united nations
ucational, scientific
and cultural
organization

ternational atomic
energy agency

the
abdus salam
international centre for theoretical physics

SMR/1108 - 6

COURSE ON "MEDITERRANEAN SEA(S) CIRCULATION & ECOSYSTEM FUNCTIONING"

2 - 20 November 1998

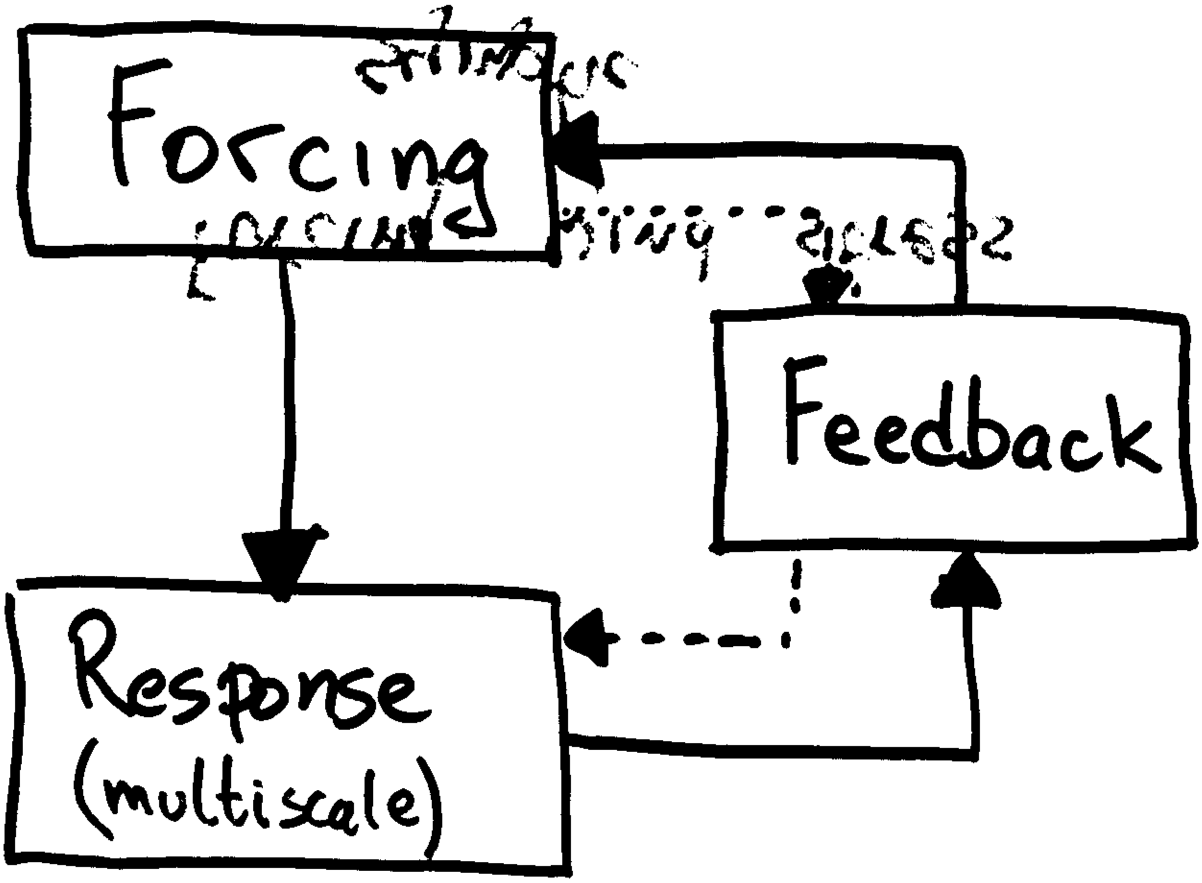
Trieste, Italy

* * *

"Dynamics of the Mediterranean Seas: Introduction"

(Transparencies)

S. BRENNER
Israel Oceanographic & Limnological
Research Institute
Haifa, Israel


Forcing
Feedback
Response
(multiscale)

Forcing

- Topography
  - Direct - bathymetry
  - Indirect - mountain ranges → wind stress

- Surface forcing
  - Wind stress
  - Heat flux ←→ $\left\{\begin{array}{l}\text{climatological}\\ \text{synoptic}\\ \text{diurnal}\end{array}\right.$
  - E-P

- Exchange through straits
  - Gibraltar basinwide
  - Sicily
  - Bosphorous } sub-basin
  - Otranto

- Fresh water input
  - River discharge
  - Precipitation
  - Black Sea

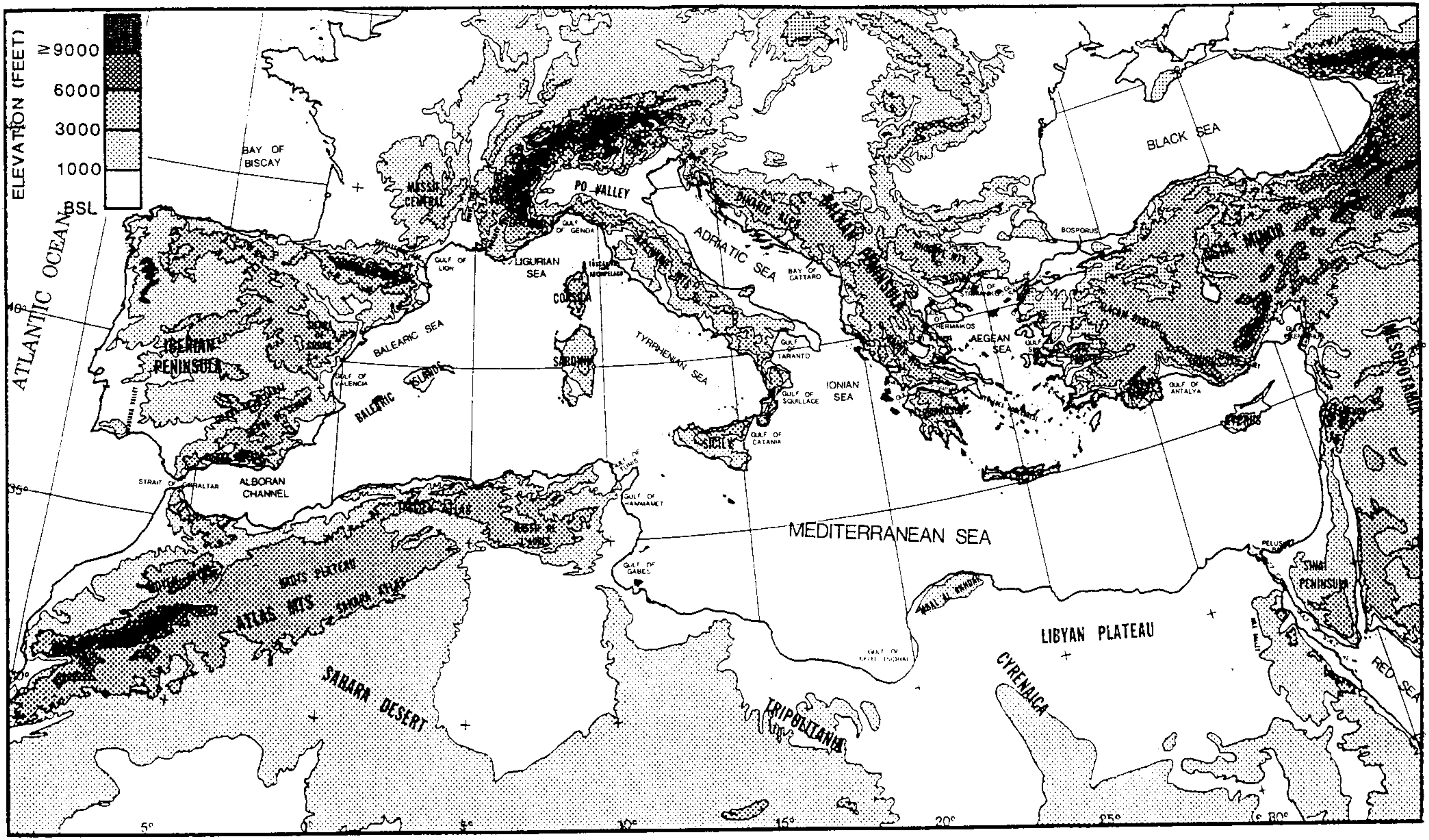


Figure I-A-2. "Three-dimensional" map showing the topography of the Mediterranean area.

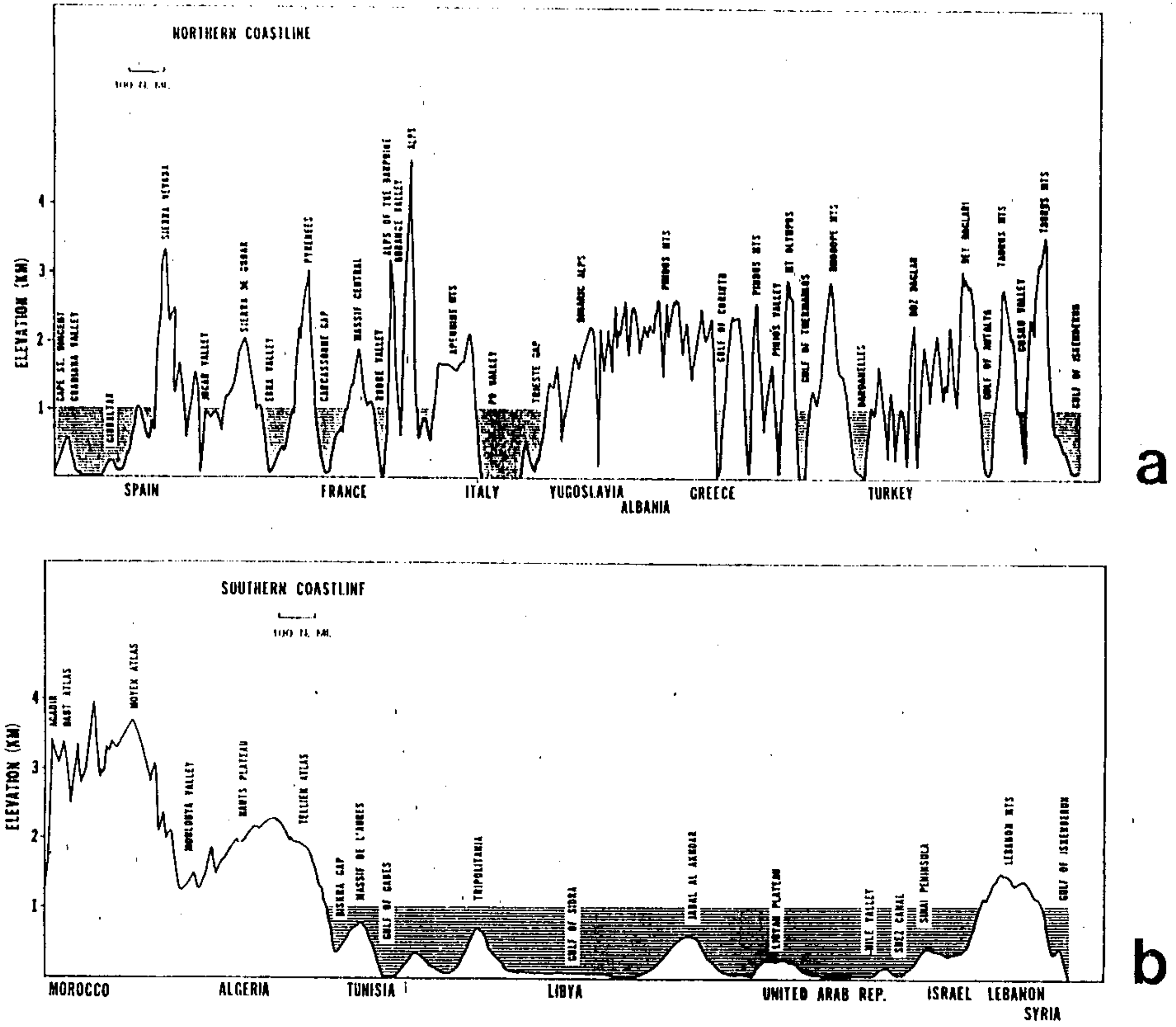


Figure I-C-1. Cross sections, approximately parallel to (a) the northern and (b) the southern shores of the Mediterranean, and roughly 100 miles inland from the shore. Major orographic obstacles and gaps between mountains are indicated. Gaps below 1000 m are shaded.

