WESTERN BOUNDARY CURRENTS IN FRONT OF FRENCH GUIANA

C. COLIN[1] et B. BOURLES[1]

Résumé

Les résultats principaux des campagnes effectuées lors du programme NOE (1989-1991) sont présentés. Ce programme concerne l'étude de la variabilité des transports de masse et de chaleur au large de la Guyane Française. Les résultats indiquent une forte variabilité des courants de surface, (caractérisée par la rétroflexion), et de subsurface. Ils confirment la présence d'un fort courant Sud-Est profond situé à la rupture du plateau continental entre les immersions 1000m à 3000m. Les études de la variabilité des courants de surface et de subsurface pourront aider à expliquer les déplacements de bancs de vase le long des côtes de Guyane.

Abstract

Main results from NOE programme sea operations (1989-1991) are presented. This programme concerns the study of the seasonal variability of mass and heat transports in front of French Guiana. Results show a strong variability of the surface, characterized by the retroflection, and of the subsurface currents. They confirm the existence of a Southeastward Deep Western Boundary Current, located at the shelfbreak, from 1000m to 3000 m depth. The surface and subsurface variability studies may be helpful to explain the displacements of mudbanks along the Guiana French coast.

Key words: winds, currents, temperature, salinity.

Mots Clé: vents, courants, température, salinité.

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I INTRODUCTION

The main objectives of the NOE programme ("Nord Ouest Equatorial" experiment) conducted by the ORSTOM Center of Cayenne in the equatorial Atlantic Ocean are devoted to the seasonal variability study of mass and heat transports along the portion of the western boundary located in front of French Guiana. This country presents a particular geographical position for the exchanges between both hemispheres.

Several sea operations have been scheduled to fulfill the scientific objectives of the NOE programme: hydrological (CTD) profiles and current measurements (*Pegasus* profiles and direct measurements from subsurface moorings). These operations have been achieved from 1989 to 1991 in front of Cayenne during different cruises carried out either by the "*N.O. Andre Nizery*" of ORSTOM (May, June, July 1989 and January, February, March and October 1990) or by the U.S. *Research Vessels* "*Malcolm Baldridge*" and "*Mount Mitchell*" of NOAA (September 1989, February and September 1990, January 1991). The NOAA cruises are part of the STACS (SubTropical Atlantic Climate Studies) programme conducted by the Atlantic Oceanographic and Meteorological Laboratory (NOAA/Miami) in relation with the Rosenstiel School of Marine and Atmospheric Science (University of Miami) and the Institute für Mereskunde (University of Kiel, Germany). Here are presented the main preliminary results drawn from CTD (*Sea Bird* SBE19) and *Pegasus* tracks and subsurface mooring observations.

II SURFACE WIND

The wind conditions in front of French Guiana are strongly connected to the geographical position of the InterTropical Convergence Zone (ITCZ) induced by the two Anticyclonic Systems (*Açores* and *Ste Helena* respectively North and South of the equator). They are: Northeast Trade Winds regime in boreal winter (the ITCZ is located at that time South of the equator in the West) and Southeast Trade Winds regime in summer following the Northward displacement of the ITCZ, starting in May-June in the western part of the equatorial Atlantic (**Figure 1**). These general offshore wind conditions are in good agreement with the monthly mean compass cards defined over a fifteen year period (1976-1990) at the European Rocket Base Weather Center (Centre Spatial Guyanais) located at Kourou (60 km North of cayenne). Compared to the mean, the May and June 1989 observed offshore wind speeds are higher (speeds up to 20-25 knots were currently observed on board the "*Andre Nizery*" during the cruises) while the directions are still Northeasterly instead of Southeasterly. In summer (July and September) 1989 and in 1990, the winds observed offshore were not statistically different to both the mean onshore and the generals monthly mean wind distributions over the equatorial Atlantic (*Servain* 1990).

III CURRENTS

III.1 Surface currents

The surface currents are tightly related to the surface wind distribution. The *Pegasus* (free falling current profiler located by two acoustic transponders deployed on the sea floor) data exhibit two opposite situations in front of Cayenne:

- In winter (February 1990), the Guiana Current (GC) is: i) strong with speeds up to 120 cm/s; ii) confined to the first 200 meters; iii) narrow (width less than 150 nautical miles off the coast); iv) situated both on and off the shelfbreak; v) drawing up surface waters located seaward (**Figure 2**). The horizontal distribution of the surface current deduced from the *Pegasus* array highlights obviously the continuous flow, as suggested earlier by the shipdrift (*Richardson and McKee,* 1984), drifters (*Richardson and Reverdin,* 1987) and NASA CZCS images (*Muller-Karger et al.,* 1988) of equatorial warm fresh waters between the equator and the Gulf Stream through the Caribbean Sea. This explains at that time the maximum displacement (# 800m/year) of mudbanks (10^9 tons/year in mean of sediments rejected by the Amazon River) to the Northwest, all along the coast (*Prost,* 1990);

- In summer on the contrary, GC has completely disappeared North of Cayenne (the ITCZ is now located around 10°N) and the current at the shelfbreak is to the South-East (surface to 100m depth) suggesting the presence of a cyclonic gyre closed to the coast (**Figure 3**). Offshore, GC veers to the South-East ("retroflection effect") between 4°N and 6°N and now feeds the NECC (North Equatorial Counter Current) as suggested before by the drifters. This could explain the presence of Amazon fresh waters far from the coast in agreement with the NASA *CZCS* images; this veering induced, South of Cayenne, a strong anticyclonic gyre associated with a deepening of the thermocline. This retroflection effect can be due to several mechanisms: i) increase of the volume transport of the South Equatorial Current (*Anderson and Moore,* 1979) in association both with the coastline angle and bathymetry (*St*

Guily, 1957; *Ou and DeRuijter*, 1986); **ii)** increase of the vertical component of the windcurl in the central part of the equatorial Atlantic Ocean (*Philander and Pacanowski*, 1986); **iii)** potential vorticity front (*Csanady*, 1985)....All these mechanisms probably stand together and only Ocean Global Circulation Model simulations (*GFDL, NCAR, LODYC*...) forced by mean monthly observed winds (*Servain*, 1990 and 1991) and Inverse Methods would allow (after a validation by the data collected) a better understanding of the dynamics of this area. North of Cayenne, the displacement of the mudbanks linked to the Amazon discharges is weaker (# 100m/year) at that season (*Prost*, 1990).

