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

"The Adriatic Sea Coastal and Open Ocean System: A Study Case"

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Italy

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

The Adriatic Sea coastal and open ocean system: a study case

by

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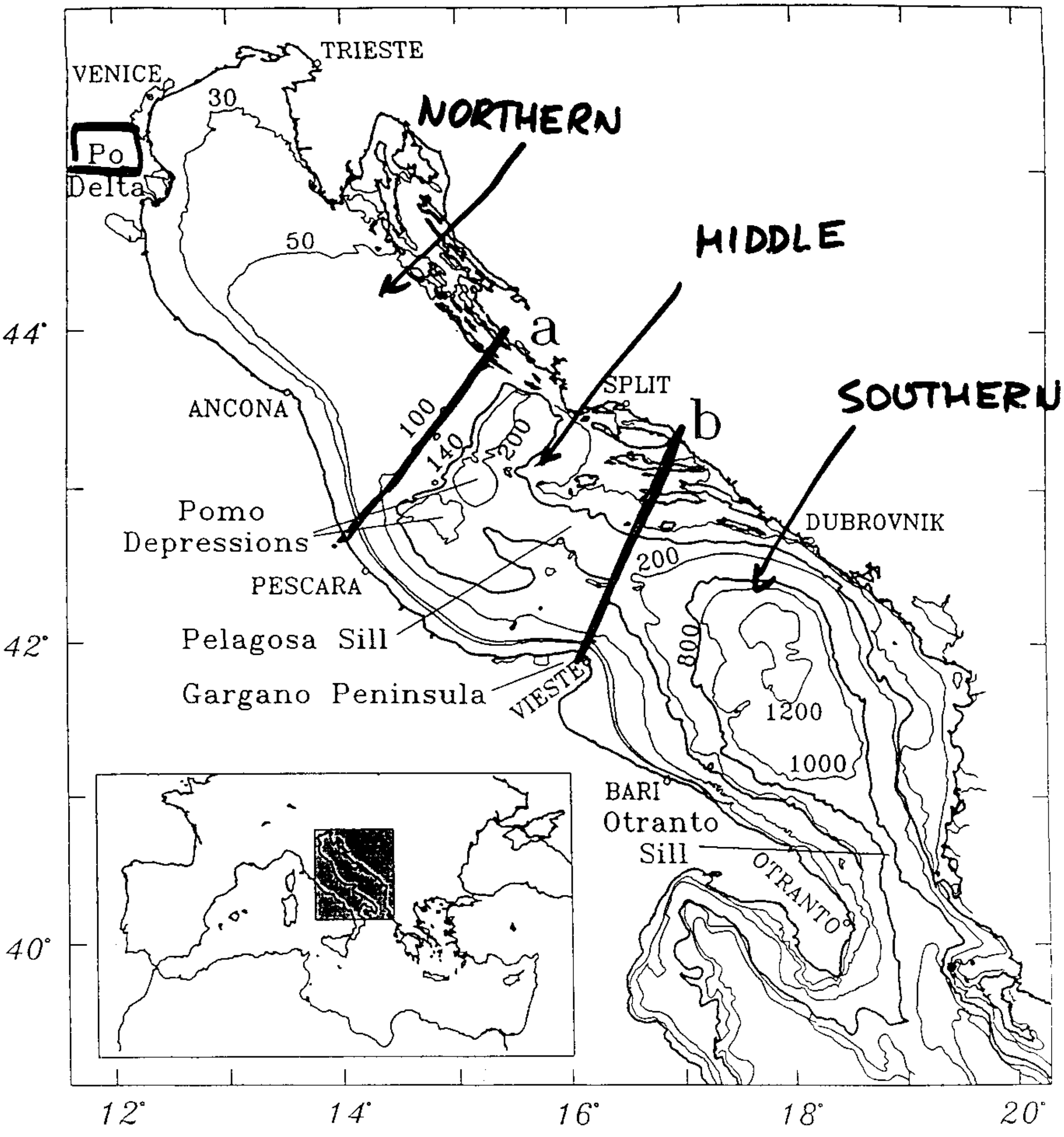
Subdivided in:

1) Observational evidence of the general circulation
2) Meteorological conditions and air-sea interaction studies
3) Modelling of the general circulation with climatological forcings
4) Effects of bottom boundary layers on the coastal and open ocean circulation
5) Biogeochemical cycles and ecosystem modelling

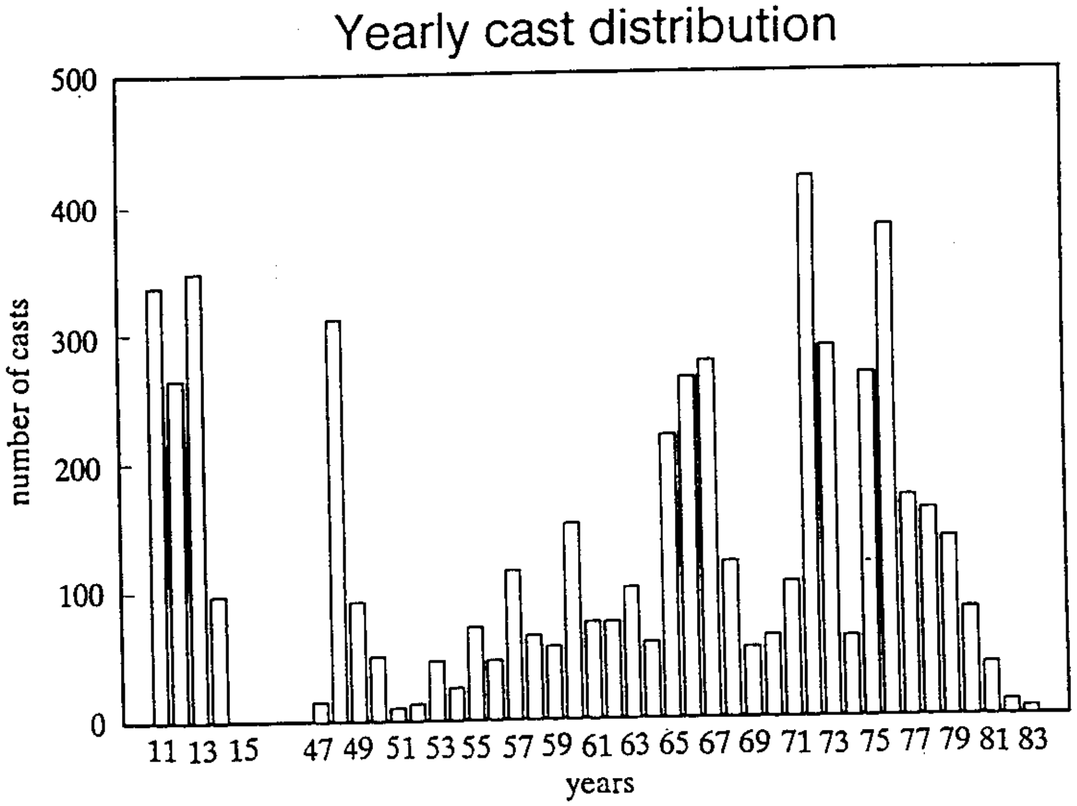
BATHYMETRY & GEOMETRY



- * large shelf area for the Mediterranean
- * deep to very deep areas within the basin
- * narrow continental shelf on the Eastern side, steep; less on western side

OBSERVATIONS OF HYDROGRAPHY

ATOS-1 data set



Artegiani et al., JPO, in press, June 1997
Part I and Part II

FIG. 4

CLIMATOLOGICAL ADRIATIC DATA SET (7000-10'00
(HYDROGRAPHY + BIOCHEMICAL PARAM.) CASTS)

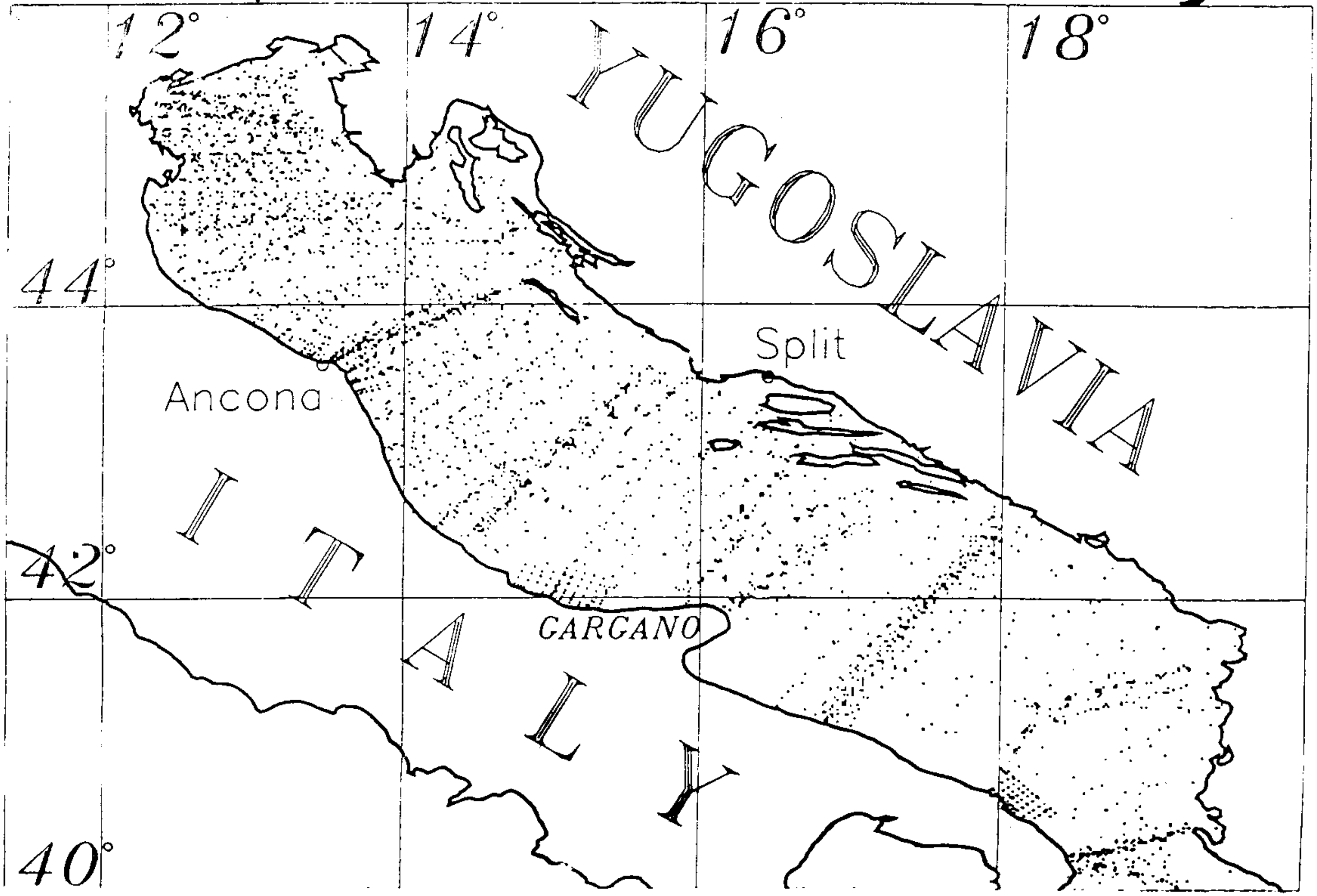


Fig 8

— WINTER — SUMMER
— SPRING — AUTUMN

SHALLOW DYNAMICS REGION

NORTHERN ADRIATIC (DEPTH < 100m)

INTERMEDIATE REGION

CENTRAL ADRIATIC

DEEP OPEN OCEAN REGION

SOUTHERN ADRIATIC

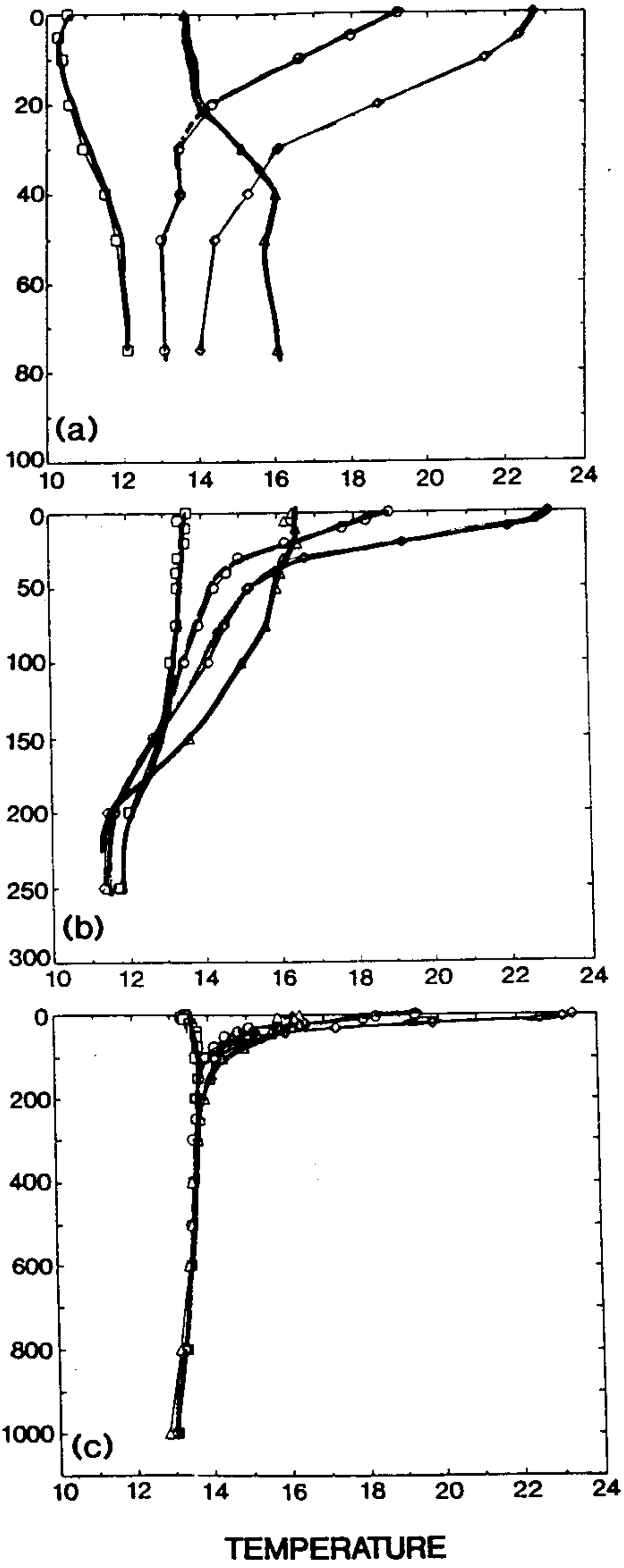


FIG.6

— WINTER — SUMMER

— SPRING — AUTUMN

RIVER RUNOFF INFLUENCE

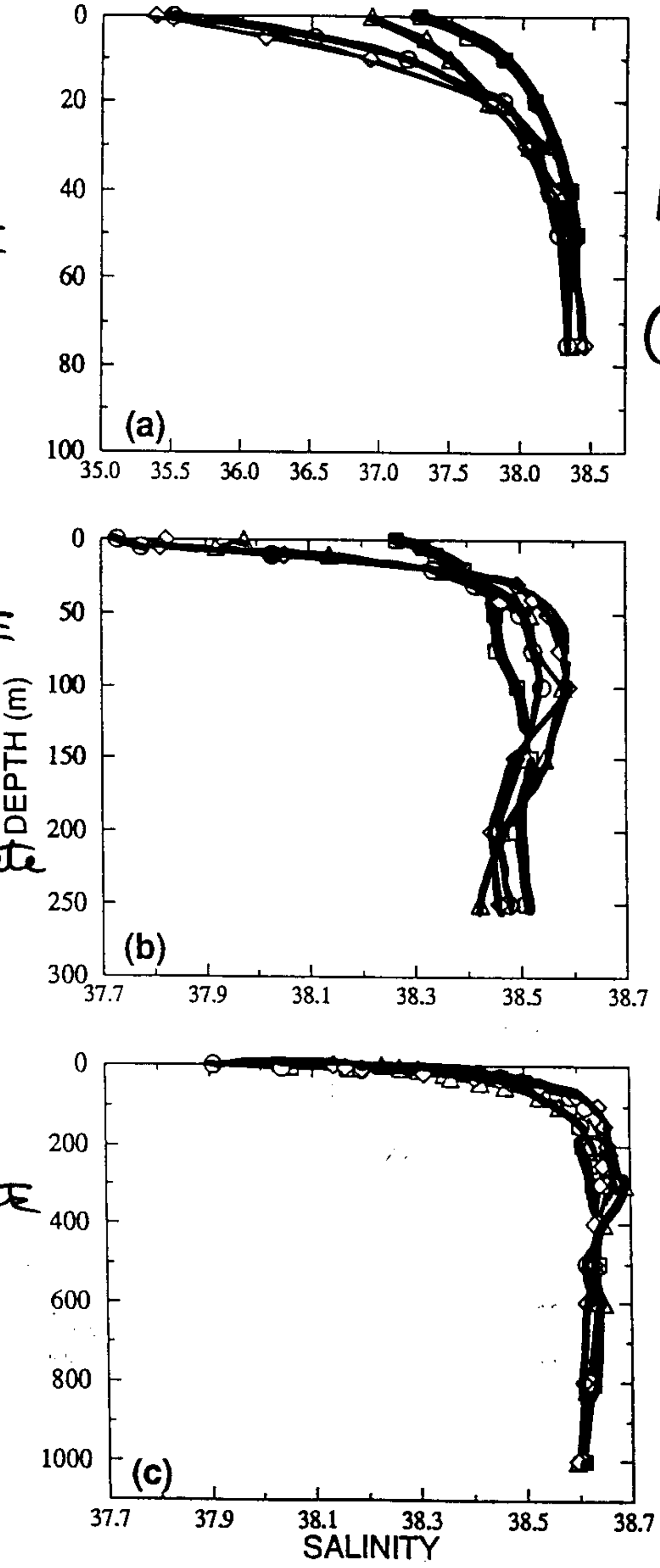
NORTHERN ADRIATIC (DEPTH < 100 m)

SUBSURFACE SALINITY MAXIMUM (Levantine Intermediate Water)

MIDDLE ADRIATIC

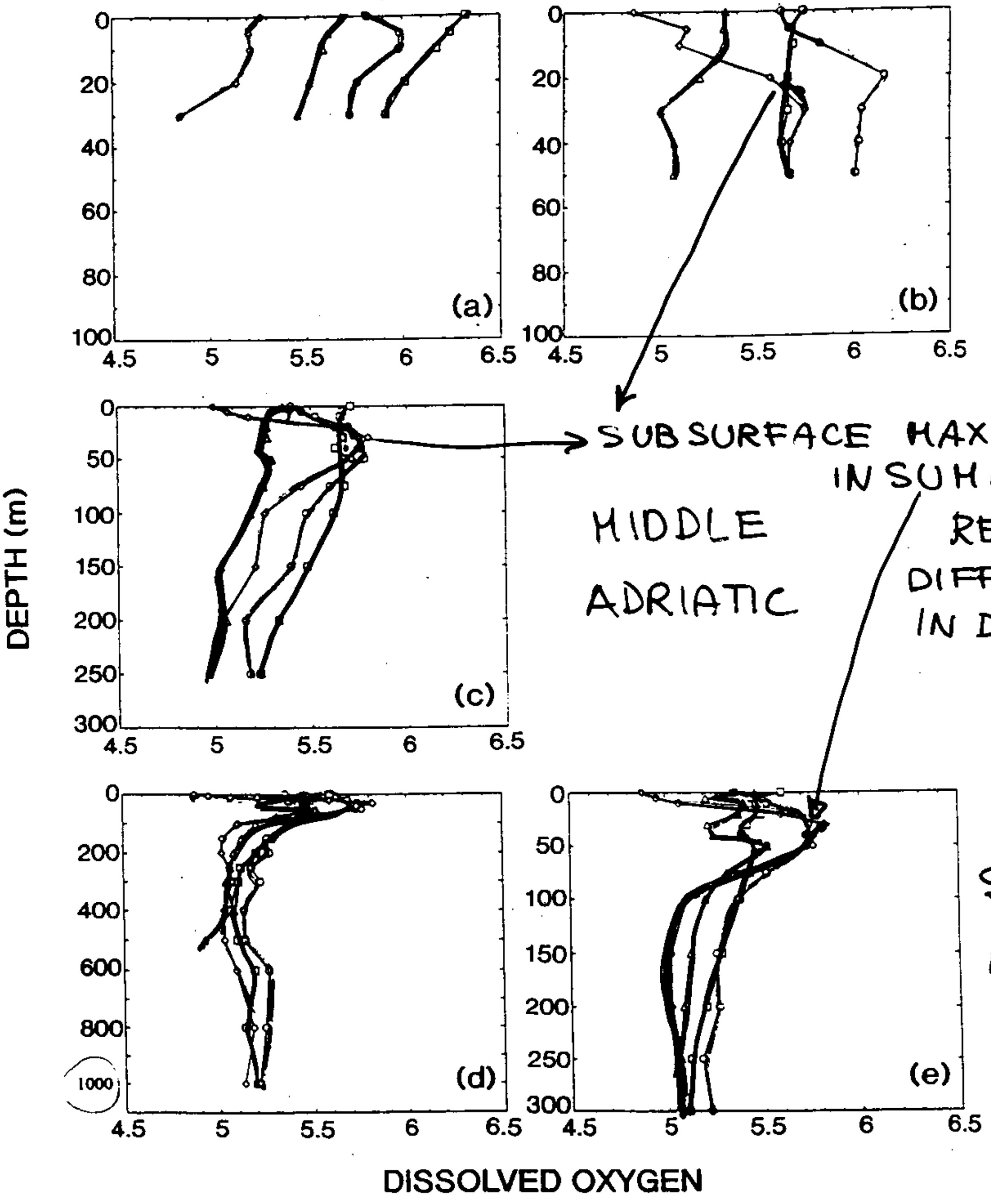
SUBSURFACE SALINITY MAXIMUM (LIW)

SOUTHERN ADRIATIC



WELL OXYGENATED BASIN

DEPTH <40m DEPTH >40m



NORTHERN ADRIATIC

MIDDLE ADRIATIC

SOUTHERN ADRIATIC.

SUBSURFACE MAXIMUM IN SUMMER, REINFORCES DIFFERENCES IN DYNAMICS

— WINTER -. SUMMER

— SPRING — AUTUMN

FIG. 9

TEMPERATURE FLD'S
SURFACE

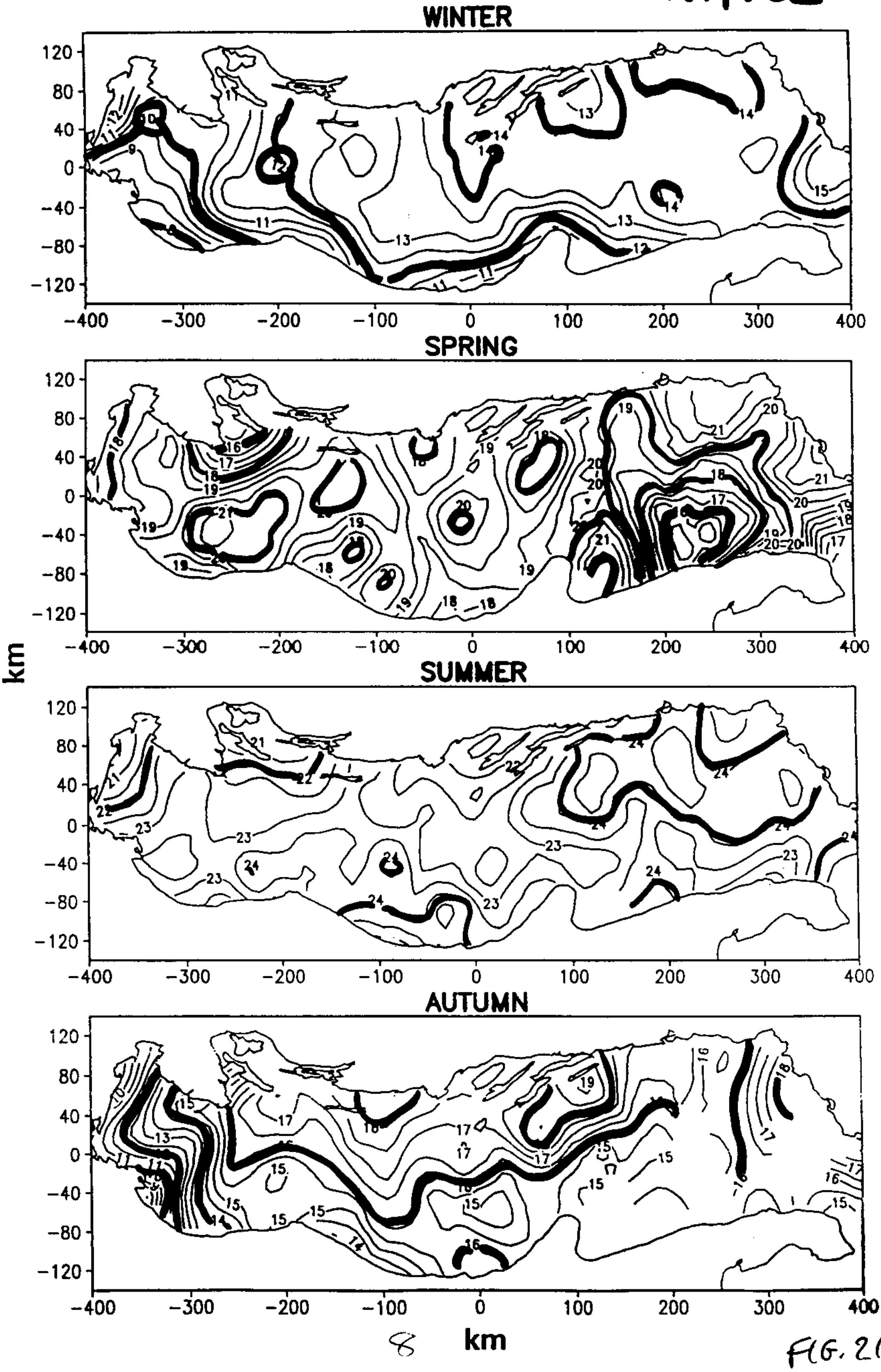


FIG. 2(a)