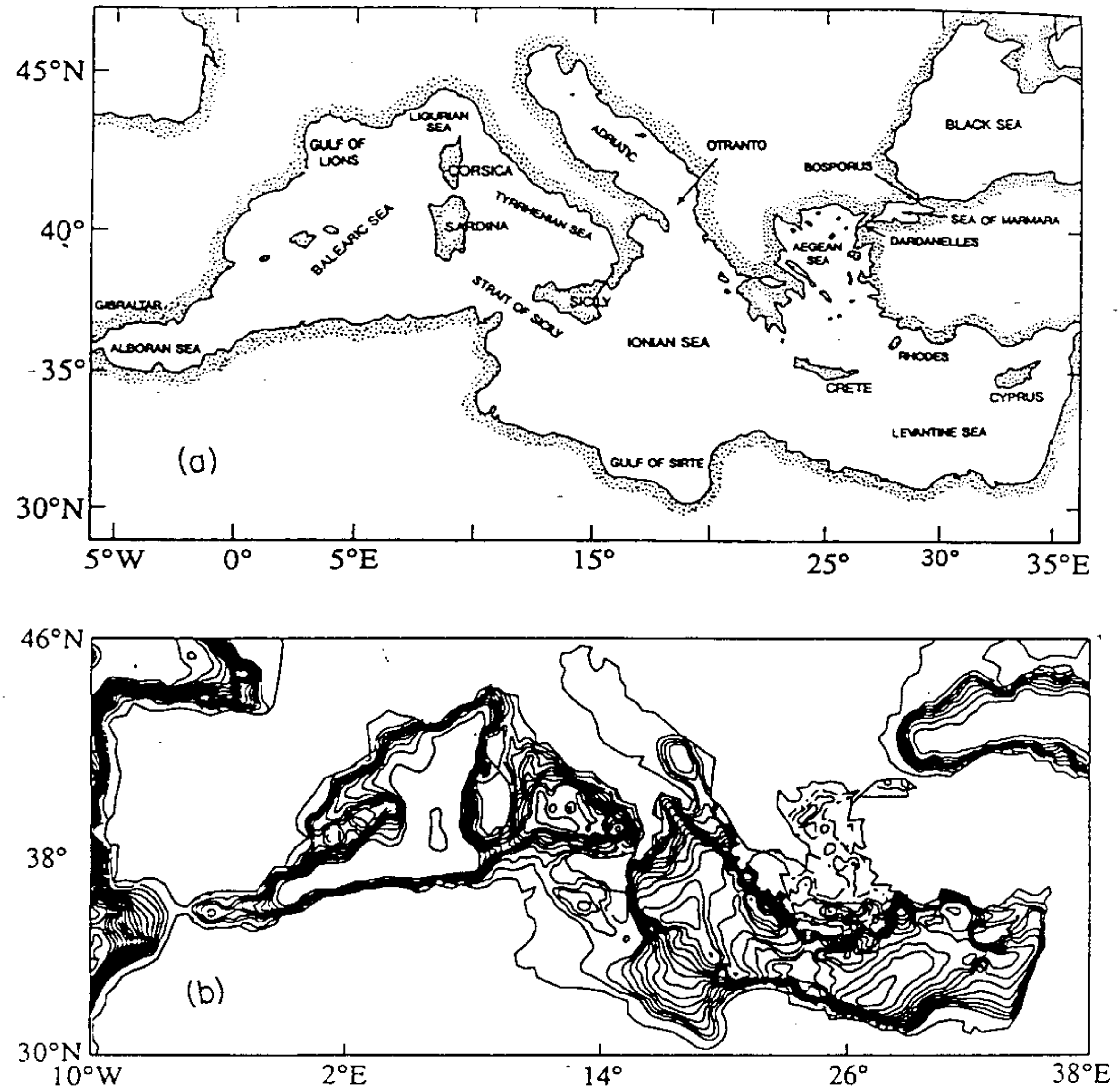


Fig. 1. The Mediterranean Sea (a) basin configuration; (b) bottom topography.

Forcing - topography

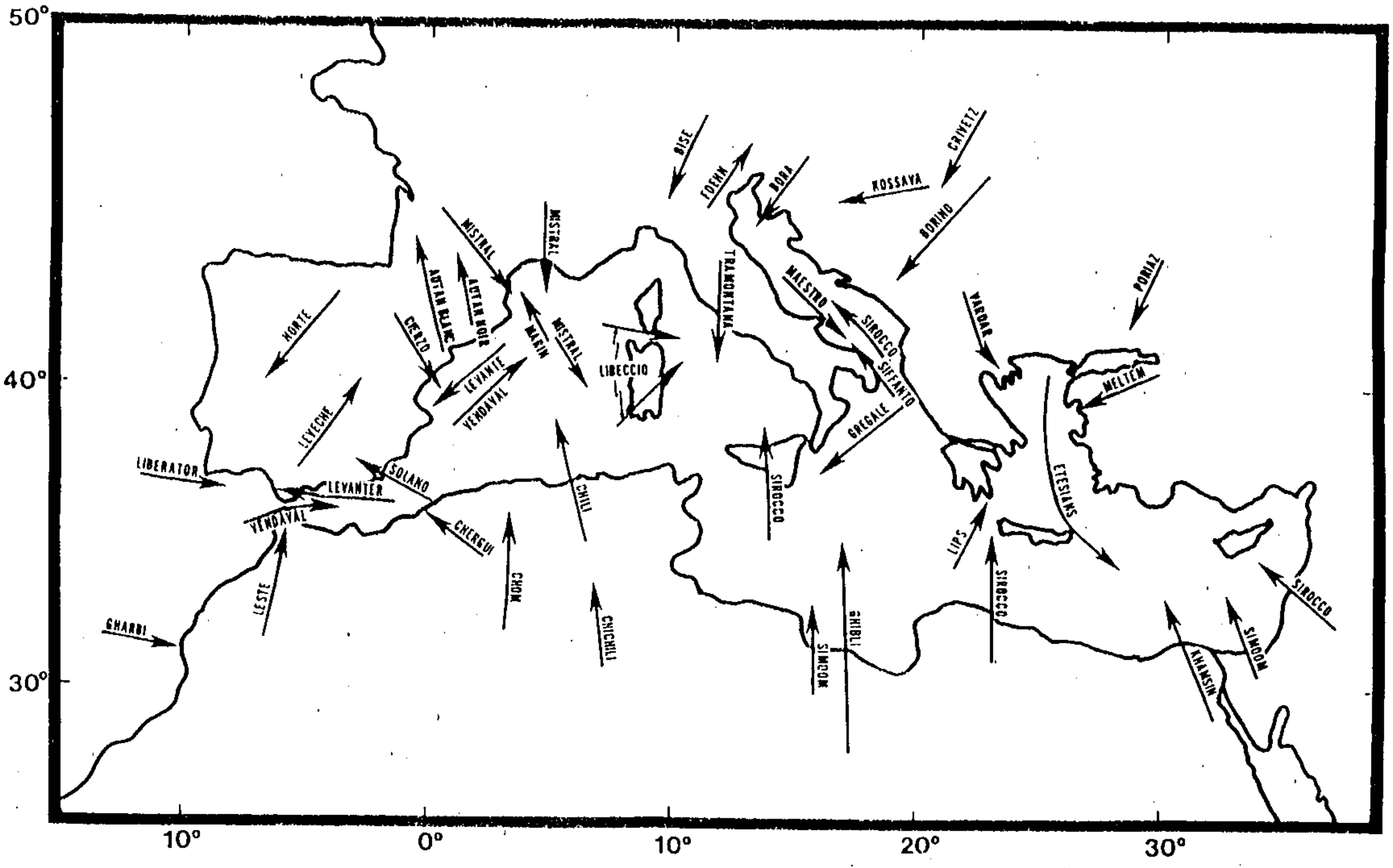


Figure I-C-2. Major wind systems in the Mediterranean region.

coincide with the mean positions of jet maxima in the STJ belt. As shown in Figure III-B-3, this belt is usually deformed into a planetary 3-wave pattern.

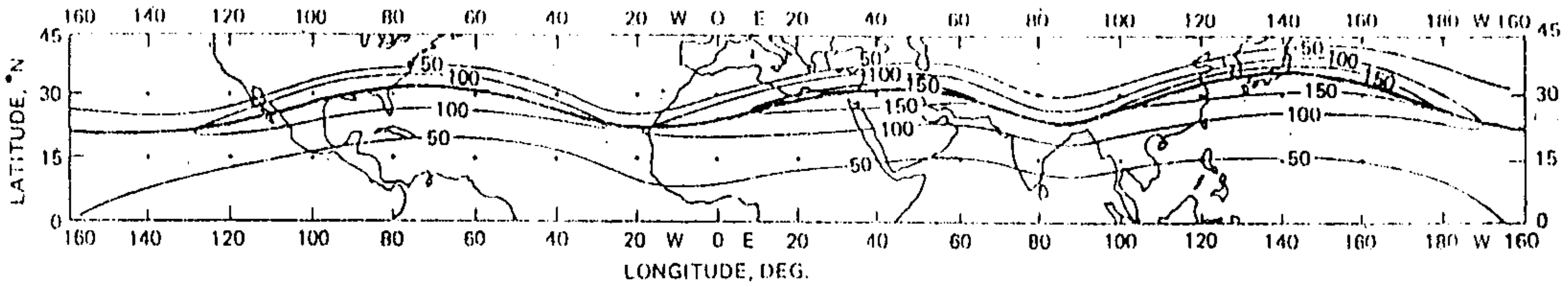


Figure III-B-3. Mean subtropical jet stream of the winter of 1955-1956. Isotach analysis at the 200-mb surface, with isotachs drawn at 50 kt intervals. The mean latitude of the jet axis is 27.5°N (from Reiter, 1969).

