INTERNATIONAL ATOMIC ENERGY AGENCY
UNITED NATIONS EDUCATIONAL, SCIENTIFIC AND CULTURAL ORGANIZATION
INTERNATIONAL CENTRE FOR THEORETICAL PHYSICS
I.C.T.P., P.O. BOX 586, 34100 TRIESTE, ITALY, CABLE CENTRATOM TRIESTE

H4.SMR/845-11

Second Winter College on Optics

20 February - 10 March 1995

Optics for Environmental Sensing

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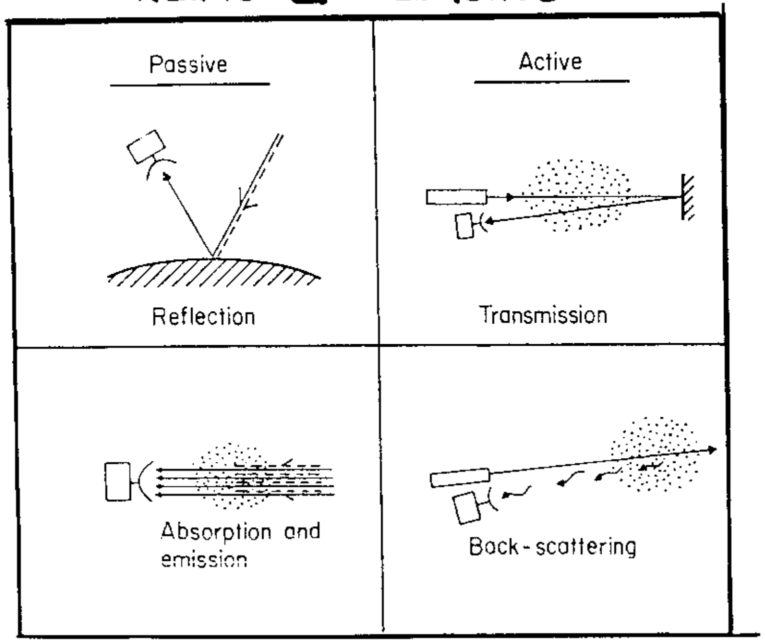
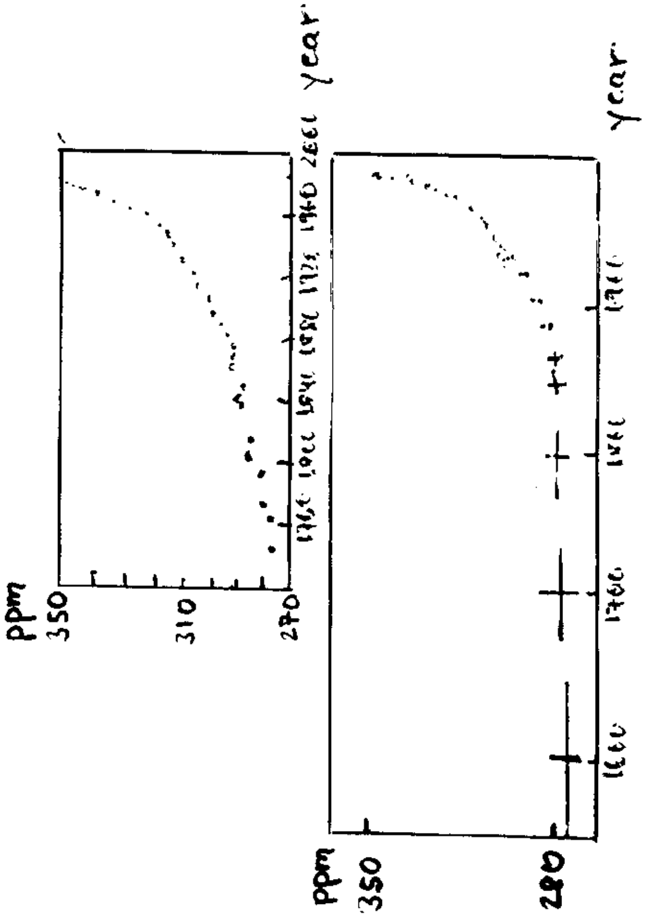
Lund Institute of Technology
Dept. of Physics
Lund, Sweden

