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INTERNATIONAL CENTRE FOR THEORETICAL PHYSICS
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SMR/989 - 21

"Course on Shallow Water and Shelf Sea Dynamics"
7 - 25 April 1997

"The "Mad-Sea" (Marrobbio) Phenomenon in the Strait of Sicily"

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Mexico/USA

Please note: These are preliminary notes intended for internal distribution only.

"MARROBBIO"

The "Mad-Sea" phenomenon in the Strait of Sicily.

Julio Candela

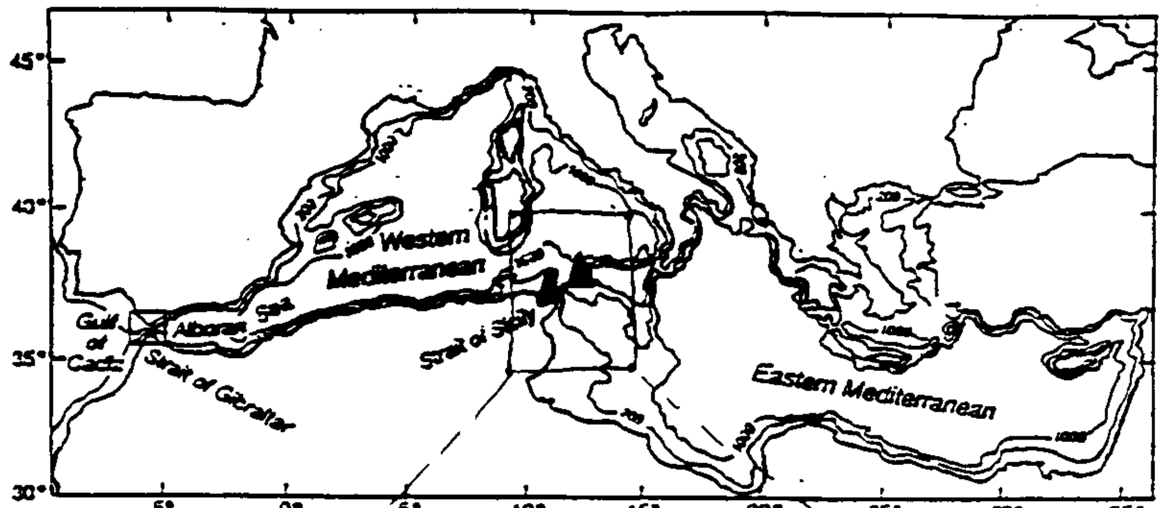
CICESE/WHOI

IN COLLABORATION WITH
SALVO MANZOLA CNR, MAZARA DEL VALLO, IT.
CHERIFF SAMARI INSTOP, TUNIS

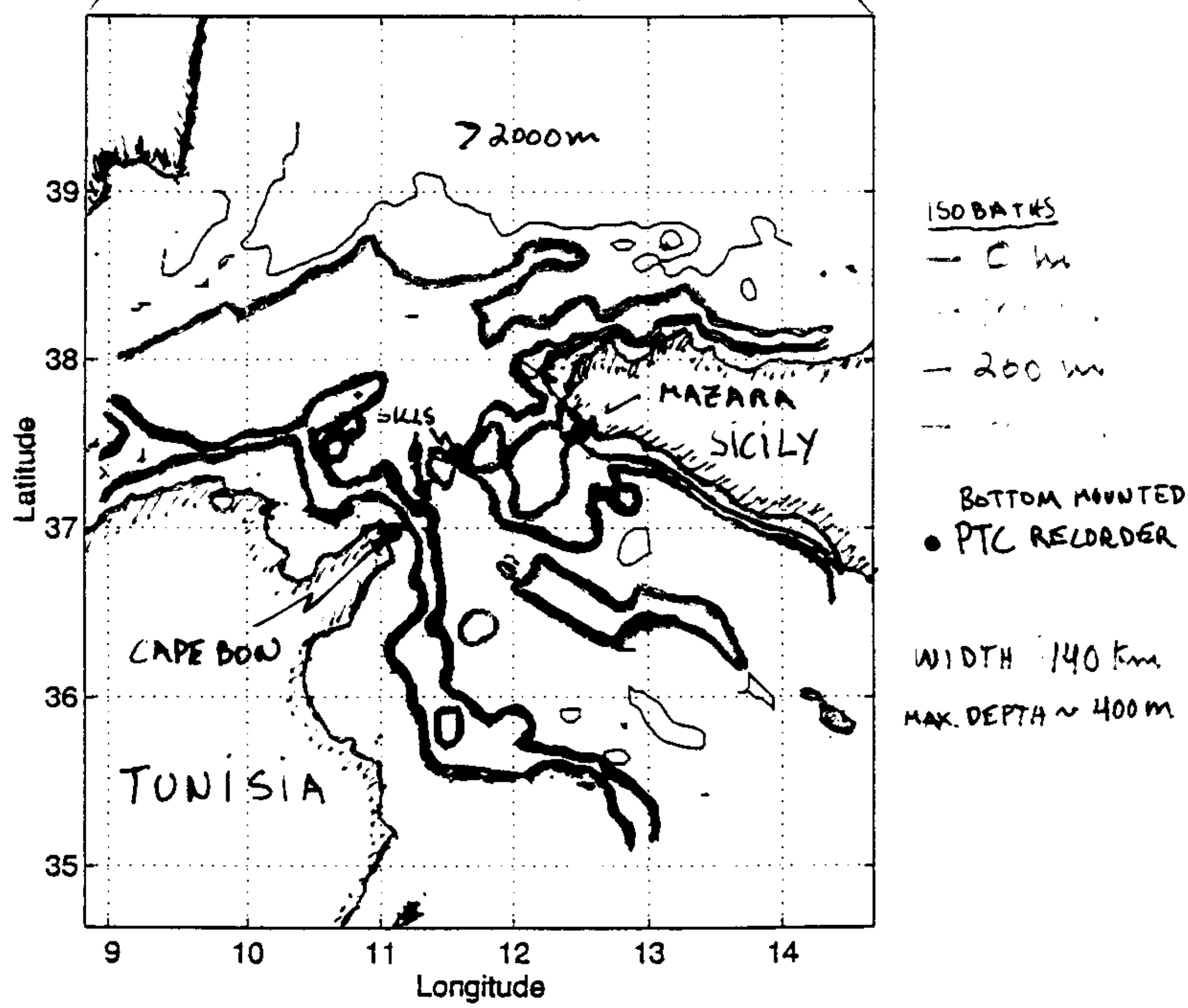
This talk:

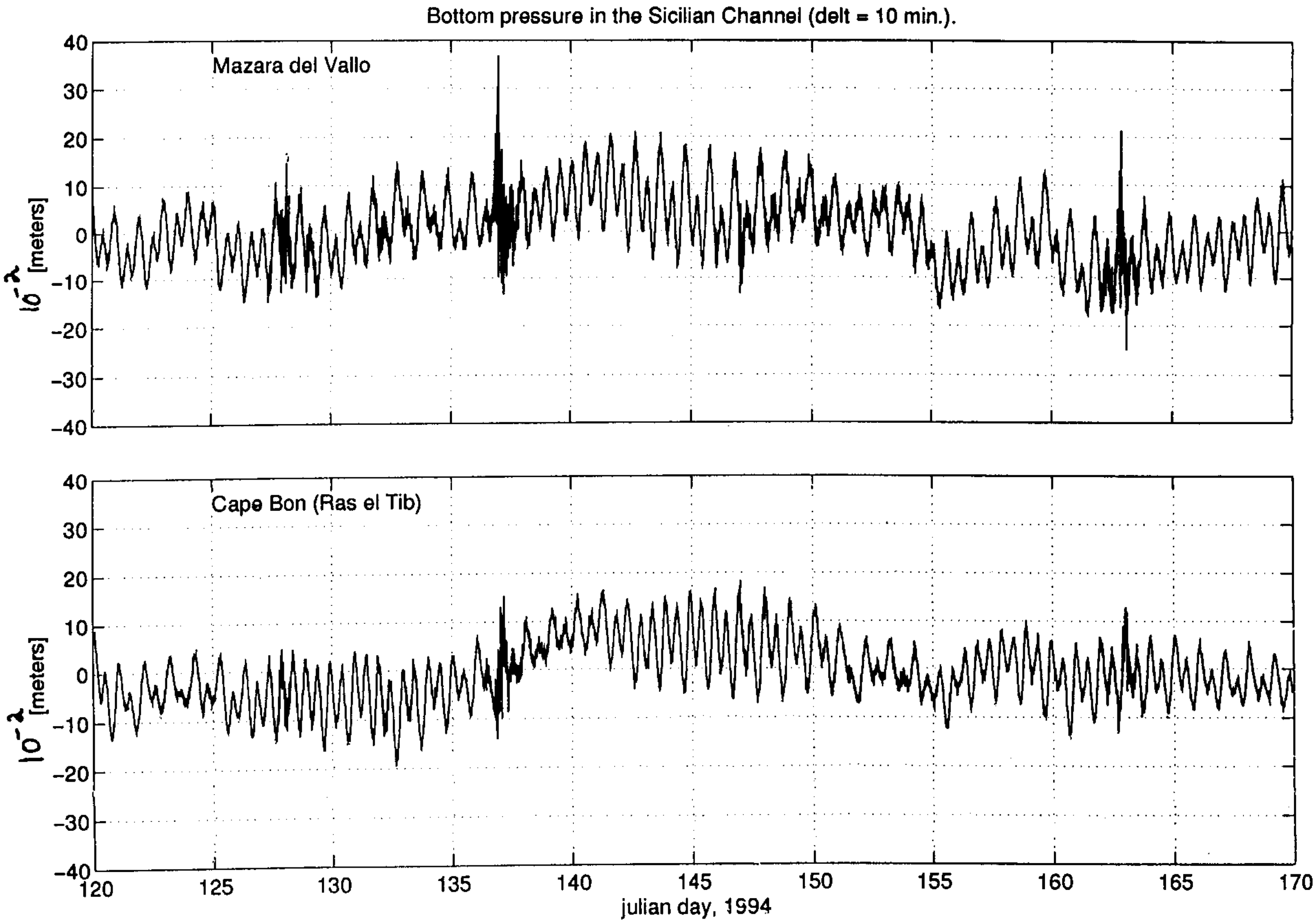
- Description of bottom pressure observations in the Strait of Sicily.
- Characteristics of the *Mad-Sea* phenomenon.
- Search for possible forcing mechanisms.
- Construction of the regional gravitational *Normal Modes*.
- Use *Normal Mode* representation to numerically investigate plausible forcing mechanisms and reconstruct the observed spectra and cross-spectra at the measuring locations.
- Conclusions.

MEDITERRANEAN SEA

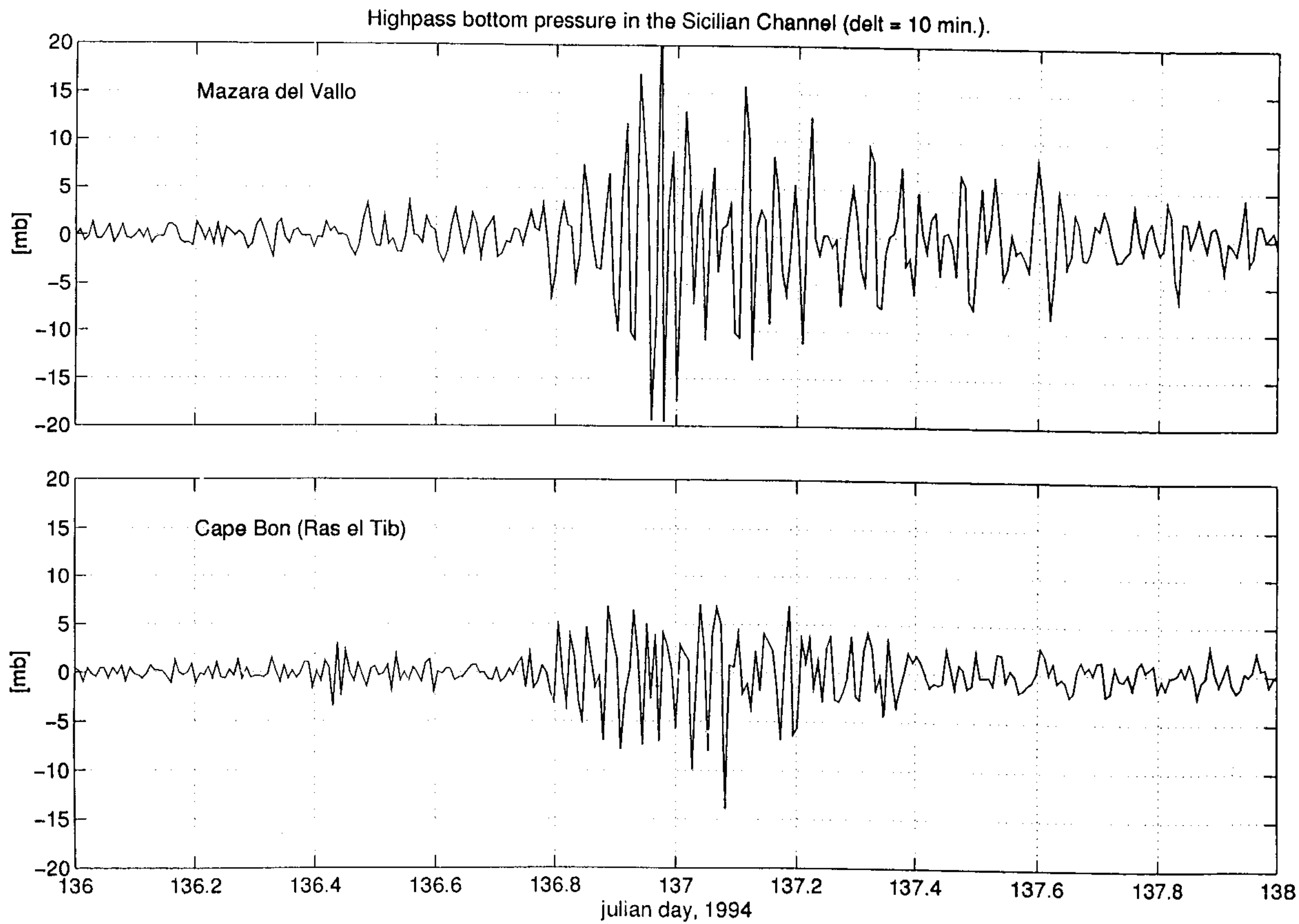


Strait of Sicily



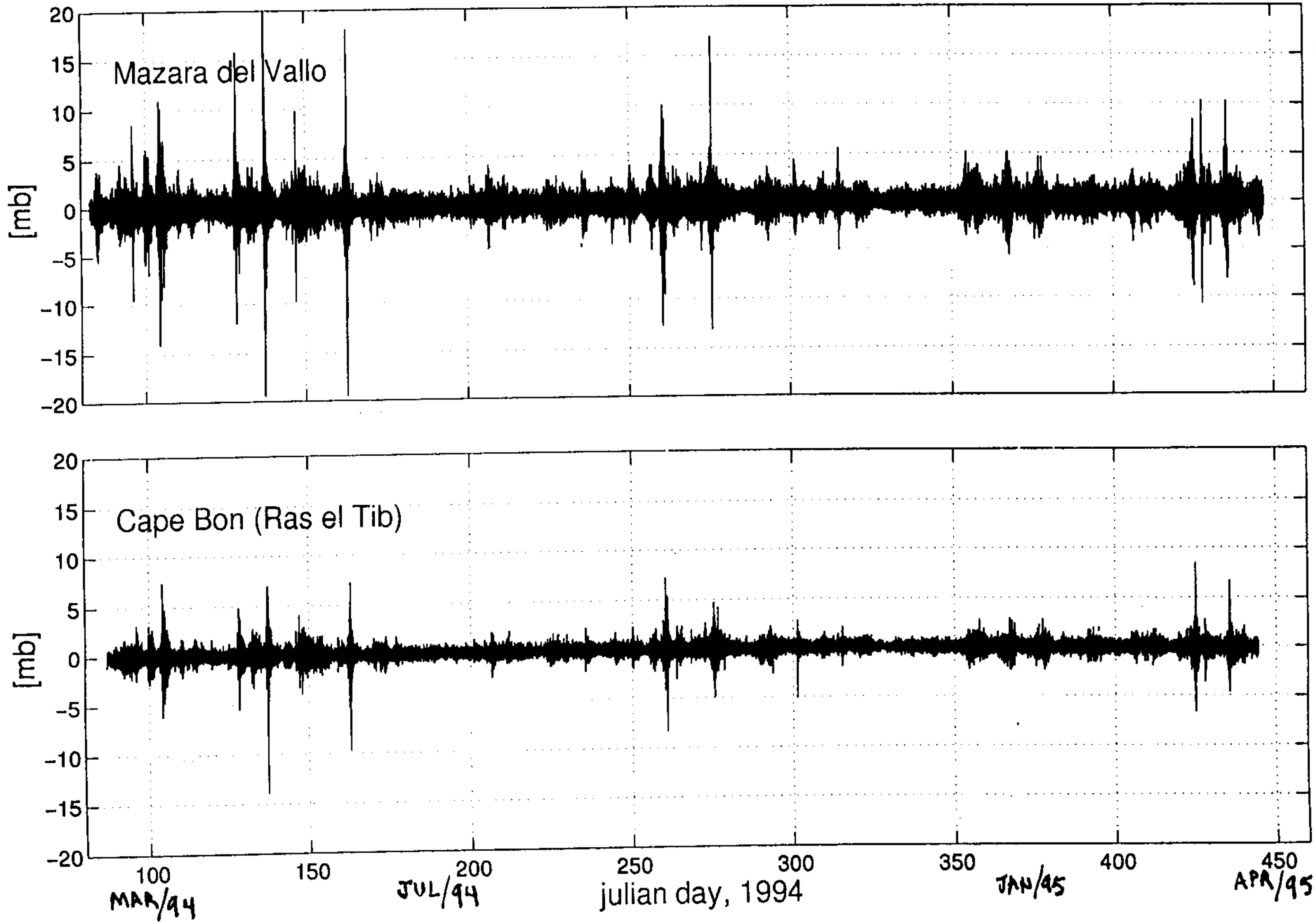

Bottom pressure in the Sicilian Channel (delt = 10 min.).
Mazara del Vallo
Cape Bon (Ras el Tib)
10^{-2} [meters]
10^{-2} [meters]
julian day, 1994
40
30
20
10
0
-10
-20
-30
-40
120
125
130
135
140
145
150
155
160
165
170

3



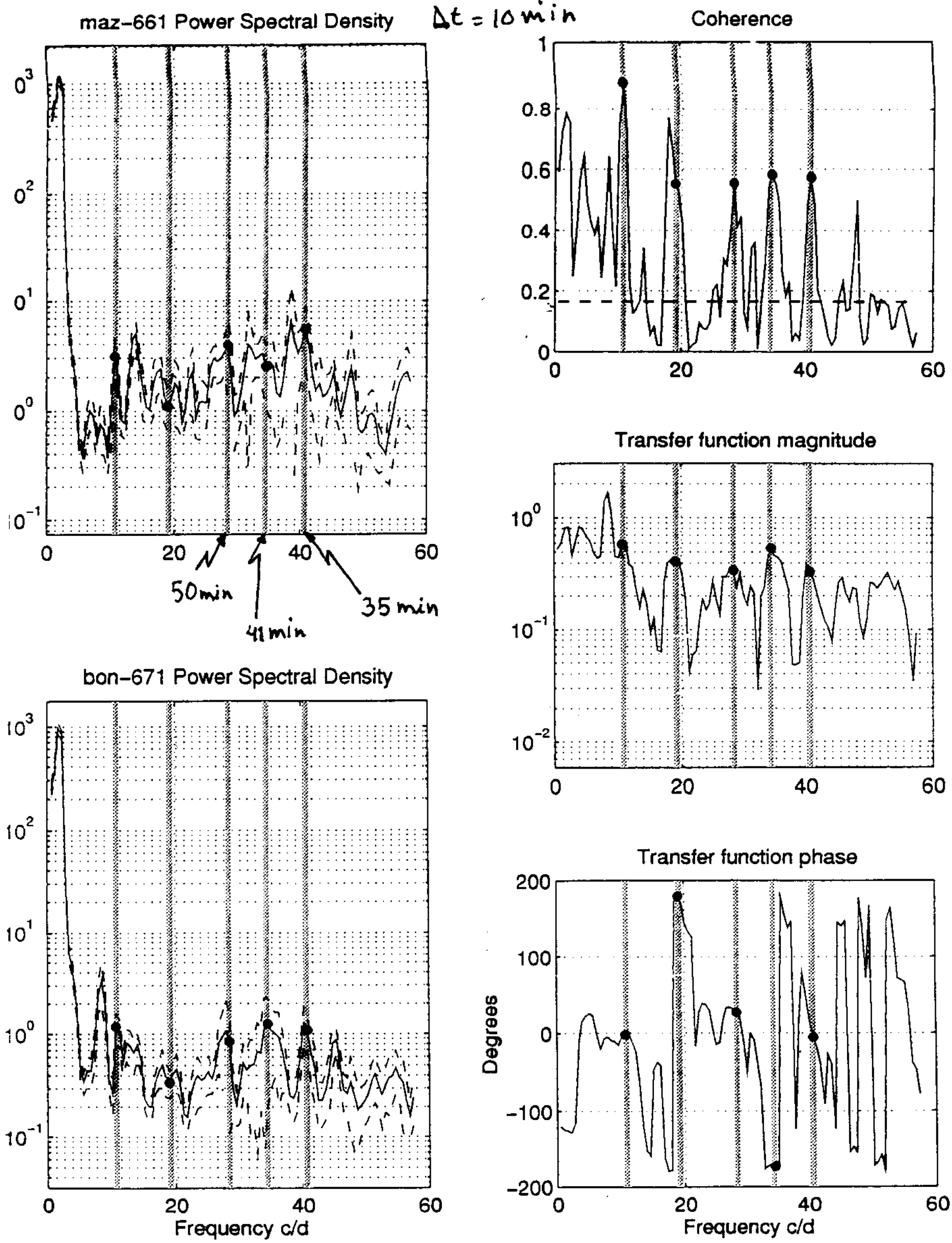
Highpass bottom pressure in the Sicilian Channel (delt = 10 min.).
Mazara del Vallo
Cape Bon (Ras el Tib)
[mb]
julian day, 1994

