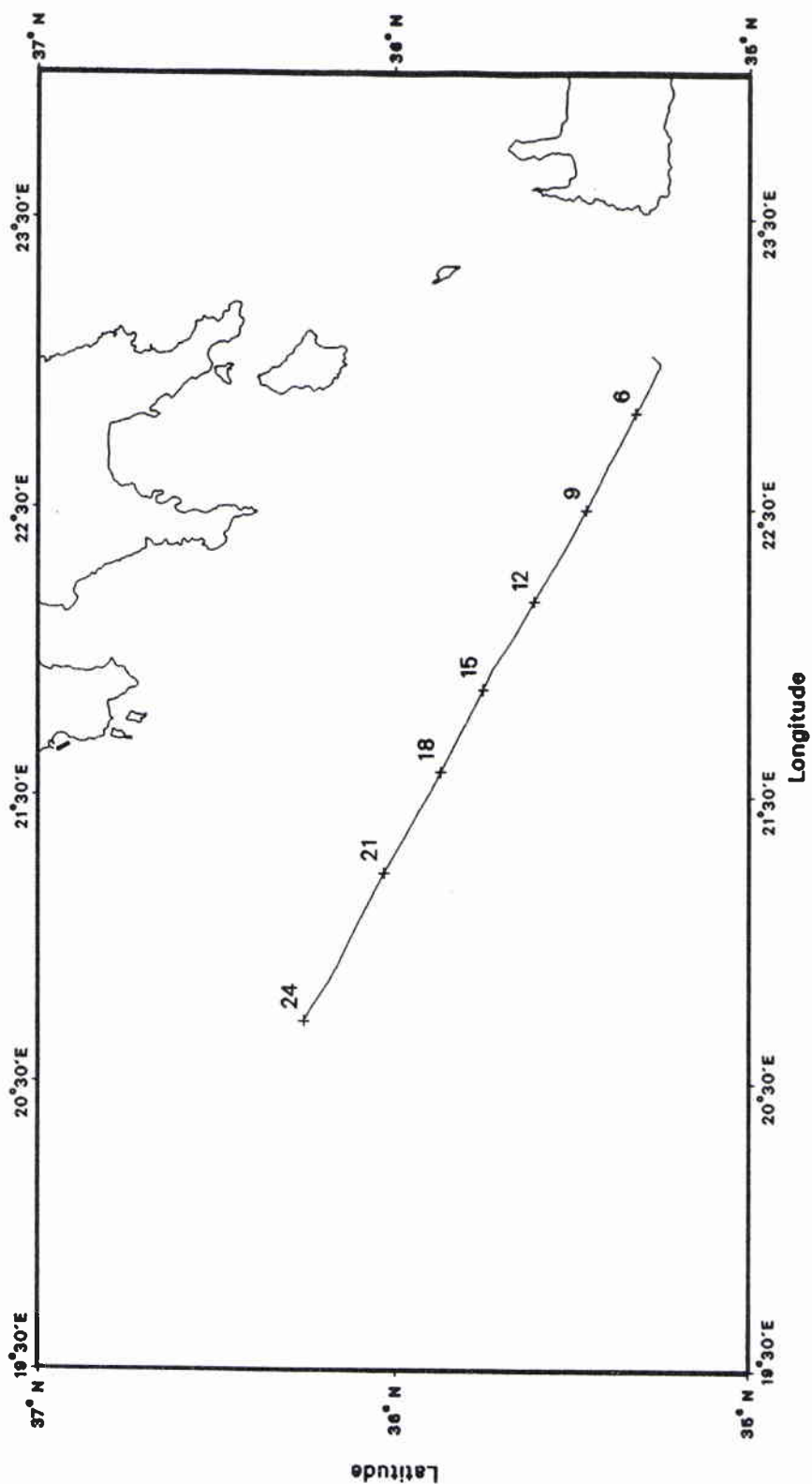


Figure A11

R/V Alliance 12 June 1990 MASTEX

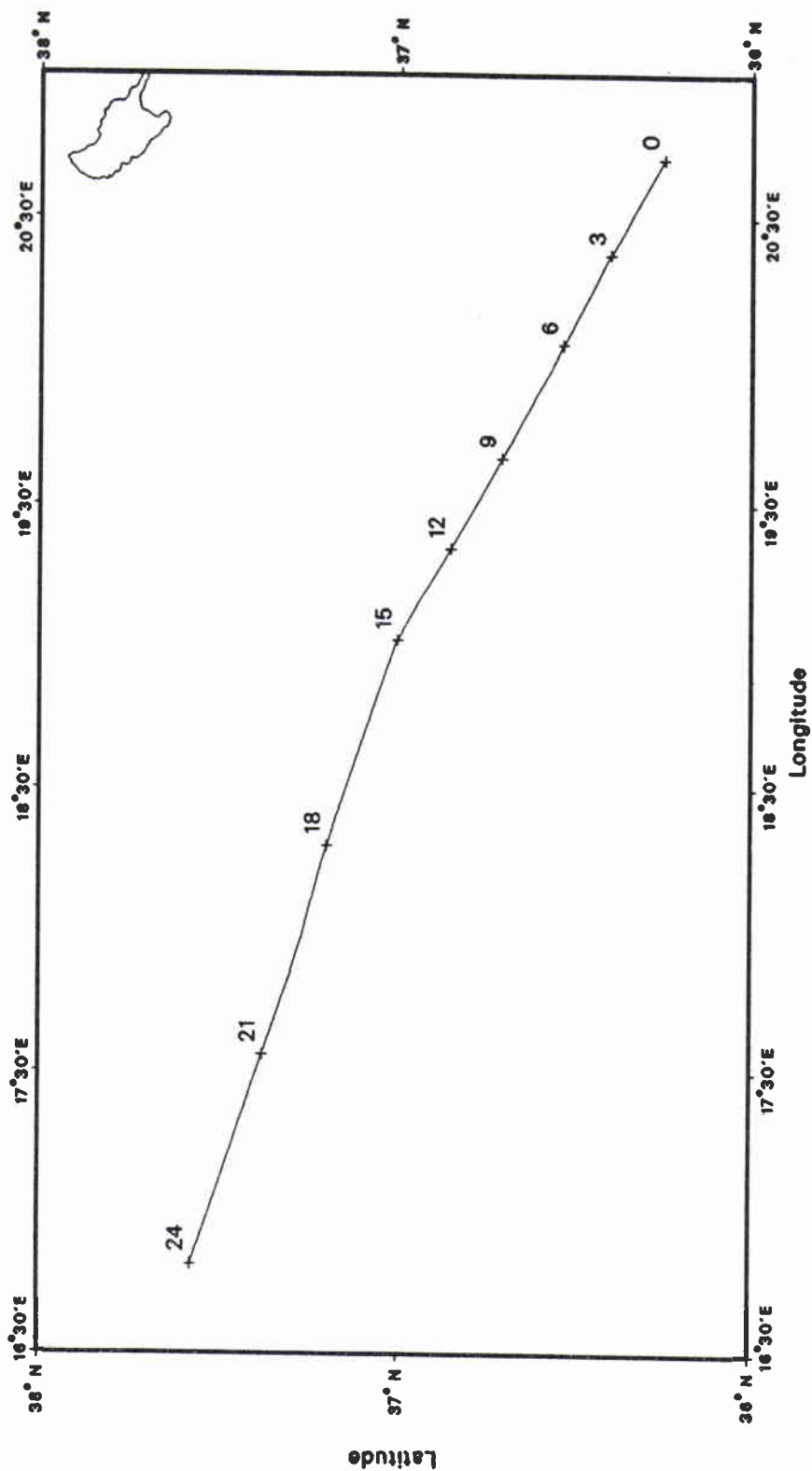


Figure A12

SACLANTCEN SM-264

Appendix B

Surface meteorological variables

Daily time-series plots of true wind speed and direction, air temperature, relative humidity, and surface pressure are presented with full temporal resolution in Figs. B1–B12. The spikes in the true wind direction and, to a lesser degree, speed result from the imperfect compensation for the ship's motion when the vessel was making rapid manoeuvres; the relative winds being averages over one-minute intervals while the ship's navigation data are spot samples within those intervals. The large excursions in surface pressure on June 6 are associated with the erection of the stern instrument mast on which the barometer vent is mounted. Unphysical spikes in the pressure trace before this date are caused by deficient exposure of the barometer vent which was susceptible to spurious effects caused by wind.