This strong seasonal variability of the surface flow has been observed both in 1989 and 1990. In January 1991 the surface current distribution was similar to the one observed for the same period of time in 1990. In all cases, the observed surface currents (*Ekman* drift) were consistent with the offshore wind distribution.

III.2 Subsurface currents

In the 200-500m layer, the currents are still influenced by the seasonal distribution of the wind:

- in winter, the current at that level is very strong and trapped (width less than 75n.m.) along the shelfbreak (**Figure 4**); speeds up to 35 cm/s are currently observed (February 1990 and January 1991); the maximum speed (100cm/s !) seems to occur late spring (June 1989); offshore the current is to the Northwest showing at that level the presence of a well-defined cyclonic gyre, in the opposite sense to the surface one. The currentmeter observations got at 275m depth on the subsurface mooring deployed at **6°12'N** and **51°01'W** from March 31 to November 18, 1990 (**Figure 5**), confirm the *Pegasus* current profiles, at that level and for the same period of time; the current observed at level is weak because of **i)** the location of the currentmeter close to the boundary between the Northwestward surface flow and the Southeastward subsurface flow, underneath; **ii)** the location of the mooring close to the vertical boundary between the two subsurface Southeastward (shoreward) and Northwestward (seaward) currents as inferred from the Pegasus profiles;

- in summer (September 1989 and 1990), the situation is now completely different (**Figure 6**). The subsurface Intermediate Southeastward current: **i)** has disappeared; **ii)** is now replaced by a strong Northwestward current; this corresponds to the vertical extension of the surface current that, then and as mentioned above, is maximum in speed. Speeds up to 120cm/s are currently observed offshore at that level (the absolute maximum 190cm/s has been recorded in September 1989 close to the shelfbreak). Further East, the *Pegasus* profiles show now a Southeastward current that corresponds to the seaward part of a strong anticyclonic gyre in place of the cyclonic one, seen in winter. This reflects, also there, the presence of a strong recirculation of the flow. A rough computation of the coastal part of the gyre leads to a volume transport of about 90Sv (1 Sverdrup = 10^6 m3/s). Smaller current velocities (120cm/s) have been recorded in September 1990, compared to September 1989, indicating at least at that particular time, the influence of a possible interannual variability. The moored current measurements clearly exhibit an increase of the Westward component of the flow at that time in 1990 at 275m and 500m depths; following the Northward displacement of the **ITCZ**; this is not the case on the 800m depth record, level of the AntArctic Intermediate Water, which remains constant during the entire duration of the series (**Figure 5**).

The spectra of the zonal (*u*) and meridional (*v*) components of the current velocity (*Colin et al.*, 1991) at 275, 500 and 800m depths (example in **Figure 7a**) exhibit energy peaks at: i) the semi-diurnal frequency with more energy in "*u*" than in "*v*"; **ii)** in the period band 40-60 days which could be related to the retroflection effect of the surface current (*Johns et al.*, 1990).

III.3 Deep currents

Below 1000m depth, strong currents are still present and seem permanent: Southeastward current, also called **DWBC** (Deep Western Boundary Current) located at the shelfbreak (width less than 75n.m.) and Northwestward further East (**Figures 4 and 5**). Speeds up to 30cm/s have been deduced from *Pegasus* profiles between 1000m and 3000m depths (level of the **DWBC**) in February 1990, September 1990, January 1991 with a mean volume transport of around 20Sv. Both currents are associated with high salinity values (North Atlantic Deep Water) showing, one more time, the presence of a strong cyclonic recirculation of the flow at that level (as in the 200-500m layer). A maximum instantaneous speed of 100cm/s (!) has been recorded in the **DWBC** in September 1989 at 2000m depth (*Colin*, 1989); in 1991 the velocity was smaller; suggesting the signature of an interannual variability at that level. These deep equatorward (shelfbreak) and poleward (open sea) flows have been reported further North (12°N) from geostrophic computations; they are both associated with maxima of *Freon 11* (*Fine and Molinari*, 1988). The mooring current measurements (**Figure 5**) confirm the *Pegasus* profiles: **i)** mean speed around 30cm/s; **ii)** permanent Southeastward flow at 1400, 2000 and 2700m depths with a maximum speed at 2000m depth. The change in direction of the

DWBC in October and November 1990 does not mean a reverse of this current but rather the reflect of a variation in the width of the **DWBC**, the location of the mooring, as mentionned above, beeing quite close to its eastern boundary.

The spectra of the "*u*" and "*v*" components of the velocity at these different depths exhibit no preferential energy peaks except at the semi-diurnal frequency (example in **Figure 7b**) with now more energy in the "*v*" than in the "*u*" spectrum.

IV TEMPERATURE

IV.1 At the surface

The monthly variability of the Sea Surface Temperature (SST) is weak (< 2°C) in the West compares to the one observed in the eastern equatorial area (# 7-8°C) during the same period of the year (Colin, 1991). From the several cruises carried out at different seasons we observed (figure 8) that: i) SST minima appear on the shelf in May-June 1989 when the Northeast Trade Winds are blowing; the presence of coastal cold waters is due to both advection (from the North-East) and vertical friction, consequence of the upward displacement of the thermocline (in geostrophic equilibrium with the strong coastal surface current); ii) in June (1989) which represents a transition period linked to the passage of the ITCZ above French Guiana, the SST minimum moves offshore; iii) in July 1989, a frontal zone oriented in a direction perpendicular to the coast is observed, South of 5°N; this corresponds to the presence of the anticyclonic gyre, Southeast of Cayenne, associated with the retroflection of GC (figure not shown); iv) in October (1990), North of the retroflection area of GC, the SST decreases first (in agreement with the presence of the cyclonic gyre) and then increases, despite the direction of the wind which is parallel to the coast and so in favour for an *Ekman* type coastal upwelling all along the coast.