REMOTE SENSING

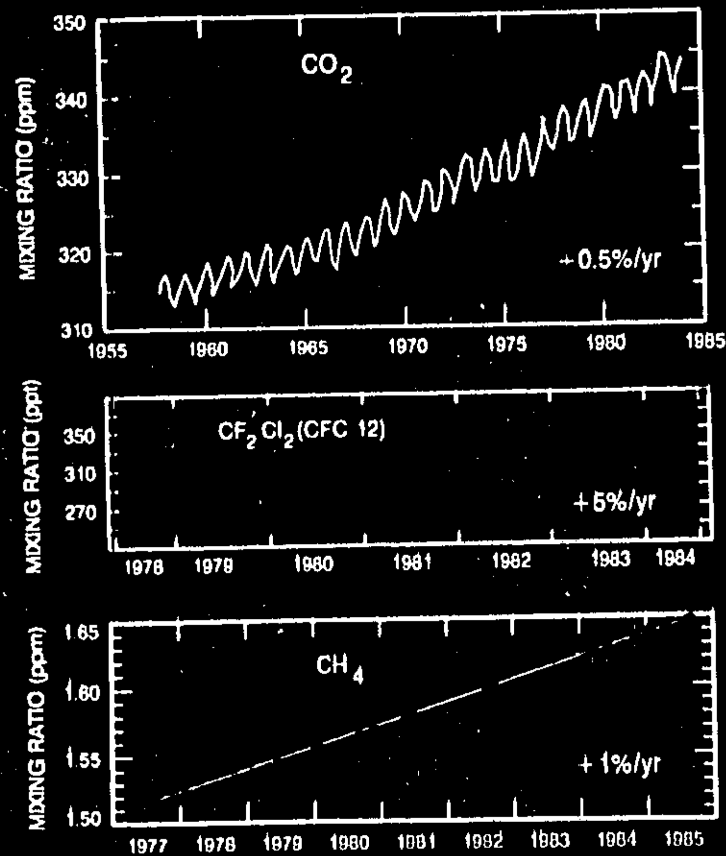


ATMOSPHERIC CO_2 CONCENTRATION



CHANGES IN GLOBAL ATMOSPHERIC COMPOSITION

THE FACTS - INCREASING TRACE GAS CONCENTRATION



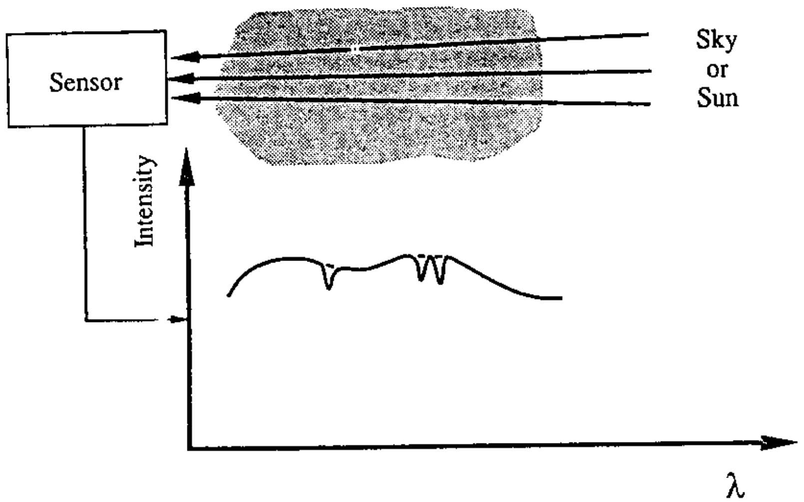
SOURCES

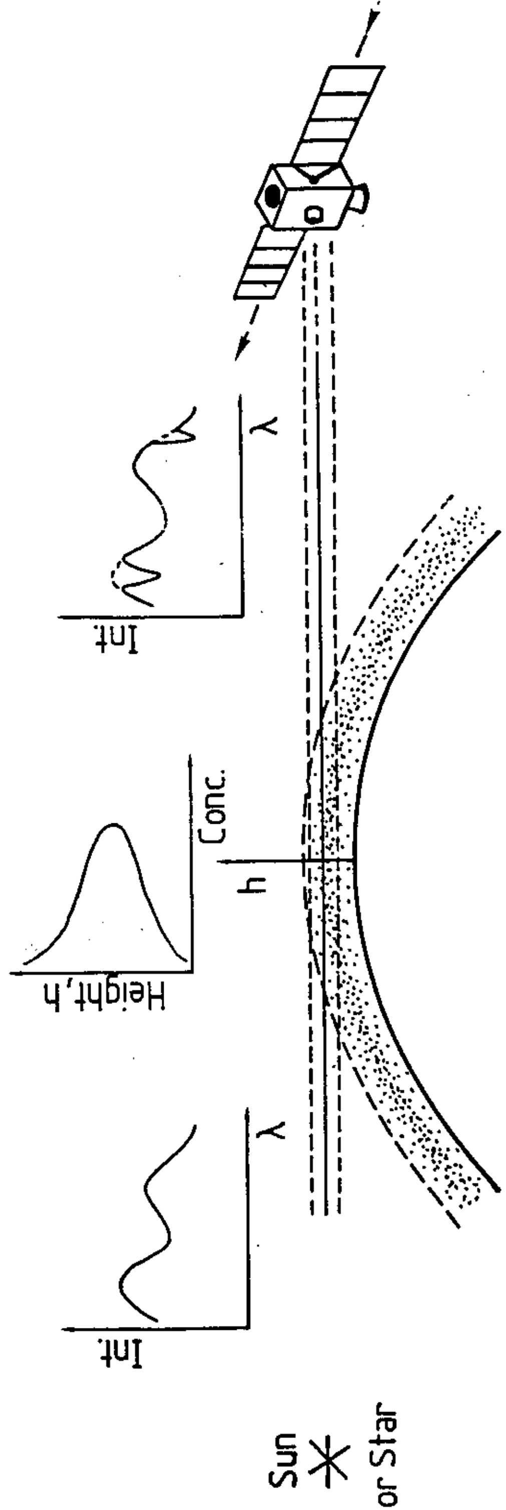
FOSSIL FUEL CONSUMPTION
FOREST BURNING

REFRIGERANTS
FOAM BLOWING
SOLVENTS

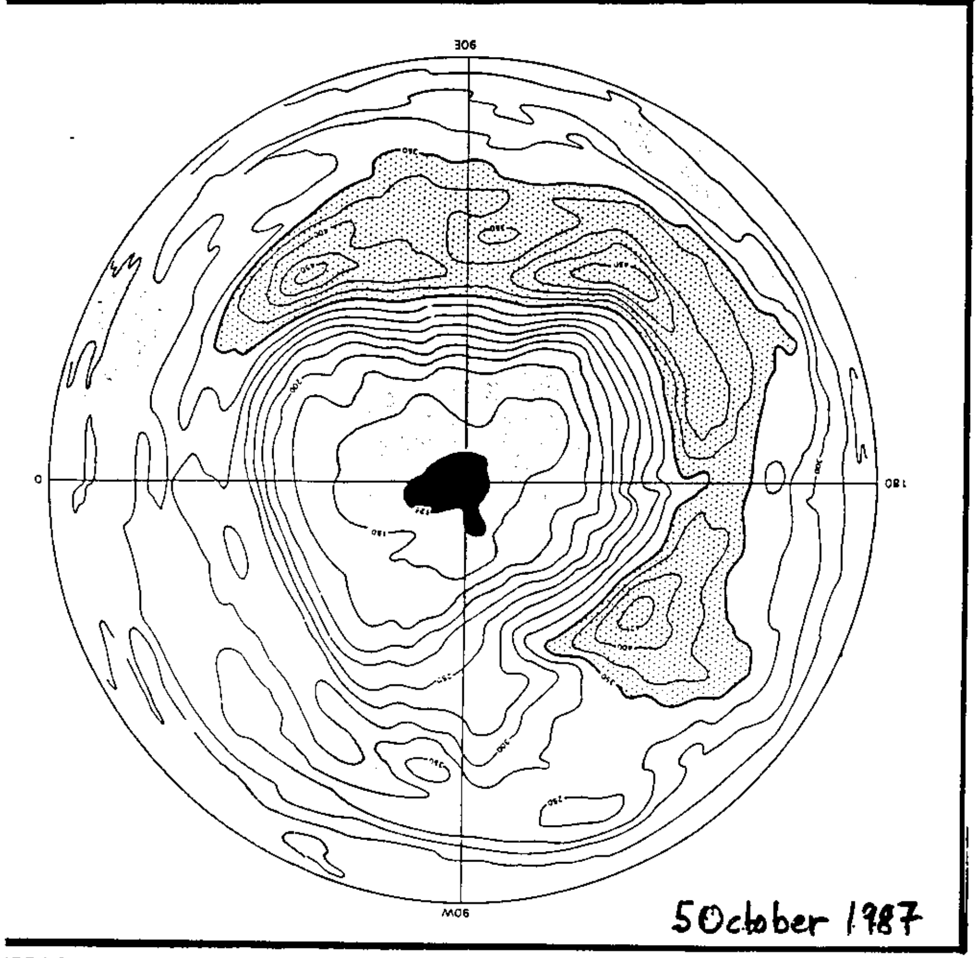
RICE PADDIES?
MARSHLANDS?
ENTERIC FERMENTATION?

⟹ CAN LEAD TO SIGNIFICANT GLOBAL WARMING VIA "GREENHOUSE" EFFECT


Sensor
Sky
or
Sun
Intensity
λ


Int.
λ
Height, h
Conc.
h
Int.
λ
Sun
or Star

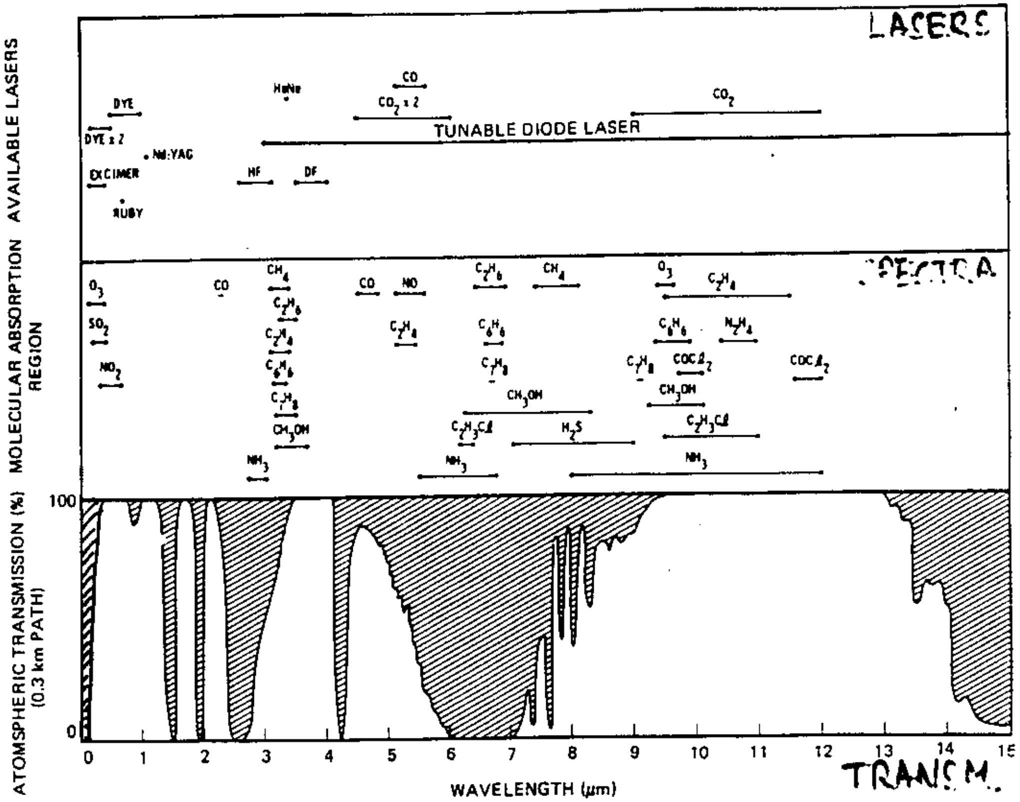
NIMBUS 7 TOTAL OZON MAPPING SPECTROMETER (TOMS)



IRE 1.2 Observations from the Total Ozone Mapping Spectrometer (TOMS) on the Nimbus 7 llite show that the ozone hole covers much of the Antarctic. On 5 October 1987 ozone values were than 200 DU over the whole of the continent. Surrounding the region of low ozone is a rather ible band of high column ozone in which ozone values frequently exceed 400 DU. At low latitudes mn ozone is approximately 250 DU.