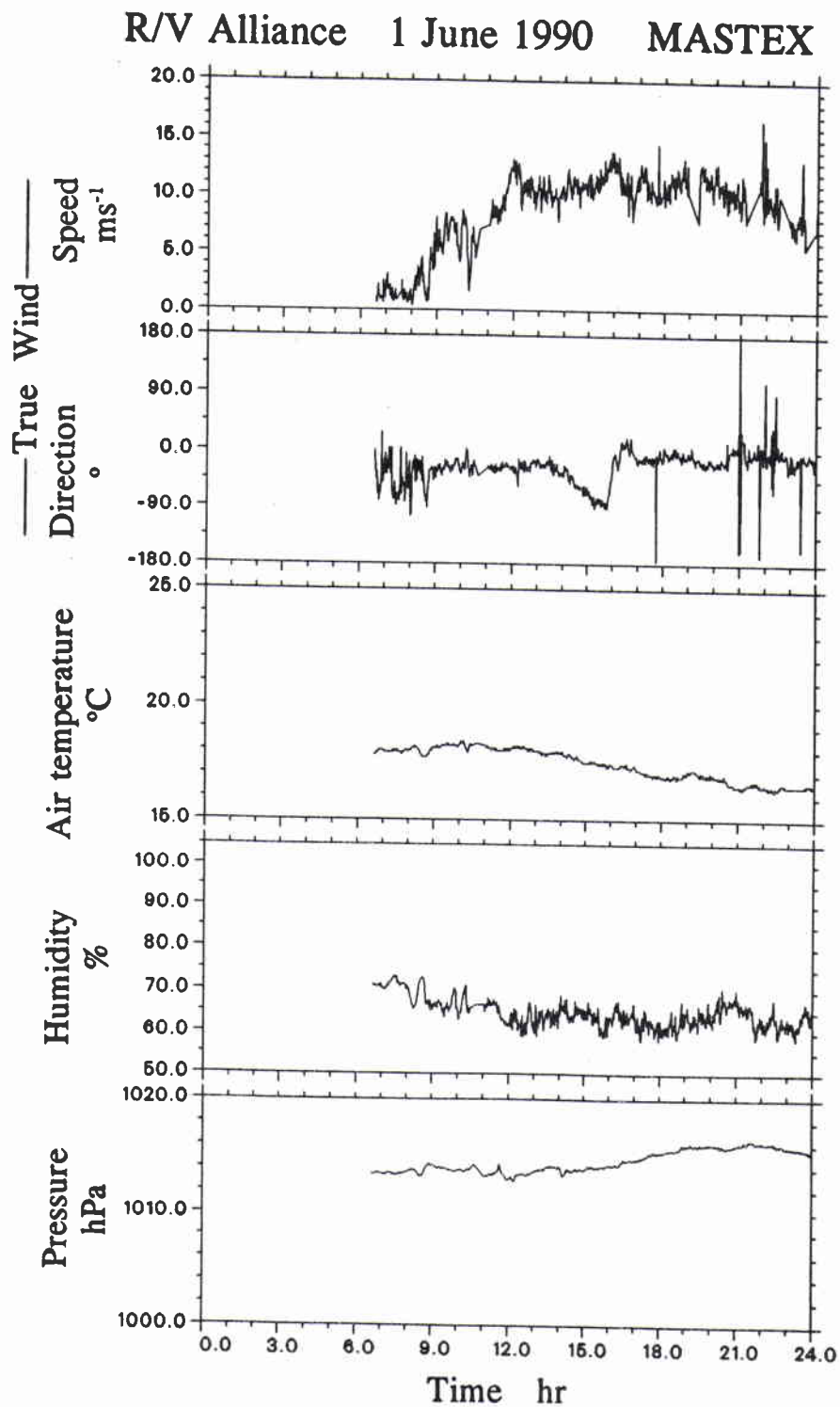


Figure B1

SACLANTCEN SM-264

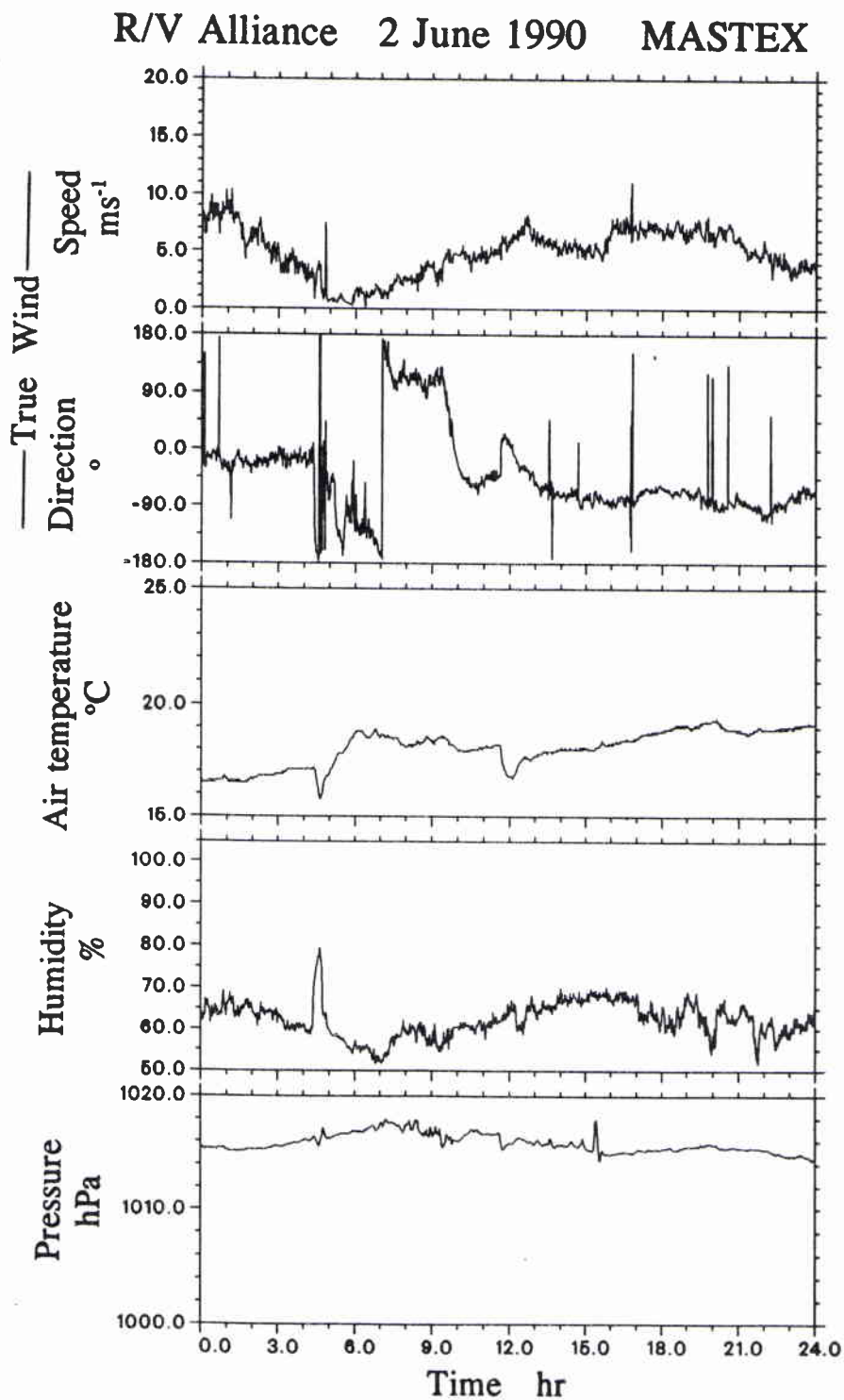


Figure B2

R/V Alliance 3 June 1990 MASTEX

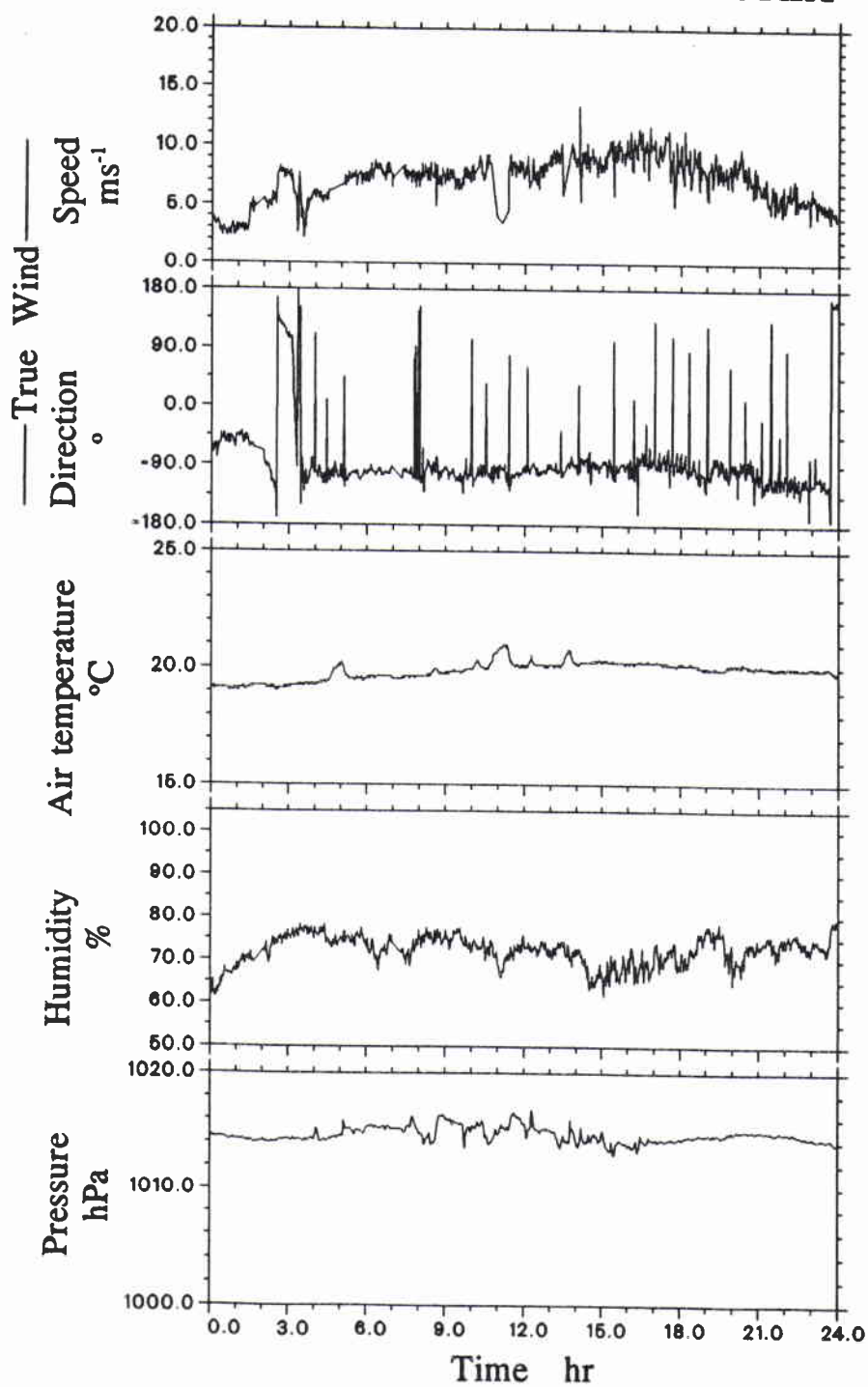


Figure B3

SACLANTCEN SM-264

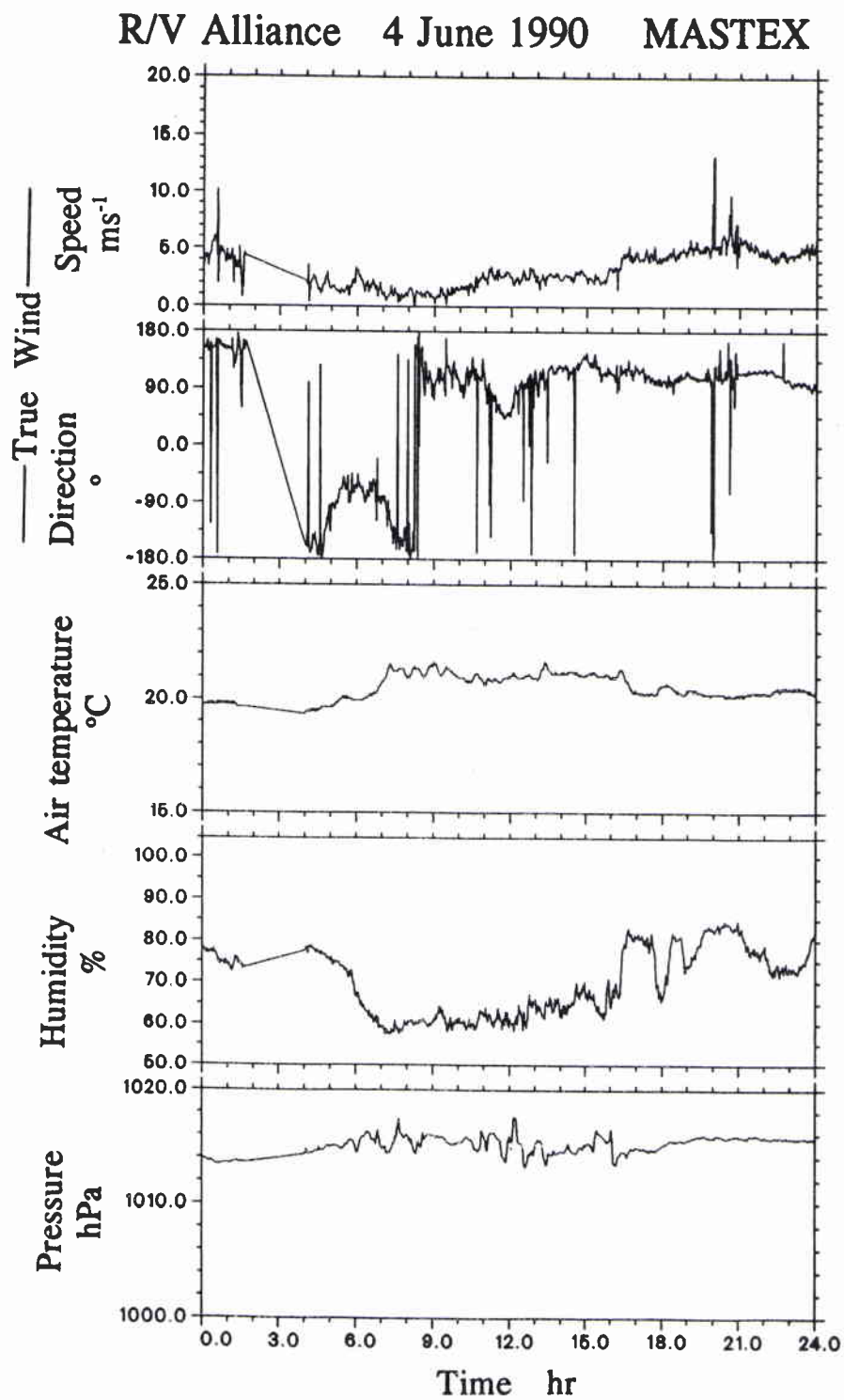


Figure B4

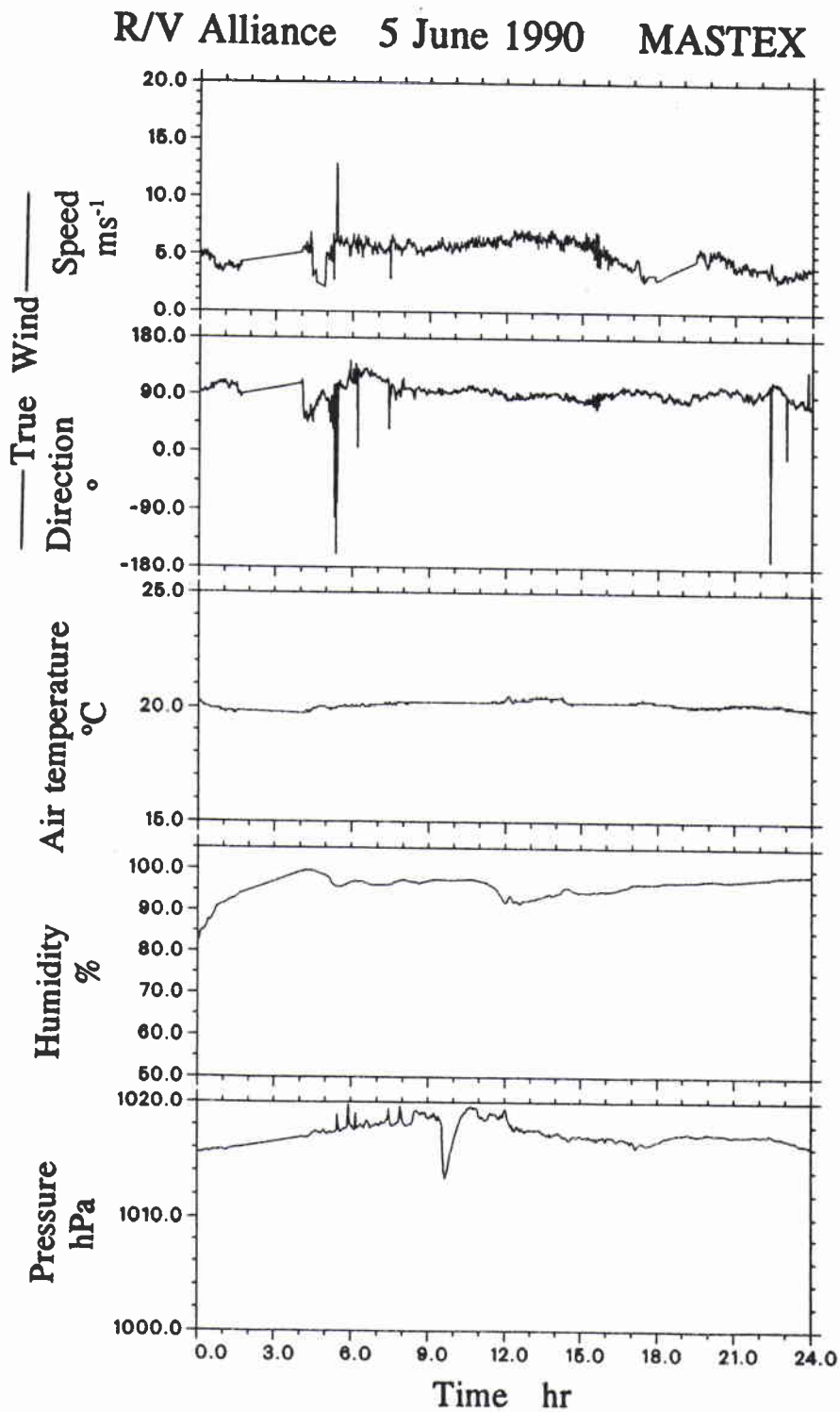


Figure B5

SACLANTCEN SM-264

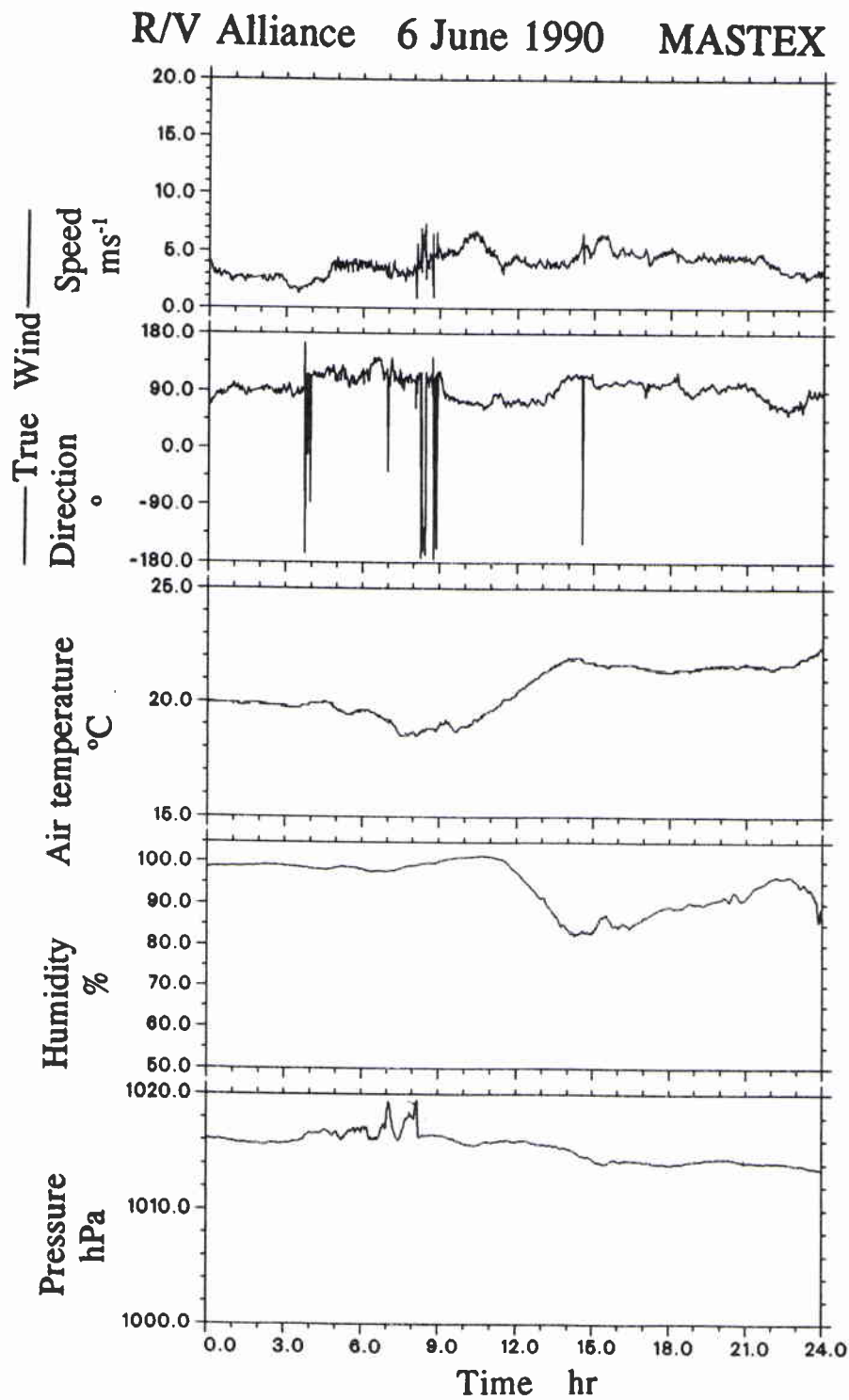


Figure B6

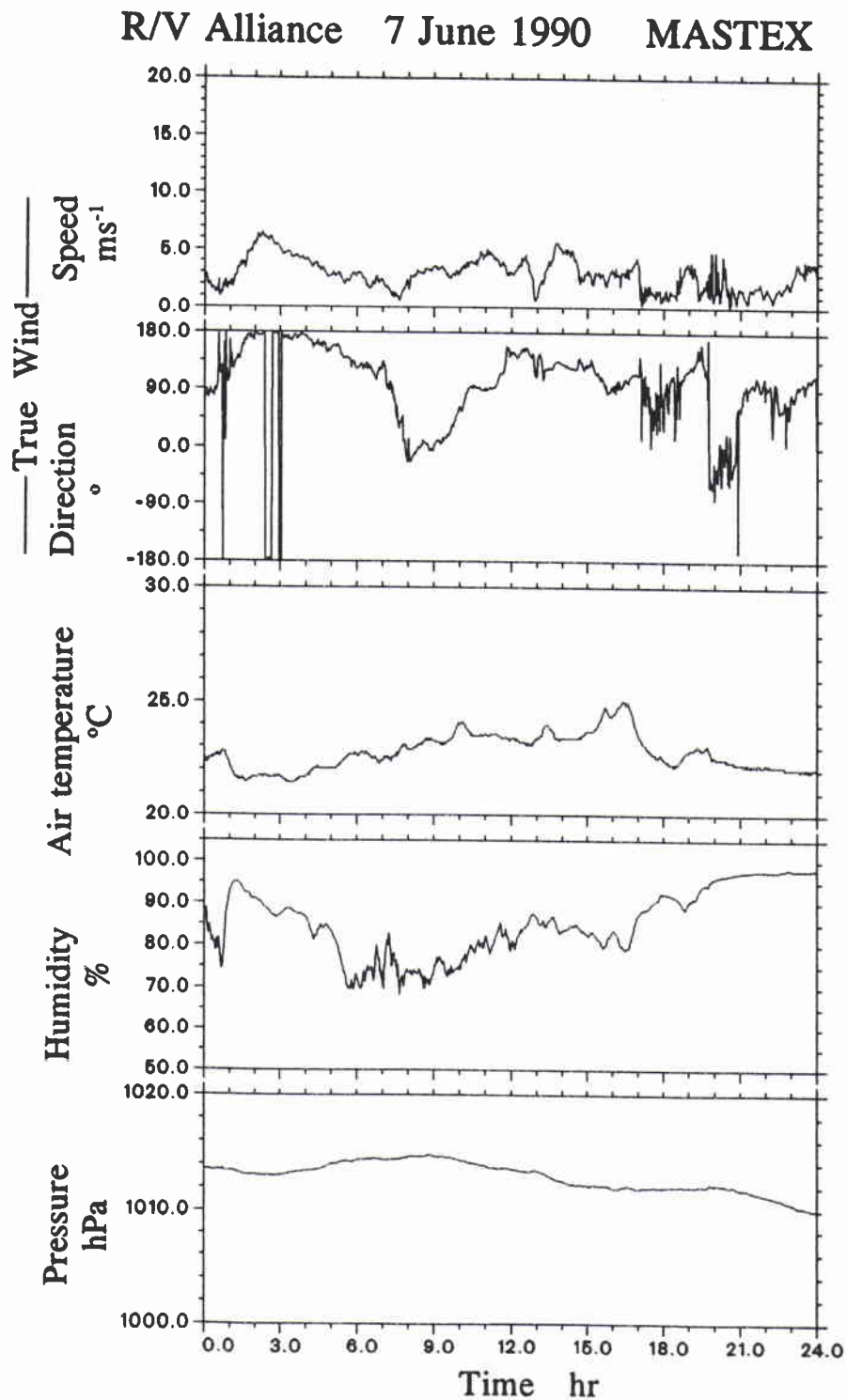


Figure B7

SACLANTCEN SM-264

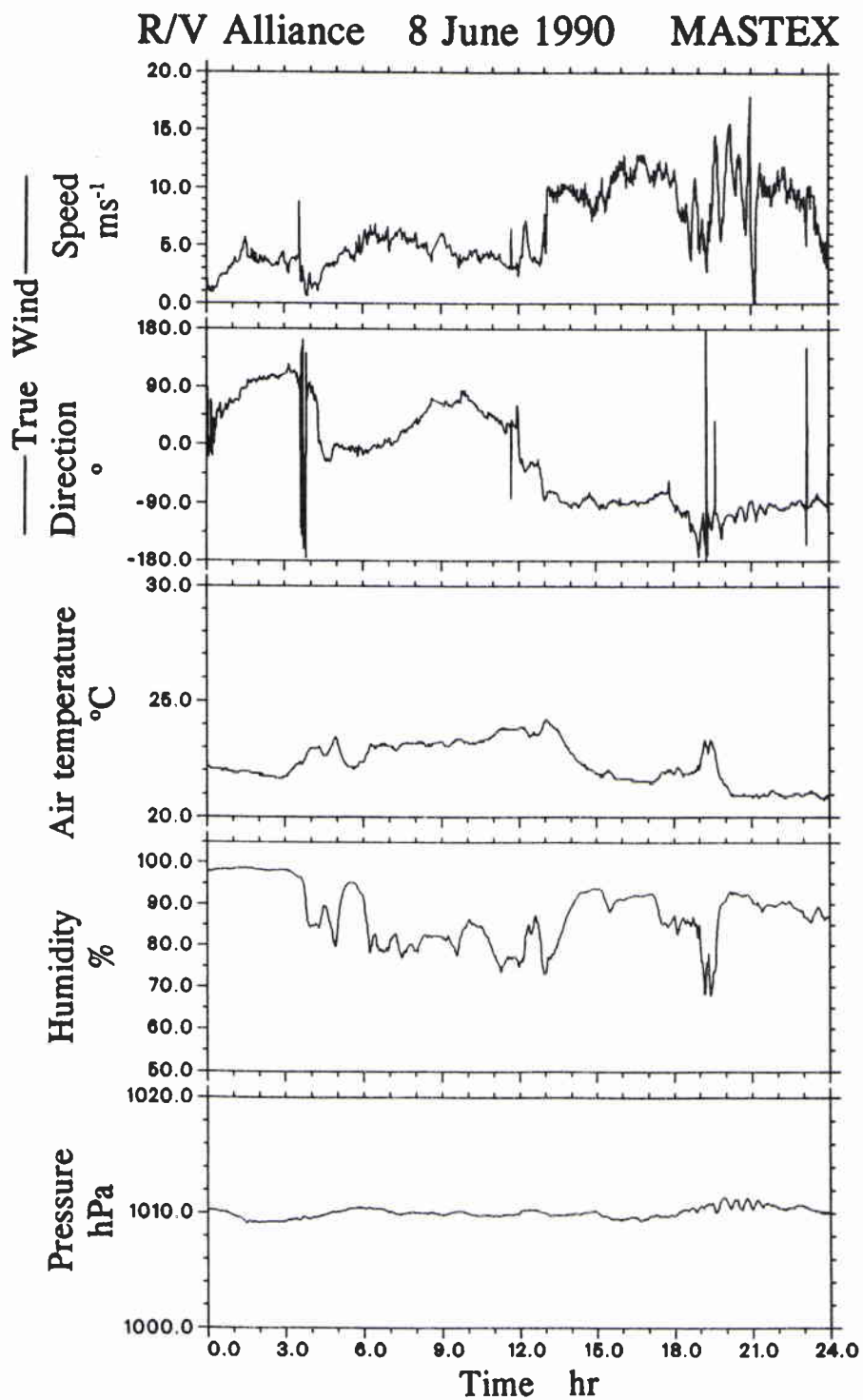


Figure B8

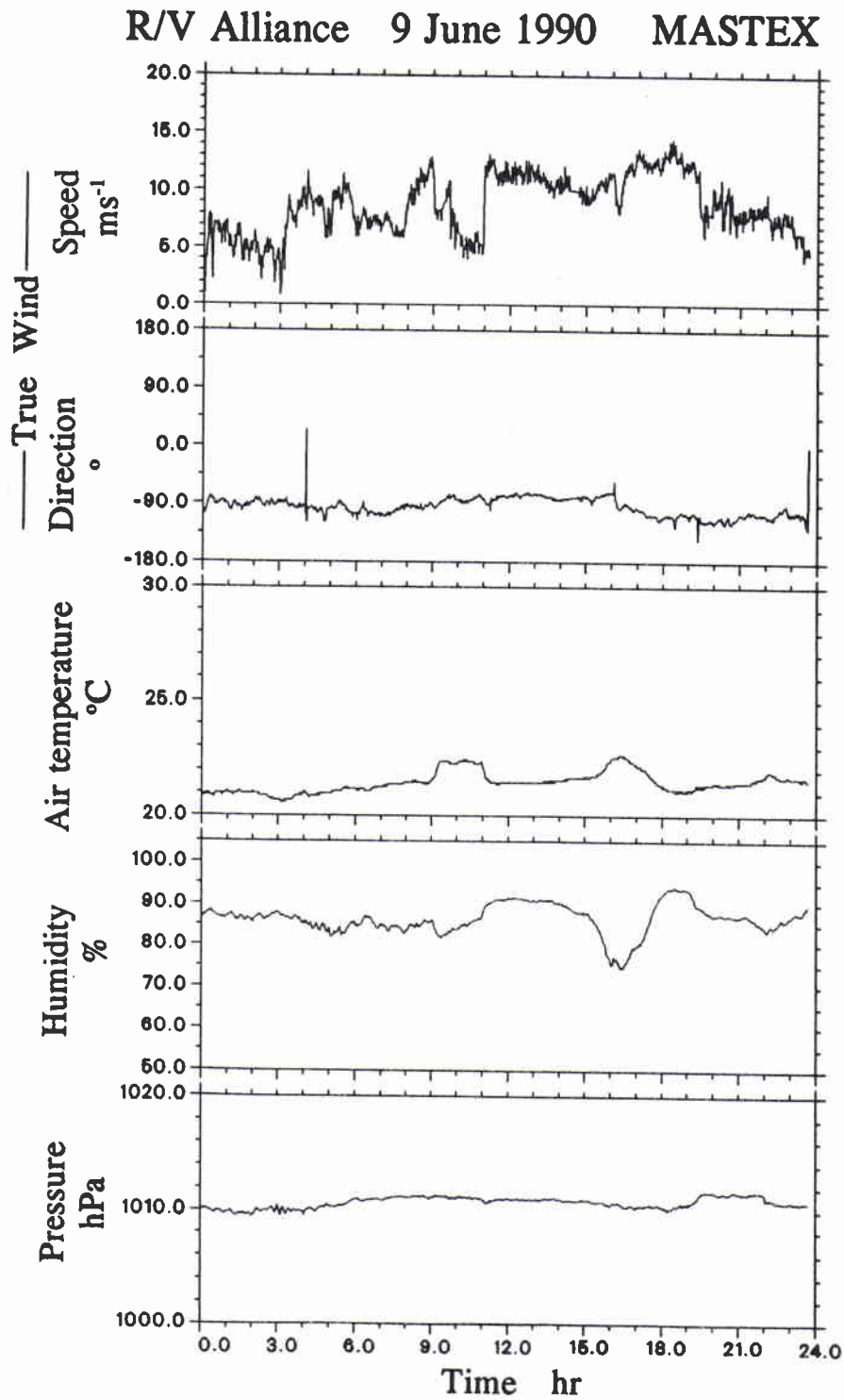


Figure B9

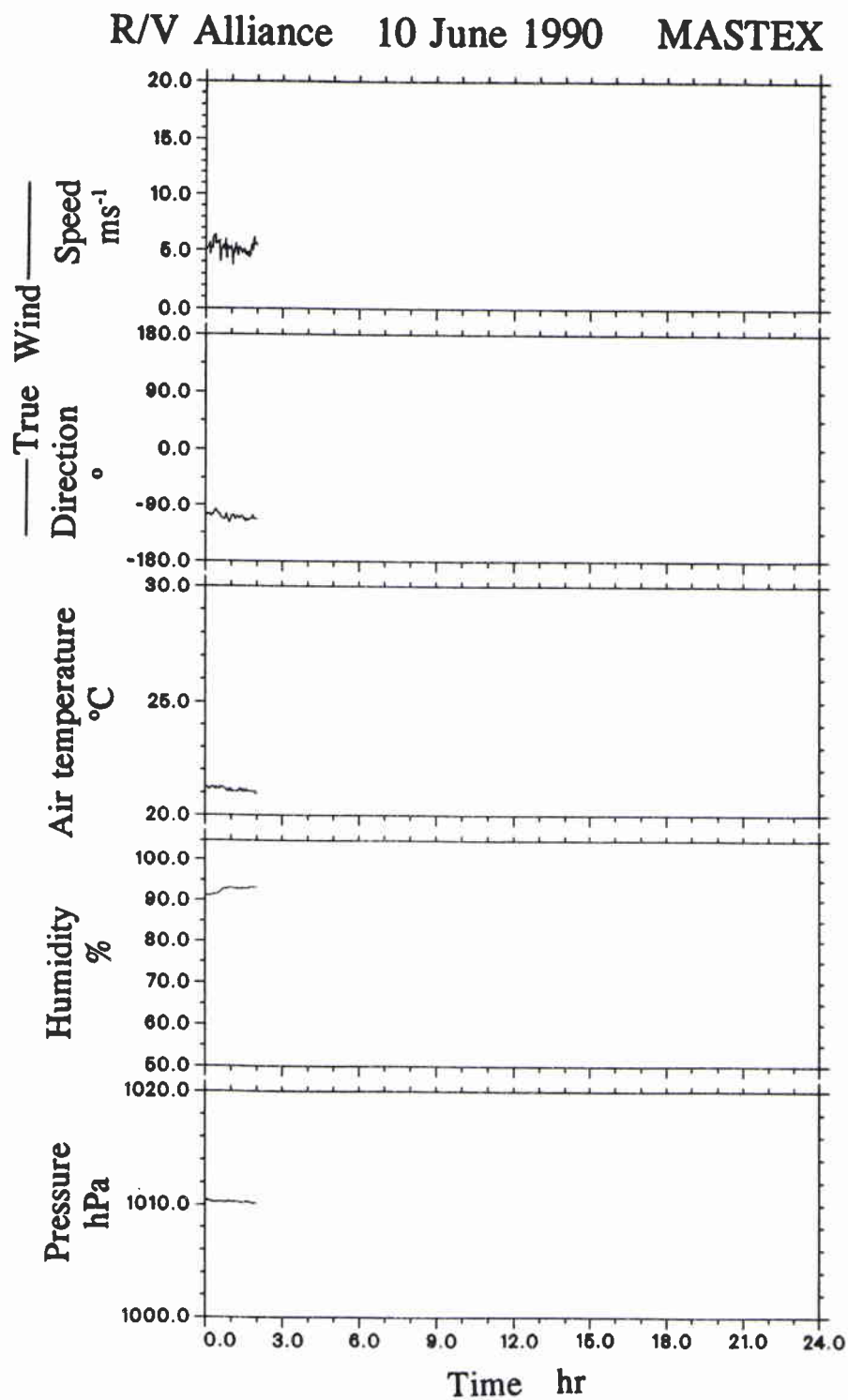
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Figure B10

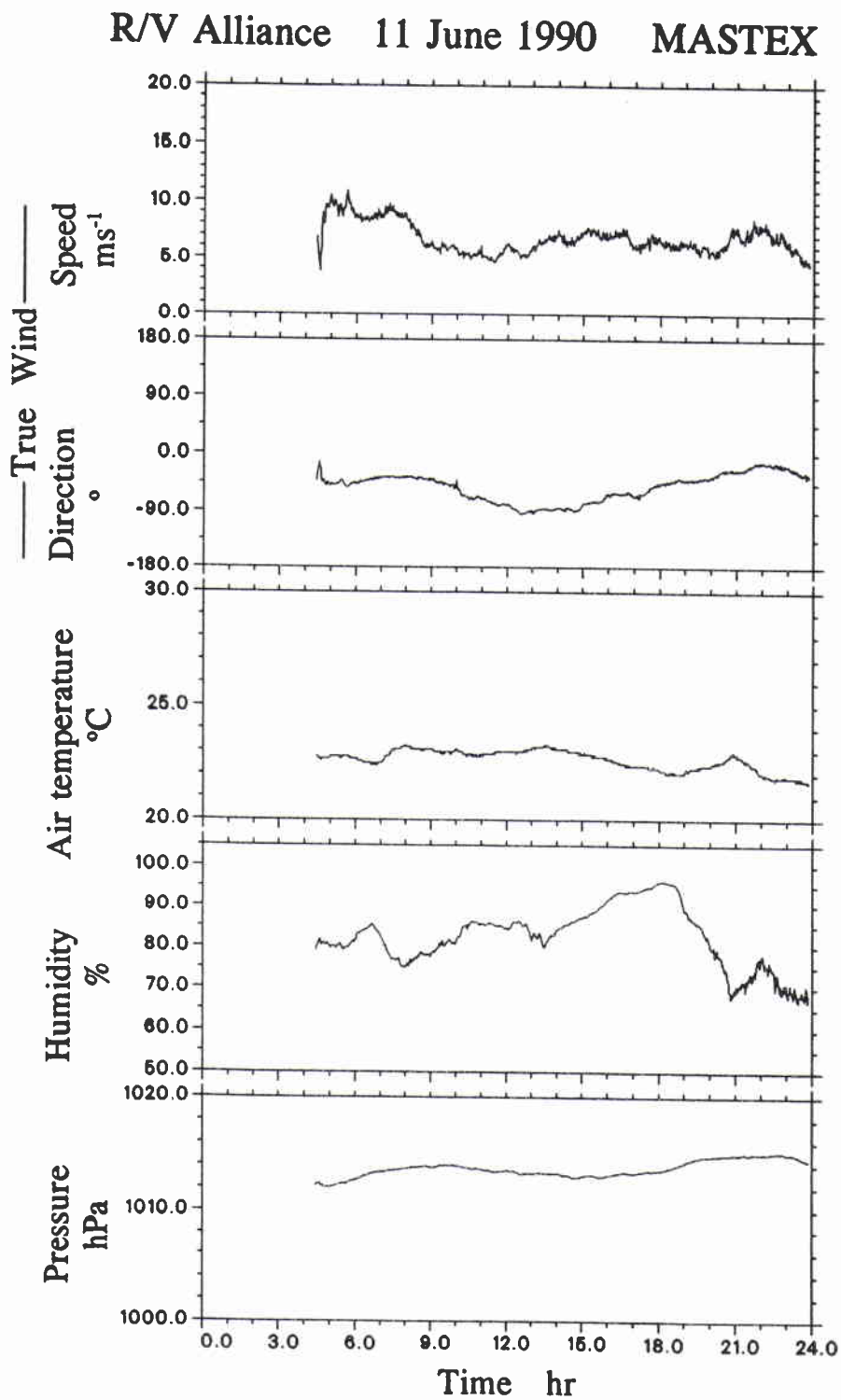


Figure B11

SACLANTCEN SM-264

R/V Alliance 12 June 1990 MASTEX

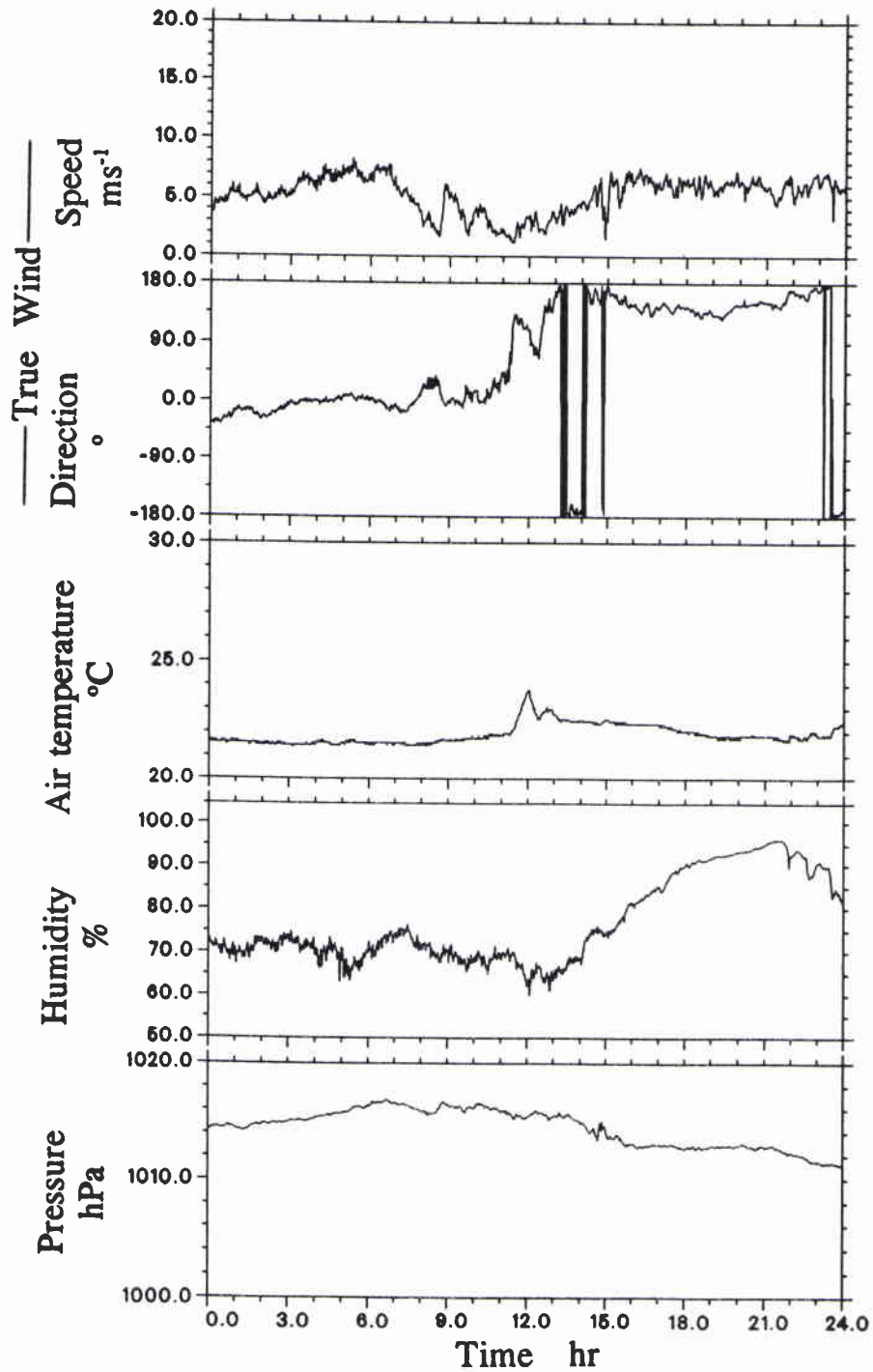


Figure B12

Appendix C

Surface radiation

Time-series of the radiative terms of the surface heat budget are shown in Figs. C1–C12. These are the measured hemispheric downwelling short-wave radiation (insolation), and hemispheric downwelling long-wave radiation. Also shown are the calculated upwelling long-wave radiation, net long-wave radiation, and net surface radiation.