IV.2 20°C isotherm

The topography of the 20°C isotherm (identified as the central part of the thermocline) in front of Cayenne, depends strongly upon the dynamics of the current system at the surface: i) in winter, the 20°C isotherm tilts to the coast (all along the coast) and the maximum depth is located around 100m off the shelfbreak; ii) in summer, the minimum depth of the 20°C isotherm moves, as SST, in a direction perpendicular to the coast separating the two anticyclonic gyres located respectively South of 5°N (Amazonian, the main one) and North of 8°N (Demerara); this is naturally linked to the retroflection of GC; the Amazonian gyre induces an important deepening (from 100 to 200m depth) of the 20°C isotherm, South of 5°N. This spatial variability of the depth of the 20°C isotherm is in good agreement with the one reported previously by *Bruce et al.* (1985).

Compared to the seasonal coastal temperature variability observed in front of Ivory Coast, similarities emerge with the temperature variation in front of Cayenne: i) the tilt of the thermocline towards the coast is, in both cases, in geostrophic equilibrium with the observed surface current : Guinea Current for Ivory Coast and Guiana Current for French Guiana ; ii) the direction of the wind is in summer (winter) parallel (perpendicular) to the coast (*Colin,* 1991). Differences however appear between both places: i) the speed of the wind increases (decreases) in front of Abidjan (Cayenne) in summer ; the opposite is observed in winter ; ii) the frontal zone (minimum depth of the 20°C isotherm) is in summer perpendicular (parallel) to the coast in front of Cayenne (Abidjan); this explains why the local wind, despite its direction (parallel to the coast) and speed (4 to 6m/s) in summer, is unable to counterbalance, Northwestward of French Guiana, the deepening of the thermocline along the continental shelfbreak beyond the retroflection area of GC.

V SALINITY

V.1 At the surface

The Sea Surface Salinity (SSS) is, in the West, a good indicator of the coastal circulation, at the surface. In May, the Amazone fresh waters (S <30°/°°) are observed on the shelf but close to the coast. This is the situation which allows the Amazon River waters to reach directly, following the coast, the Caribbean Sea. In June, these fresh waters spread to the east due to the retroflection effect of the coastal current; salinity values of less than 15°/°° are now seen beyond the continental shelfbreak and fresh waters can be observed as far as the longitude 30°W, due to the continuity of the flow between GC and NECC.

V.2 Salinity maxima

The salinity structure in often characterized by two maxima separated by a relative minimum. The closest maximum to (farest of) the coast corresponds to the South (North) Atlantic Central Water. The maximum values of SACW

(NACW) decrease from the South (North) to the North (South) in front of French Guiana. In winter-spring (May 1989), the main maximum (36.60°/°°) corresponds to SACW; in summer (July 1989), the opposite is observed; furthermore NACW maximum (36.80°/°°) is at that time at a lower depth (95m instead of 120m depth).

VI CONCLUSIONS

The preliminary current results got during the NOE cruises, either from *Pegasus* profiles or from direct current measurements drawn from a subsurface mooring, exhibit very interesting features either at the surface or in the subsurface and deep layers. It is the first time that a joined (France, USA, Germany) specific study of the Western Boundary Current System is undertaken in the equatorial Atlantic. We have now to go further in order to achieve the main scientific goals: seasonal variability of mass and heat transports and the dynamics linked to the retroflection effect of the coastal current. Cruises with the *N.O. Nizery* are now over. The last two NOE will be made on board the sections NOAA ships in 1991 (June and September) during the STACS cruises in order: i) to precise the dynamics with two more *Pegasus* sections and ii) to recover the two subsurface moorings deployed (bottom depths of respectively 3000m and 4200m) in November 1990. All these current observations of different types will allow a validation of an OGCM in order to get a better description of the currents and their dynamics along the North Equatorial Western boundary of the Atlantic Ocean.

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SERVAIN J. (1991). Observatoire Permanent de l' Océan Atlantique Tropical (avec un modèle assimilant les observations). *Bull. Ocean Atl. Trop.*, 2, Nos 1 et 2.

FIGURES LIST

Figure 1:
Horizontal distribution of surface winds over the Intertropical area of the Atlantic Ocean in April and August 1989. The dashed line indicates the mean position of the InterTropical Convergence Zone (adapted from Servain).

Figure 2.:
Horizontal distribution of Pegasus surface current in January 1991 along the North Western Boundary of the equatorial Atlantic. The dashed vectors in front of Cayenne indicate the Pegasus surface current observed in February 1990 (courtesy of K. Leaman for data collected out of the French Guiana area).