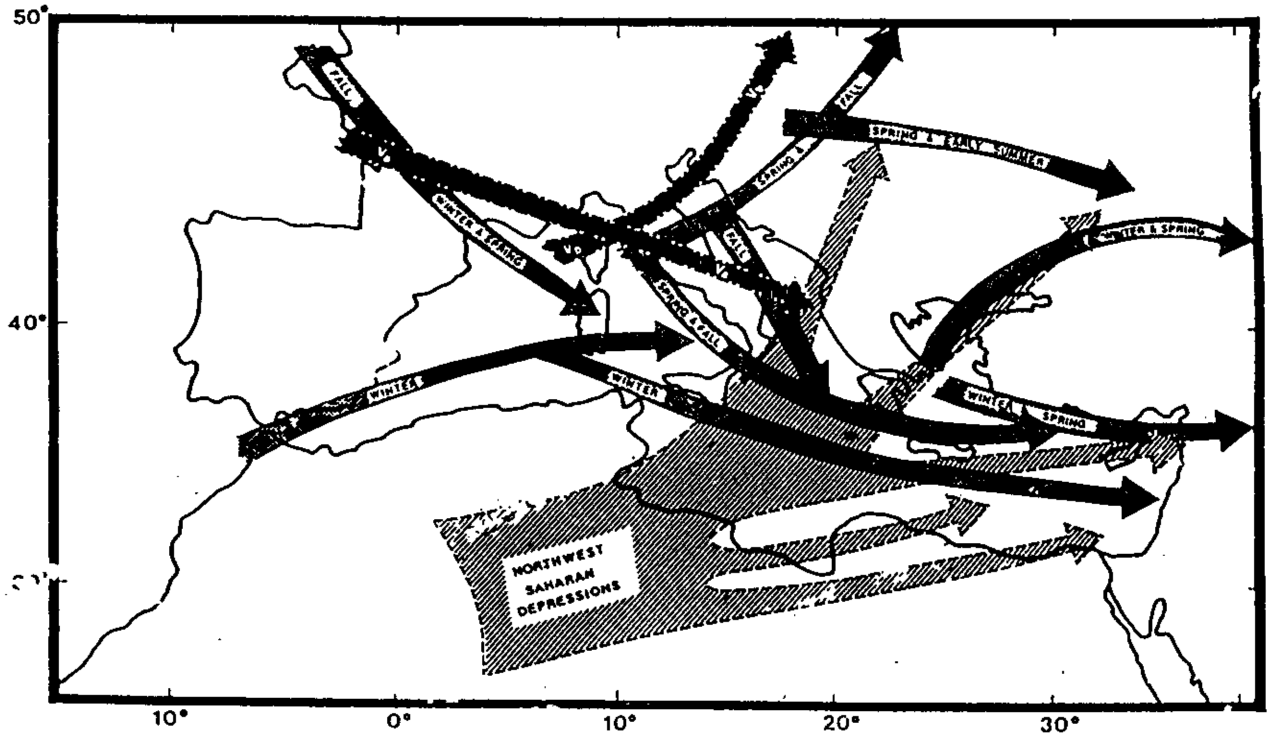


Figure III-E-1. Major cyclone tracks in the Mediterranean region (after Black, 1969; Reiter, 1971, and Fitzpatrick, 1970). Tracks Va and Vb are according to classification by van Bebber.

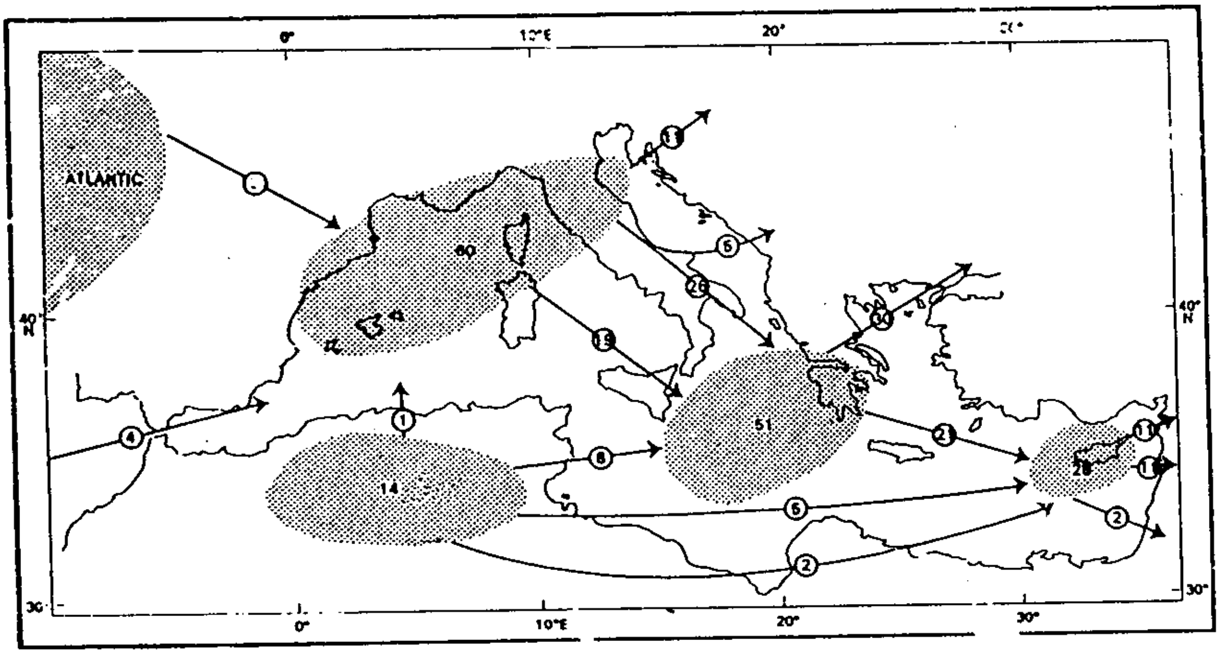


Fig. 3 Tracks of Mediterranean depressions. Numbers indicate average annual frequencies. (After Mediterranean Pilot, 1976). Produced from portion(s) of Mediterranean Pilot Vol V 6th Edition (1976) with the sanction of the Controller, HM Stationary Office and of the Hydrographer of the Navy.

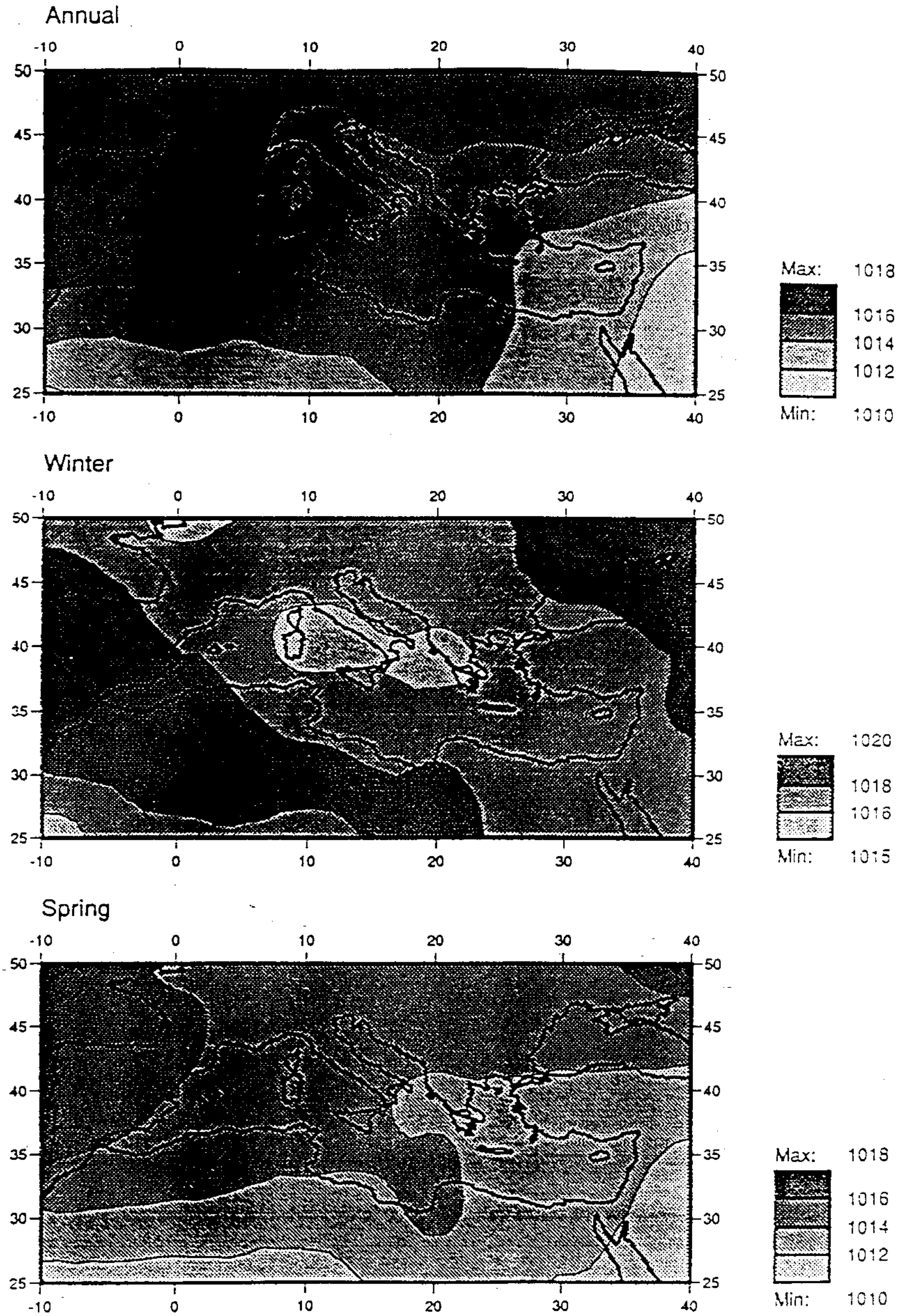


Fig. 2.2 Observed MSLP pressure (mb)

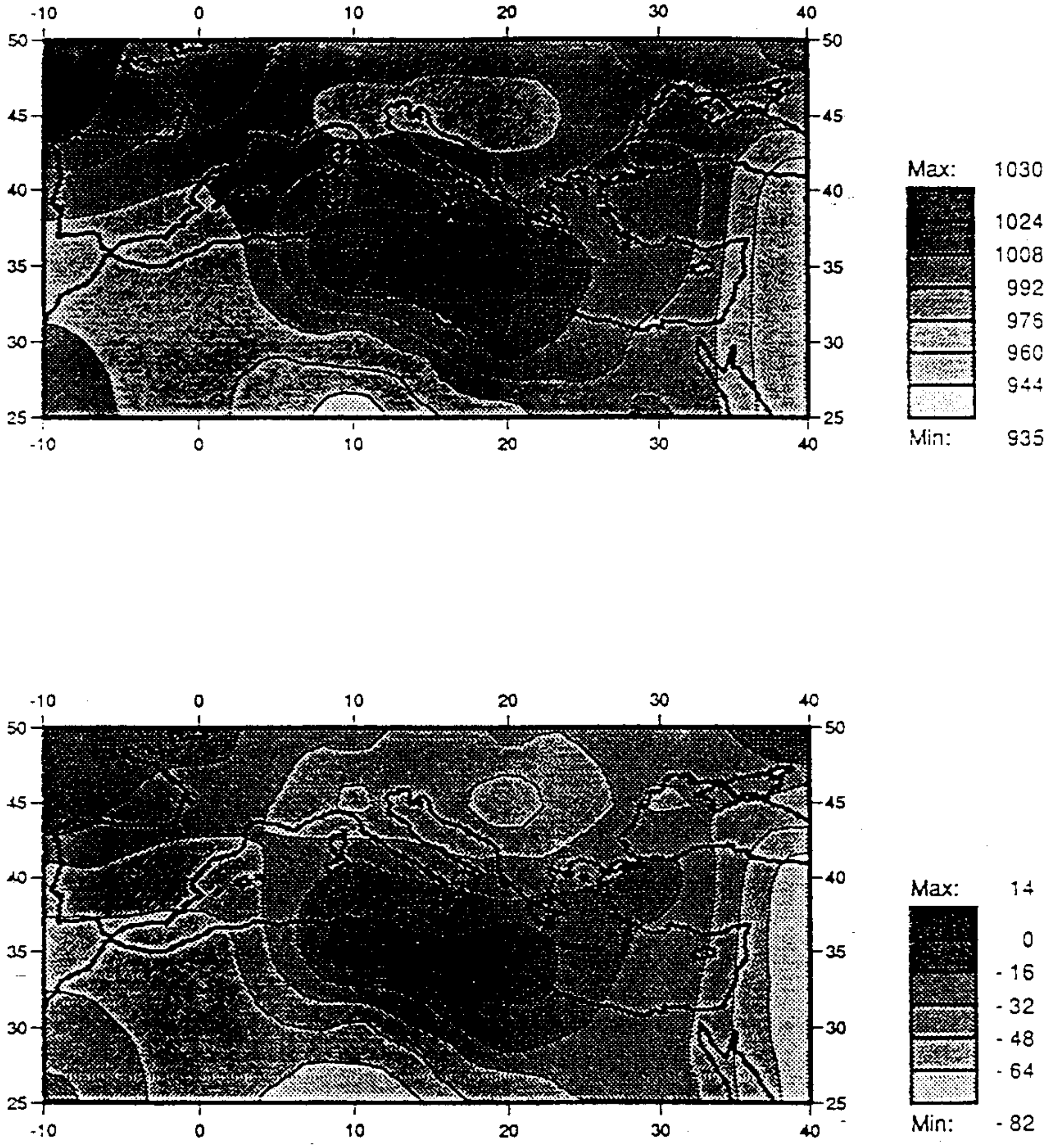


Fig. 2.3 cont. Winter MSLP control run (above) and control/observed differences (below) in mb: GFDL GCM