SACLANTCEN SM-264

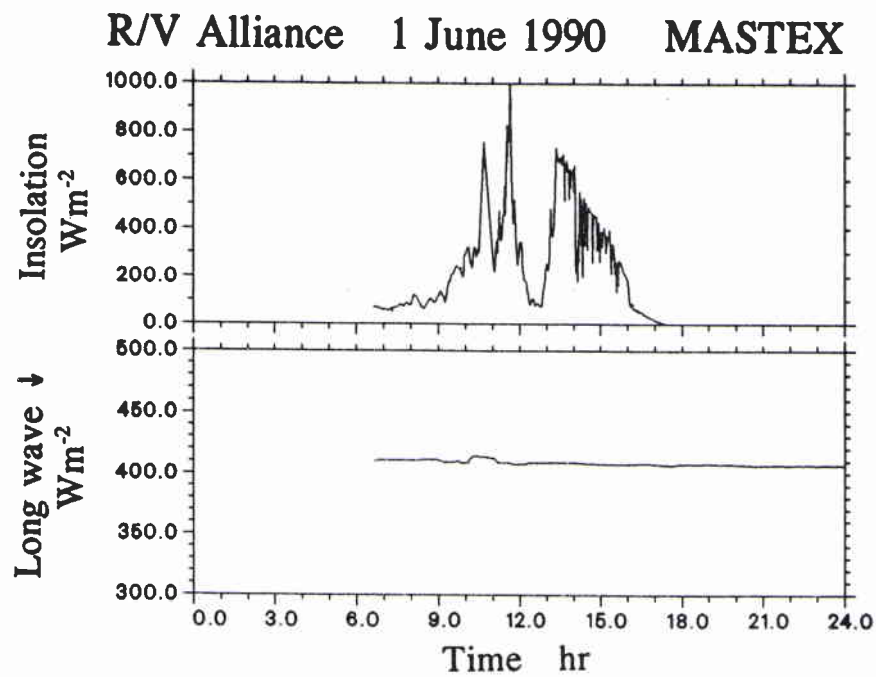


Figure C1

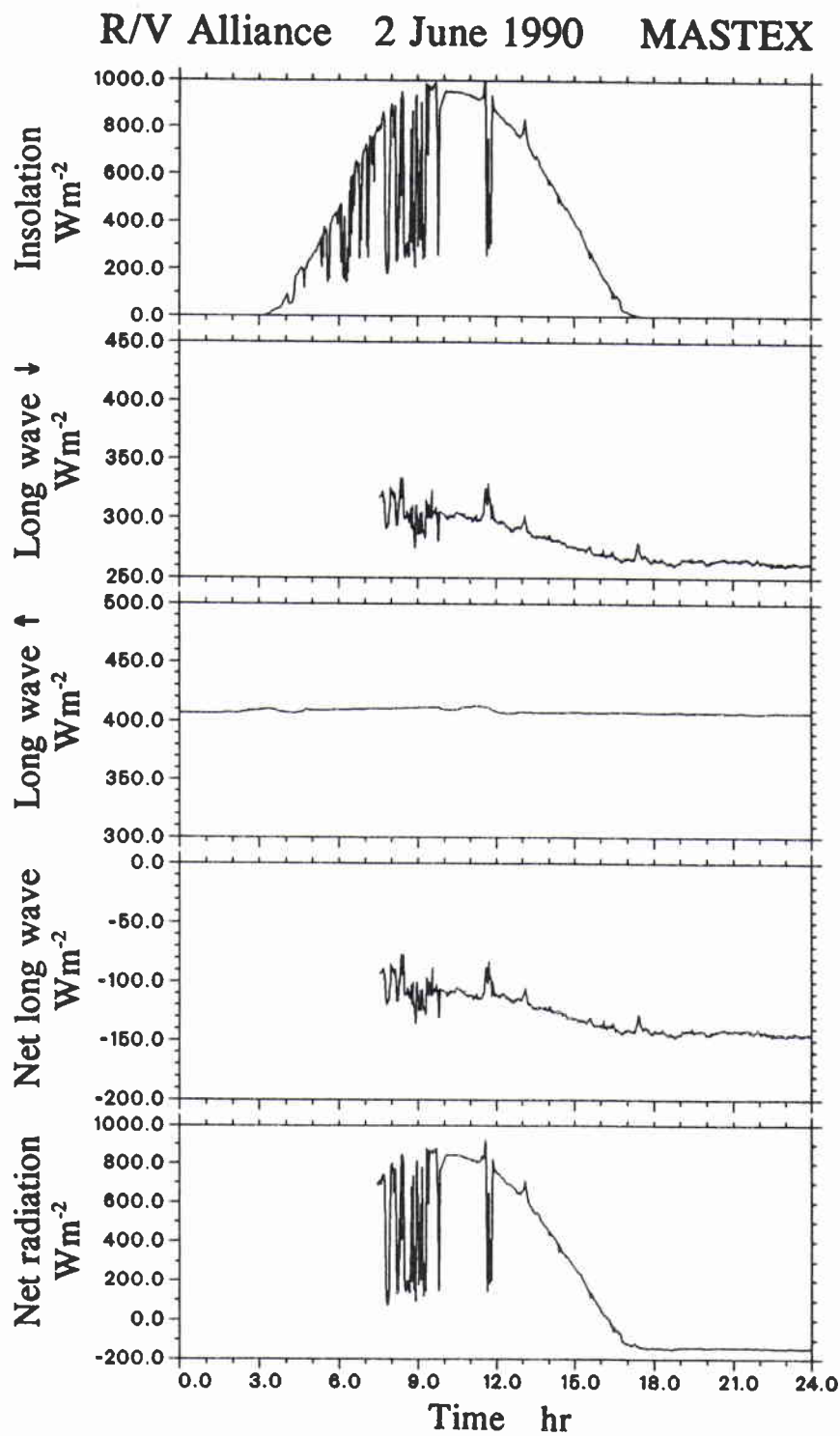


Figure C2

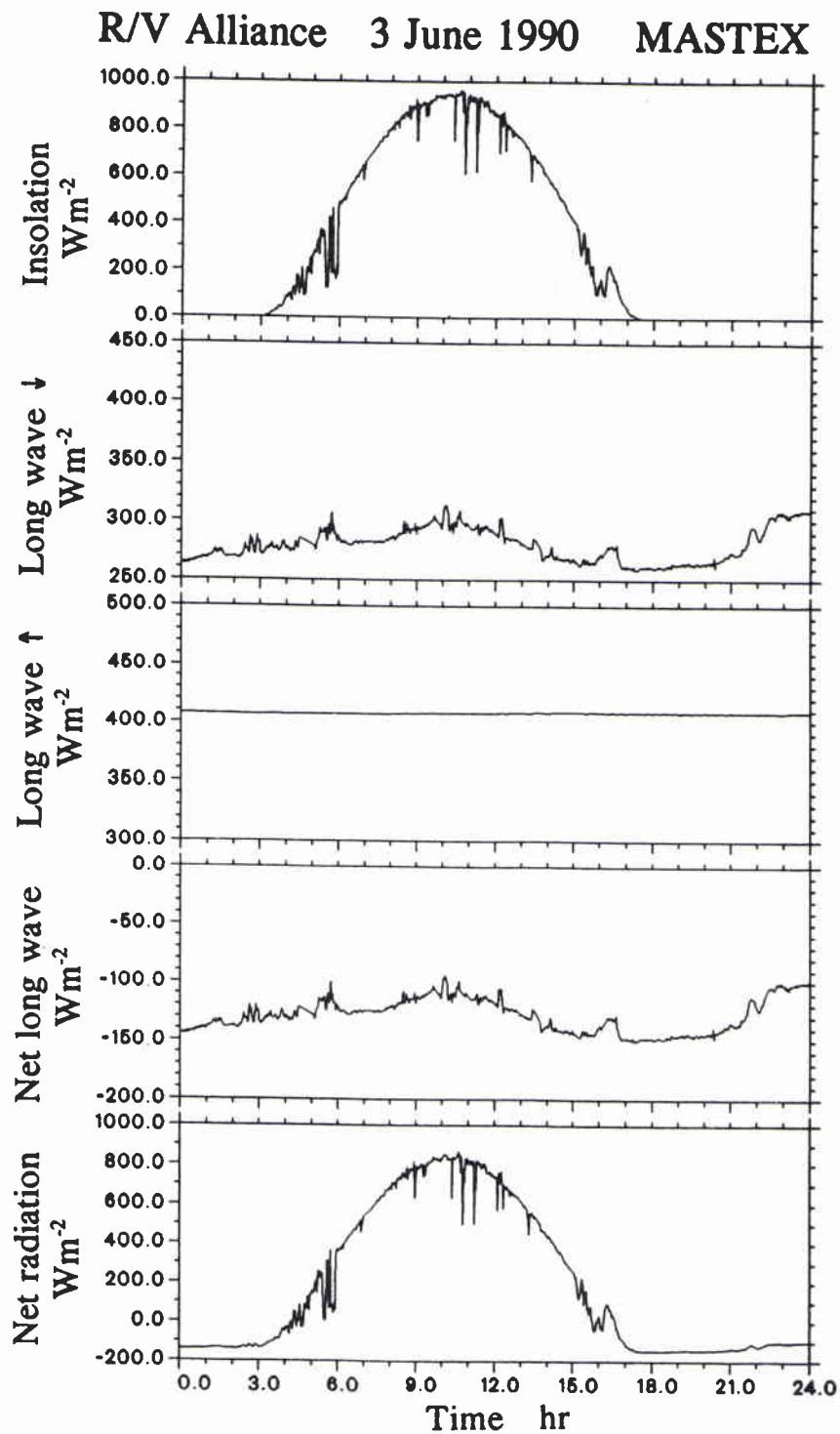
SACLANTCEN SM-264

Figure C3

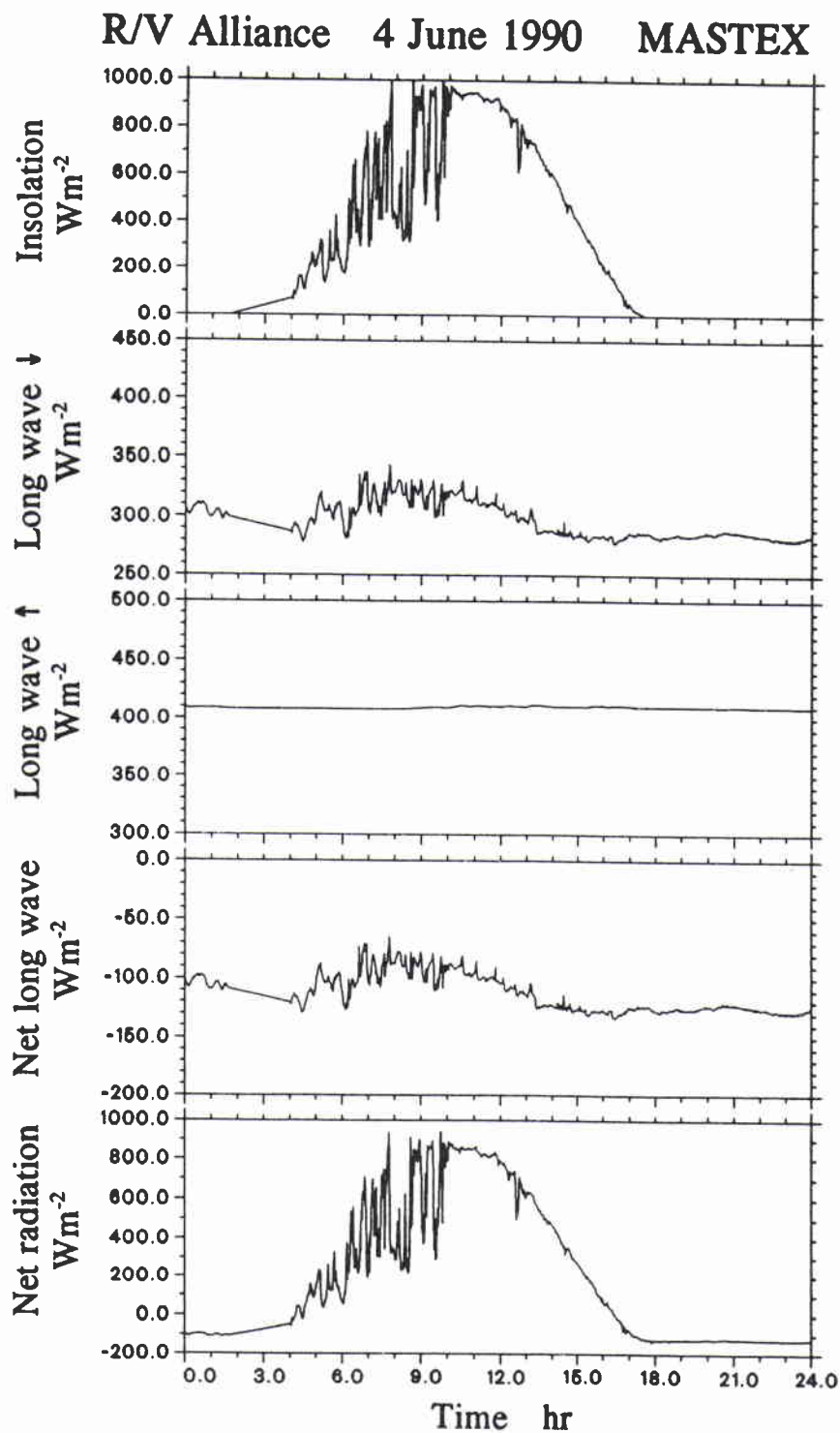


Figure C4

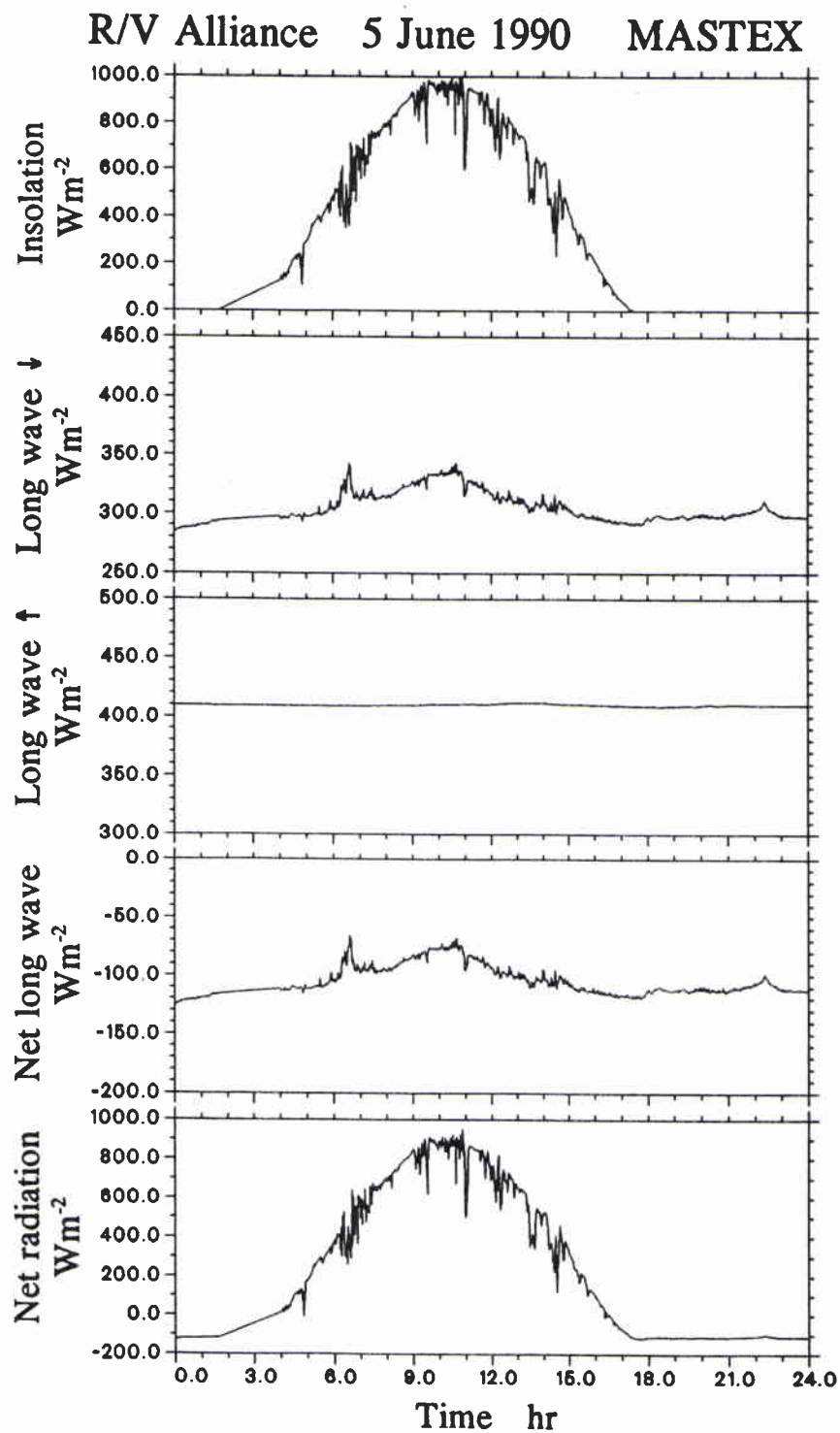
SACLANTCEN SM-264

Figure C5

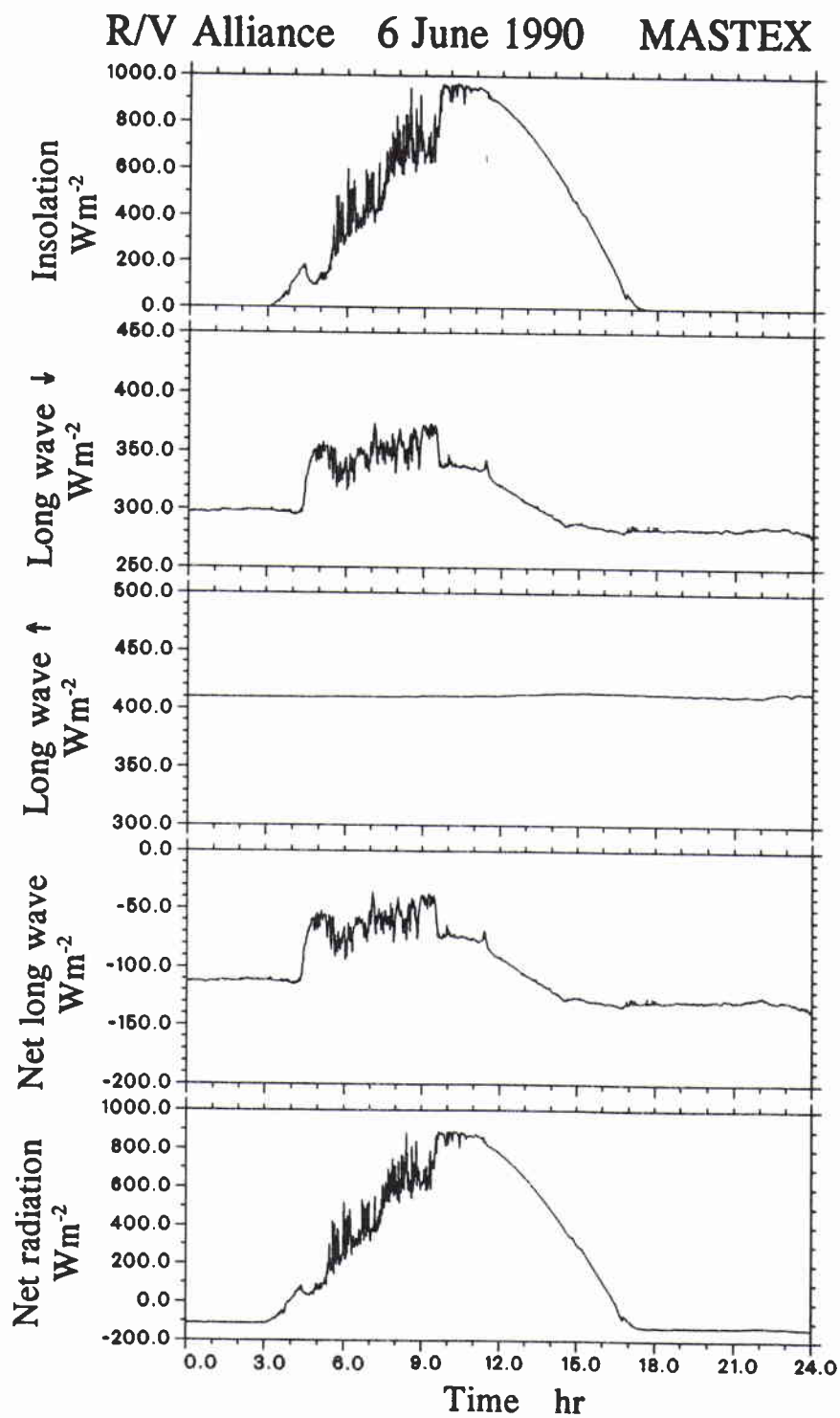


Figure C6

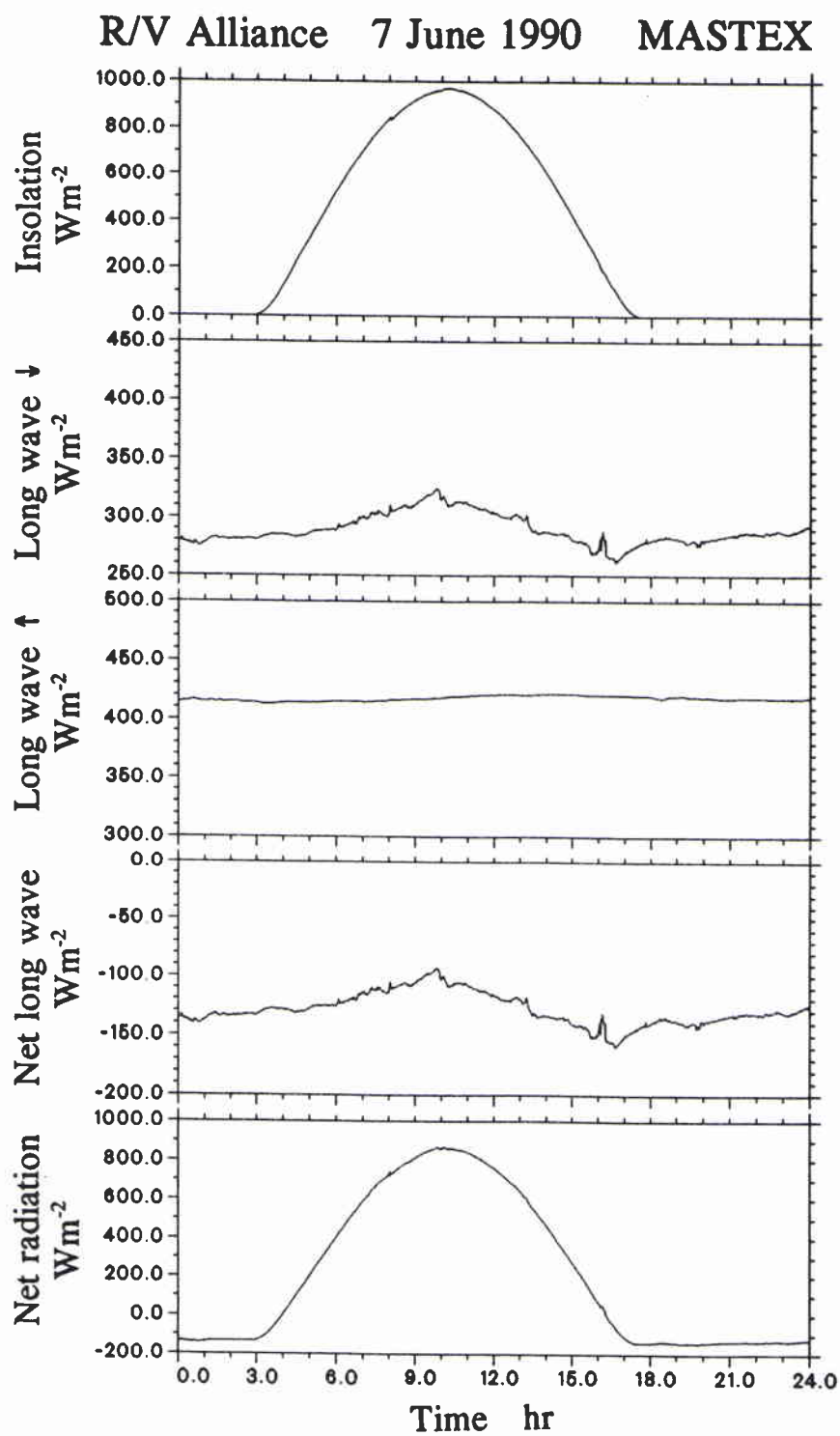
SACLANTCEN SM-264

Figure C7

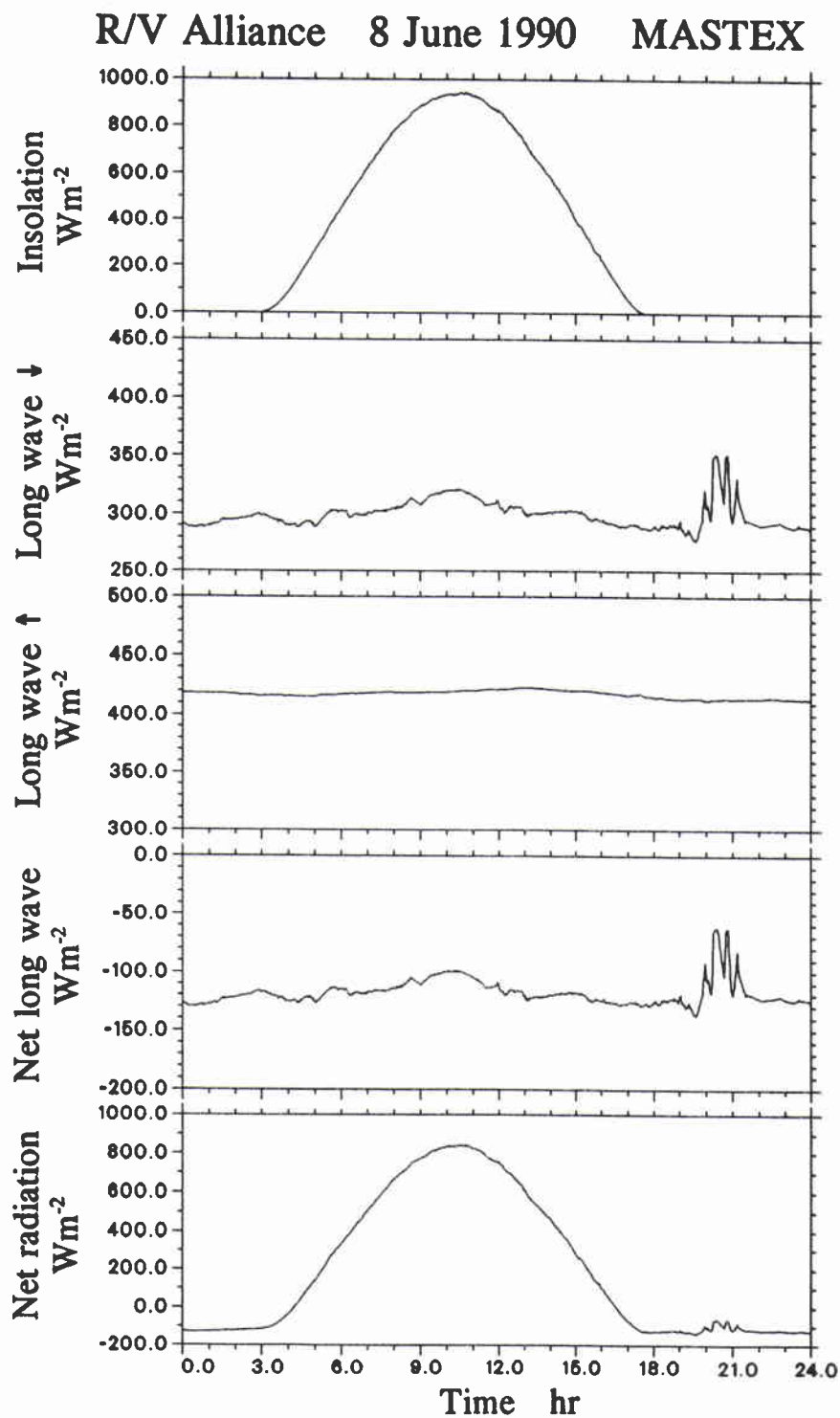


Figure C8

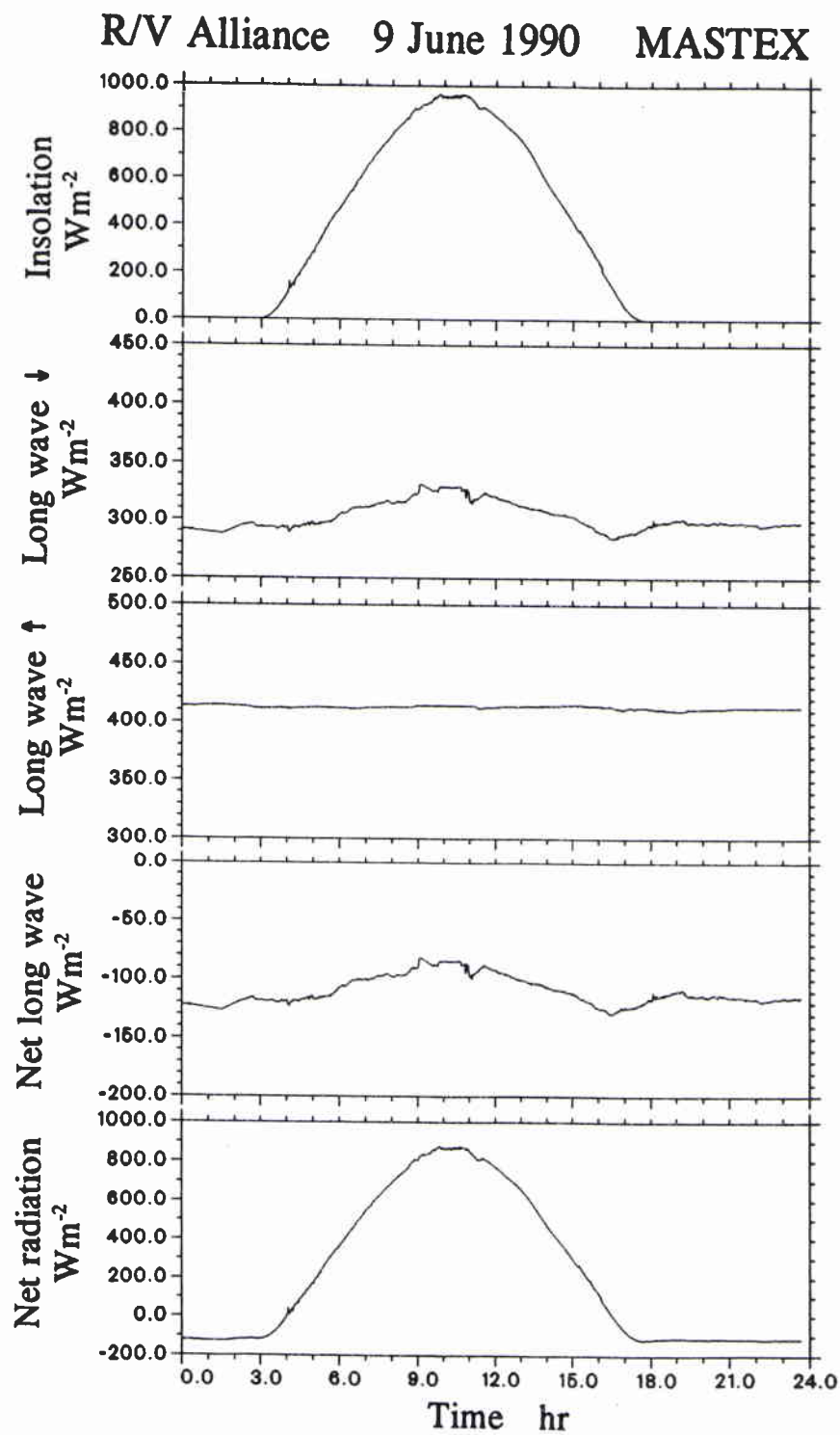
SACLANTCEN SM-264

Figure C9

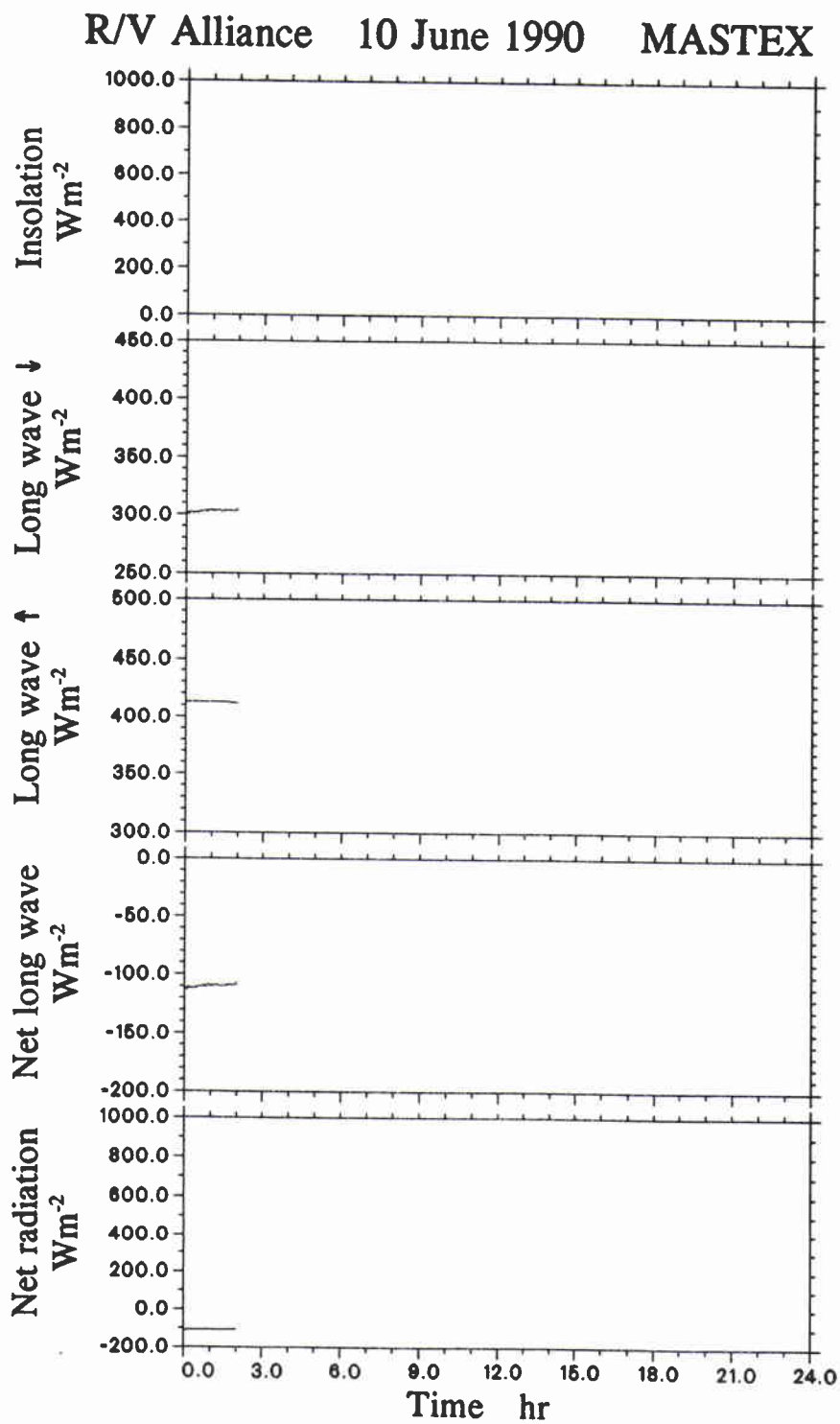


Figure C10

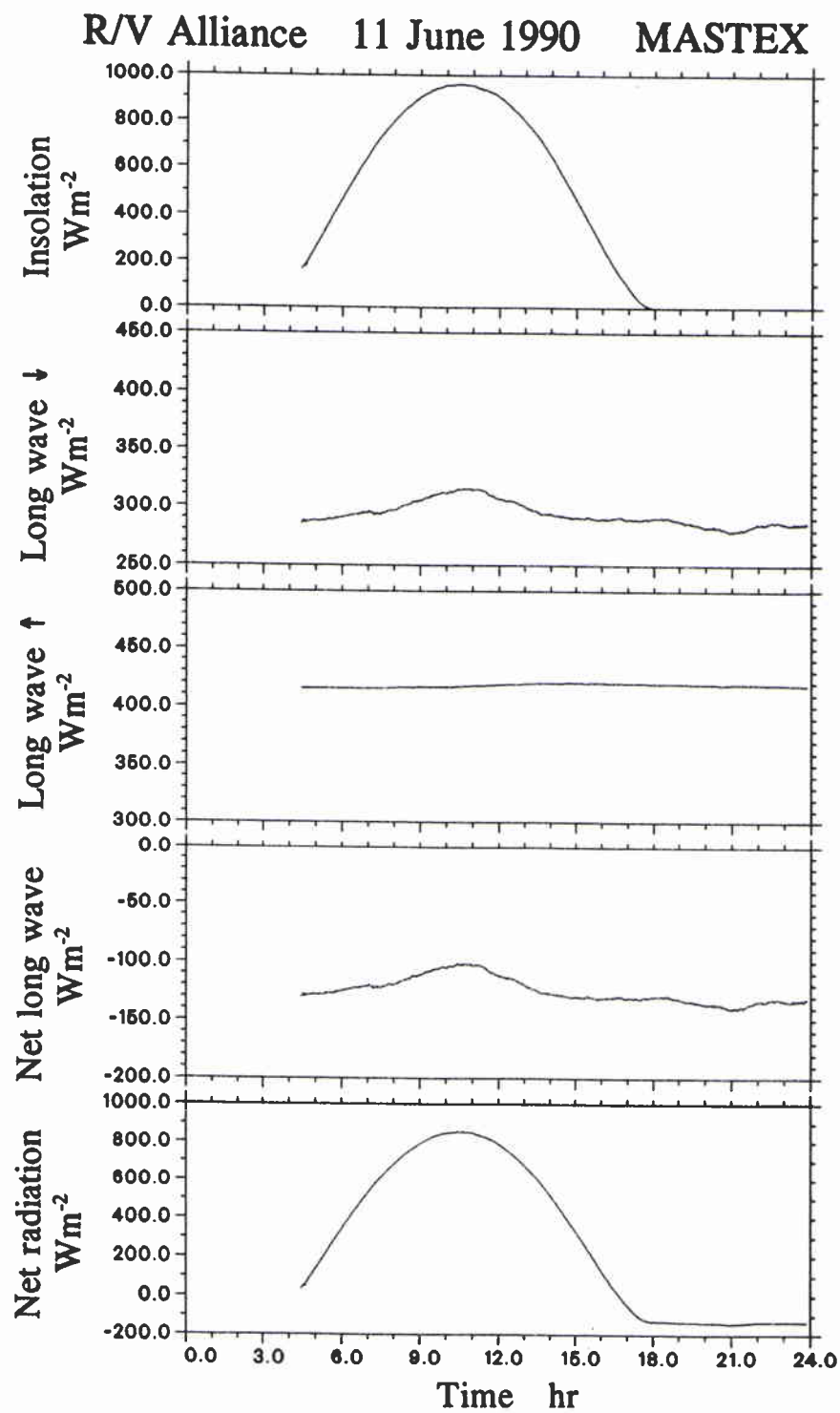
SACLANTCEN SM-264

Figure C11

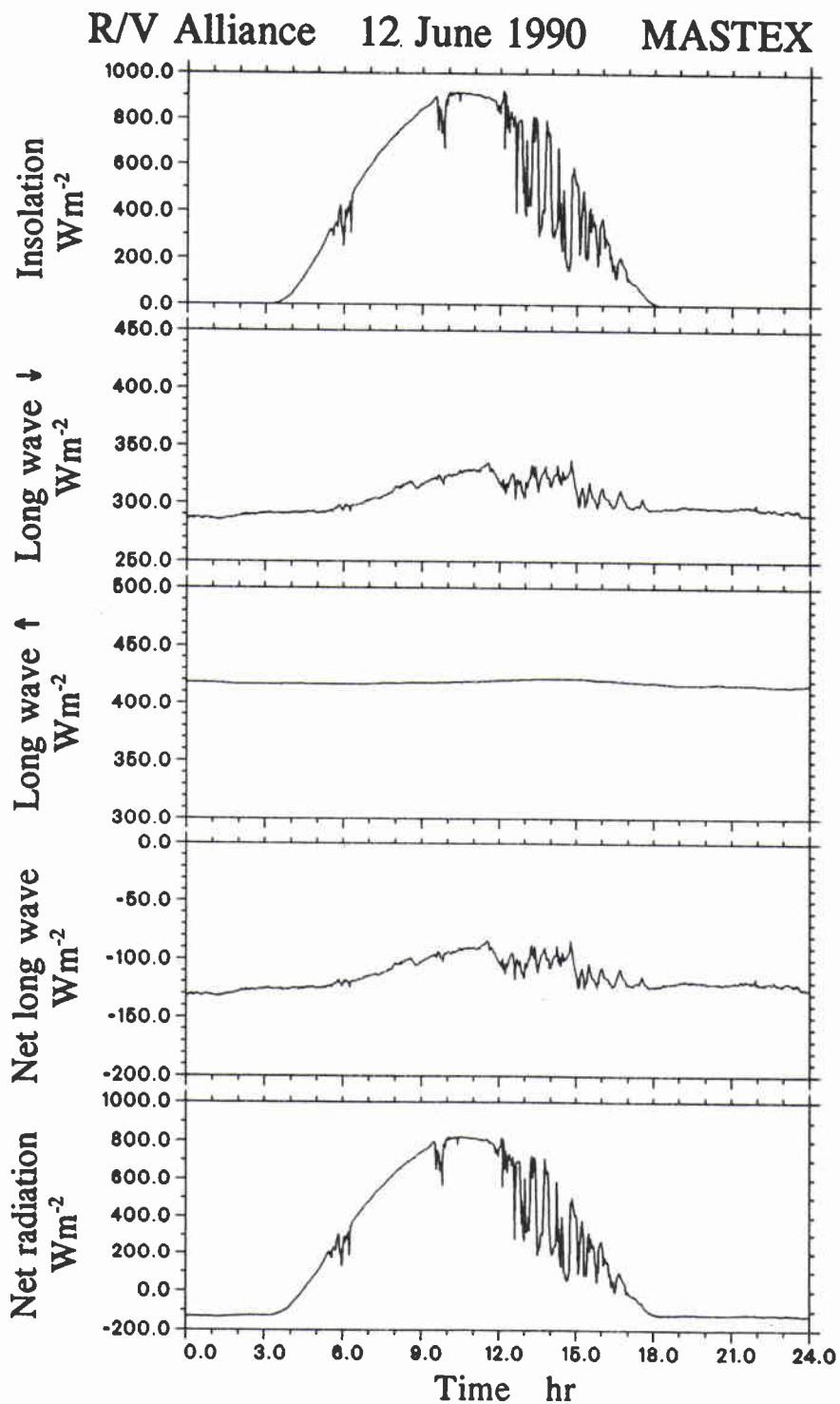


Figure C12

Appendix D

Near surface temperature gradients

Near-surface temperature time-series are given as daily plots in Figs. D1–D11 with the smooth trace being the Sea-Bird measurements taken at a depth of about 3 m and resolved to 0.01°C and the discontinuous trace being the cappello measurement from about 10 cm depth and resolved to 0.1°C .