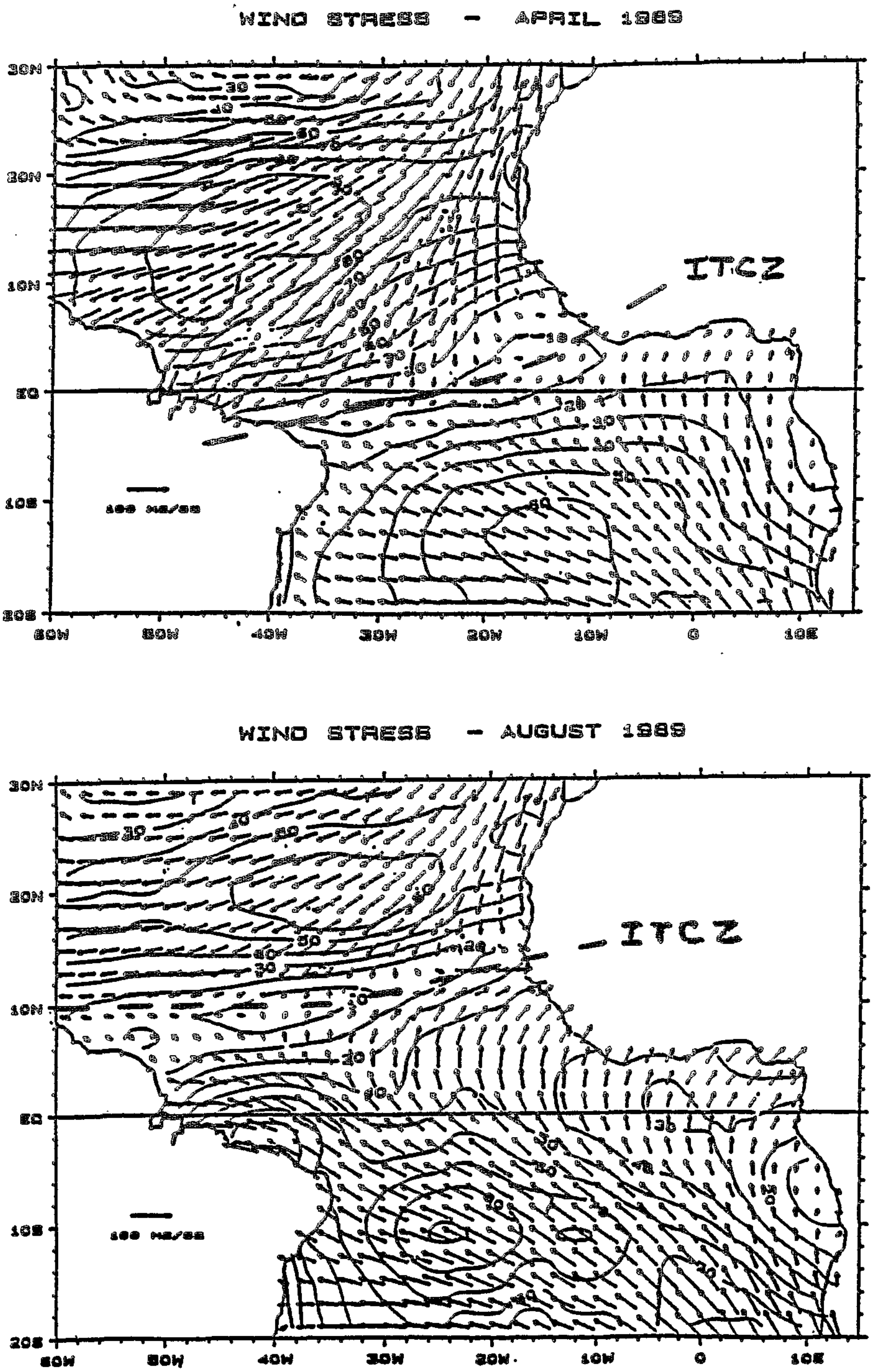
Figure 3 :
Horizontal distribution of Pegasus surface current in September 1990 along the North Western Boundary of the equatorial Atlantic. The dashed vectors in front of Cayenne indicate the Pegasus surface current observed in September 1989 (courtesy of K. Leaman for data collected out of the French Guiana area).

Figure 4 :
Vertical Pegasus profiles of zonal (E/W, full line) and meridional (N/S, dashed line) components (positive eastward and northward) of the current velocity at stations 2, 3, 4, 5, 7 and 8 in front of French Guiana in January 1991 (see map for the geographical location of the stations).

Figure 5 :
Vector plots of current measurements got in front of French Guiana (6°12'N-51°01'W) from March 31 to November 18, 1990 at 275, 500, 800, 1400, 2000 and 2700m depths (northward direction is upward).

Figure 6 :
Vertical Pegasus profiles of zonal (E/W, full line) and meridional (N/S, dashed line) components (positive eastward and northward) of the current velocity at stations 3, 4, 5, 6, 7 and 8 in front of French Guiana in September 1990 (see map for the geographical location of the stations).

Figure 7 :
Spectra of the zonal (u) and meridional (v) components of the current velocity records at 275 and 2000m depths. The confidence interval (95%) corresponds to 16 degrees of freedom.


WIND STRESS - APRIL 1989
ITCZ
30N
20N
10N
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50W
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30W
20W
10W
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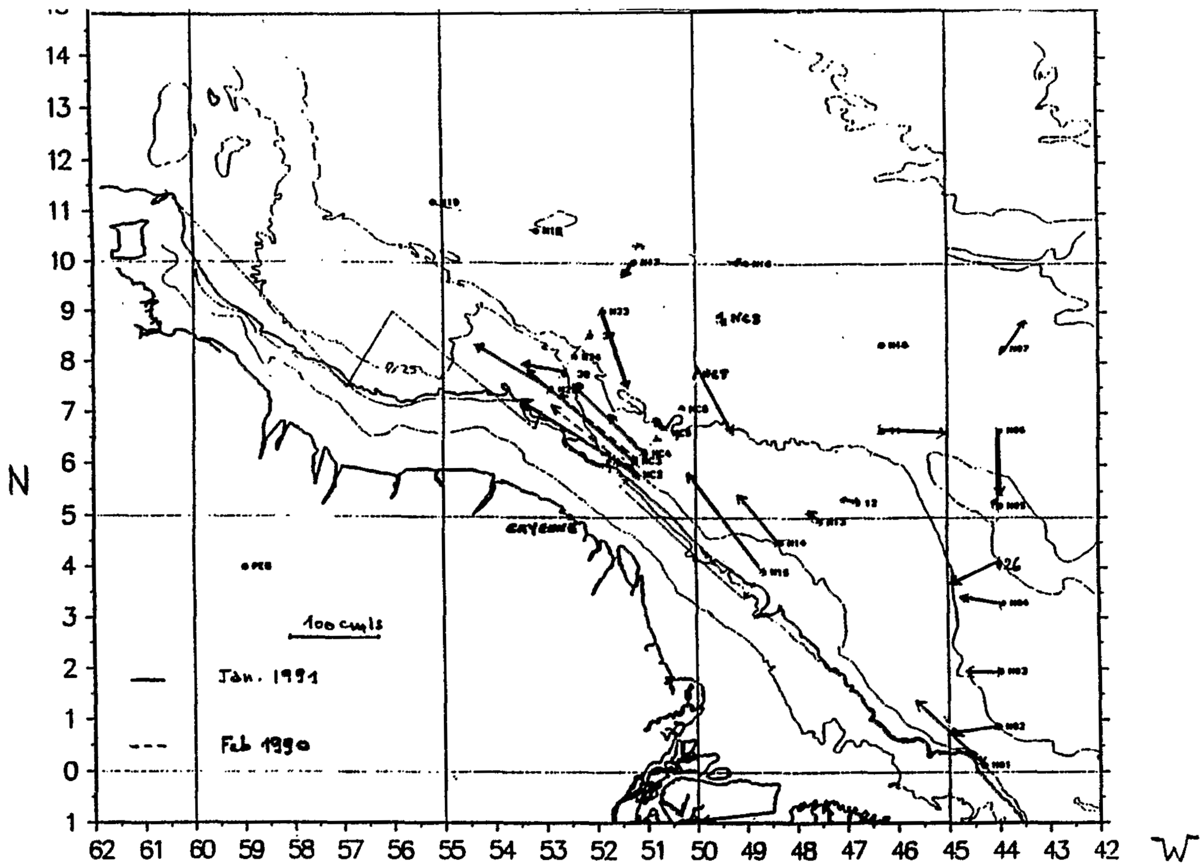
10E
WIND STRESS - AUGUST 1989
ITCZ