SALINITY FIELDS

SURFACE

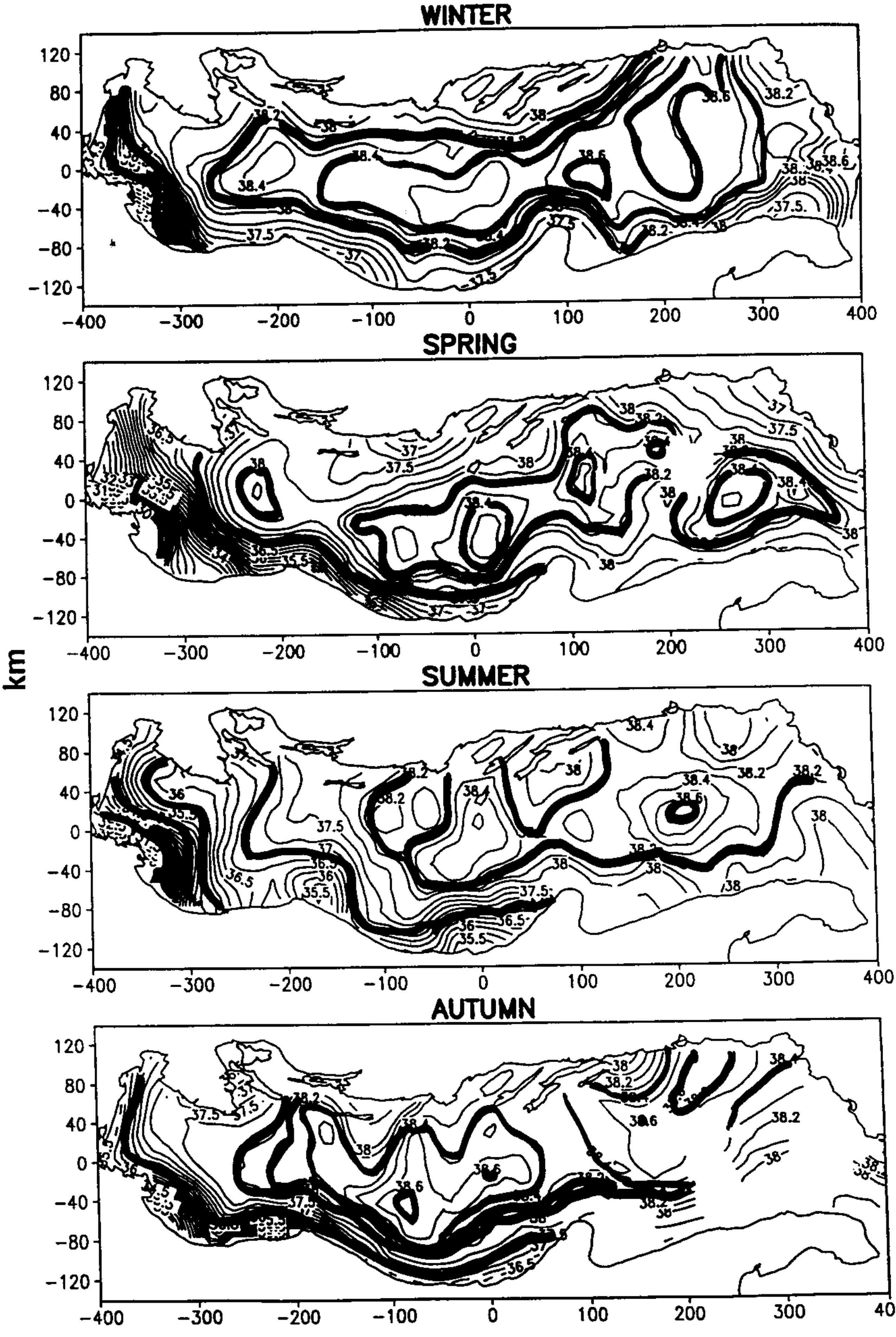
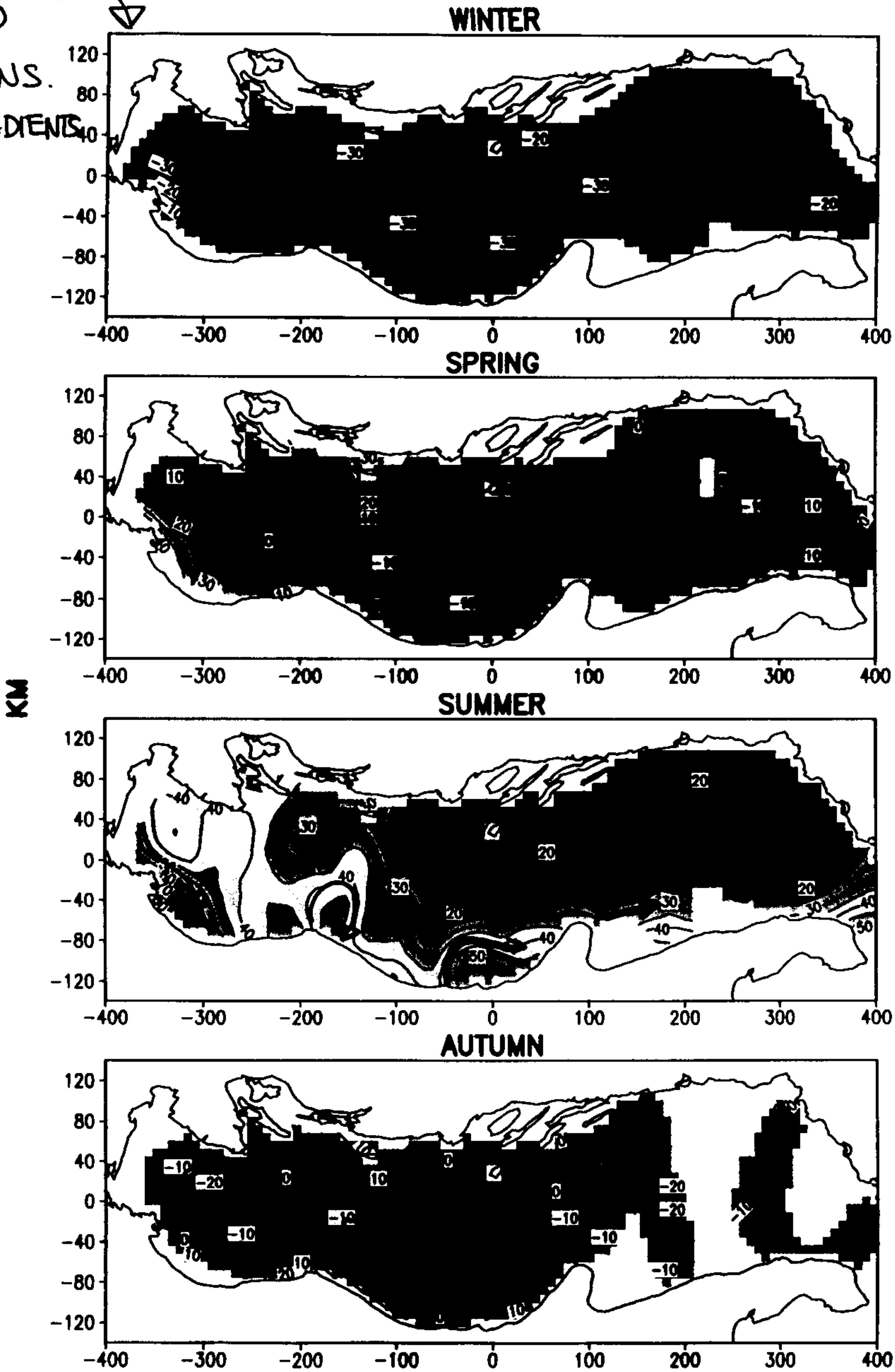


FIG. 2(b)

DYNAMIC HEIGHT AT SURFACE REFERRED TO 30 M.

ALMOST NO DENS. GRADIENTS



DYNAMIC HEIGHT AT SURFACE
REFERRED TO 140m.

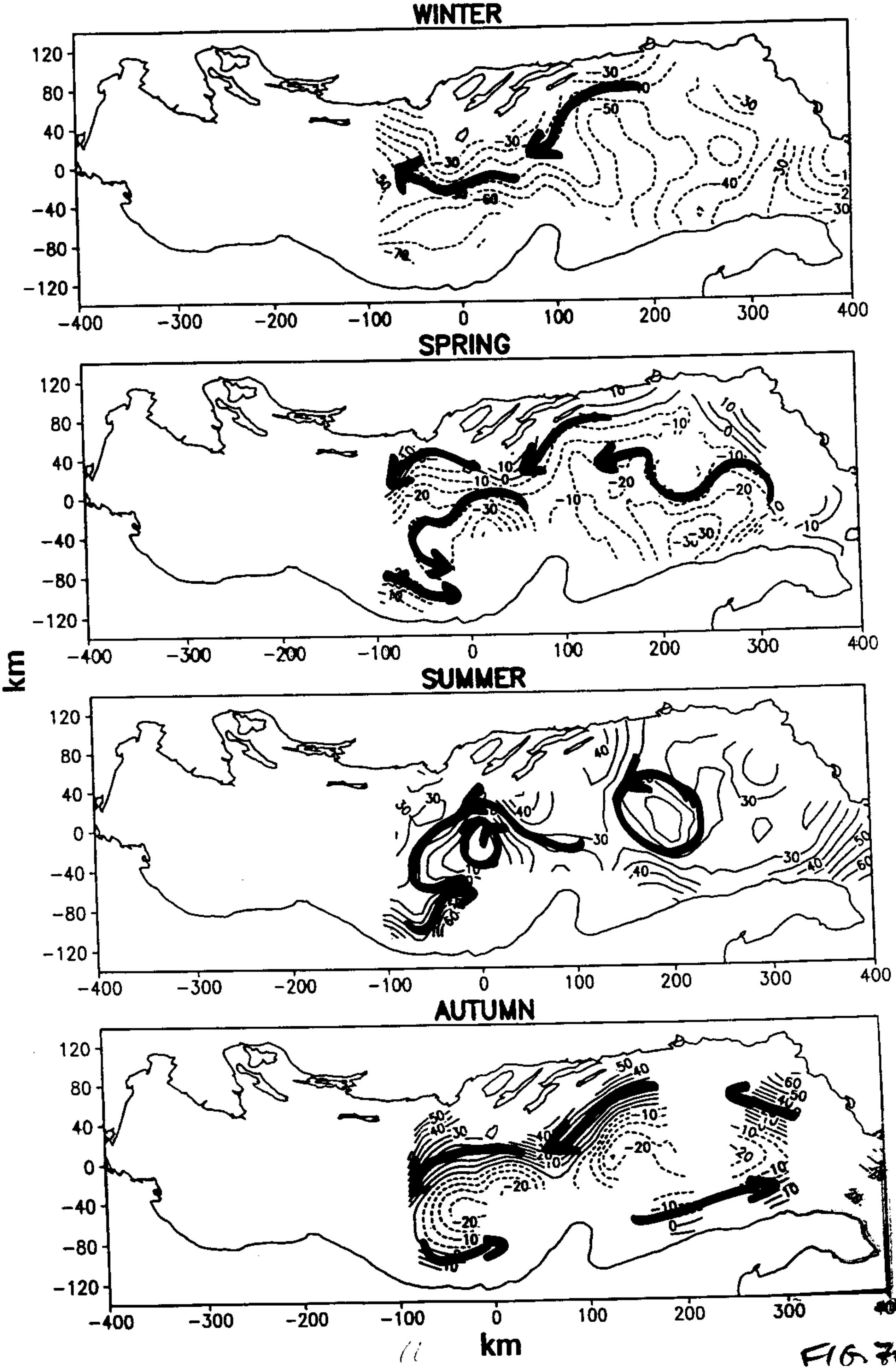
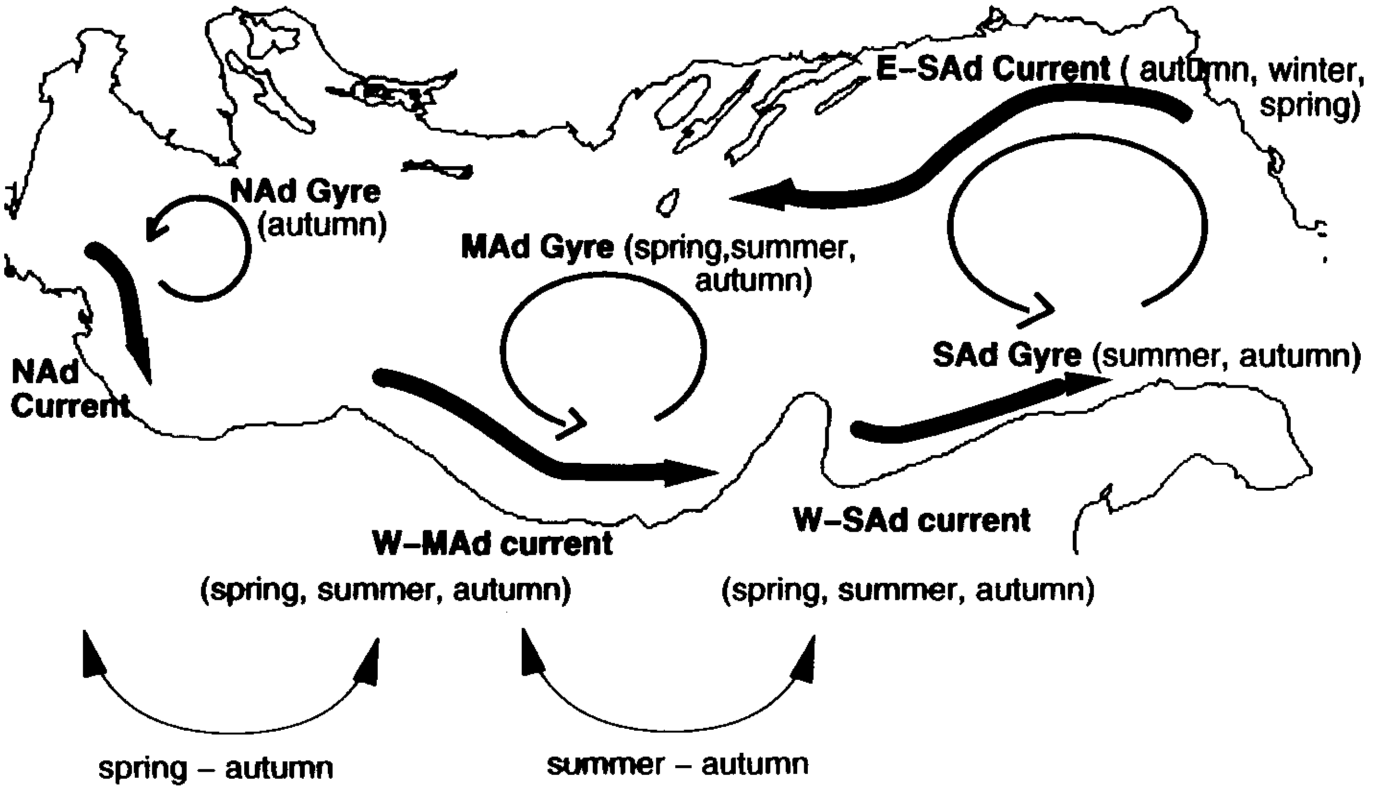
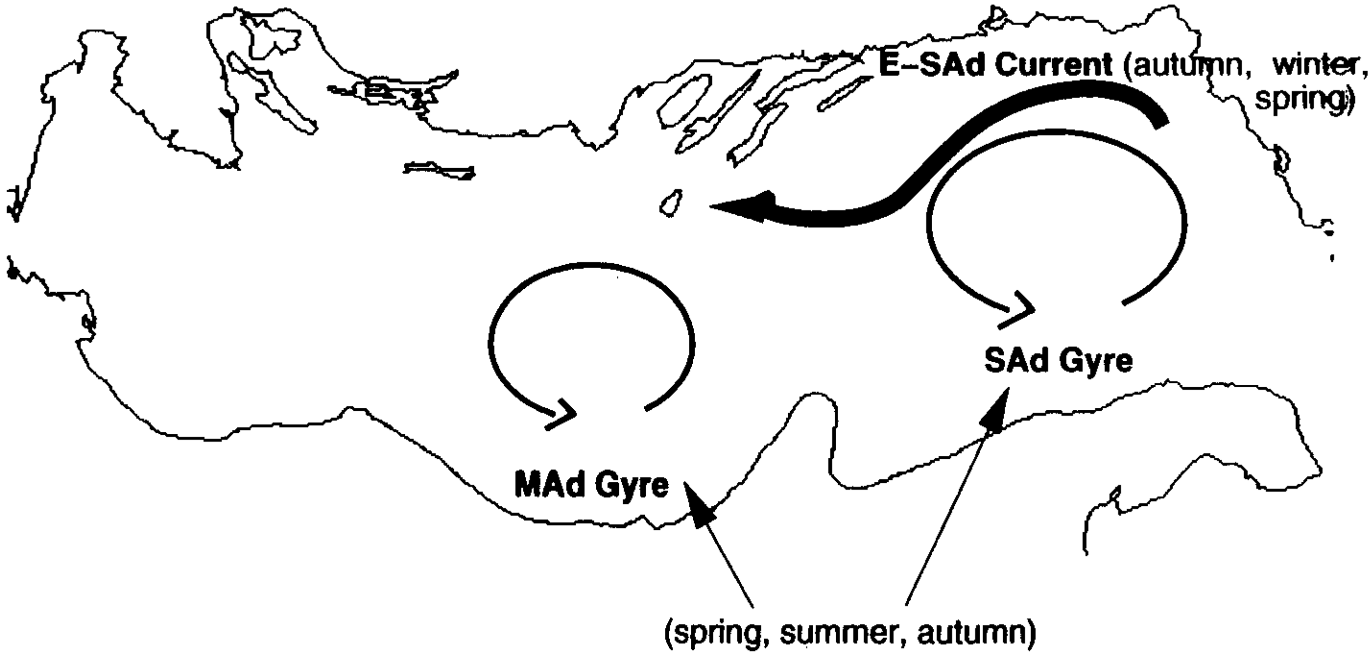


FIG. 7(b)

SURFACE



UPPER THERMOCLINE (75 m.)



SUMMARY OF HYDROGRAPHIC PROPERTIES

1) Basin has 3 distinct hydrographic structures
   - * Northern : seasonal cycle penetrates to bottom
   - * Middle: some deep structure persists throughout the year – transitional
   - * Southern: open ocean region, seasonal cycle down to 150 m only

2) Salt gradients always present and low salinity waters from run-off dominate also in the south

3) Winter density gradients are small due to COMPENSATION BETWEEN SALT & TEMPERATURE

4) GENERAL CIRCULATION CYCLONIC but with sub-basin structures, jet segments which are seasonal as well as gyres

VARIABILITY IMPORTANT!

METEOROLOGICAL CONDITIONS AND AIR-SEA FLUXES

* Need to define the overall basin heat budget, e.g.,

$Q = Q_S$ short wave radiation flx

$-Q_B$ long wave radiation flx

$-Q_H$ sensible heat flx

$-Q_E$ latent heat flx

how much is $\overline{\langle Q \rangle}^{time}_{area}$?

* Need to define water budget

$$W = E - P - R$$

E = evaporation $\left(\frac{m}{yr}\right)$

P = precipitation "

R = river run-off

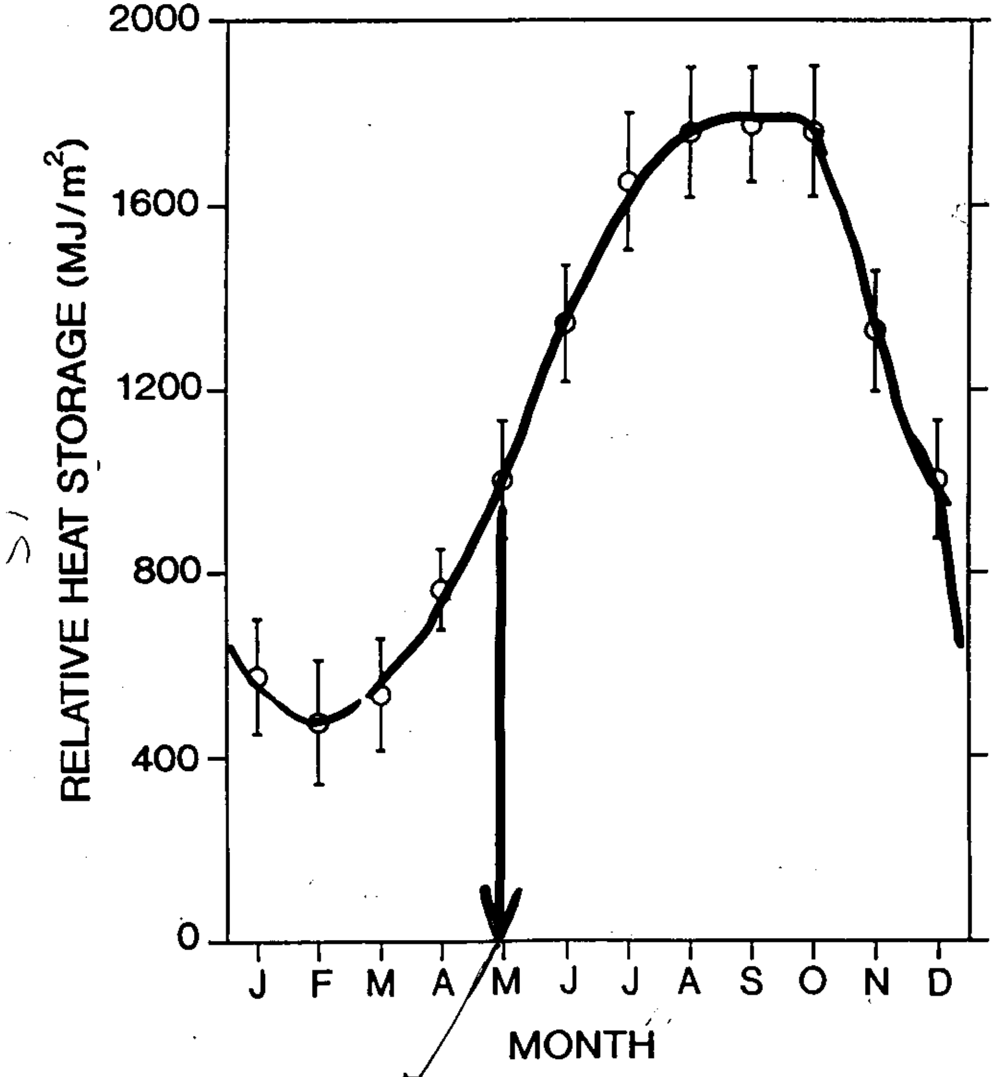
* Need to define WIND STRESS

$$\vec{\tau}_W = C_D \, |W| \, \vec{W}$$

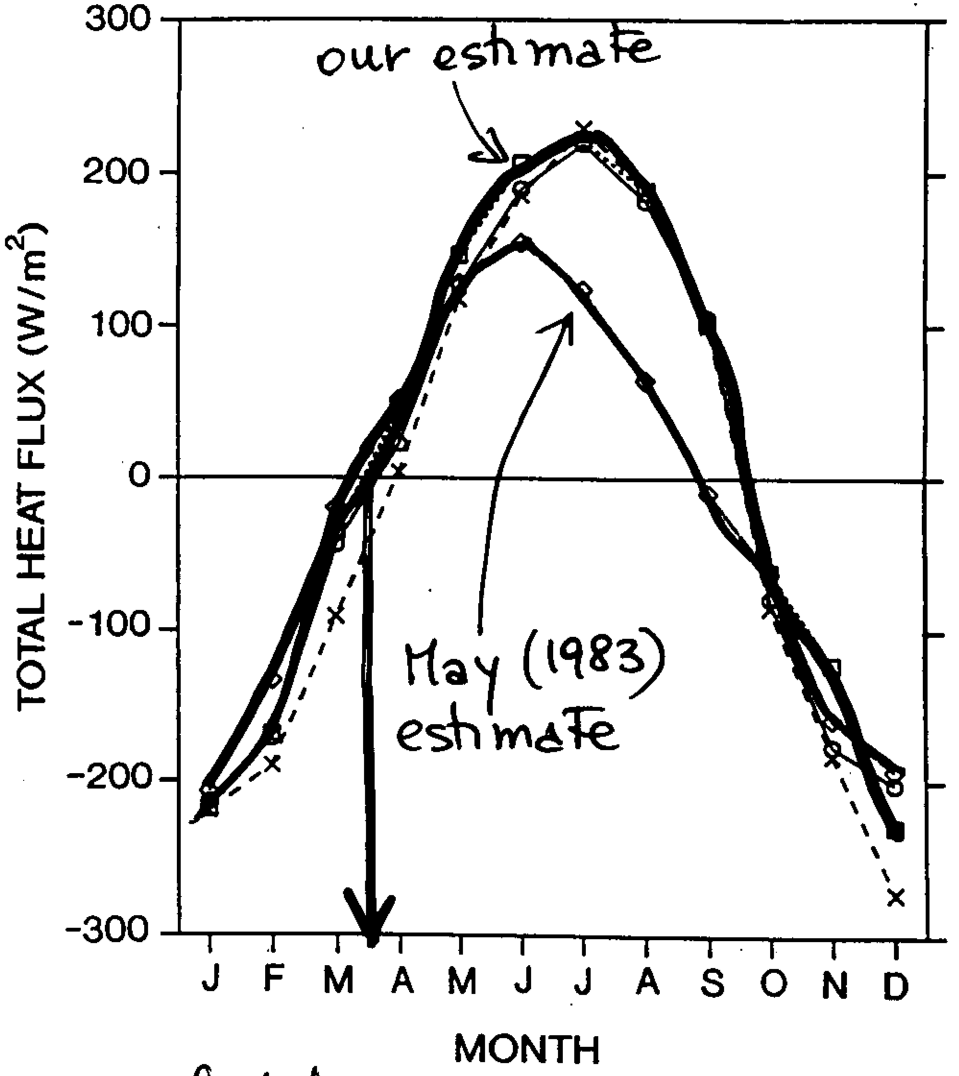
W = 10 m. winds

HEAT STORAGE

$$HS = \frac{D}{H}\int_{-H}^{0} c_p\rho\,(T-T_o) \text{ or } \int_{-D}^{0} c_p\rho\,(T-T_o) \text{ for } H<D$$



ANNUAL CYCLE ON
HEAT FLUX
AVERAGE ~ -20 W/m²



HS ~ 1.5-2 mouth shifted with respect to heat budget

Heat Storage equation

starting from

$$\frac{\partial T}{\partial t} + \vec{\nabla}\cdot(\vec{v}_3 T) = K_H \nabla^2 T + K_V \frac{\partial^2 T}{\partial z^2}$$

and defining

$$HS = \int_{-D}^{0} \rho C_p (T - T_0)\, dz$$

we have

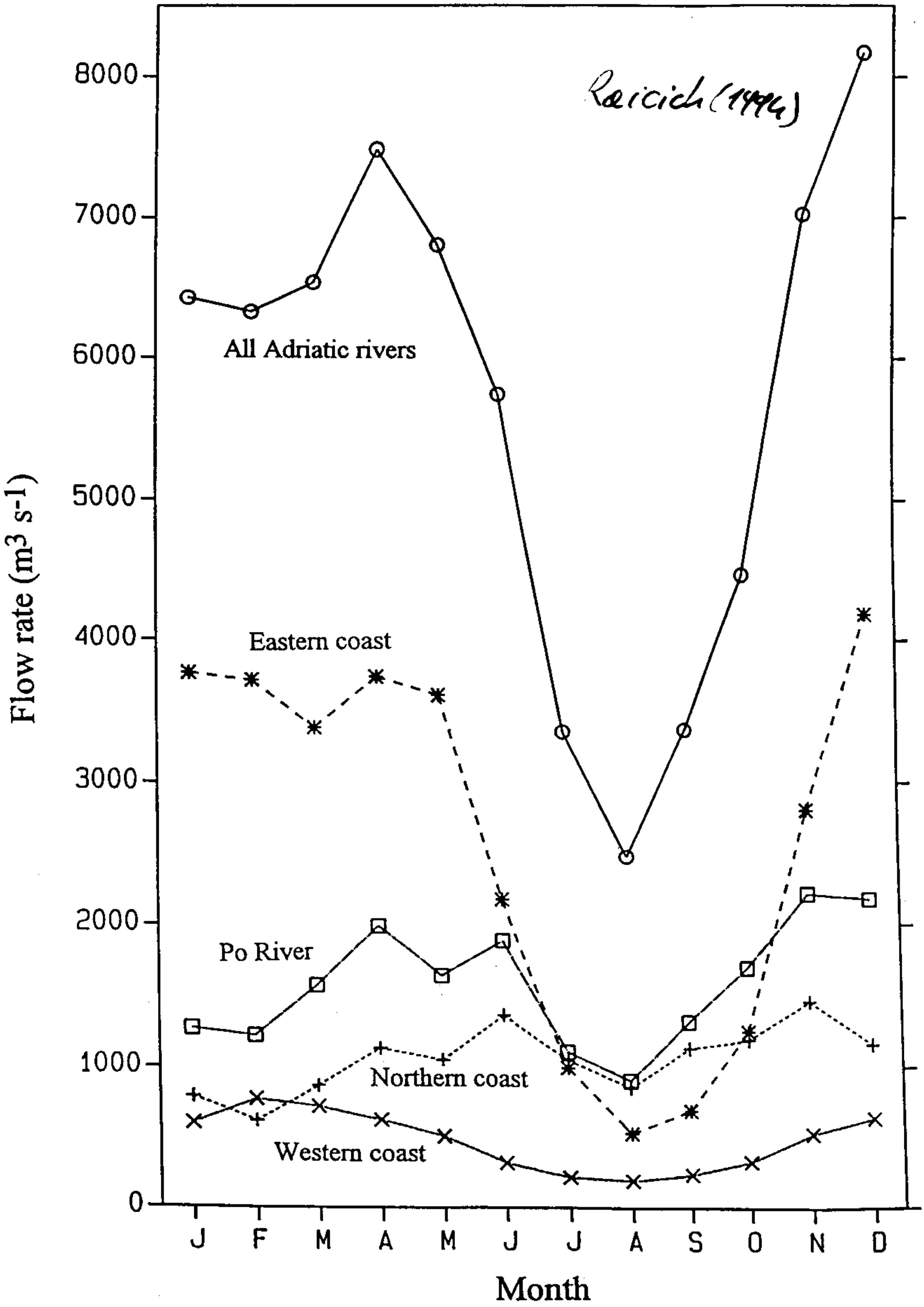
$$\frac{\partial HS}{\partial t} + \vec{\nabla}\cdot(\vec{v}_2 HS) + \overset{\text{rigid lid}}{\cancel{wHS\big|_0}} - wHS\big|_{-D} = K_H \nabla^2 HS + \mathbf{Q} - K_V \frac{\partial HS}{\partial z}\Big|_{-D}$$

where $K_V \frac{\partial T}{\partial z} = Q$, the heat flux.