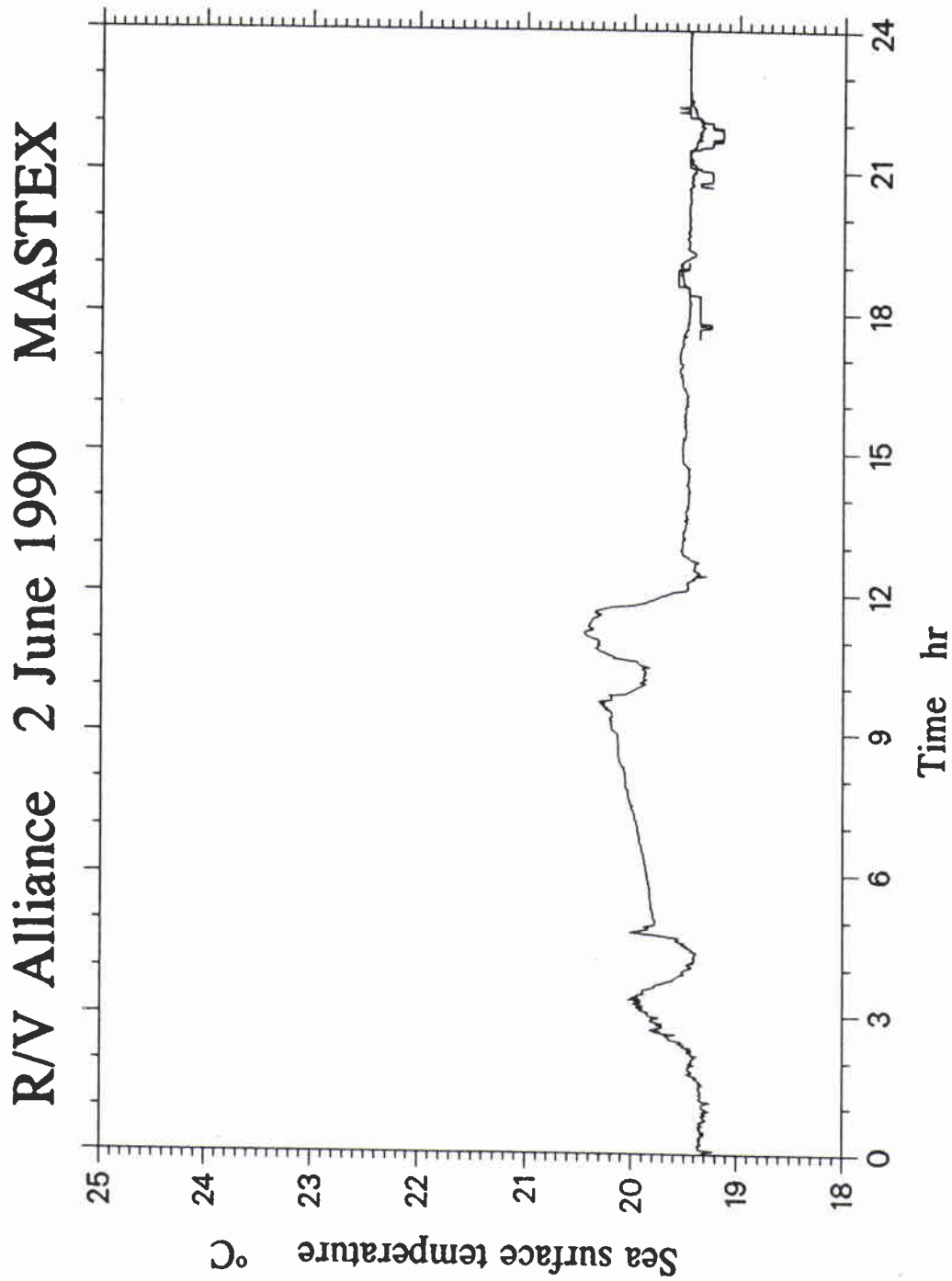


Figure D1

SACLANTCEN SM-264

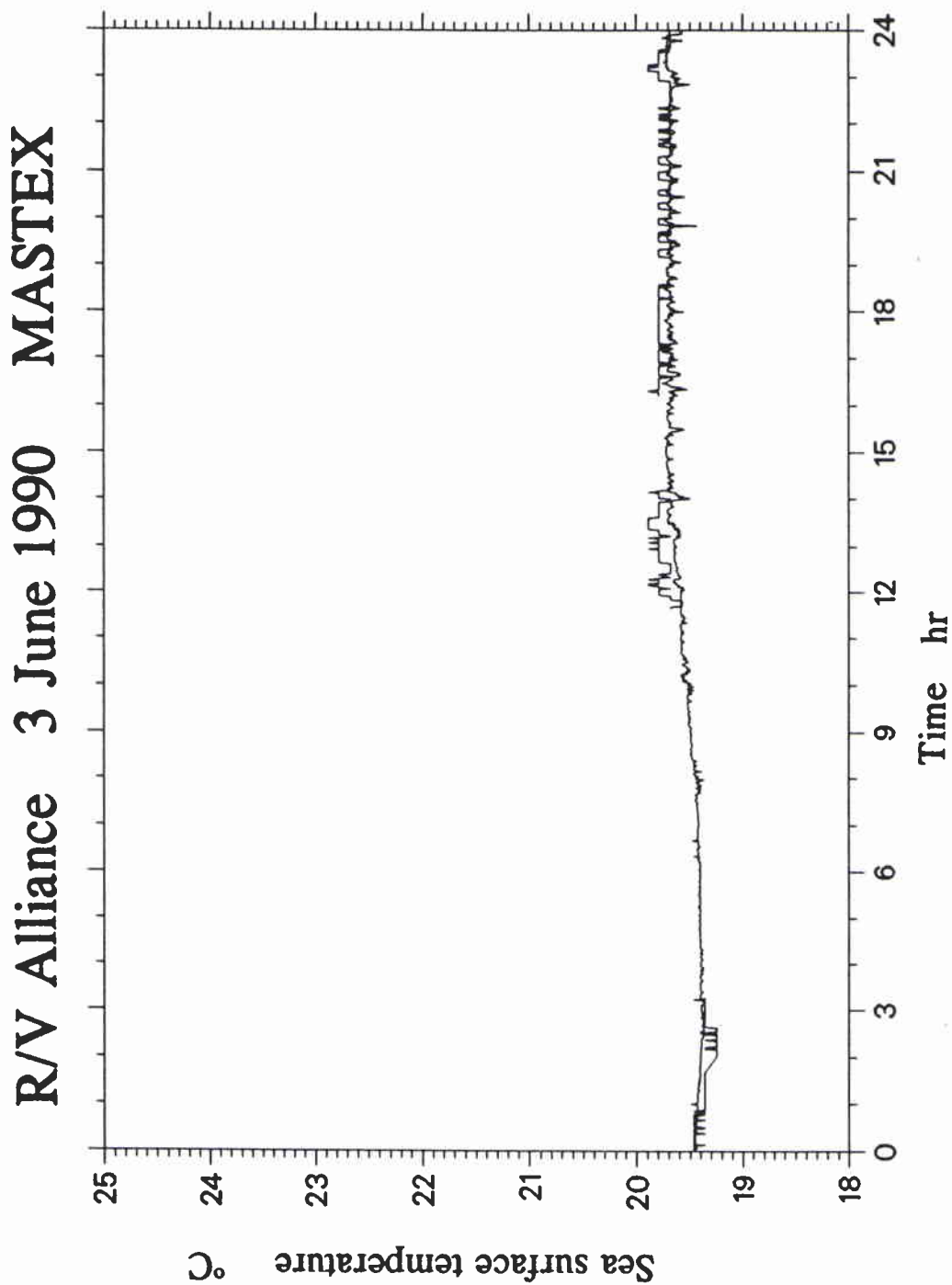


Figure D2

SACLANTCEN SM-264

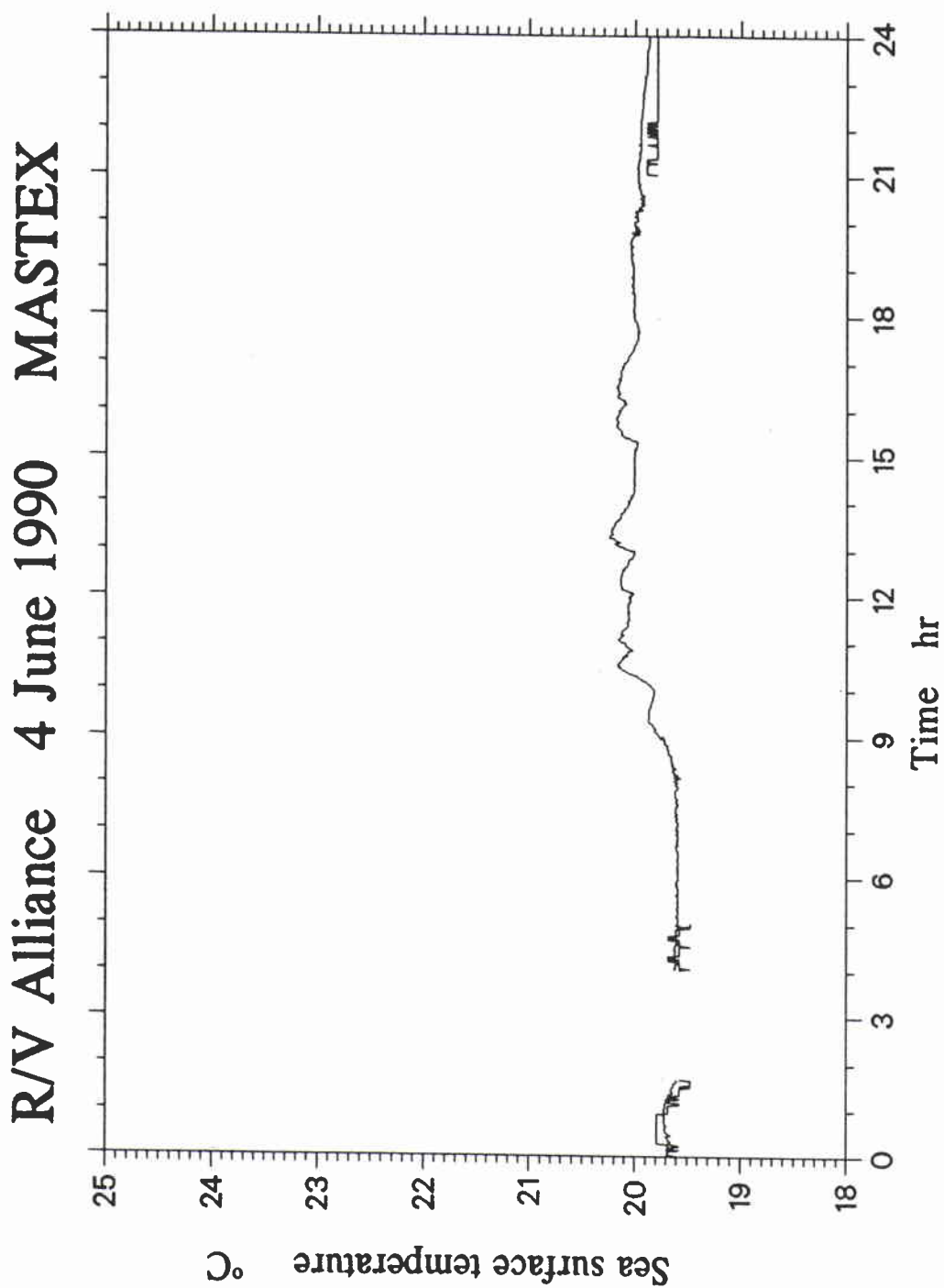


Figure D3

SACLANTCEN SM-264

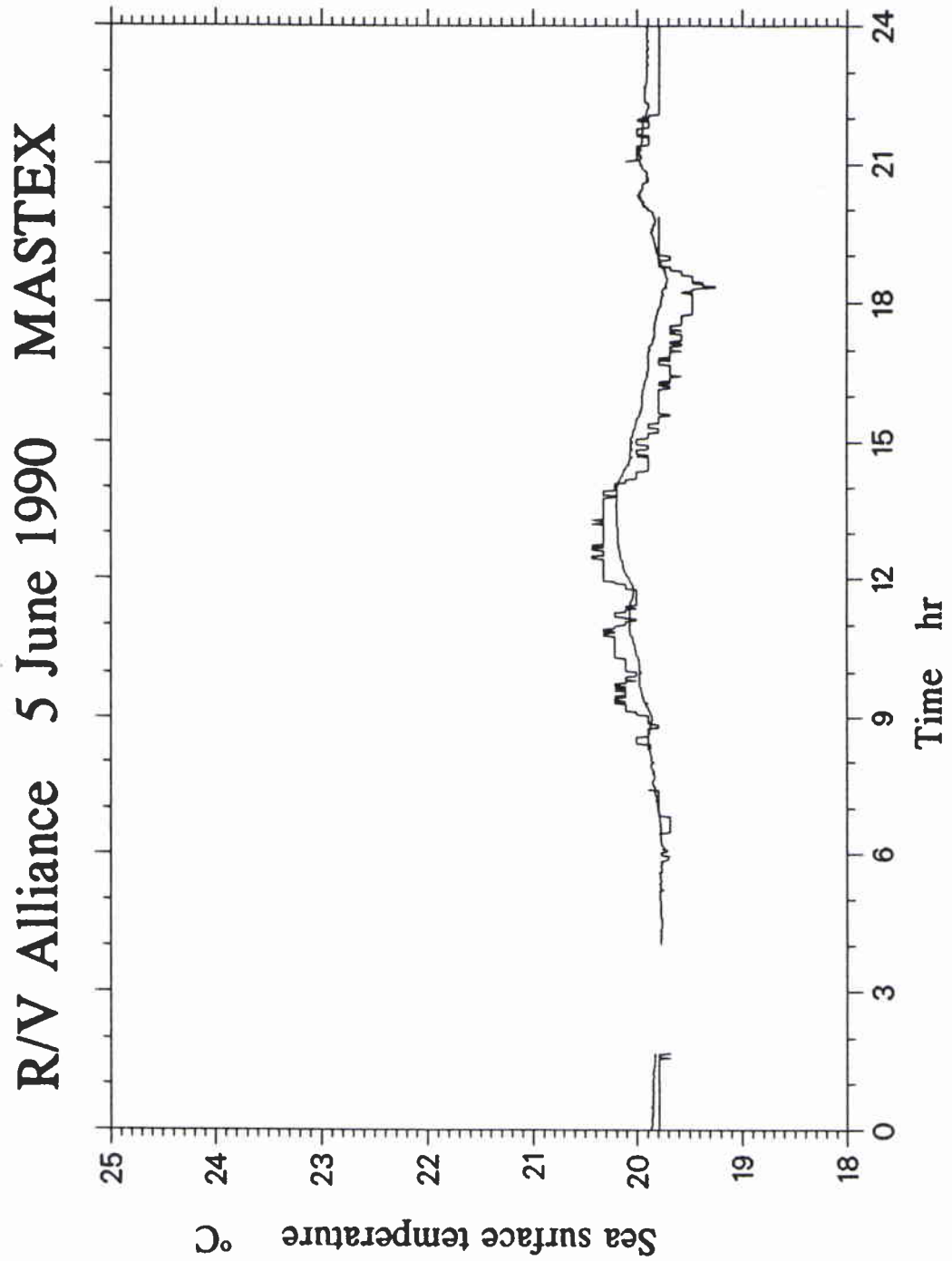


Figure D4

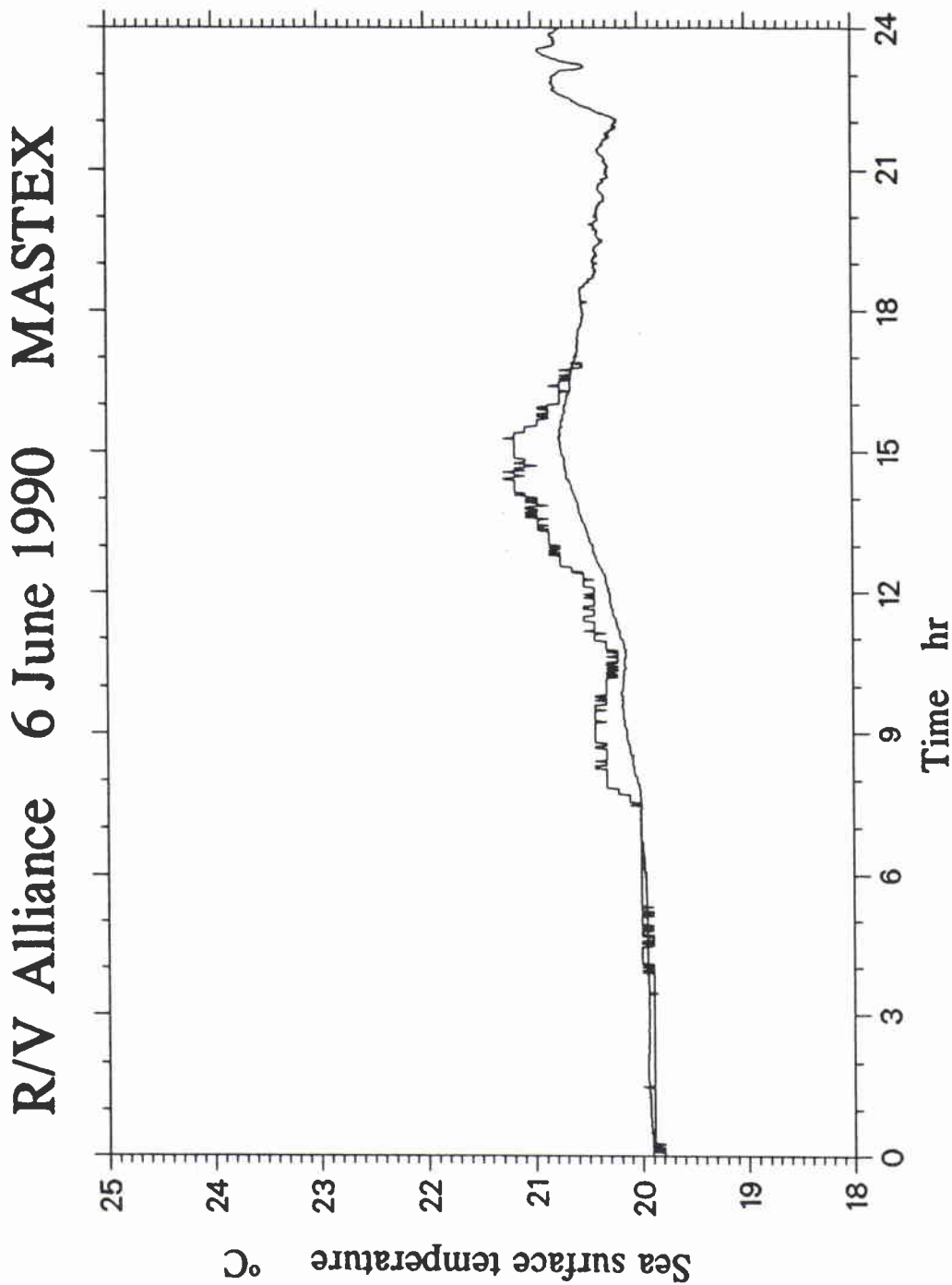


Figure D5

SACLANTCEN SM-264

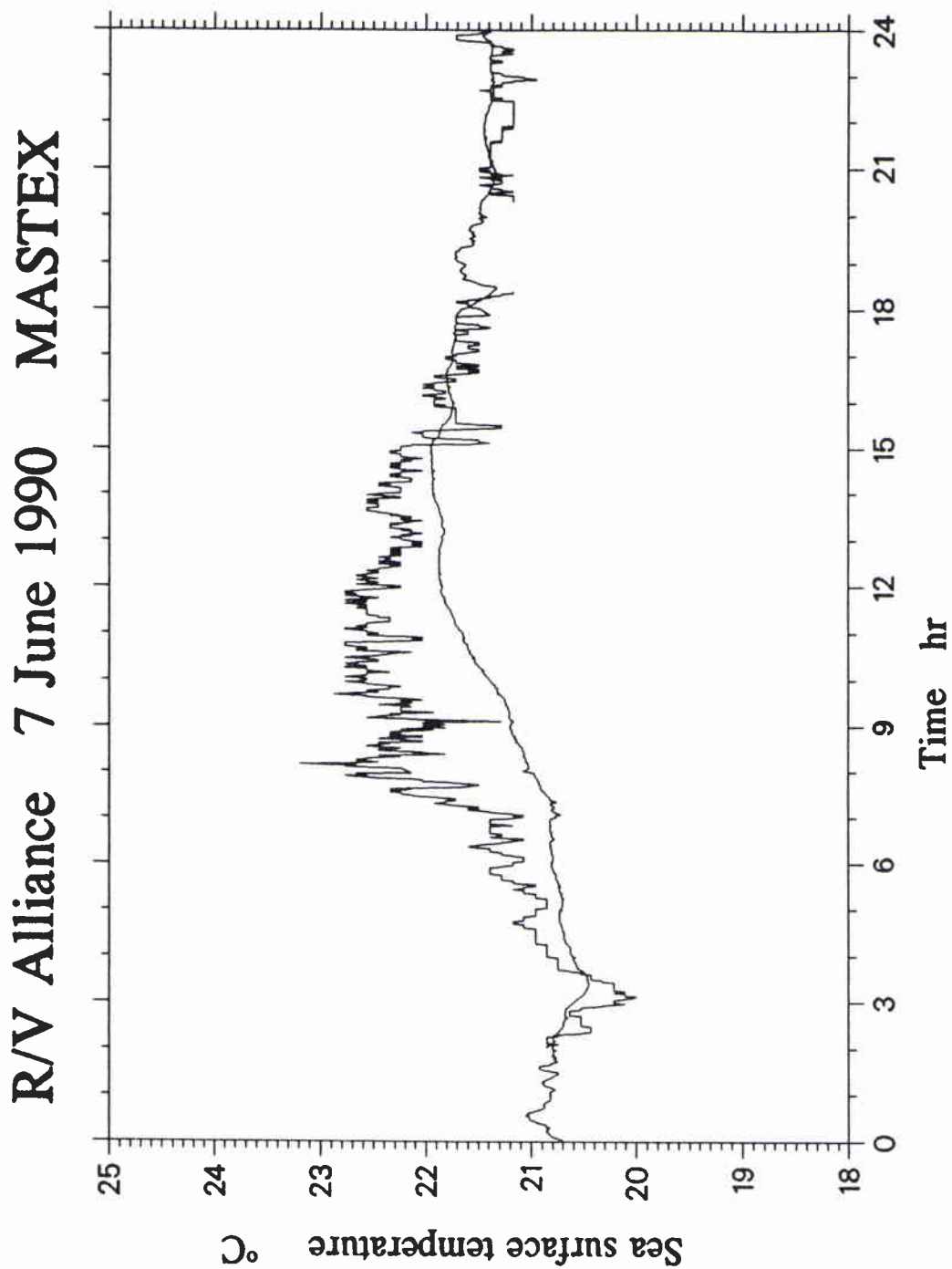


Figure D6

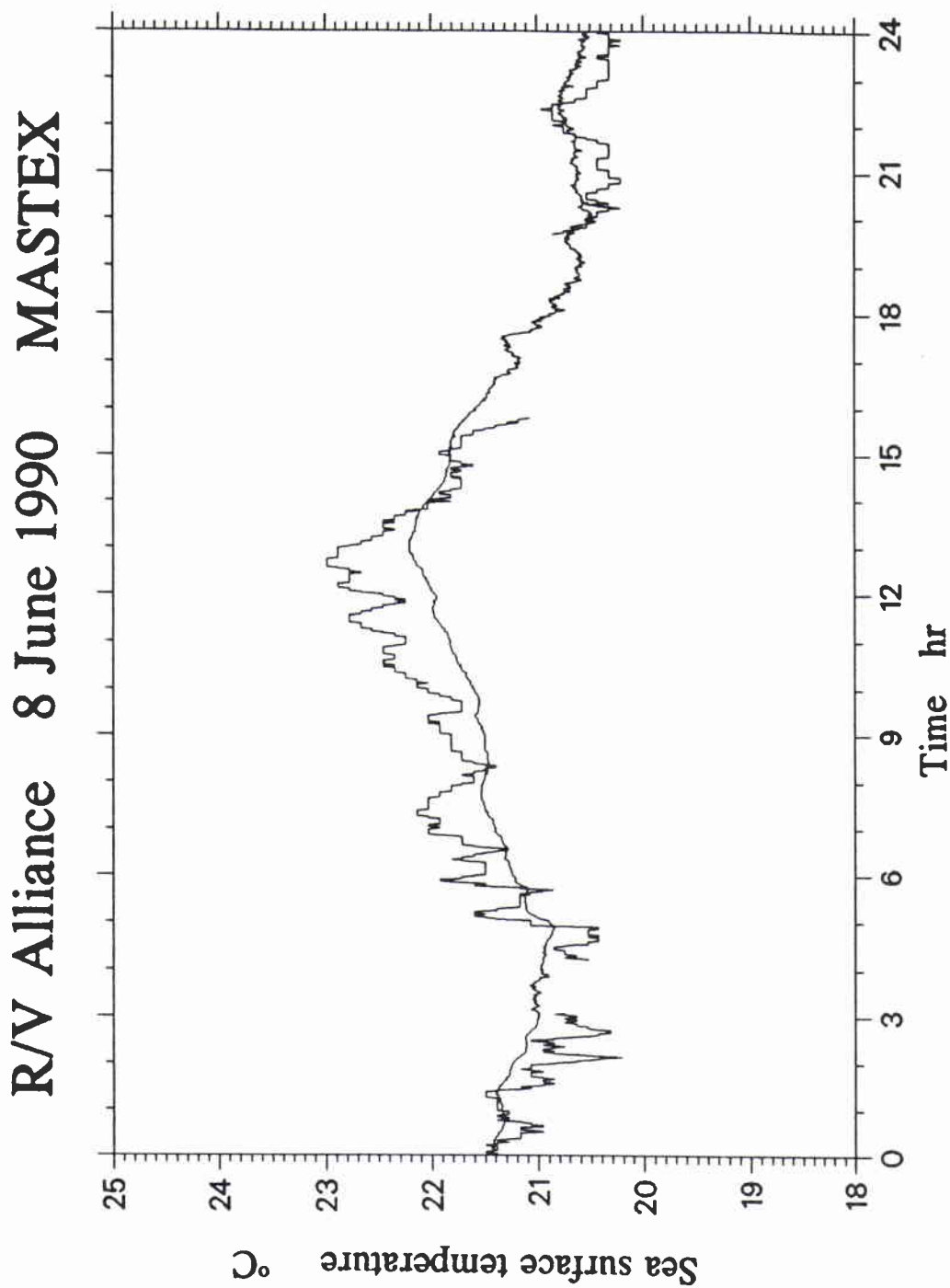


Figure D7

SACLANTCEN SM-264

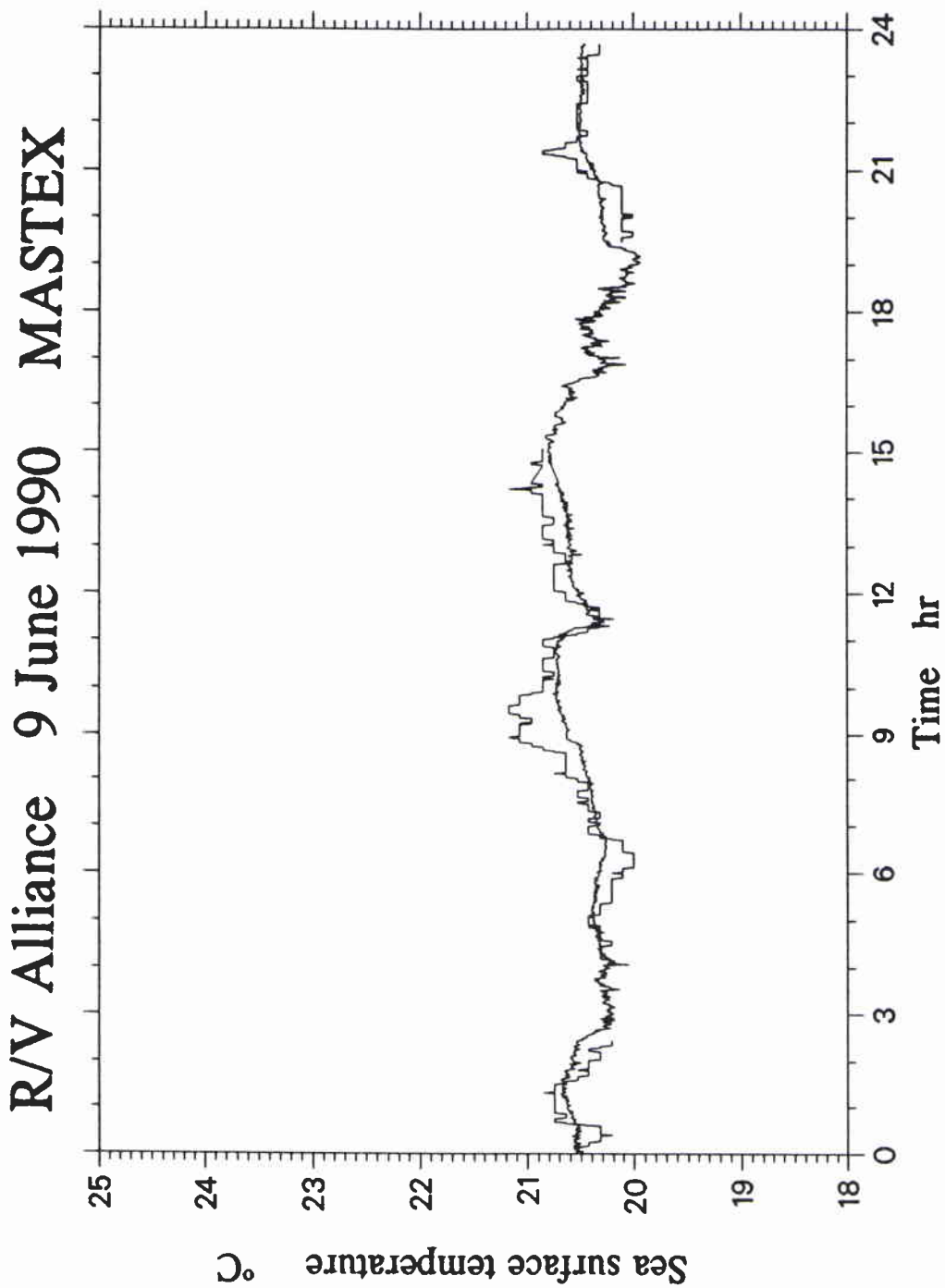


Figure D8

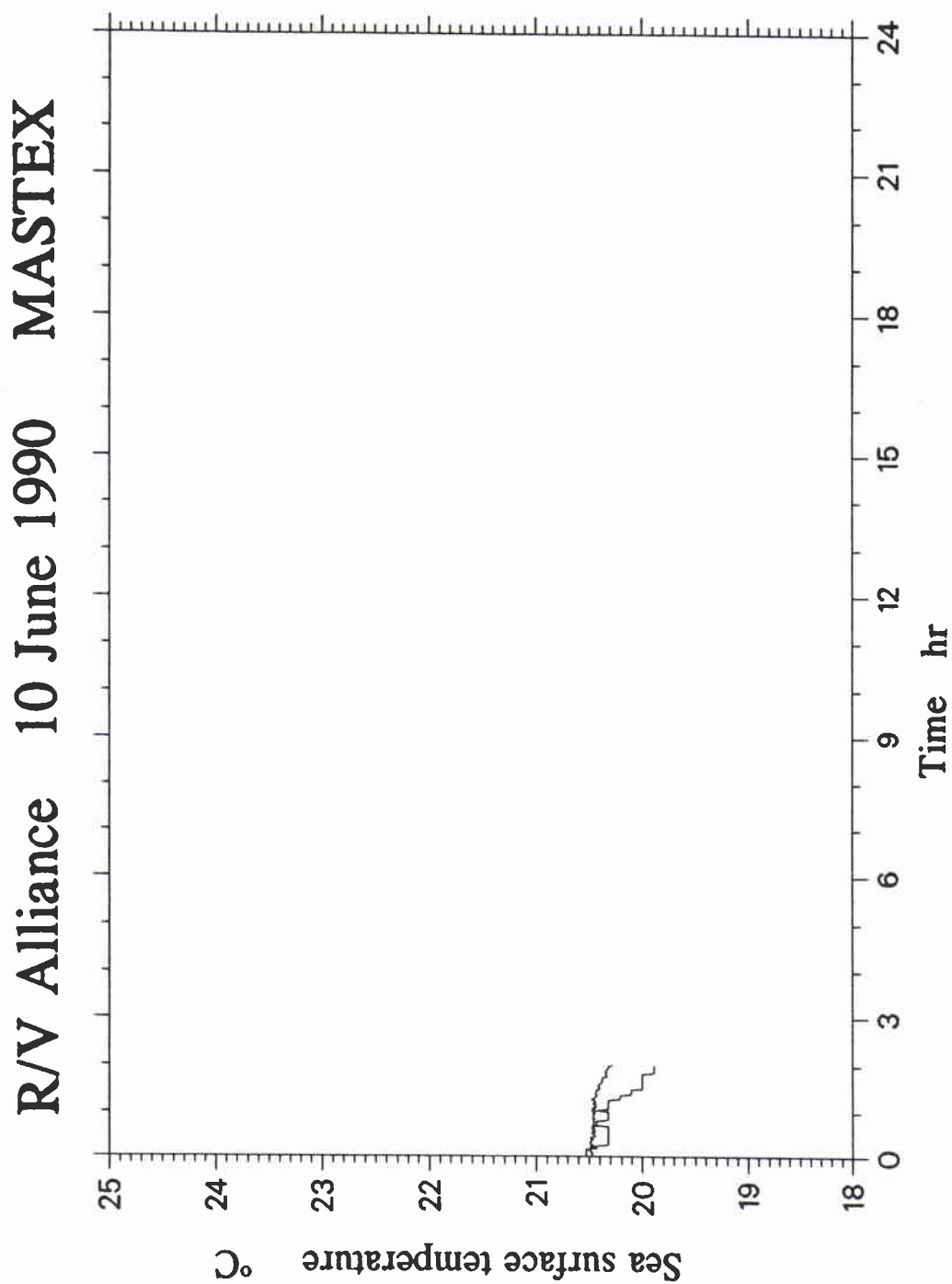


Figure D9

SACLANTCEN SM-264

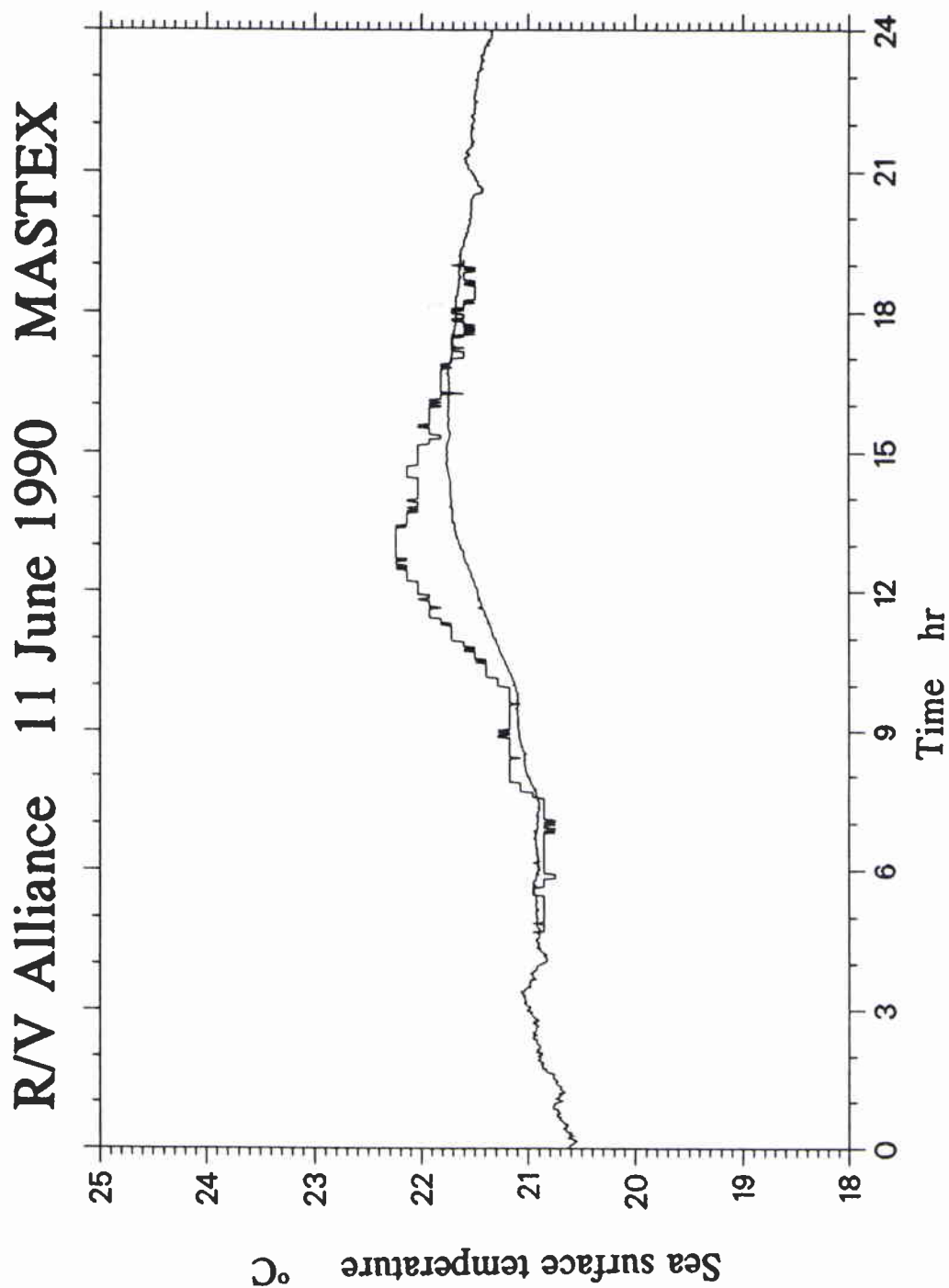


Figure D10

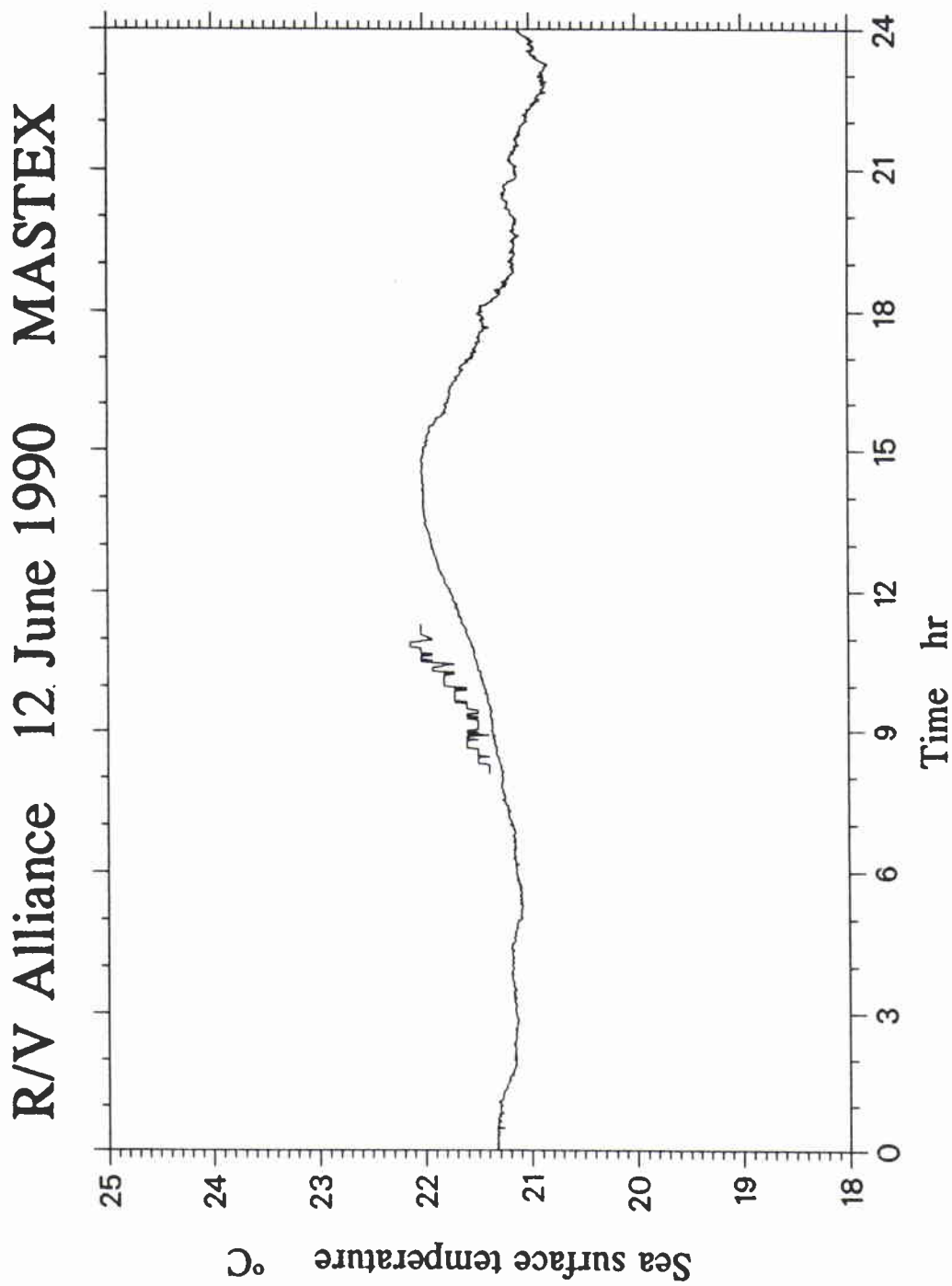


Figure D11

SACLANTCEN SM-264

Appendix E

Air-sea temperature differences

The air and sea temperatures, and their differences, are shown in Figs. E1–E12. The sea temperature is that measured at a depth of about 3 m by the Sea-Bird sensor.