Figure 1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54
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45
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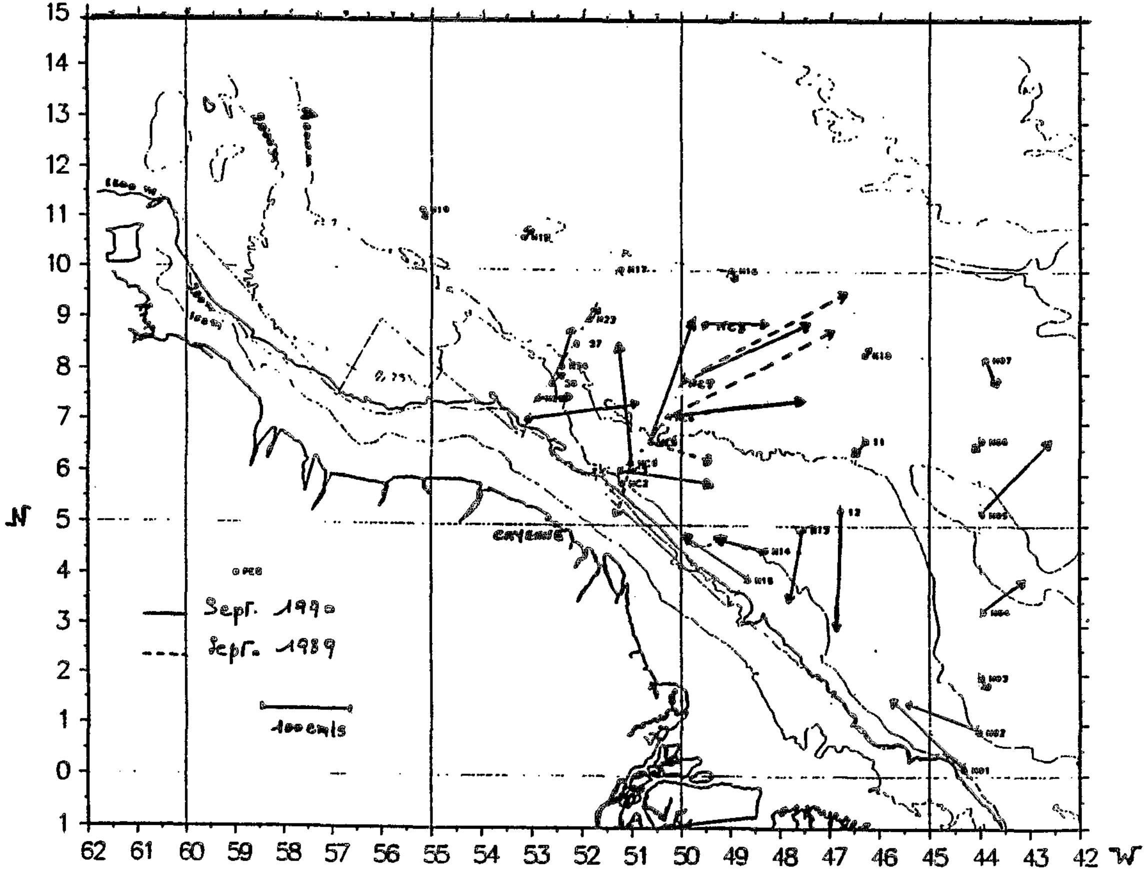
43
42
CAYENNE
100 cm/s
Jan. 1991
Feb 1990

Figure 2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W
CAYENNE
Sept. 1990
Sept. 1989
100 cm/s