4


Mazara del Vallo
Cape Bon (Ras el Tib)
[mb]
julian day, 1994
MAR/94
JUL/94
JAN/95
APR/95

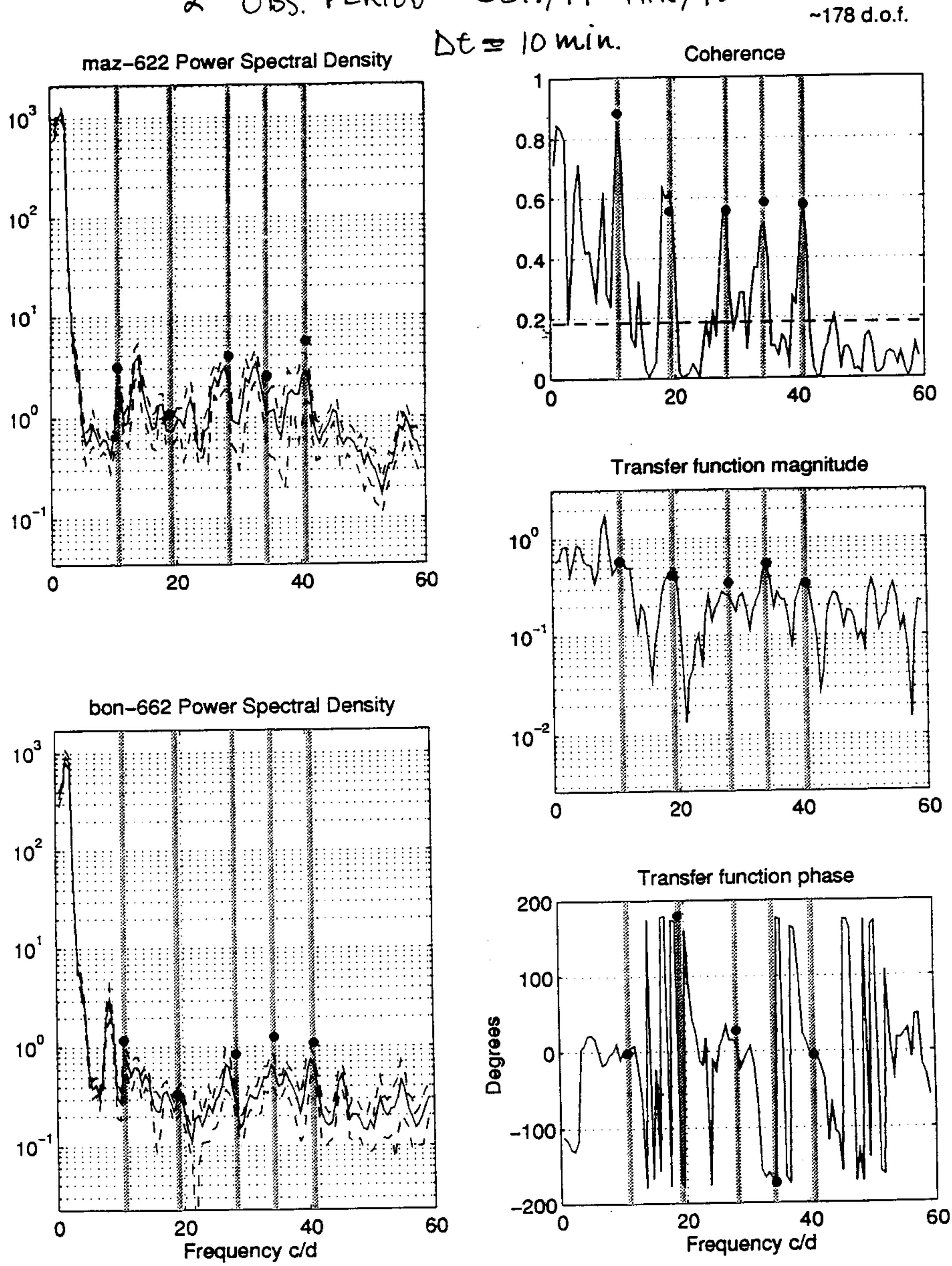
5

1st OBS. PERIOD MAR/94 - OCT./94 ~221 d.o.f.



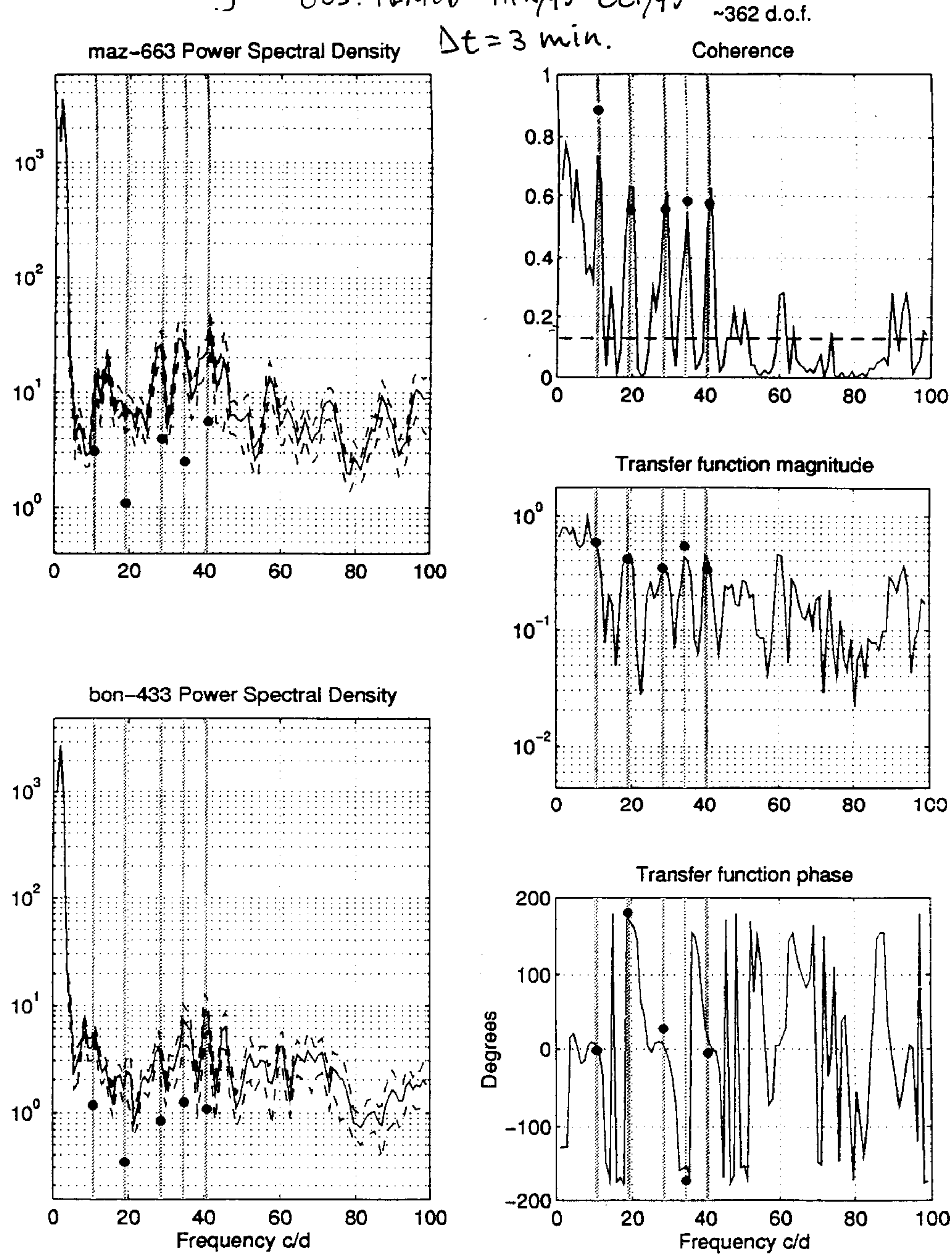
2nd OBS. PERIOD OCT./94- APR/95

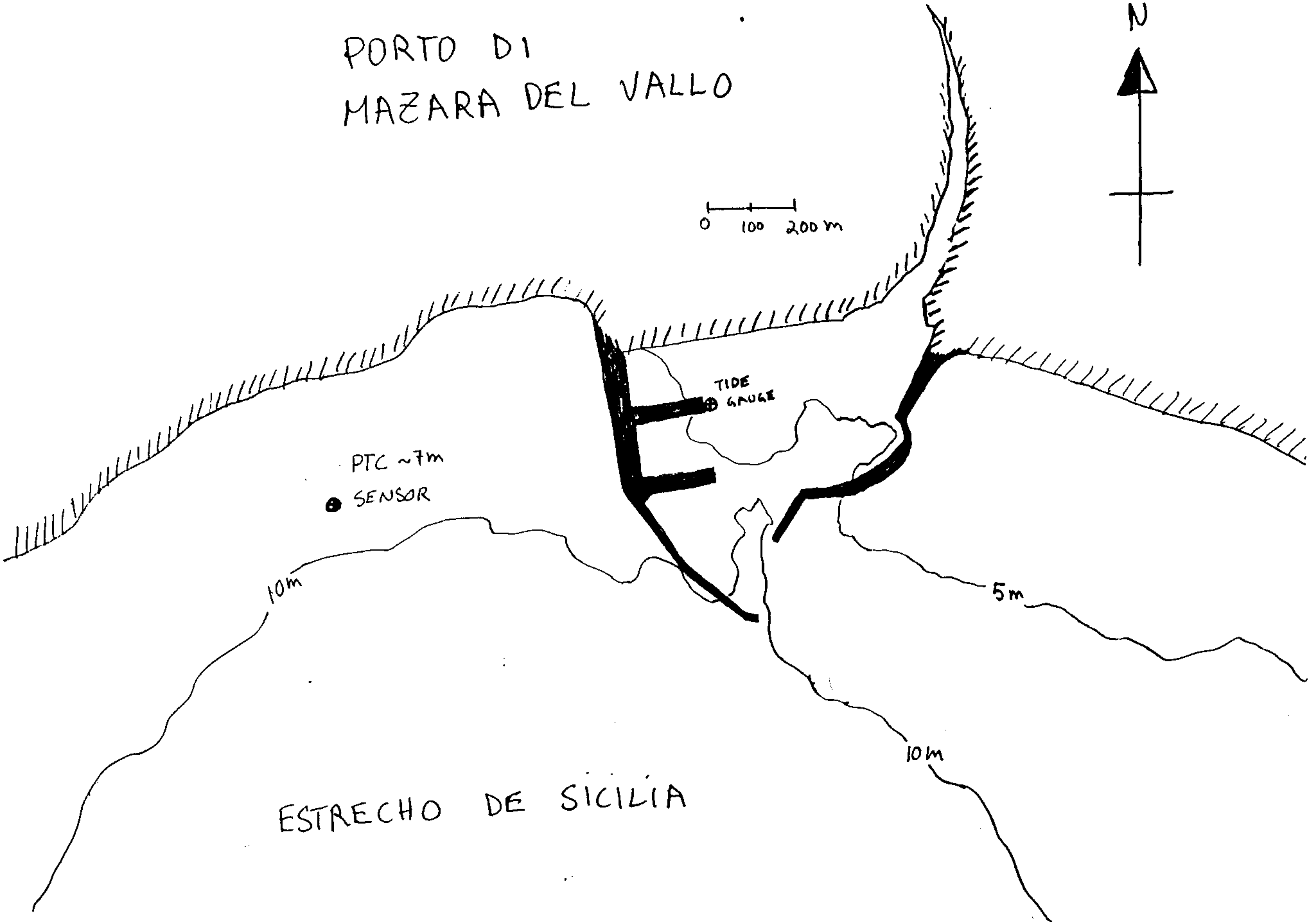
$\Delta t \approx 10$ min.



3rd OBS. PERIOD APR/95 - OCT/95

Δt = 3 min.



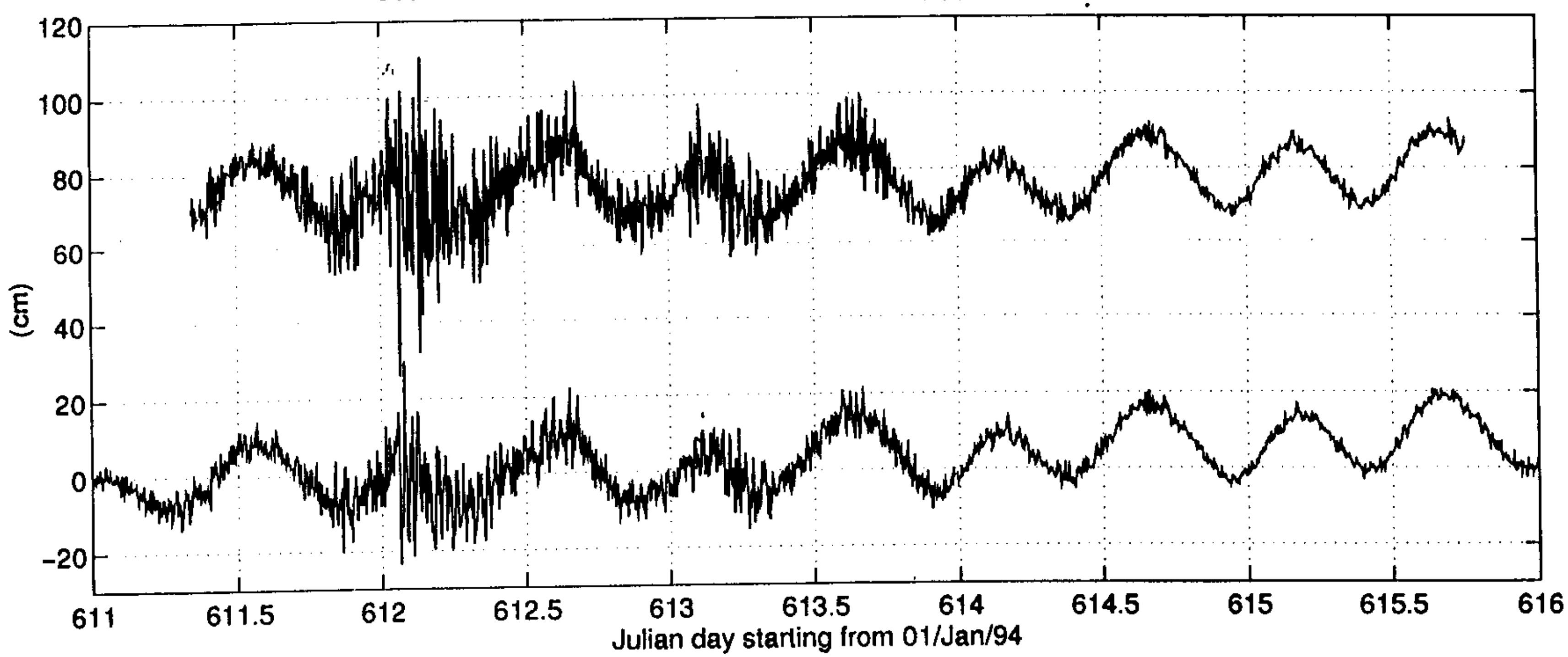

PORTO DI
MAZARA DEL VALLO
N
0 100 200 m
TIDE GAUGE
PTC ~7m
SENSOR
10m
5m
10m
ESTRECHO DE SICILIA

Marrobbio — *Si verifica raramente: una o due volte all'anno, ma assume notevoli proporzioni. E' un fenomeno di innalzamento e abbassamento improvviso del livello del mare, d'ampiezza variabile da pochi centimetri a più di un metro; si verifica essenzialmente lungo le coste meridionali della Sicilia. Sembra che il fenomeno sia dovuto ad improvvisi squilibri della pressione atmosferica i quali produrrebbero librazioni o bilanciamenti delle acque.*

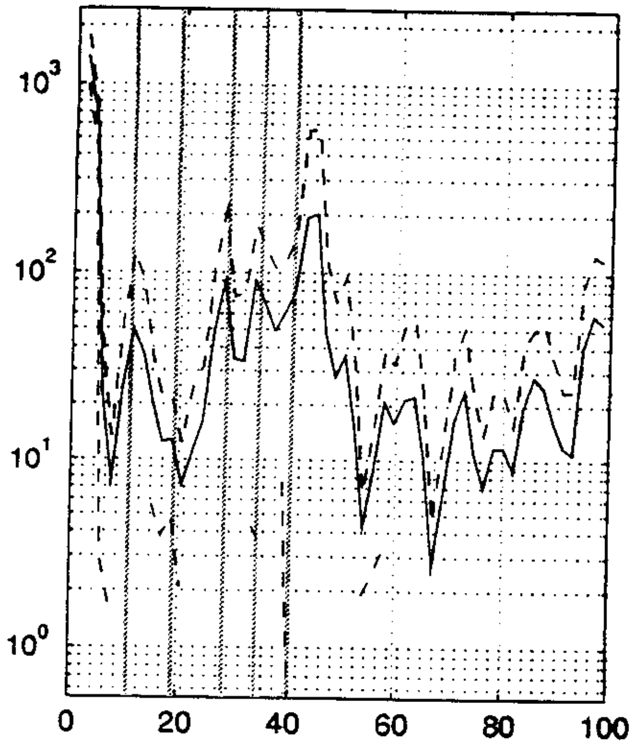
Il marrobbio è preannunciato da una atmosfera calma e da un cielo dall'aspetto livido. Allora le acque si innalzano bruscamente dal loro livello normale e si precipitano nelle insenature con sorprendente rapidità. Dopo pochi minuti, le acque si ritirano con la stessa rapidità e, smuovendo il fondo, portano alla superficie alghe e pesci, mentre l'aria si impregna di un odore sgradevole.

Il fenomeno, che può durare da 30 minuti a due ore, è generalmente preceduto da venti occidentali e seguito da venti sciroccali e di solito accompagna la comparsa o lo spostamento di minimi barometrici.

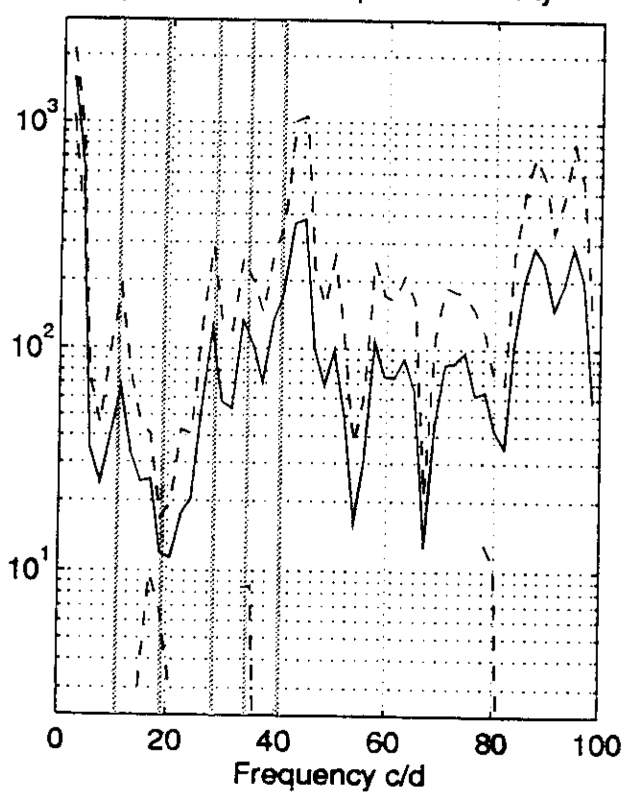
Sea level inside the Port of Mazara del Vallo (upper) and outside (lower).



maz−663 Power Spectral Density

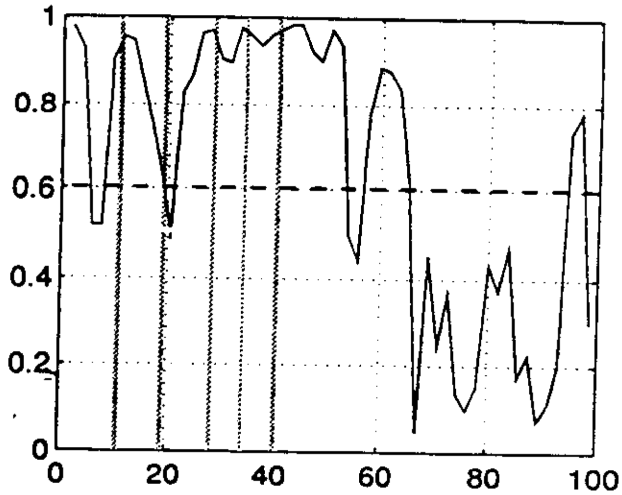


por−tma Power Spectral Density

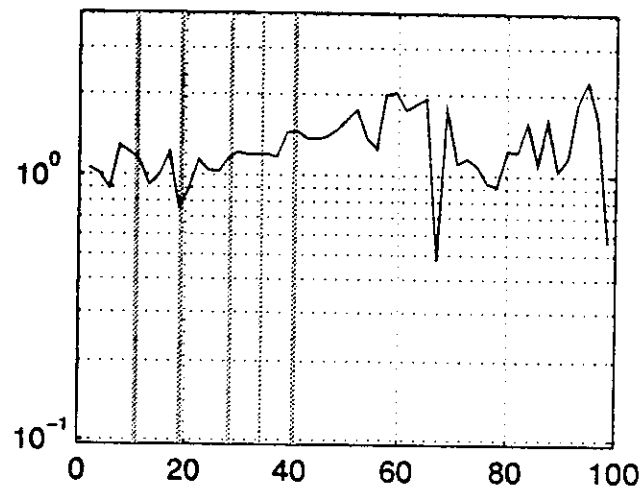


~17 d.o.f.