Integrating on the area and simplifying

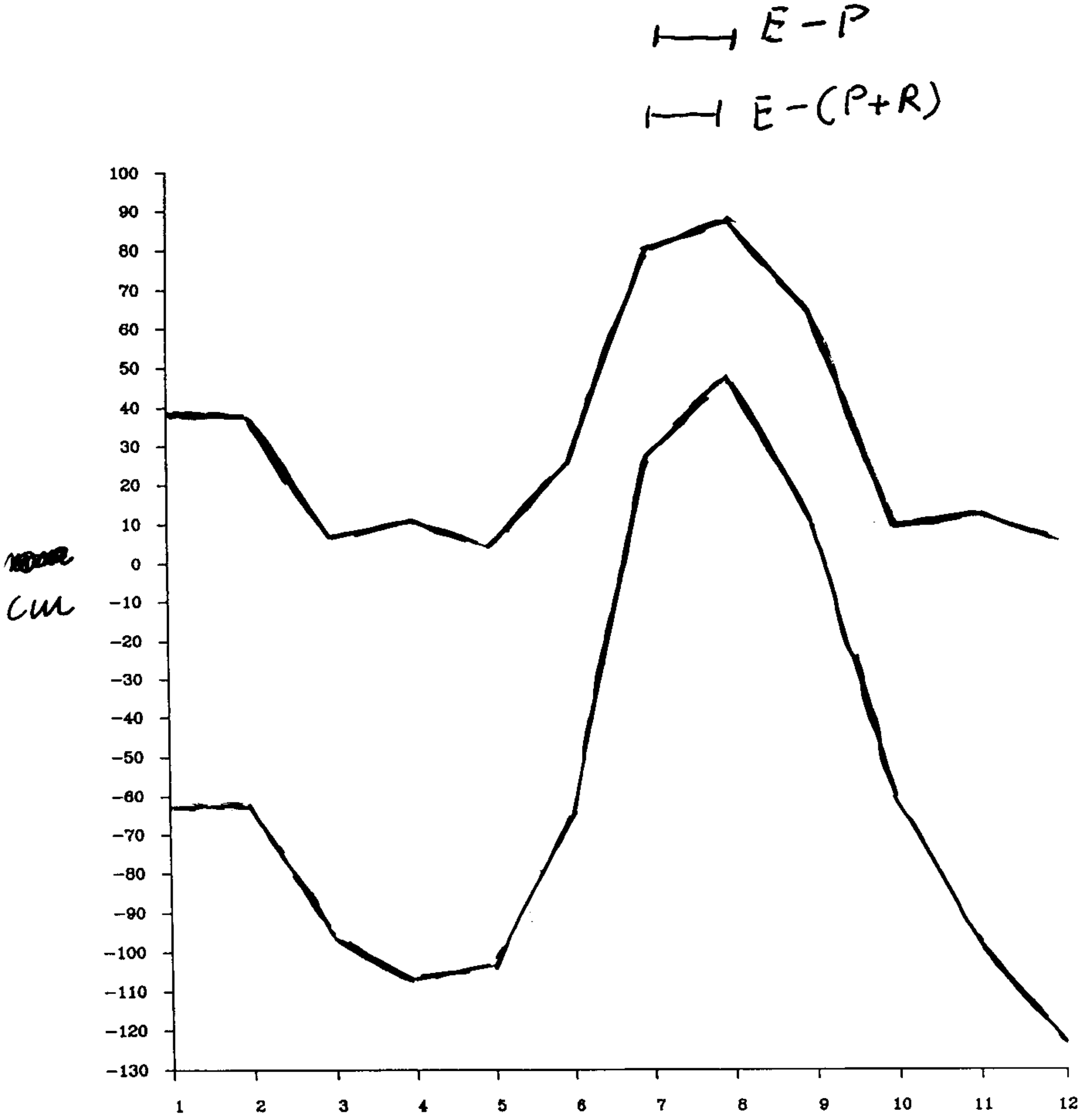
$$\frac{\partial}{\partial t}\iint HS\, dA = \iint \mathbf{Q}\, dA - \int_{\text{Otranto}} \vec{v}_2\cdot\vec{n}\, HS\, ds + \int_{\text{Otranto}} K_H \vec{\nabla}(HS)\cdot\vec{n}\, ds$$

If no Otranto then HS and Q would be exactly 3 months out of phase. Otherwise Otranto contributes and shifts differently



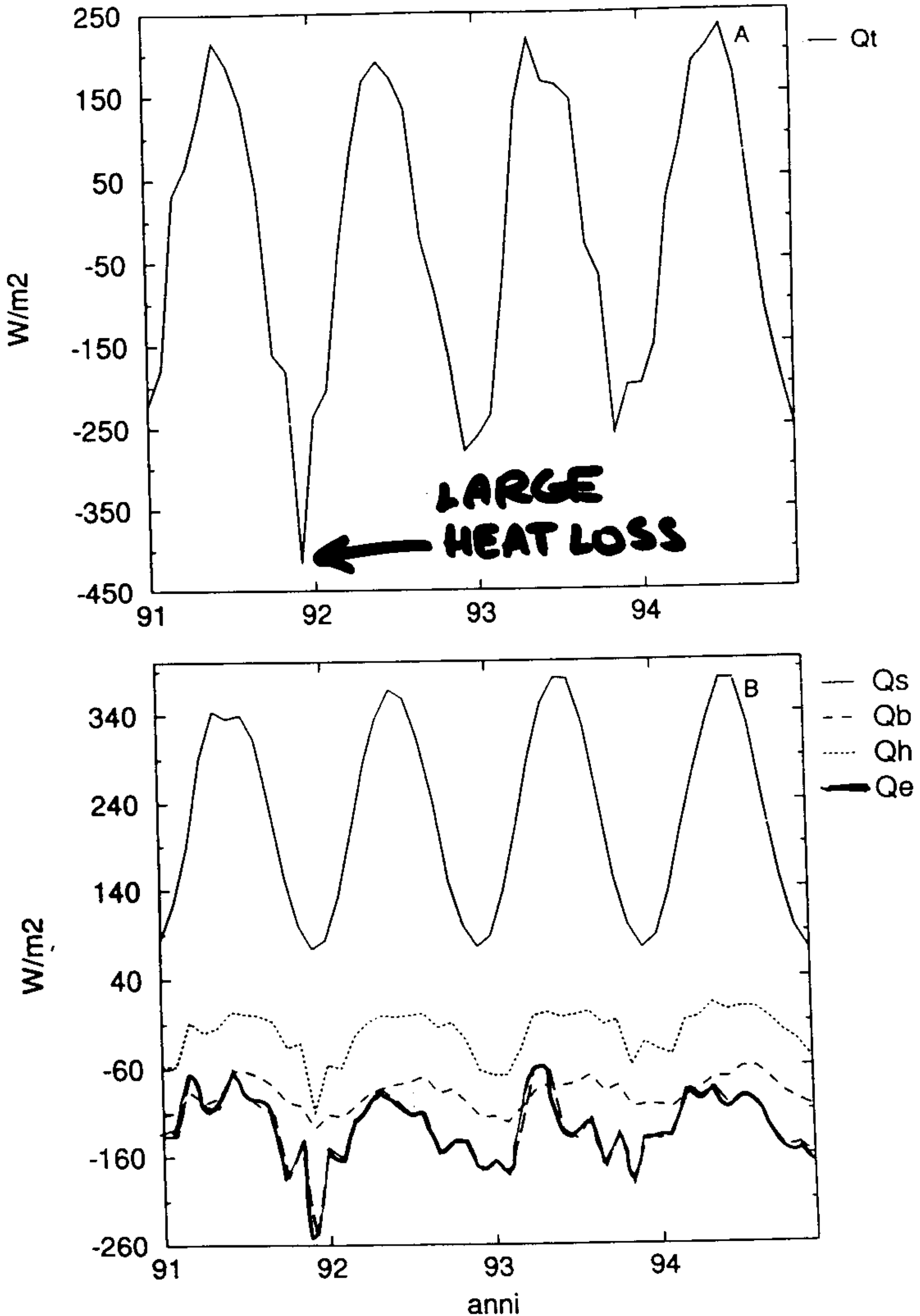
Raicich (1994)

Fig. 2 - Monthly average flow rates of the Adriatic rivers.



BASIN GAINS WATER BY RIVER RUN-OFF CONTRIBUTION

INTERANNUAL VARIATIONS OF HEAT BUDGET



ECMWF 6 hr data

Figura 4-29: Variabilitá interannuale dei flussi di calore totale (A) e delle sue componenti (B).

INTERANNUAL VARIABILITY OF HEAT FLX

medie di bacino

anno	Q_{tot}	Q_s	Q_b	Q_e	Q_h
1991	-29.21	215.62	-92.14	-124.50	-28.18
1992	-23.68	220.62	-92.42	-129.70	-22.19
1993	-23.71	227.68	-92.46	-134.73	-24.20
1994	3.83	222.18	-84.79	-118.25	-15.31
media 91-94	-18.19	221.53	-90.45	-126.80	-22.47

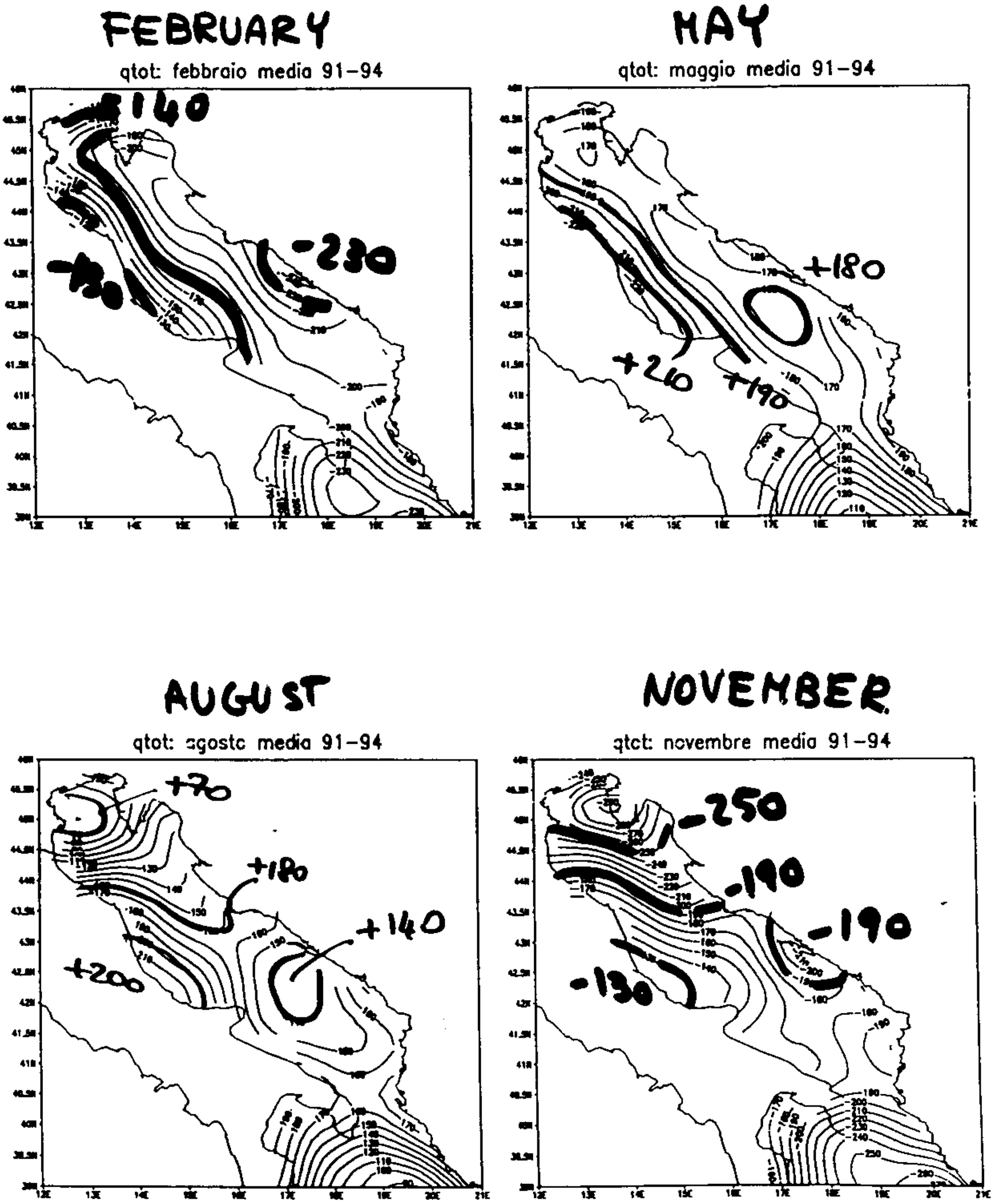
Tabella 4.8: Medie di bacino annuali di ogni componente del flusso di calore all'interfaccia aria-mare e del flusso totale

NO DEEP WATERS WERE FORMED!

(ARTEGIANI & PASCHINI
PERSONAL COMMUNICATION)

STRUCTURE OF Q AT THE SURFACE

flusso totale di calore alla superficie



cint=10.

Figura 4-20: Mappe del flusso totale di calore alla superficie del mare (W/m^2). Le linee tratteggiate indicano valori negativi.

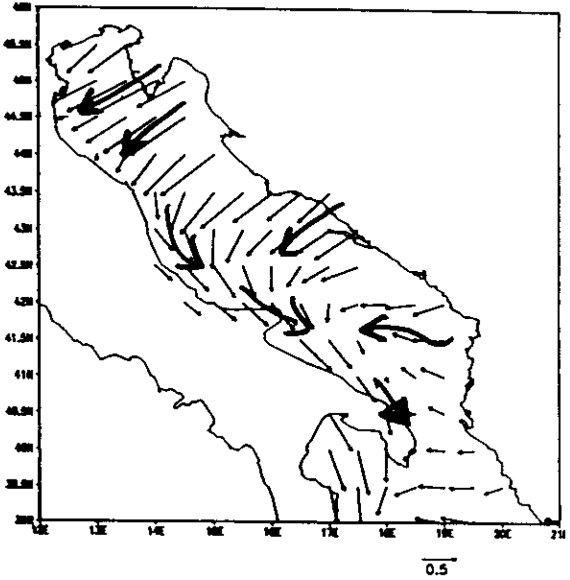
ECMWF CLIMATOLOGY

WIND STRESS CLIMATOLOGY

stress del

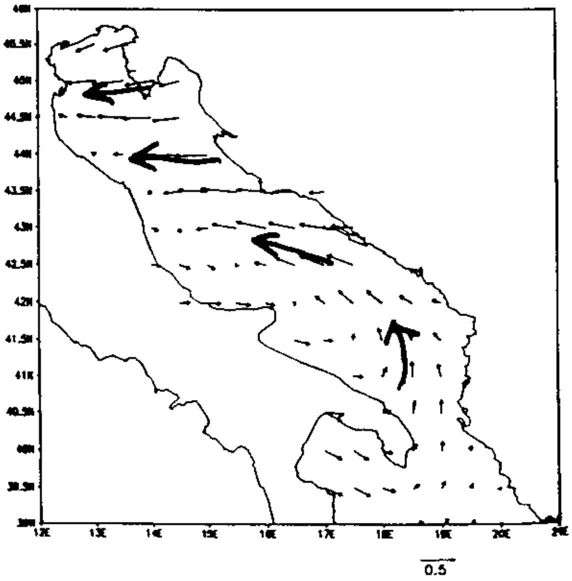
FEB.

stress - febbraio media 91-94



NOV.

stress - novembre media 91-94



0.5

Figura 4-25: Mappe di stress del vento (dyne/cm^2) sulla superficie del mare.

22

SOME KEY FEATURES OF BUOYANCY BUDGET OF BASIN

$$B = \frac{1}{C_w} g\alpha \underset{\uparrow\,\text{heat flux}}{Q} + g\beta(E-\underset{\uparrow\,\text{water flux}}{P}-R)S$$

* Overall the basin looses HEAT

$$\overline{Q}^{\,time} \sim -20 \text{ W/m}^2$$

in a long time average sense. However there are years in which the basin GAINS heat (NO DEEP WATERS?!)

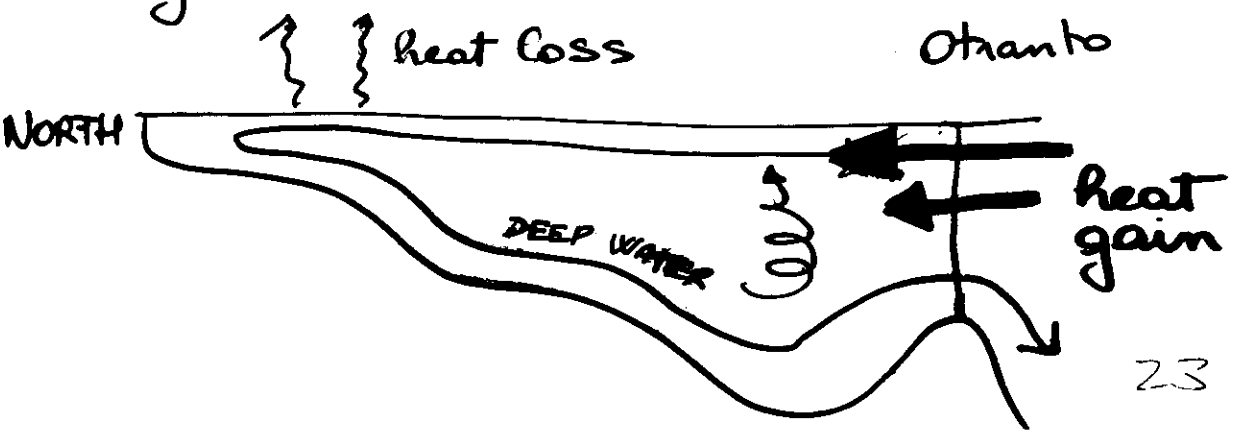
* Overall the basin gains water

$$E-P-R < 0 \sim -1.0 \text{ m/y}$$

due to river run-off

* GAINS HEAT AT OTRANTO to balance the heat losses at the surface

* EXPORTS cold, deep waters formed by heat losses



Modelling of the Adriatic Sea General Circulation

* PRIMITIVE EQUATION MODEL IN "SIGMA" COORDINATES

$$\sigma = \frac{z-\eta}{H+\eta}$$

where H is the bottom.

In z the equations are written

$$\frac{\partial u}{\partial t} + \vec{u}_z \cdot \nabla u + w\frac{\partial u}{\partial z} - fv = -\frac{1}{\rho_0}\frac{\partial p}{\partial x} + \frac{\partial}{\partial z}\left(K_M \frac{\partial u}{\partial z}\right) + F_x$$

$$\frac{\partial v}{\partial t} + \vec{u}_2 \cdot \nabla v + w\frac{\partial v}{\partial z} + fu = -\frac{1}{\rho_0}\frac{\partial p}{\partial y} + \frac{\partial}{\partial z}\left(K_M \frac{\partial v}{\partial z}\right) + F_y$$

$$\frac{\partial p}{\partial z} = -\rho g$$

$$\vec{\nabla} \cdot \vec{u} = -\frac{\partial w}{\partial z}$$

$$\rho = f(T, S, P)$$

$$\frac{\partial T}{\partial t} + \vec{u}_2 \cdot \nabla T + w\frac{\partial T}{\partial z} = \frac{\partial}{\partial z}\left(K_H \frac{\partial T}{\partial z}\right) + F_T$$

$$\frac{\partial S}{\partial t} + \vec{u}_2 \cdot \nabla S + w\frac{\partial S}{\partial z} = \frac{\partial}{\partial z}\left(K_H \frac{\partial S}{\partial z}\right) + F_S$$

K_H, K_M are functions of z and in particular 2nd order closure parameterizations

$F_{\dots}$ ... horizontal viscosity and diffusivities

- Boundary conditions are:

$z=\eta$

$$\rho_0 K_H\left(\frac{\partial u}{\partial z},\frac{\partial v}{\partial z}\right)=\left(\tau_w^{(x)},\tau_w^{(y)}\right) \quad \textbf{STRESS}$$

$$\rho_0 K_H\left(\frac{\partial T}{\partial z},\frac{\partial S}{\partial z}\right)=\left(Q\ ,\ \underset{\textbf{BUOYANCY}}{S(E-P-R)}\right)$$

$$w=\frac{\partial \eta}{\partial t}+\vec{u}_2\cdot\nabla\eta$$

$z=-H$

$$\rho_0 K_H\left(\frac{\partial u}{\partial z},\frac{\partial v}{\partial z}\right)=\left(\tau_H^{(x)},\tau_H^{(y)}\right)$$

$$\left(\frac{\partial T}{\partial z},\frac{\partial S}{\partial z}\right)=0$$

$$w=-\vec{u}_2\cdot\nabla H$$

AT OPEN BOUNDARY:

- SPECIFY (u,v) from larger model output
- radiation condition for outflow of tracers

AT RIVER SITE:

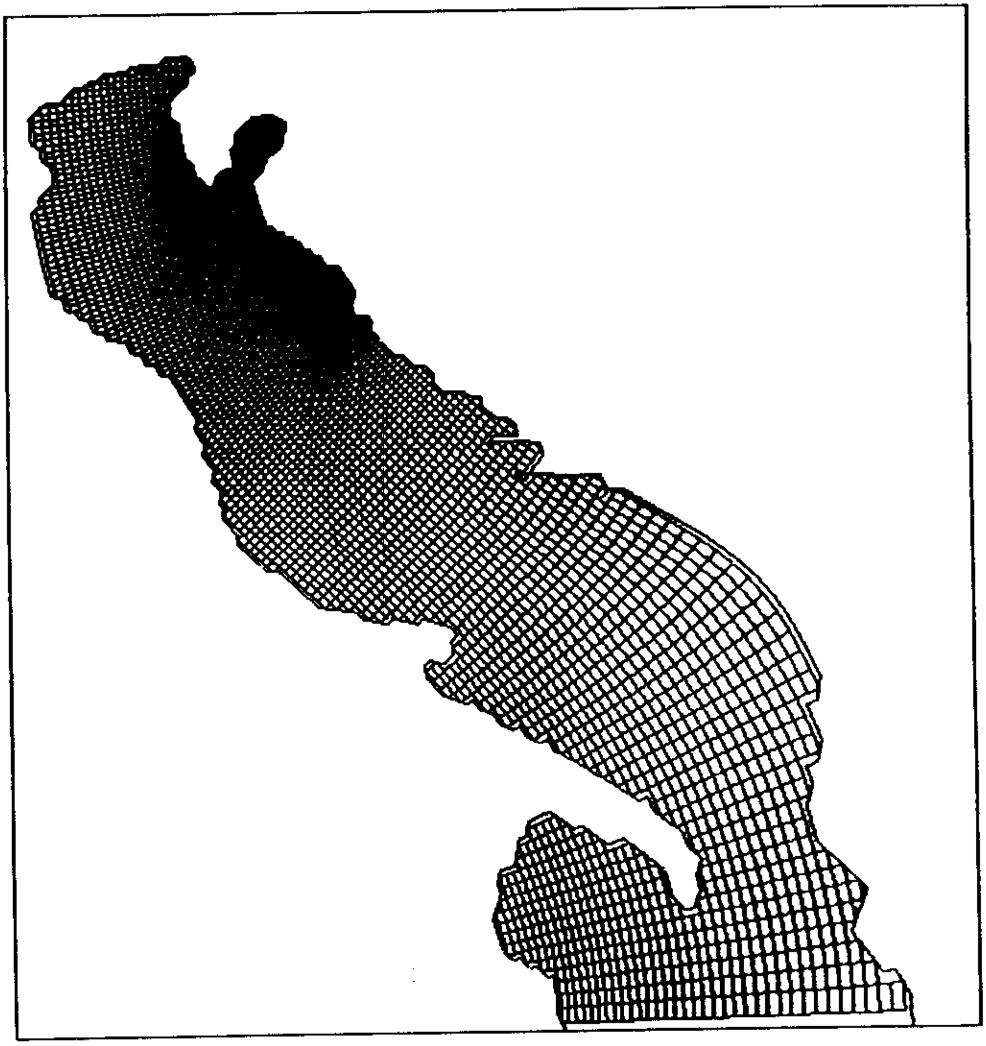
$S=S_0$ (low salinity value)

- INITIAL CONDITION:

Temperature and salinity fields from **winter climatology**

PRINCETON OCEAN MODEL

Adriatic Sea Implementation

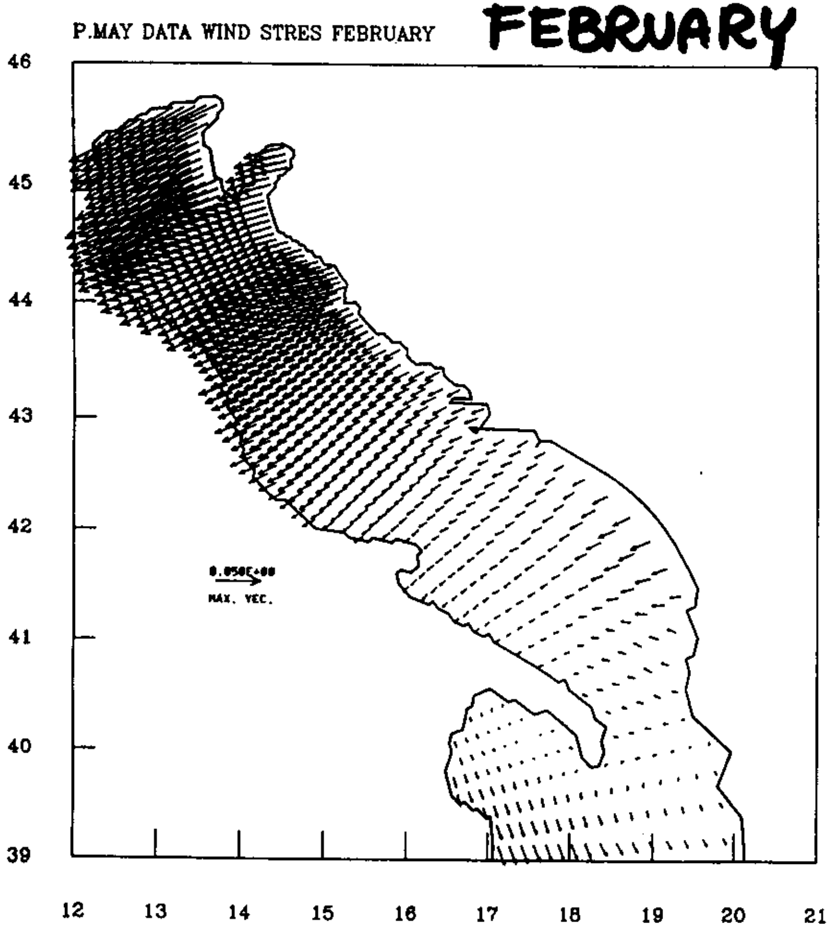


MODEL GRID

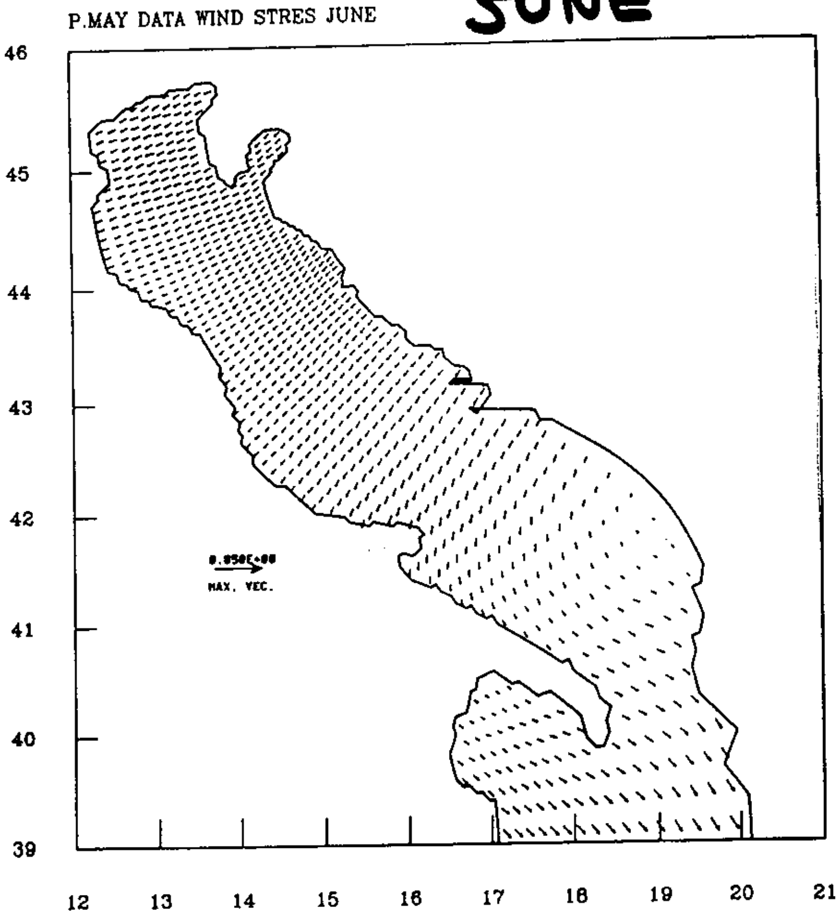
Horizontal resolution: 3–5 Km (north)
12–15 km (south)