Figure 3

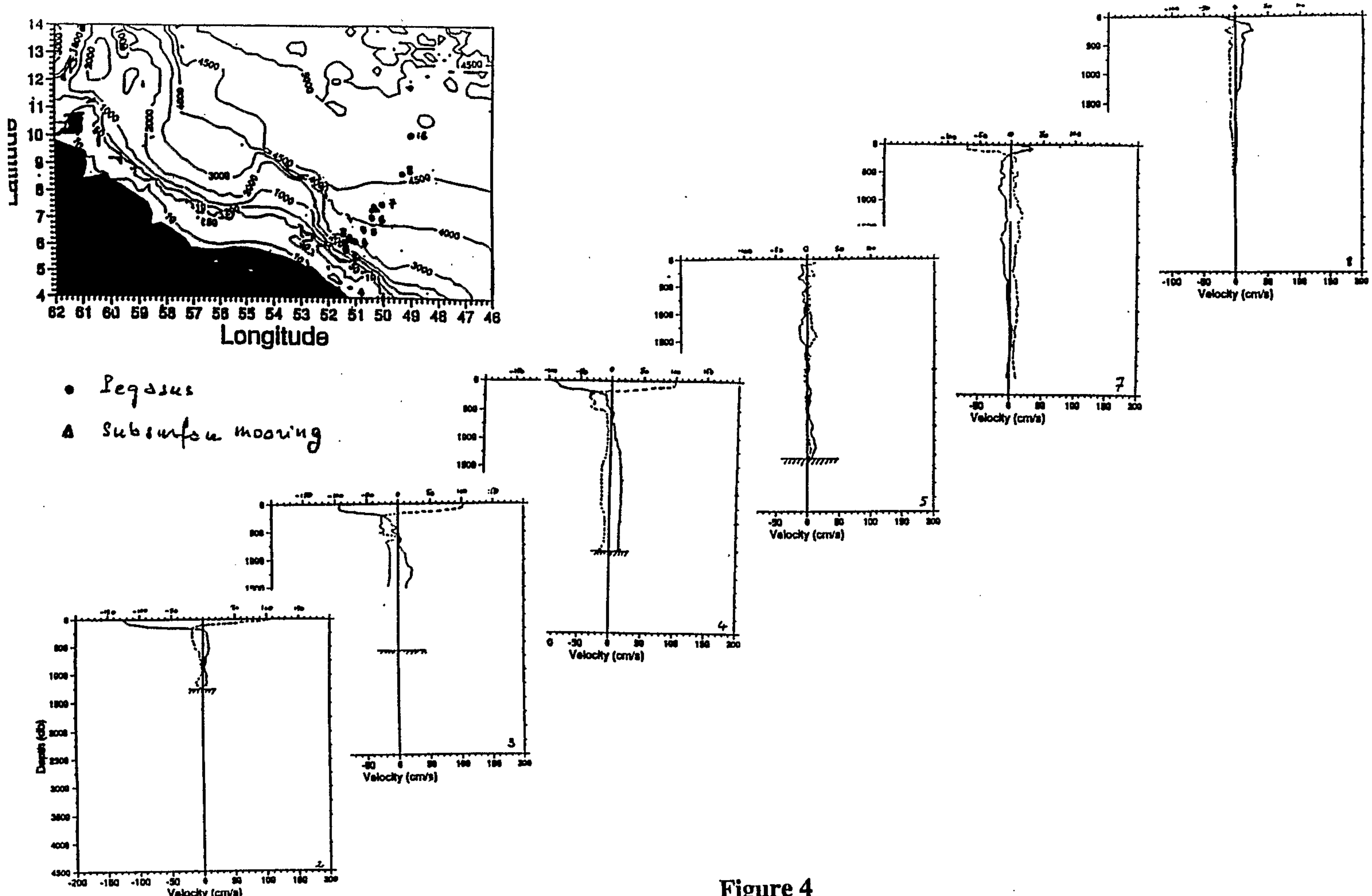
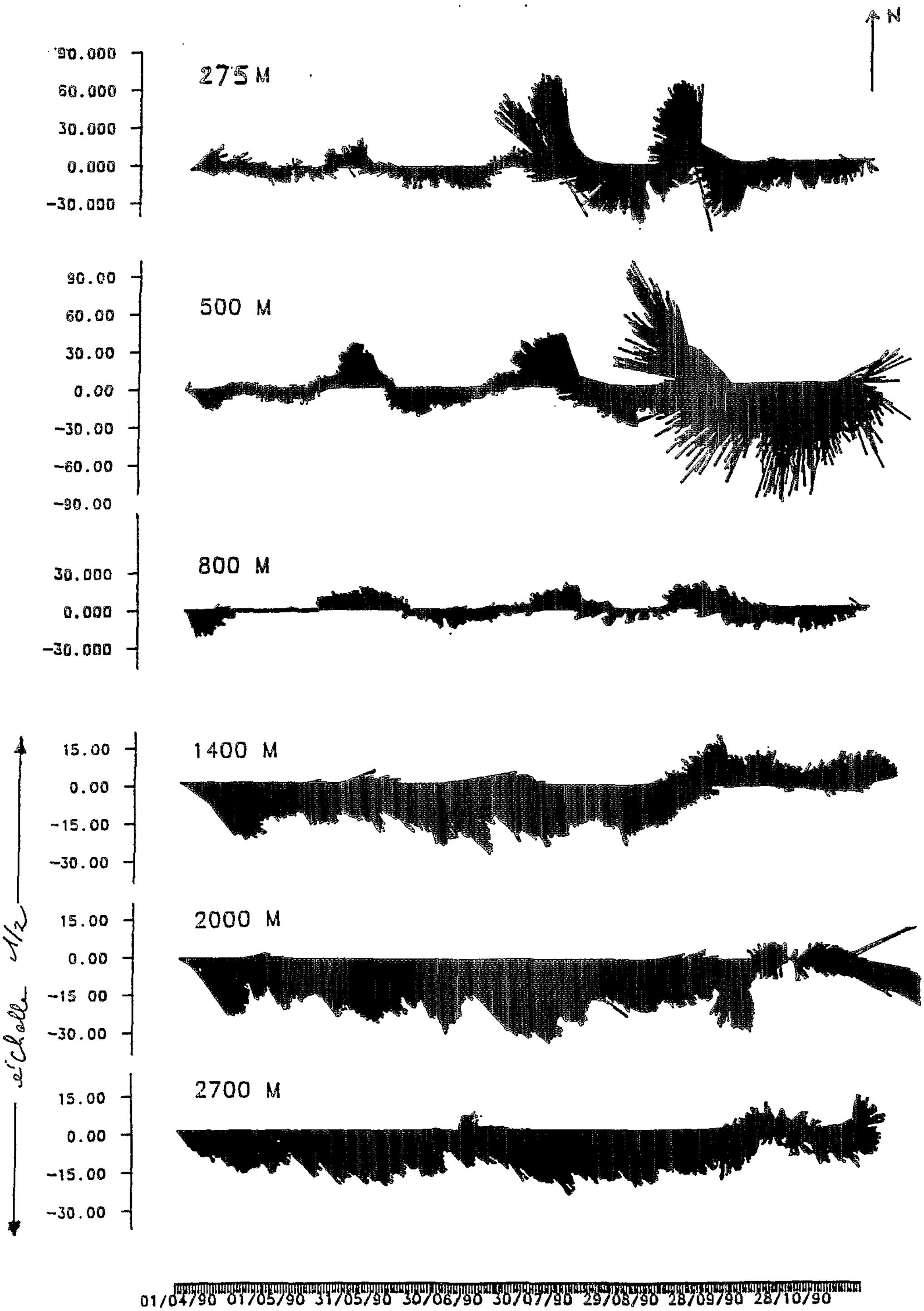