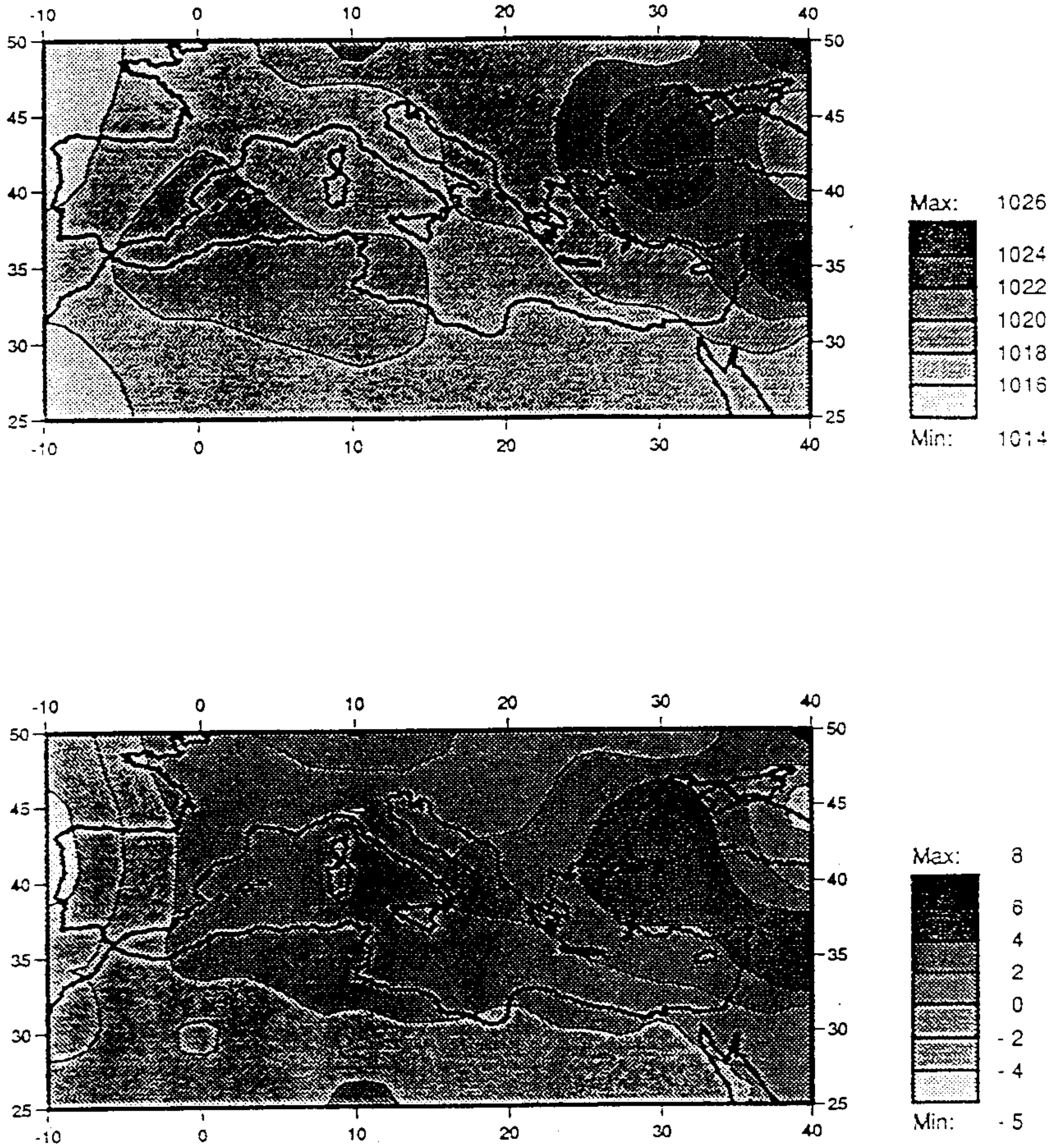


Fig. 2.4 cont. Winter MSLP control run (above) and control/observed differences (below) in mb: GISS GCM

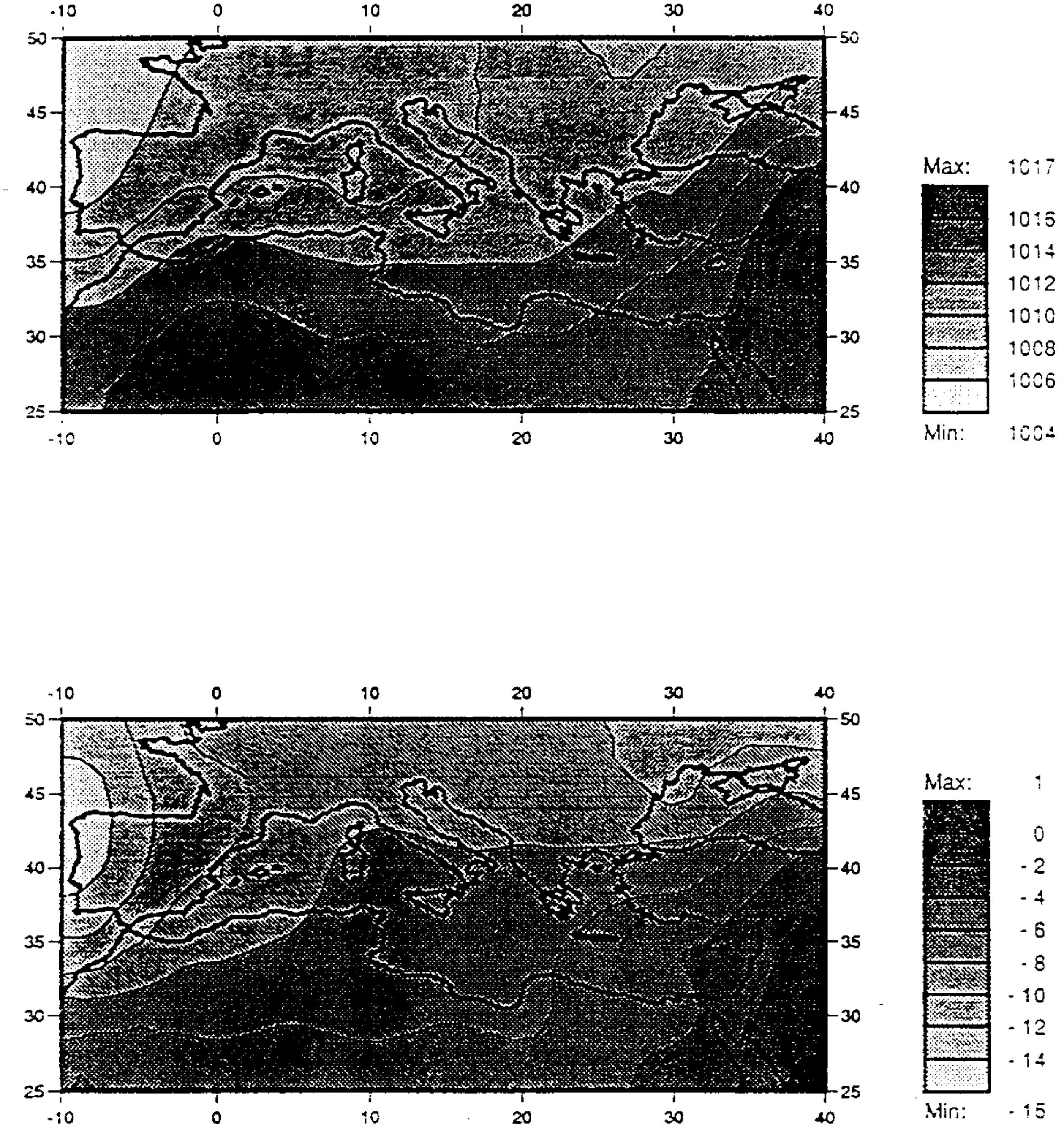


Fig. 2.5 cont. Winter MSLP control run (above) and control/observed differences (below) in mb: OSU GCM

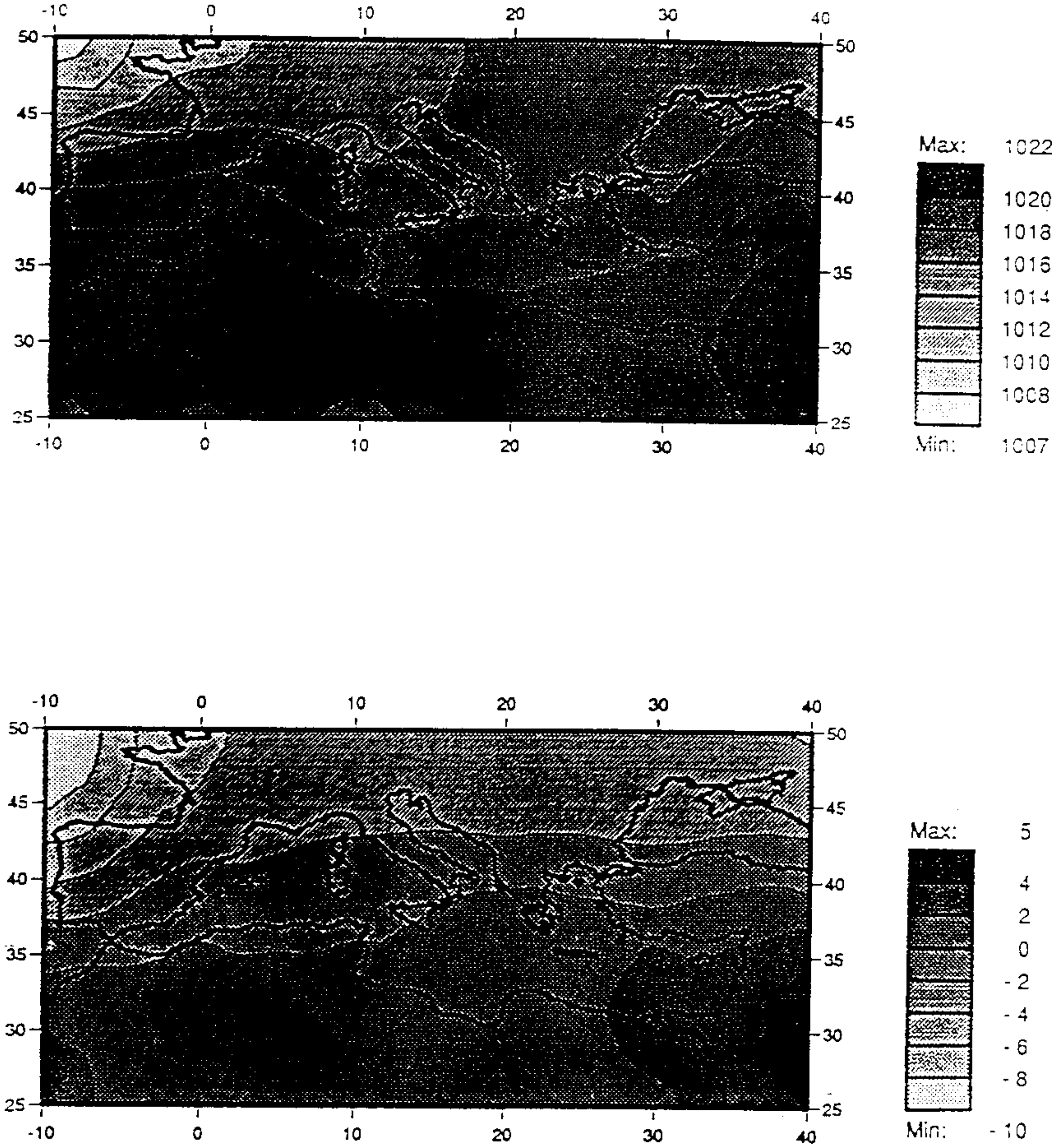


Fig. 2.6 cont. Winter MSLP control run (above) and control/observed differences (below) in mb: UKMO GCM