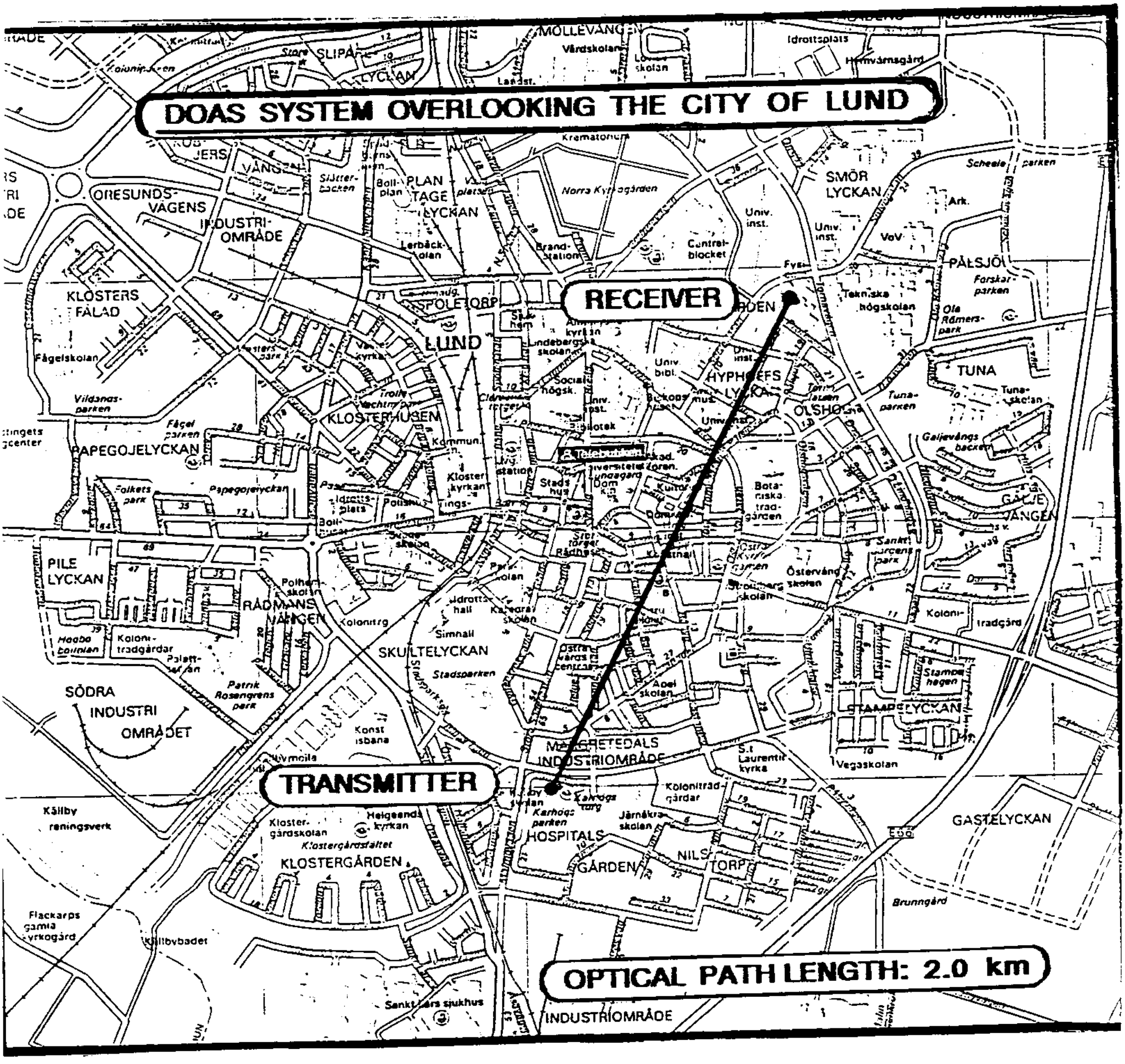
British Ozon Report 1988

SPECTROSCOPIC BACKGROUND TO ATMOSPHERIC REMOTE SENSING



TRANSM.

W. GRANT


DOAS SYSTEM OVERLOOKING THE CITY OF LUND
RECEIVER
TRANSMITTER
OPTICAL PATH LENGTH: 2.0 km
LUND
KLOSTERHUSEN
SKULTELYCKAN
HOSPITALS GÅRDEN
NILS TORP
KLOSTERGÅRDEN
PILE LYCKAN
PAPEGOJELYCKAN
SÖDRA INDUSTRI OMRÅDET
MARGRETEDALS INDUSTRIOMRÅDE
STAMPELYCKAN
GASTELYCKAN
TUNA
PÅLSJÖ
SMÖR LYCKAN
INDUSTRIOMRÅDE

5

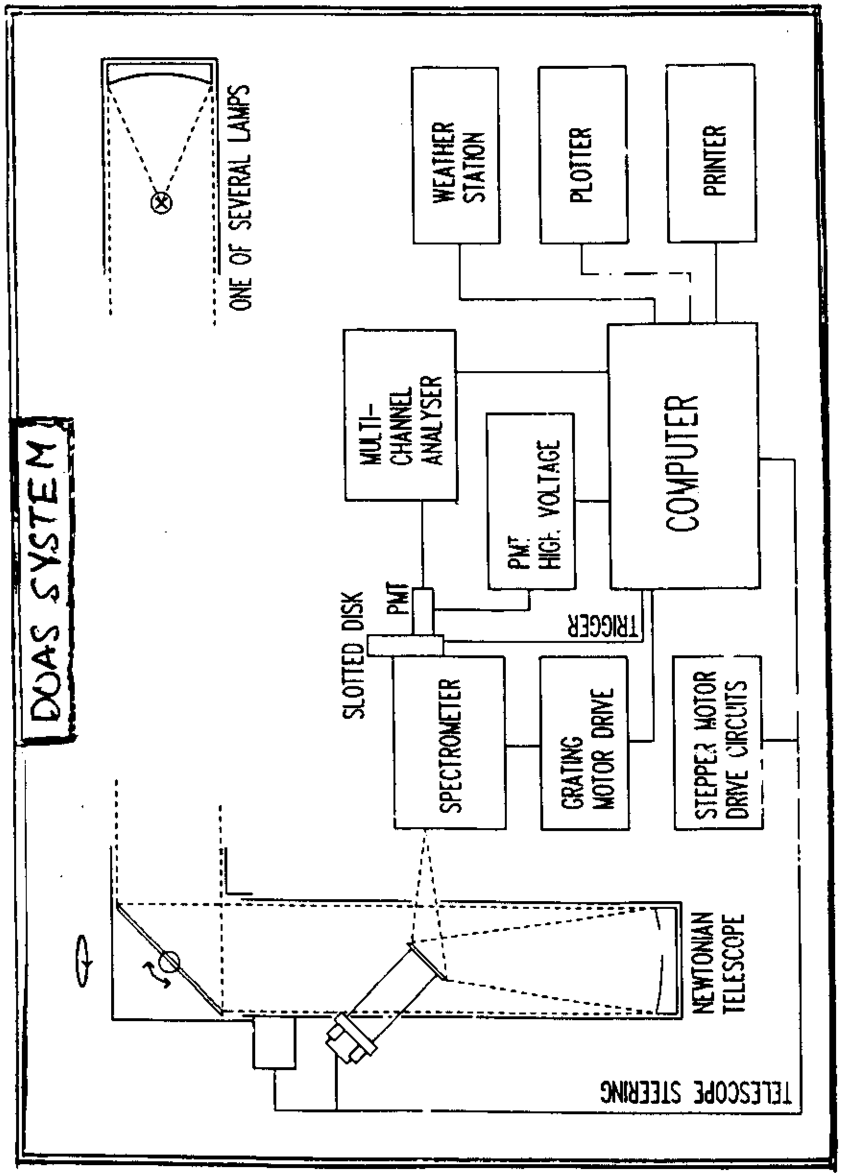
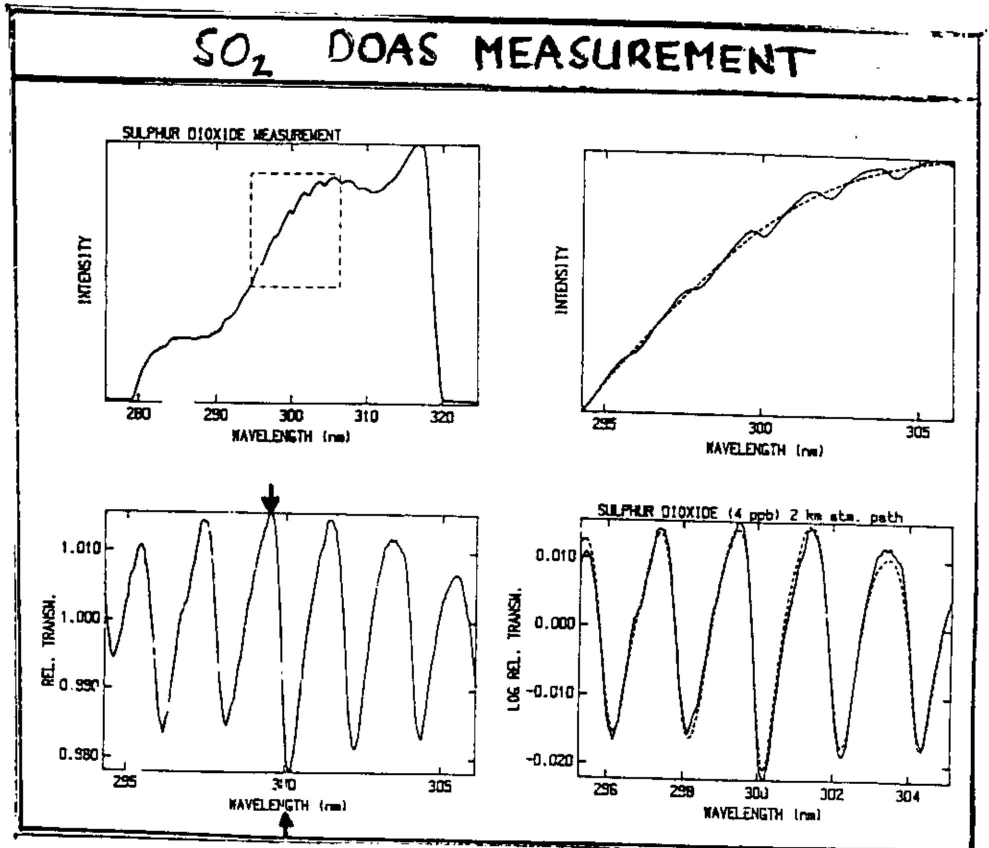