Latitude
Longitude
Pegasus
Subsurfau mooring
Velocity (cm/s)
Depth (db)

Figure 4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-60.00
-90.00
800 M
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1400 M
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échelle 1/2
01/04/90 01/05/90 31/05/90 30/06/90 30/07/90 29/08/90 28/09/90 28/10/90

Figure 5

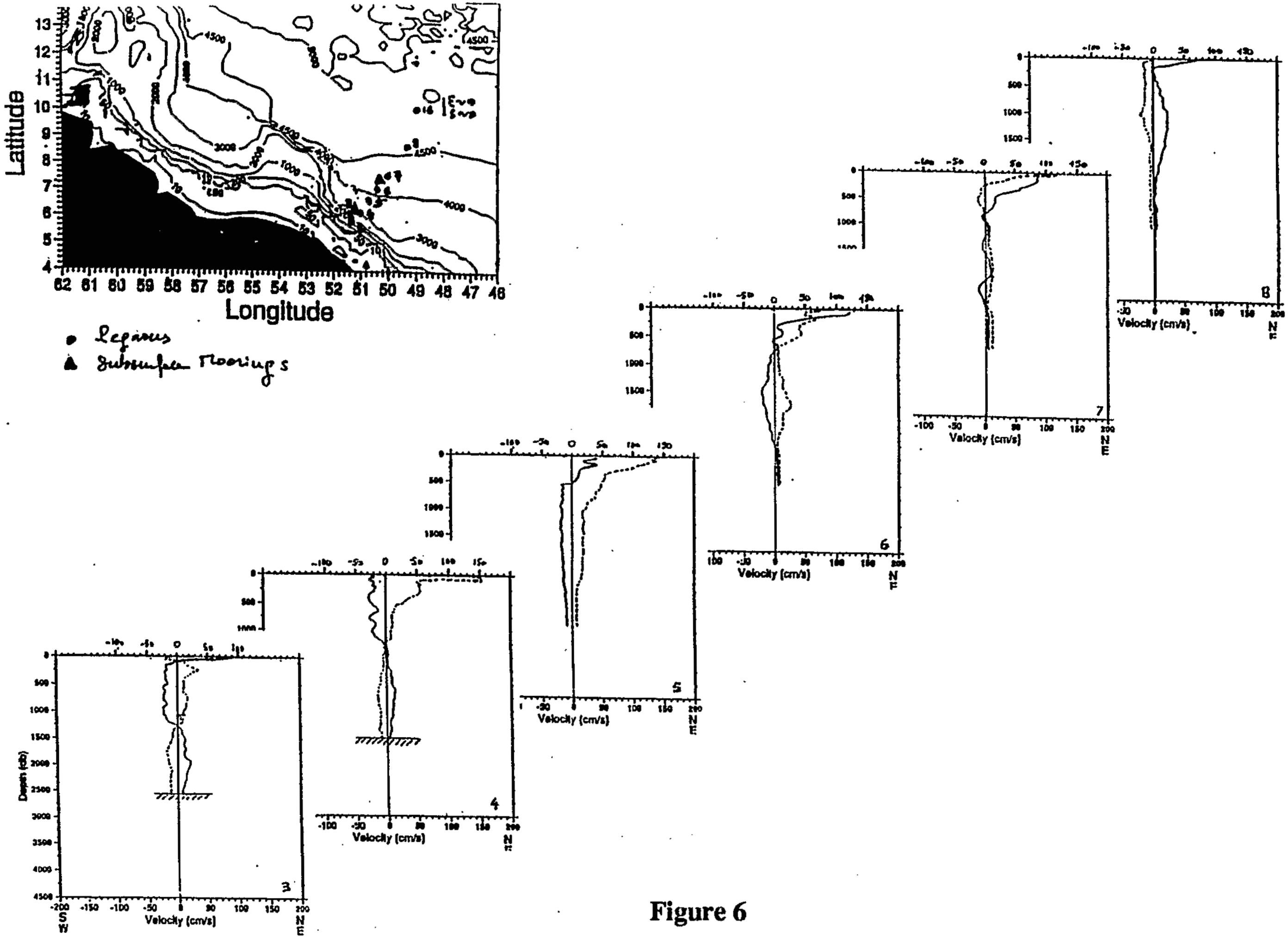
Latitude
Longitude
Pegasus
Subsurface Moorings
Depth (db)
Velocity (cm/s)
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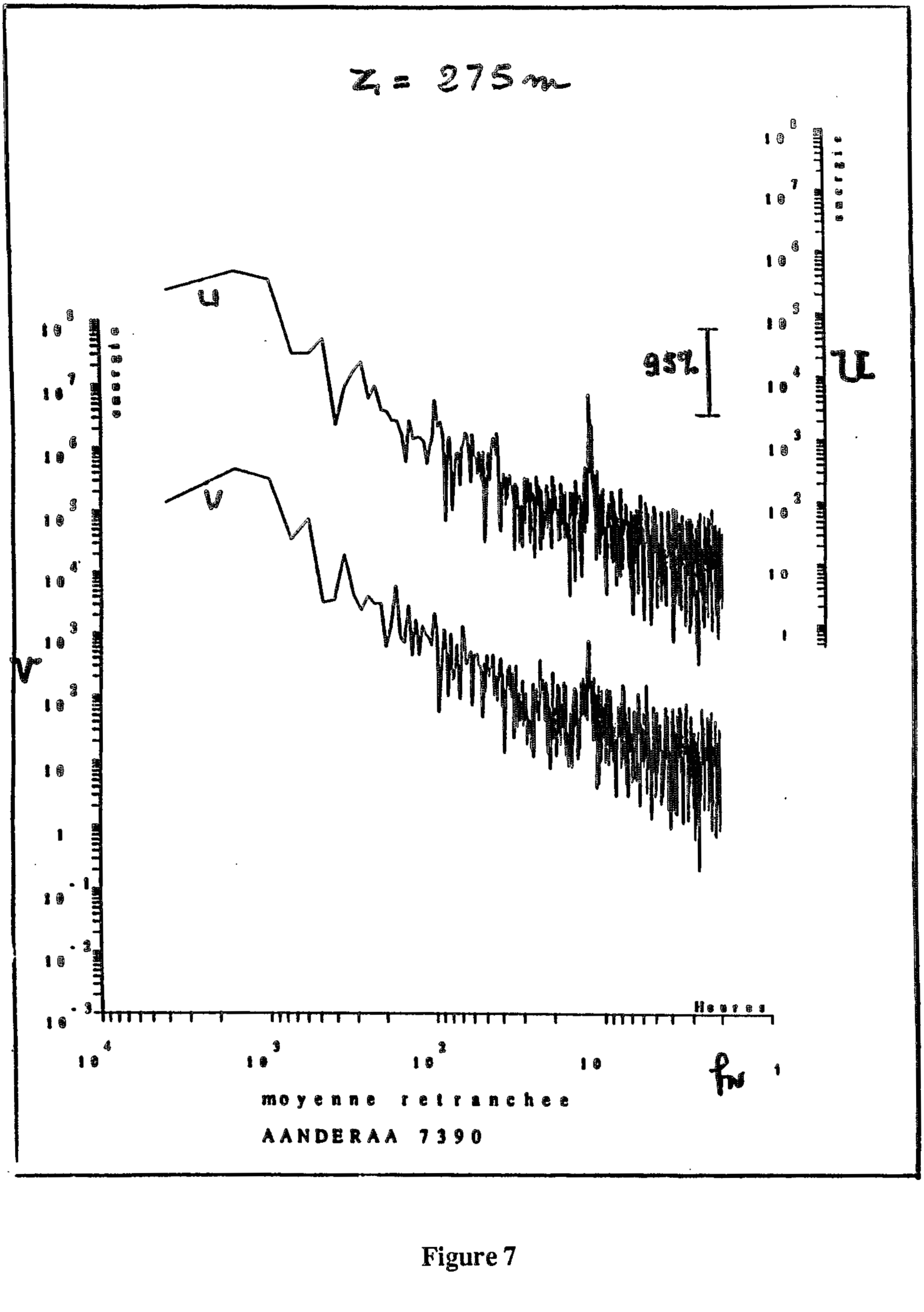
Figure 6