Vertical resolution: 21 sigma (bottom following) layers

MAY (1986) WIND STRESS FORCING



FEBRUARY



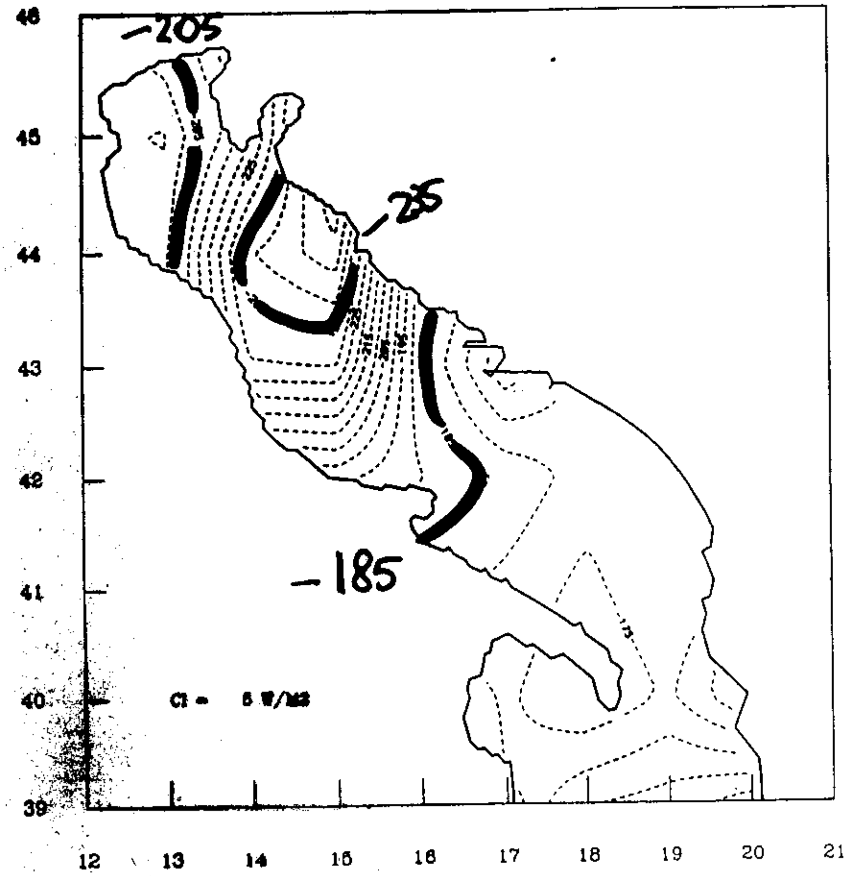
JUNE

REPEATING SEASONAL FORCING

MAY (1986) HEAT FLUX FORCING
MONTHLY MEAN VALUES

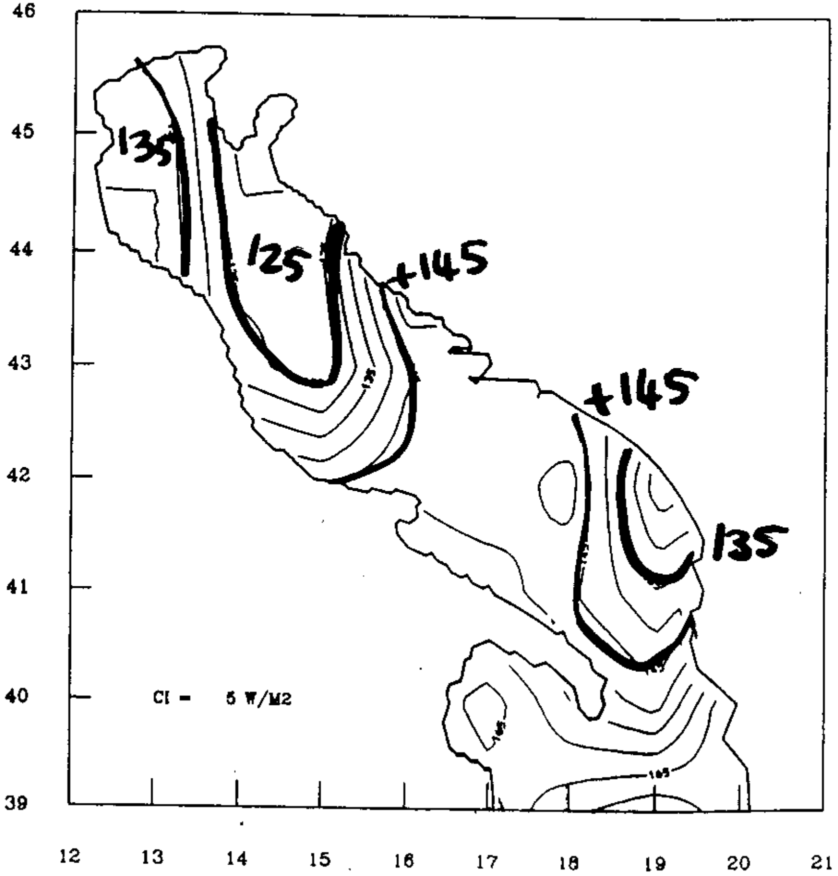
JANUARY

P.MAY DATA TOTAL HEAT FLUX JANUARY



JUNE

P.MAY DATA TOTAL HEAT FLUX JUNE

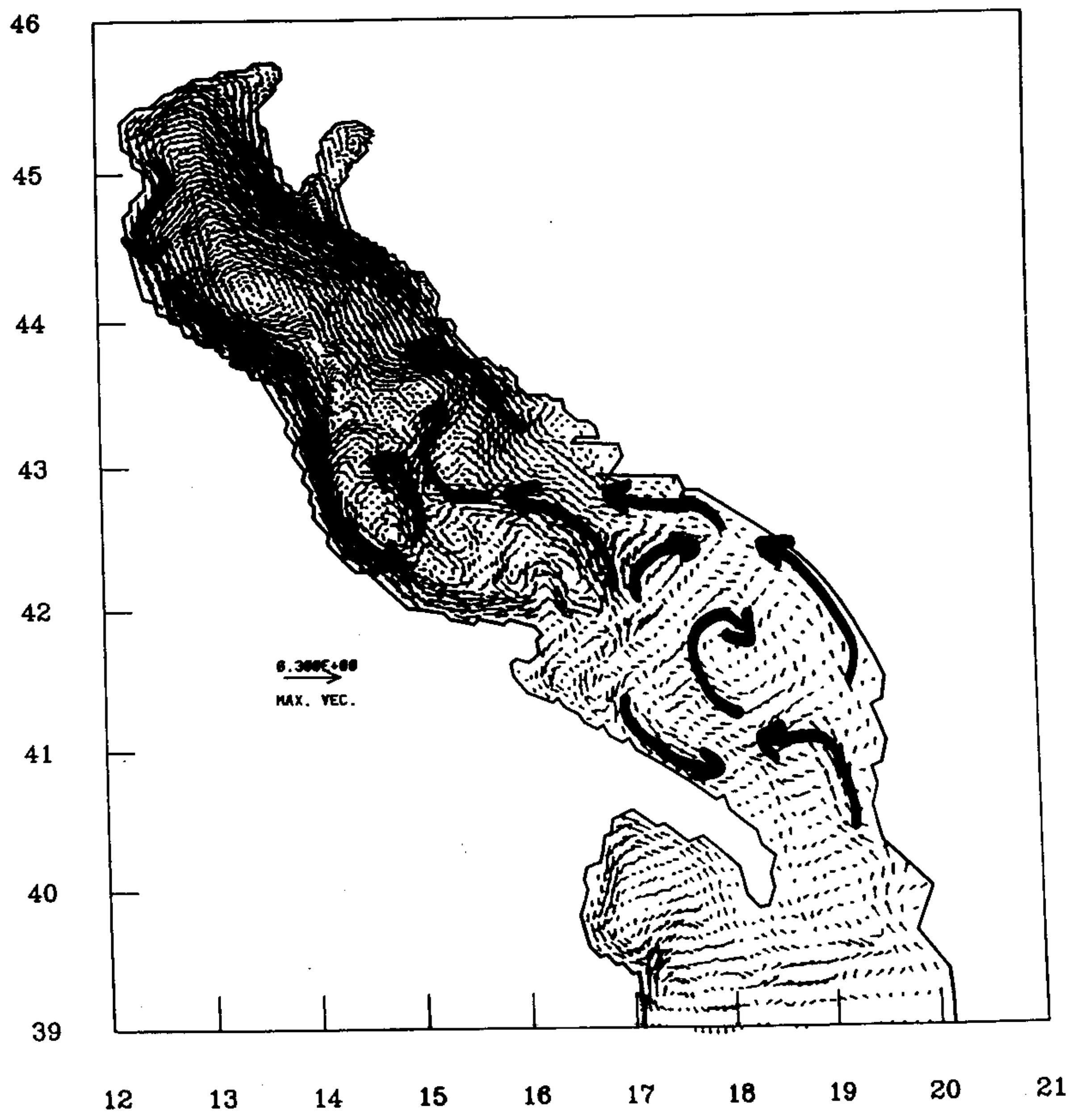


REPEATING SEASONAL FORCING

3 YEAR RUN WITH
ALL FORCINGS
(WIND, HEAT, WATER, RIVER, OTRANTO)

FEBRUARY

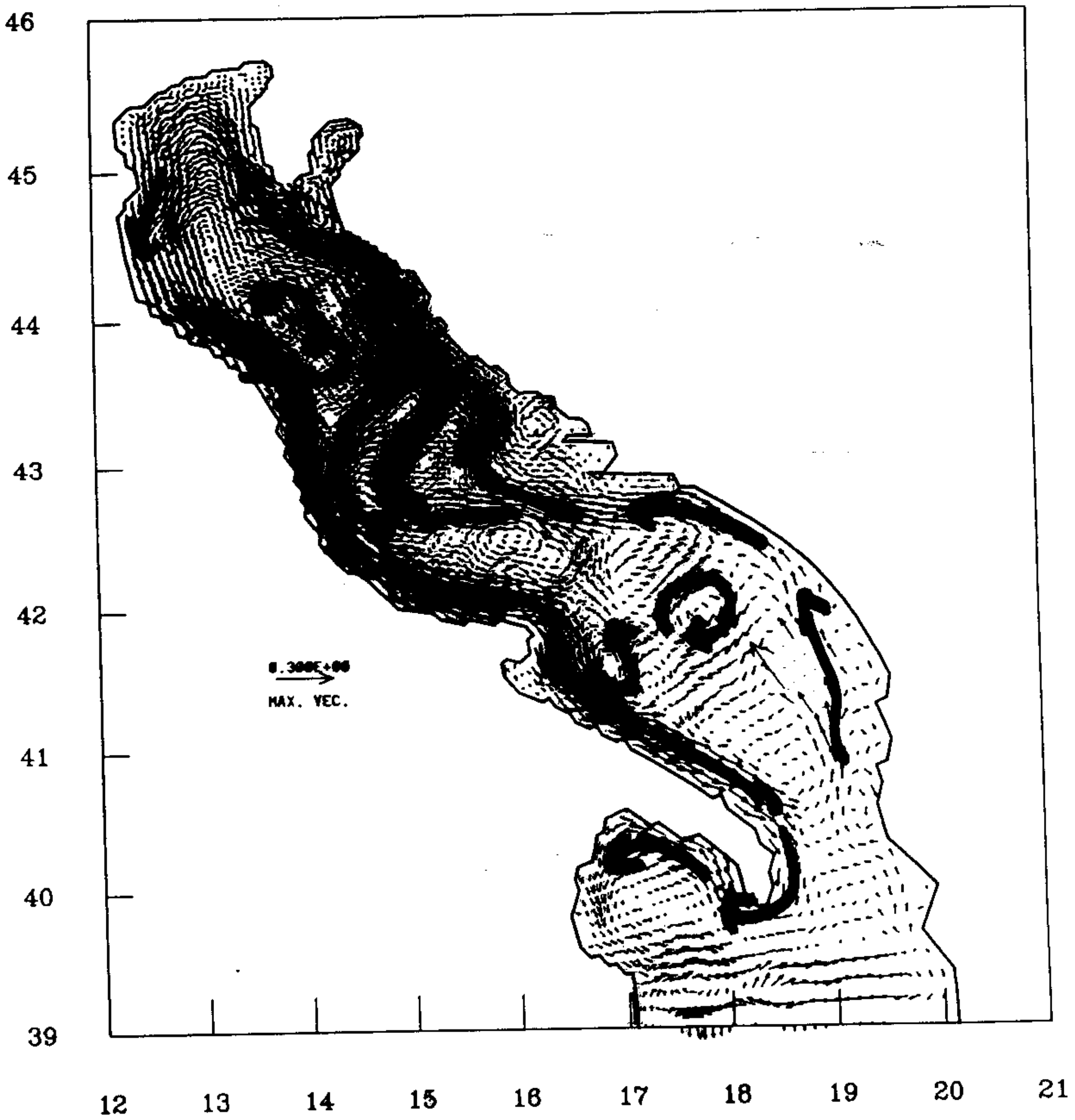
ADRI-7 VELOCITY 10 M - YEAR 1 - FEBRUARY



3 YEARS RUN

ALL FORCINGS

MAY

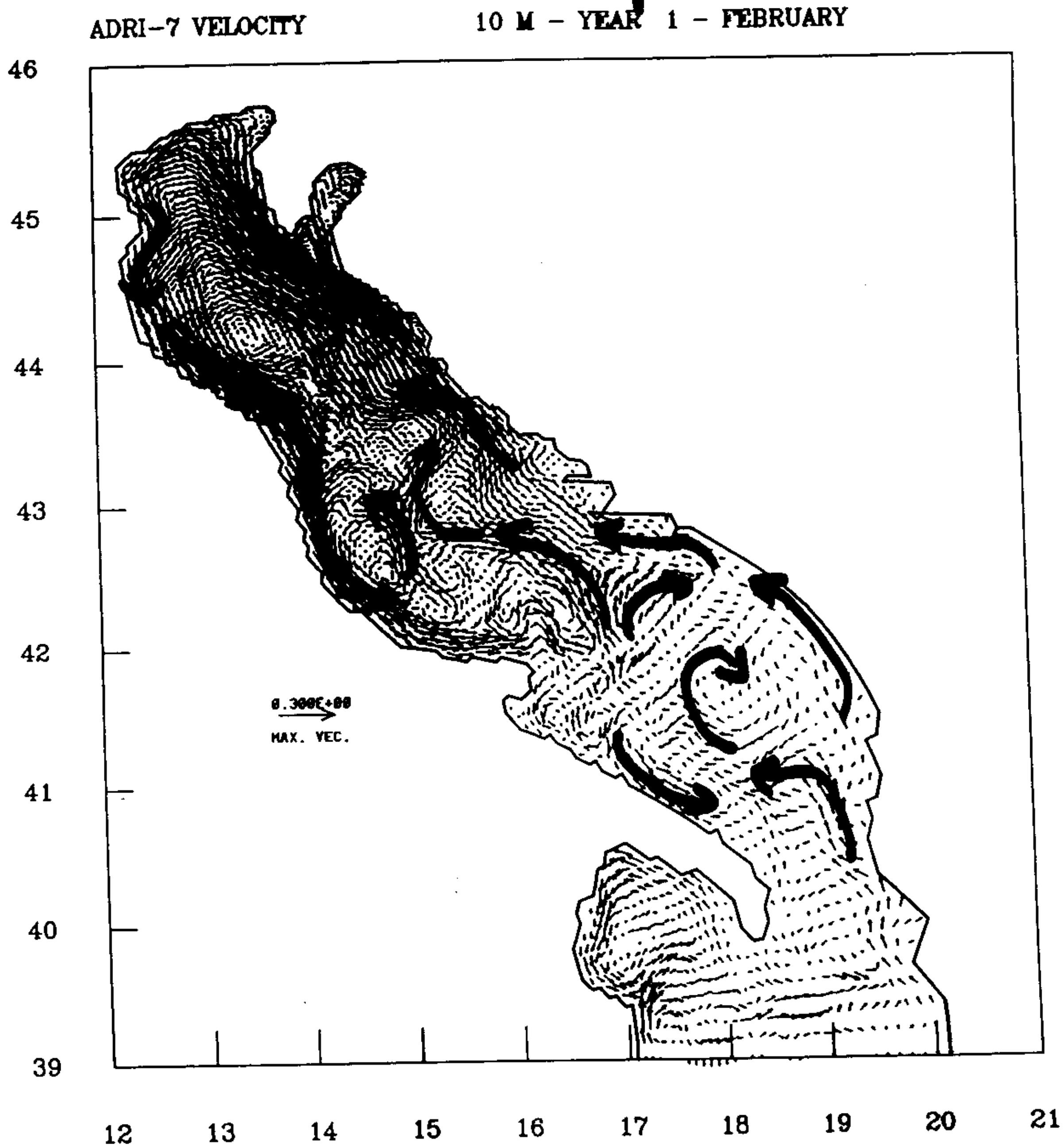


ADRI-7 VELOCITY 10 M - YEAR 1 - MAY

3 YEAR RUN WITH

ALL FORCINGS
(WIND, HEAT, WATER, RIVER, OTRANTO)

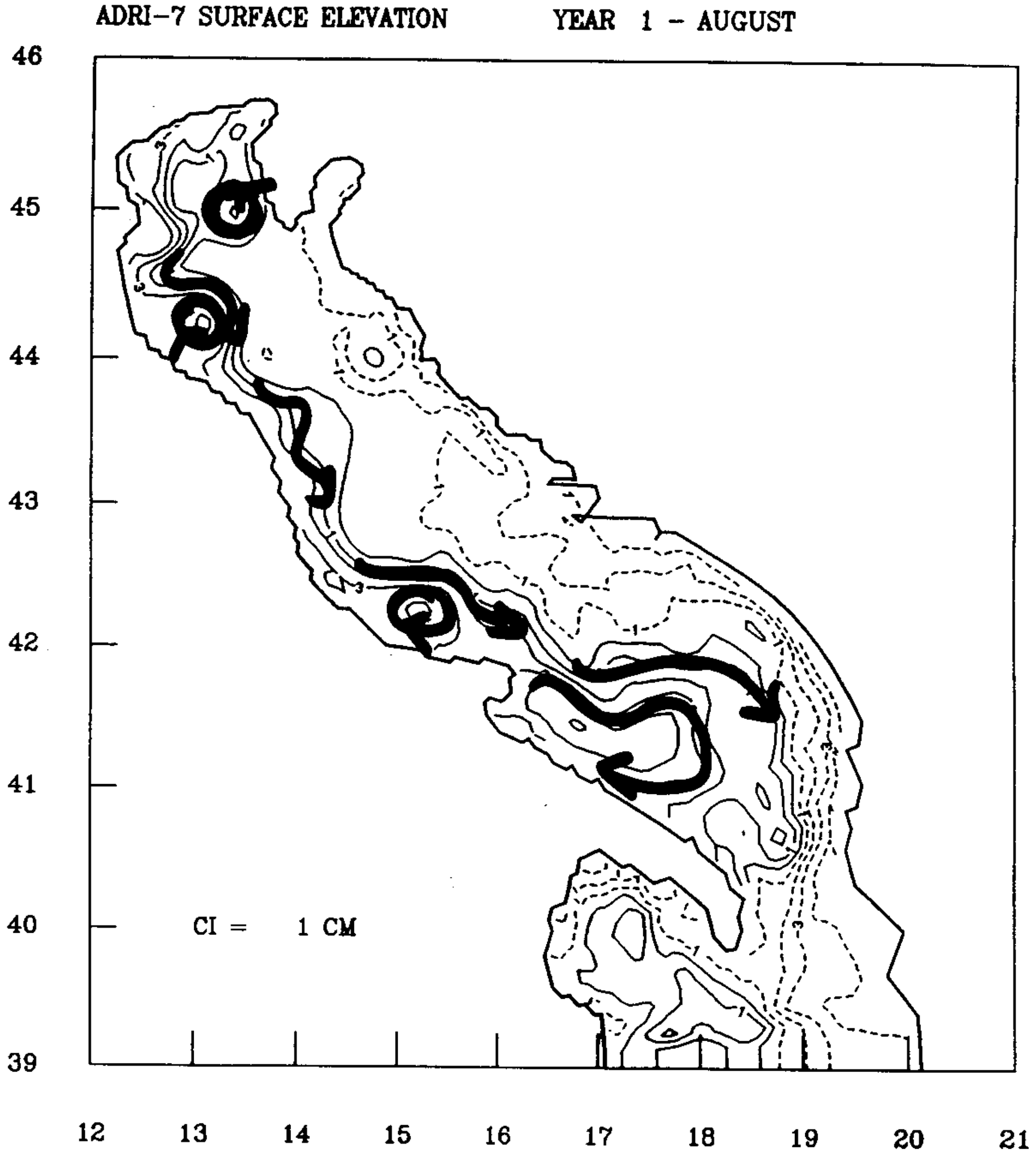
FEBRUARY



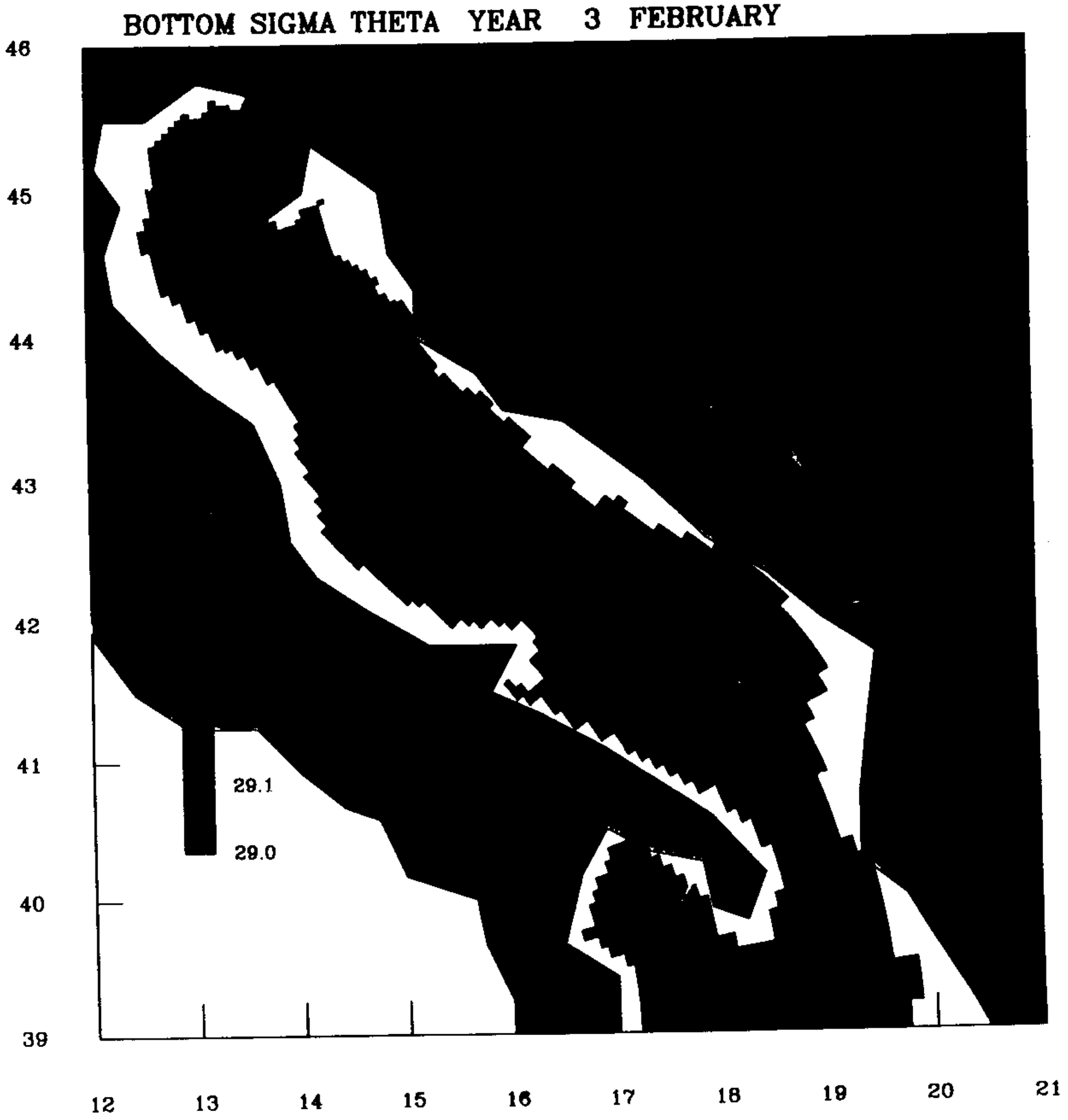
ADRI-7 VELOCITY 10 M - YEAR 1 - FEBRUARY