Surface fluxes

$$\left.\begin{array}{l}\text{Momentum}\\ \text{Mass}\\ \text{Heat}\end{array}\right\}\ \begin{array}{c}\text{turbulent}\\ \text{transfer}\\ \text{(Reynolds stress)}\end{array}\ \left\{\begin{array}{l}\overline{u'w'}\\ E-P\\ \overline{w'T'}\end{array}\right.$$

(Buoyancy)

- All are difficult, if not impossible, to measure directly.

⇒ Development of empirical formulae (bulk aerodynamic) based on "easily" measured parameters

Surface fluxes - sources

- long term (climatological)
    - based on decades of ship obs
    - motivated by heat budget studies
    - constrained by " " "
    - uncertainties ~ 20%
        - source & type of data
        - bulk aerodynamic formula
    - "coarse" spatial resolution
- synoptic
    - for model simulations, esp. forecasti
    - Reanalyses from met centers
        - ECMWF - 15 yr; NCEP - 40 yr.
        - critical assessment
        - spatial resolution ?
    - "Special" data sets
        - MEDIAS CD-ROM 1994

Coupled ocean-atmosphere models potentially most promising

Momentum flux - wind stress

Important for:
- wind driven circulation
- vertical mixing

Bulk aerodynamic formula

$$\underset{\sim}{\tau} = \rho_a C_D V \underset{\sim}{V}$$

ρ_a - air density

C_D - drag coefficient $= C_{DN} F(V, S) \sim O(10^{-3})$

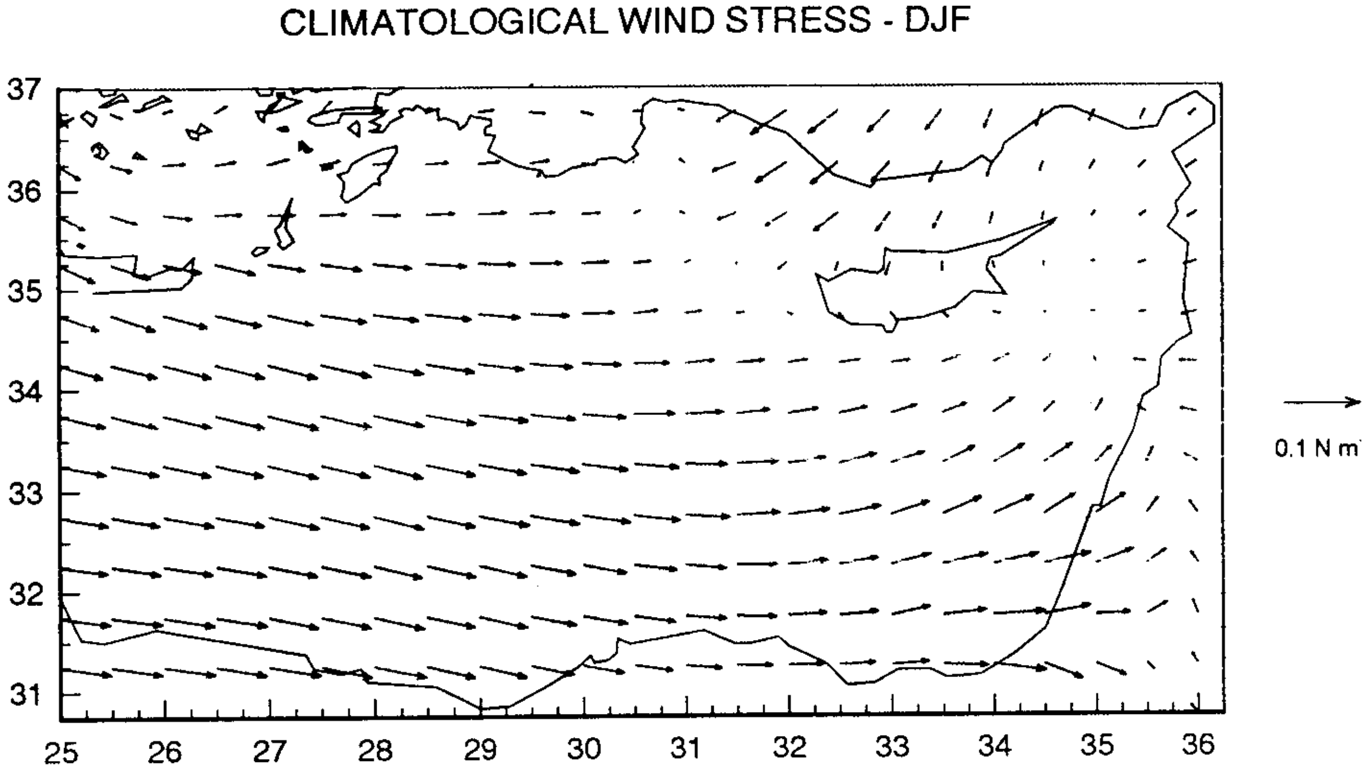
C_{DN} - neutral drag coefficiat

V · wind speed

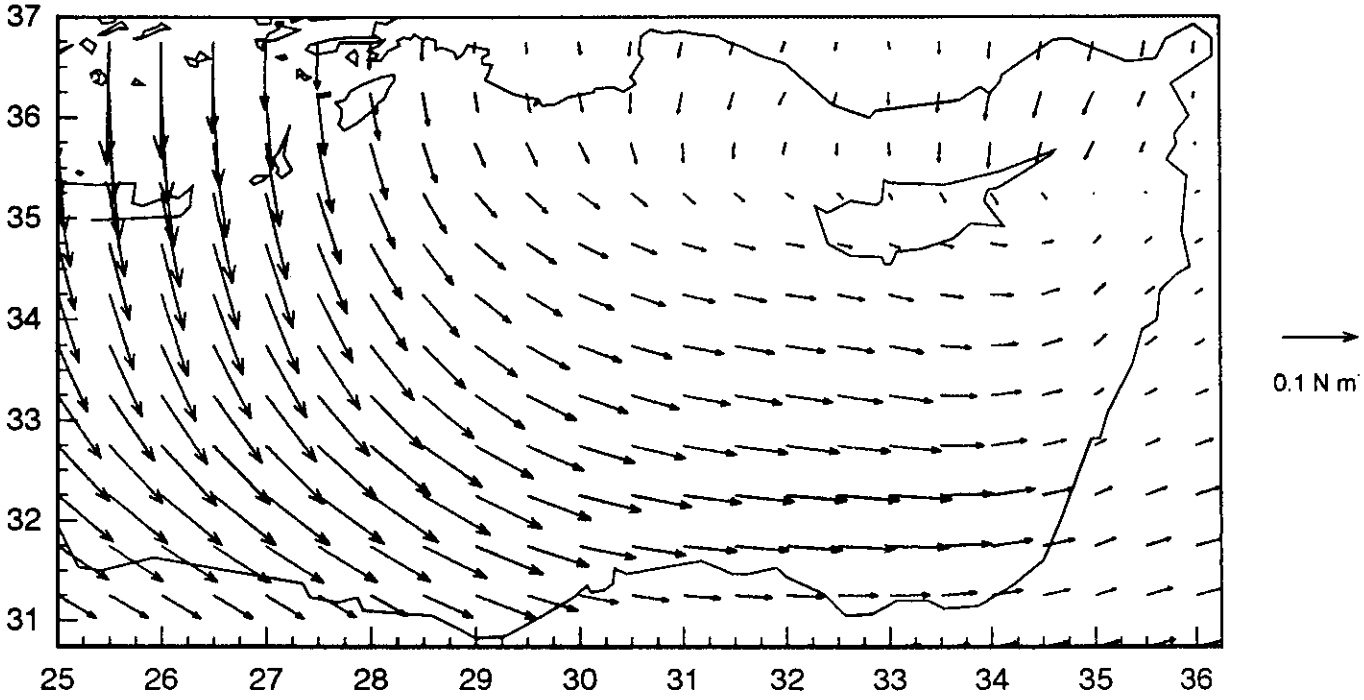
S - static stability of air

also some evidence to indicate
C_D depends on waves
(height and spectrum)

Many ocean models use climatological
(e.g. monthly mean) wind stress
must assess importance of
synoptic scale variability/fluctuations


CLIMATOLOGICAL WIND STRESS - DJF
37
36
35
34
33
32
31
25
26
27
28
29
30
31
32
33
34
35
36
0.1 N m

ECMWF WIND STRESS - DJF 1991-2



Mass transfer

- For dynamics, water is of primary interest (affects density through salinity)

For ecosystem other potentially important fluves are

CO_2; nutrients (dust)

Water

$E-P$ E - evaporation
P - precipitation

$$E = \rho_a C_E V (q_s - q)$$

C_E - transfer coefficient $= F(V, S) \sim O(10^{-3})$

q - specific humidity

q_s - saturation q at SST

P - often estimated/extropalated from land (coastal) stations

For Mediterranean $E-P>0$ concentration basin $\Rightarrow$ formation of saline water mass