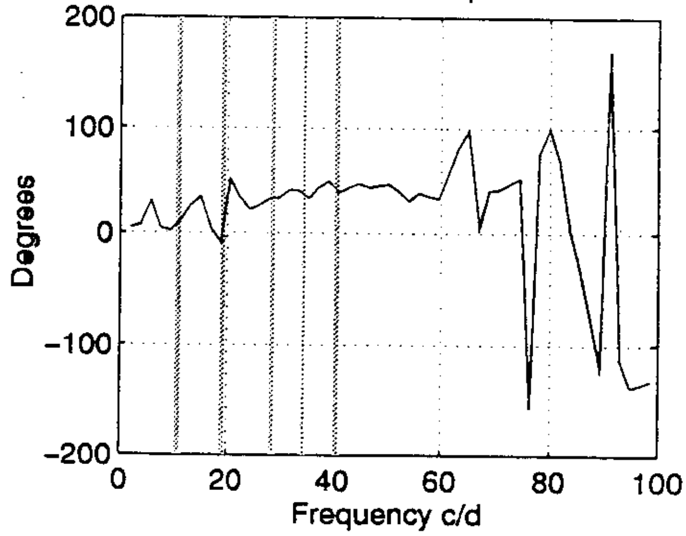
Coherence



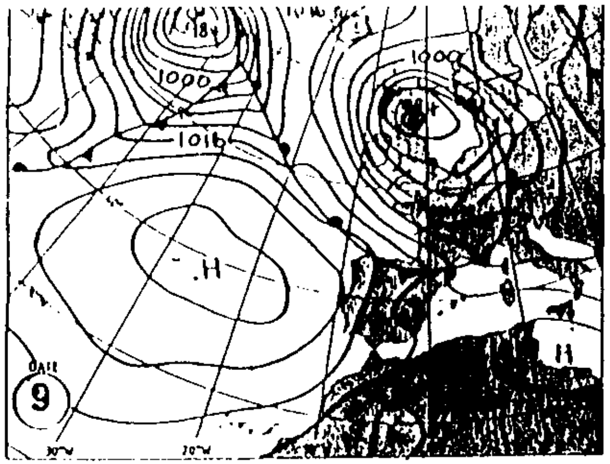
Transfer function magnitude

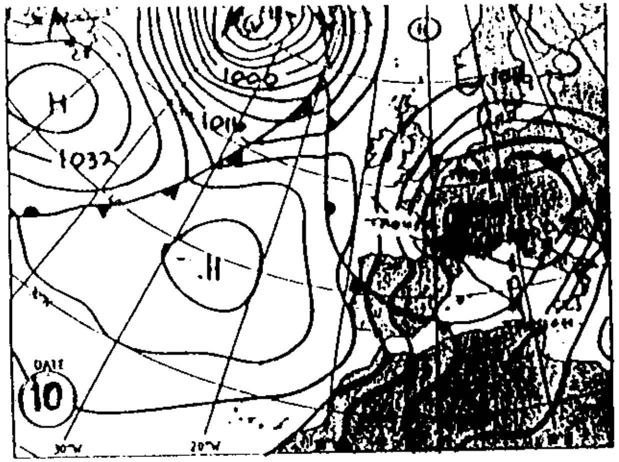


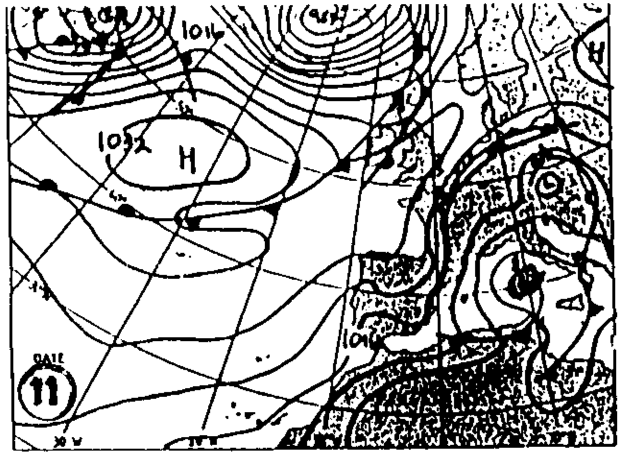
Transfer function phase

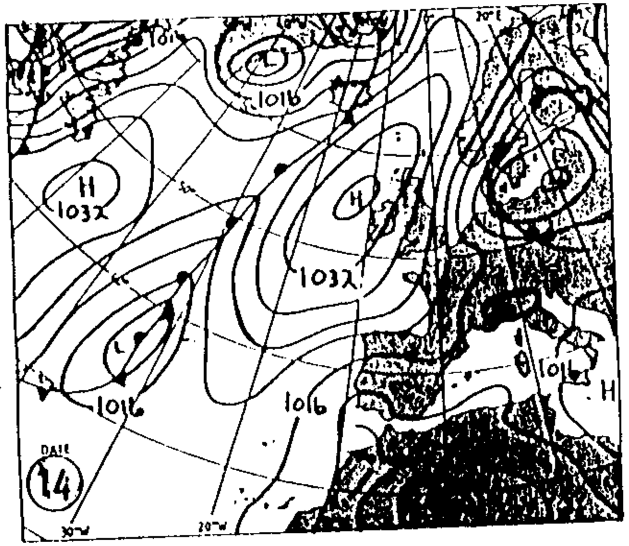


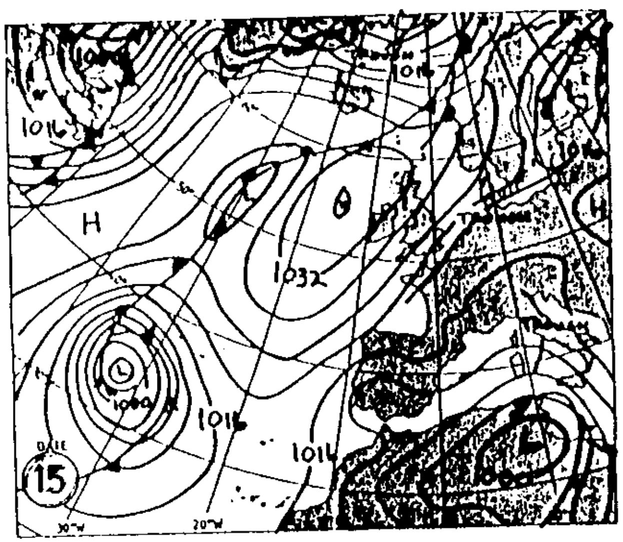
APRIL / 1994.

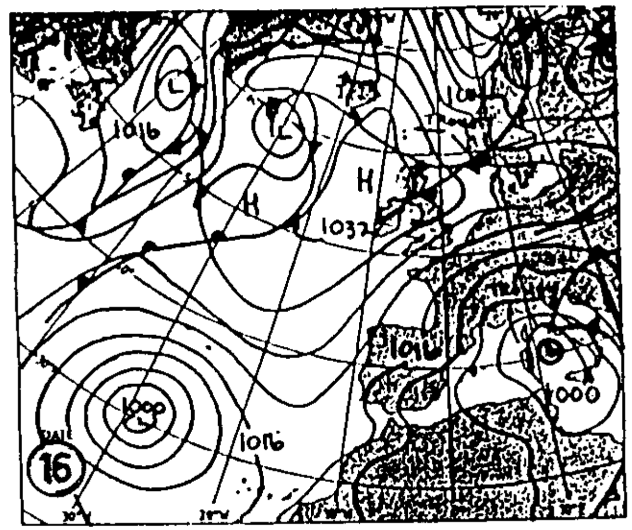

1000
1016
H
DATE
9

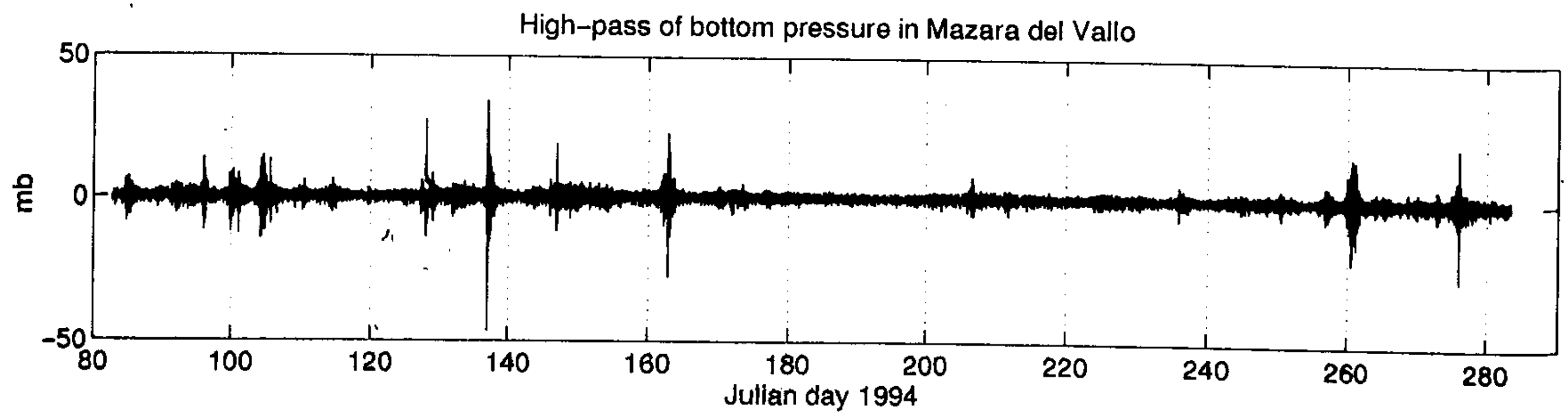

H
1032
1000
1016
DATE
10

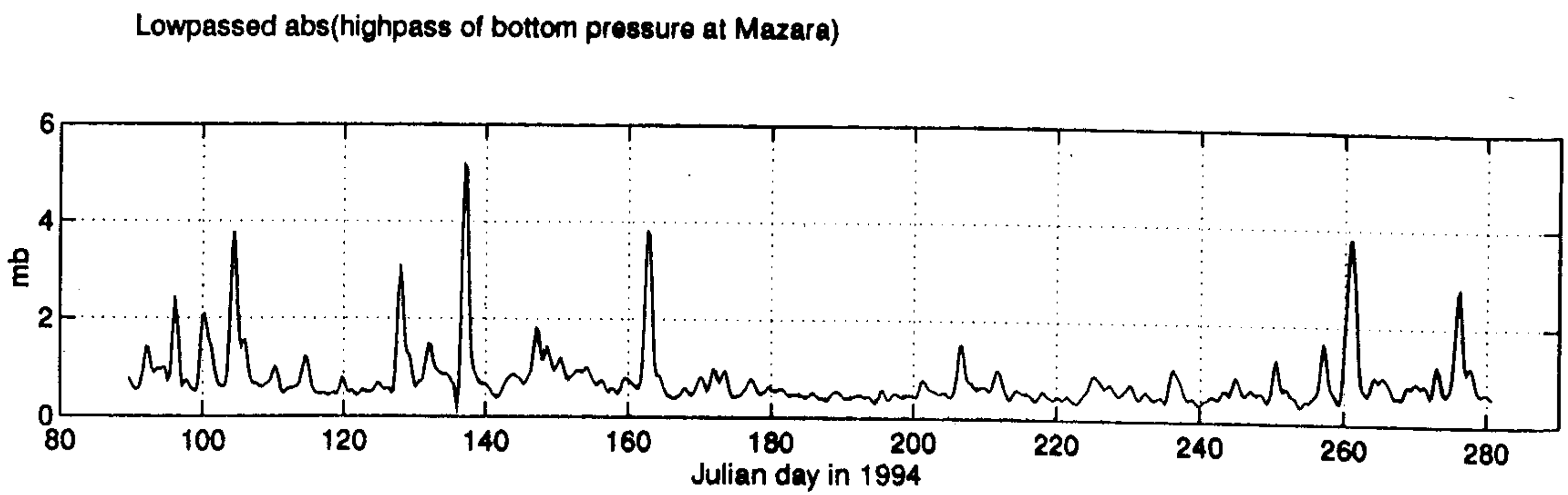

1016
1032
H
DATE
11


H
1032
1016
DATE
14


1016
H
1032
1000
DATE
15


1016
H
1032
1000
DATE
16

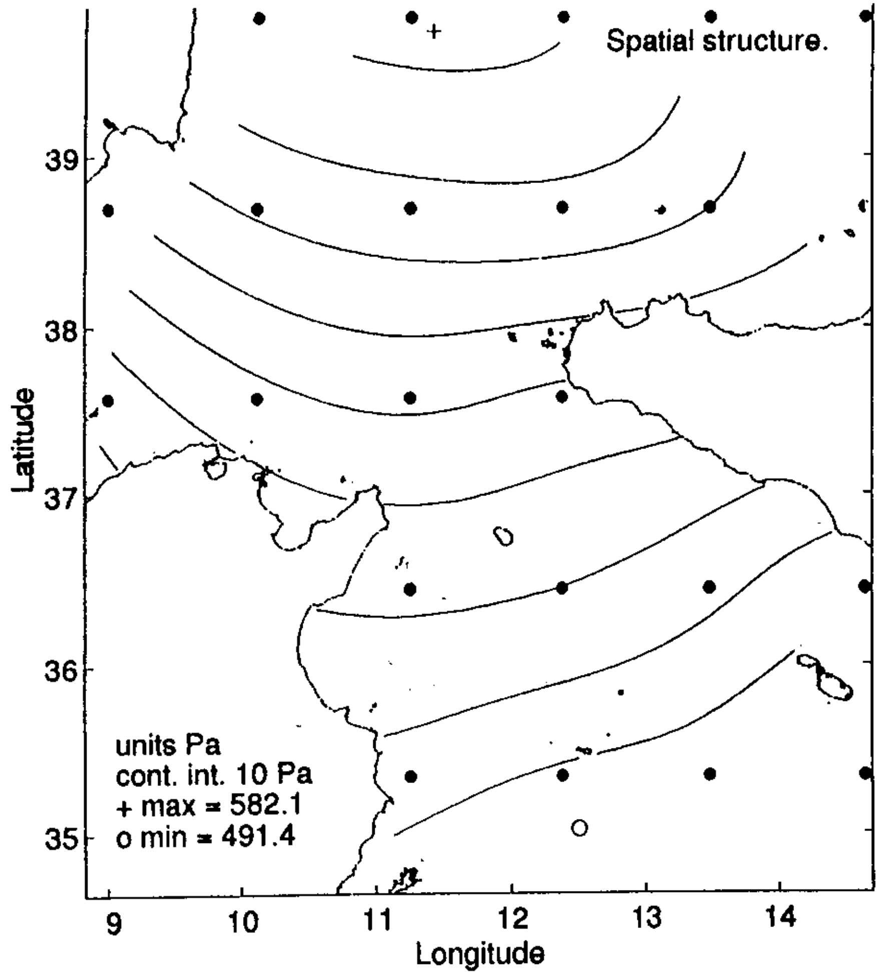

High-pass of bottom pressure in Mazara del Vallo
50
0
-50
mb
80
100
120
140
160
180
200
220
240
260
280
Julian day 1994

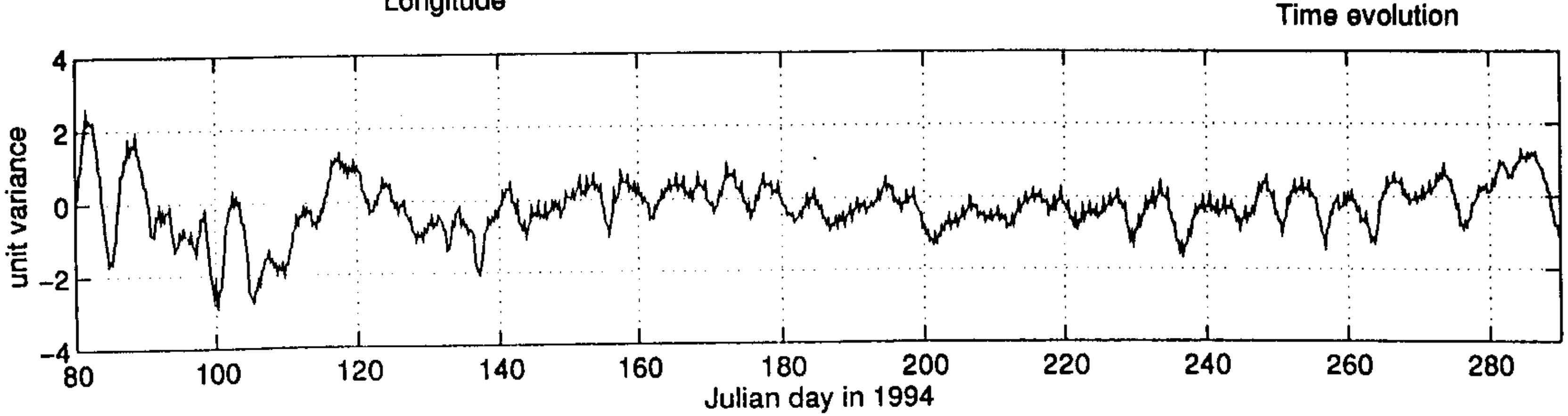

Lowpassed abs(highpass of bottom pressure at Mazara)
6
4
2
0
mb
80
100
120
140
160
180
200
220
240
260
280
Julian day in 1994