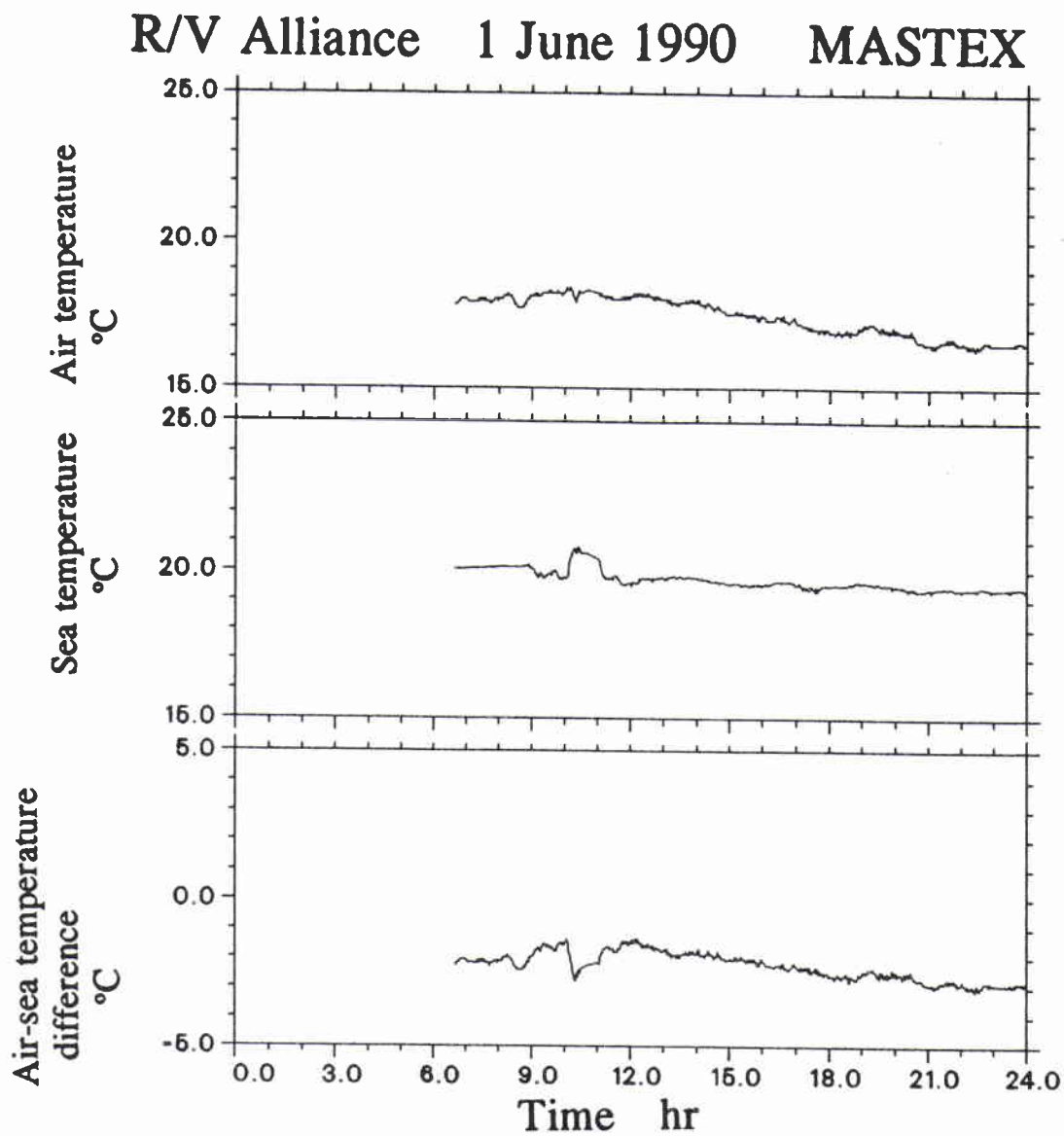


Figure E1

SACLANTCEN SM-264

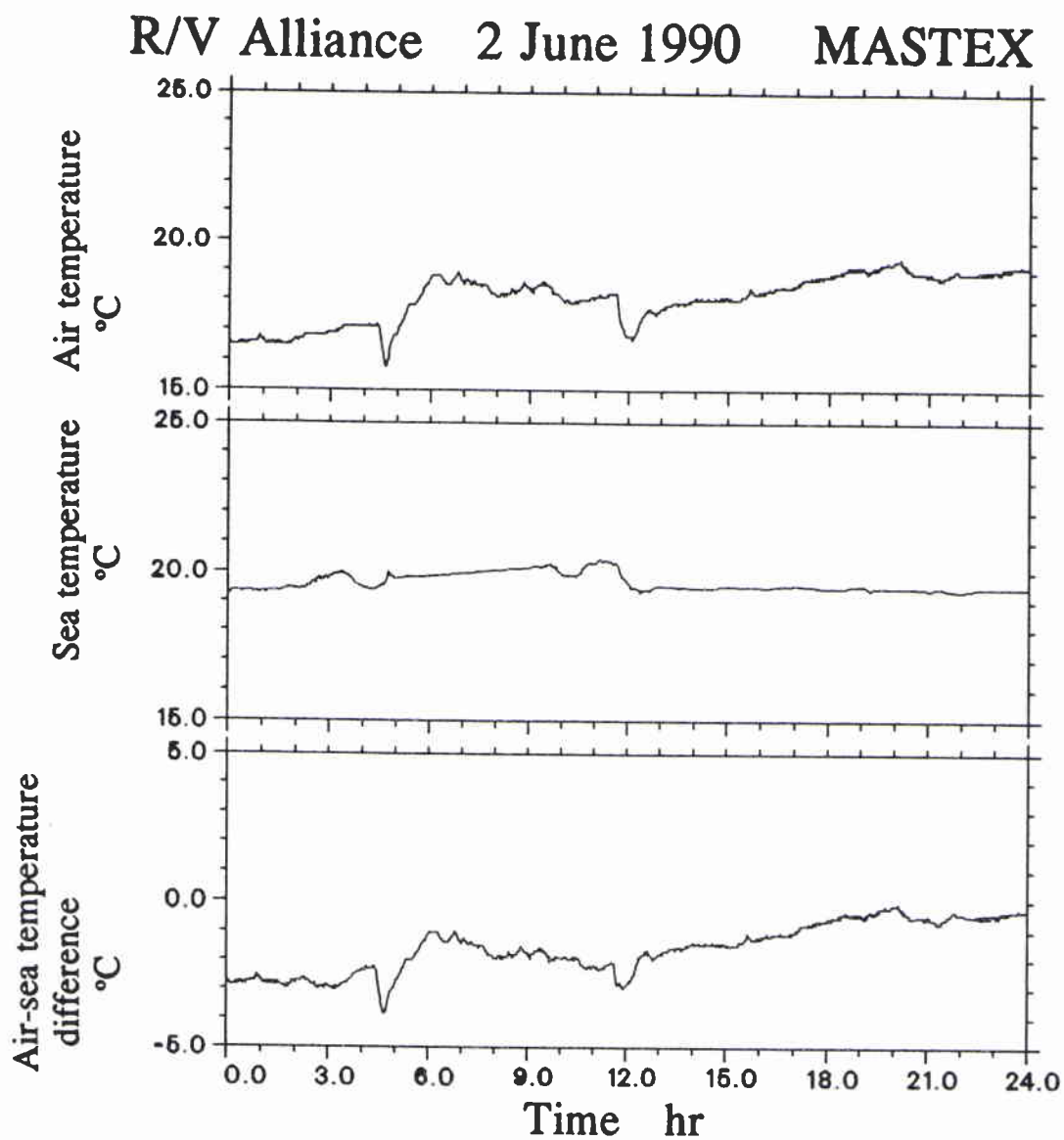


Figure E2

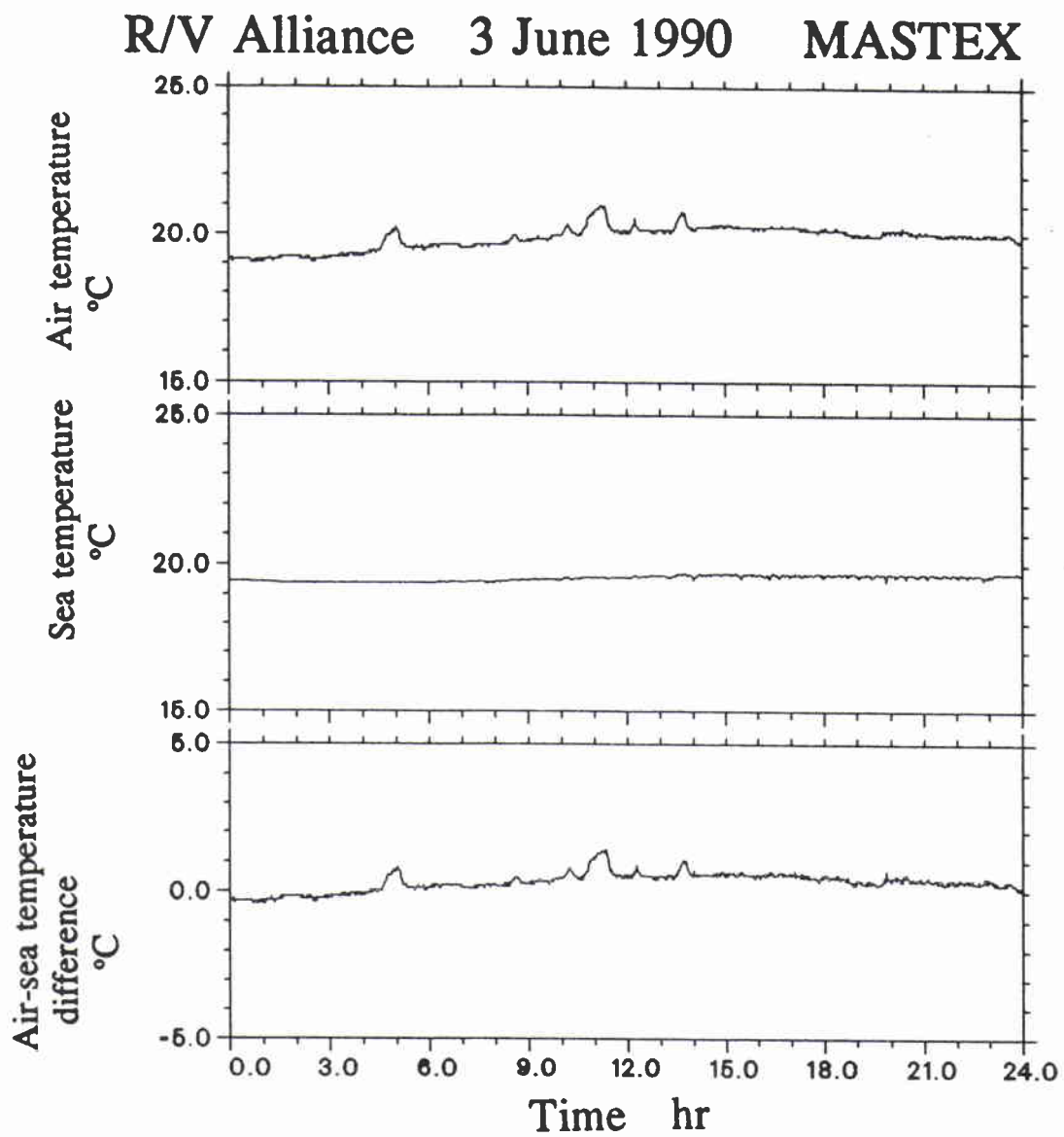


Figure E3

SACLANTCEN SM-264

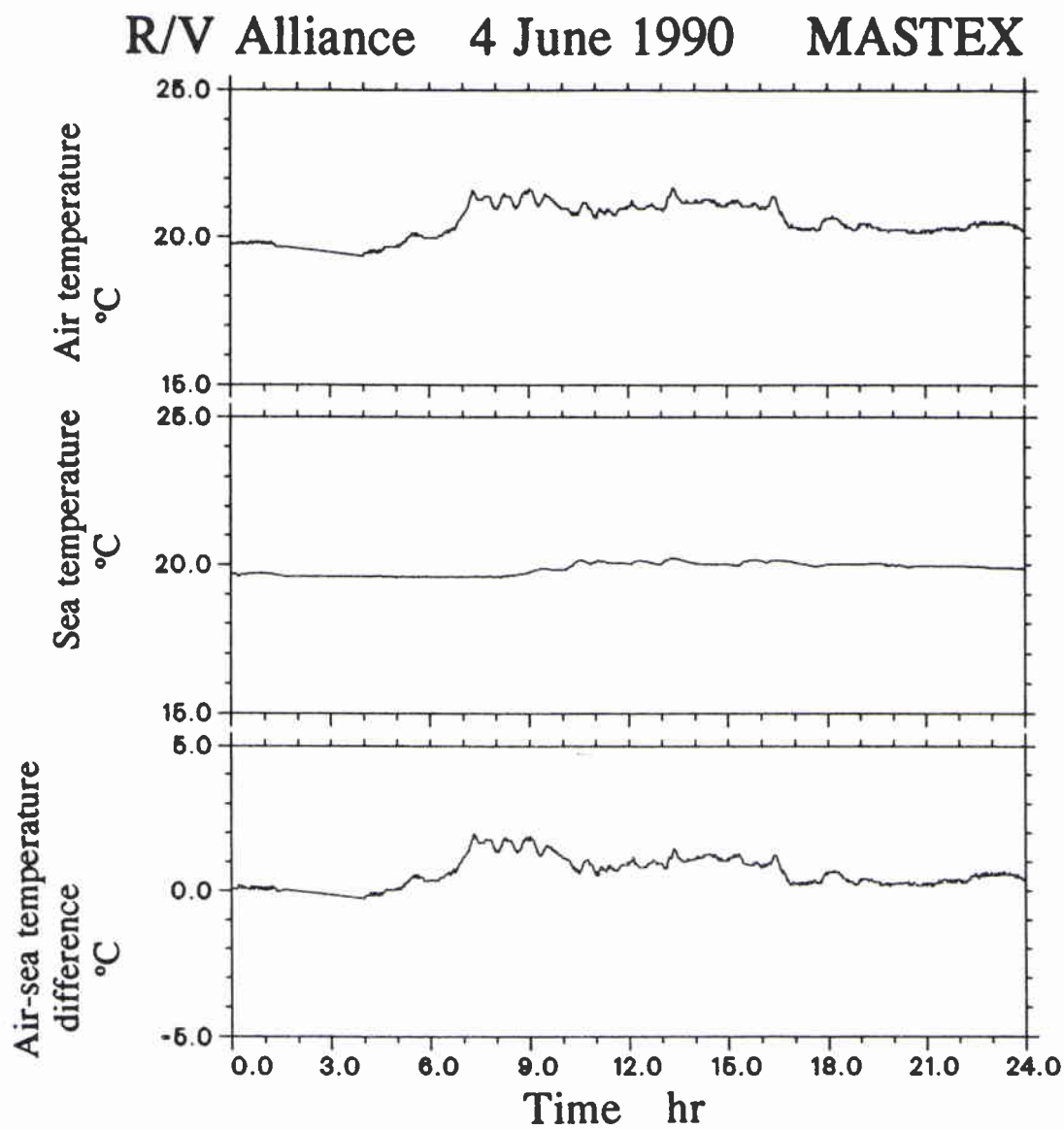


Figure E4

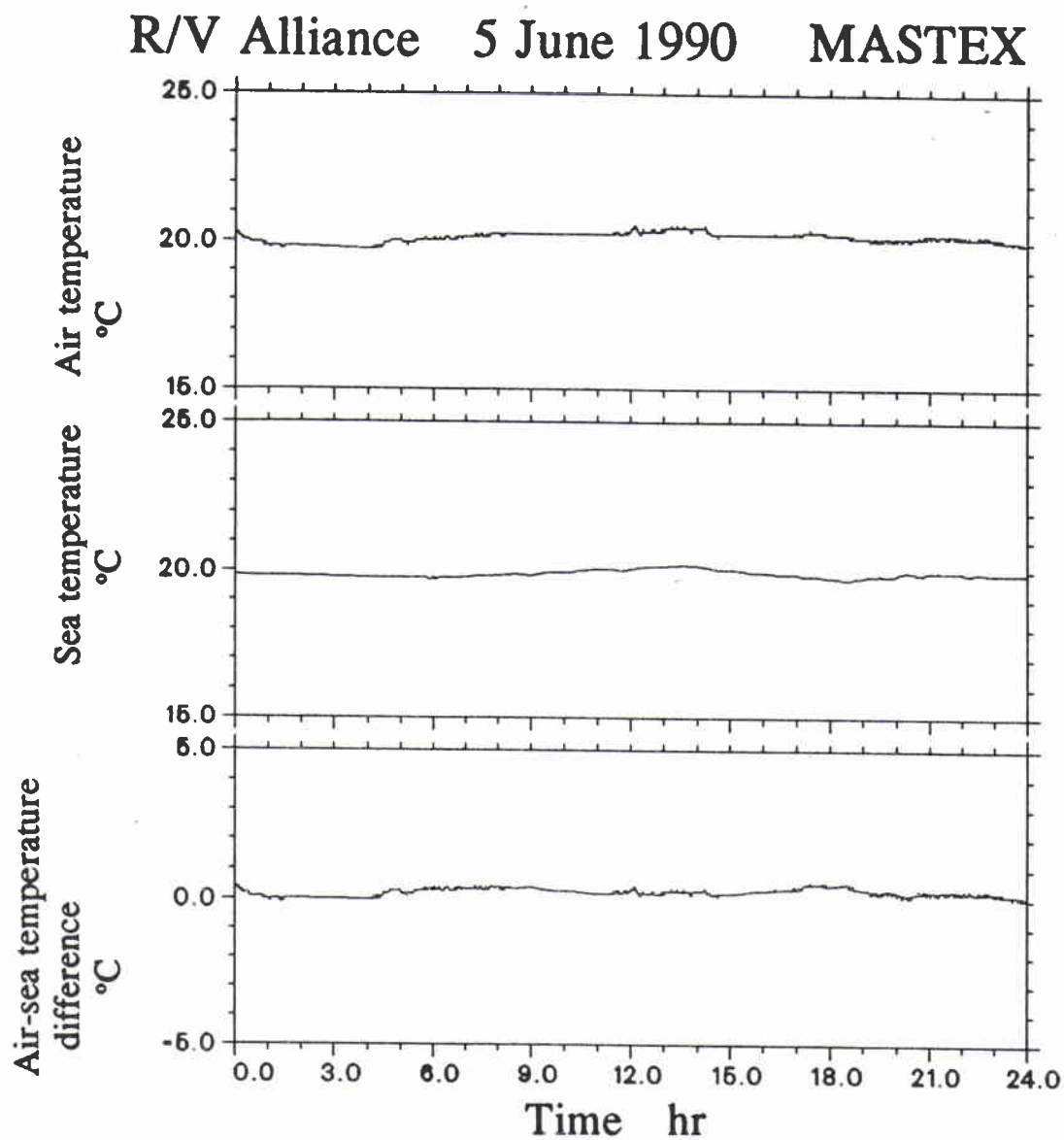


Figure E5

SACLANTCEN SM-264

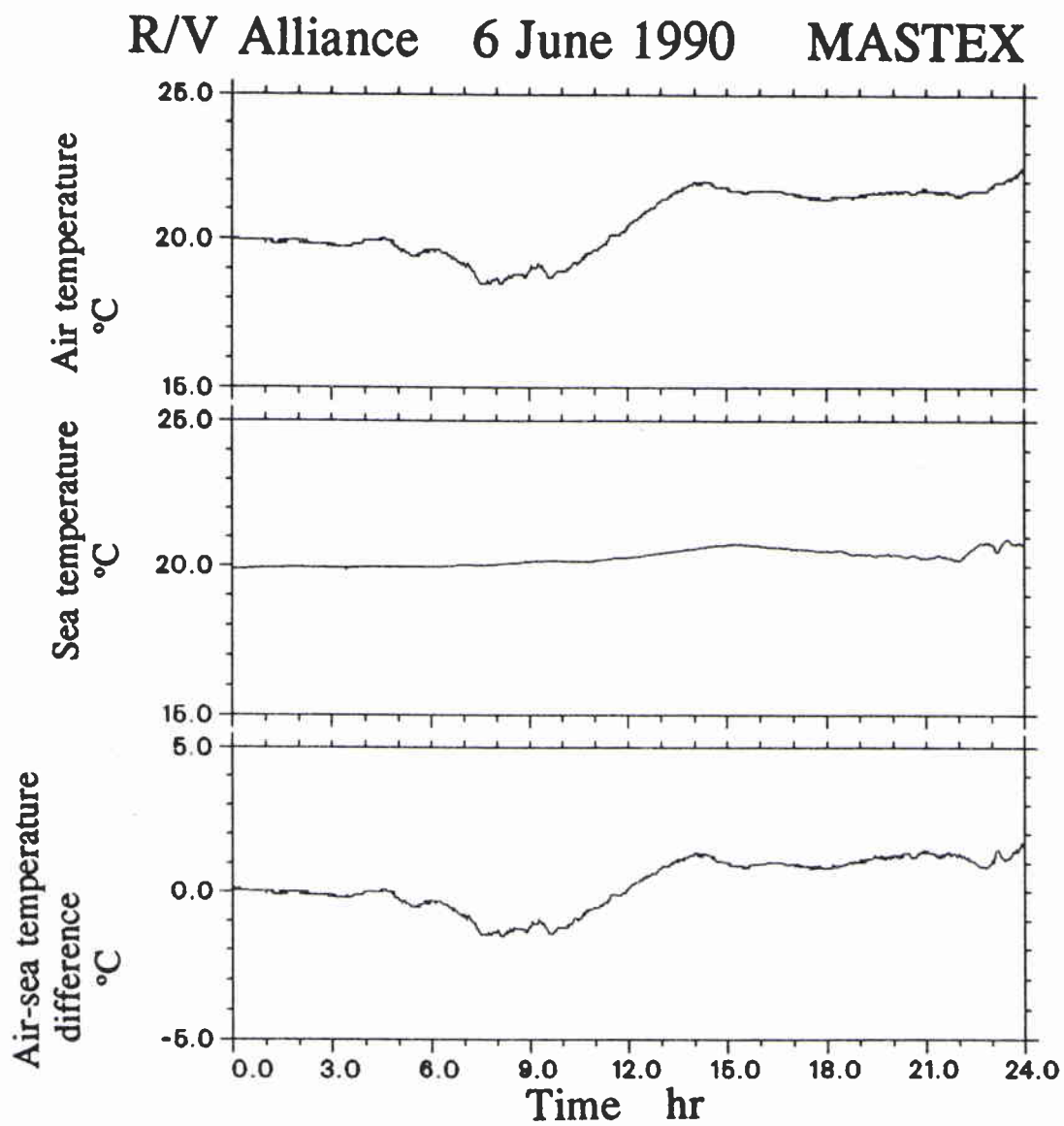


Figure E6

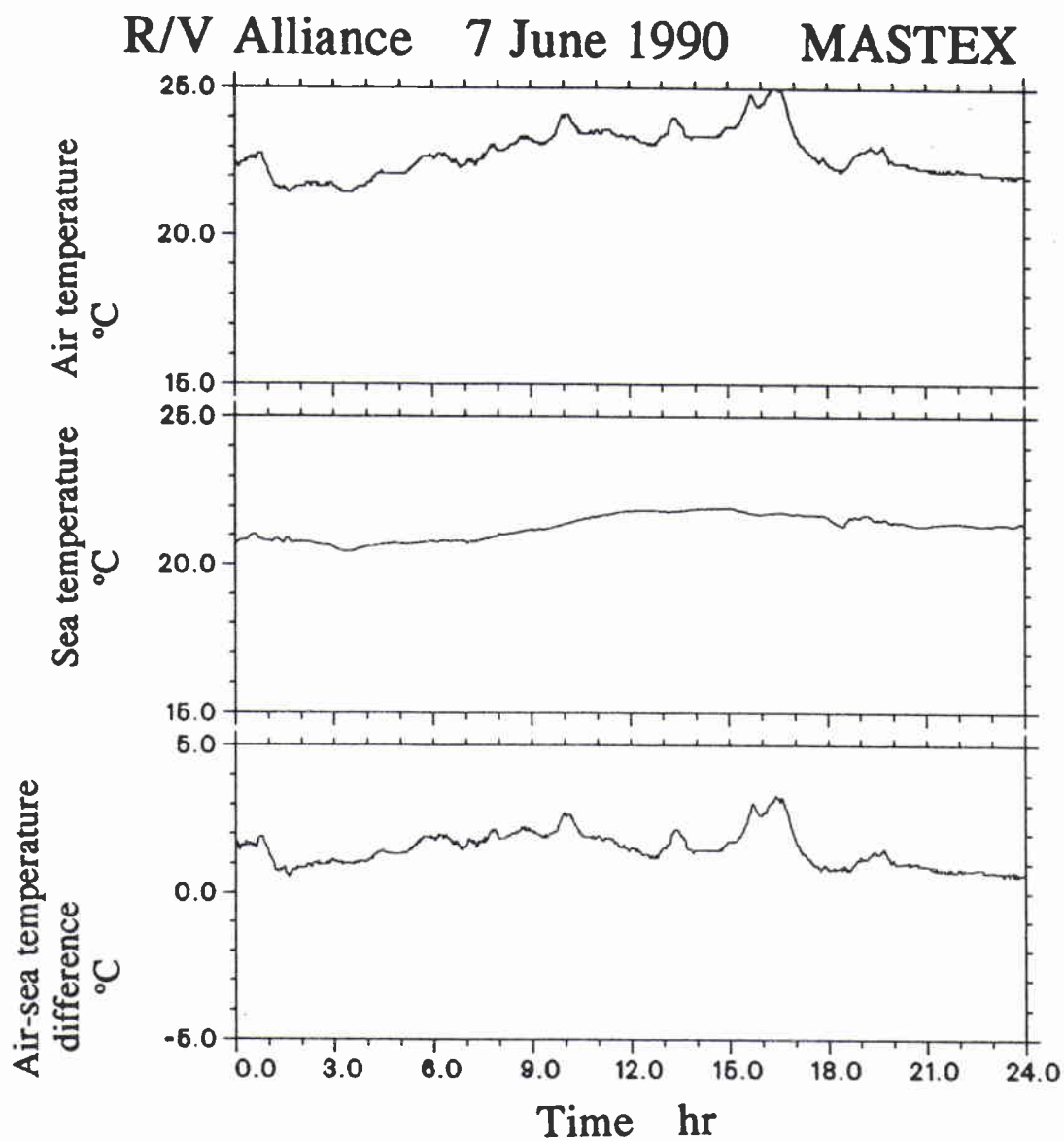


Figure E7

SACLANTCEN SM-264

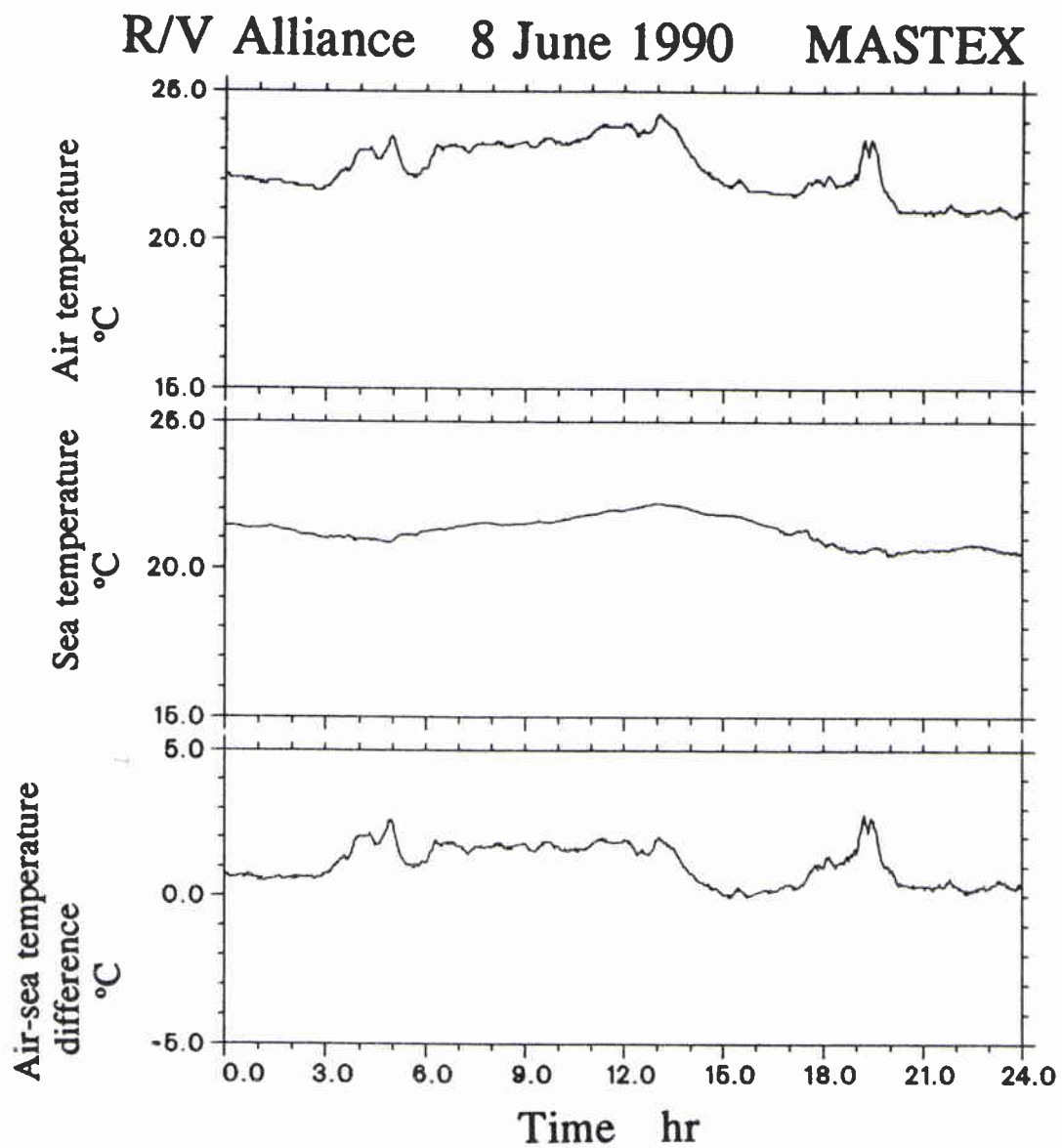


Figure E8

R/V Alliance 9 June 1990 MASTEX

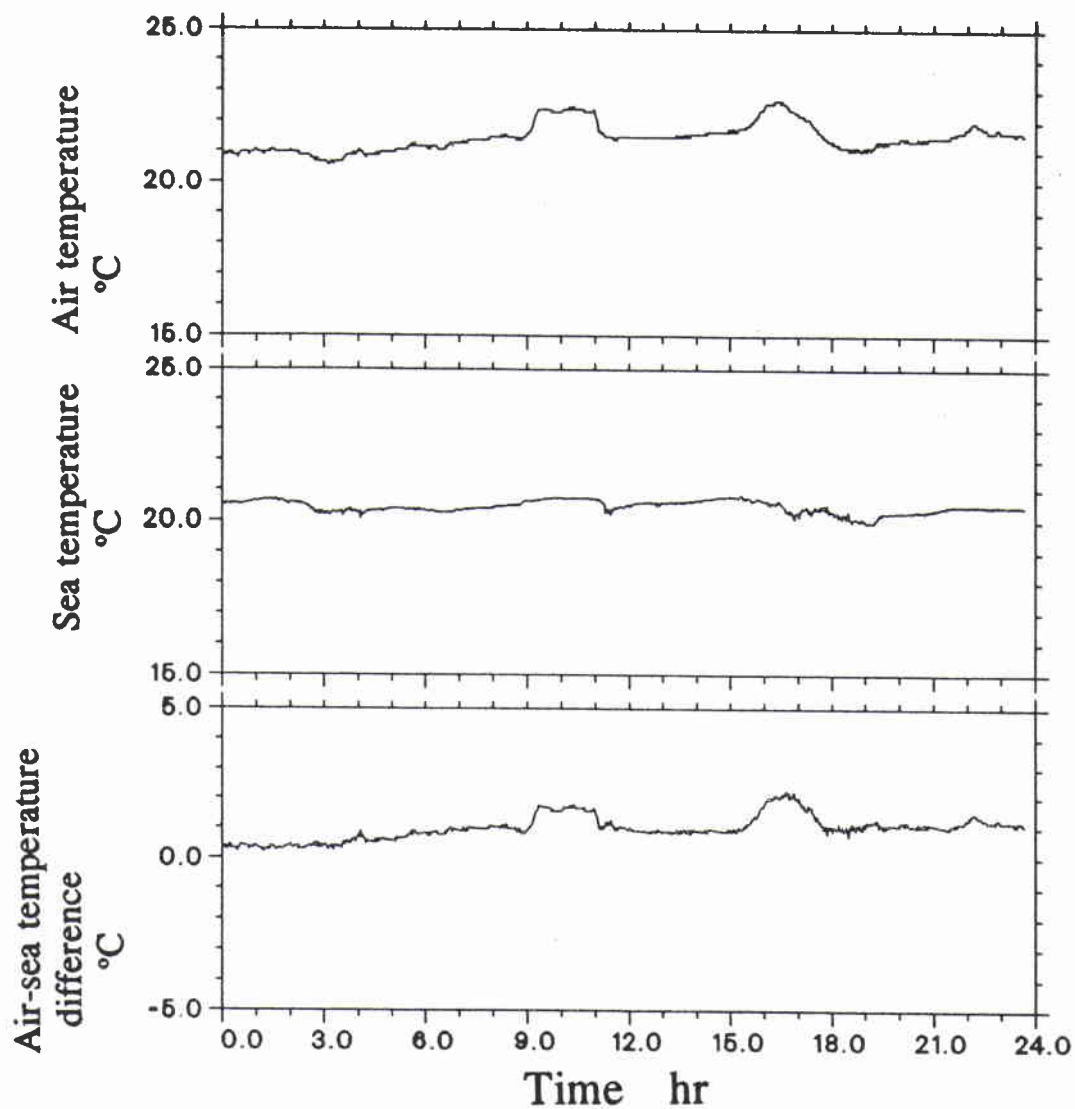


Figure E9

SACLANTCEN SM-264

R/V Alliance 10 June 1990 MASTEX

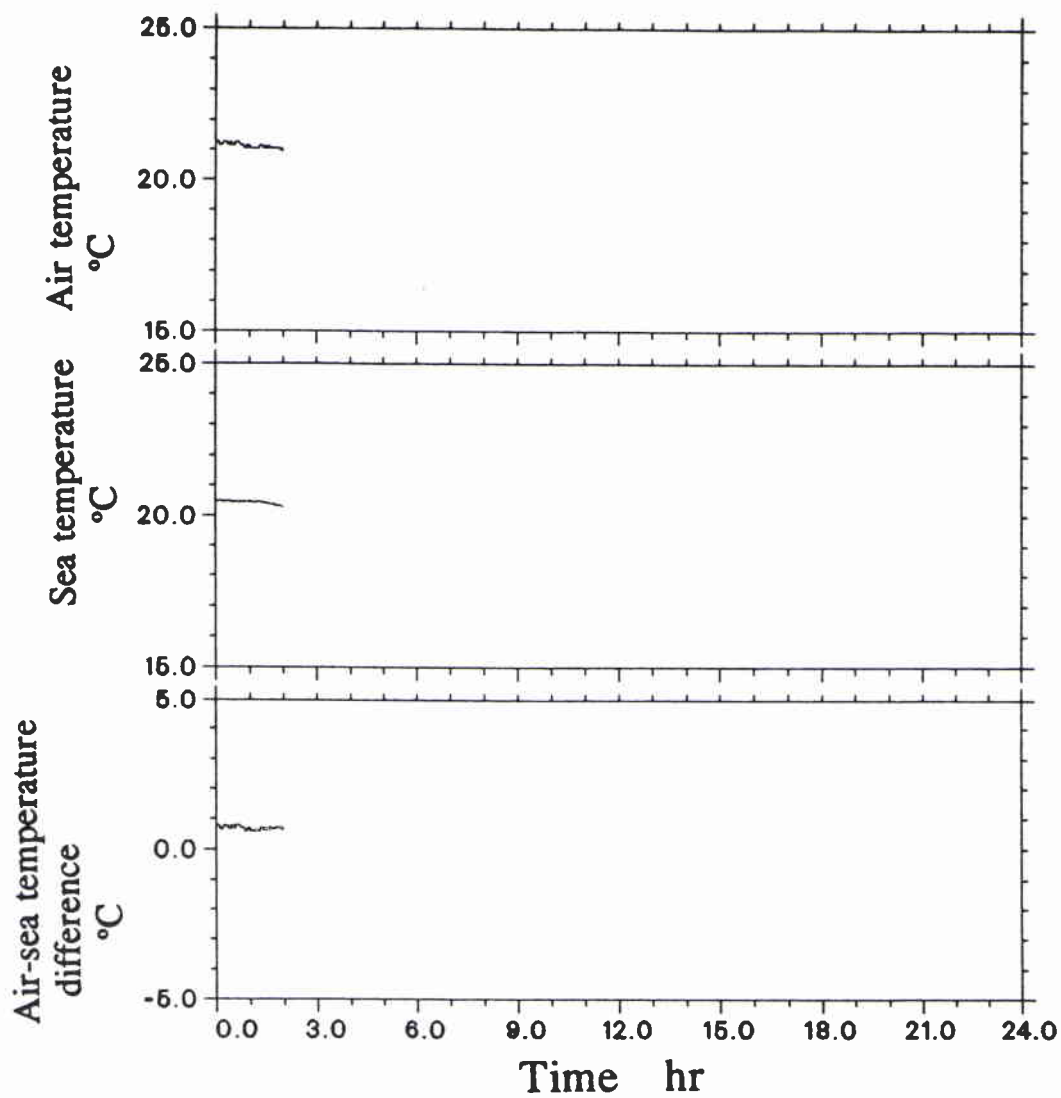
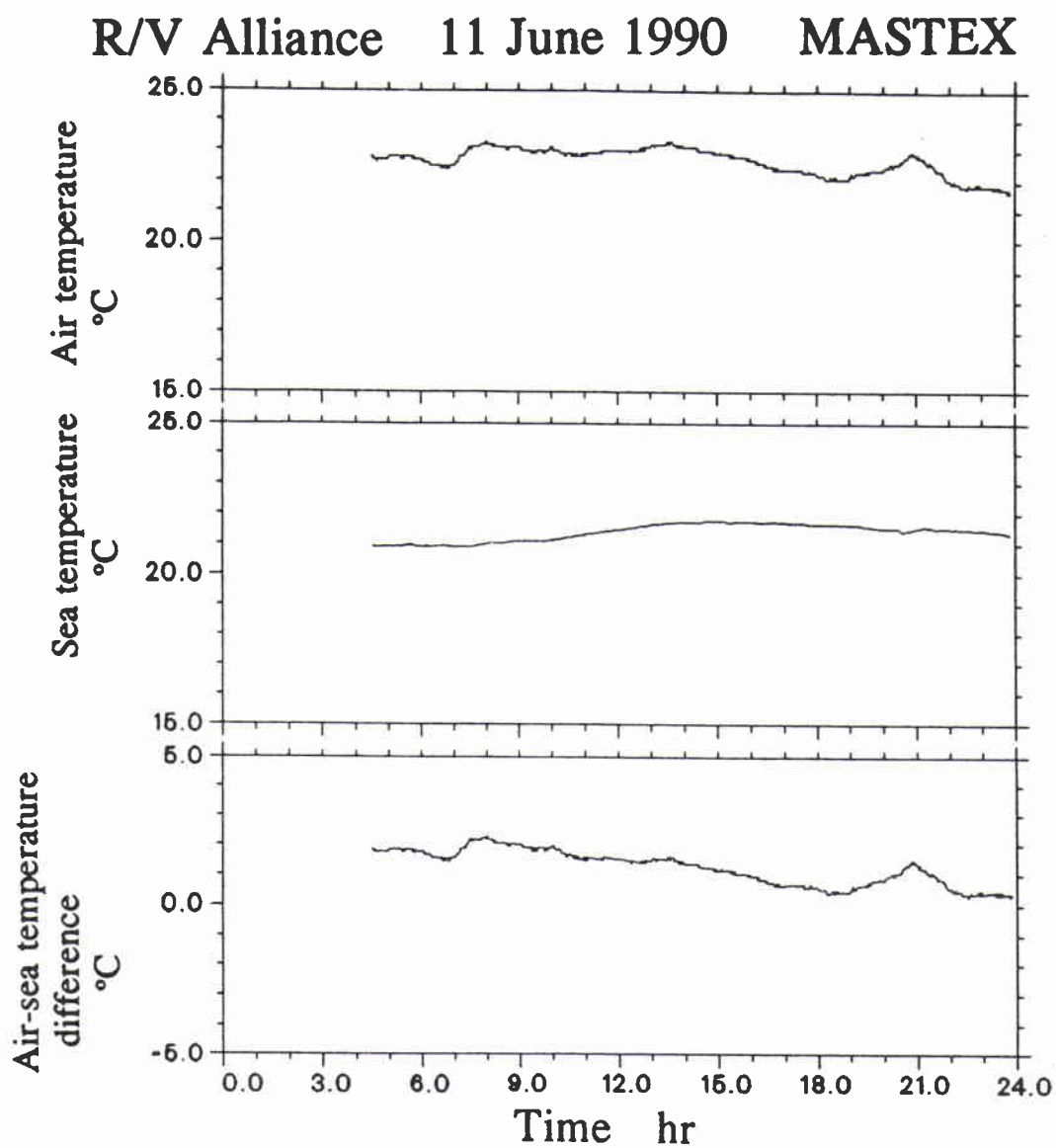