Fig. 3a

Fig. 3b



Edner et al. Appl. Opt. to appear

Fig. 3c

Fig. 3d

Fig. 4a

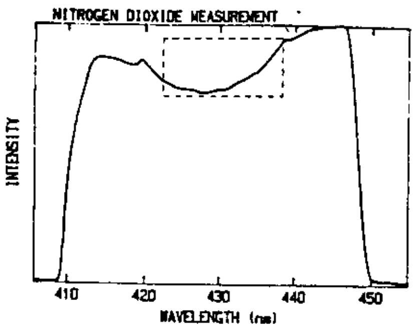
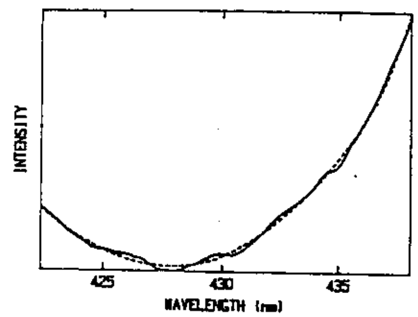
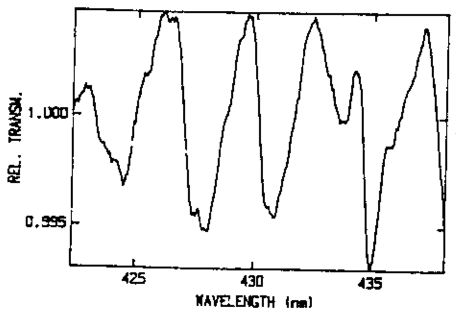


Fig. 4b





ig. 4c

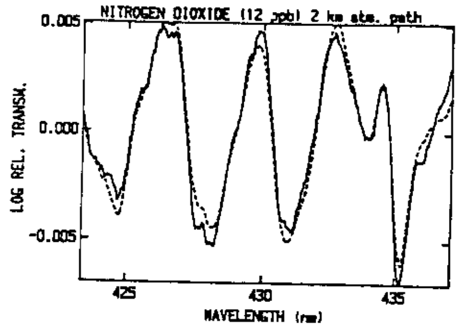
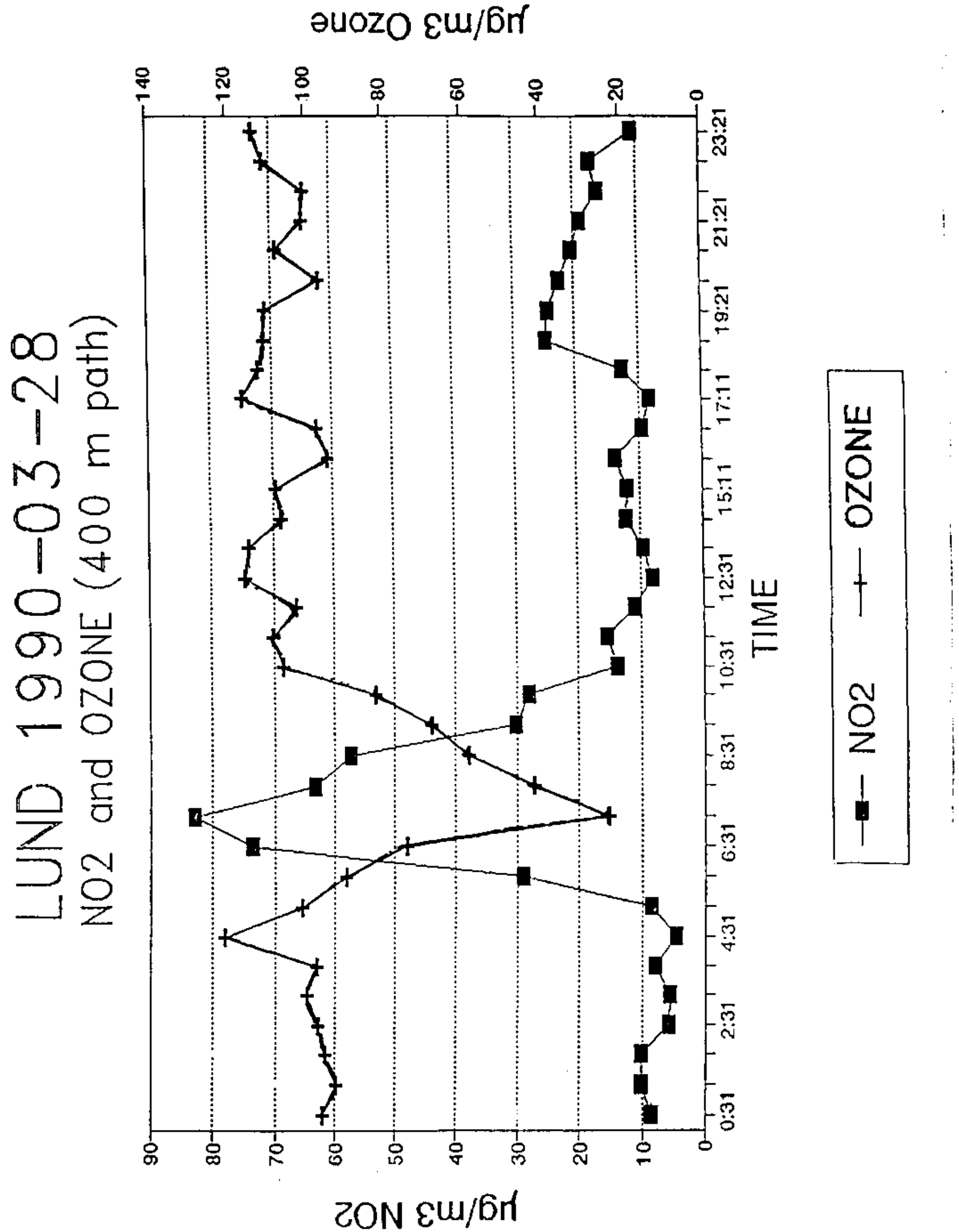
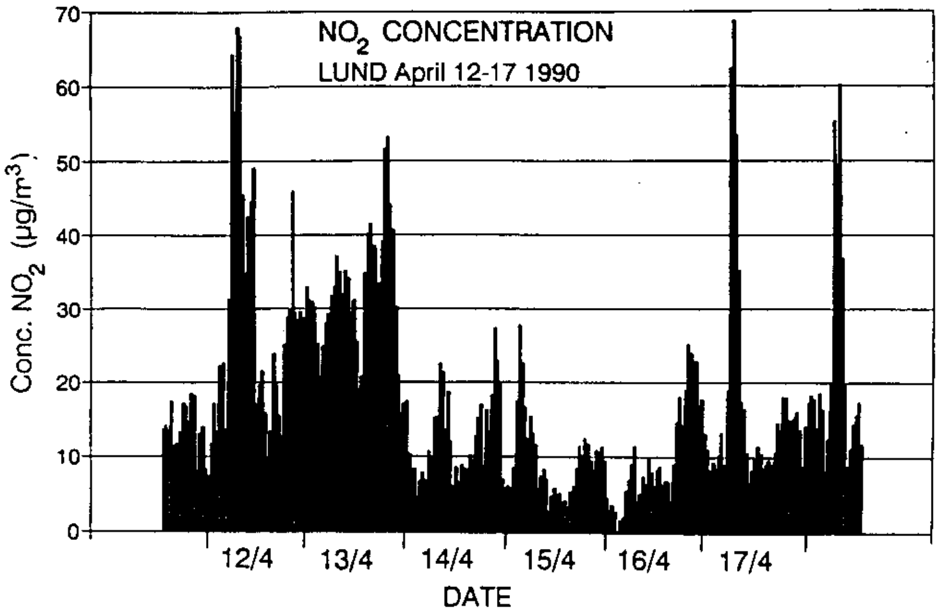