ECMWF 6h SURFACE DATA

Atmospheric Pressure

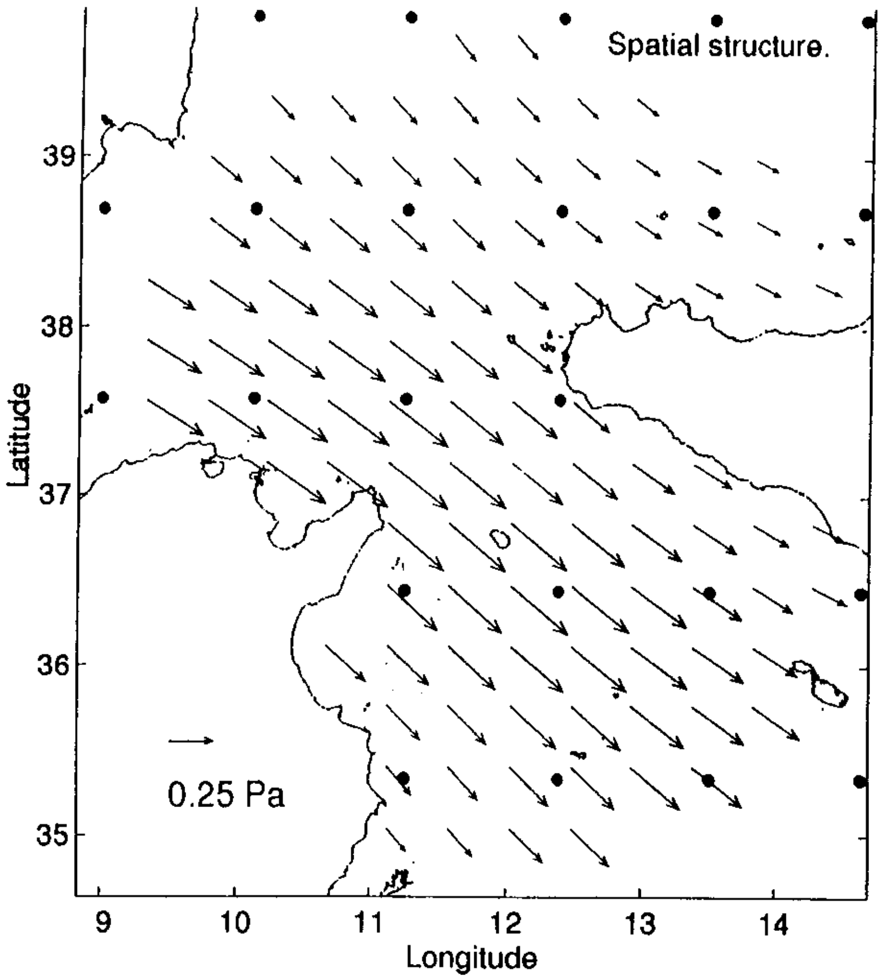
Eof # 1, pc = 91.81

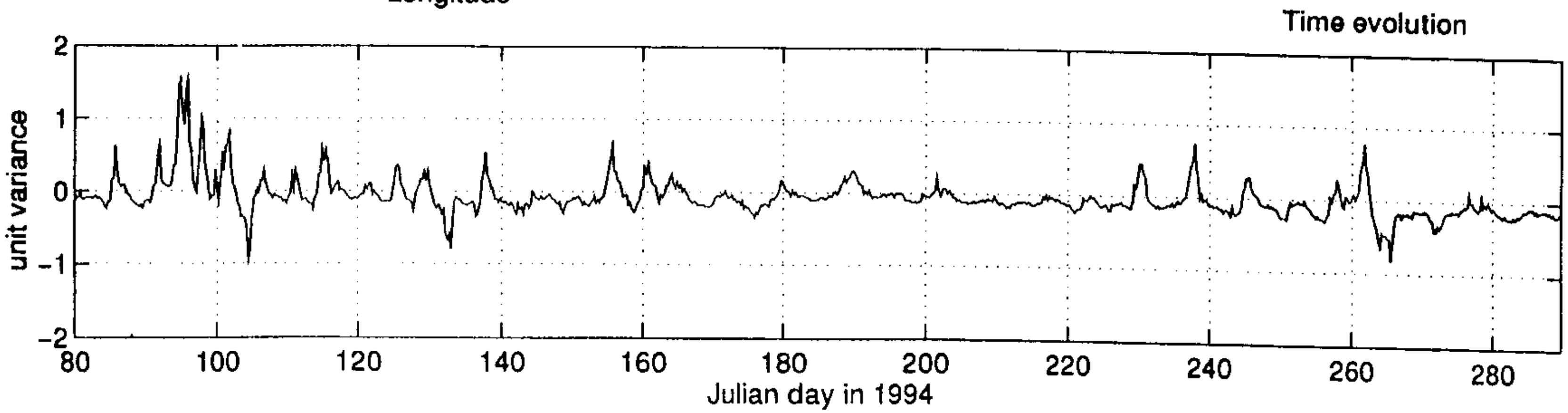


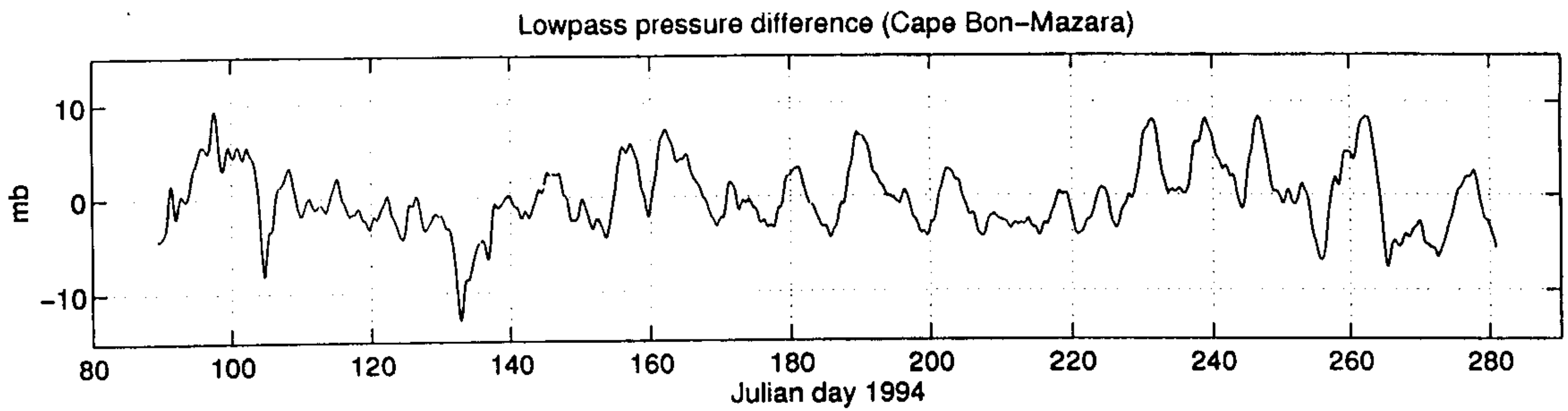


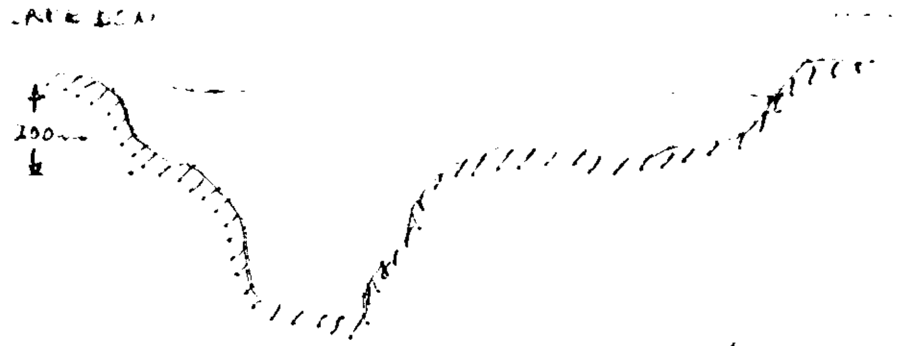
Wind Stress

Eof # 1, pc = 54.66






Lowpass pressure difference (Cape Bon–Mazara)
mb
10
0
−10
80
100
120
140
160
180
200
220
240
260
280
Julian day 1994



$C_D = 0.003$

$U = 0.6$

$u_g = -\frac{1}{\rho f}\frac{\Delta P}{L}$

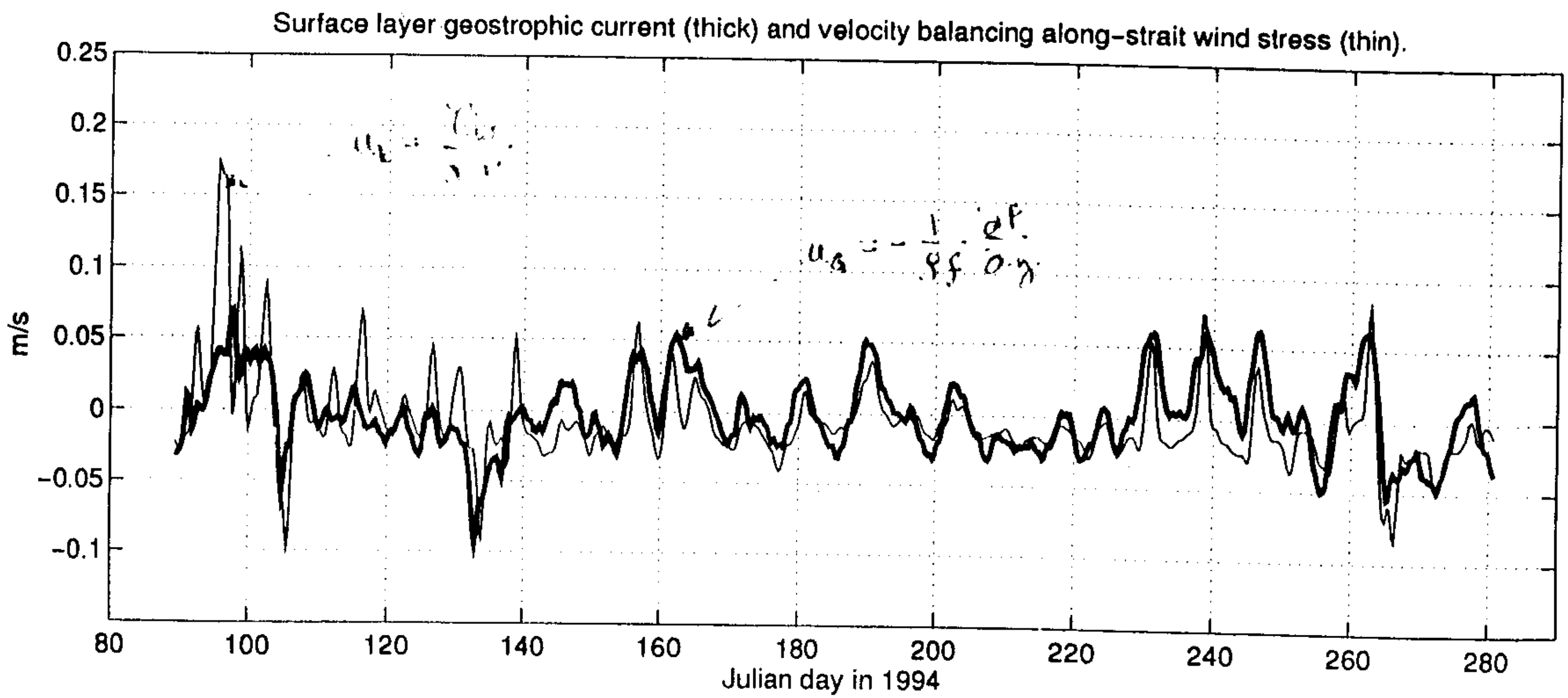
$u_b = \frac{\tau_s}{\rho r}$

$r = C_D U$

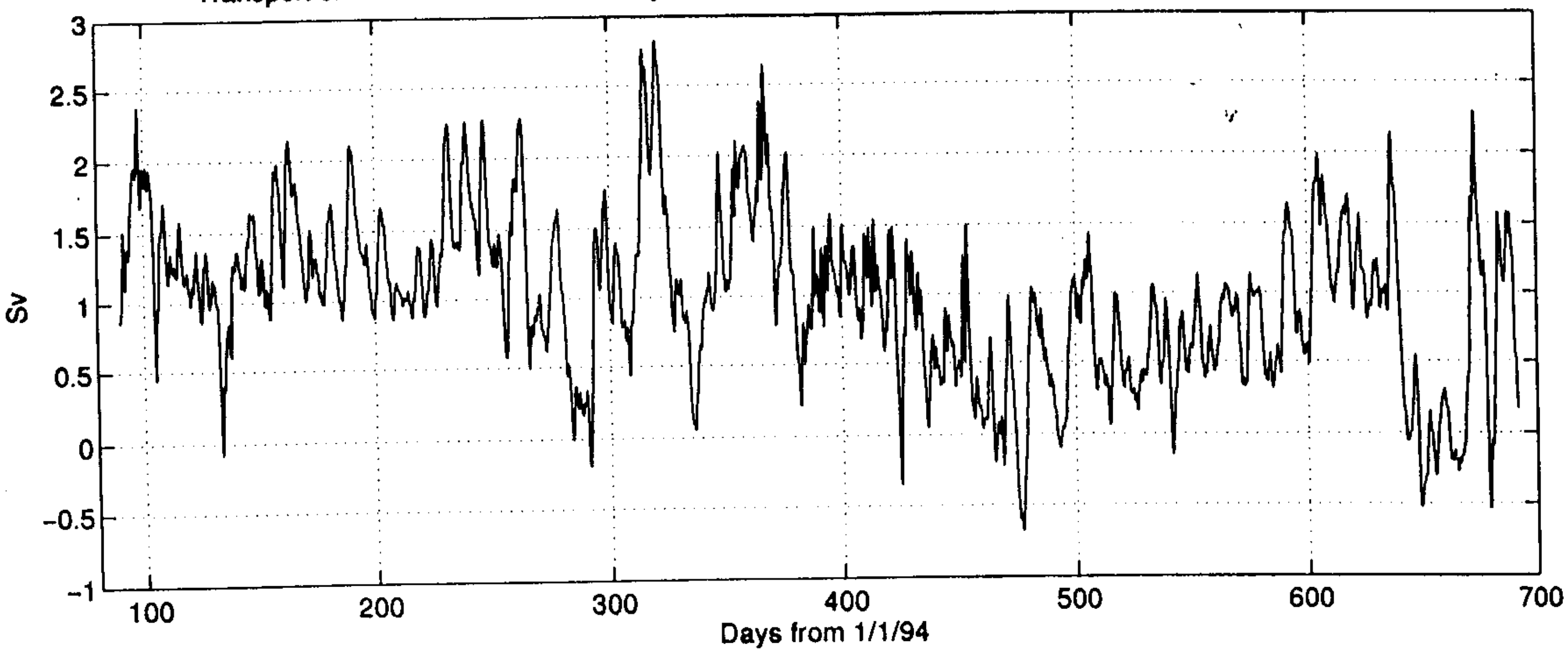
CROSS-STRAIT $\quad f u = -\frac{1}{\rho}\frac{\partial P}{\partial y}$

ALONG-STRAIT $\quad \frac{\partial u}{\partial t} - f v = -\frac{1}{\rho}\frac{\partial P}{\partial x} + \frac{\tau_w}{\rho h} - \frac{\tau_b}{\rho h} \; ; \quad \frac{\tau_b}{\rho h} \sim \frac{r u_b}{h}$

main balance



Transport of MAW in the Strait of Sicily deduced from pressure diff. across, h=100m, added mean=1Sv.



Linear barotropic equations without rotation or friction.

$$\eta_t + \nabla \cdot (hu) = 0$$

$$\vec{u}_t + g\nabla\eta = 0$$

$$\vec{u}\,,\ \eta \propto e^{i\omega t}$$

Eliminating $\vec{u}$ in favor of η we have:

$$\boxed{\nabla \cdot (h\nabla\eta) = -\frac{\omega^2}{g}\eta = -\lambda\eta}$$

with B.C. $\boxed{h\nabla\eta \cdot \hat{n} = 0}$ @ solid boundaries.

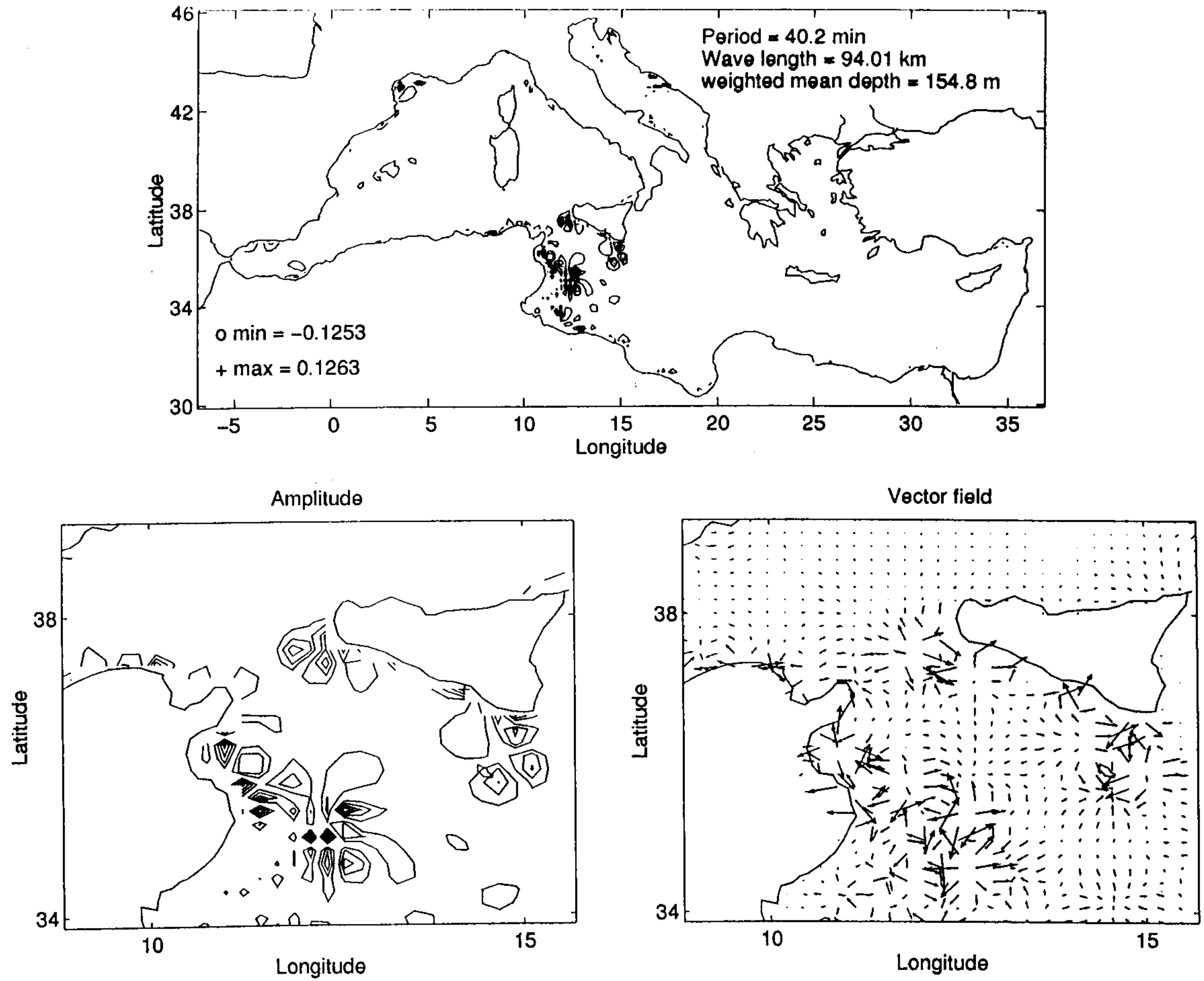
The eigensolutions are the barotropic ***Normal Modes*** possible with the given geometrical configuration.

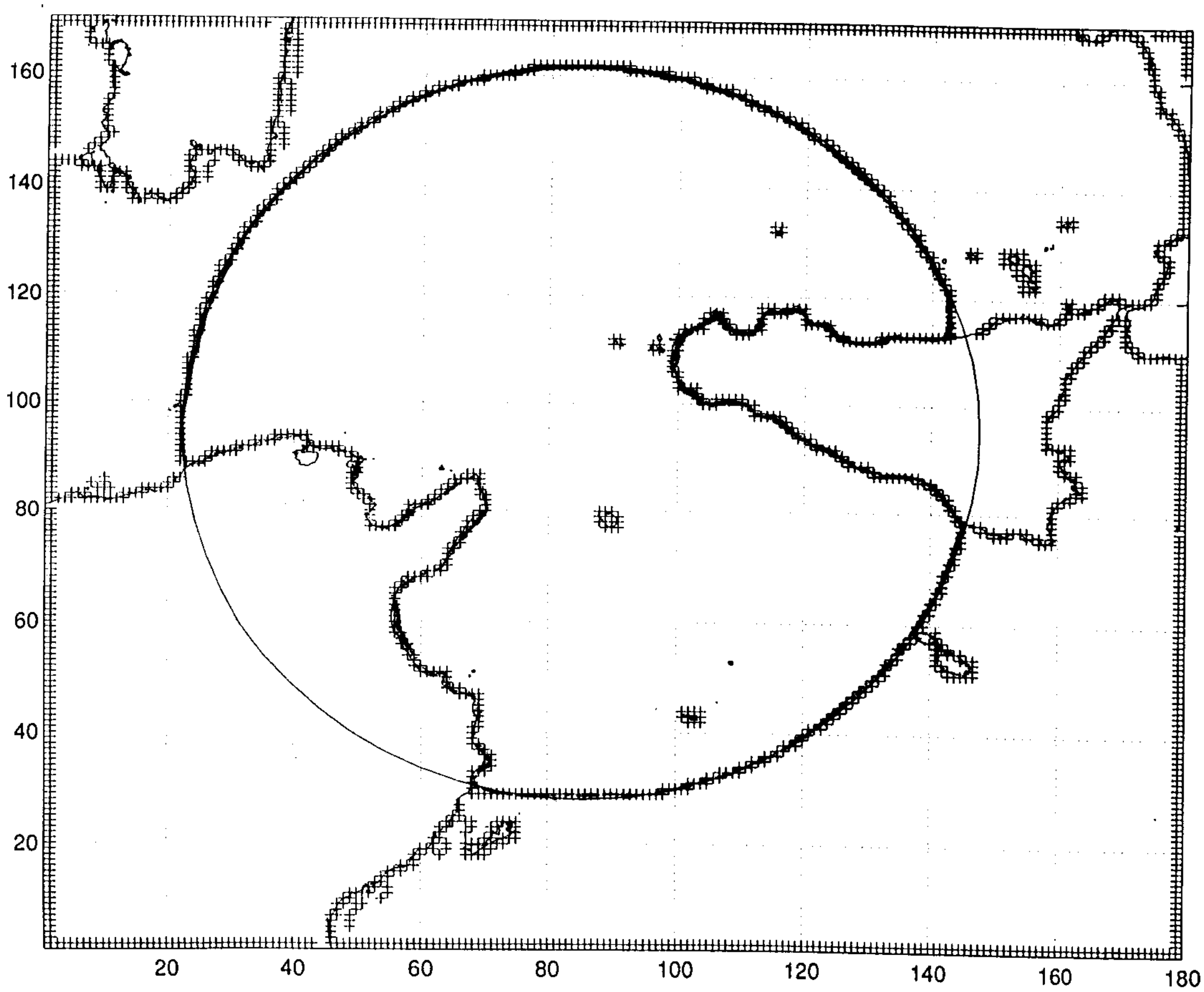
FOR A FLAT BOTTOM

$$\eta_{tt} + gh\left(\eta_{xx} + \eta_{yy}\right) = 0$$

IF $\eta \propto e^{-i\omega + lx + ky}$

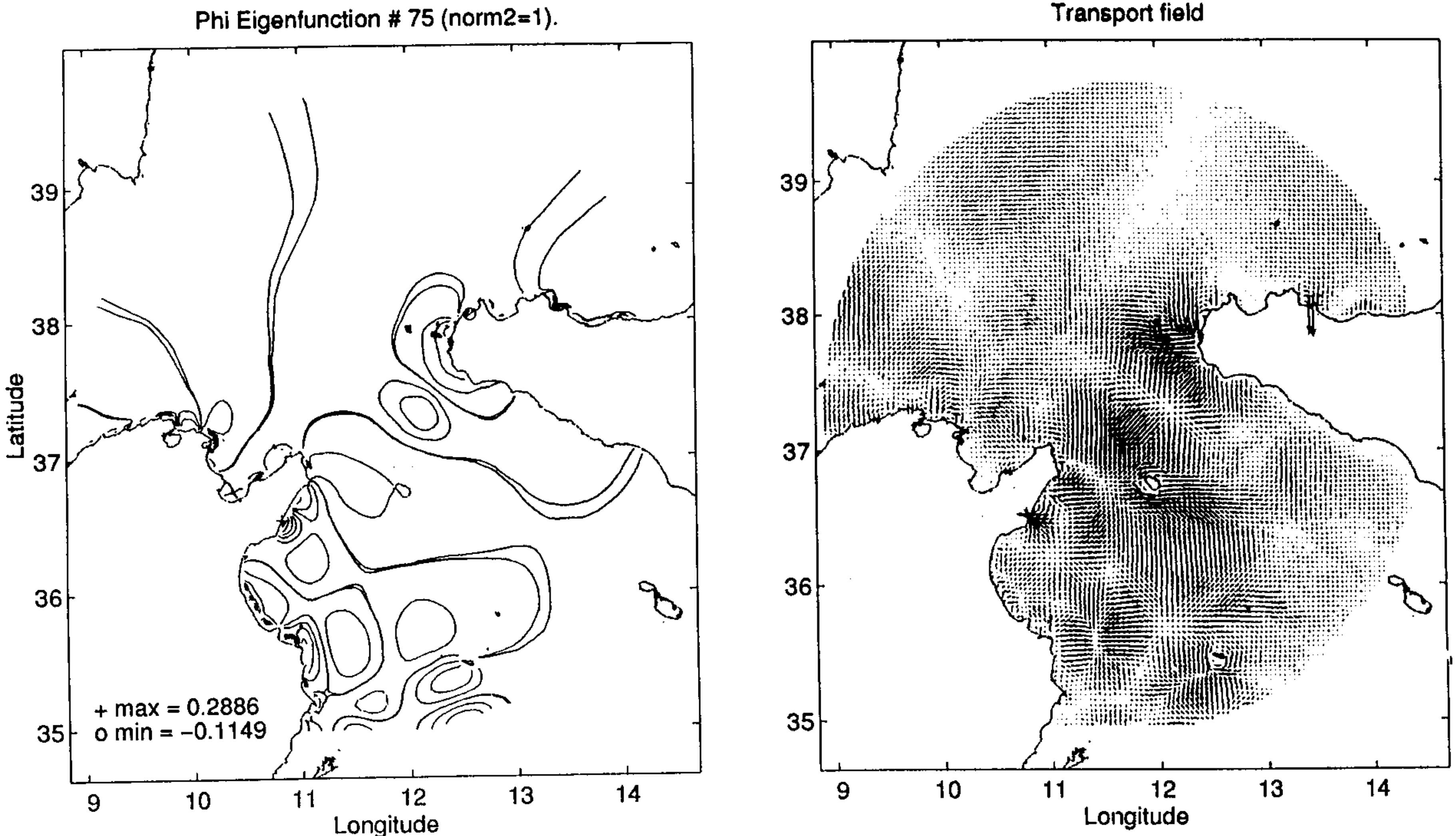
$$\boxed{\omega^2 = gh\left(l^2 + k^2\right)}$$ DISPERSION RELATION