		Med	EM.	W.M.	
(m/yr)	E	1.54	1.61	1.40	(Bethoux)
	P	0.59	0.59	0.60	

WM

EM

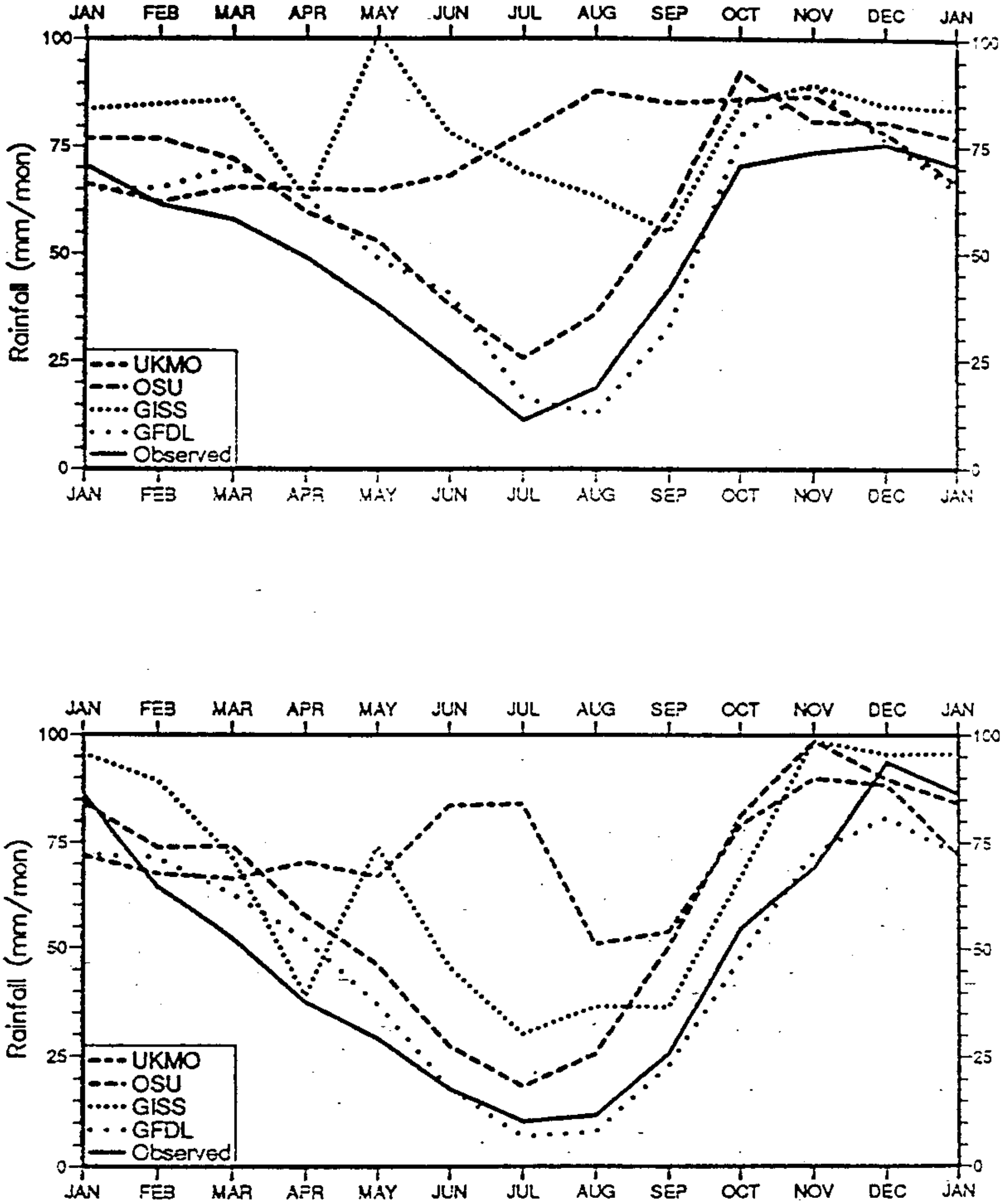


Fig. 2.7 Seasonal cycle of observed and control run precipitation in the western (above) and eastern (below) Mediterranean Basin

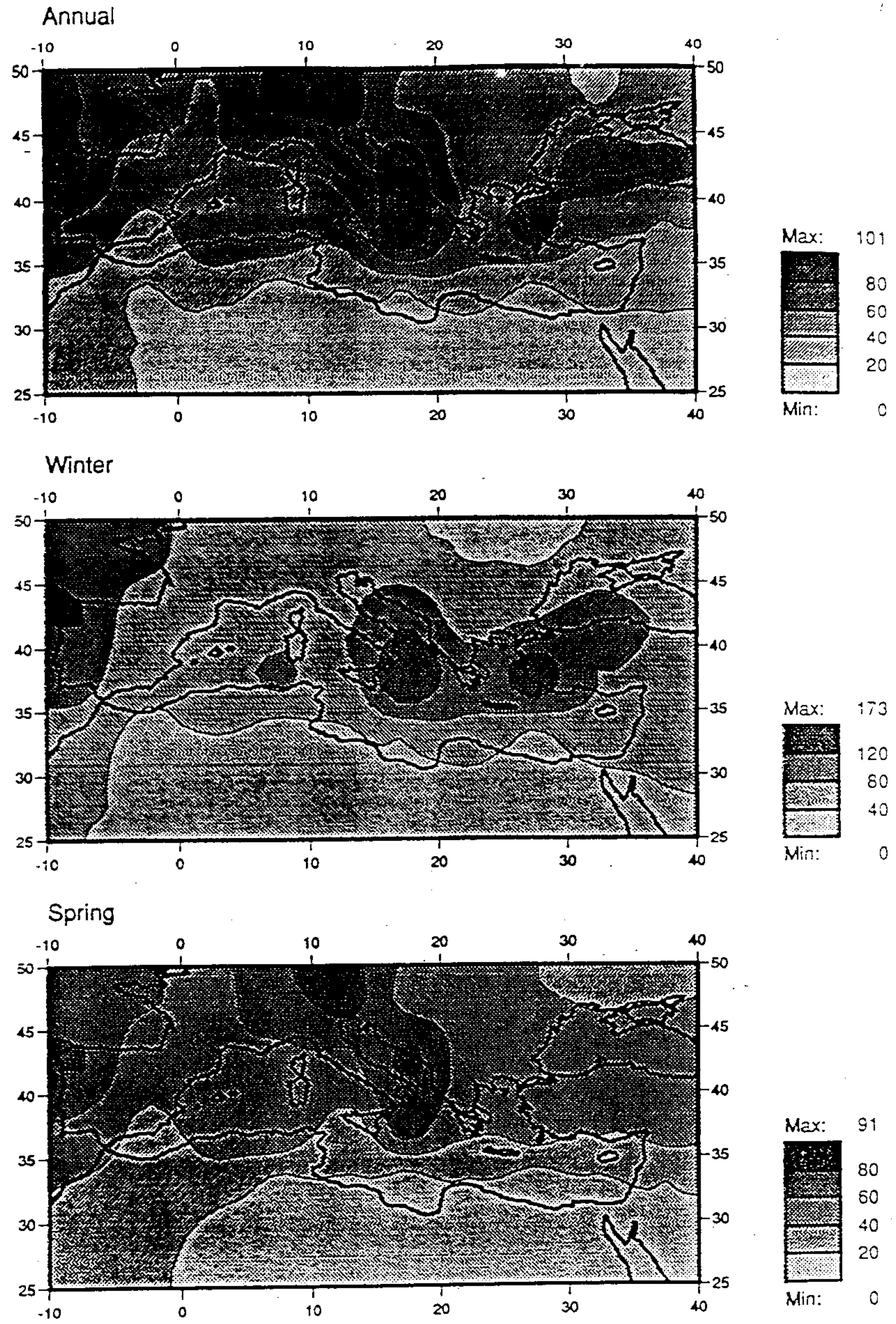


Fig. 2.8 Observed precipitation (mm/month)

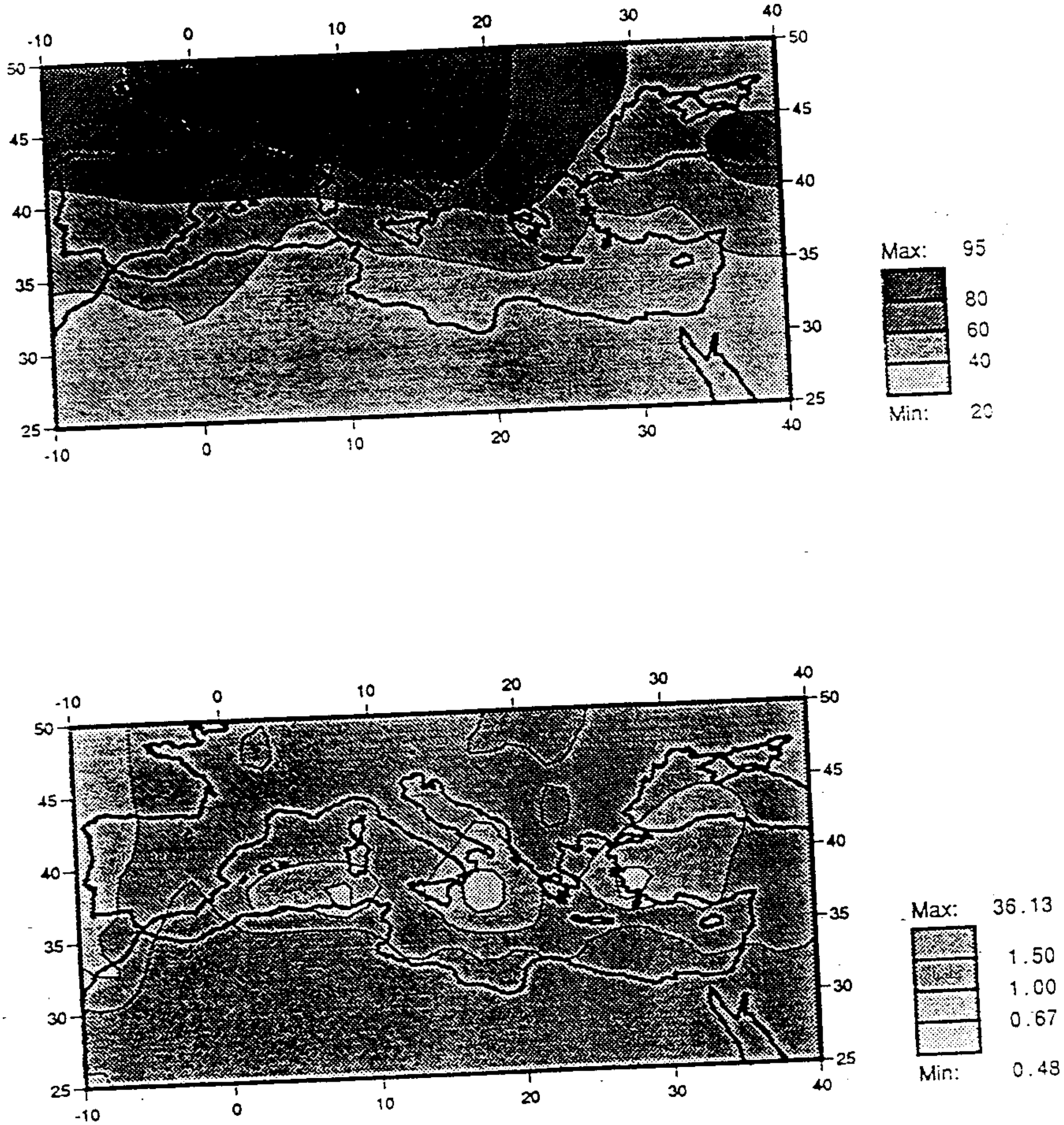


Fig. 2.9 Annual control run precipitation (above, mm/month) and modelled-to-observed precipitation ratios (below): GFDL GCM