Z₁ = 275 m
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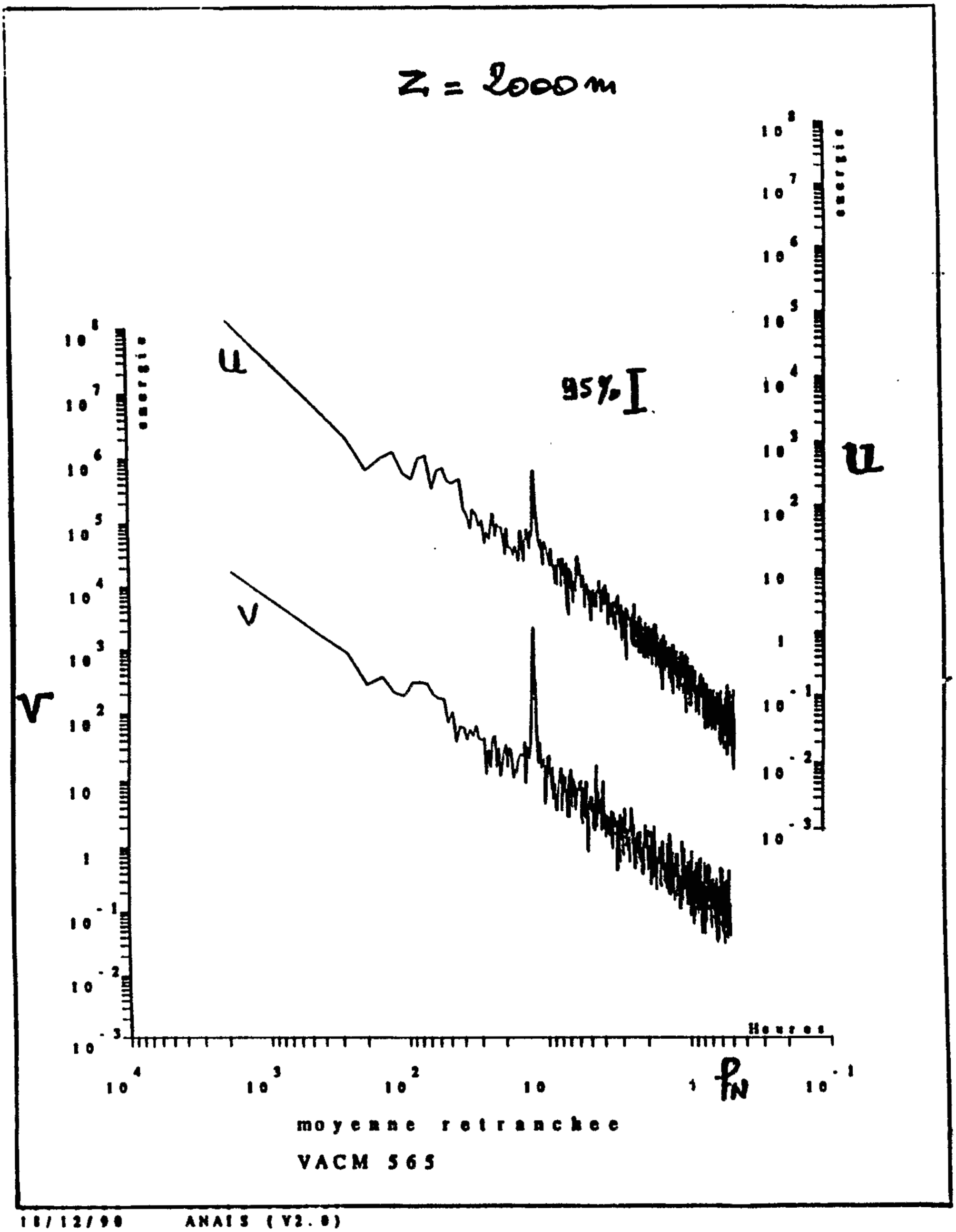
Figure 7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energie
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moyenne retranchee
VACM 565
18/12/90 ANAIS (V2.0)

Figure 7