Figure E10

**Figure E11**

SACLANTCEN SM-264

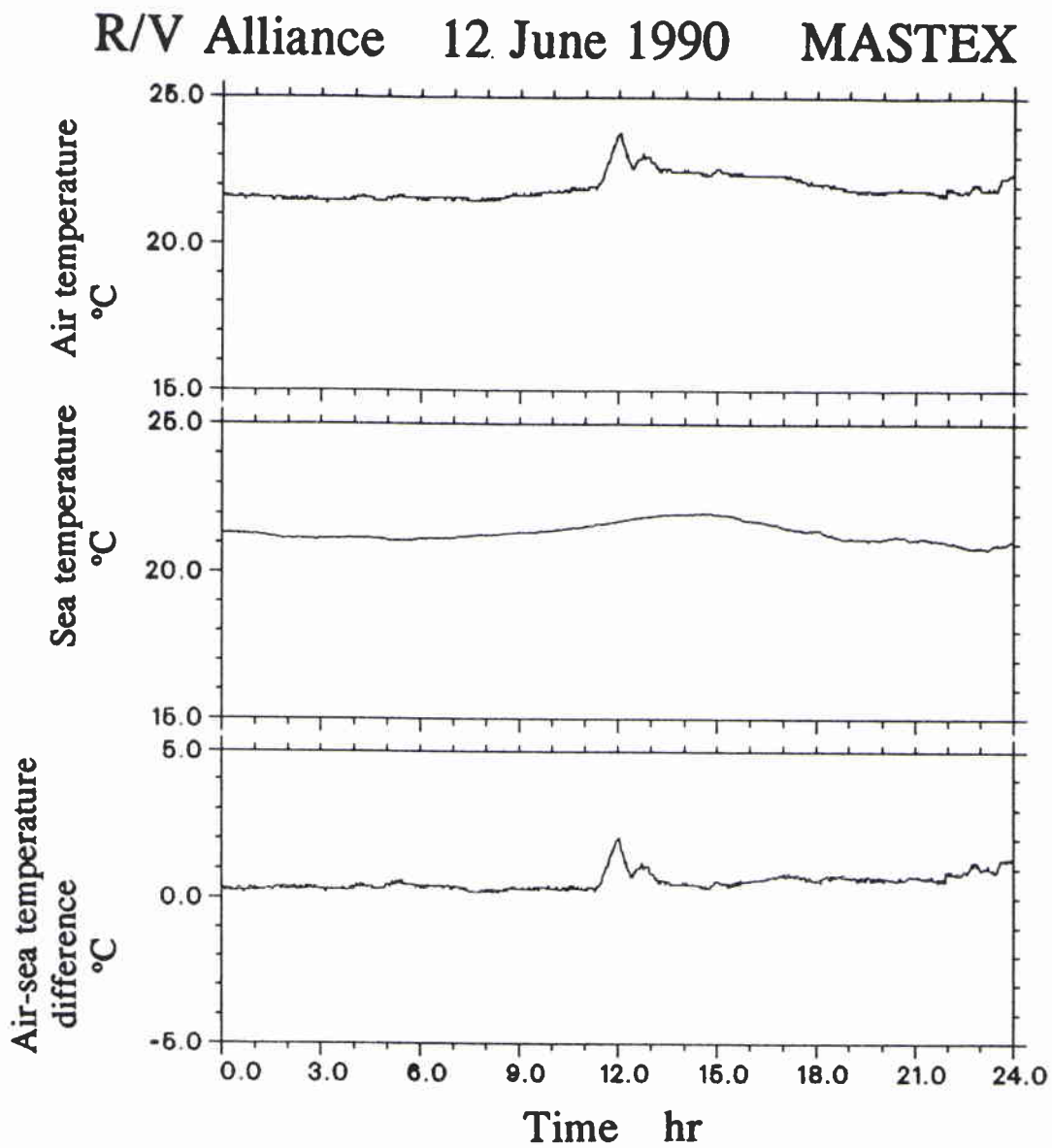


Figure E12

Appendix F

Turbulent air-sea exchanges and the net surface heat flux

The derived variables include the total turbulent air-sea heat exchange and the latent and sensible component fluxes (Figs. F1–F12). The Bowen ratio is the ratio between the sensible and latent heat exchanges, and the surface energy budget is the sum of the turbulent and radiative fluxes. In this representation, positive values indicate a heat flow from the ocean to the atmosphere.

SACLANTCEN SM-264

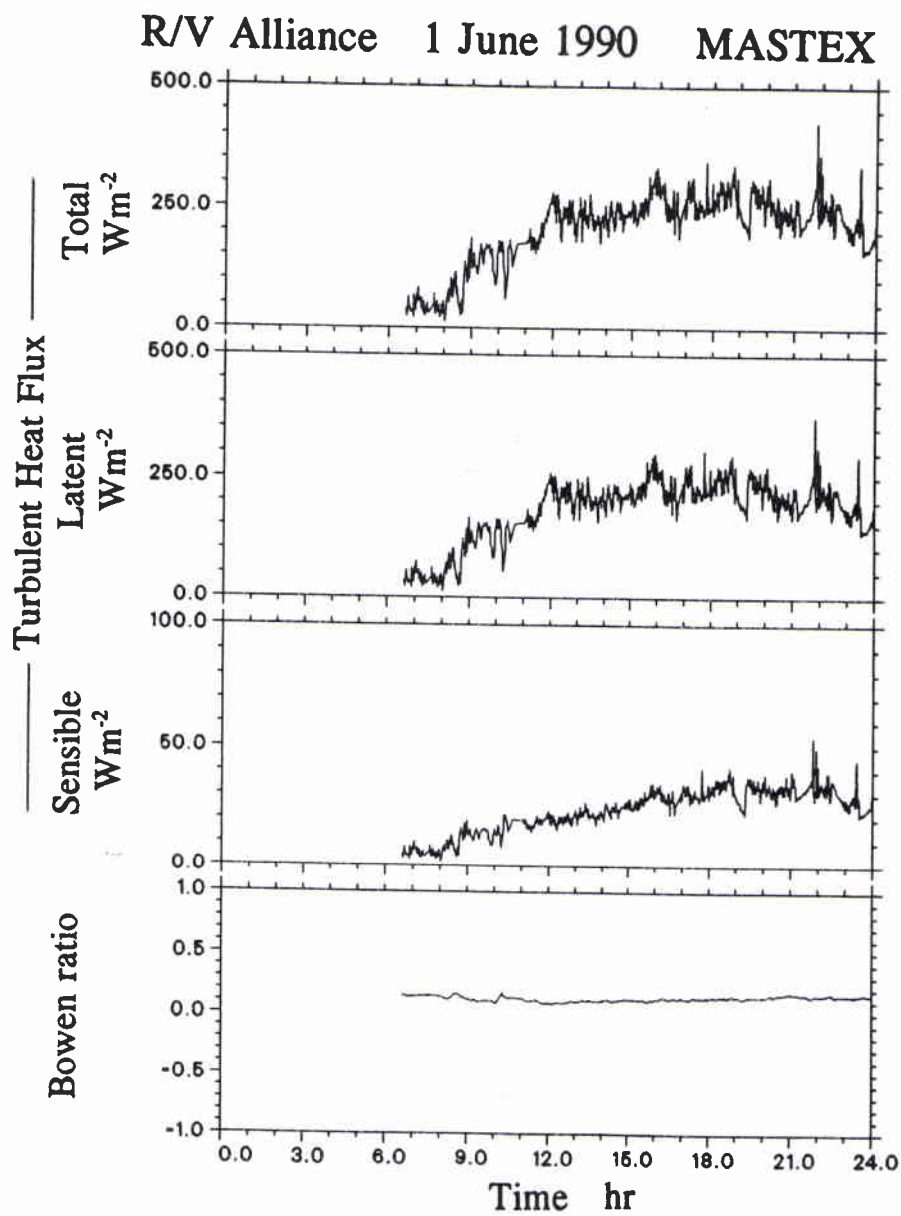


Figure F1

R/V Alliance 2 June 1990 MASTEX

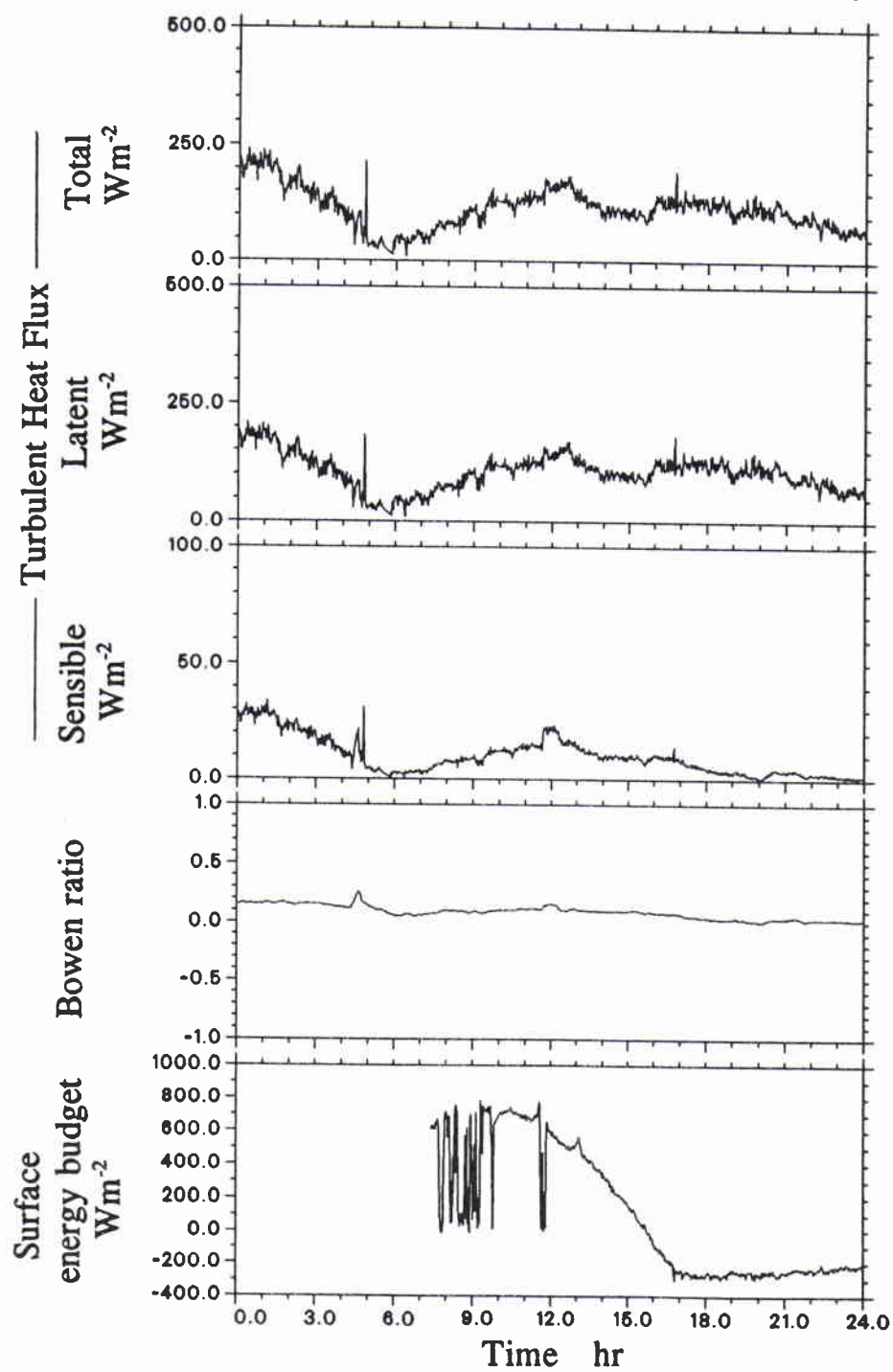


Figure F2

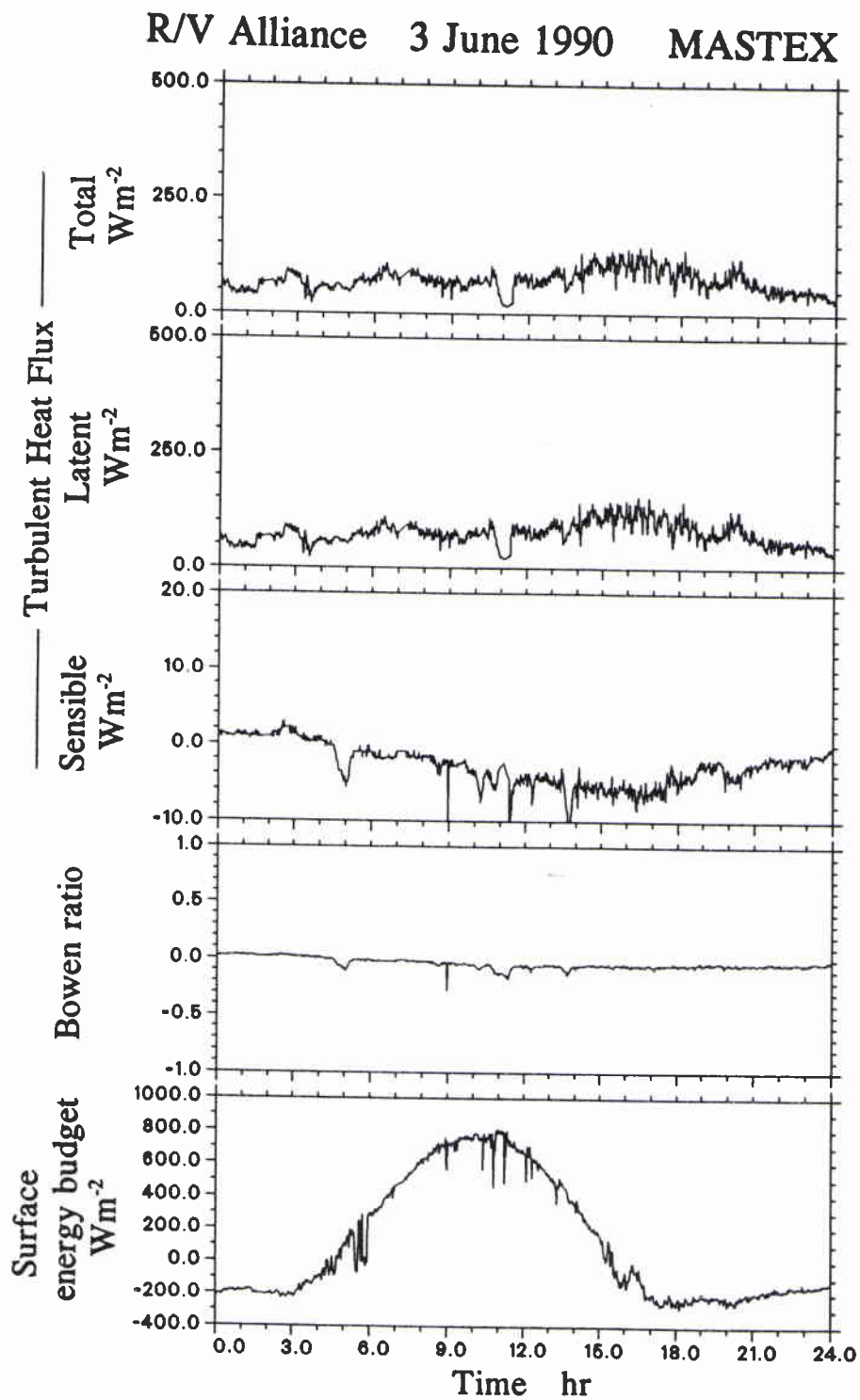
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Figure F3

R/V Alliance 4 June 1990 MASTEX

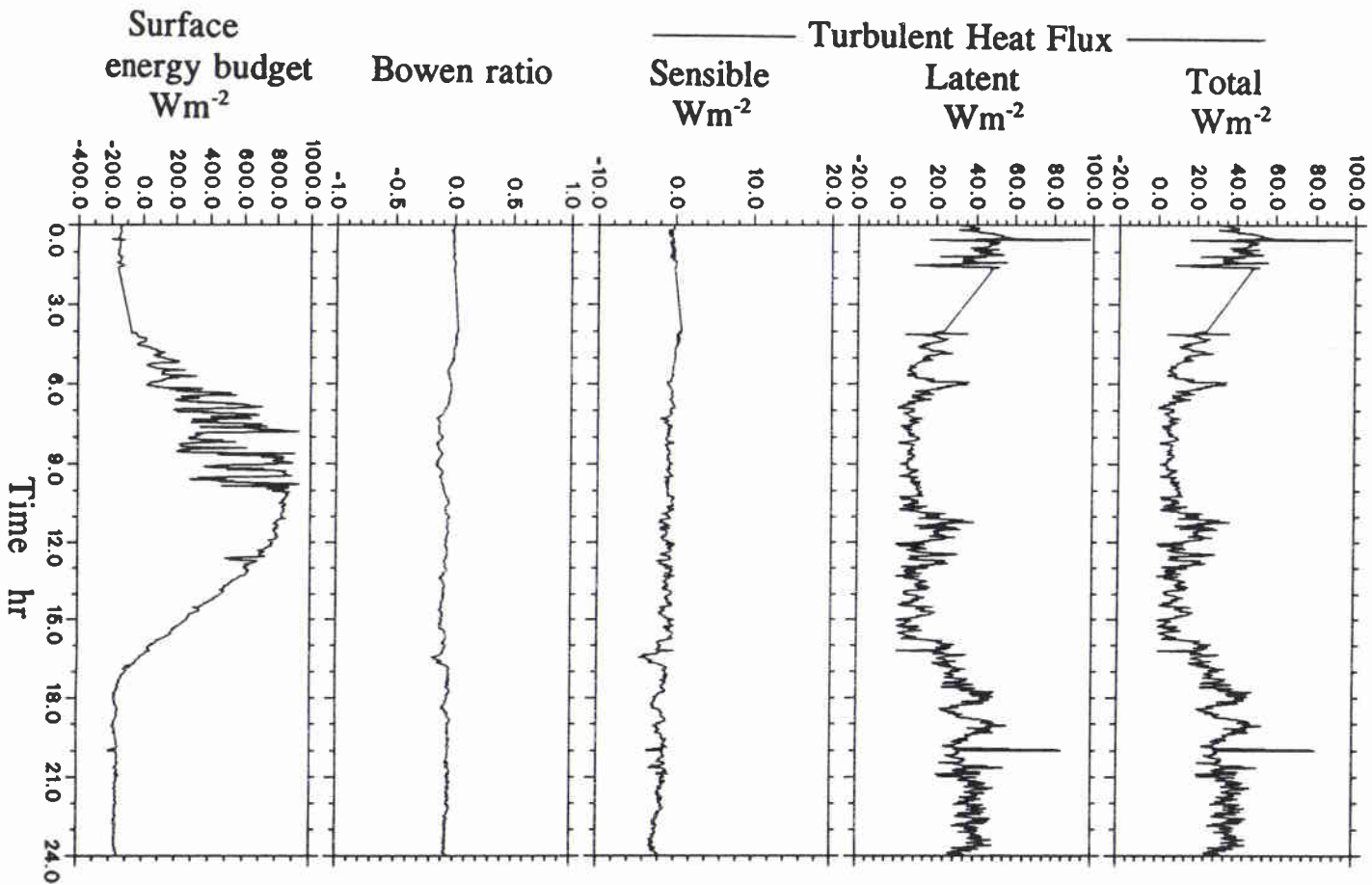


Figure F4

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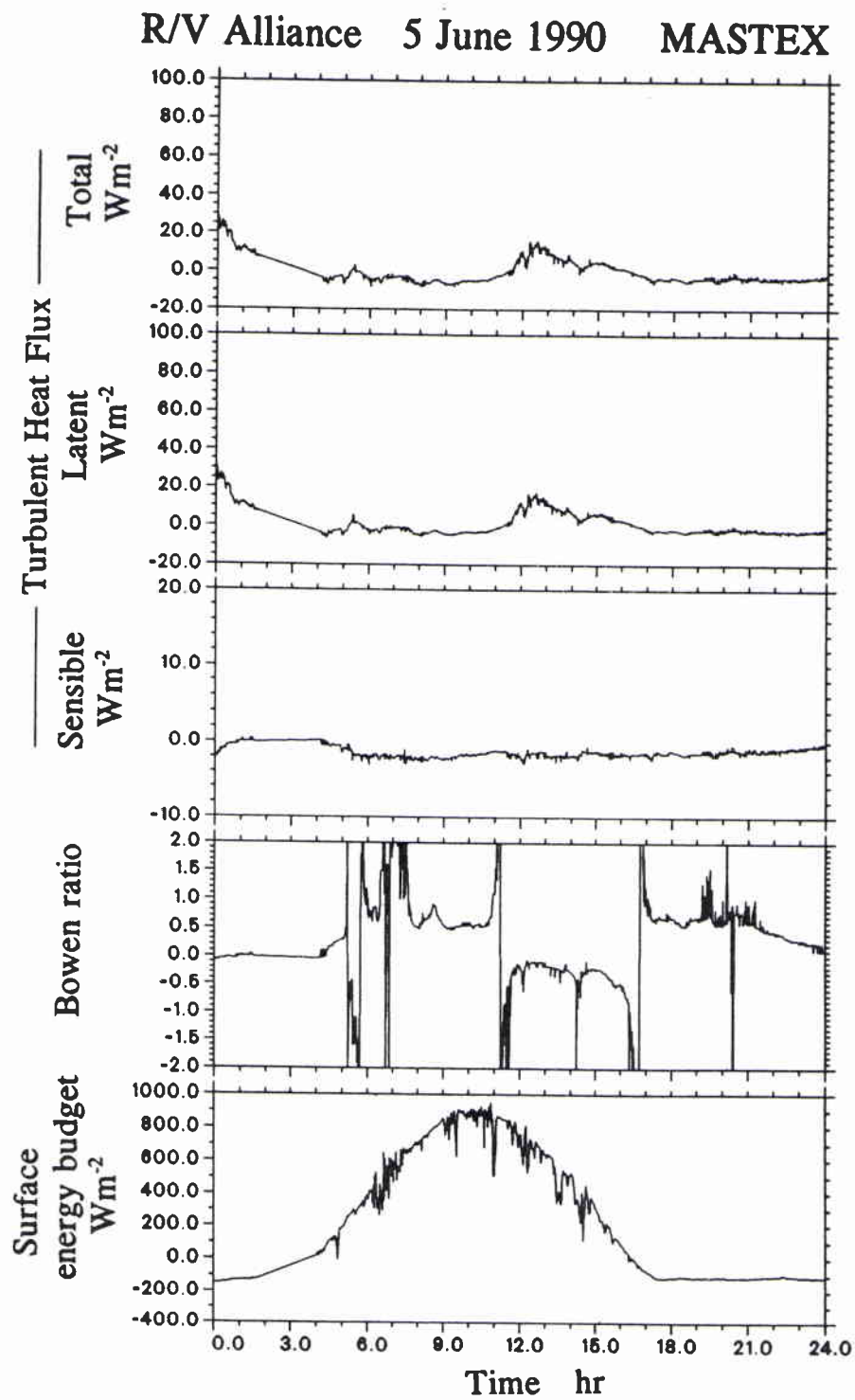


Figure F5

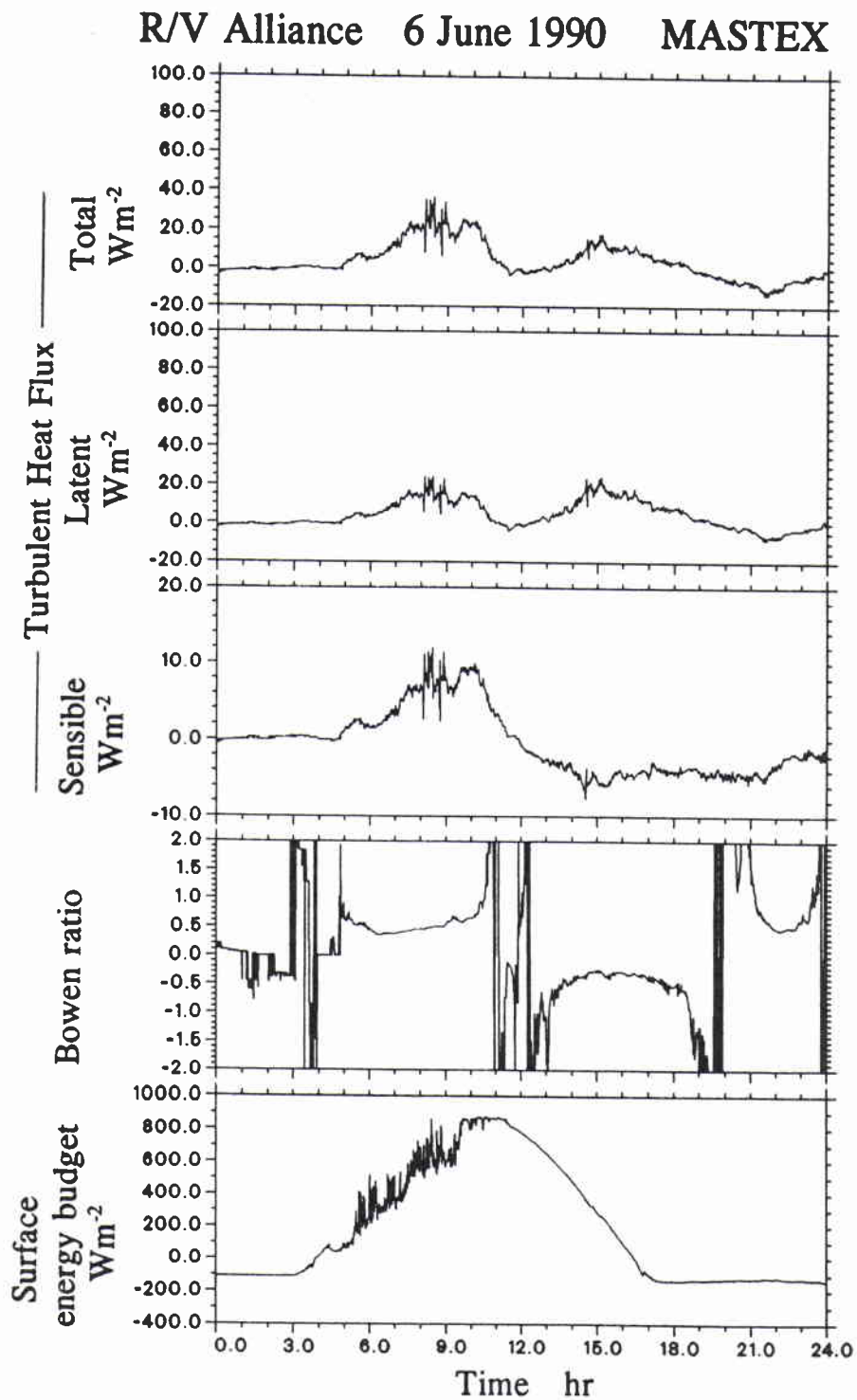


Figure F6

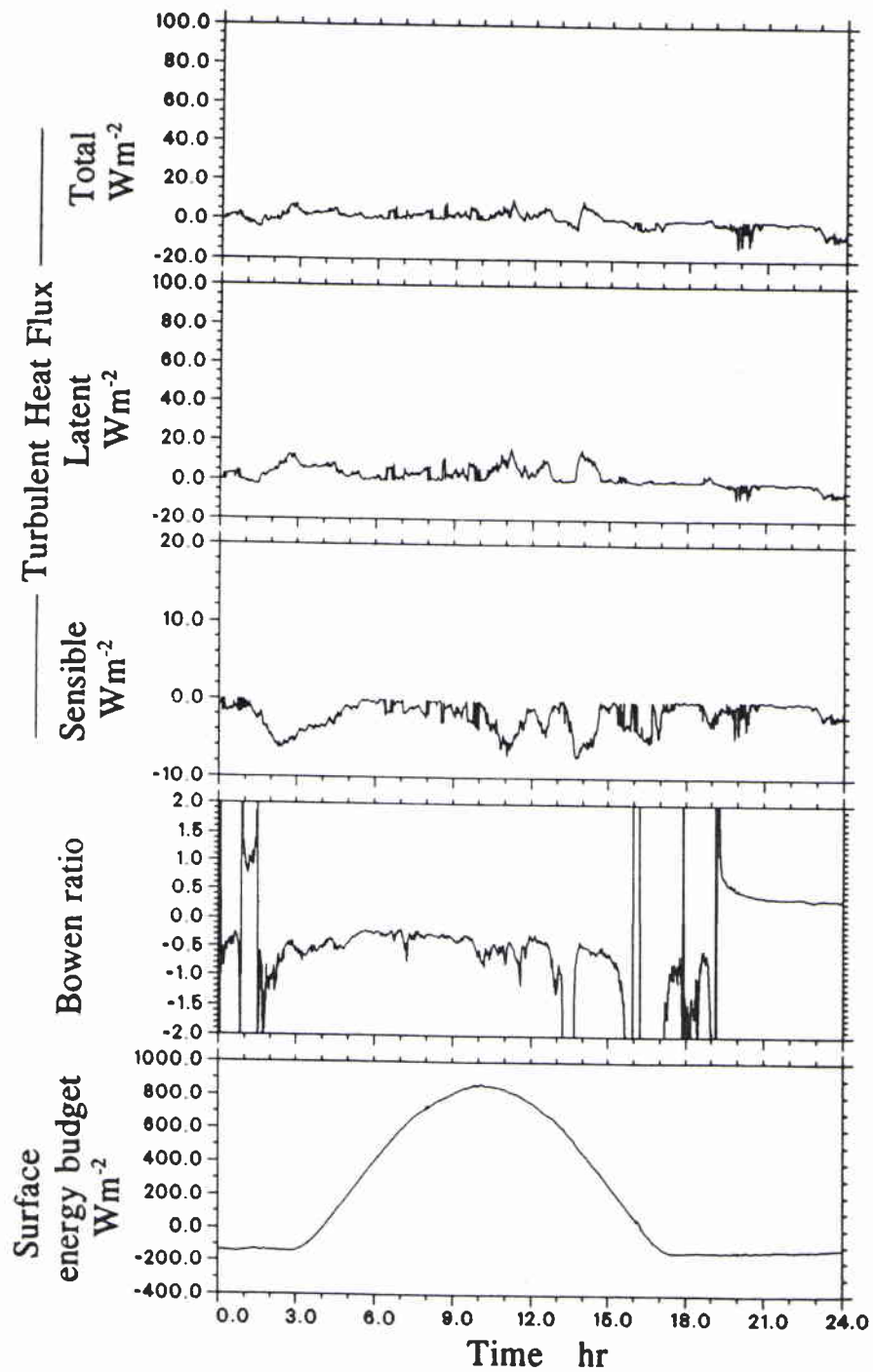
SACLANTCEN SM-264**R/V Alliance 7 June 1990 MASTEX**