SEA SURFACE ELEVATION

AUGUST

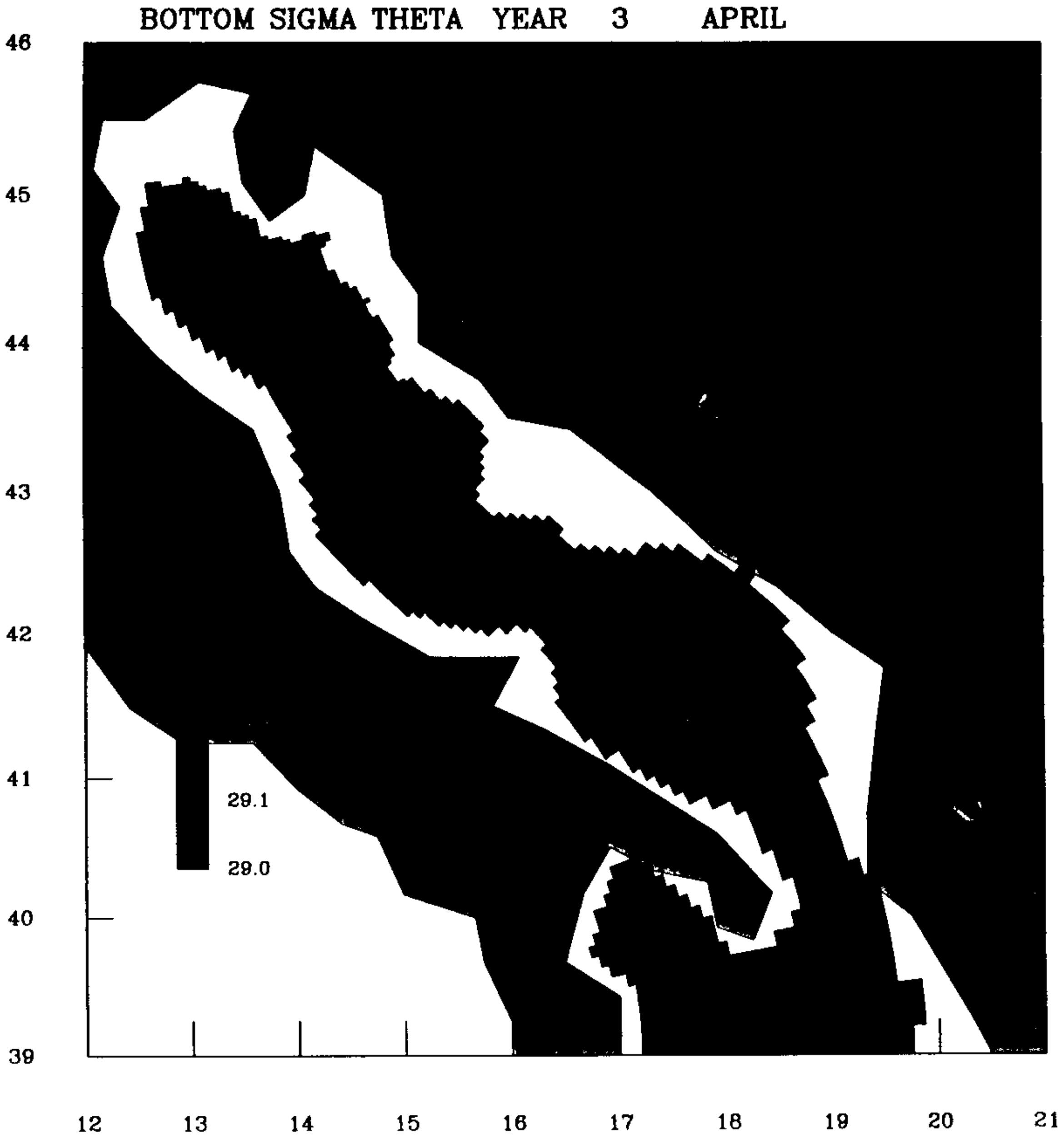


DEEP WATER FORMATION
OCCUR EVERY WINTER



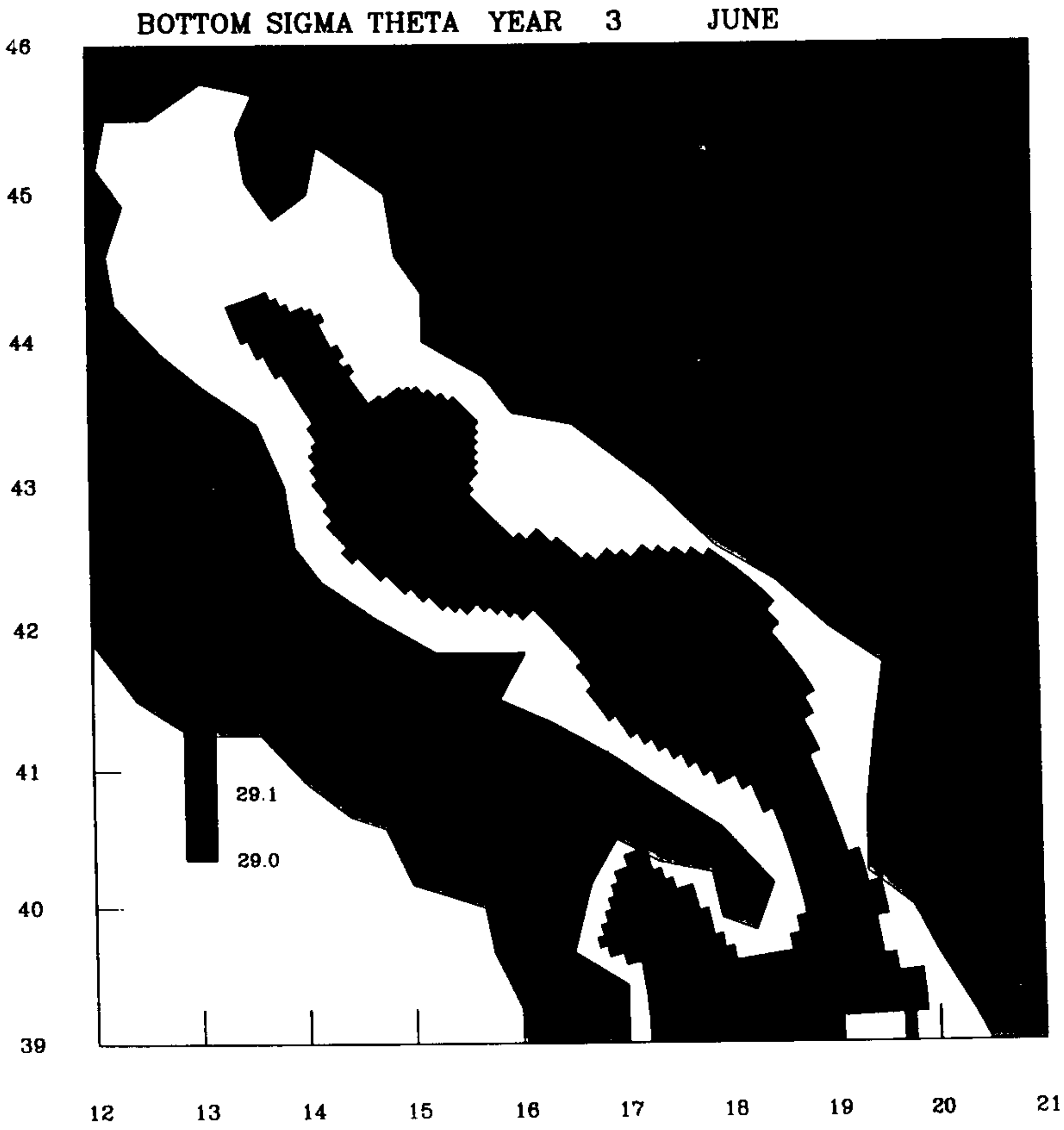
POOL OF DENSE WATER FORMS...

DEEP WATER FORMATION
OCCURS EVERY WINTER



DEEP WATER SLIDES
DOWN INTO MIDDLE ADRIATIC
PITS

DEEP WATER FORMATION OCCURS EVERY WINTER



NEW DEEP WATER IS LEFT INSIDE THE POMO PITS (MIDDLE ADRIATIC)

HOW DO THE DIFFERENT FORCINGS WORK DURING WINTER?

HEAT

WOULD PRODUCE NORTWARD JET

SALT (PO)

WOULD PRODUCE SOUTWARD JET

WIND STRESS

high η along the coasts

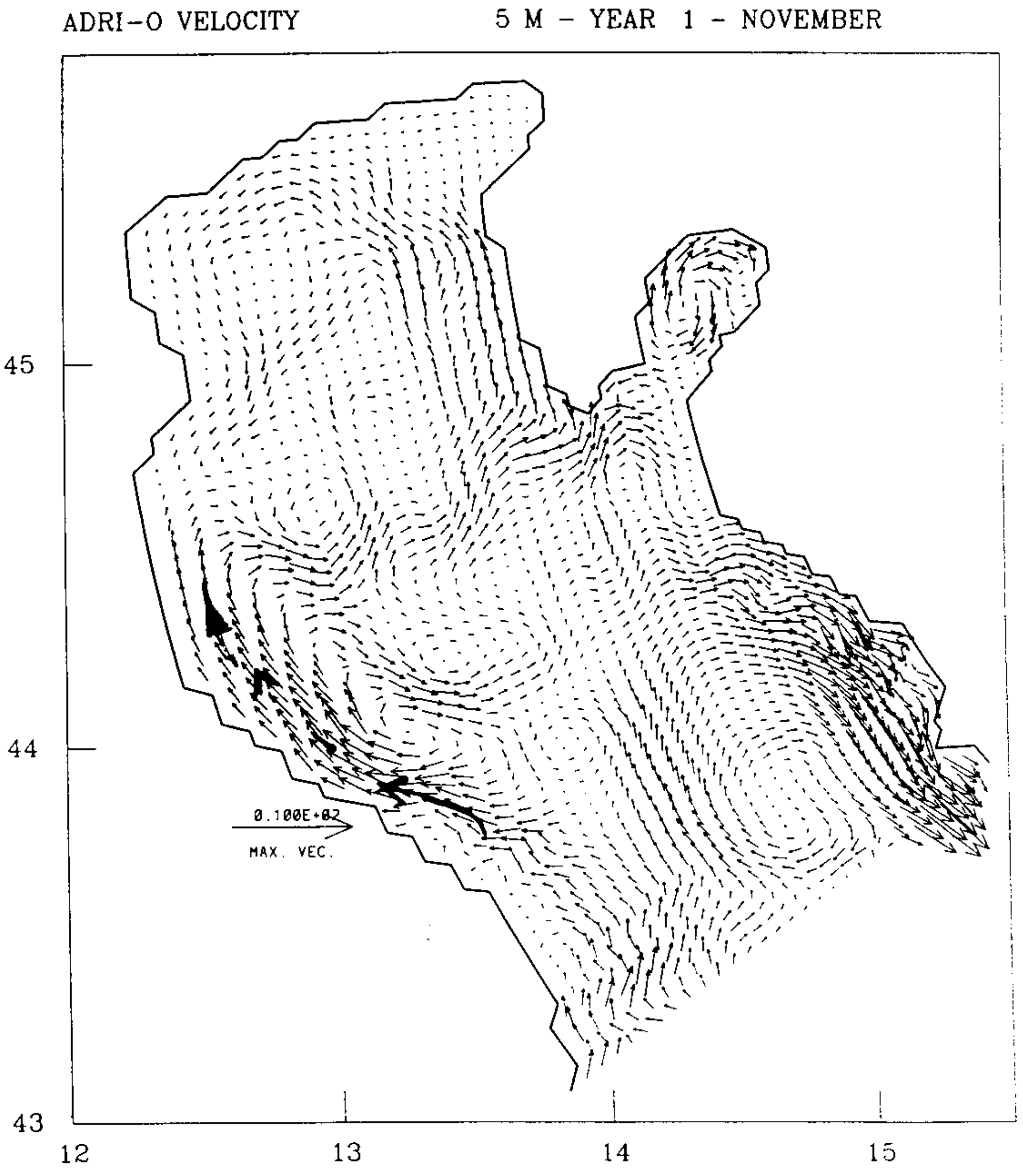
$$v \propto \frac{\partial \eta}{\partial y}$$

SOUTHWARD JET

CAN HEAT FORCING REVERSE THE SOUTHWARD JE

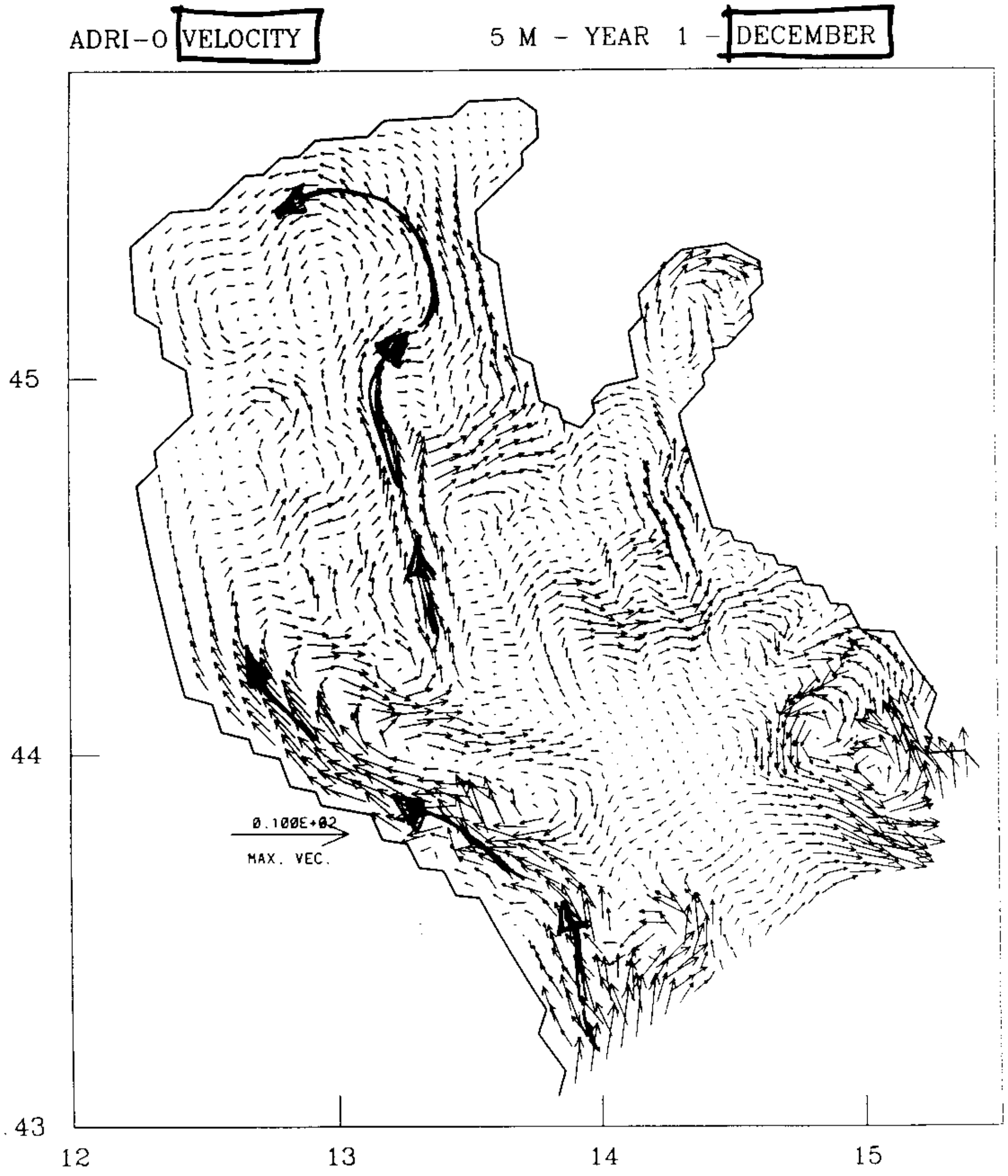
ALL SALT EFFECTS ARE TAKEN OUT

ONLY WINDS & HEAT FLUXES ARE LEFT



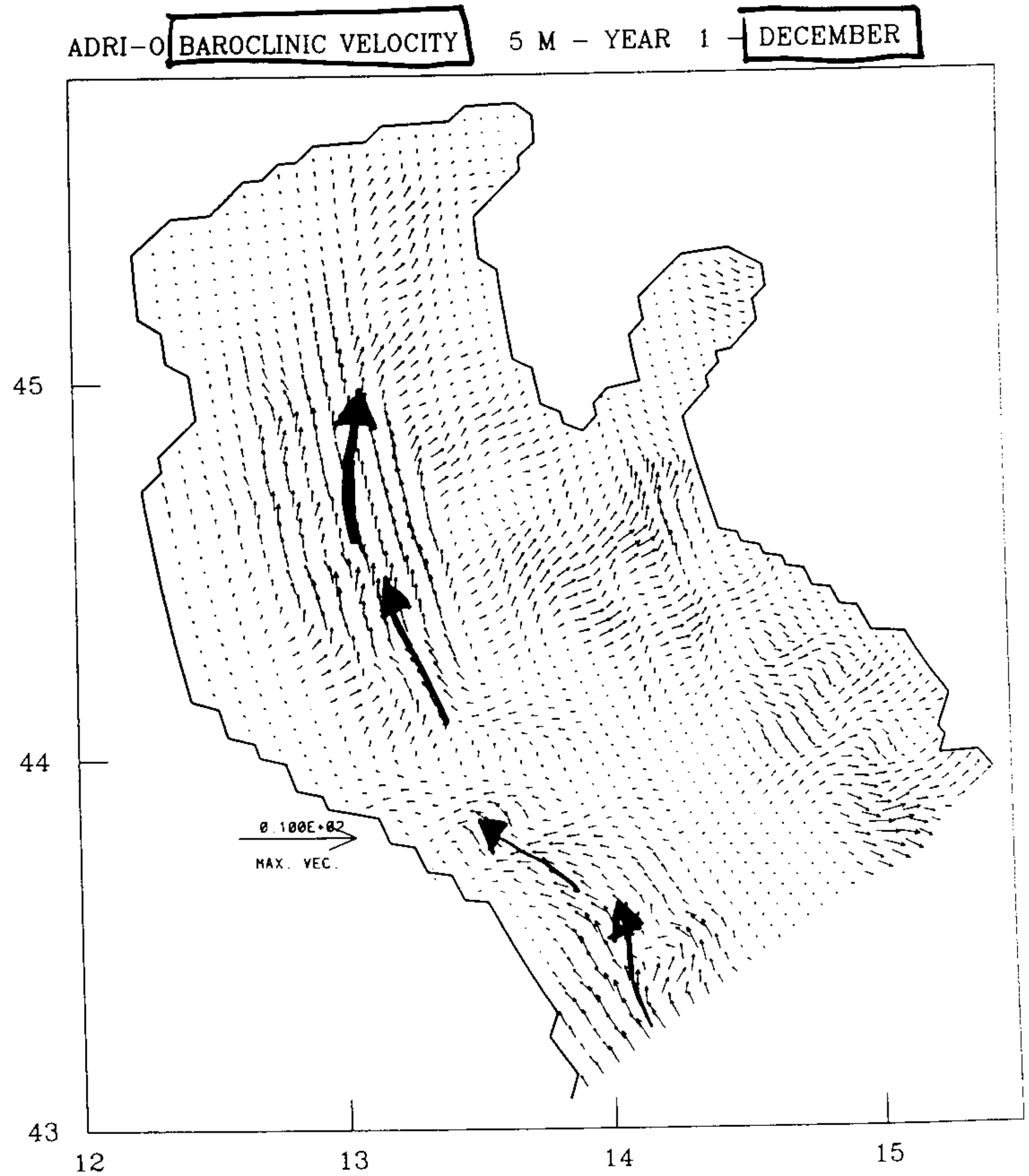
ALL SALT EFFECTS ARE TAKEN OUT

ONLY WINDS & HEAT FLUXES LEFT



ALL SALT EFFECTS ARE TAKEN OUT

ONLY WINDS & HEAT FLUXES LEFT



SUMMARY ON MODELLING

1) ADRIATIC SEA GENERAL CIRCULATION GENERALLY CYCLONIC DUE TO PREVAILING WIND STRESS CURL AND SALT/T BALANCE

2) LOW SALINITY SOURCE (PO & NORTHERN RIVERS COMPENSATES LOW TEMPERATURE WATERS IN DENSITY. WHEN THIS MECHANISM IS NOT COMPLETE OR DEFICIENT, IT IS POSSIBLE TO HAVE WESTERN COAST SOUTWARD JET

3) ADRIATIC IS THE FIRST SYSTEM WHERE LOW SALINITY WATERS FROM RUN-OFF CAN REGULATE THE FUNCTIONING OF THE SYSTEM BECAUSE OF CONCOMITANT HEAT LOSSES, PRODUCING COMPENSATION.

EFFECTS OF BOTTOM BOUNDARY LAYER ON THE COASTAL & GENERAL CIRCULATION OF ADRIATIC SEA

Background

→ It is known that velocities are larger at the surface than at the bottom of the ocean. Why?

→ Because there is a *pressure compensation effect* due to *bottom boundary layer*

Let's take the bottom geostrophic velocity field:

$$f(u_H, v_H) = \left(-g\frac{\partial \eta}{\partial y} - \int_{-H}^{0} \frac{\partial b}{\partial y} dz, +g\frac{\partial \eta}{\partial x} + \int_{-H}^{0} \frac{\partial b}{\partial x} dz\right)$$

where $b = g\rho/\rho_0$, ρ is the **density**, η the surface elevation

THUS IF $u_H, v_H \approx 0$ at the bottom the "η" term should be balanced by the baroclinic integral term. THIS IS THE PRESSURE COMPENSATION EFFECT

→ For short time scales ($\lesssim 1$ day)

MacCready & Rhines (1991, 1993)

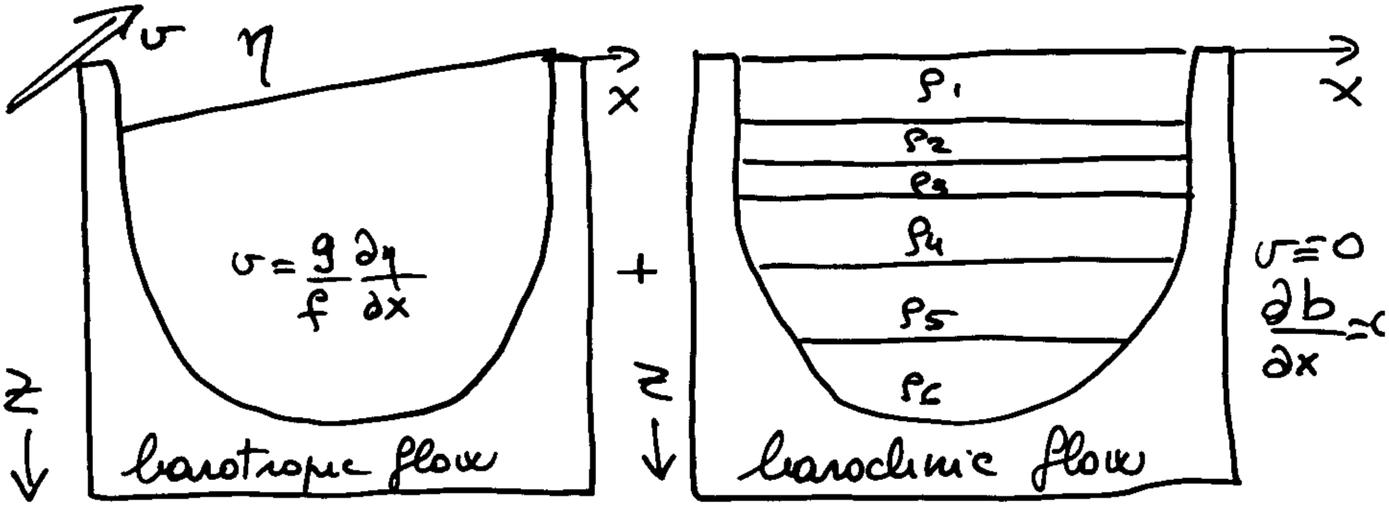
Garrett et al. (1993)

→ For long time scales ($\gtrsim 1$ year)

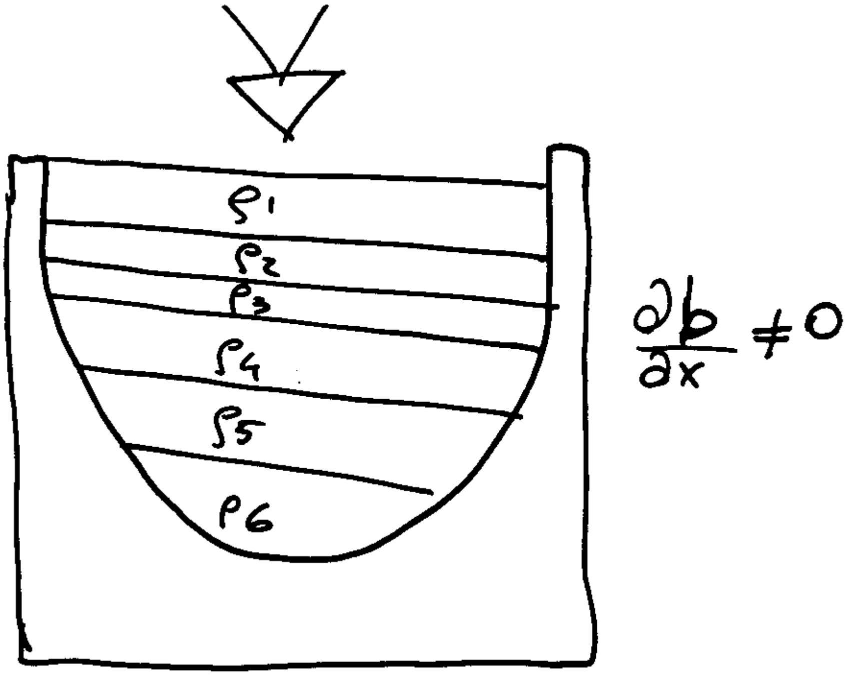
Mellor & Wang (1996)

The pressure compensation effect is produced by bottom boundary layer dynamics which creates an Ekman transport altering the overlaying stratified flow.

SCHEMATIC OF PROCESS



AT INITIAL TIME



TIME $t > 0$

time scales of days to years

Let's take the linearized 2-D primitive equations in x-z plane

$$\begin{cases} \dfrac{\partial u}{\partial x} + \dfrac{\partial w}{\partial z} = 0 \\ \dfrac{\partial u}{\partial t} - f v = -g \dfrac{\partial \eta}{\partial x} - \displaystyle\int_z^0 \dfrac{\partial b}{\partial x} dz' + \dfrac{\partial \tau_{zx}}{\partial z} \\ \dfrac{\partial v}{\partial t} + f u = \dfrac{\partial \tau_{zy}}{\partial z} \\ \dfrac{\partial \rho}{\partial t} + \dfrac{\partial}{\partial x}(u \rho) + \dfrac{\partial}{\partial z}(w \rho) = 0 \end{cases}$$

τ_{zy} are the Reynold stresses.

Separate between "barotropic" flow field

$$\overline{\vec{u}} = \frac{1}{D} \int_{-H}^{\eta} \vec{u} \, dz \quad ; \quad D = H + \eta$$

and baroclinic flow

$$\vec{u}' = \vec{u} - \overline{\vec{u}}$$

the barotropic flow equation is (at steady state):

$$\begin{cases} -f\bar{v} = -g\dfrac{\partial\eta}{\partial x} \boxed{-\dfrac{1}{D}\displaystyle\int_{-H}^{\eta}dz\int_{z}^{0}\dfrac{\partial b}{\partial x}dz'} \boxed{-\tau_H^{(x)}} \\ \\ +f\bar{u} = -\tau_H^{(y)} \end{cases}$$

and the baroclinic:

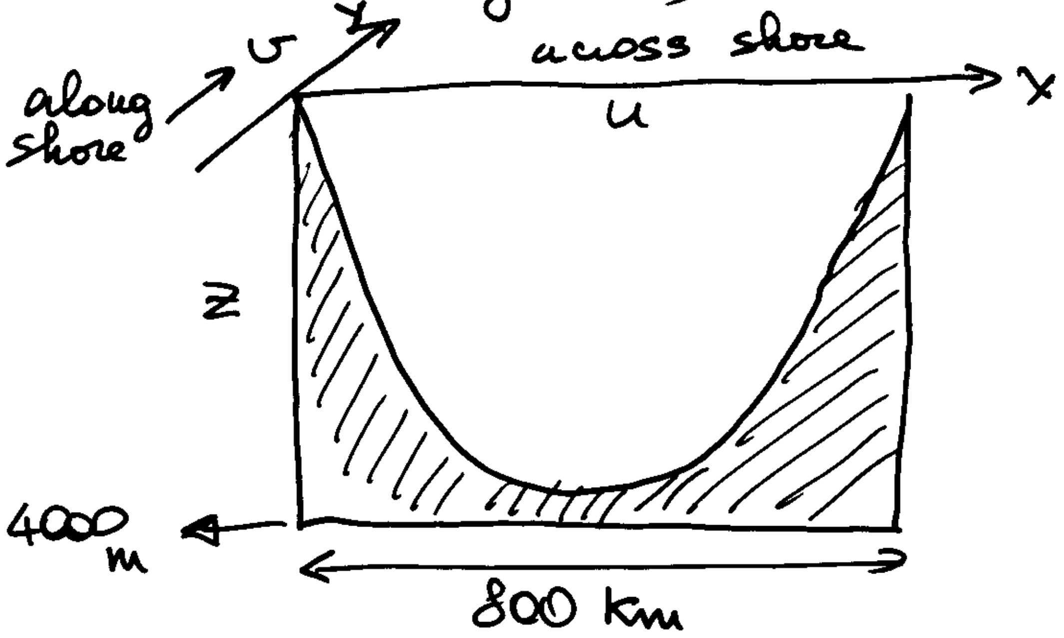
$$\begin{cases} -f v' = -\displaystyle\int_{z}^{0}\dfrac{\partial b}{\partial x}dz \boxed{+\dfrac{1}{D}\displaystyle\int_{-H}^{\eta}dz\int_{z}^{0}\dfrac{\partial b}{\partial x}dz'} \boxed{+\tau_H^{(x)}} + \dfrac{\partial\tau_{zx}}{\partial z} \\ \\ f u' = \dfrac{\partial\tau_{zy}}{\partial z} + \tau_H^{(y)} \end{cases}$$

where $\vec{\tau}_H$ is the bottom stress.

- $\vec{\tau}_H$ enters with equal amplitude and opposite sign the barotropic and baroclinic equations. THUS IT IS A "CONVERSION" TERM between the two momentum equations.