Fig. 4d

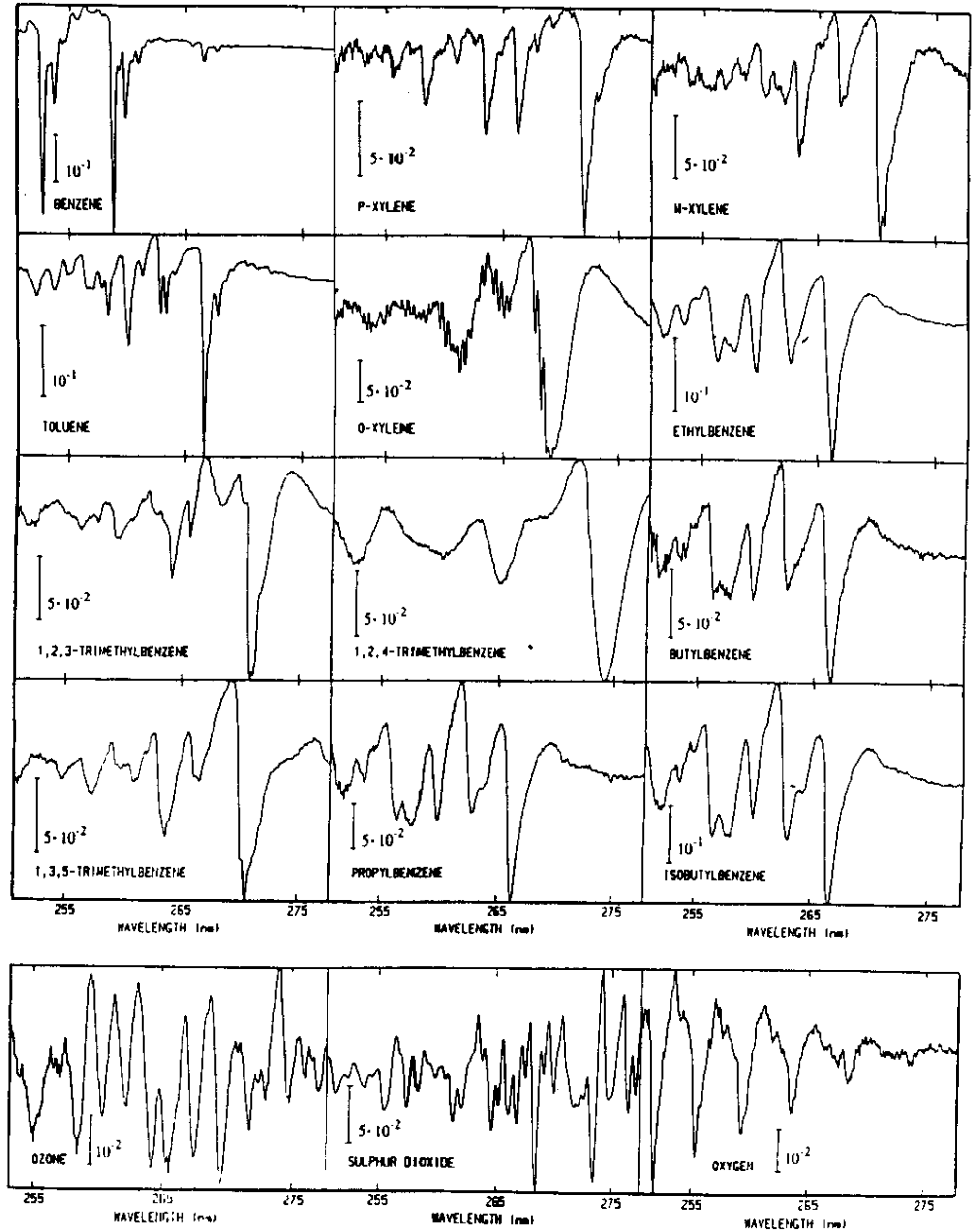


4

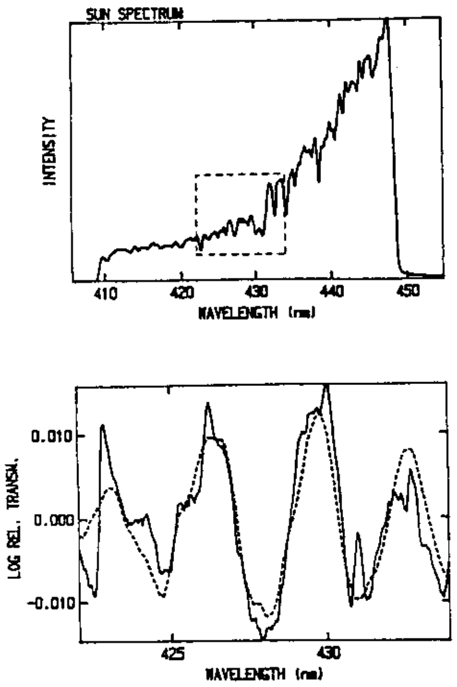
Fig. 8



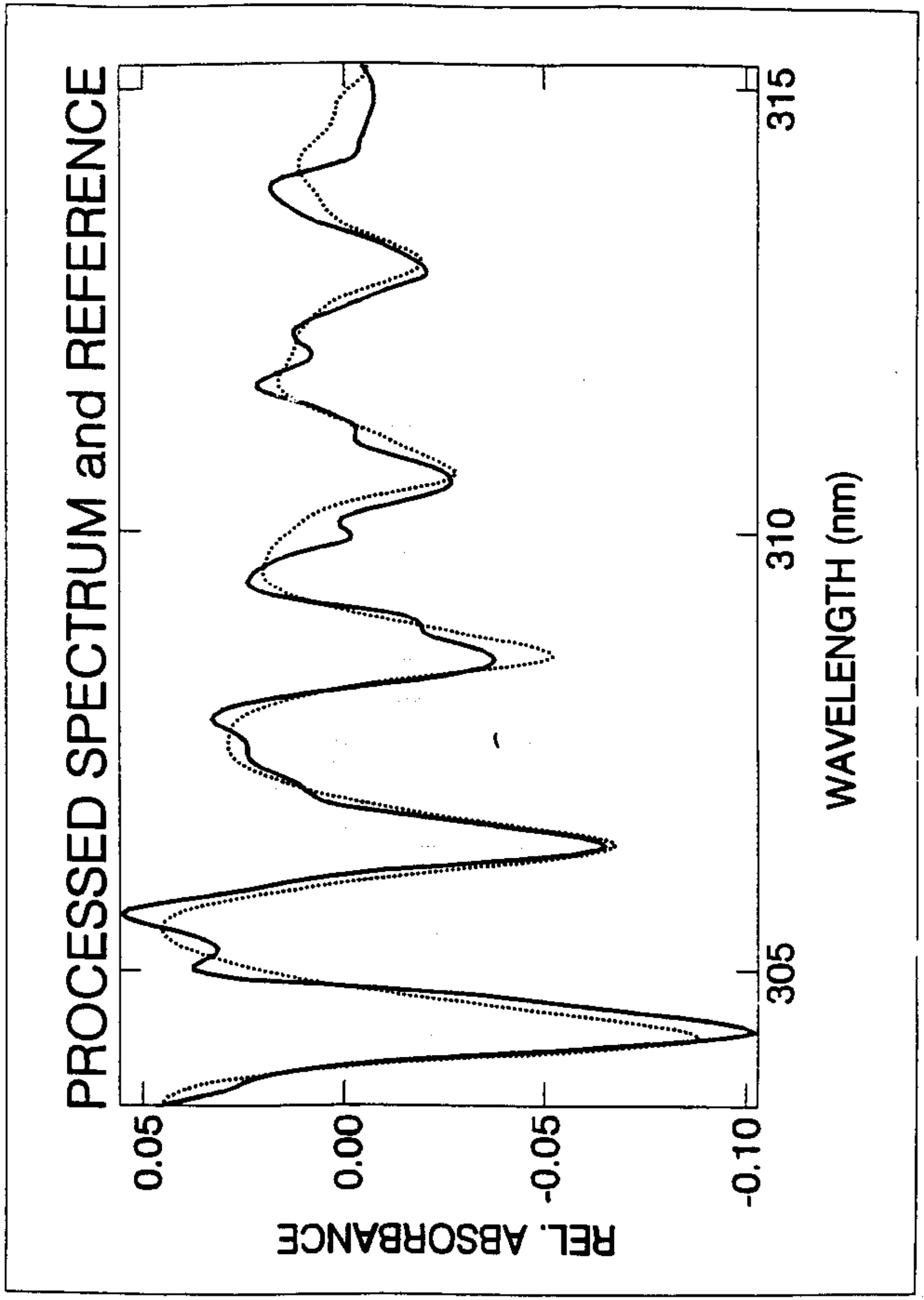
HYDROCARBONS



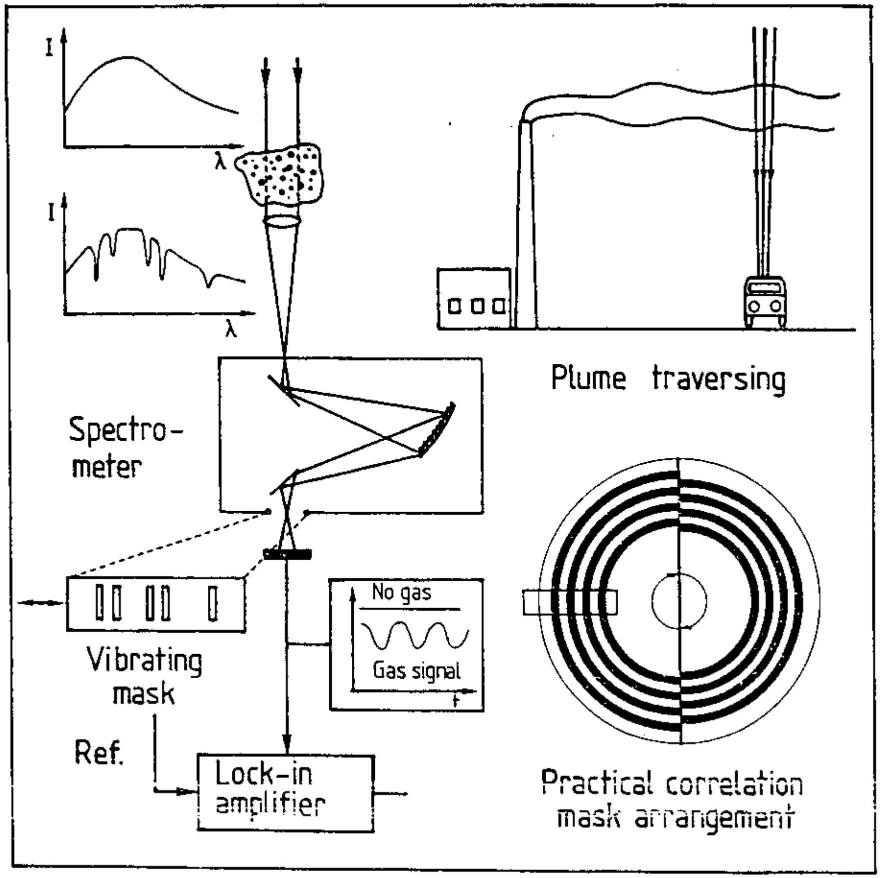
5a


SUN SPECTRUM
INTENSITY
410
420
430
440
450
WAVELENGTH (nm)
LOG REL. TRANSM.
0.010
0.000
-0.010
425
430
WAVELENGTH (nm)