Period = 40.2 min
Wave length = 94.01 km
weighted mean depth = 154.8 m
o min = −0.1253
+ max = 0.1263
Latitude
Longitude
Amplitude
Vector field



160
140
120
100
80
60
40
20
20
40
60
80
100
120
140
160
180

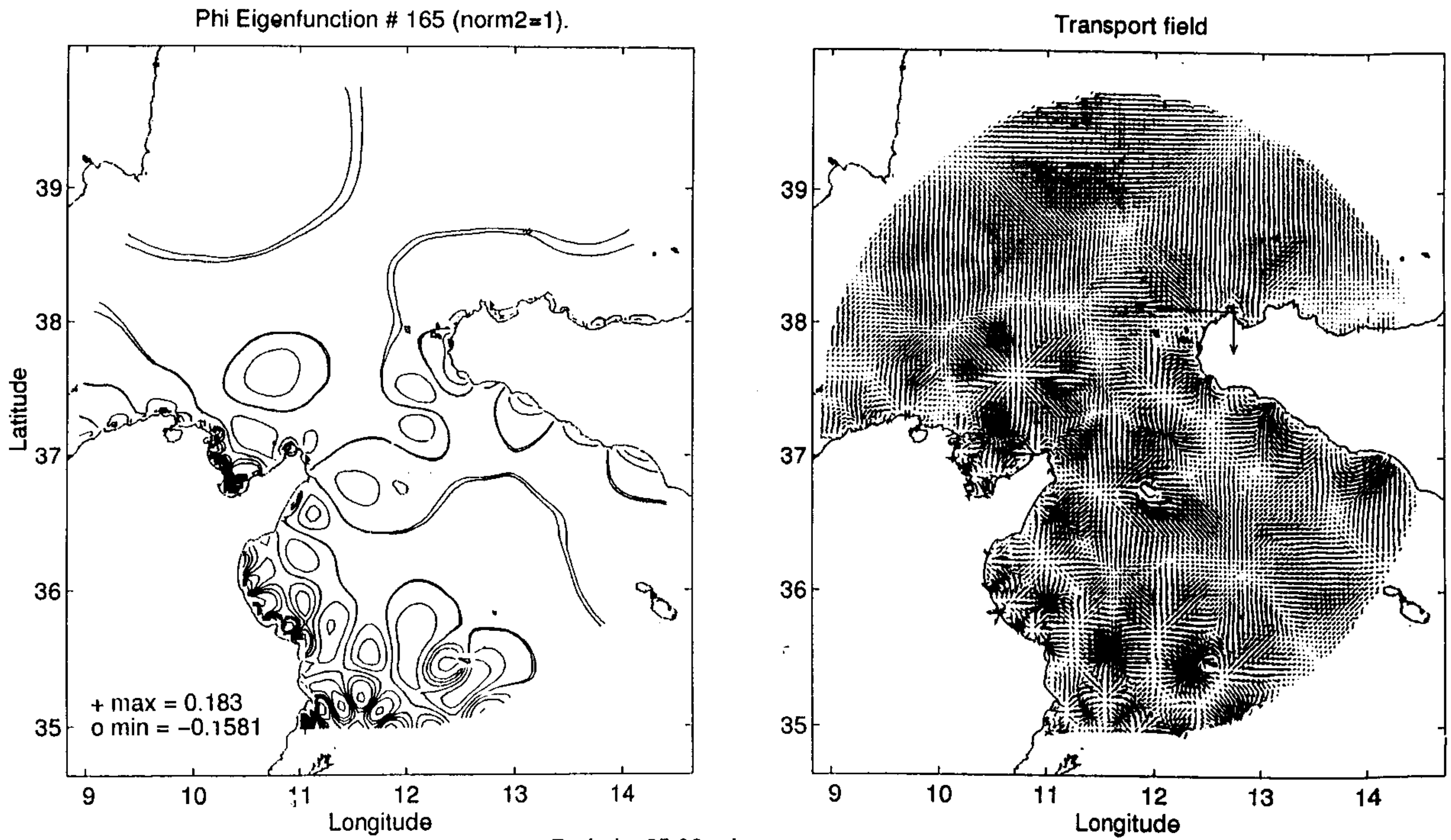
23



Period = 51.15 min
Wave length = 92.33 km
weighted mean depth = 92.25 m

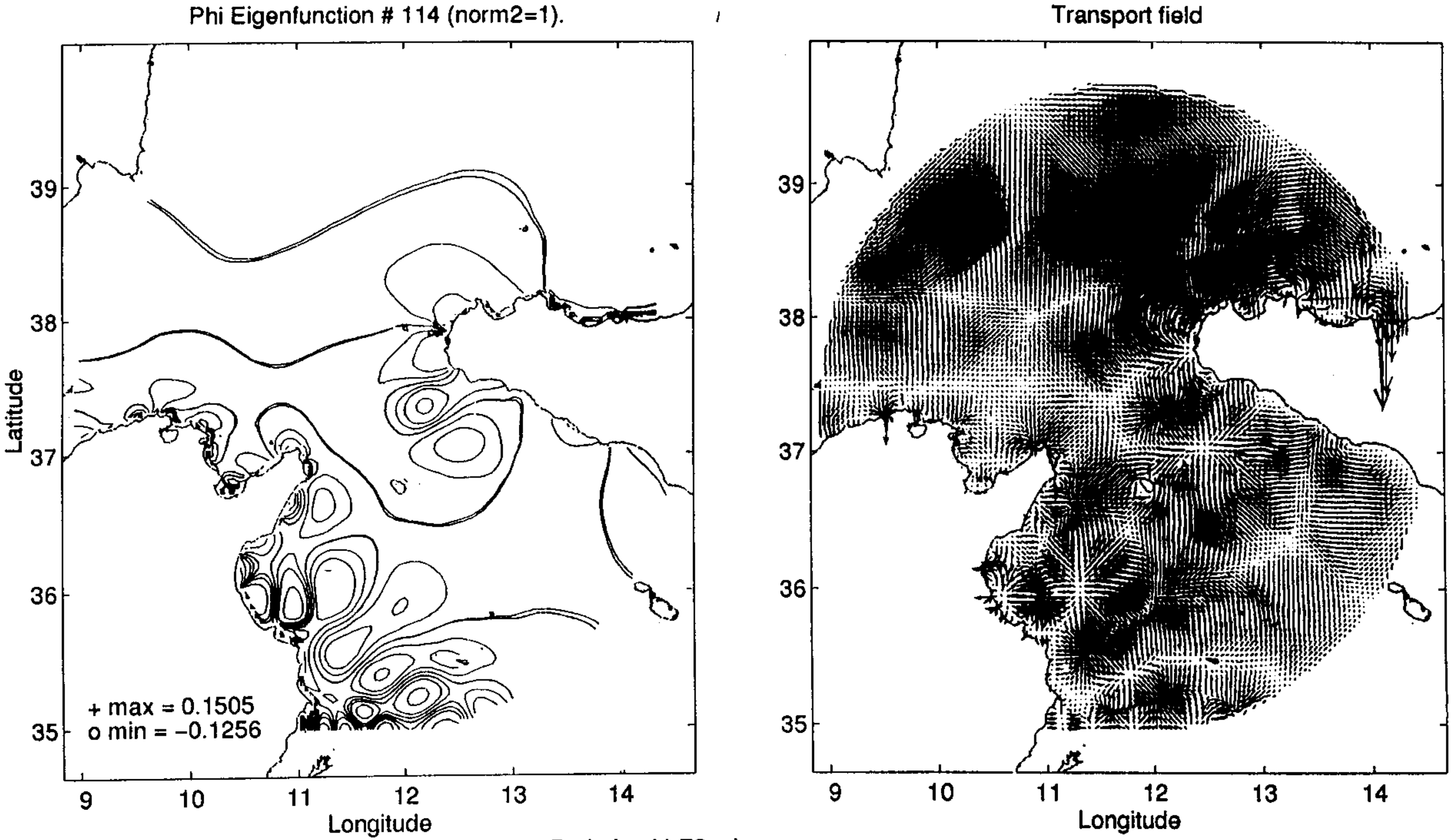
$$T = \frac{2\pi}{(g\lambda)^{1/2}}$$

$$\bar{h} = \frac{\int h\eta^2}{\int \eta^2} \; ; \quad L = 2\pi\left(\frac{\bar{h}}{\lambda}\right)^{1/2}$$

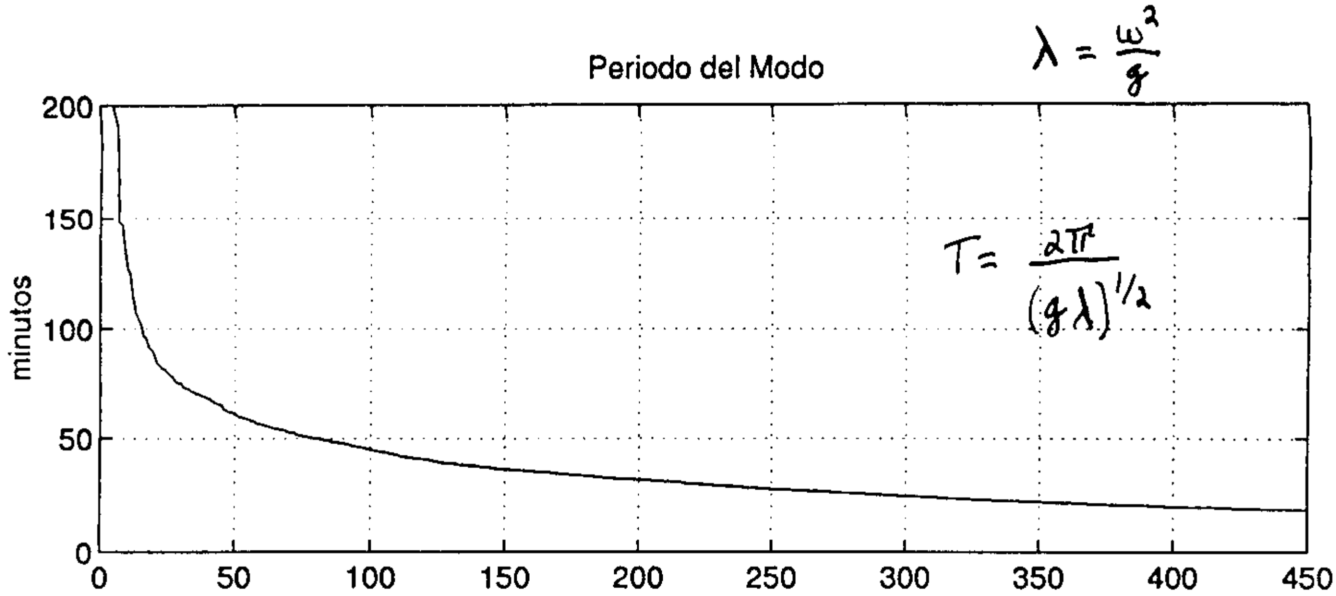


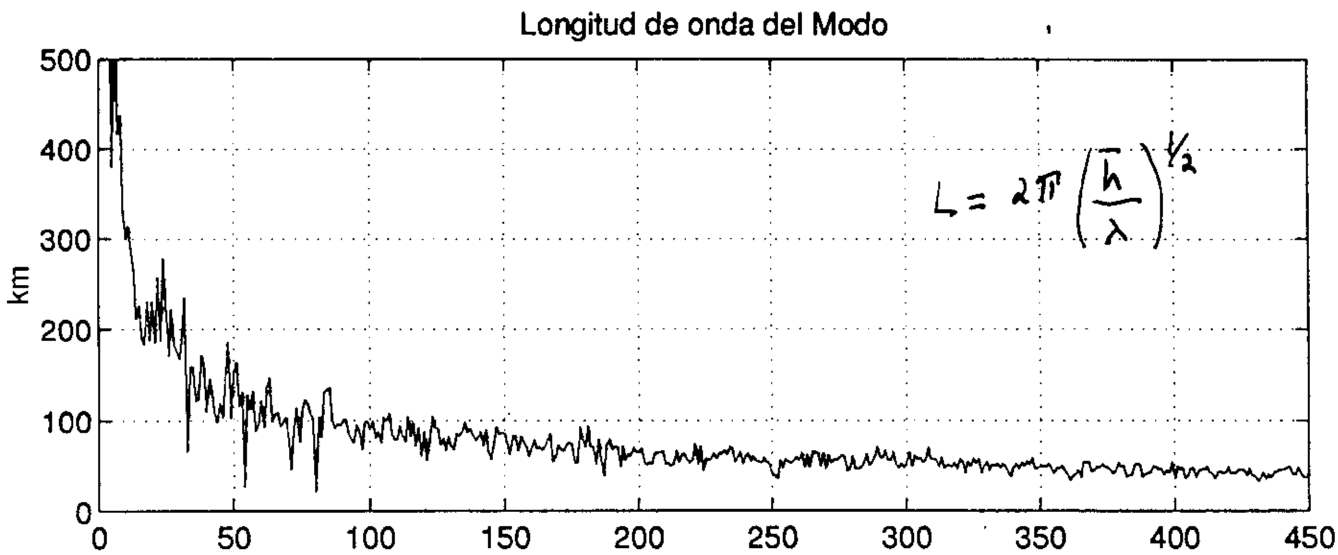
Period = 35.08 min
Wave length = 55.33 km
weighted mean depth = 70.46 m

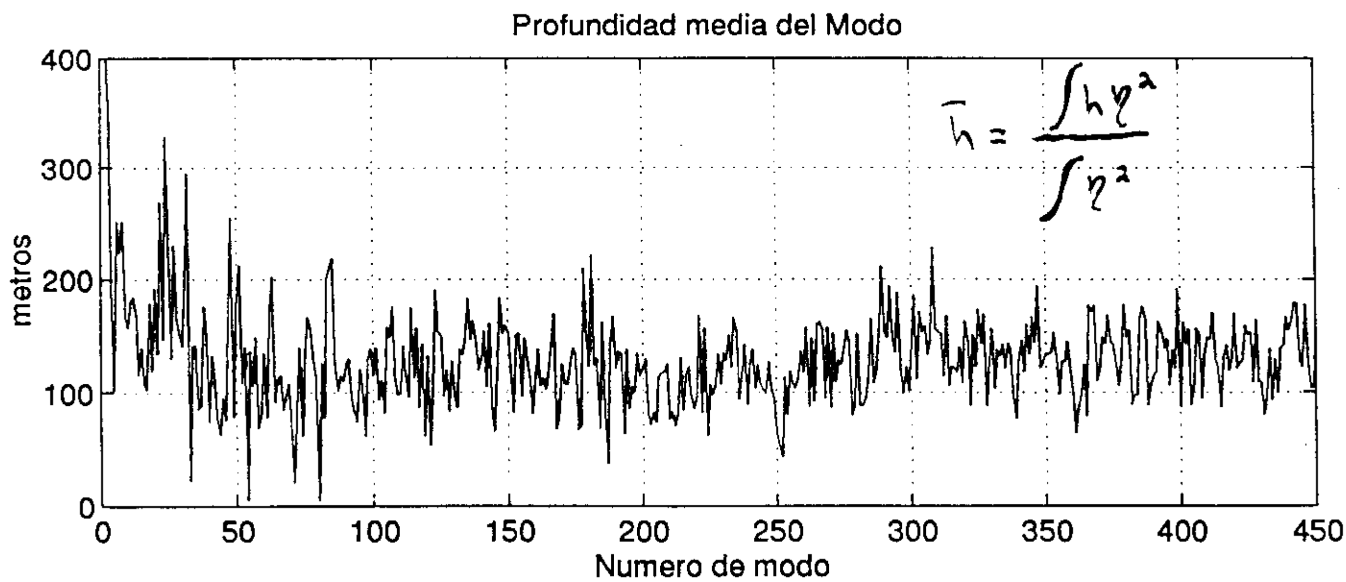
24



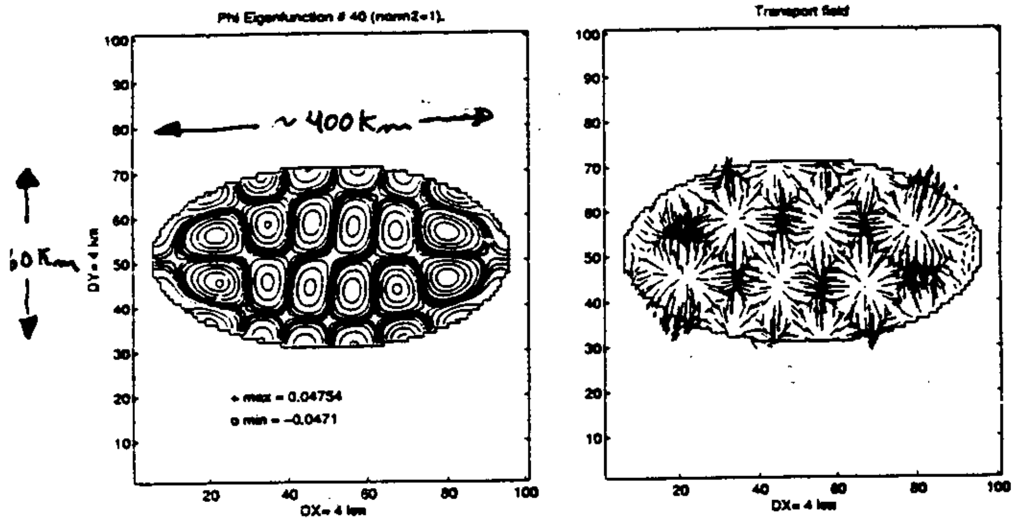
Period = 41.72 min
Wave length = 102.5 km
weighted mean depth = 170.9 m


Periodo del Modo
$\lambda = \frac{\omega^2}{g}$
$T = \frac{2\pi}{(g\lambda)^{1/2}}$
minutos
200
150
100
50
0
0
50
100
150
200
250
300
350
400
450

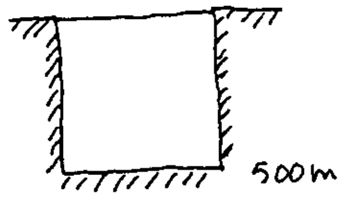

Longitud de onda del Modo
$L = 2\pi \left(\frac{\bar{h}}{\lambda}\right)^{1/2}$
km
500
400
300
200
100
0
0
50
100
150
200
250
300
350
400
450