- Mellor & Wang showed that this mechanism is at work in deep basins and for long time scales (~yrs)

Mellor & Wang (1996) Model Set-up



The initial condition is

1) $\frac{\partial \eta}{\partial x} > 0$ to represent North Atlantic conditions across subtropical gyre

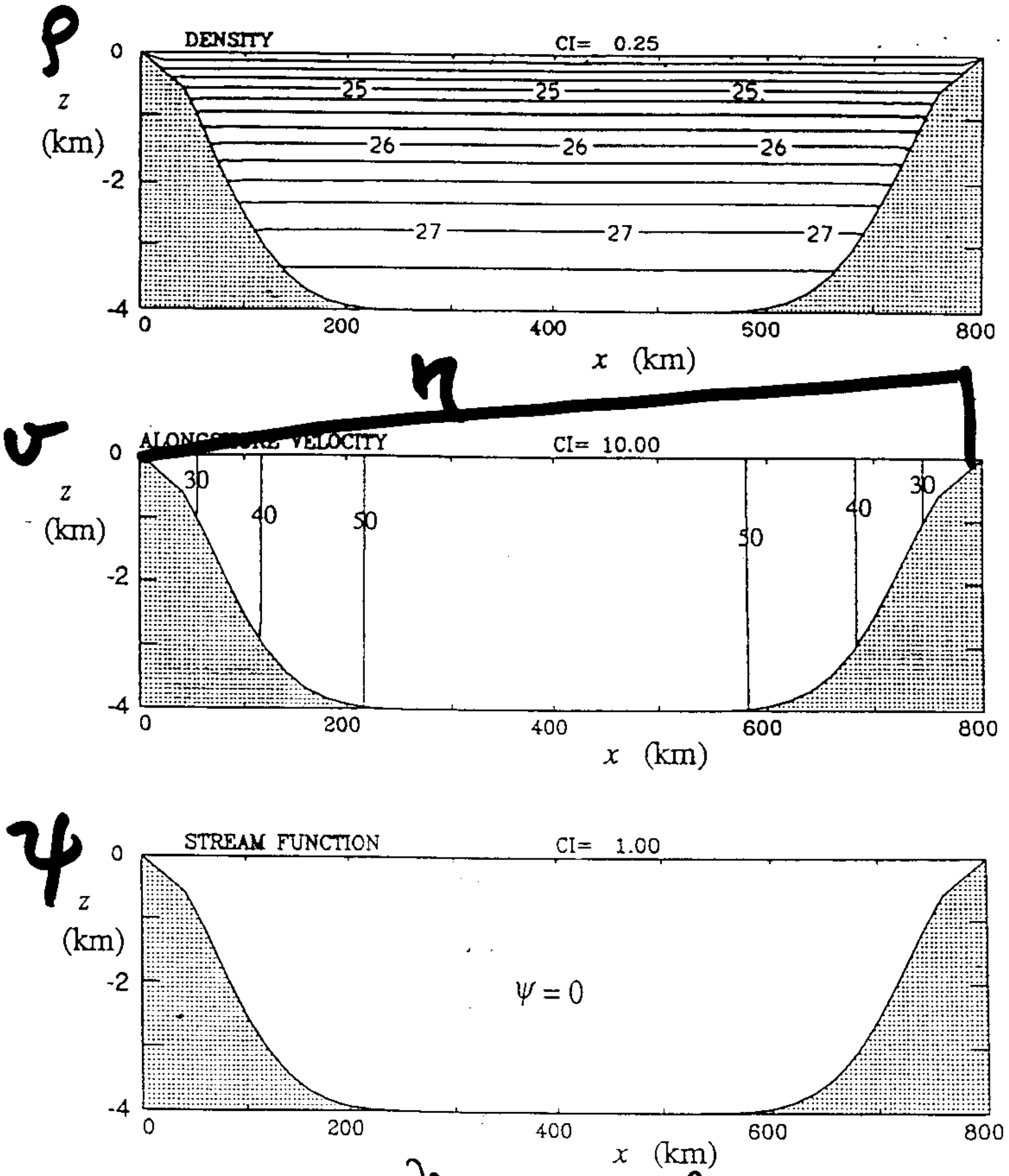
2) flat isopycnals in x, exponential in z

THUS, throughout the integration, the integrated flow rate is imposed to be equal to the initial one.

$$v_{INITIAL} = \frac{g}{f} \left.\frac{\partial \eta}{\partial x}\right|_{initial}$$

For the Atlantic $v_{INITIAL} = 50 \frac{cm}{s}$

INITIAL CONDITION



$$u = -\frac{\partial \psi}{\partial z} \; ; \quad w = \frac{\partial \psi}{\partial x}$$

Figure 4: Control run at t = 10 yr. Same as Fig. 2b but with free slip at the bottom.

MELLOR & WANG (1996)

t=60 days

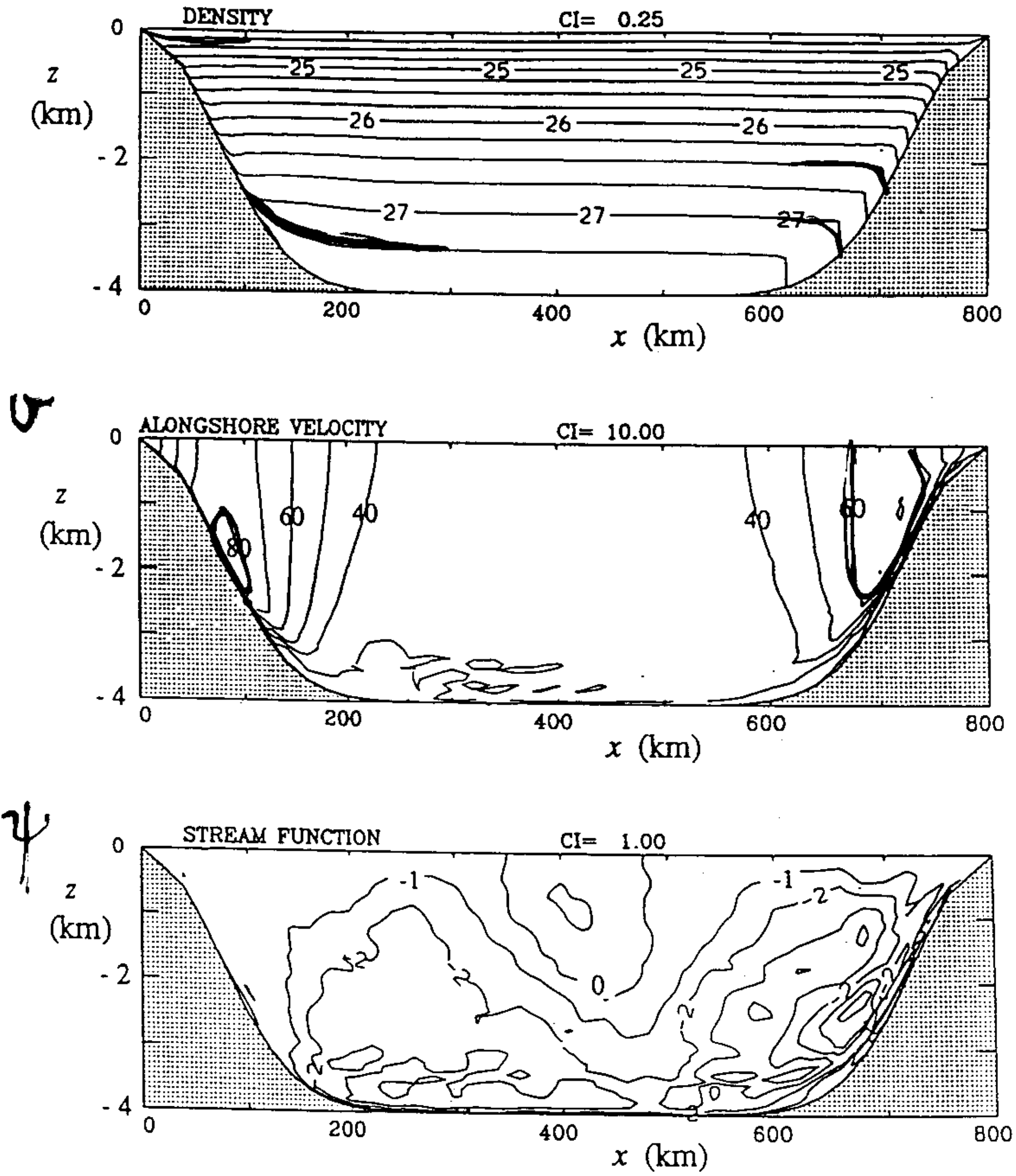


Figure 2a. Density (sigma units), along-shore velocity (cm s^{-1}) and cross-shore stream function (m^2 s^{-1}) for the along-shore, elevation gradient driven flow at t = 60 days. The cross-shore elevation is nearly linear with respect to x and $\partial\eta/\partial x \cong 0.56\times10^{-5}$

t=10 years

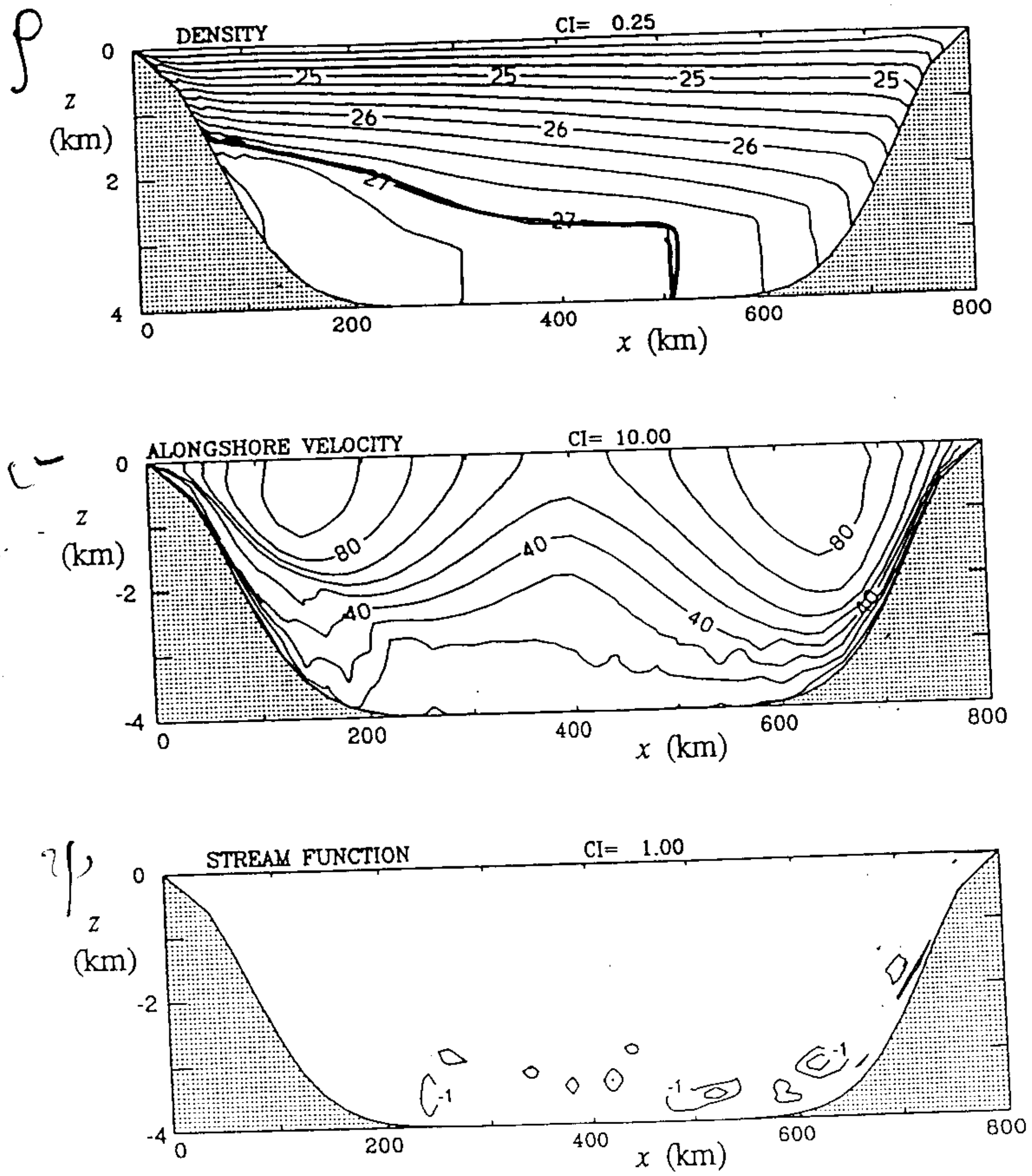


Figure 2b: Same as Fig. 2a but for t = 10 years. Zero contours have been excluded.The cross-shore elevation is nearly linear with respect to x and $\partial\eta/\partial x \cong 0.74\times10^{-5}$

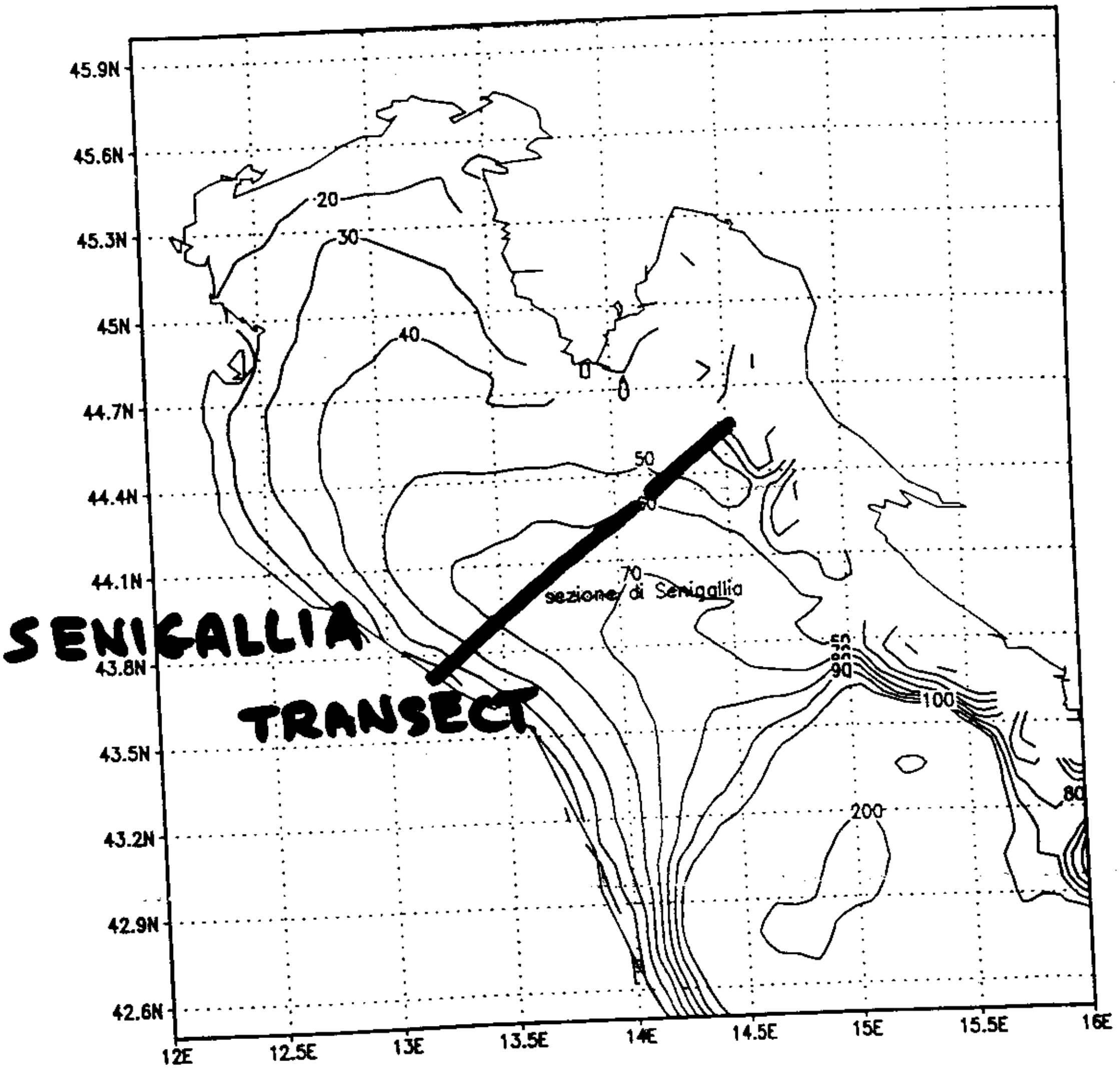


Figura 2-20: posizione della sezione verticale di Senigallia

SENIGALLIA SECTION

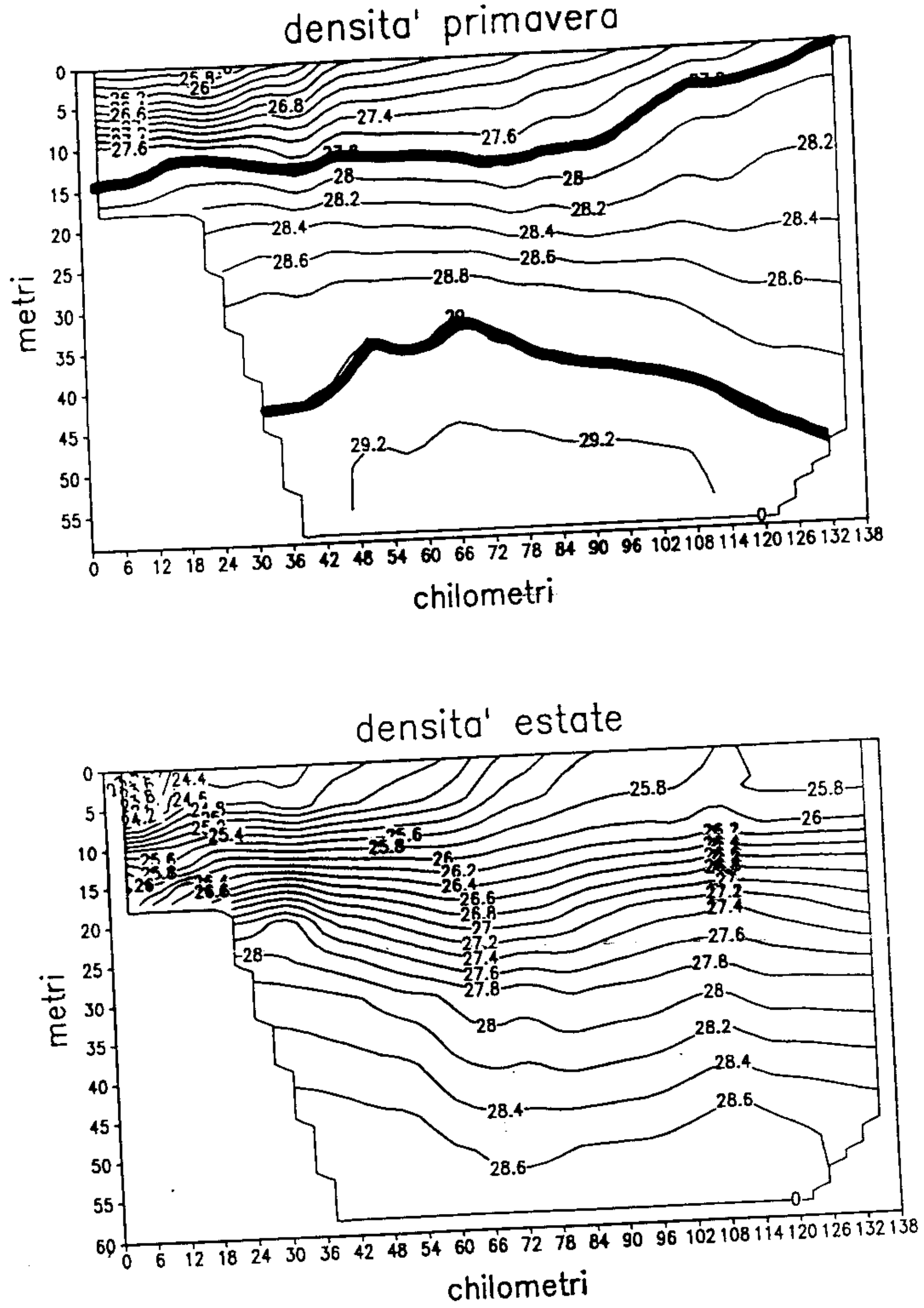
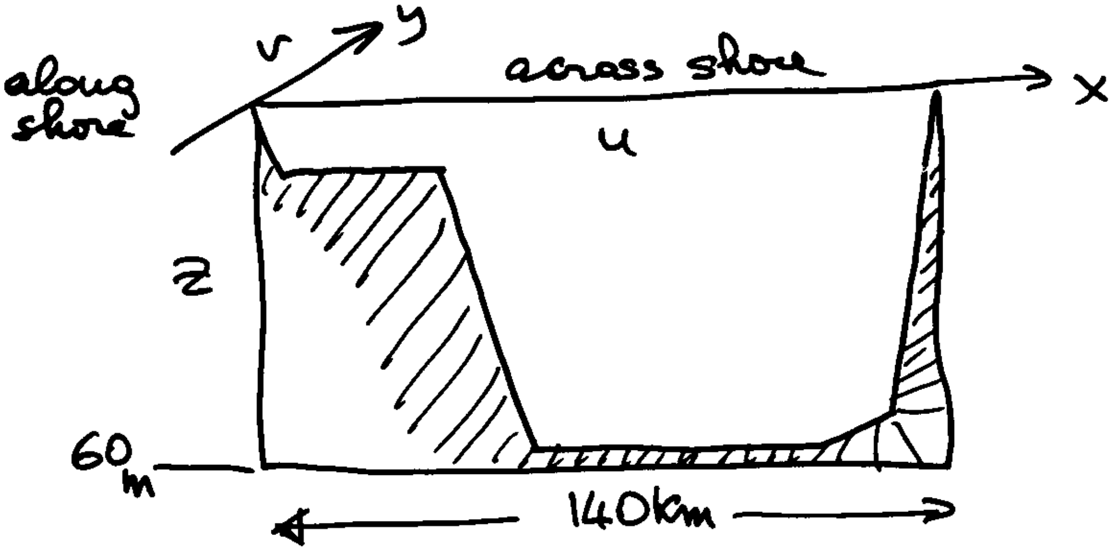


Figura 2-28: campi di densitá **prodotti con la** tecnica di analisi oggettiva orizzontale

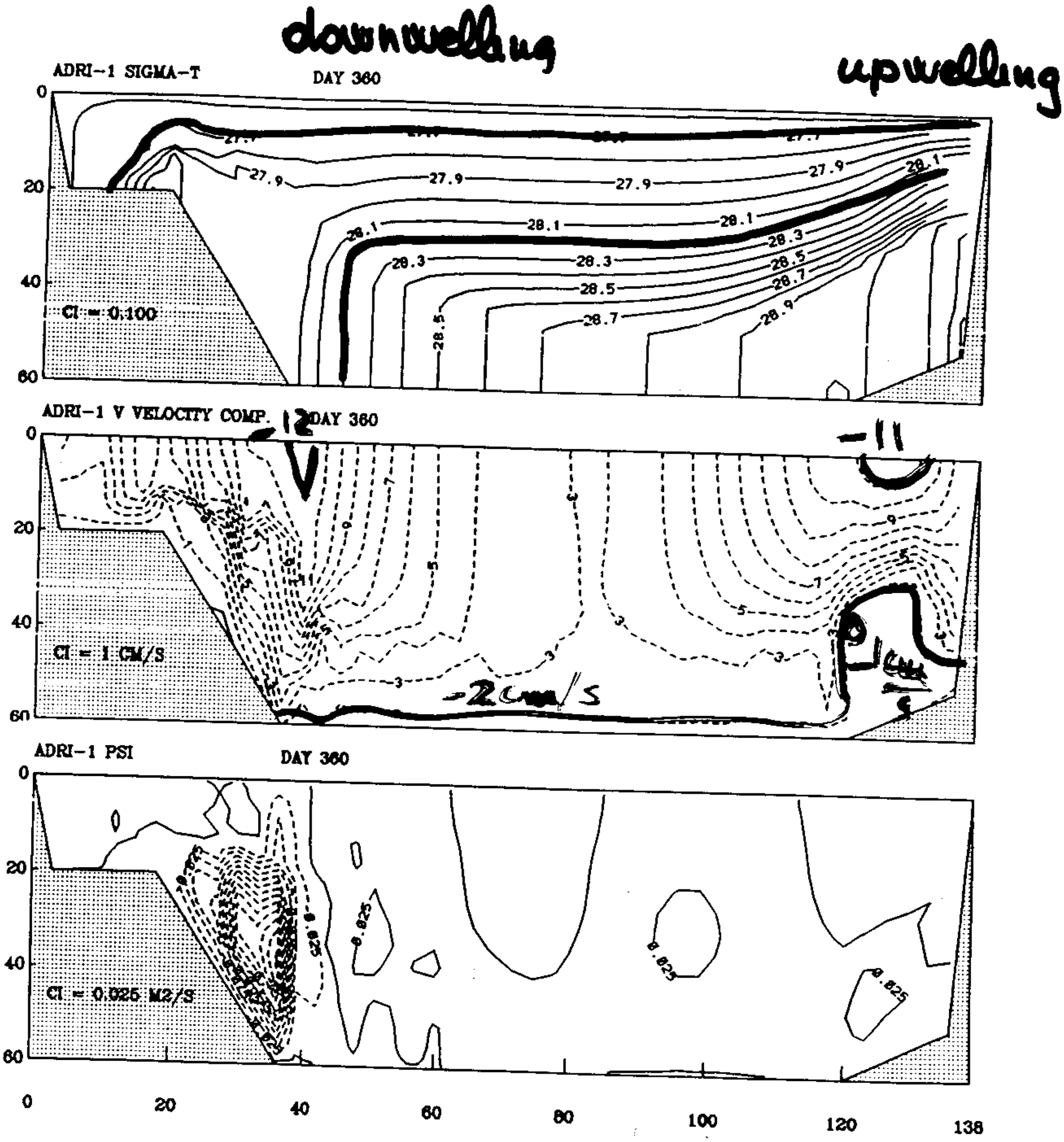
What happens for shallow basins like the Adriatic?

Take a different model set-up, like the Adriatic at Senigallia section



- initial surface slope $\frac{\partial \eta}{\partial x} < 0$ so that v is SOUTHWARD
- $v_{INITIAL}$ VARIED FROM $-1 \frac{cm}{sec} \rightarrow -5 \frac{cm}{sec}$
- INITIAL DENSITY STRUCTURE FROM DATA AND INITIALLY ISOPYCNALS FLAT

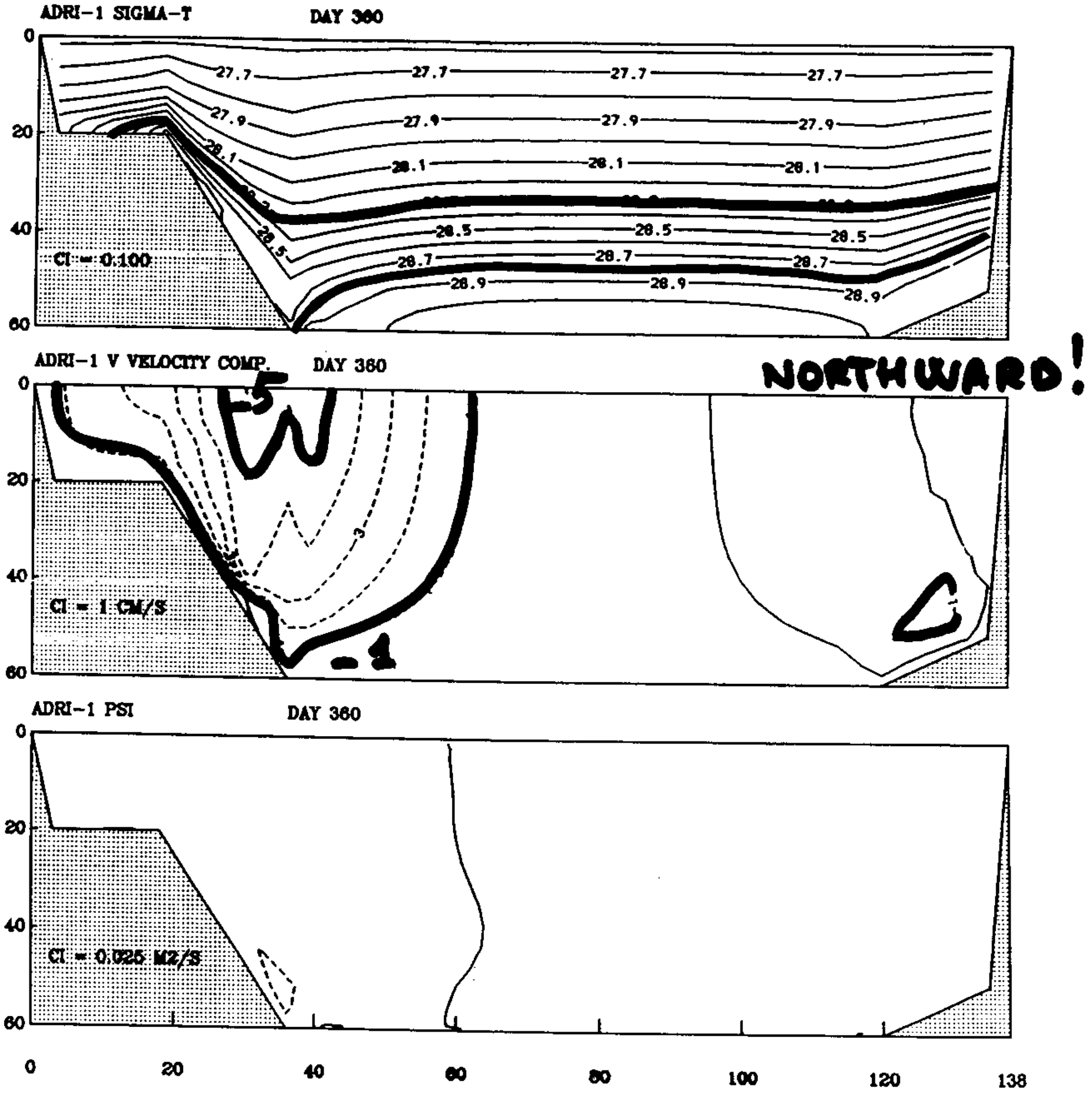
$v_{INITIAL} = -5 \frac{cm}{s}$



BOTTOM BOUNDARY LAYER MODIFIES DENSITY STRUCTURE AS IN OBSERVATIONS

Figura 4-20: esperimento Prim05, densitá, velocitá lungo costa e trasporto dopo 360 giorni

$v_{INITIAL} = 1 \frac{cm}{s}$



NORTHWARD!