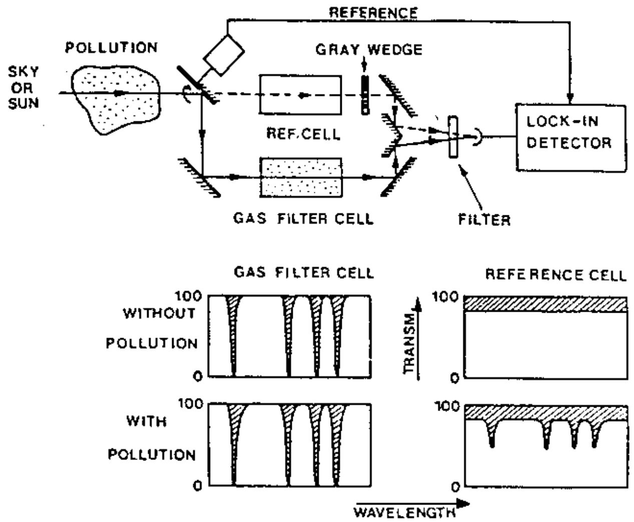
5b

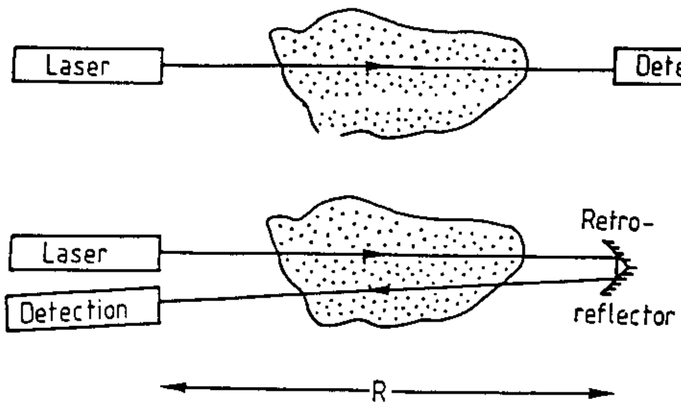

PROCESSED SPECTRUM and REFERENCE
REL. ABSORBANCE
0.05
0.00
-0.05
-0.10
305
310
315
WAVELENGTH (nm)

Correlation Spectrometer



(Barringer instrument)




Laser
Detection
Laser
Detection
Retro-
reflector
R

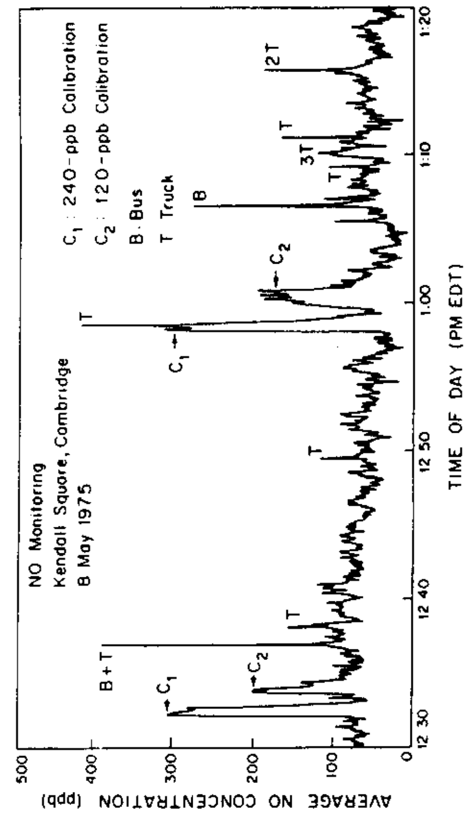

NO Monitoring
Kendall Square, Cambridge
8 May 1975
C_1 : 240-ppb Calibration
C_2 : 120-ppb Calibration
B Bus
T Truck
AVERAGE NO CONCENTRATION (ppb)
TIME OF DAY (PM EDT)

Figure 3.3

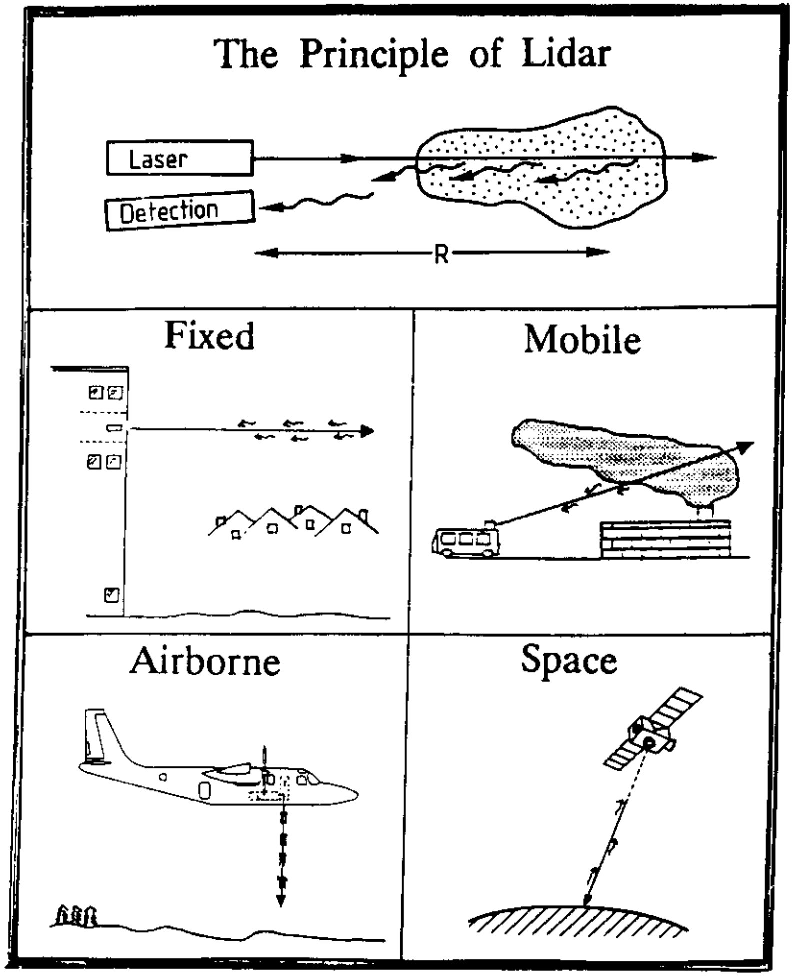
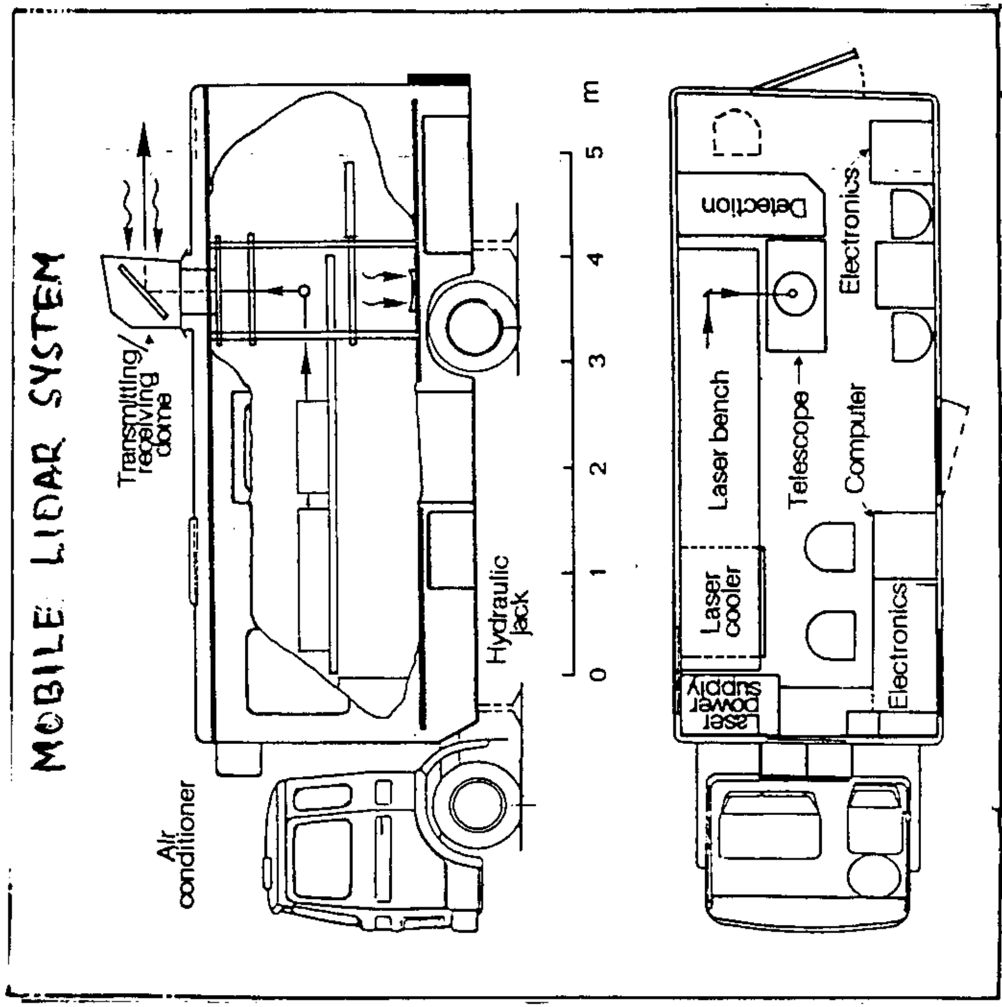