Profundidad media del Modo
$\bar{h} = \frac{\int h \eta^2}{\int \eta^2}$
metros
400
300
200
100
0
0
50
100
150
200
250
300
350
400
450
Numero de modo

NORMAL MODES IN AN ELLIPTIC SEA



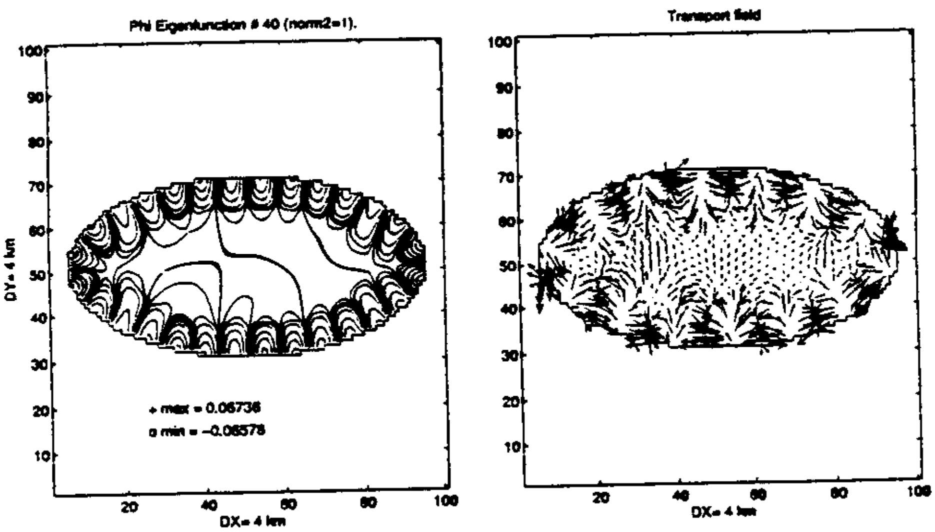
FLAT BOTTOM



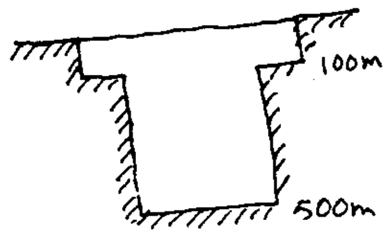
T= 16 min

λ = 68 Km

$\bar{h}$ = 500 m



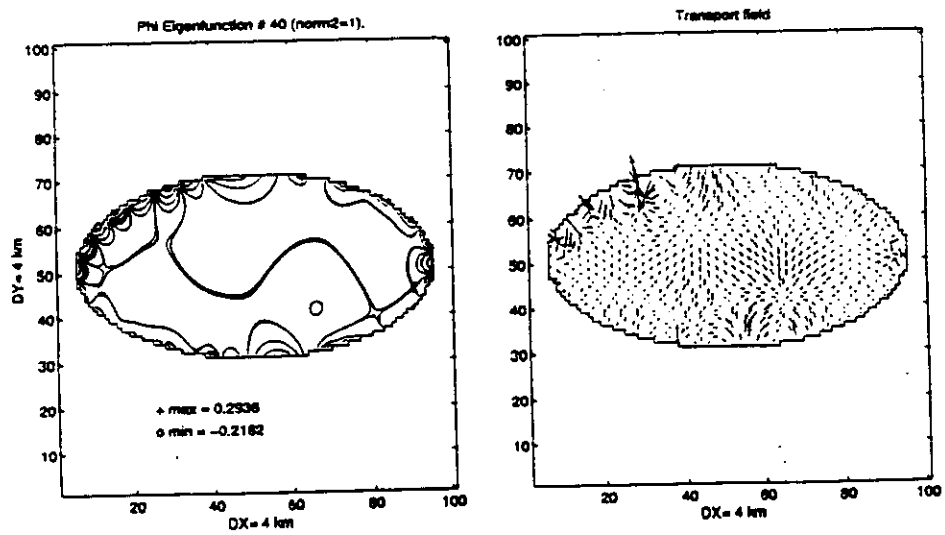
STEP SHELF



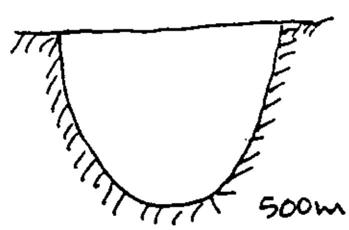
T= 29 min

λ = 56 Km

$\bar{h}$ = 103 m



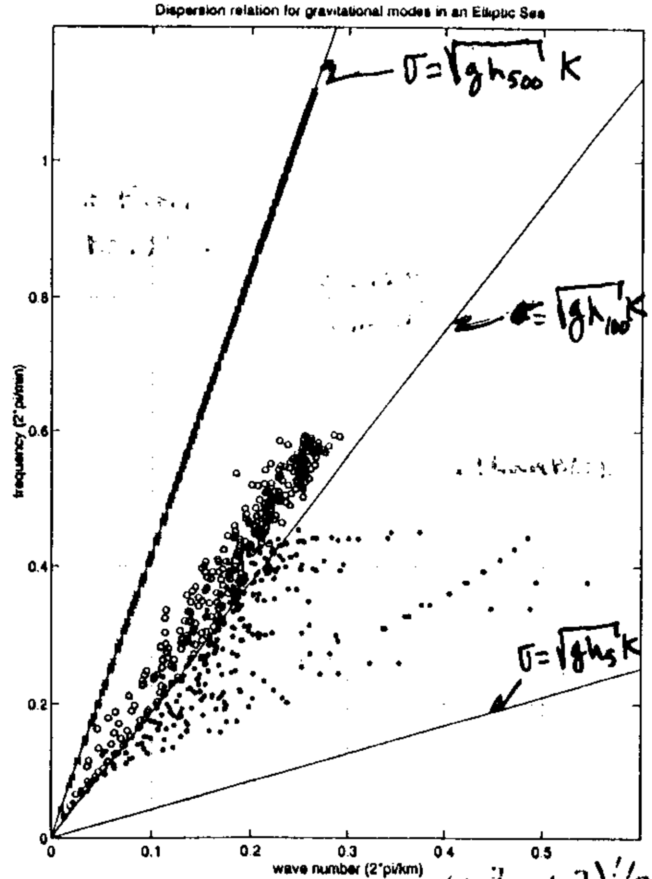
PARABOLIC



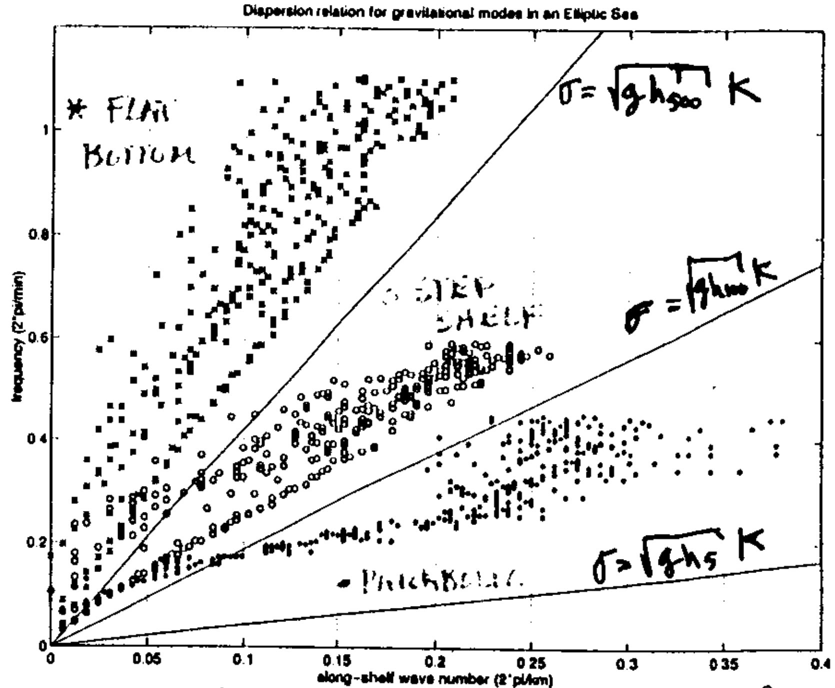
T= 37 min

λ = 46 Km

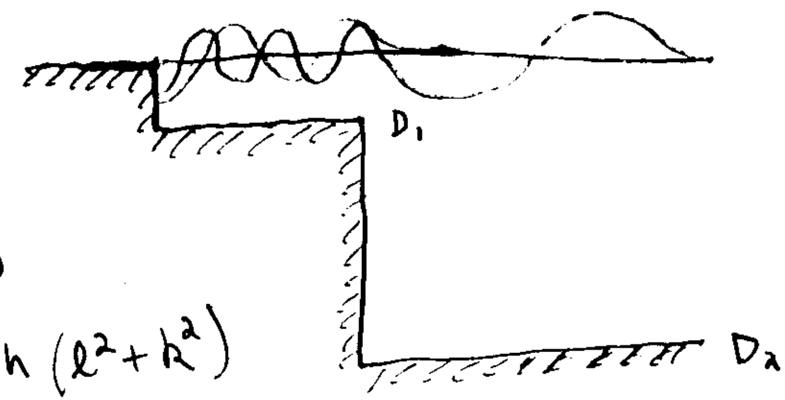
$\bar{h}$ = 44 m



TOTAL WAVE # $= (k^2 + l^2)^{1/2} = K$

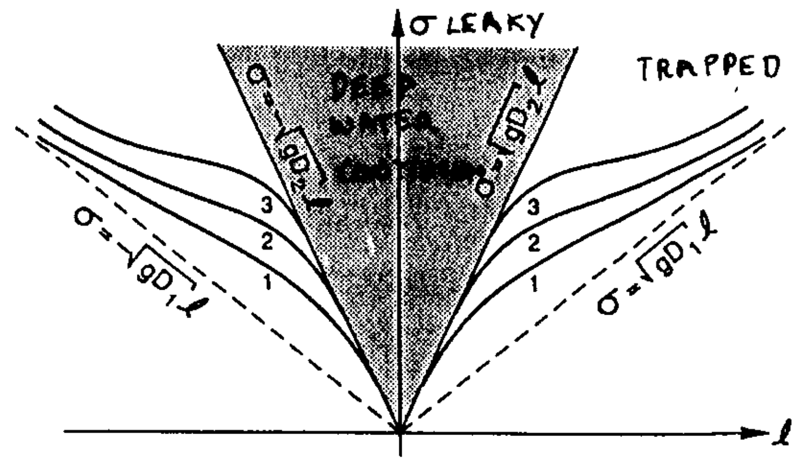


ALONG-COAST WAVE NUMBER.



$\sigma = \omega$

$\sigma^2 = gh(l^2 + k^2)$



DISPERSION RELATION FOR A SEMI-INFINITE STEP SHELF

Shallow water equations without rotation.

$$\boxed{\begin{array}{llll} \eta_t + \nabla \cdot (h\vec{u}) & = & 0 & (1) \\ \vec{u}_t + g\nabla\eta & = & g\nabla\eta_a + \tau_w/h - \tau_b/h & (2) \end{array}}$$

$$\eta_a = -\frac{P_a}{\rho_0 g} ; \quad \tau_w = \frac{\rho_a}{\rho_o} C_D \mid W \mid W ; \quad \tau_b = C_D u^\star \vec{u}$$

B.C. $\quad h\vec{u} \cdot \hat{n} = 0 \quad @ \ \partial D$

Velocity and sea surface elevation representations.

$$\nabla \cdot (h\nabla\phi_i) = -\lambda_i \phi_i \quad @ \ D$$

$$h\nabla\phi_i \cdot \hat{n} = 0 \ @ \ \partial D$$

$$\boxed{\vec{u} = \nabla\phi \ ;} \quad \boxed{\phi = \sum_{i\geq 1}^{n\phi} P_i \phi_i \ ;}$$

$$\boxed{\eta = \sum_{i\geq 0}^{n\phi} N_i \eta_i \ ;} \quad \boxed{\eta_i = c_i \phi_i}$$

Scalar product; Projection over eigenfunctions.

$$(f, g) = \int_D f \cdot g \, d\sigma \ ; \quad (\eta_i, (1)) \text{ and } (h\nabla\phi_i, (2))$$

Defining $\quad y = \begin{pmatrix} N \\ P \end{pmatrix}$

The system of equations is:

$$\boxed{\frac{dy}{dt} = My + f}$$

Time integration

The system of ordinary differential equations

$$\boxed{\frac{dy}{dt} = My + f \qquad (1)}$$

can be decoupled by an eig-decomposition of the matrix M.
In general we have the decompositions

$$M^T V = V\Lambda \; ; \qquad MZ = Z\Lambda^T$$

Using these we can transform equation (1) into a diagonal system of decoupled, complex valued, differential equations

$$\boxed{\frac{dY^T}{dt} = Y^T\Lambda + F^T \qquad (2)}$$

where $Y^T = y^T V$; $M^T V = V\Lambda$; and $\underline{\underline{F^T = f^T V}}$.

With the transformation $\mathrm{Y}^{\mathrm{T}}\mathcal{Z} = \mathrm{y}^{\mathrm{T}}$; where $\mathcal{Z} = D^{-1}Z^T$; $Z^T V = D$ we can always go back to the space of our original coefficients.

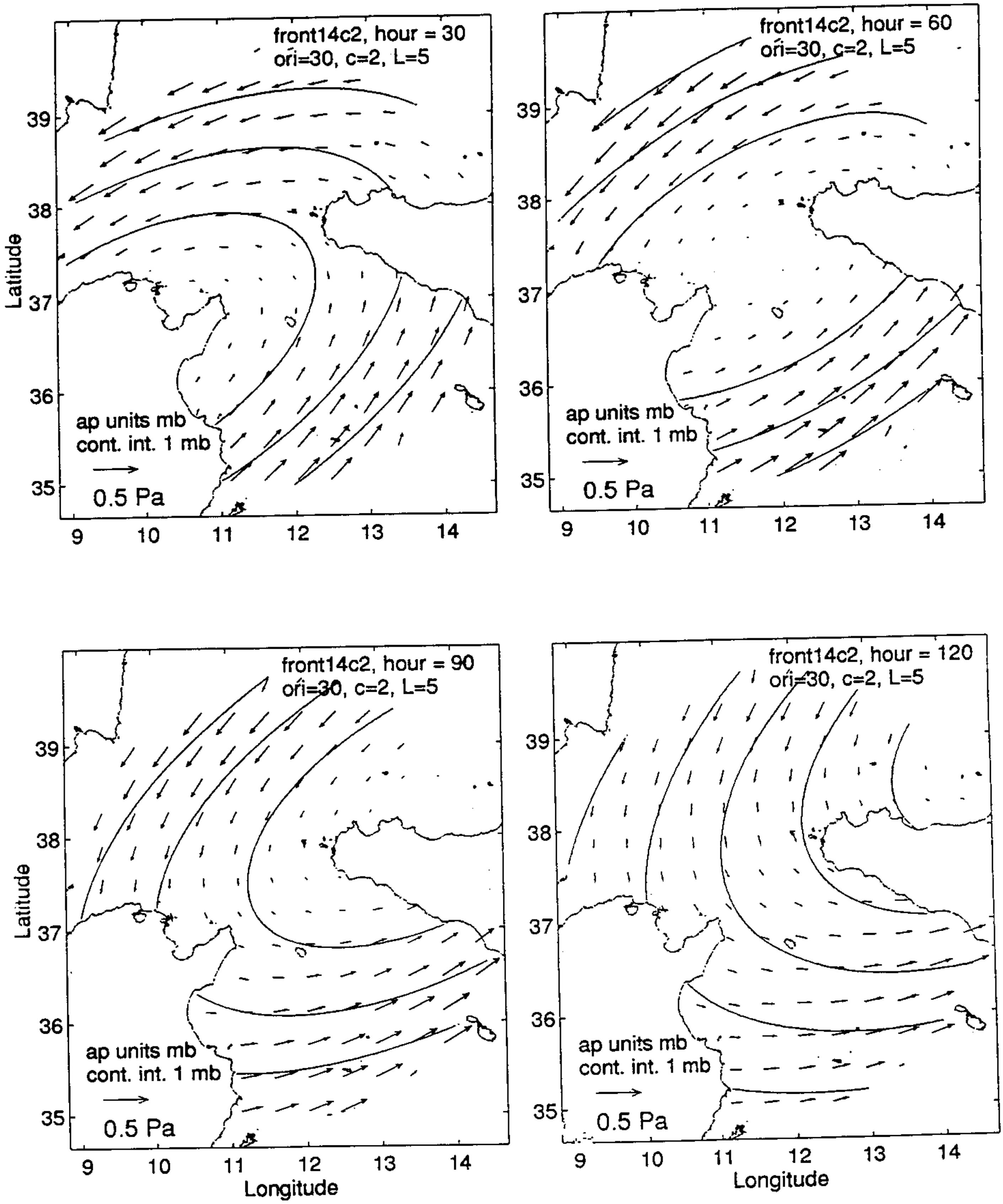
System (2) permits a quasi-analytical integration. For a given eigenvalue λ we have:

$$Y(\Delta t) = Y_j e^{\lambda\Delta t} + \int_0^{\Delta t}[F_j + (F_{j+1} - F_j)s]e^{\lambda(\Delta t - s)}ds;$$

which is numerically implemented:

$$\boxed{Y_{j+1} = \gamma Y_j + \kappa F_j + \kappa_1(F_{j+1} - F_j);}$$

where $\gamma = \mathrm{e}^{\lambda\Delta \mathrm{t}}$; $\kappa = \frac{1}{\lambda}(\mathrm{e}^{\lambda\Delta \mathrm{t}} - 1)$ and $\kappa_1 = \frac{1}{\lambda}(\kappa - \Delta\mathrm{t})$.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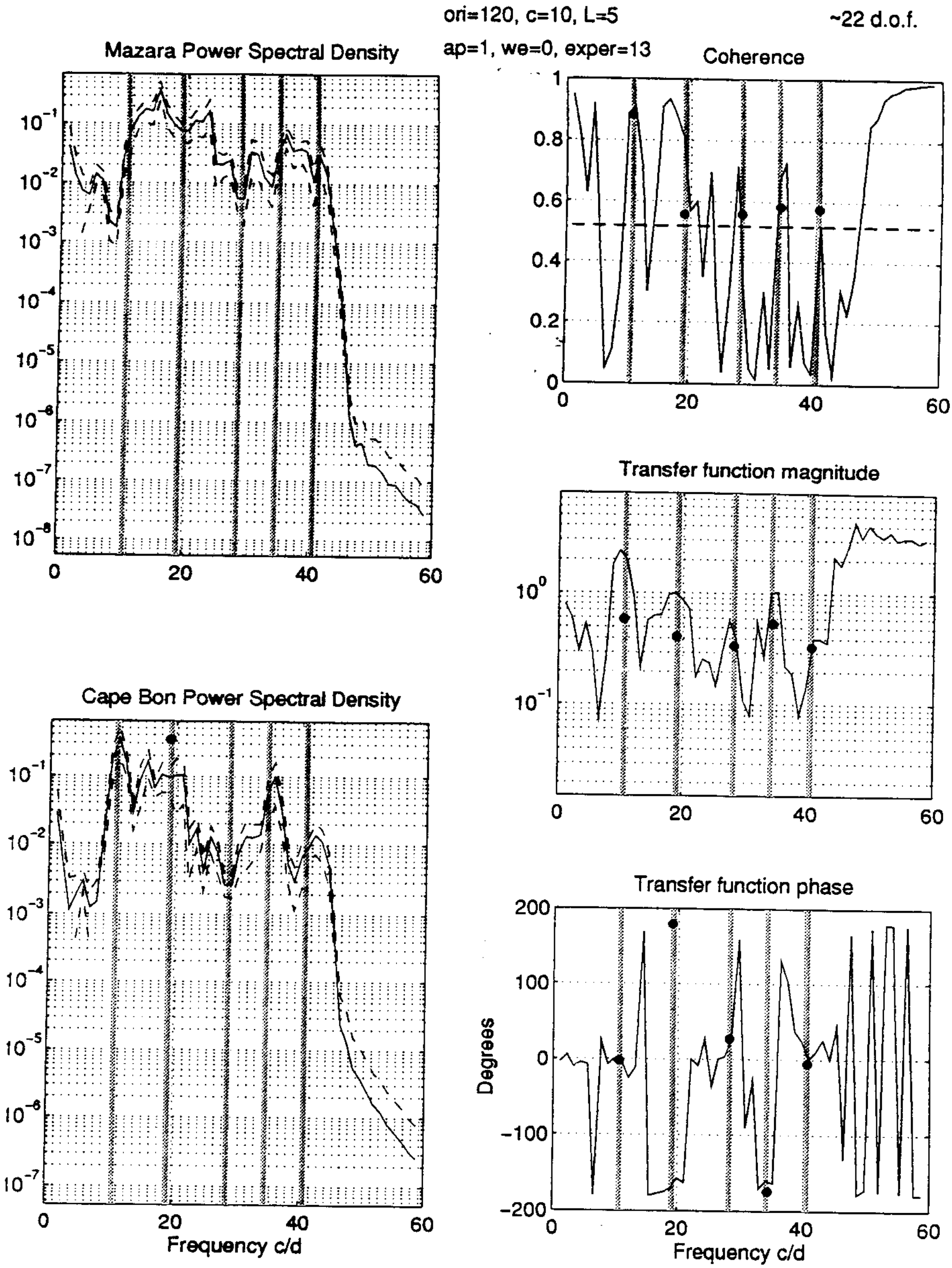
ori=30, c=2, L=5
ap units mb
cont. int. 1 mb
0.5 Pa
front14c2, hour = 60
ori=30, c=2, L=5
ap units mb
cont. int. 1 mb
0.5 Pa
front14c2, hour = 90
ori=30, c=2, L=5
ap units mb
cont. int. 1 mb
0.5 Pa
front14c2, hour = 120
ori=30, c=2, L=5
ap units mb
cont. int. 1 mb
0.5 Pa
Latitude
Longitude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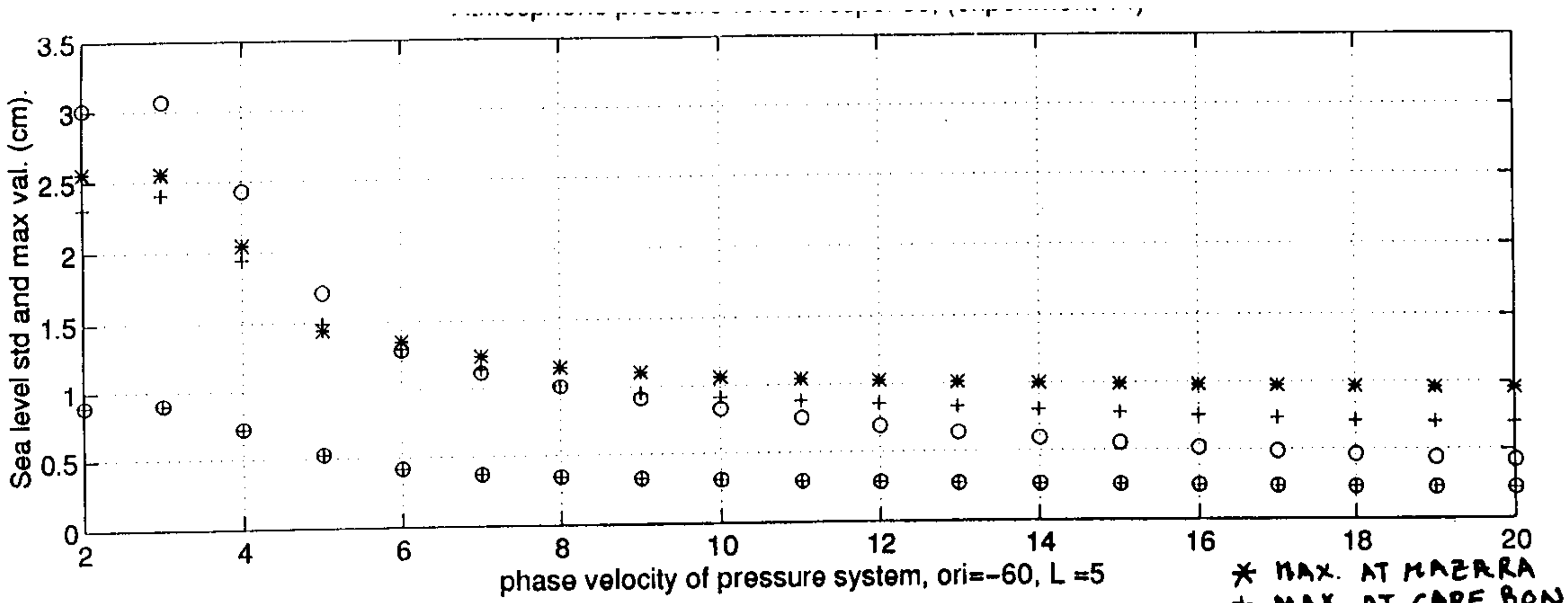
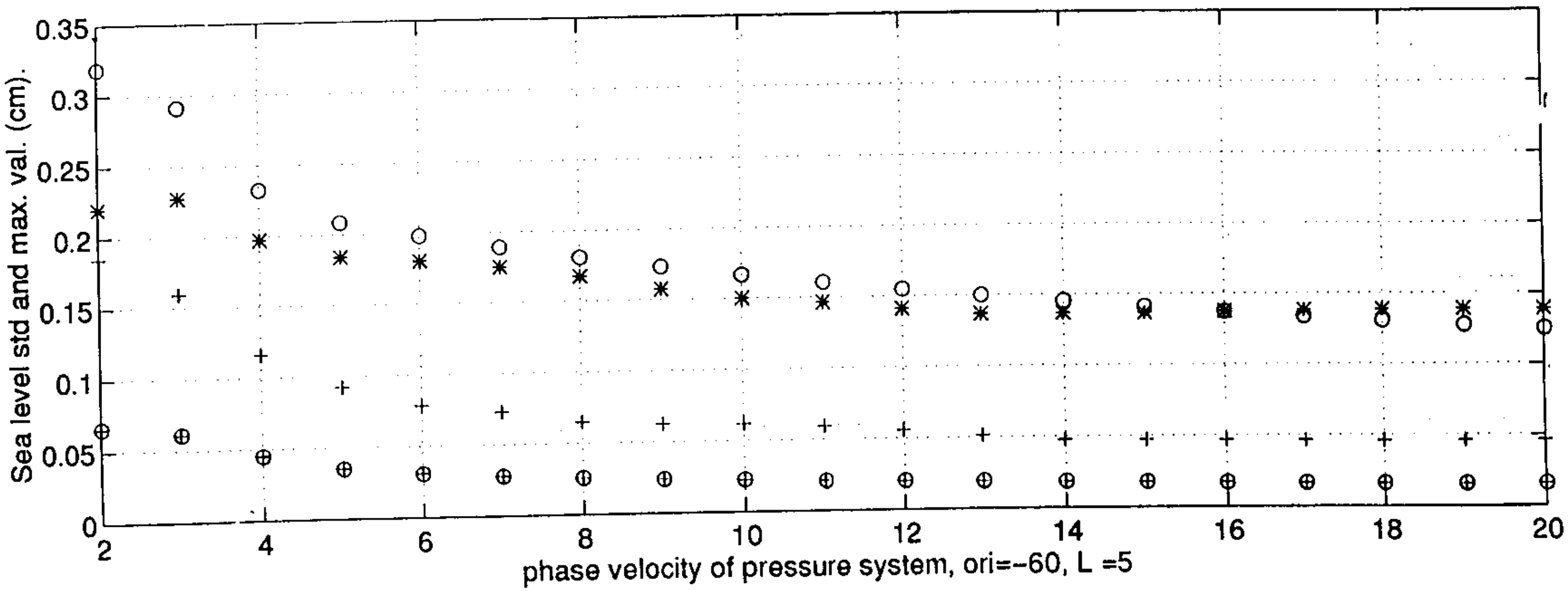
ap=1, we=0, exper=13
~22 d.o.f.
Mazara Power Spectral Density
Coherence
Transfer function magnitude
Cape Bon Power Spectral Density
Transfer function phase
Degrees
Frequency c/d
Frequency c/d



Wind forced response, (experiment 14)



PLATZMAN (1958)

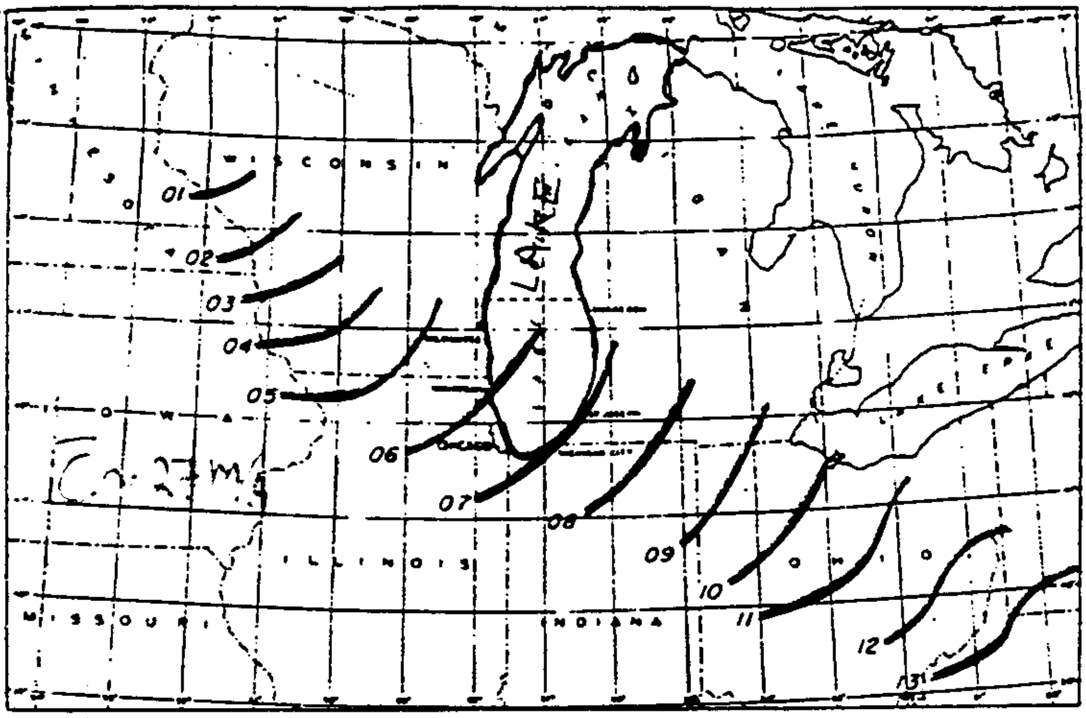
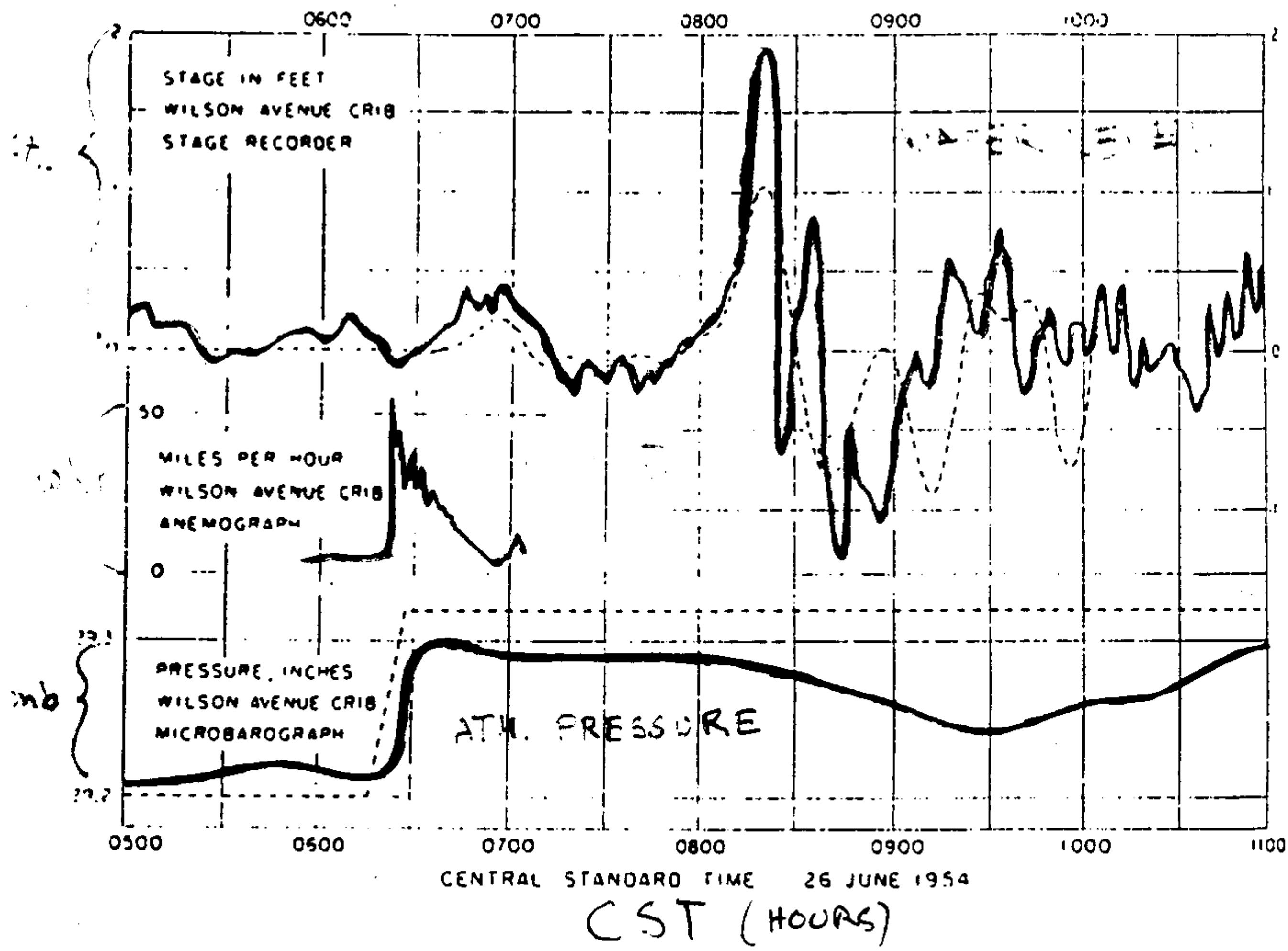


Figure 1. Isochrones of the pressure-jump line of 26 June 1954, in Central Standard Time (based upon an analysis by HOLLEYMAN, [6].



MONSERRAT ET AL. (1991)

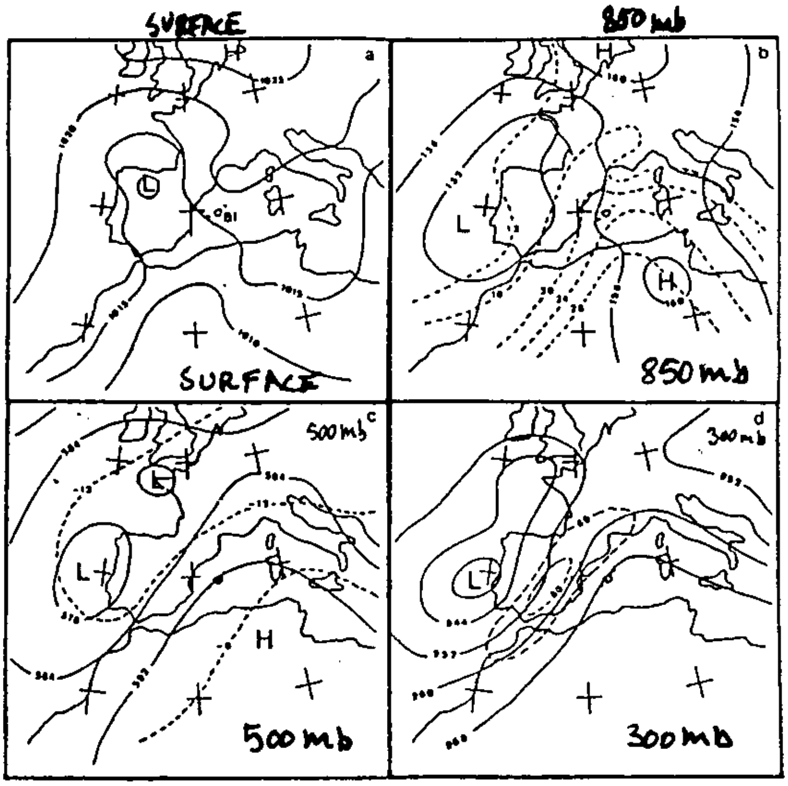


Fig. 3. Synoptic analysis corresponding July 6, 1989 at 0000 GMT. From the daily European Meteorological Bulletin. a) Surface, b) 850 mb, c) 500 mb, d) 300 mb. Dashed lines are isotherms in b) and c), and are isotachs in d). Balearic Islands are marked in a) with the letters BI.

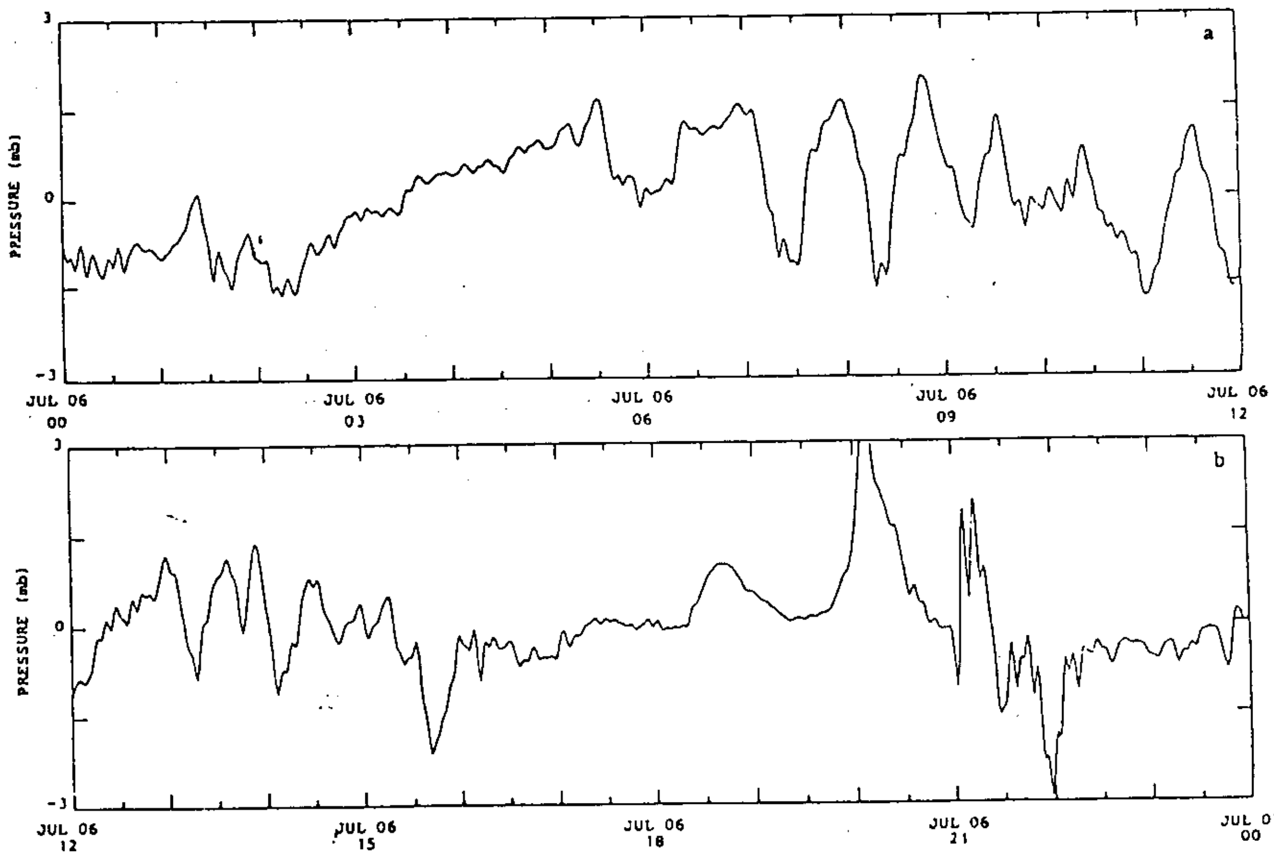
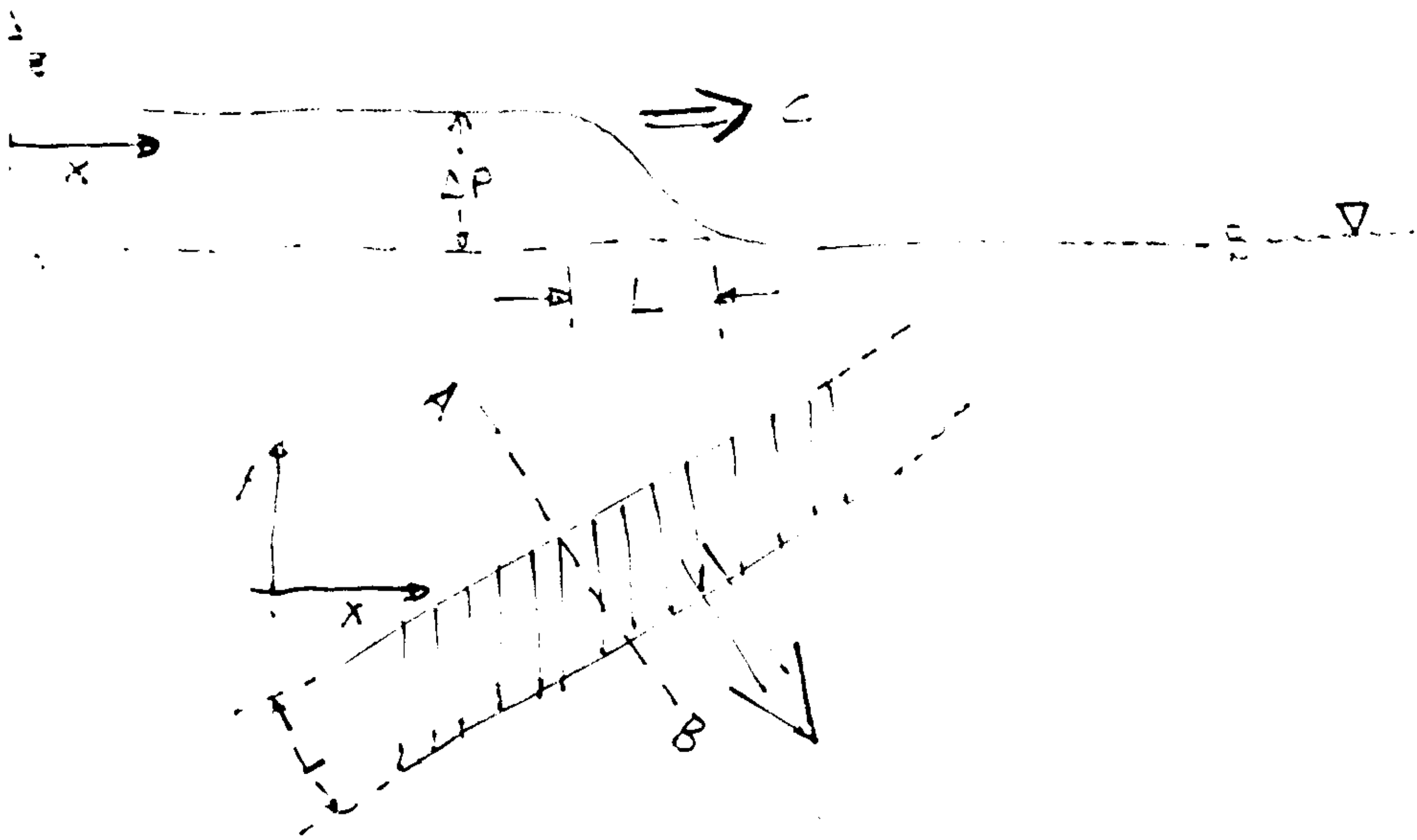