BOTTOM BOUNDARY LAYER REINFORCES CYCLONIC CIRCULATION IN THE BASIN!

Figura 4-22: esperimento Prim01, densitá, velocitá lungo costa e trasporto dopo 360 giorni

SUMMARY

BOTTOM BOUNDARY LAYER IMPORTANT MECHANISM ALSO IN ADRIATIC TO SUBSTAIN

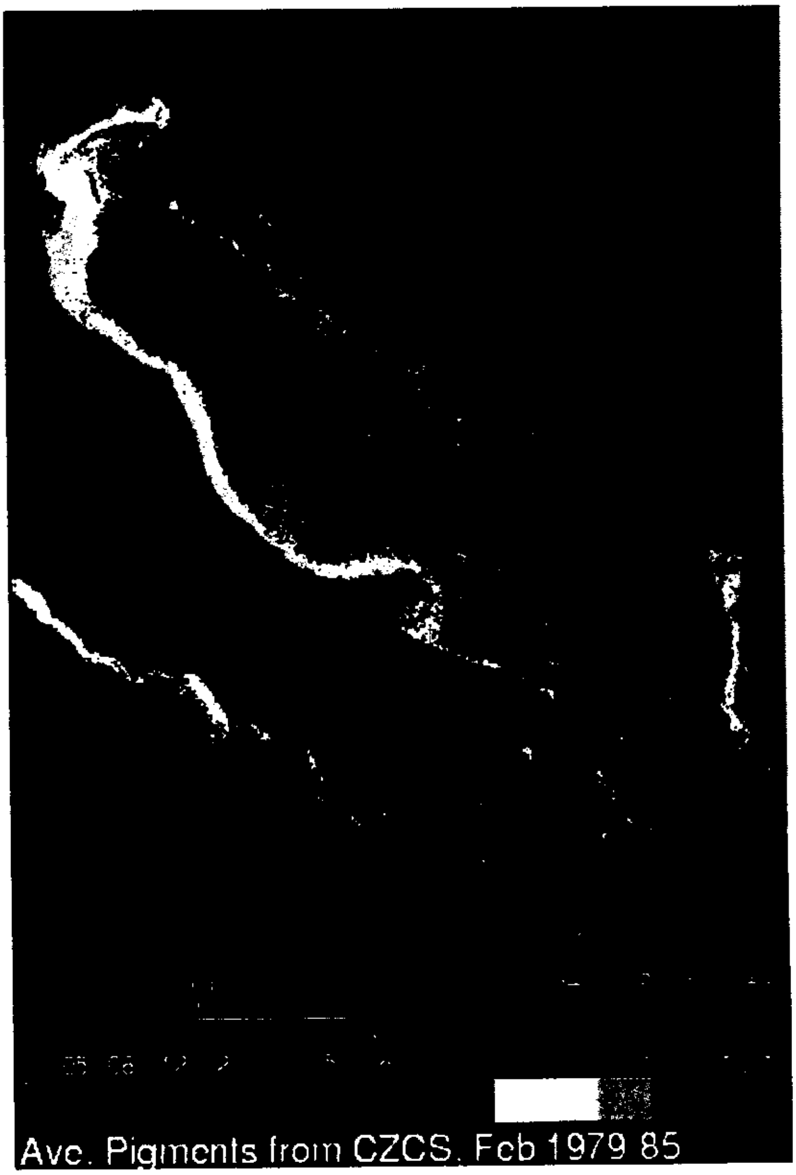
- DOWNWELLING / UPWELLING OF DENSITY STRUCTURE ACROSS THE BASIN
- CYCLONIC FLOW TENDENCY IN GENERAL CIRCULATION
- COASTAL JETS ON EASTERN / WESTER SIDES

THE ADRIATIC SEA BIOCHEMICAL SYSTEM : OBSERVATIONS & ECOSYSTEM MODELLING

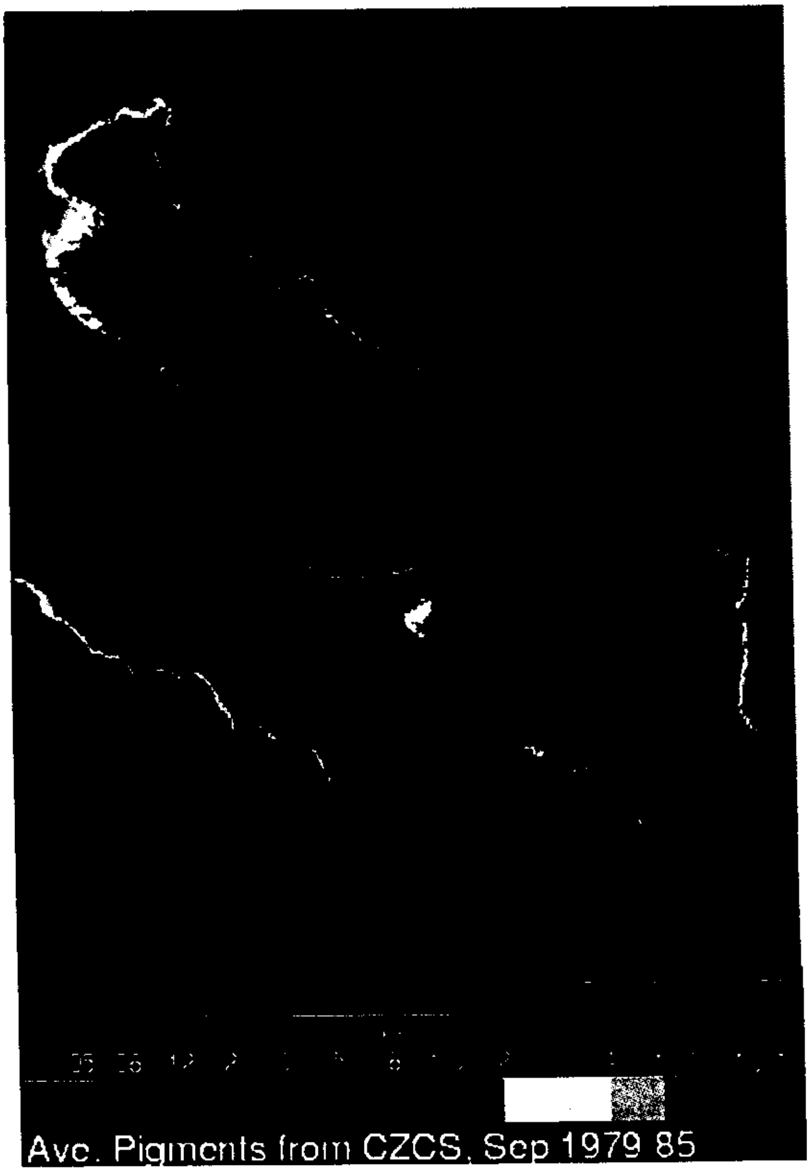
* **CZCS SURFACE CHLOROPHYLL**
  → North - South oligotrophic gradient
  why? Only Po?

* **IN SITY DATA : NUTRIENTS**
  → Phosphorous limitation? in the North?

* **COMPLEX ECOSYSTEM MODEL COUPLED TO PHYSICAL MODEL**
  → phytoplankton cycle captured as a combination of water column physics and nutrient input from rivers



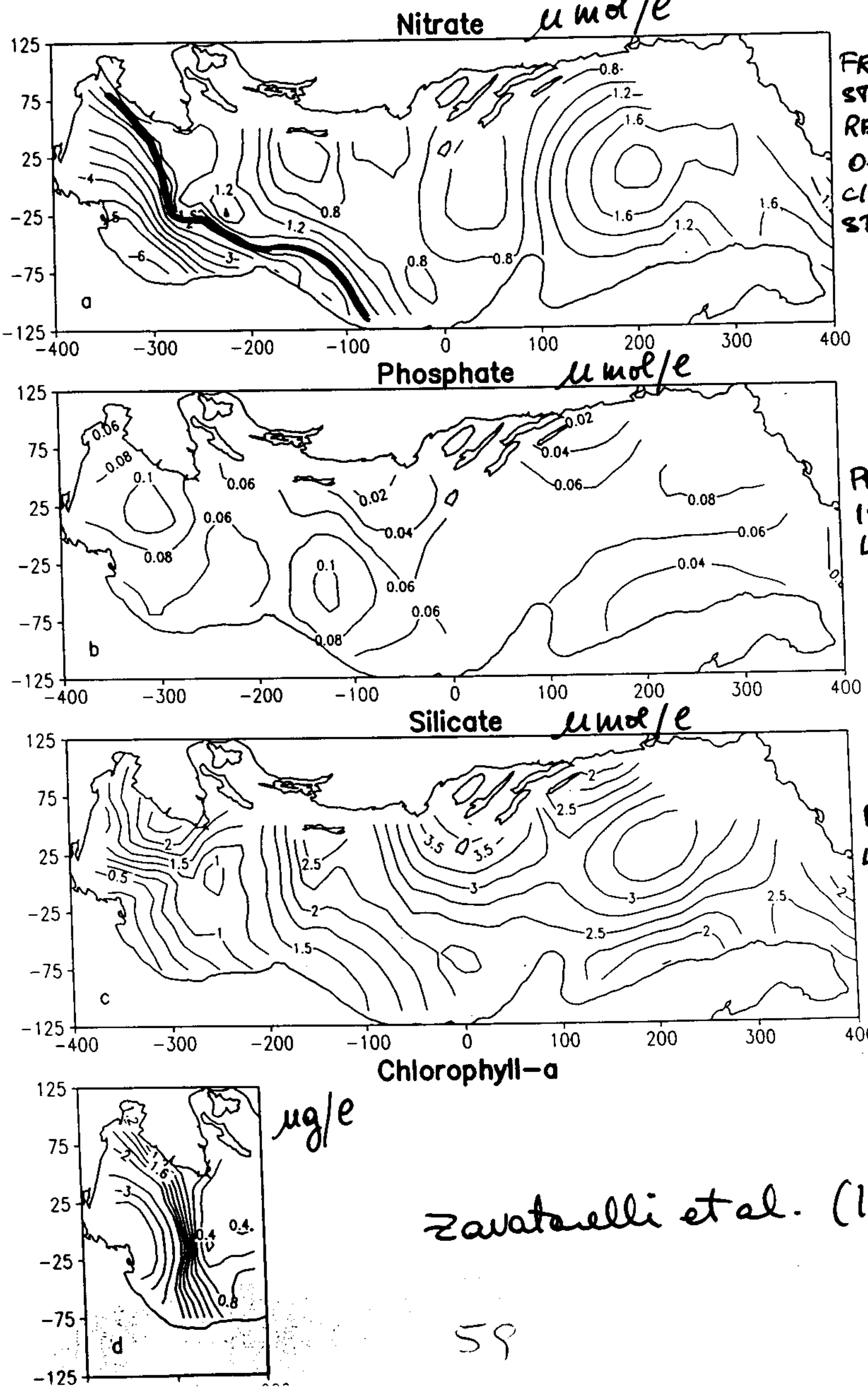
Ave. Pigments from CZCS. Feb 1979 85



Avc. Pigmcnts from CZCS, Sep 1979 85

Avc. Pigments from CZCS. Dec 1979 85

WINTER, SURFACE



FRONTAL STRUCTURE REMINDS OF CIRCULAT. STRUCTURE

PHOSPH. IS LIMITING

PARTLY LIMITING

Zavatarelli et al. (1997)

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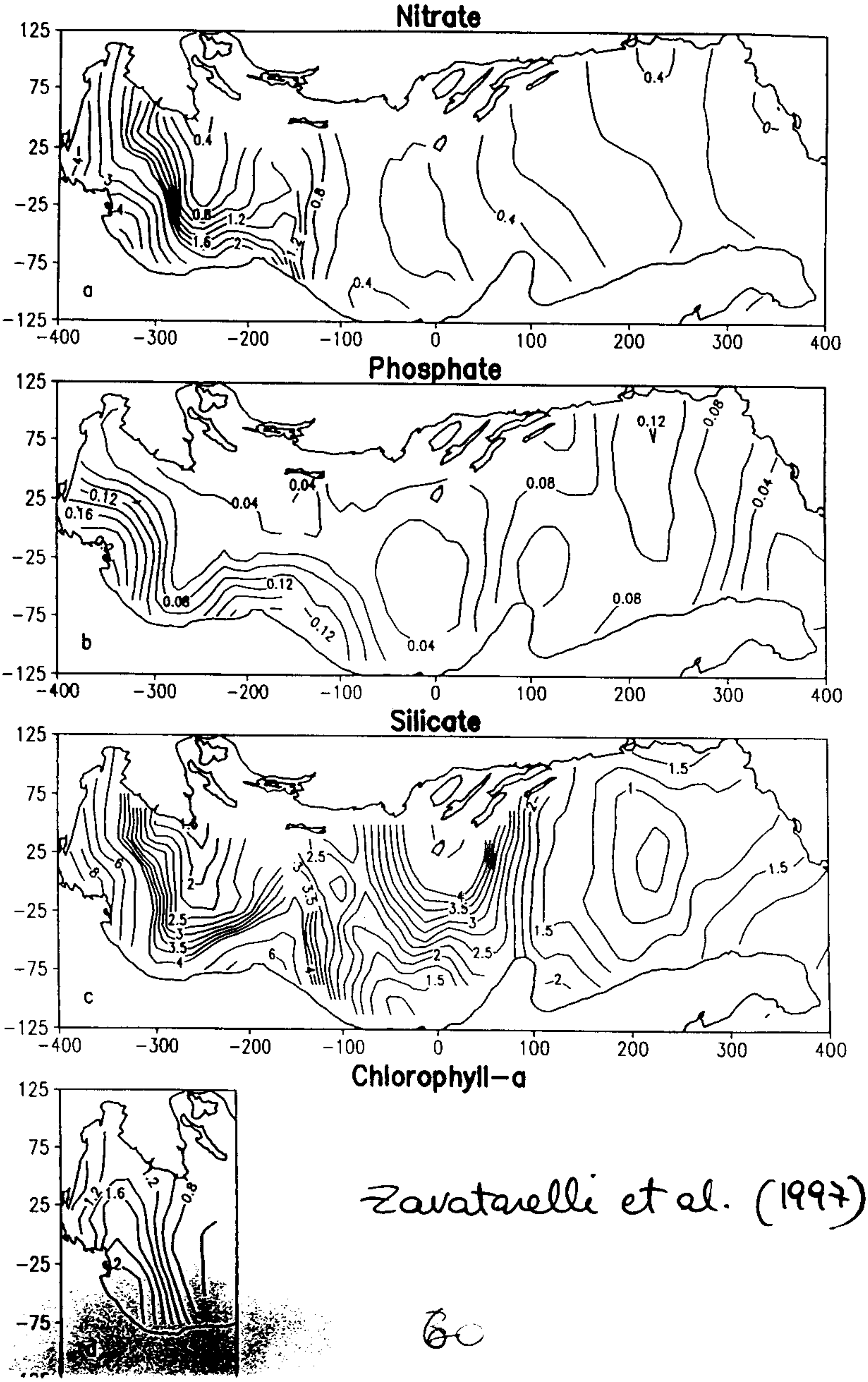
AUTUMN, SURFACE



Zavatarelli et al. (1997)

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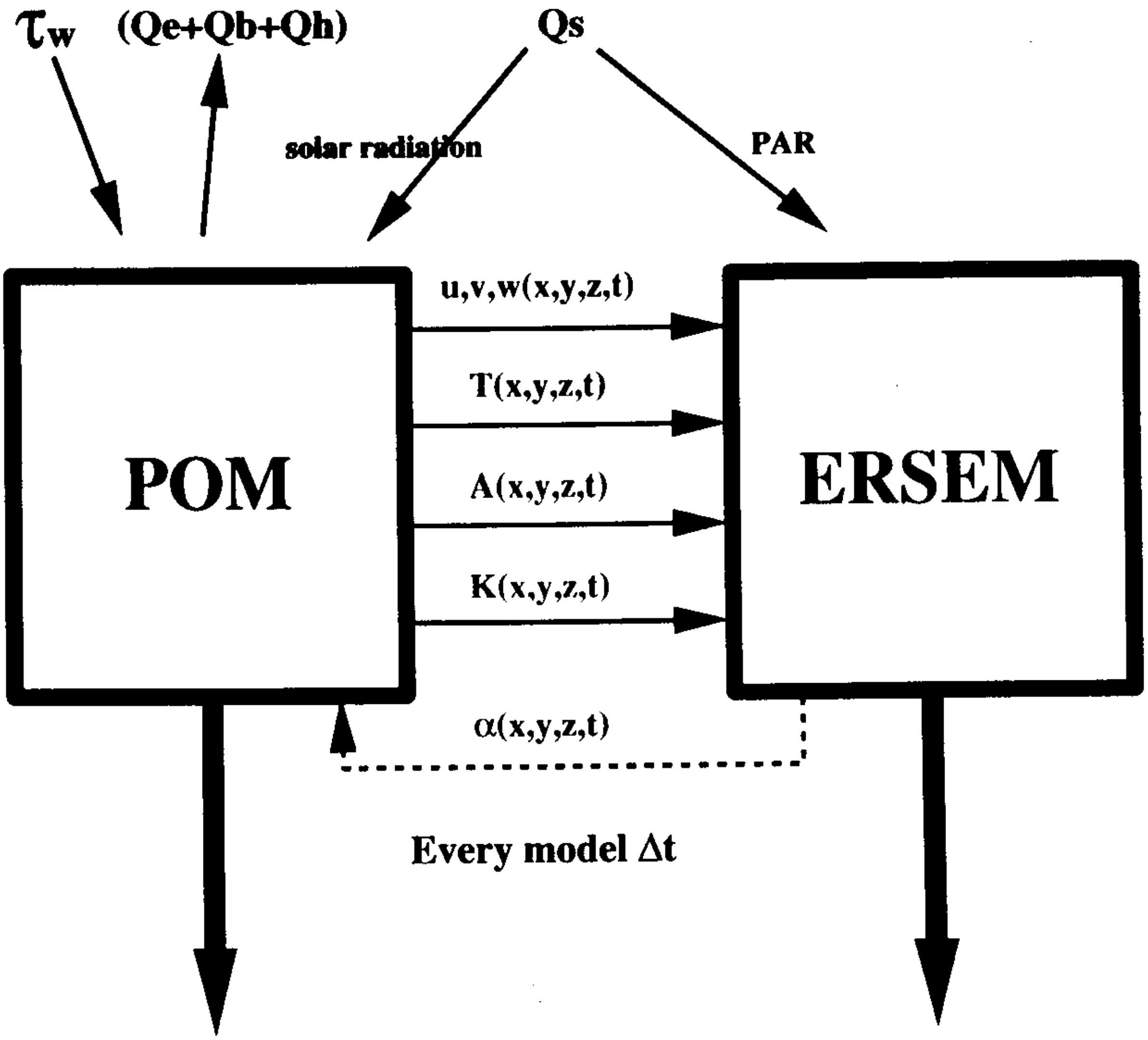
POM/ERSEM Coupling



τ_w (Qe+Qb+Qh)

Qs

solar radiation

PAR

POM

ERSEM

u,v,w(x,y,z,t)

T(x,y,z,t)

A(x,y,z,t)

K(x,y,z,t)

α(x,y,z,t)

Every model Δt

Spatial and temporal evolution of physical properties

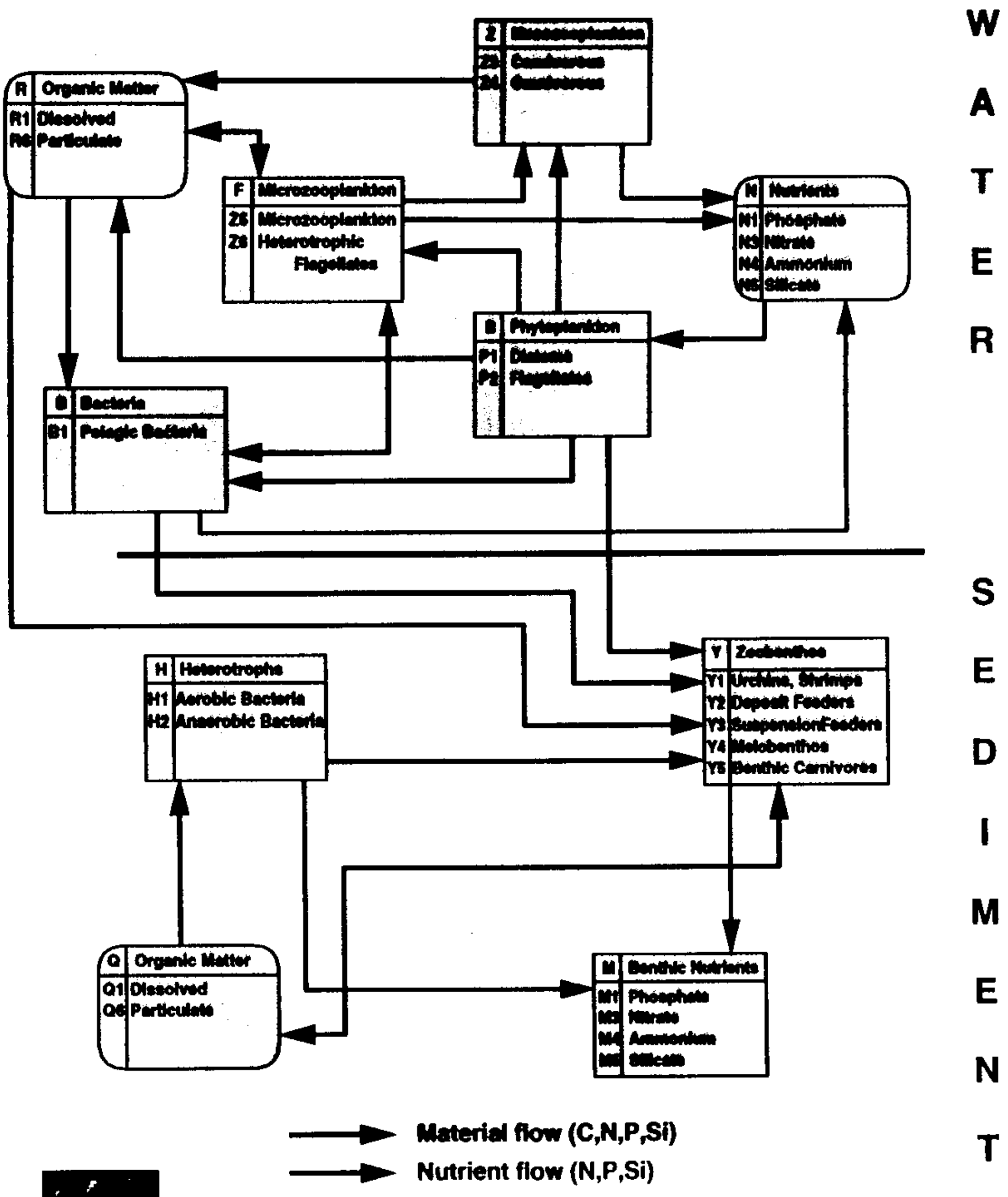
Spatial and temporal evolution of biogeochemical properties

IMGA

Numerical Laboratory

ERSEM

(Baretta et al., 1995)



W A T E R

S E D I M E N T

Z Mesozooplankton
Z3 Carnivorous
Z4 Omnivorous

R Organic Matter
R1 Dissolved
R6 Particulate

F Microzooplankton
Z5 Microzooplankton
Z6 Heterotrophic Flagellates

N Nutrients
N1 Phosphate
N3 Nitrate
N4 Ammonium
N5 Silicate

P Phytoplankton
P1 Diatoms
P2 Flagellates

B Bacteria
B1 Pelagic Bacteria

Y Zoobenthos
Y1 Urchins, Shrimps
Y2 Deposit Feeders
Y3 SuspensionFeeders
Y4 Meiobenthos
Y5 Benthic Carnivores

H Heterotrophs
H1 Aerobic Bacteria
H2 Anaerobic Bacteria

Q Organic Matter
Q1 Dissolved
Q6 Particulate

M Benthic Nutrients
M1 Phosphate
M3 Nitrate
M4 Ammonium
M5 Silicate

Material flow (C,N,P,Si)

Nutrient flow (N,P,Si)

IMGA

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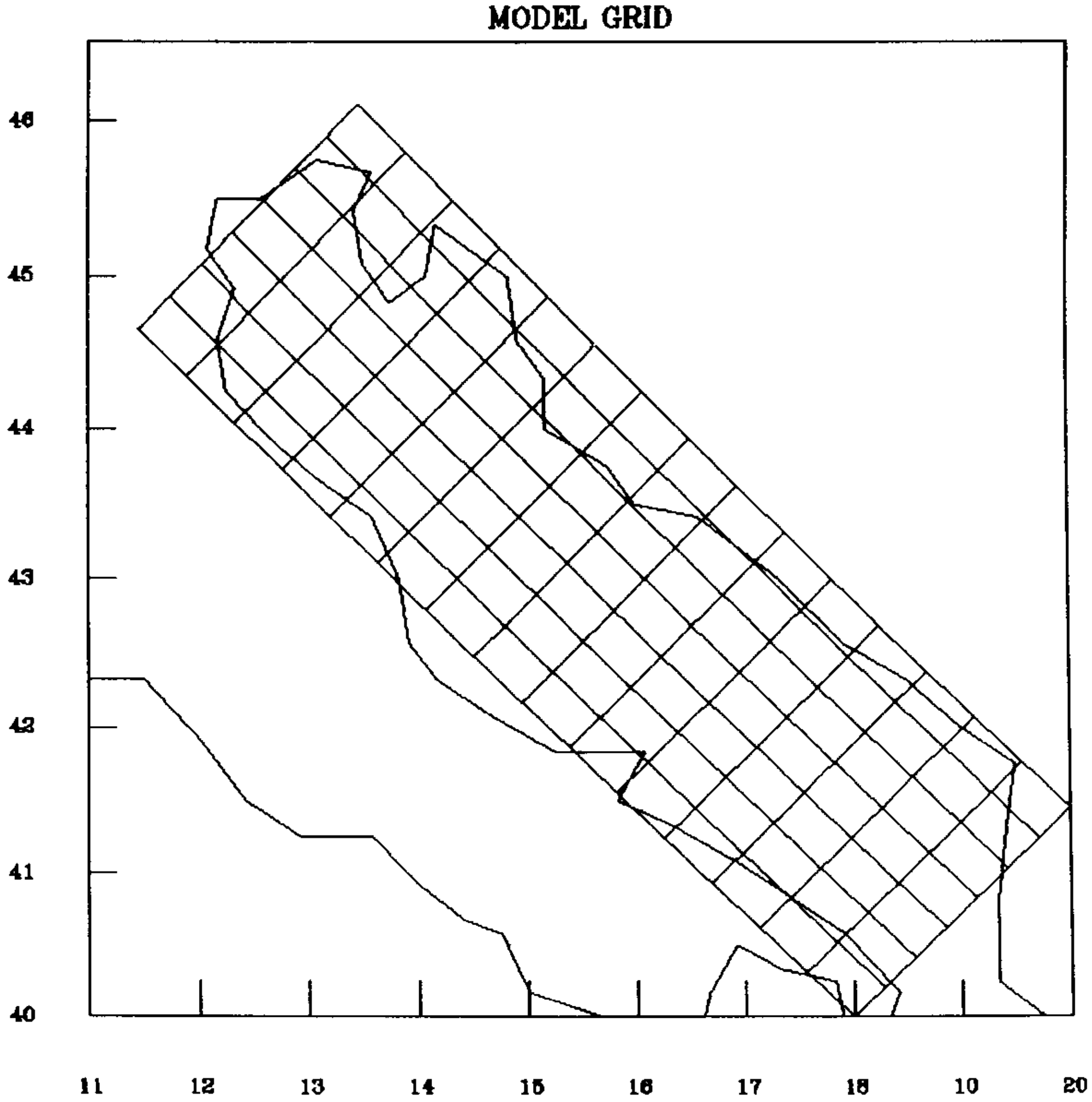
POM/ERSEM ECOSYSTEM MODEL