Figure 3.7



Edner, Fredriksson, Sunesson, Svanberg, Unéus, Wendt, Appl. Opt. 26, 4330, 1987,

Figure 3

[redacted]

[redacted]

No sample collection.
Probe regions inaccessible or otherwise difficult to sample.
Covering large areas. Path-averaged measurements give often more representative values than point monitors.
3-D charting.

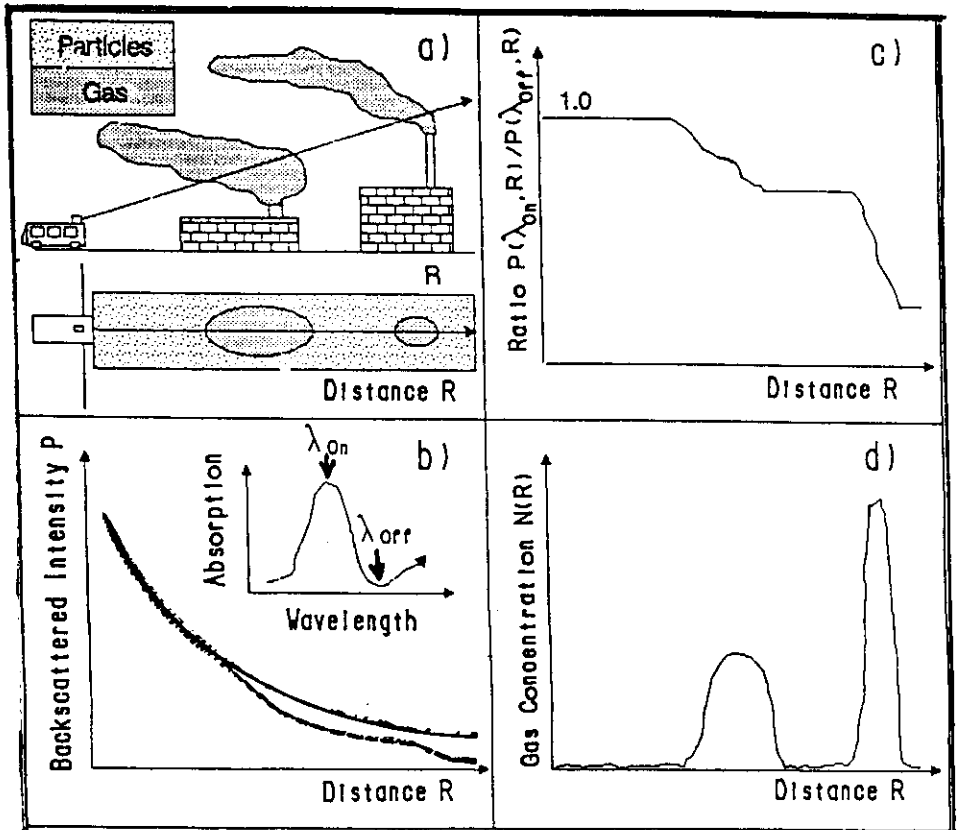
[redacted]

[redacted]

[redacted]

[redacted]

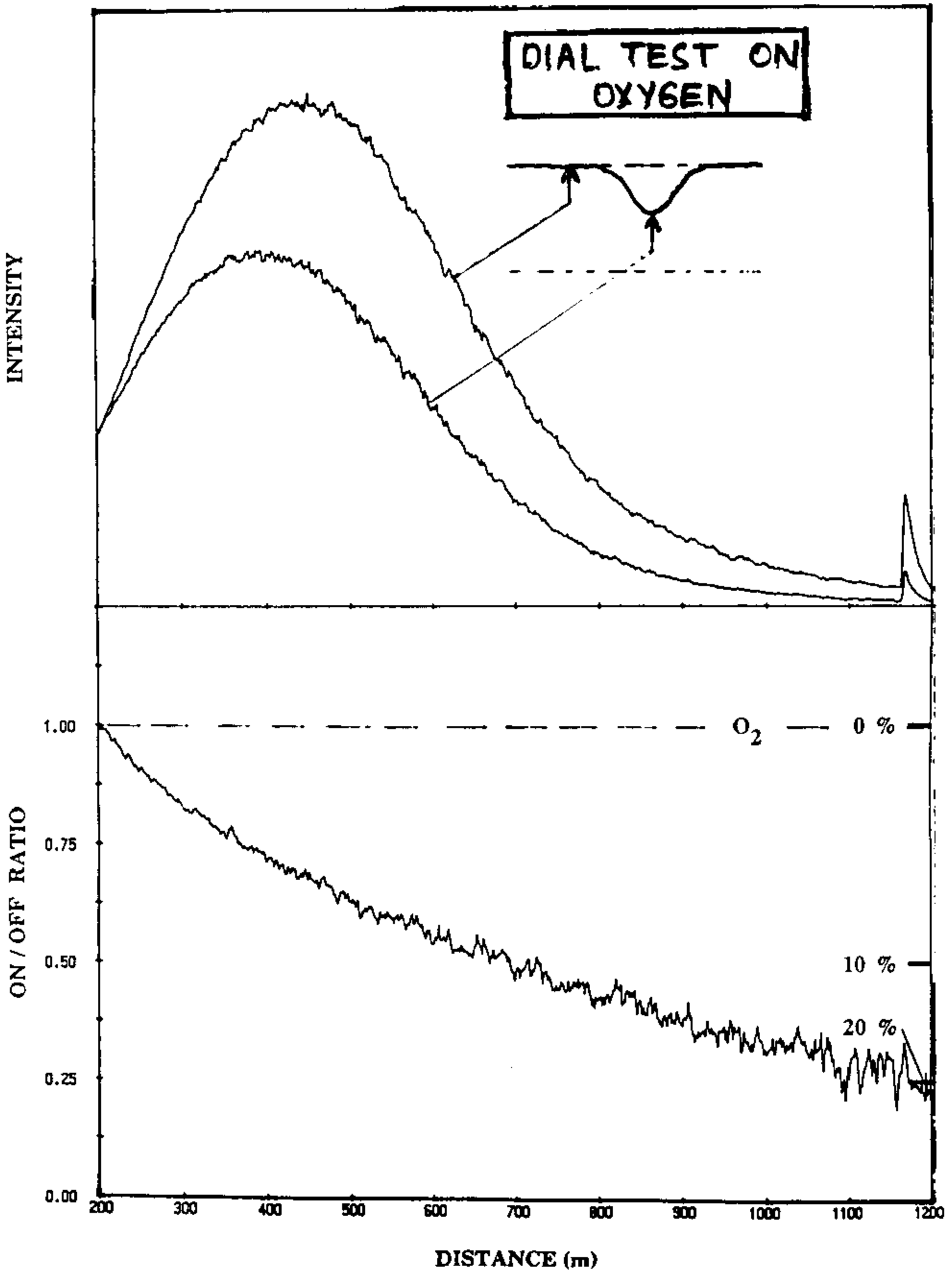
PRINCIPLE OF DIFFERENTIAL ABSORPTION LIDAR (DIAL)



Dial Equation:

$$P(\lambda_{on},R)/P(\lambda_{off},R) = \mathrm{Exp}(-2[\sigma(\lambda_{on}) - \sigma(\lambda_{off})]\int_0^R N(R')\,dR')$$