Figure F7

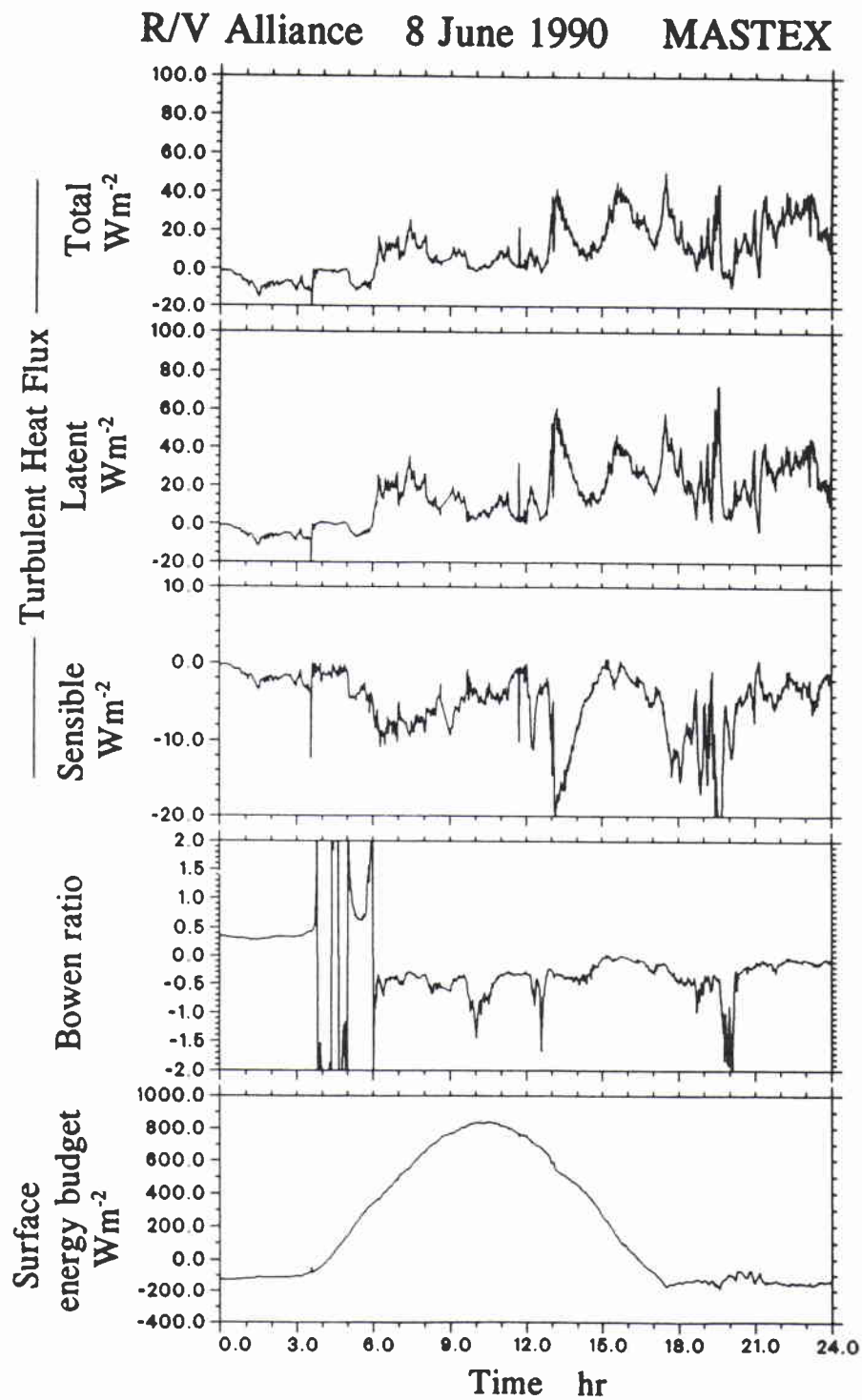


Figure F8

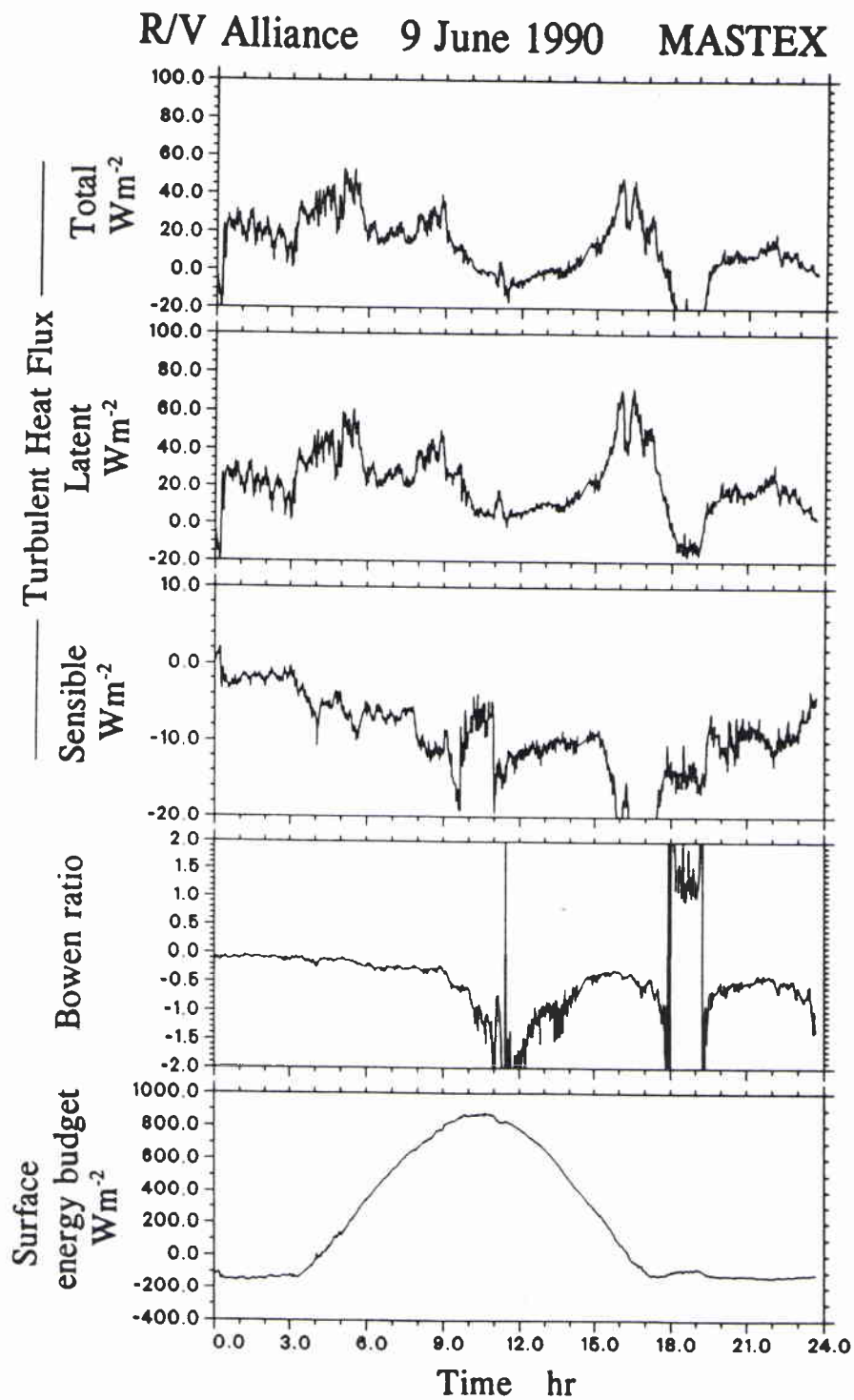
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Figure F9

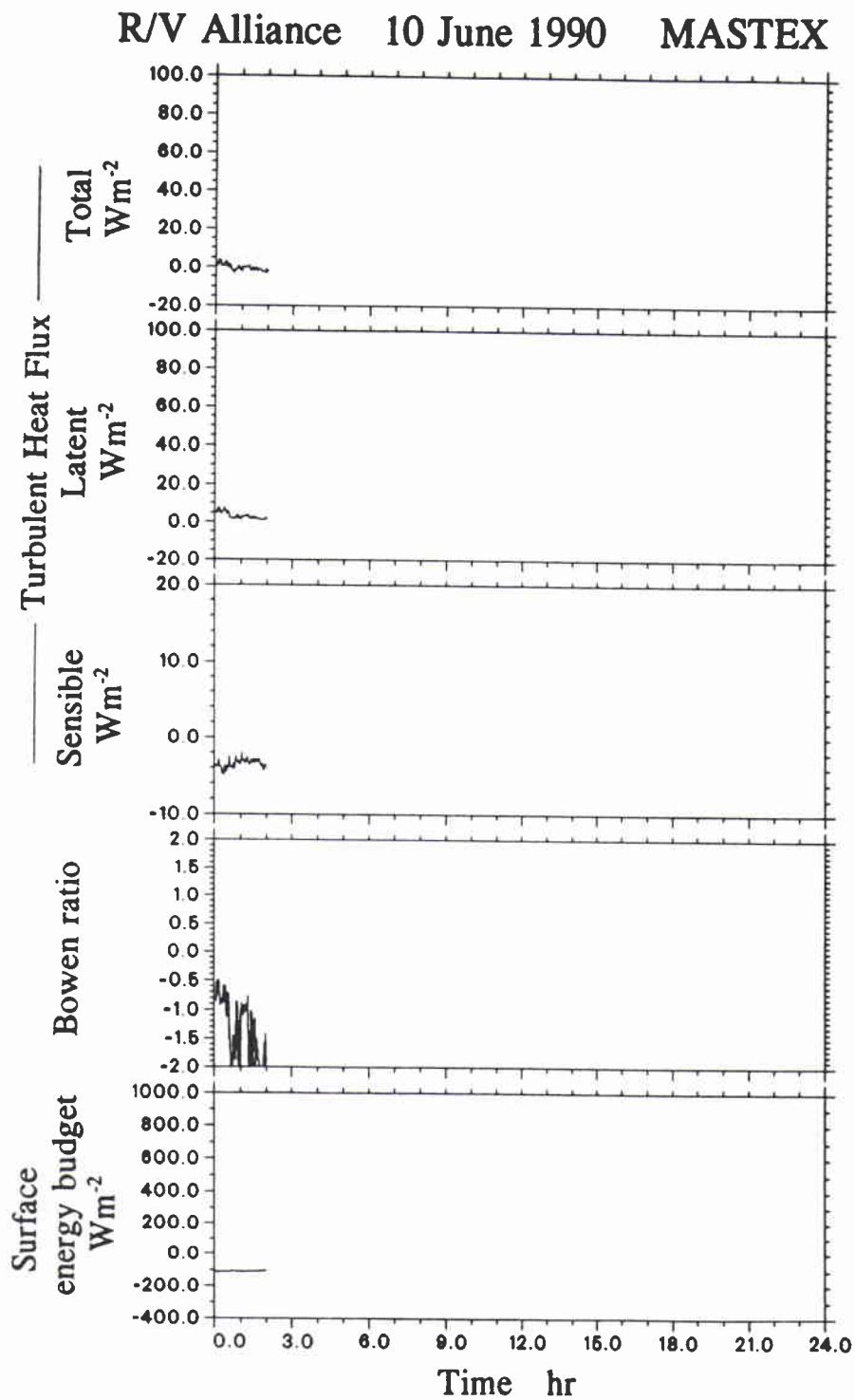


Figure F10

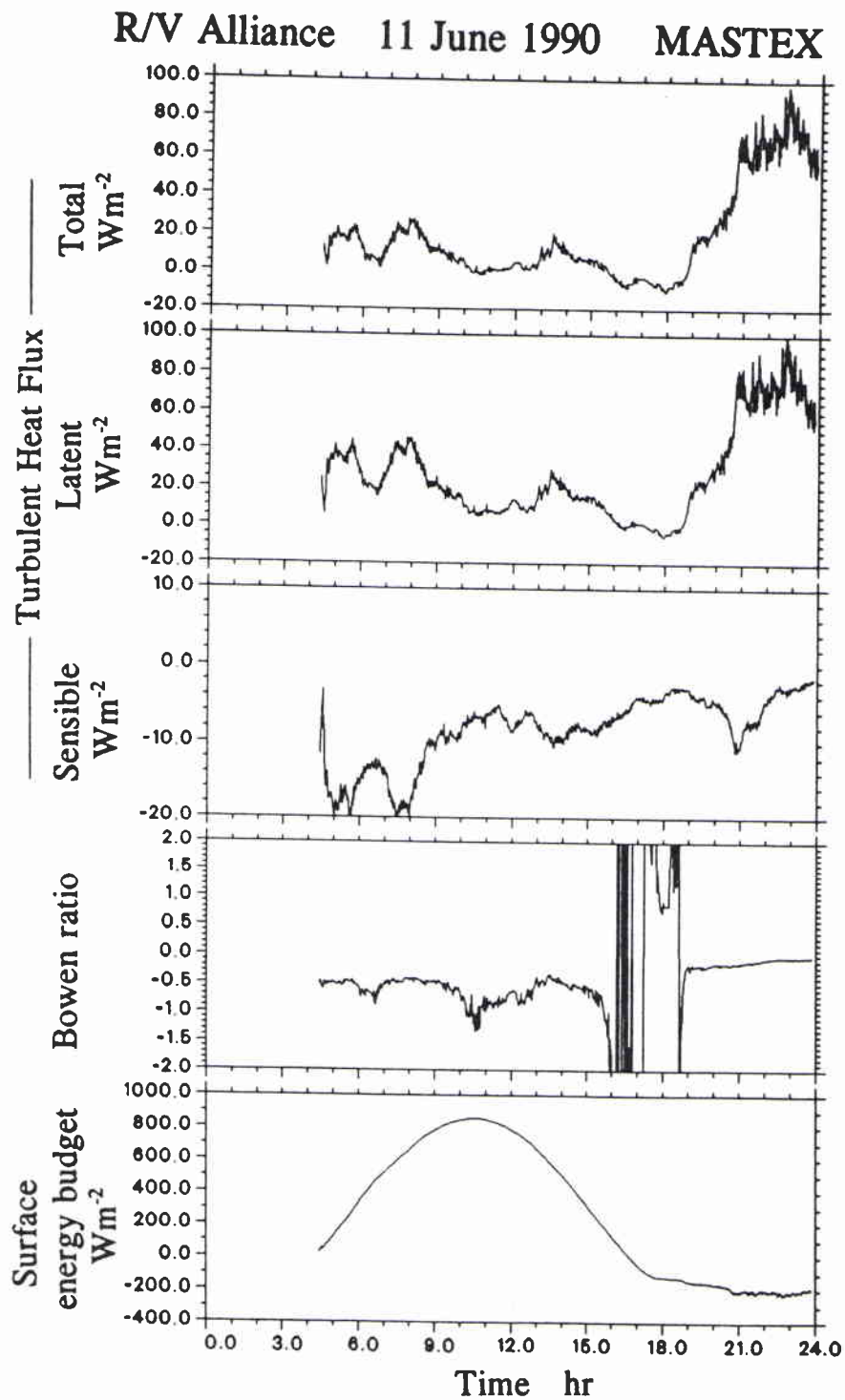
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Figure F11

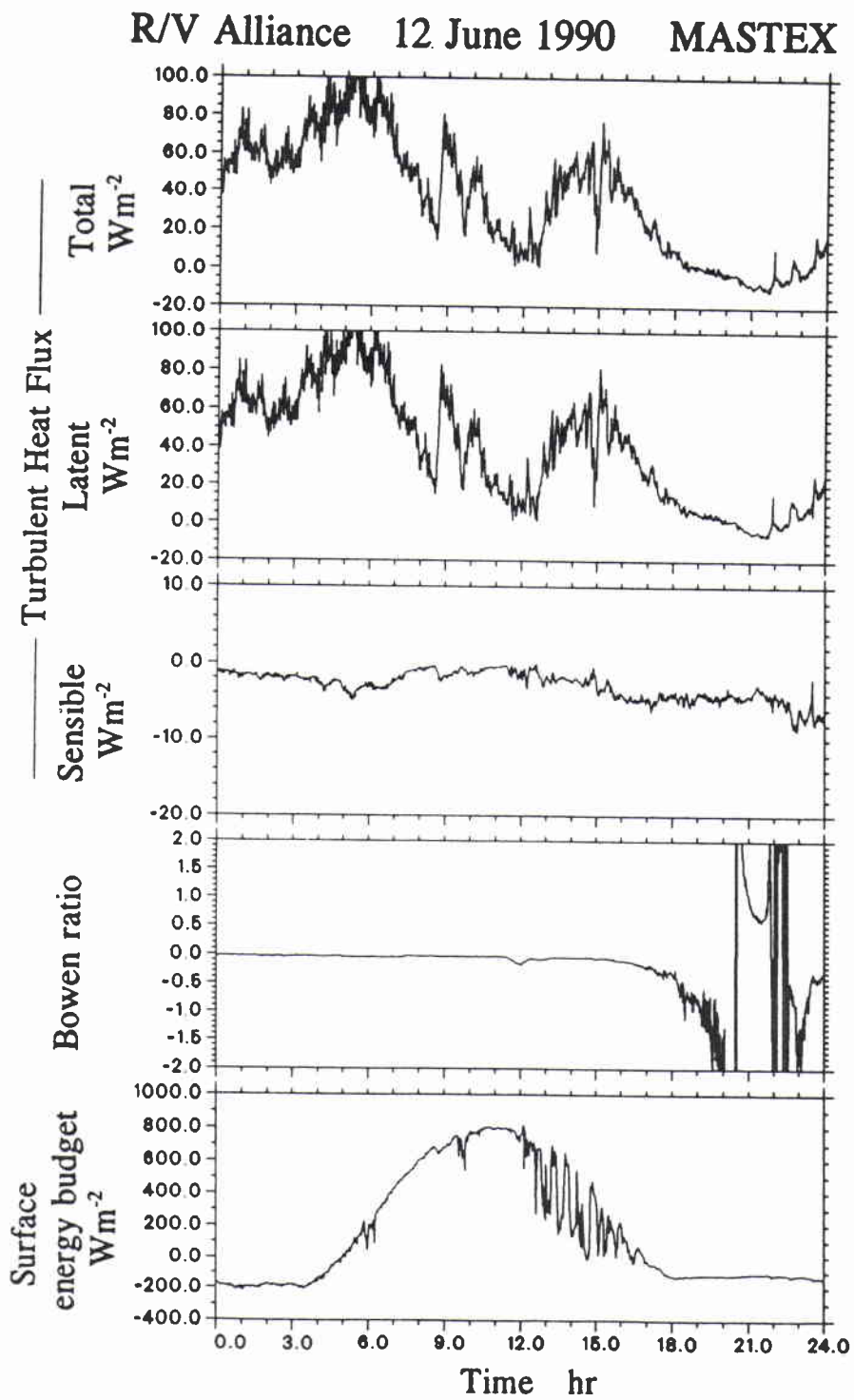


Figure F12

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Appendix G

Atmospheric profiles

The atmospheric profiles are presented against a vertical axis of atmospheric pressure in Figs. G1–G14. Each profile is identified by the time and location of the radiosonde launch. The measured variables are temperature and humidity and the absolute humidity and wet bulb depression were calculated using standard meteorological algorithms. The absolute humidity trace is shown magnified by a factor of ten as a dashed line for humidities below 1 gm^{-3} .