Idealized Adriatic Sea Implementation



Horizontal resolution: **25 Km**

Vertical resolution: **11 sigma (bottom following) layers**

Sloping bottom (50 to 500 m)

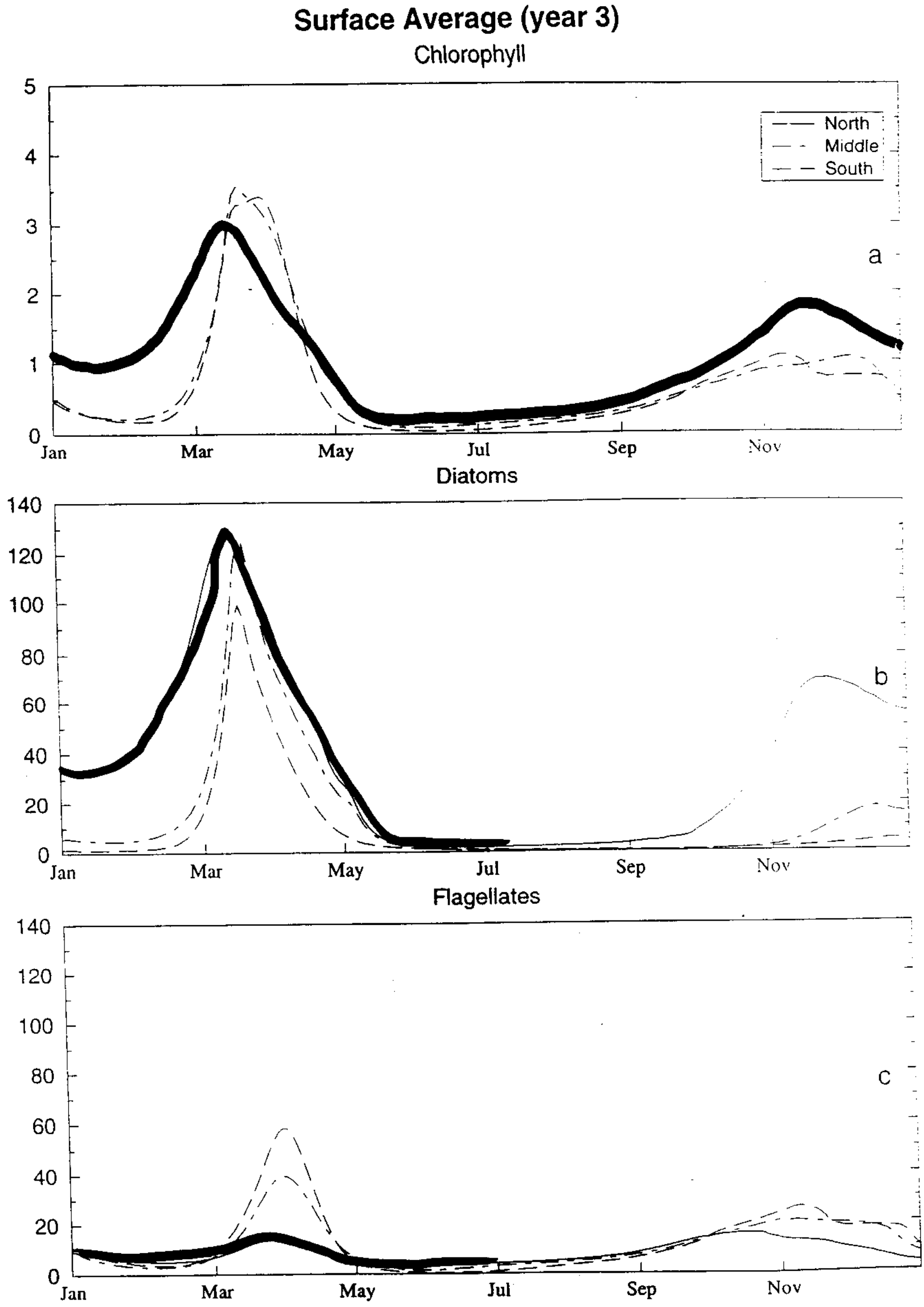

Surface Average (year 3)
Chlorophyll
North
Middle
South
a
0
1
2
3
4
5
Jan
Mar
May
Jul
Sep
Nov
Diatoms
b
0
20
40
60
80
100
120
140
Jan
Mar
May
Jul
Sep
Nov
Flagellates
c
0
20
40
60
80
100
120
140
Jan
Mar
May
Jul
Sep
Nov

Fig 4

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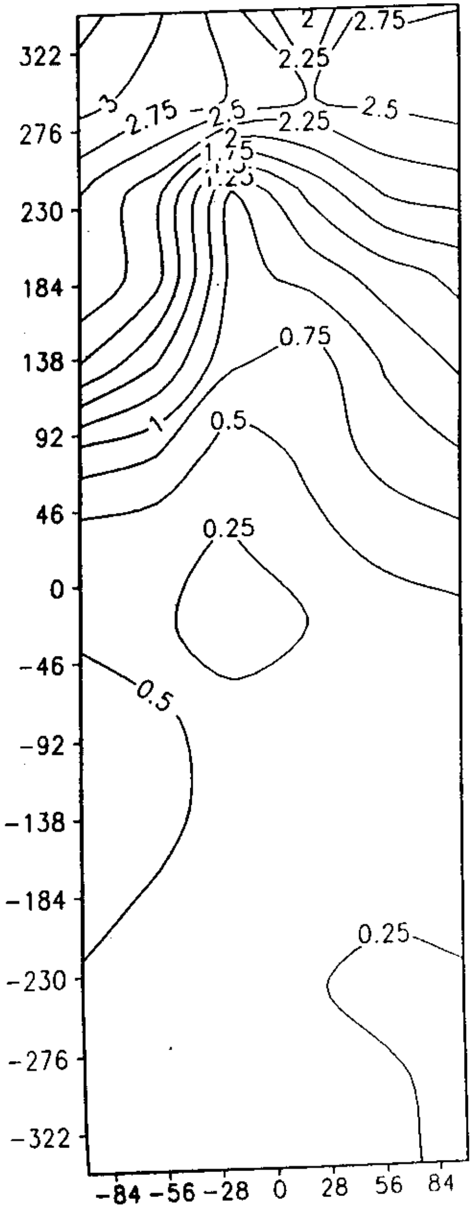
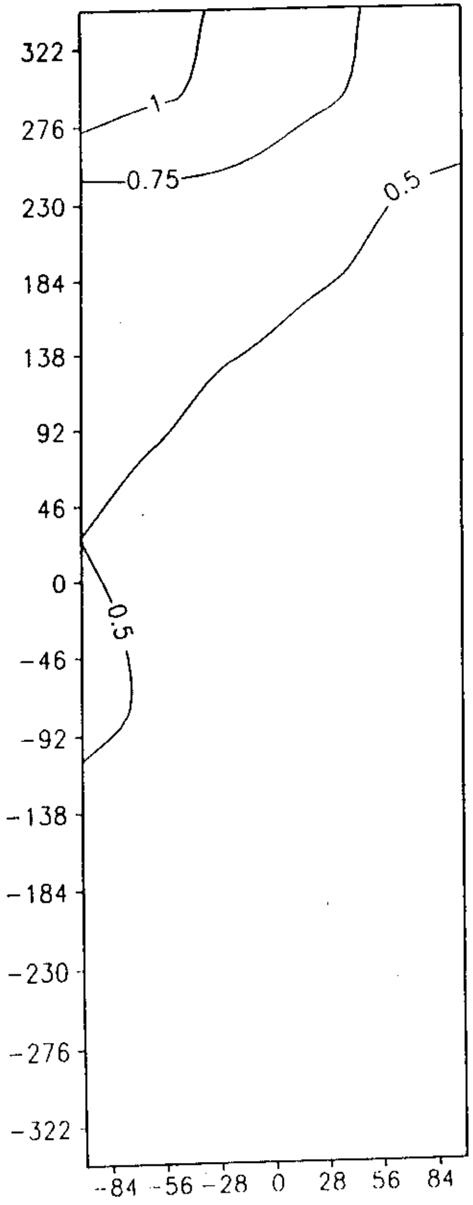
Chlorophyll mg/m^3
depth = 0 m



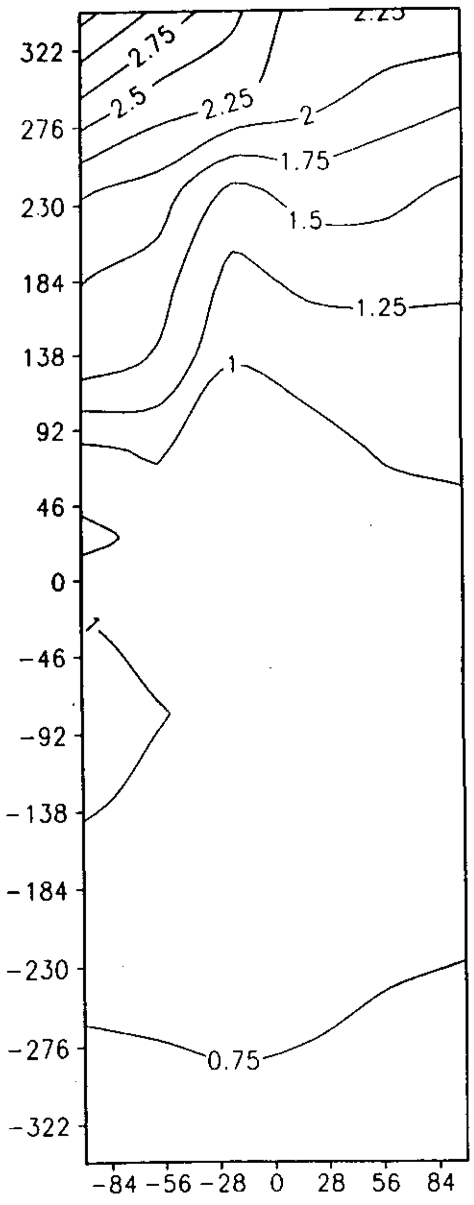
February

Chlorophyll mgC/m^3
depth = 0 m



September

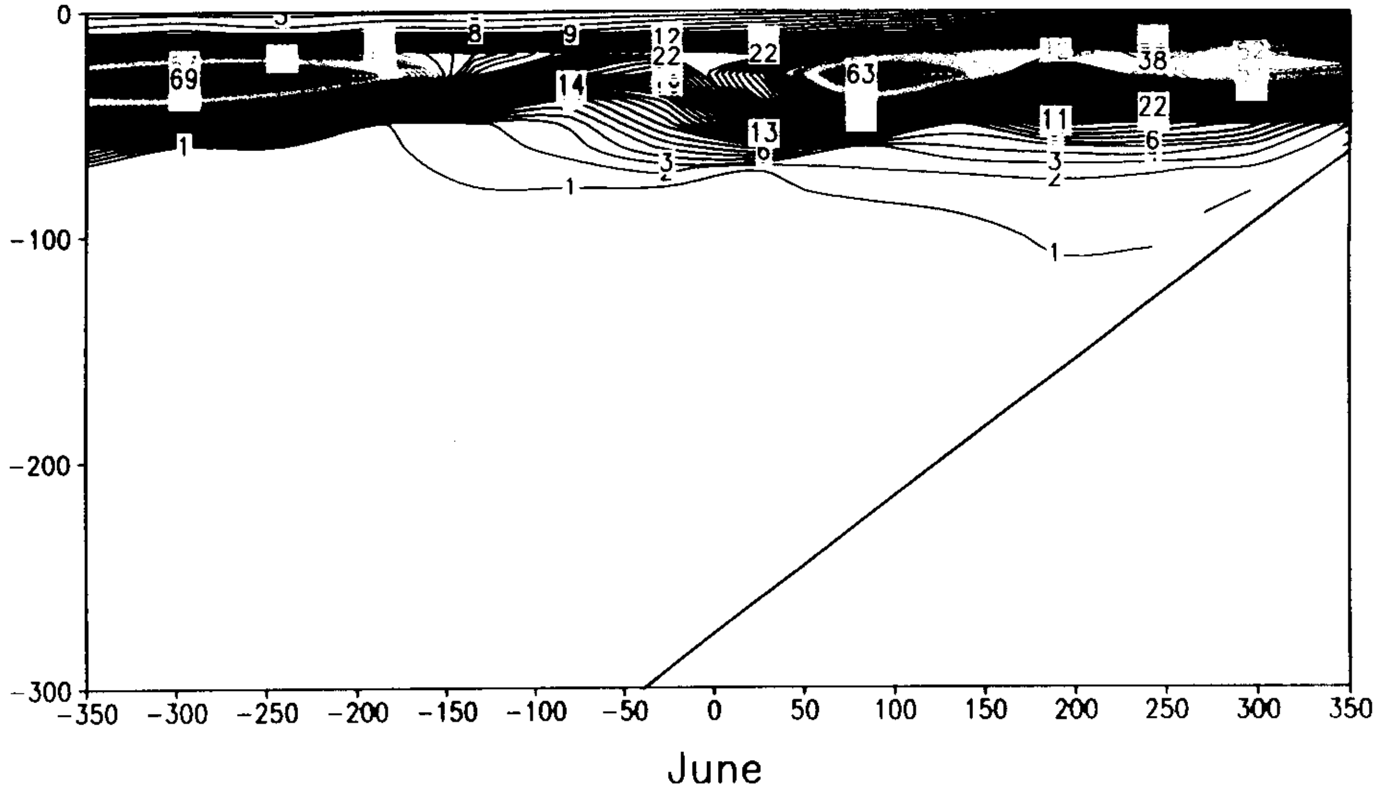
Chlorophyll mgC/m^3
depth = 0 m



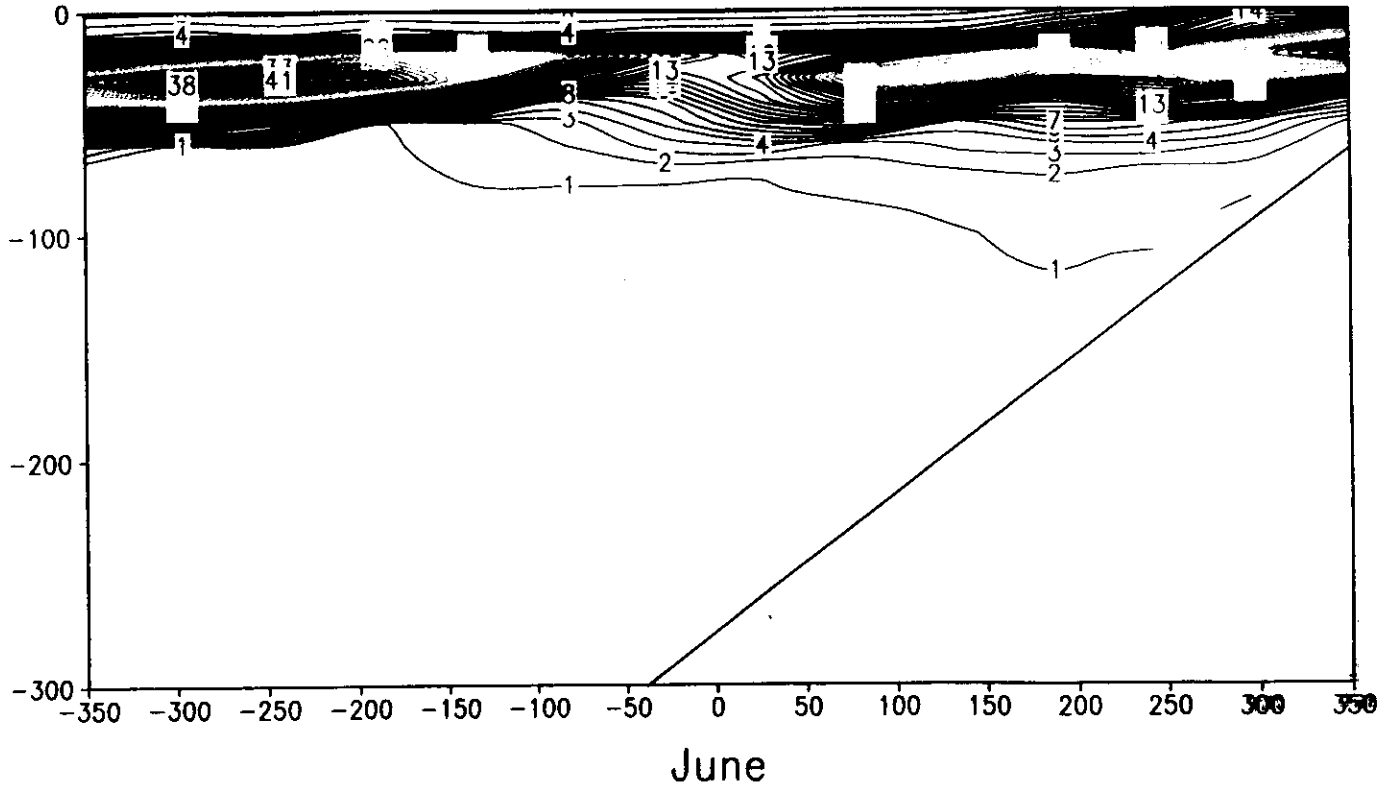
December

SUBSURFACE PHYT. MAXIMA

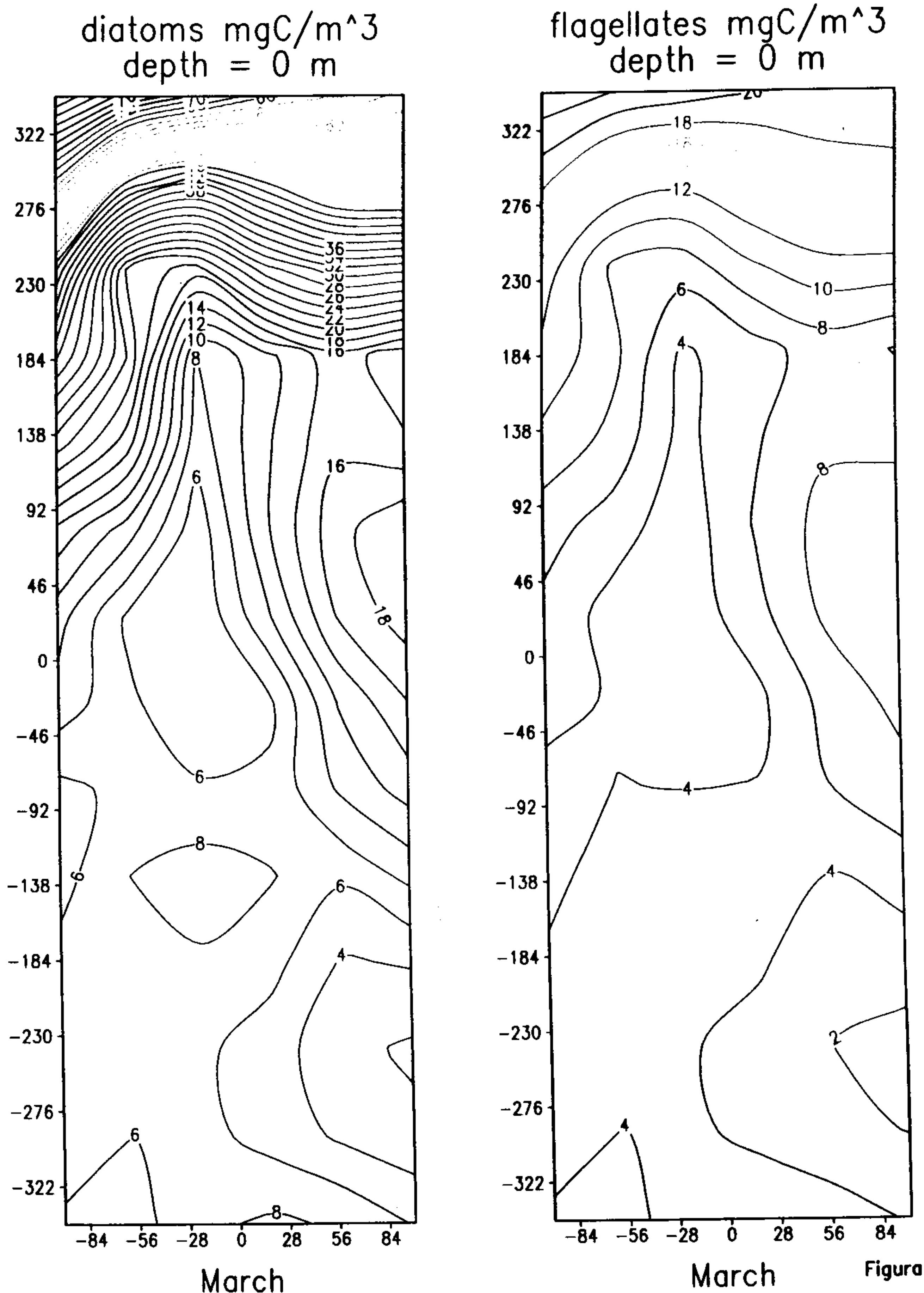
diatoms mgC/m^3



flagellates mgC/m^3

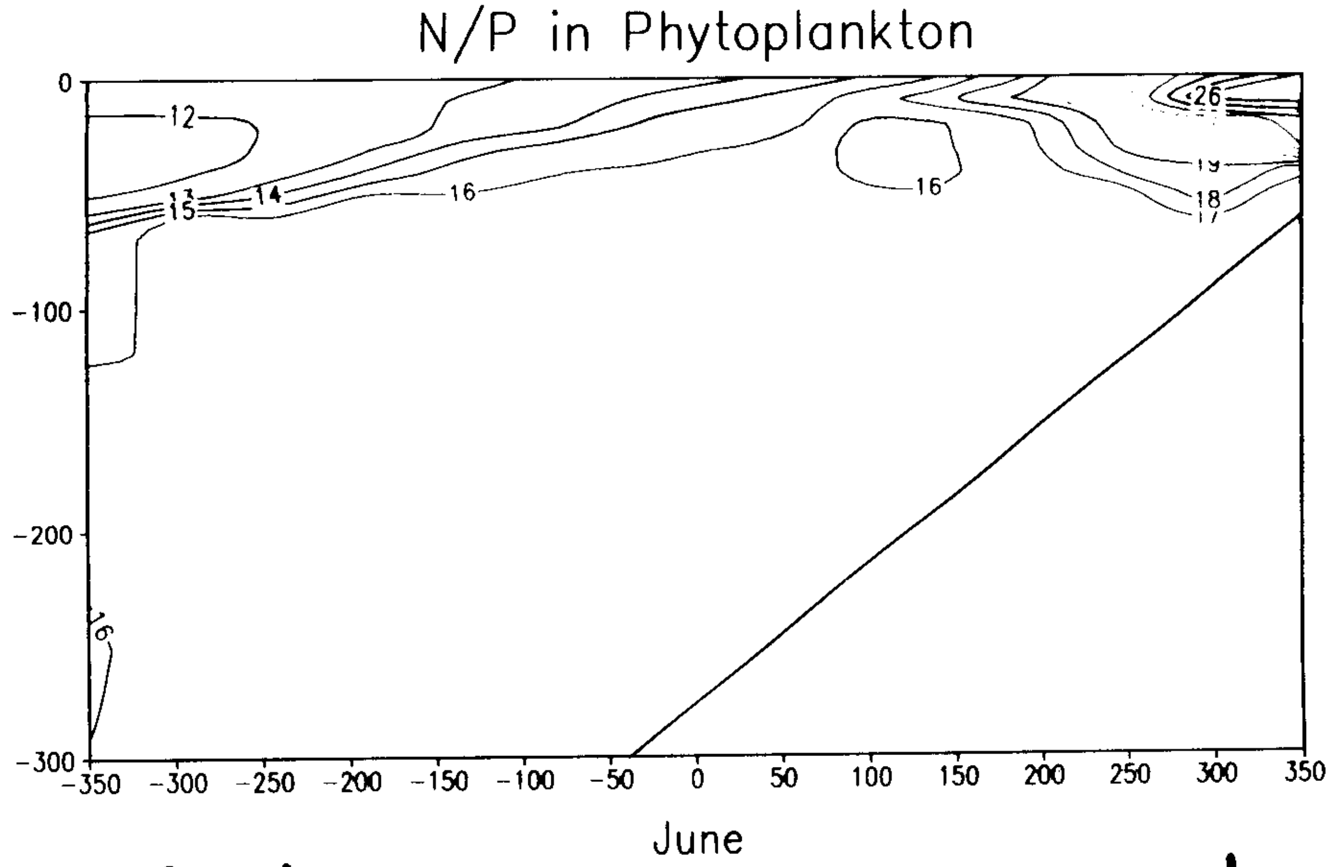


GrADS: COLA/IGES



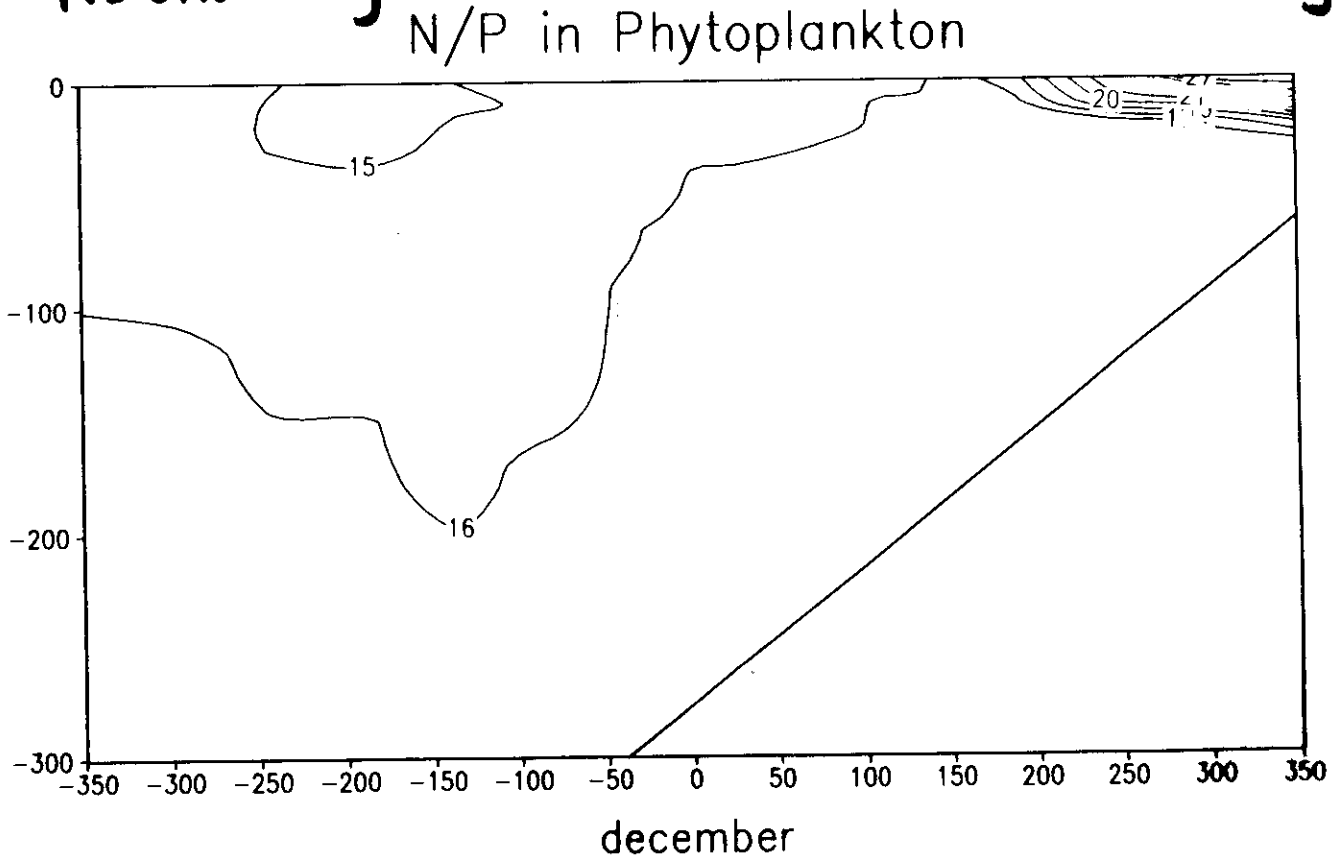
GrADS: COLA/IGES

Figura 1



N- Limiting

P- Limiting



GrADS: COLA/IGES