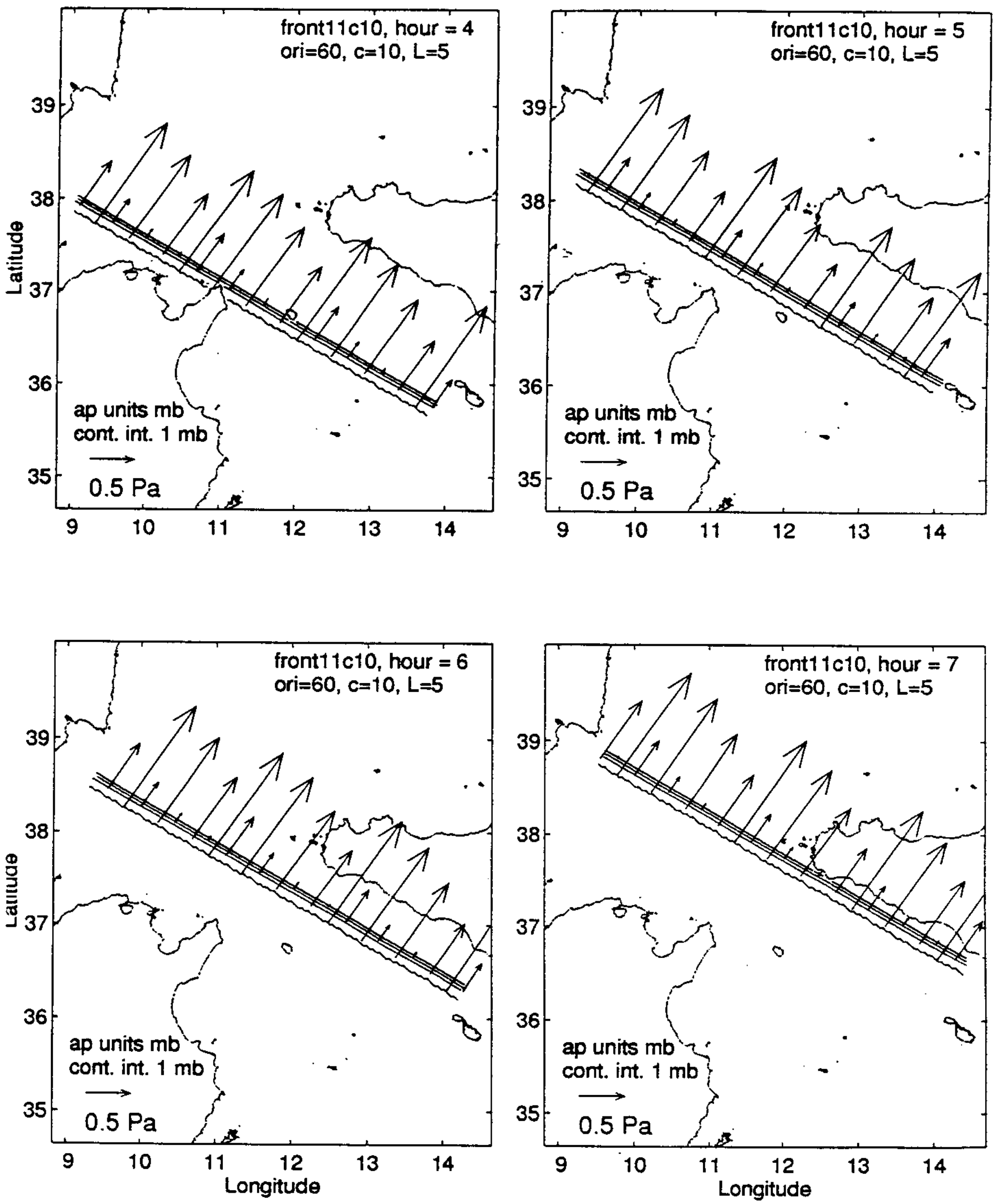
Fig. 1. Pressure trace in Ciutadella. a) From July 6 at 0000 GMT to July 6 at 1200 GMT, 1989. b) from July 6 at 1200 GMT to July 7 at 0000 GMT, 1989. Periods shorter than 5 min have been filtered

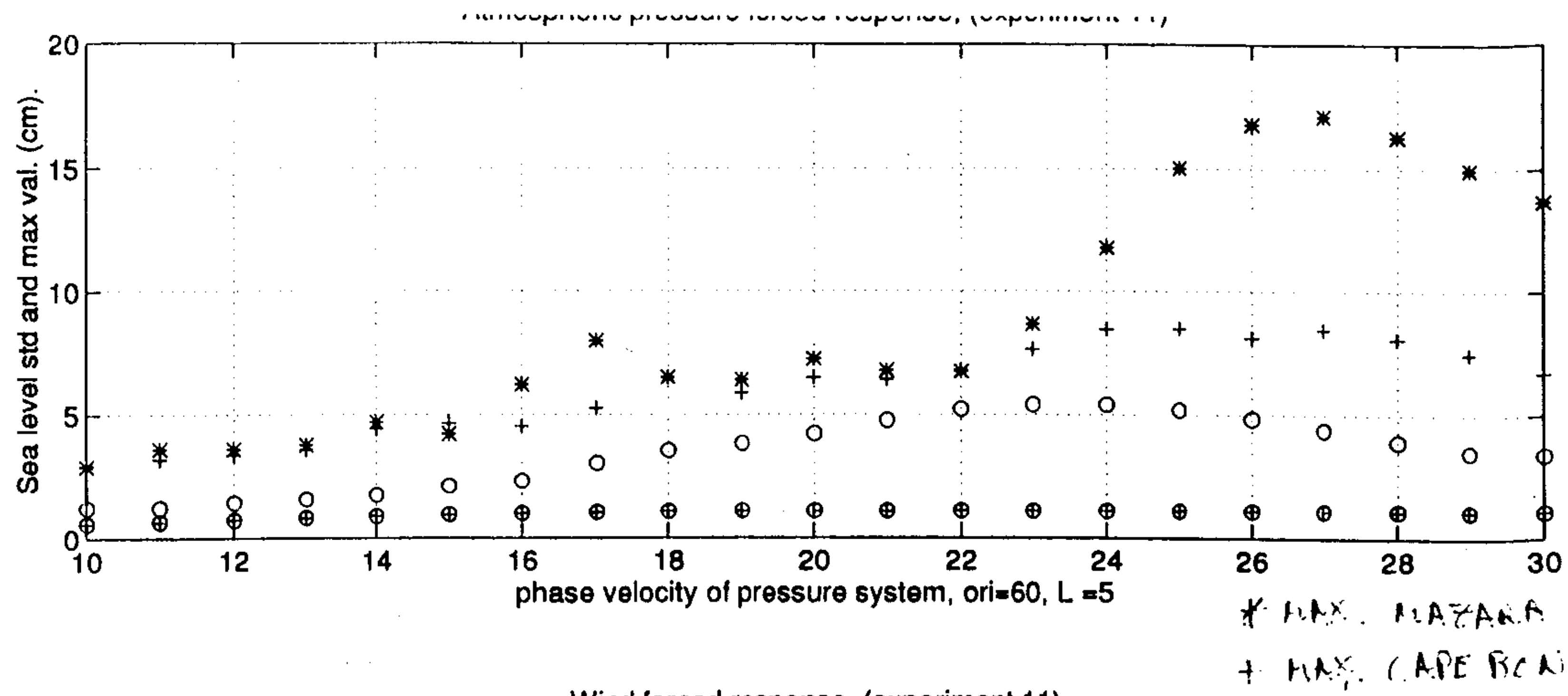
PROPAGATING PRESSURE JUMP IN THE ATMOSPHERE

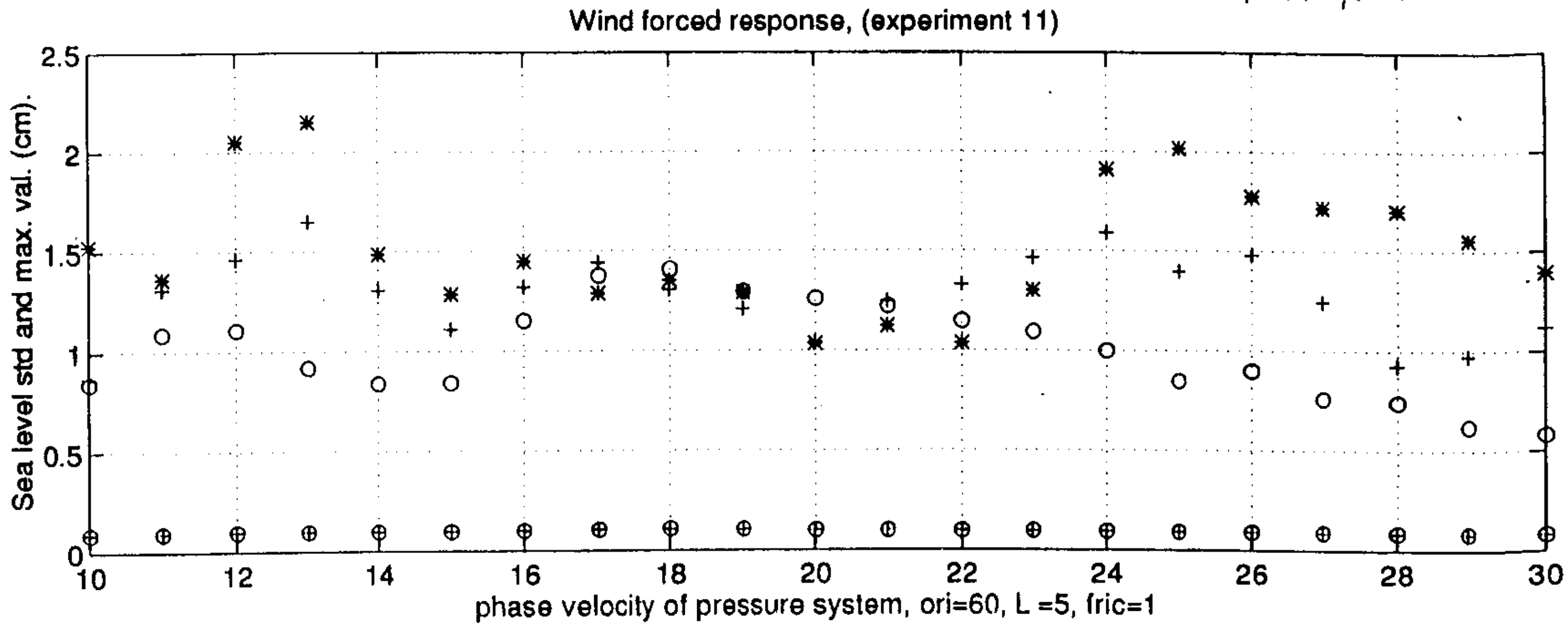


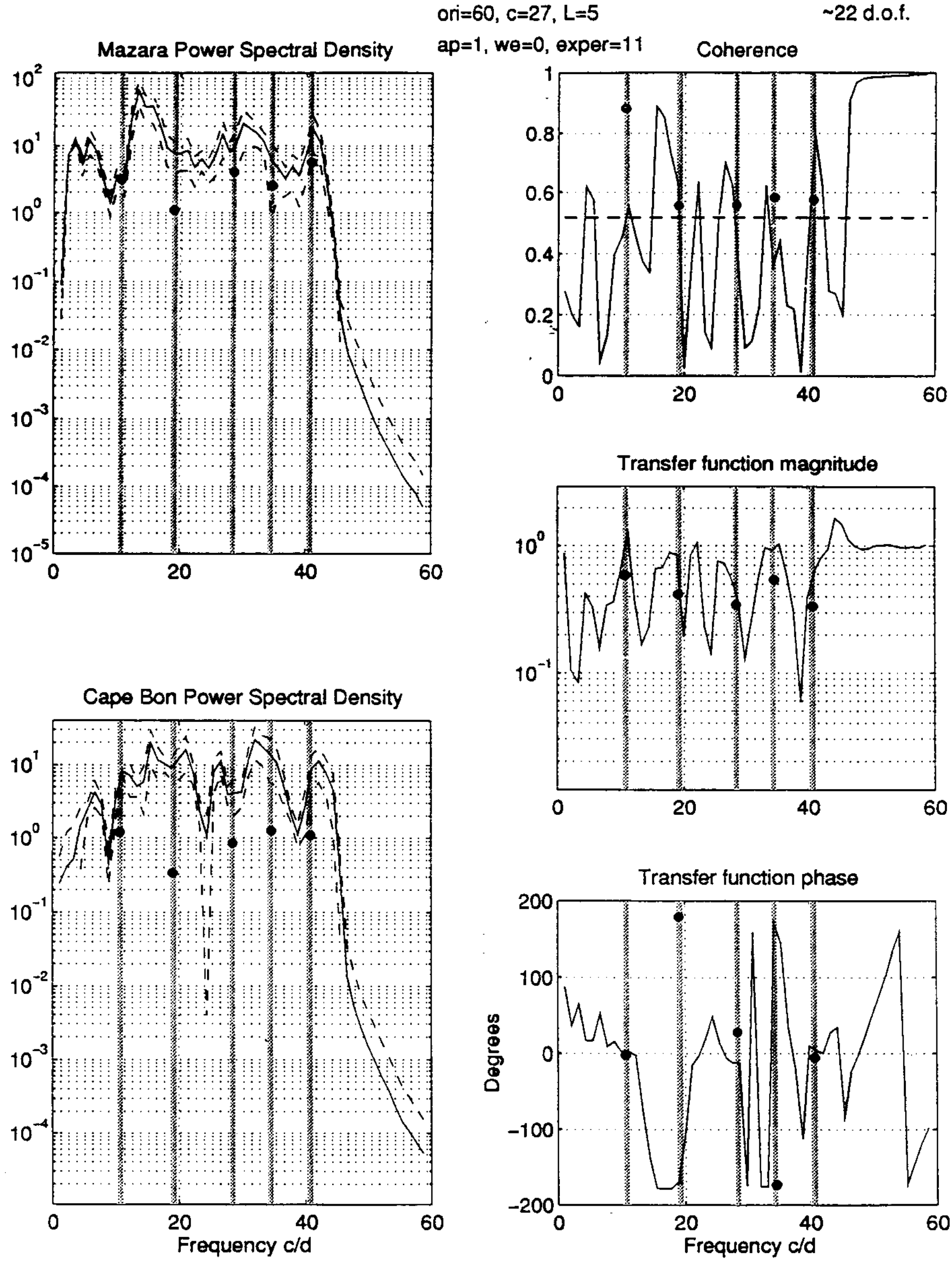
COUPLING BETWEEN FORCING AND RESPONSE

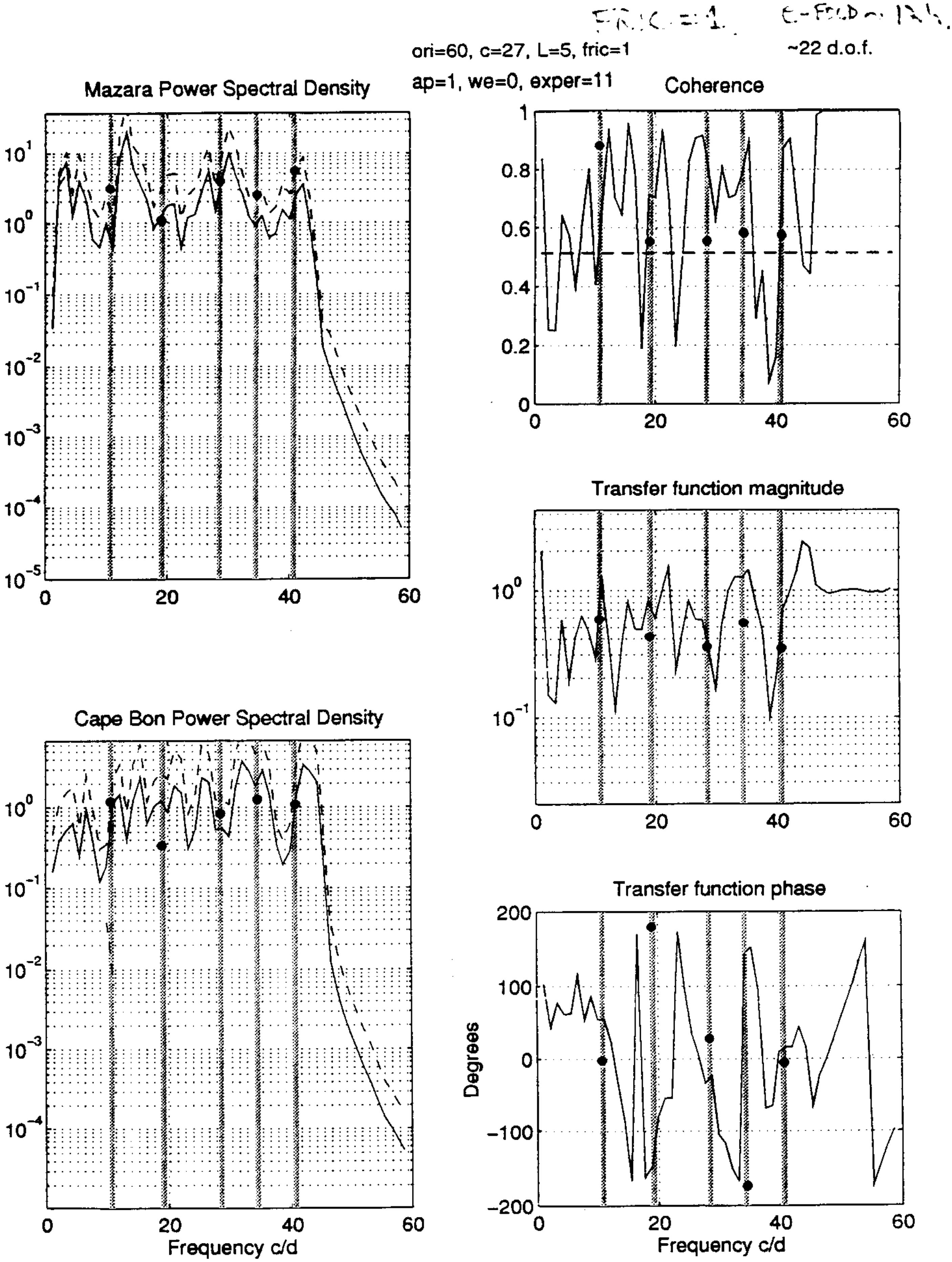
$\Delta P = 4$ mb ; $L = 20$ km.




Sea level std and max val. (cm).
phase velocity of pressure system, ori=60, L =5
MAX. MAZARA
MAX. CAPE


Wind forced response, (experiment 11)
Sea level std and max. val. (cm).
phase velocity of pressure system, ori=60, L =5, fric=1
FRIC = 1


ori=60, c=27, L=5
~22 d.o.f.
ap=1, we=0, exper=11
Mazara Power Spectral Density
Coherence
Transfer function magnitude
Cape Bon Power Spectral Density
Transfer function phase
Degrees
Frequency c/d
Frequency c/d


FRIC = 1
ori=60, c=27, L=5, fric=1
~22 d.o.f.
ap=1, we=0, exper=11
Mazara Power Spectral Density
Coherence
Transfer function magnitude
Cape Bon Power Spectral Density
Transfer function phase
Degrees
Frequency c/d
Frequency c/d

Conclusions.

- The ***Marrobbio*** has been characterized as a Regional gravitational phenomenon trapped to the Straits' topography.
- The ***Marrobbio*** in the Strait of Sicily can be excited by atmospheric gravity waves. Showing maximum response for waves propagating with phase velocities of around 27 m/s and approaching the strait along a southeast-northwest direction.
- Atmospheric pressure is the main forcing mechanism for the ***Marrobbio*** and produces a response of around an order of magnitude larger than the wind stress forcing.
- The developed methodology, based on the construction of the regional normal modes, is efficient and well adapted for studying the ***Marrobbio*** phenomenon.
- So far, this work has not explained The ***Marrobbio*** and its causes unambigously, however, it has provided enough evidence and raised well posed questions as to motivate future work.

Future work.

- Field work is required to characterize the atmospheric forcing and its causes. An experiment, based on the deployment of a small net of micro-barographs over the region, along with bottom pressure measurements in and out of the Port of Mazara is presently being planned.

IT IS
UNIVERSAL
(THE PHENOMENON)
OCCURS EVERYWHERE