3 June 90 11:30 36°01.1'N, 24°53.3'E

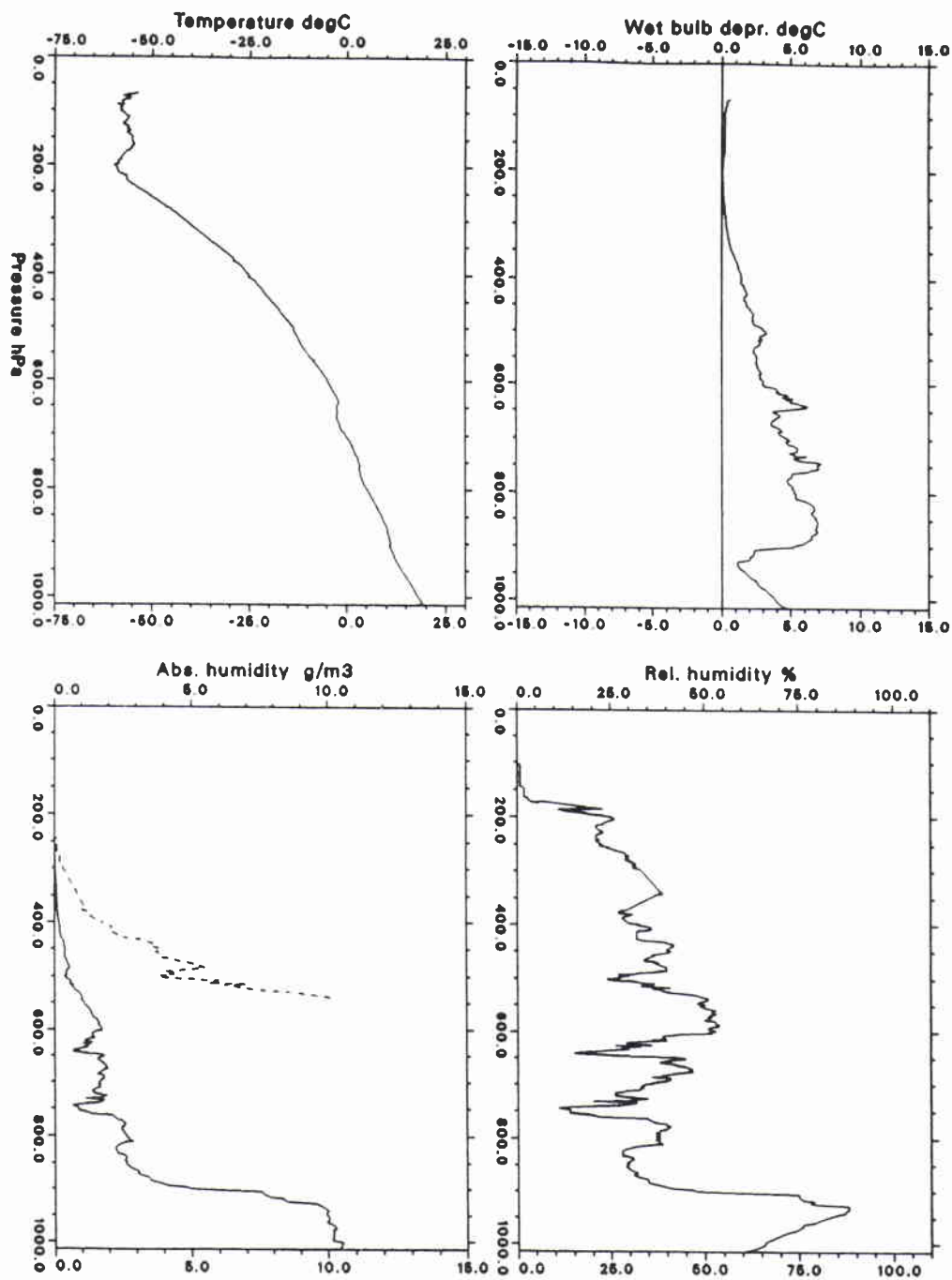


Figure G1

SACLANTCEN SM-264

4 June 90 10:45 36°00.6'N, 24°52.8'E

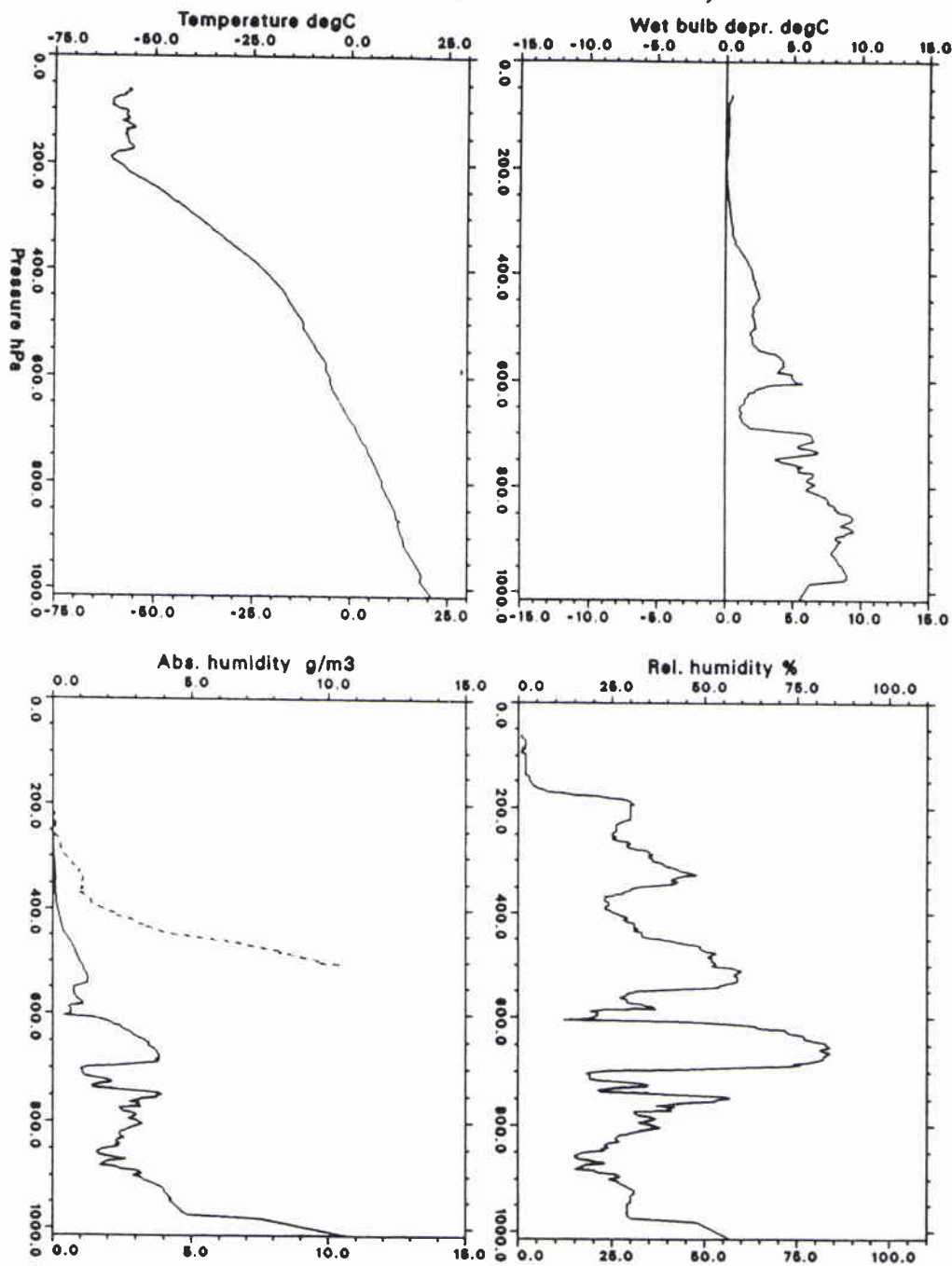


Figure G2

SACLANTCEN SM-264

5 June 90 11:13 35°57.2'N, 25°10.9'E

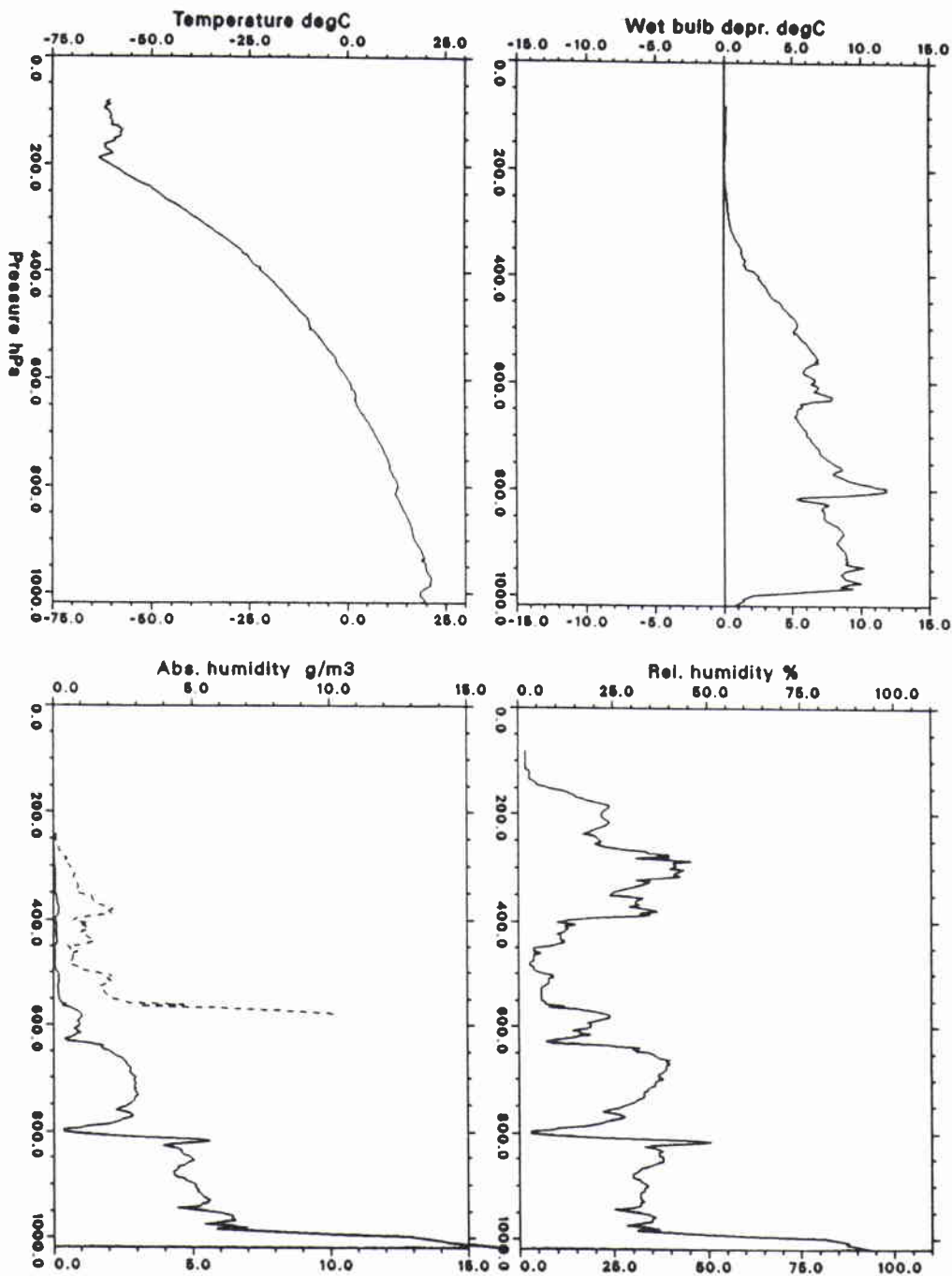


Figure G3

SACLANTCEN SM-264

6 June 90 10:50 36°01.0'N, 24°58.9'E

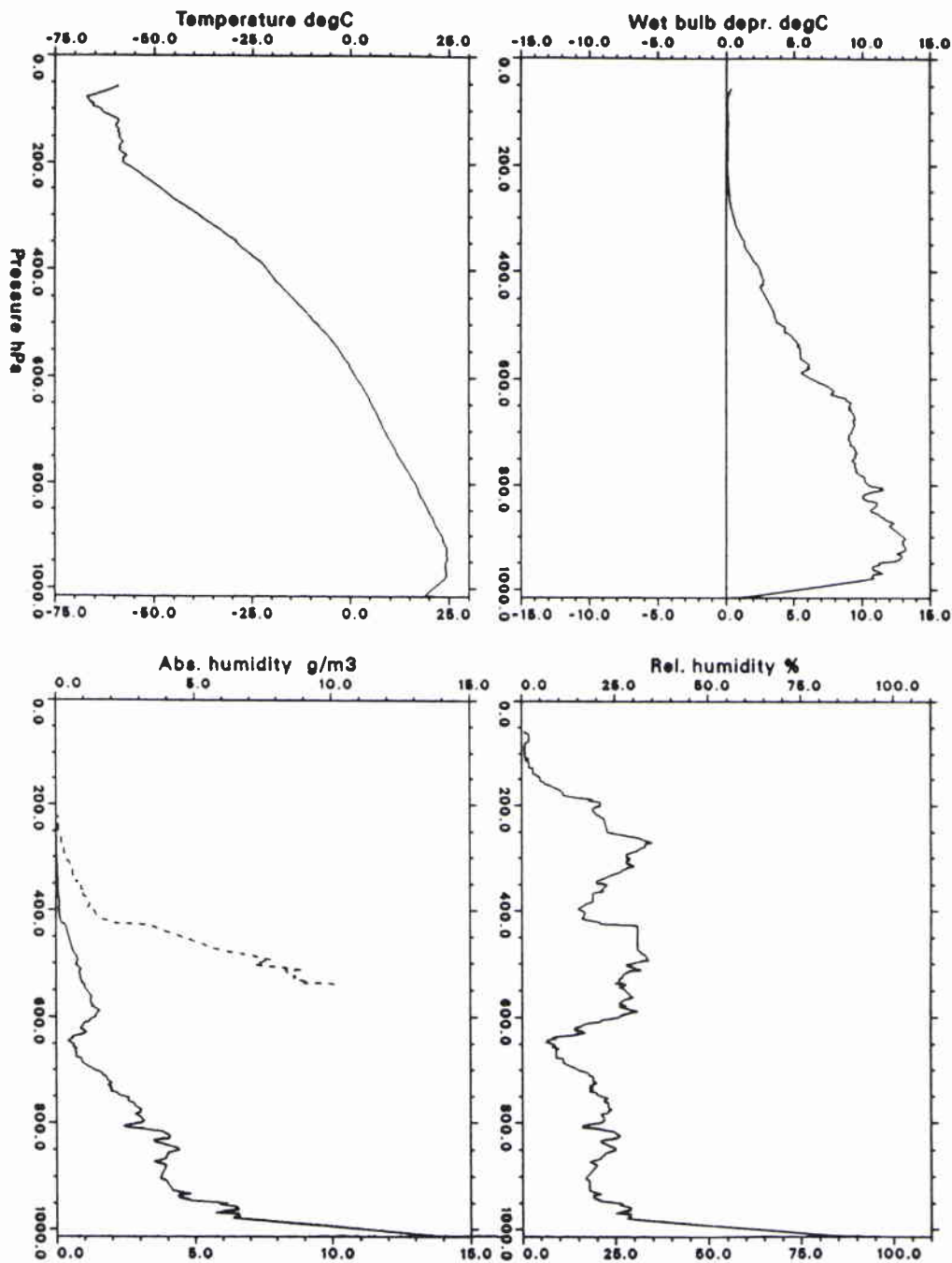


Figure G4

7 June 90 6:40 35°49.3'N, 26°57.4'E

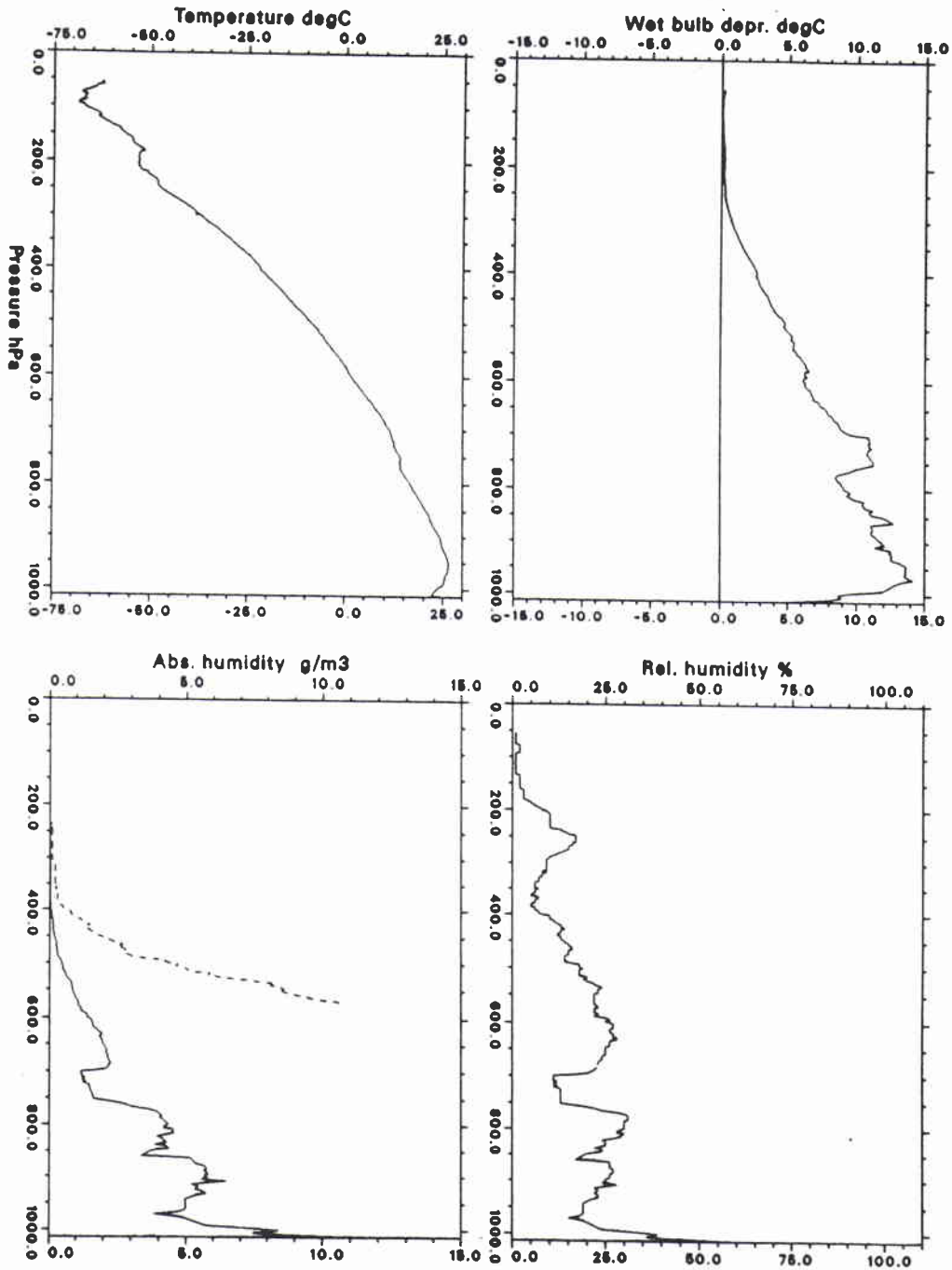


Figure G5

SACLANTCEN SM-264

7 June 90 11:15 35°40.6'N, 26°45.9'E

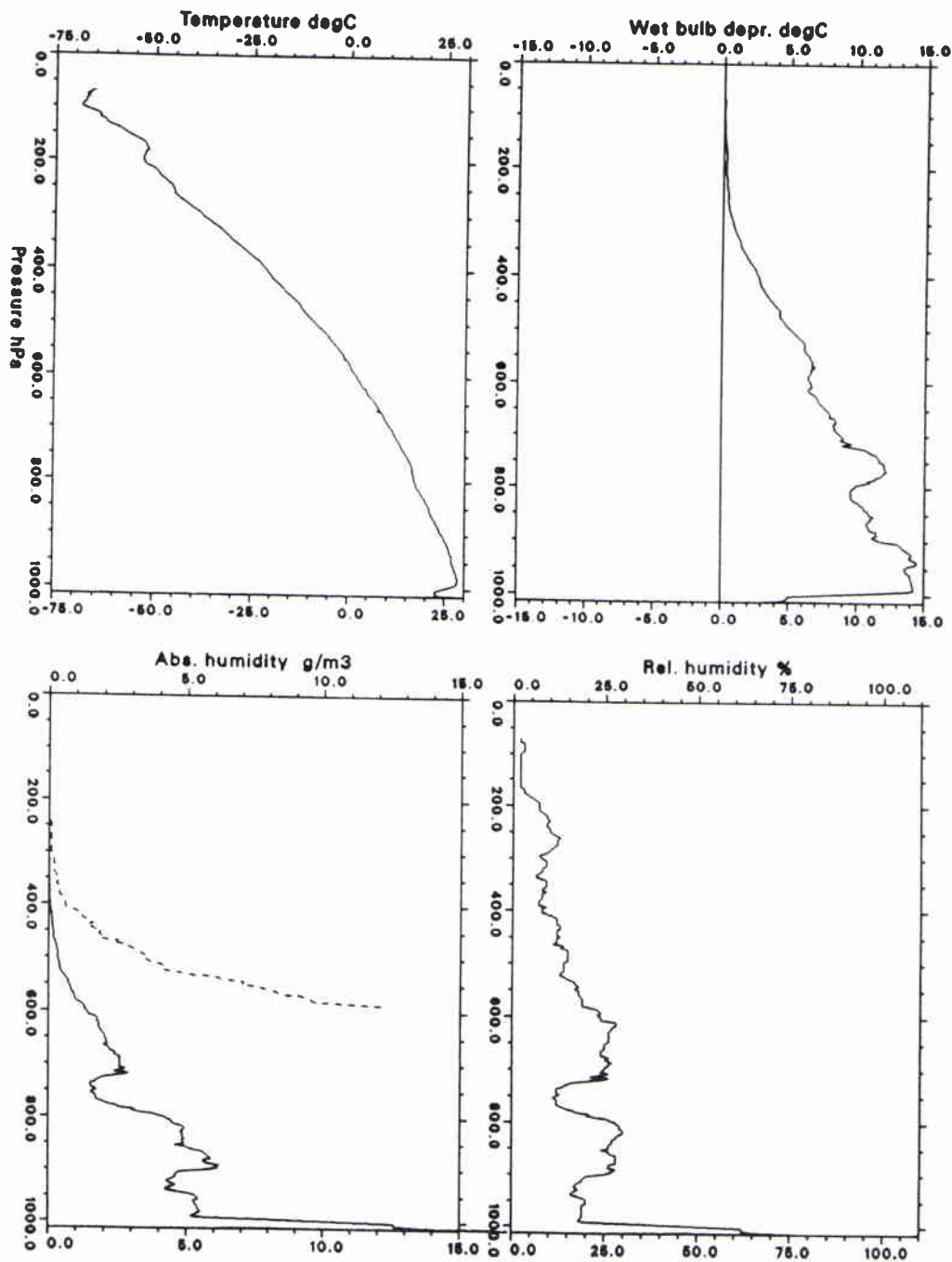


Figure G6

8 June 90 6:48 35°50.1'N, 24°43.2'E

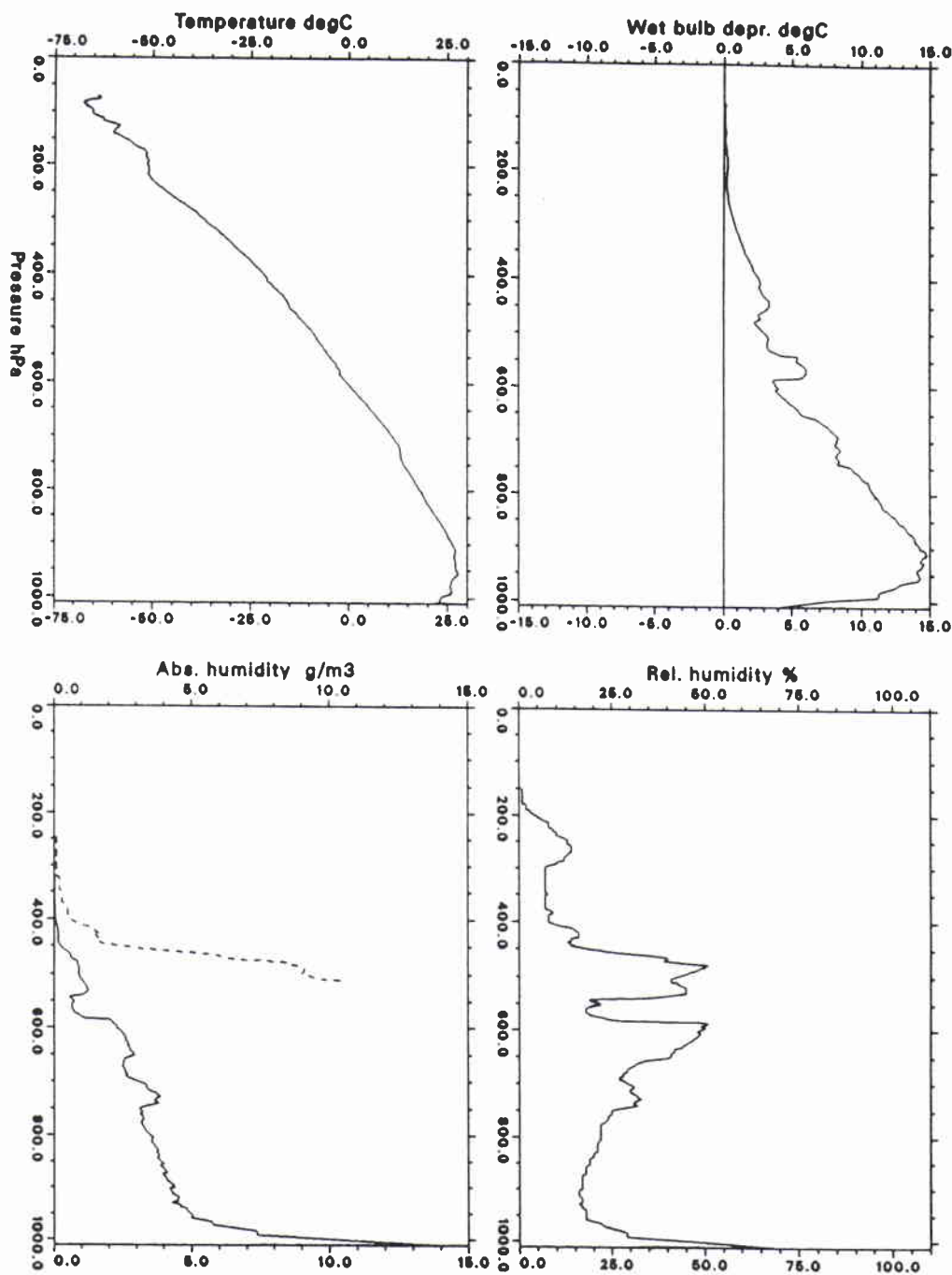


Figure G7

SACLANTCEN SM-264

8 June 90 12:30 35°50.7'N, 24°40.2'E

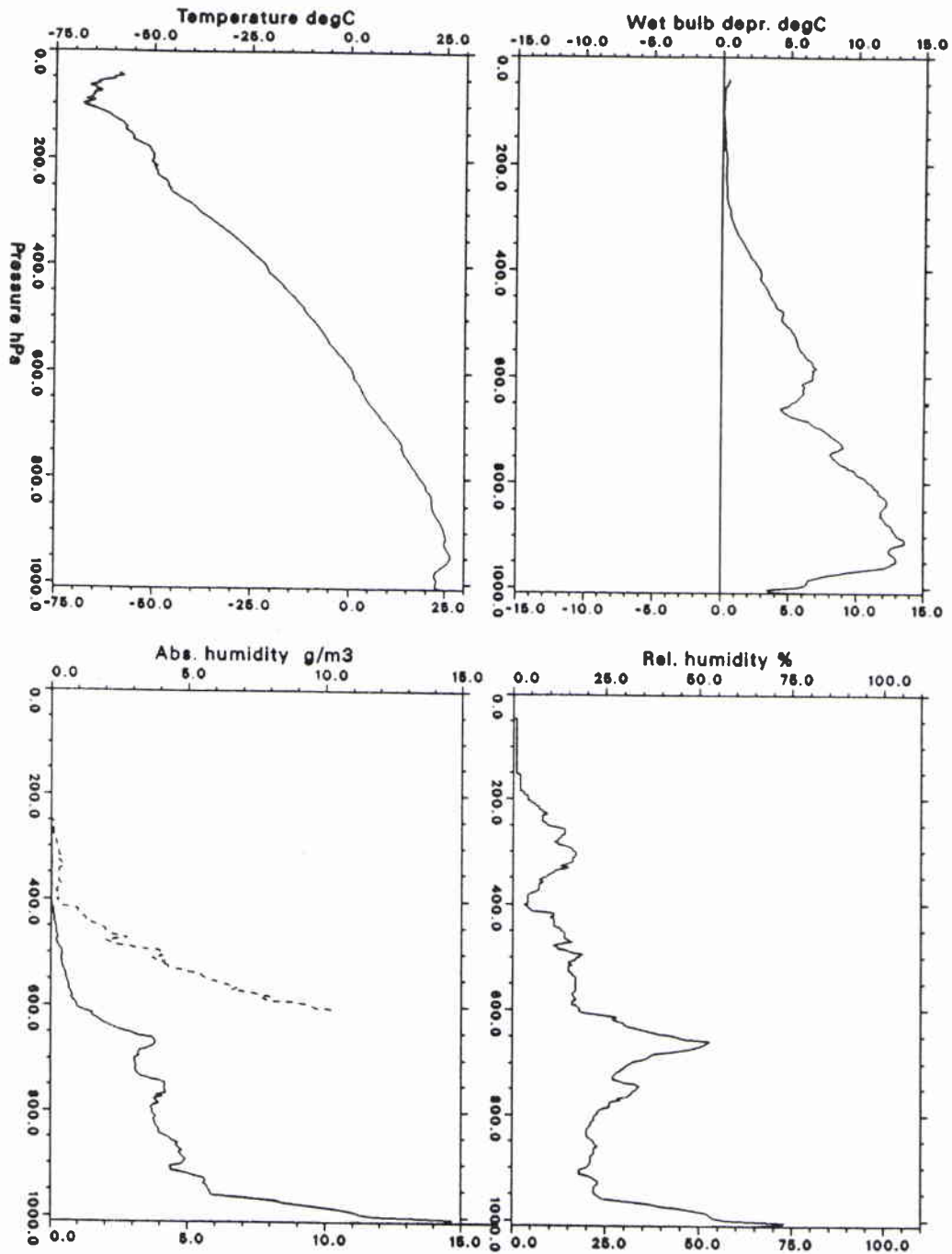


Figure G8

9 June 90 6:50 35°48.3'N, 24°48.5'E

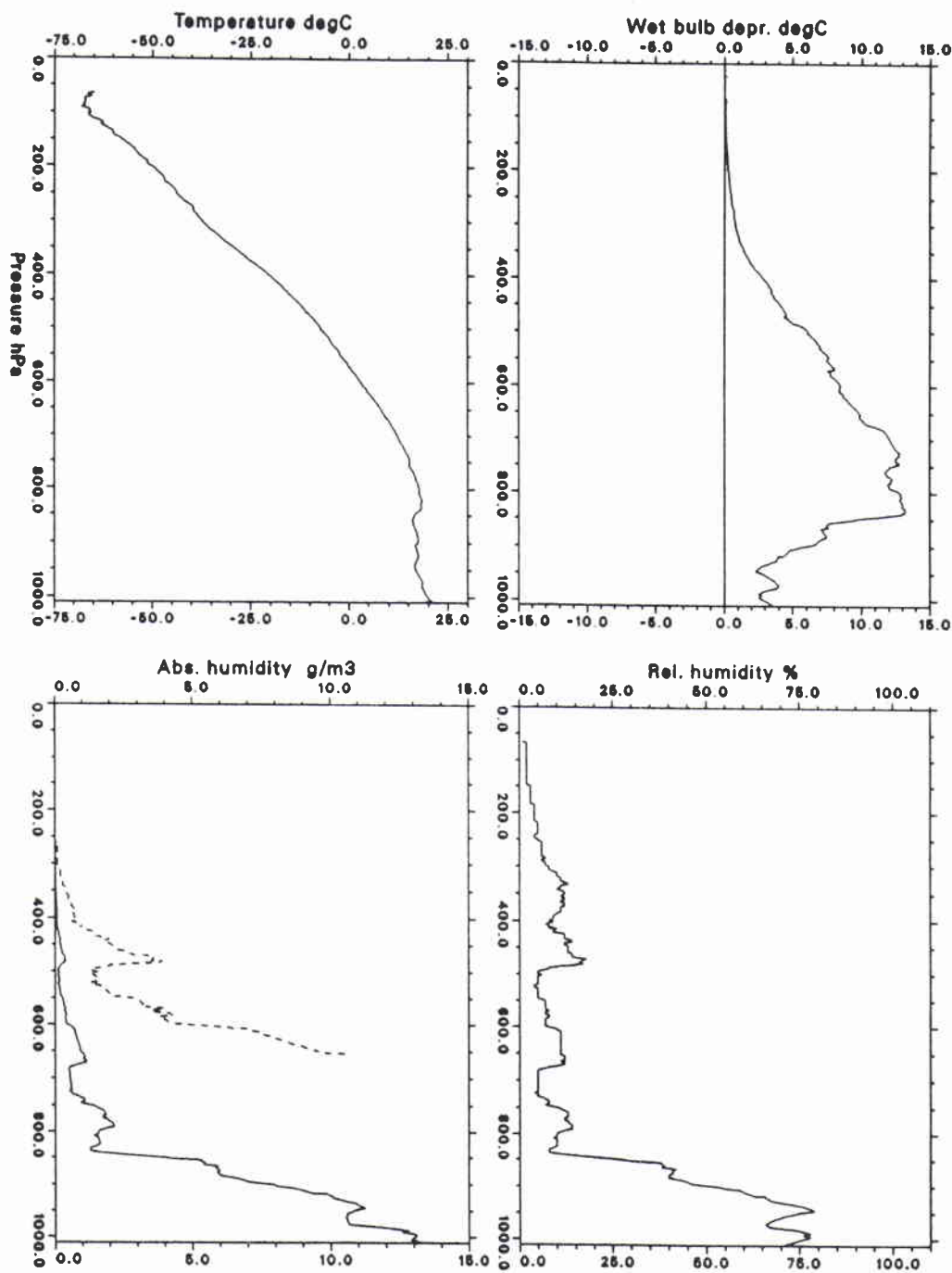


Figure G9

SACLANTCEN SM-264

9 June 90 12:30 35°48.6'N, 24°48.7'E

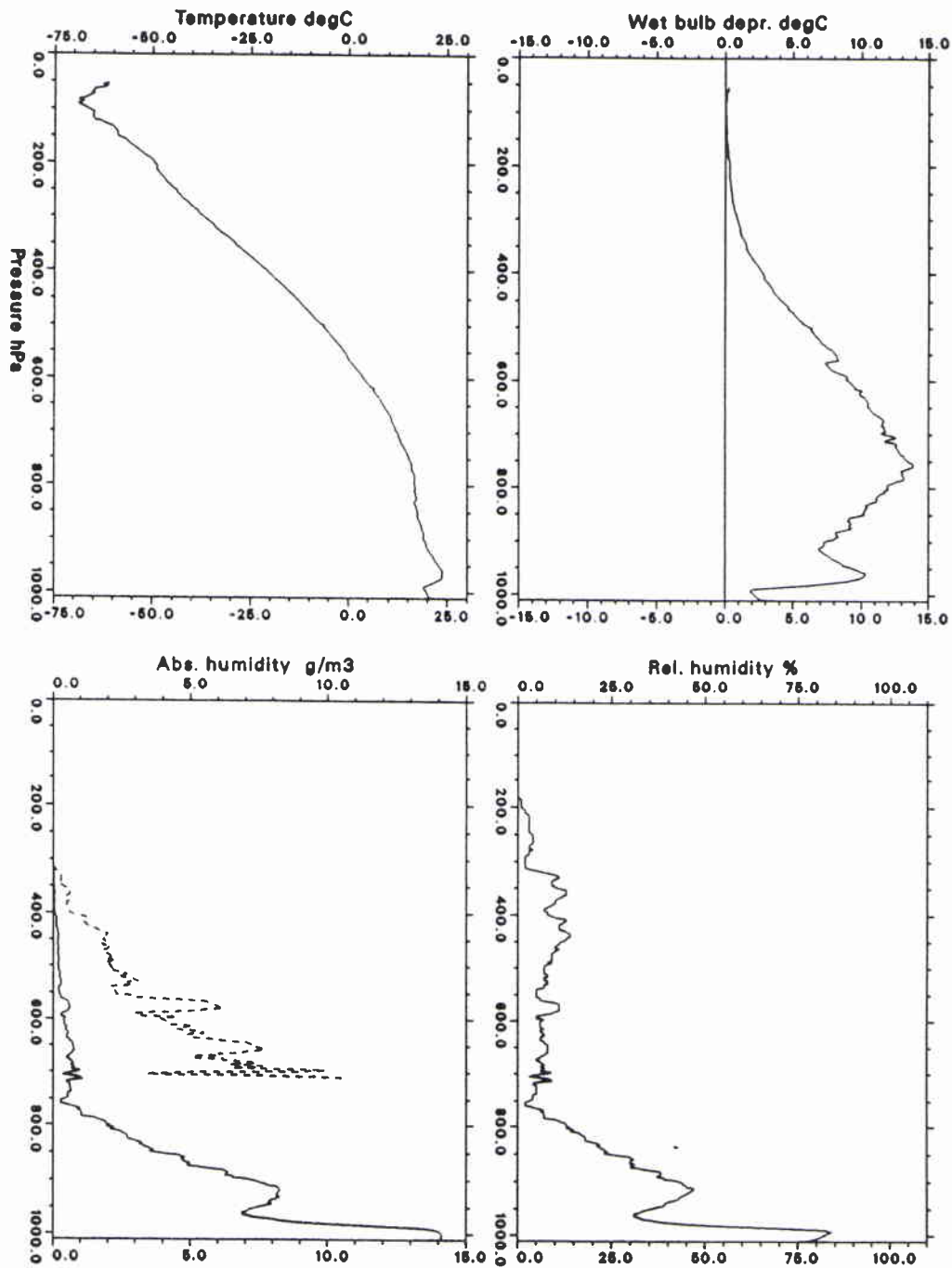


Figure G10

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11 June 90 6:27 35°20.7'N, 22°46.8'E

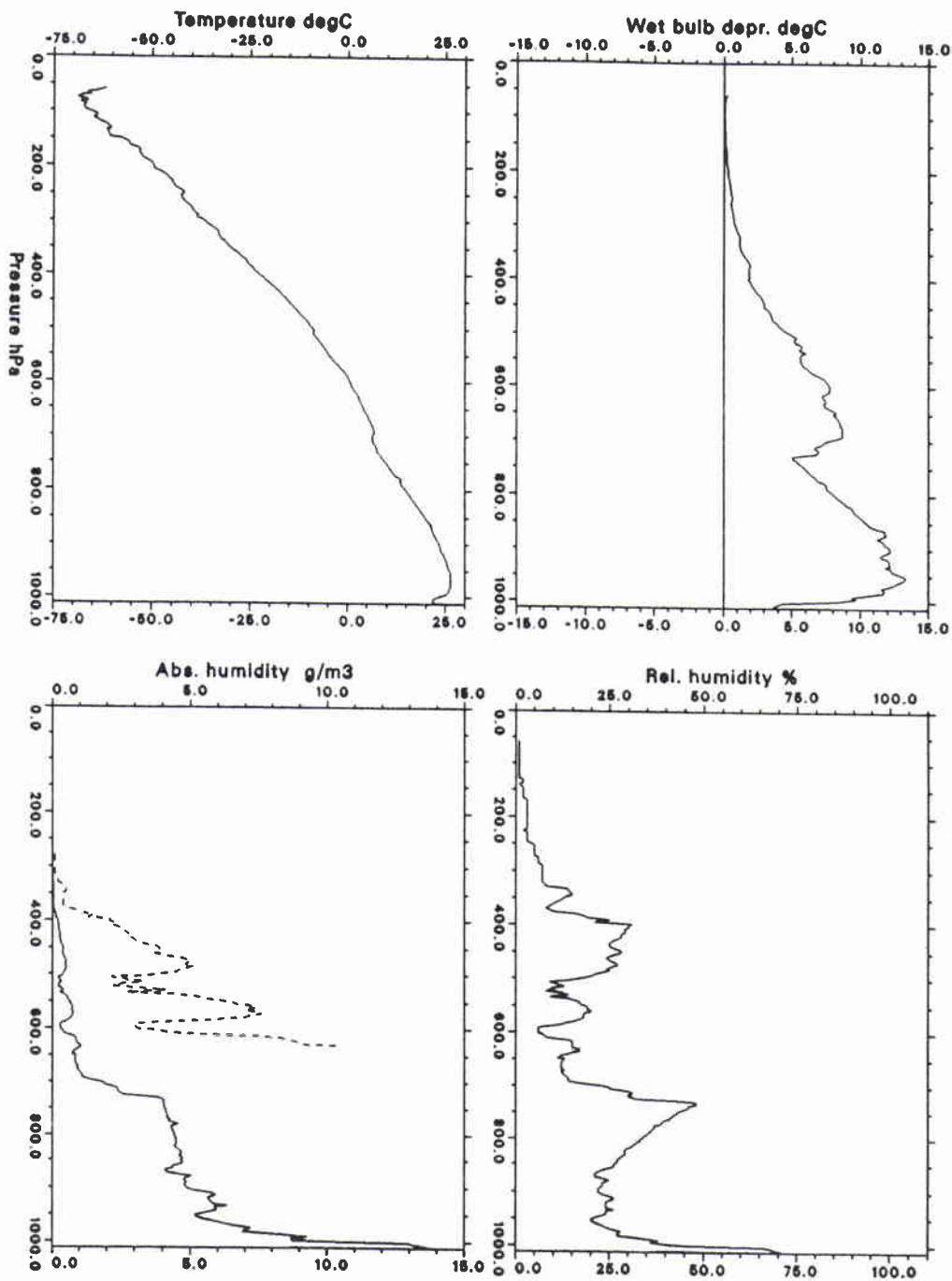


Figure G11

SACLANTCEN SM-264

11 June 90 11:40 35°35.7'N, 22°12.7'E

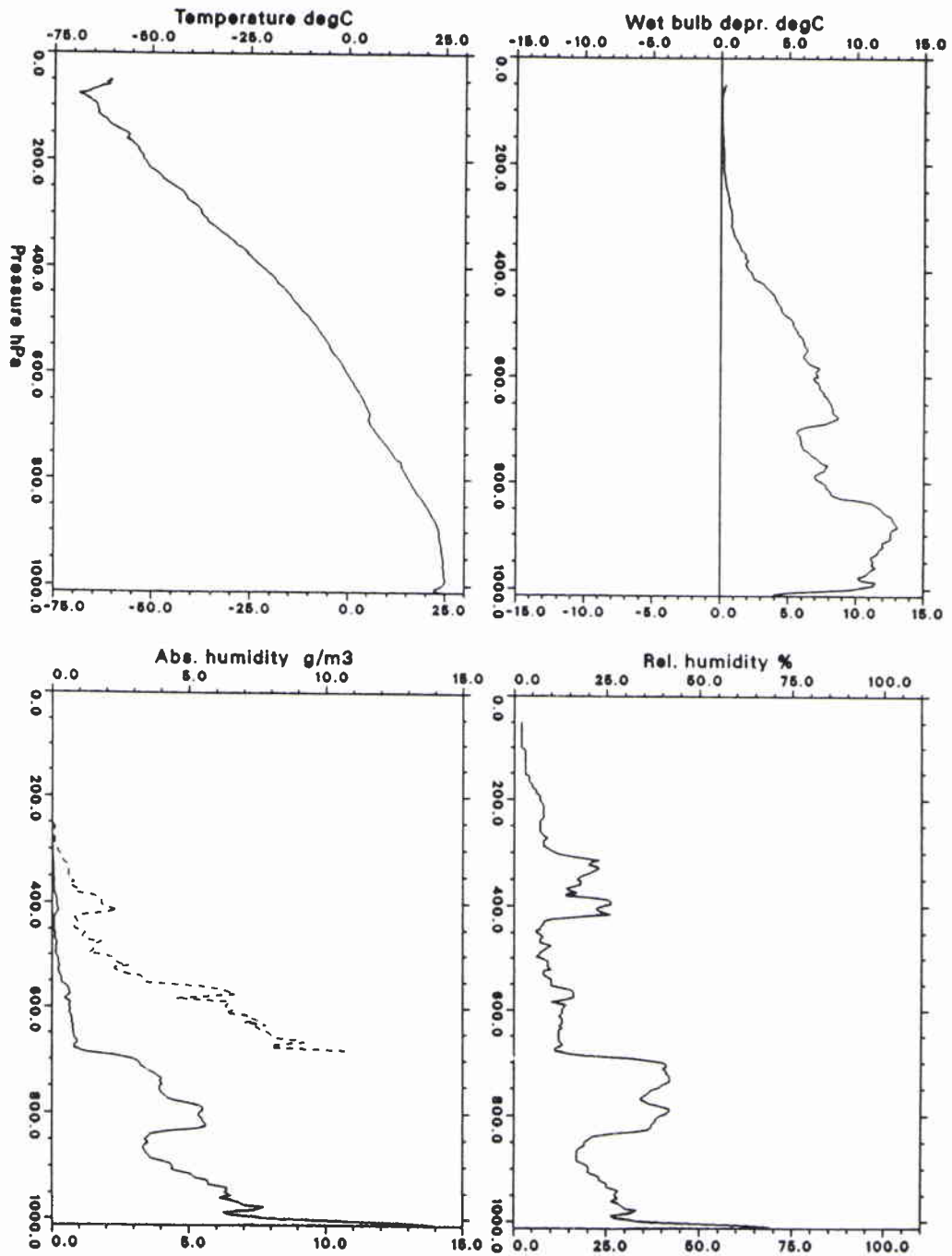


Figure G12

SACLANTCEN SM-264

12 June 90 6:23 36°23.1'N, 20°00.7'E

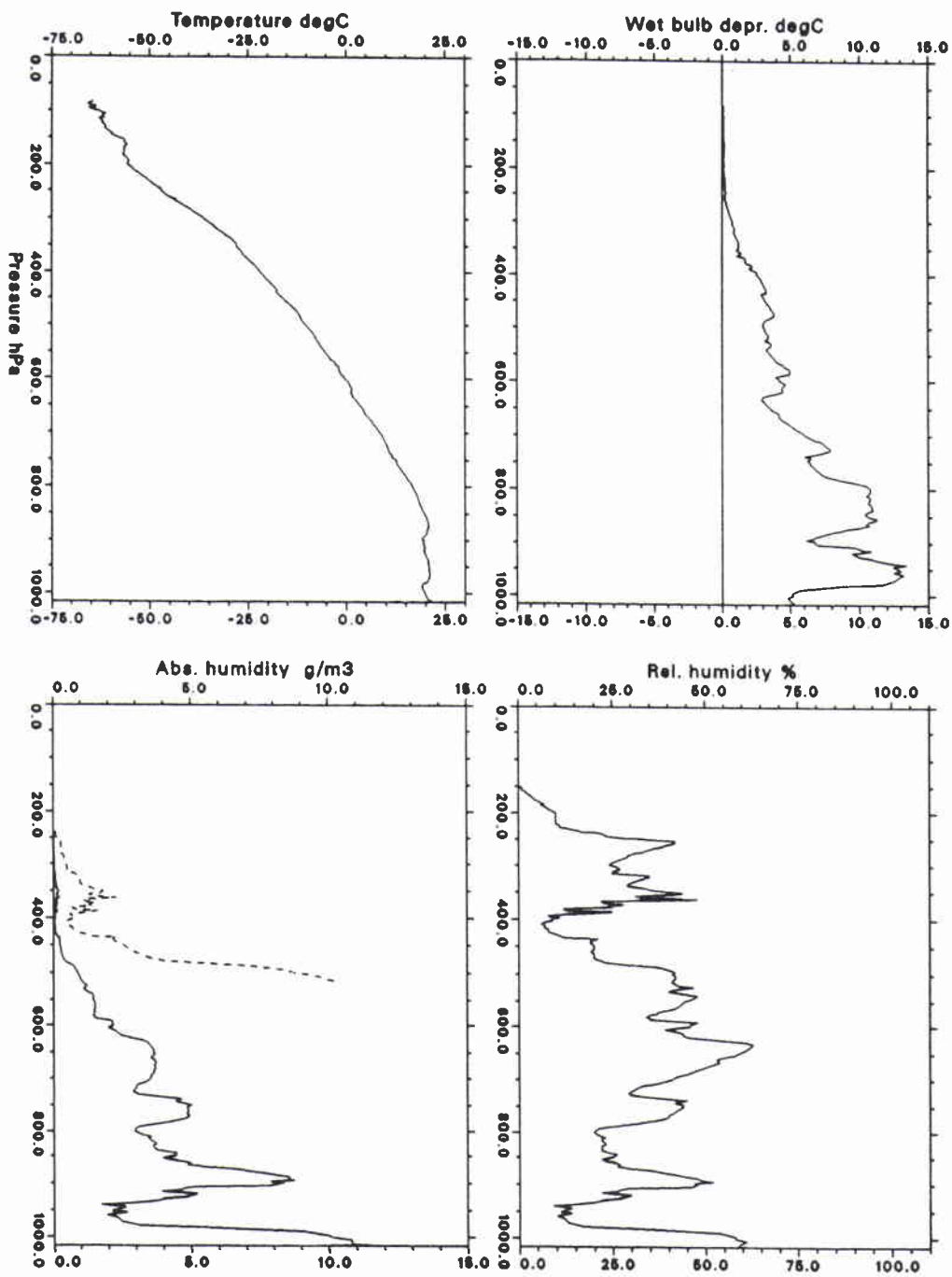


Figure G13

SACLANTCEN SM-264

12 June 90 11:45 36°50.7'N, 19°22.1'E

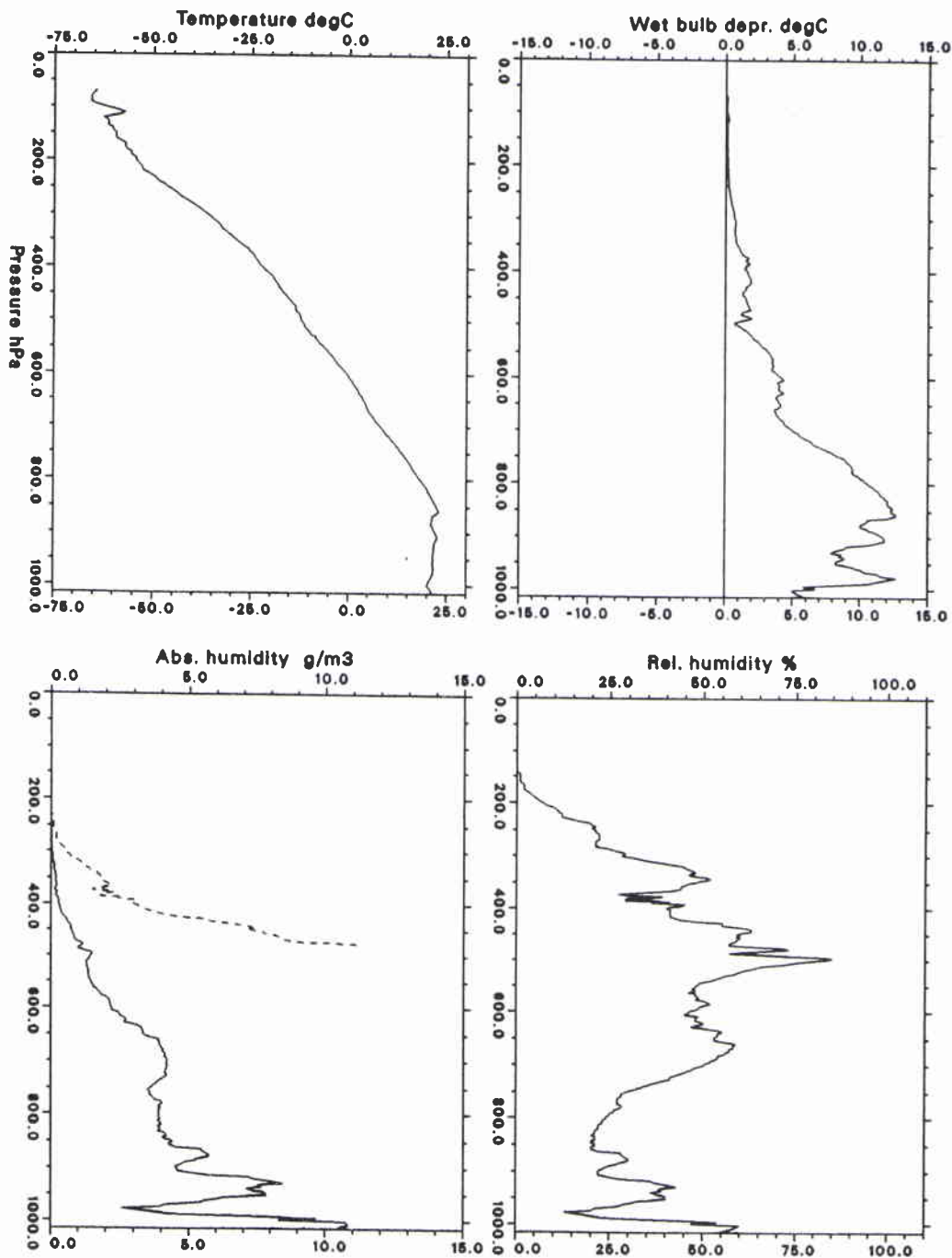


Figure G14

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Author(s) P.J. Minnett		
Title Surface measurements made from the R/V <i>Alliance</i> during the Mediterranean Aircraft-Ship Transmission Experiment (MASTEX), June 1990		
Abstract Measurements of sea-surface temperature, surface meteorology and atmospheric profiles taken during the June 1990 cruise of the R/V <i>Alliance</i> in the Aegean and Ionian Seas are presented in graphical form. True winds, net long-wave radiation and turbulent air-sea fluxes have been calculated and are also presented. The data reported form part of the 'MASTEX' (Mediterranean Aircraft-Ship Transmission Experiment) data set which includes airborne measurements from the C-130 of the UK Meteorological Research Flight.		
Keywords Aegean Sea, air-sea interaction, diurnal thermocline, Ionian Sea, meteorology, sea-surface temperature		
Issuing Organization North Atlantic Treaty Organization SACLANT Undersea Research Centre Viale San Bartolomeo 400, 19138 La Spezia, Italy [From N. America: SACLANTCEN CMR-426 (New York) APO AE 09613] tel: 0187 540 111 fax: 0187 524 600 telex: 271148 SACENT I		

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