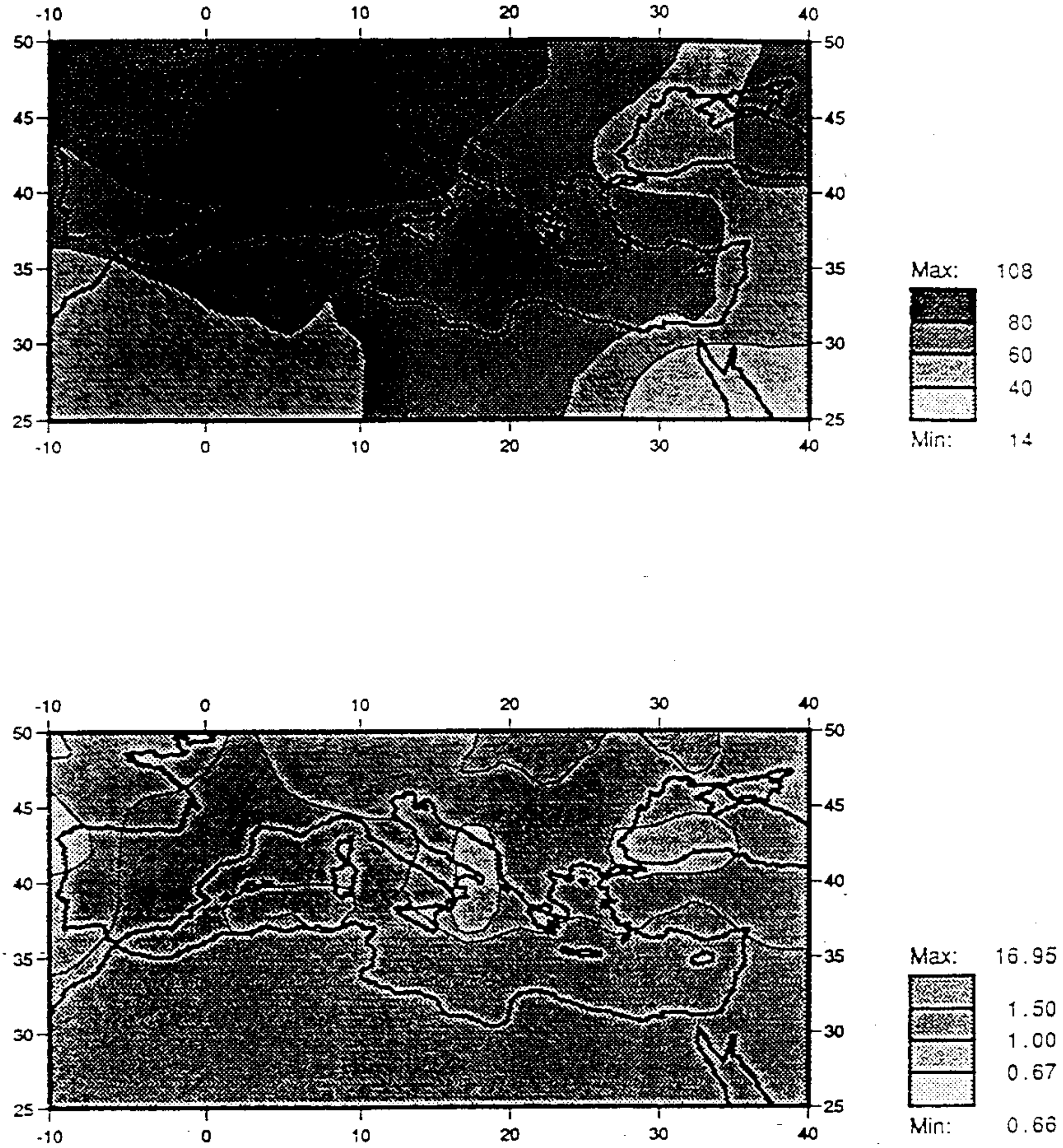


Fig. 2.10 Annual control run precipitation (above, mm/month) and modelled-to-observed precipitation ratios (below): GISS GCM

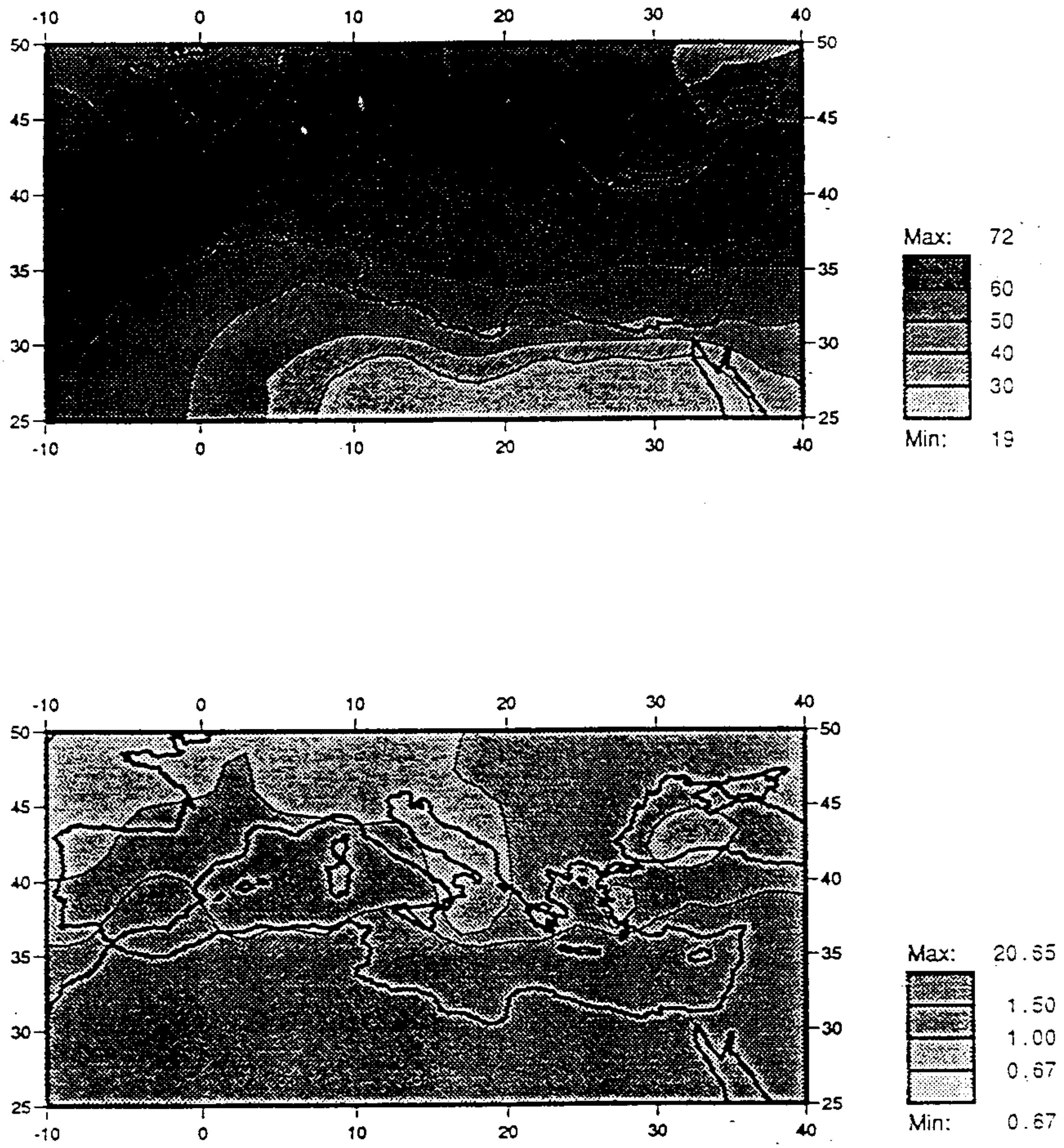


Fig. 2.11 Annual control run precipitation (above, mm/month) and modelled-to-observed precipitation ratios (below): OSU GCM

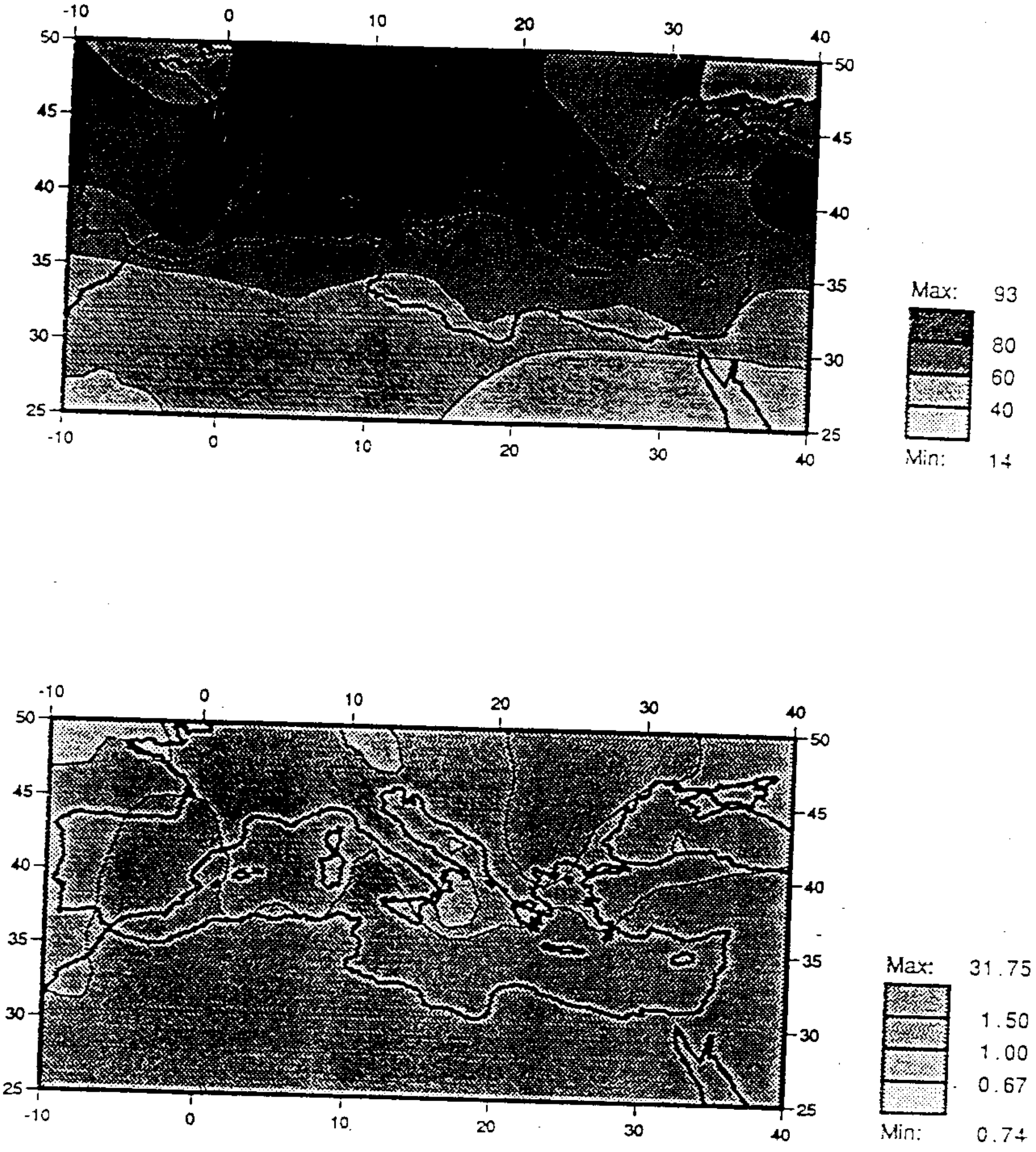


Fig. 2.12 Annual control run precipitation (above, mm/month) and modelled-to-observed precipitation ratios (below) UKMO GCM

Heat fluxes

Original motivation - heat budget

Also used to force numerical models

Heat budget

$$\frac{dQ}{dt} = A + Q_S - Q_R - Q_E - Q_H$$

Q - heat content

A - advection of heat by currents

Q_S - incoming solar radiation

Q_R - net upward IR (longwave)

Q_E - latent heat flux (evaporation)

Q_H - sensible heat flux

(Bowen ratio : Q_H / Q_E)

Incoming solar radiation (short wave)

$$Q_s = Q_o(\phi, z)\,(1-\alpha)\,F(n)$$

Q_o - clear sky flux
ϕ - latitude
z - zenith angle
α - albedo
n - cloud cover

can also allow Q_s to be penetrative
$\Rightarrow$ a fraction T_r ($\sim 0.4 - 0.5$) penetrates into water column so only $(1-T_r)$ absorbed at surface

Net upward IR (longwave)

$$Q_R = \varepsilon \sigma T_s^4 (a - b\sqrt{e})(1 - c n^d) + 4\varepsilon\sigma T_s^3 (T_s - T_a)$$

ε - emissivity ≈ 0.97
σ - Stefan-Boltzman constant
T_s - SST
a, b, c, d - empirical constants
e - vapor pressure (mb)
T_a - air temperature

Incoming solar radiation (short wave)

$$Q_s = Q_0(\phi, z)\,(1-\alpha)\,F(n)$$

Q_0 - clear sky flux
ϕ - latitude
z - zenith angle
α - albedo

n - cloud cover

can also allow Q_s to be penetrative
$\Rightarrow$ a fraction T_r ($\sim 0.4 - 0.5$)
penetrates into water column
so only $(1-T_r)$ absorbed
at surface

Net upward IR (longwave)

$$Q_R = \varepsilon \sigma T_s^4 (a - b\sqrt{e})(1 - c n^d) + 4 \varepsilon \sigma T_s^3 (T_s - T_a)$$

ε - emissivity ≈ 0.97
σ - Stefan-Boltzman constant
T_s - SST
a, b, c, d - empirical constants
e - vapor pressure (mb)
T_a - air temperature

Latent heat flux

$$Q_E = L_v E = \rho_a L_v C_E V (q_s - q)$$

L_v - latent heat of vaporization

all other symbols defined above

Sensible heat flux

$$Q_H = \rho_a c_p C_H V (T_s - T_a)$$

c_p - specific heat

C_H - transfer coefficient

typically use $C_E = C_H$

In general (but not always!!)

$$Q_E \gtrapprox Q_R \gg Q_H$$

More on heat budget later!!
but for now, typical values:

Q_s	Q_R	Q_E	Q_H	
~180	~70	~100	~10	$W m^{-2}$

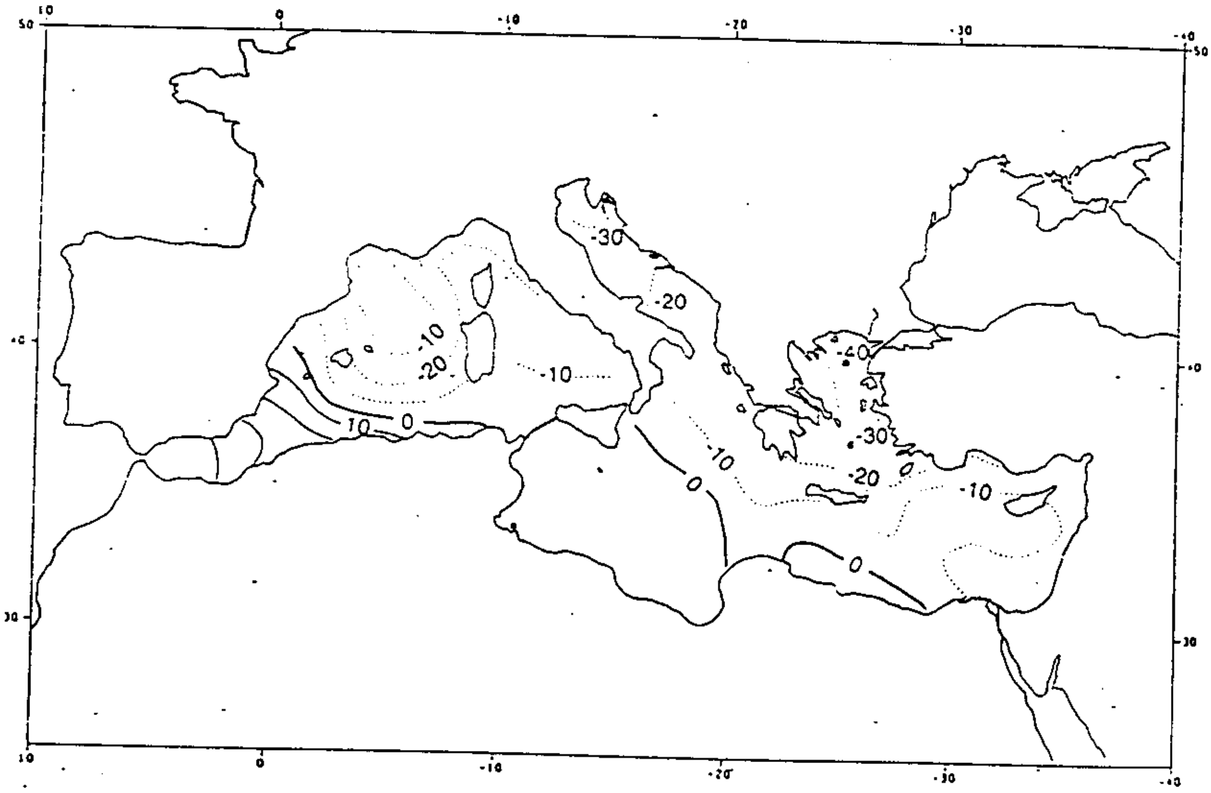


Figure 1. The spatial distribution of the long-term mean heat flux into the Mediterranean Sea (in W m^{-2}), normalised to have a spatial average of -7 W m^{-2} by multiplying the initial COADS-based insolation by 0.82. (From Garrett et al., 1993)

Buoyancy flux

combined effects of thermal and freshwater fluxes

→ dynamical forcing

$$b = -g\left(\frac{\rho-\rho_0}{\rho_0}\right) \qquad \text{buoyancy}$$

$$B = \underset{\textcircled{1}}{-\frac{g\alpha Q_t}{\rho_0 c_w}} + \frac{g\overset{\beta}{\beta} S}{\rho_0}\left(\underset{\textcircled{2}}{E} - \underset{\textcircled{3}}{P}\right) \qquad \text{b. flux}$$

$$\alpha = -\frac{1}{\rho}\frac{\partial\rho}{\partial T} \; ; \quad \beta = \frac{1}{\rho}\frac{\partial\rho}{\partial S} \qquad S\text{ - salinity}$$

For long term average:

①	②	③	
0.7	11.6	6.1	$\times 10^{-9}\ m^2 s^{-3}$

⇒ Fresh water flux dominates

For seasonal & interannual variability heat flux ① dominates

⇒ must know heat flux for proper dynamical forcing of model

Exchanges through straits

Focus on Gibraltar - it is the only one dynamically relevant in terms of communication with the ocean basin

E-P >0 over Mediterranean

→ drives lagoonal type circulation
- inflow in upper layer
- outflow in lower layer

Inflowing AW spreads throughout basin

Outflowing MW (mostly LIW + some WMDW) sink to ~ 1000m. Some spreads westward in pulses or lenses (meddies) and some spread northward and interacts with NADW.

Inflowing AW is nutrient depleted
→ Mediterranean is oligotrophic

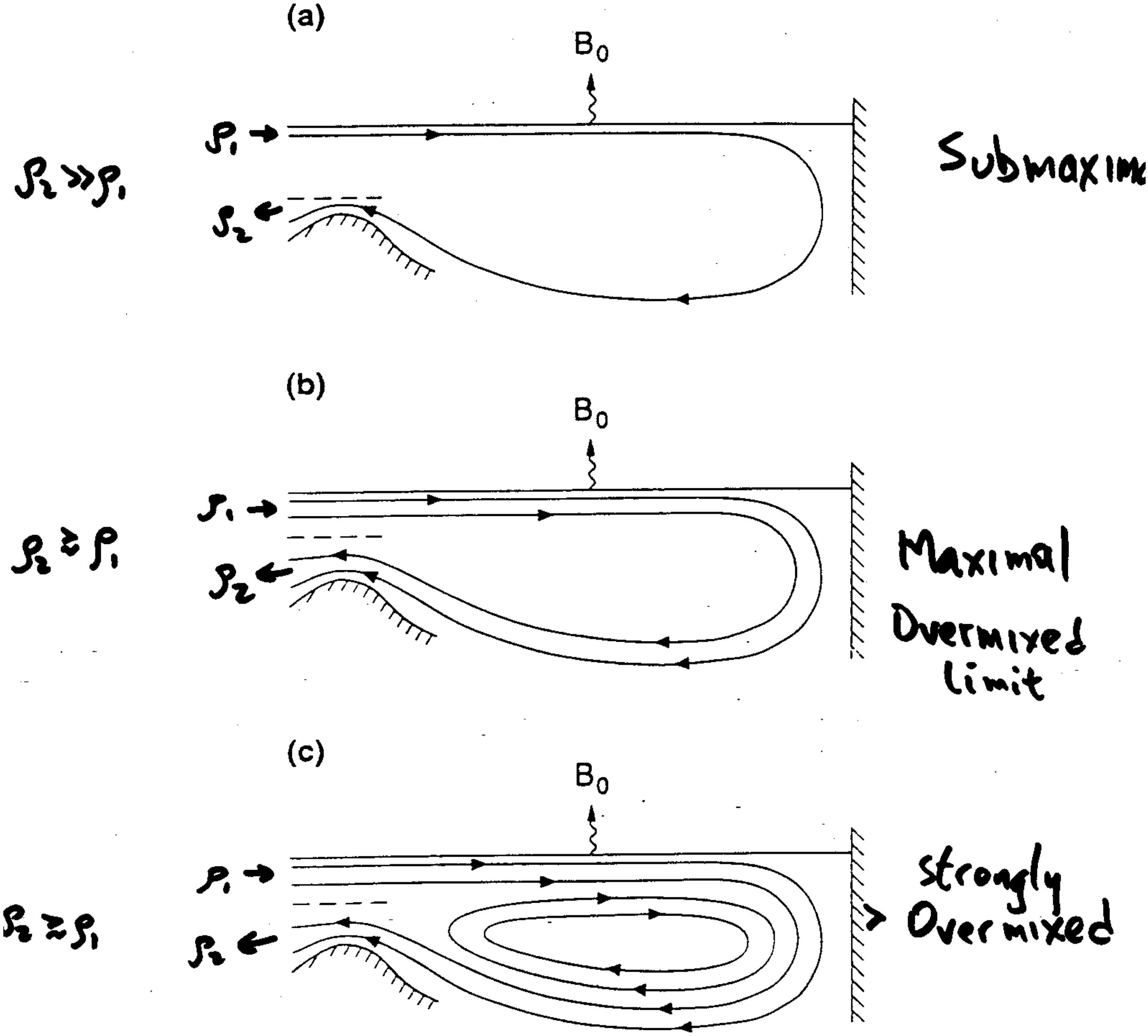

(a)
B0
ρ1
ρ2
ρ2 >> ρ1
Submaxim
(b)
B0
ρ1
ρ2
ρ2 ≳ ρ1
Maximal
Overmixed limit
(c)
B0
ρ1
ρ2
ρ2 ≳ ρ1
strongly
> Overmixed

FIG. 3

- From observations Med is near overmixed limit (maximal exchange) however there is some evidence that this is seasonally dependent
  - maximal in winter
  - submaximal in summer

- Fluctuations on various time scales (tidal, subinertial, long term) make any definitive conclusions problematic

- Most estimates of outflow are in range of 1.2-1.7 Sv although some as low as 0.8 (must be reconciled with E-P)

- $\Delta S \sim 2$ psu
  $\Delta \rho \sim 1.7$ kg/m^3