Figure 2



DIFFERENTIAL ABS. LIDAR

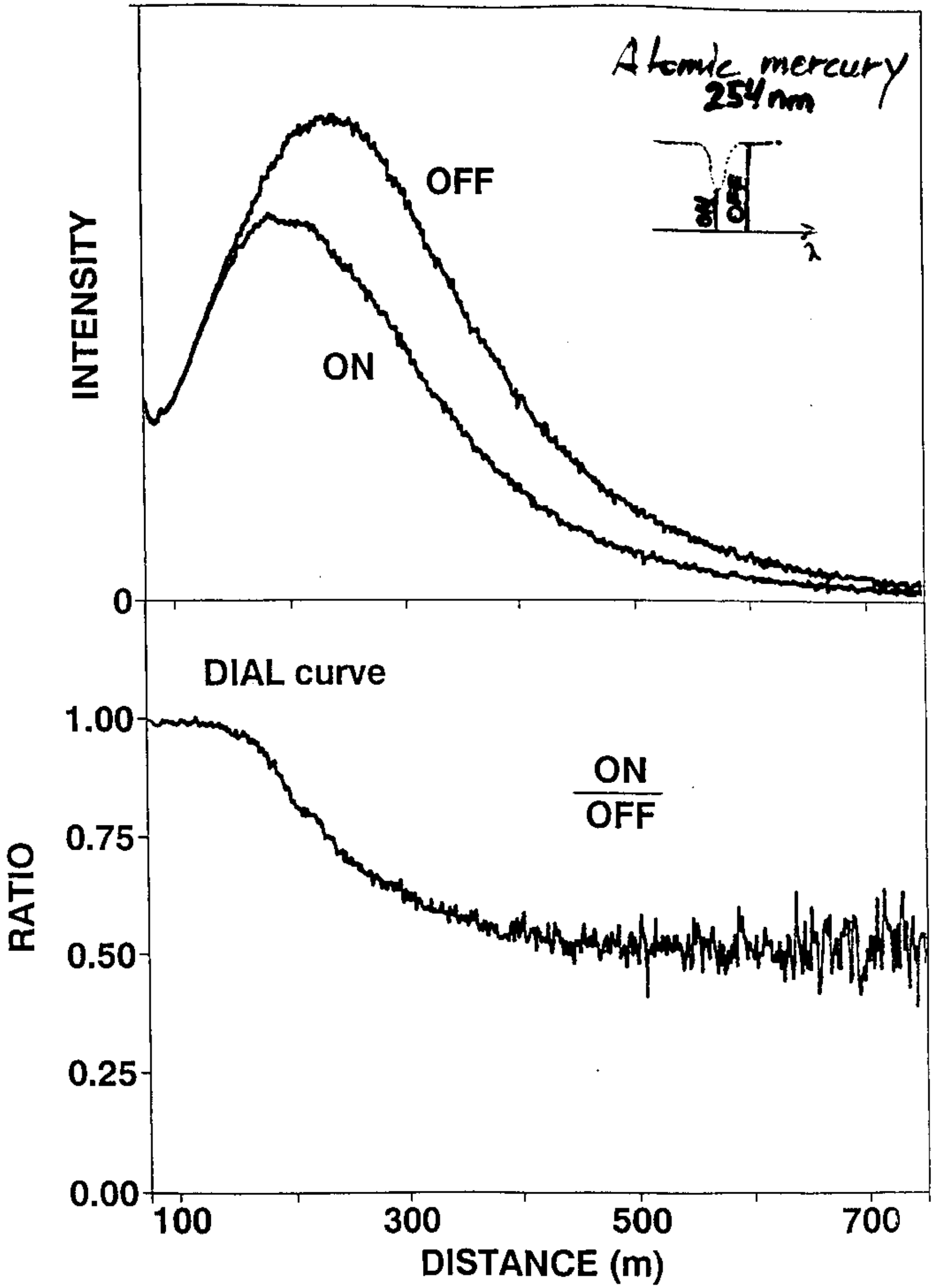
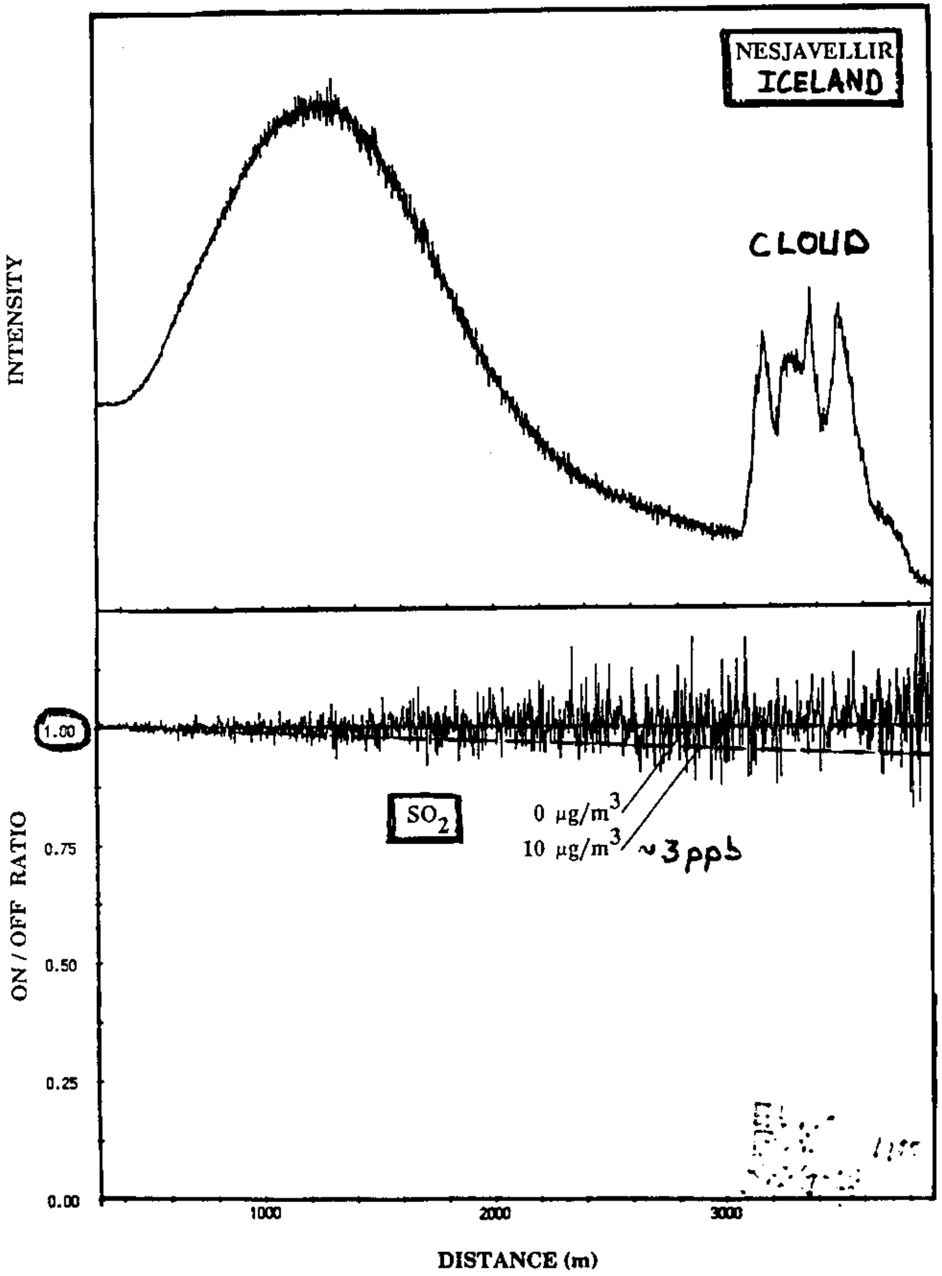
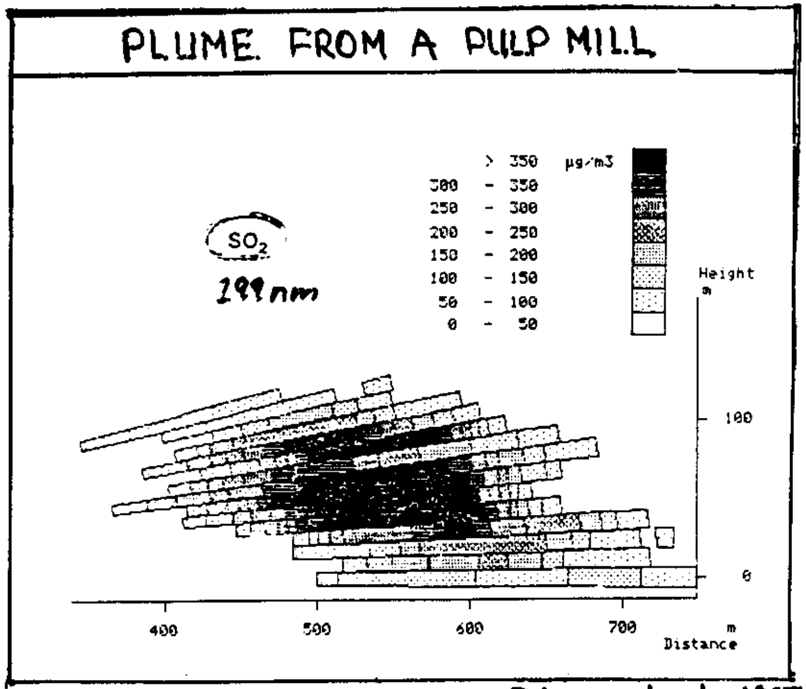


Figure 3

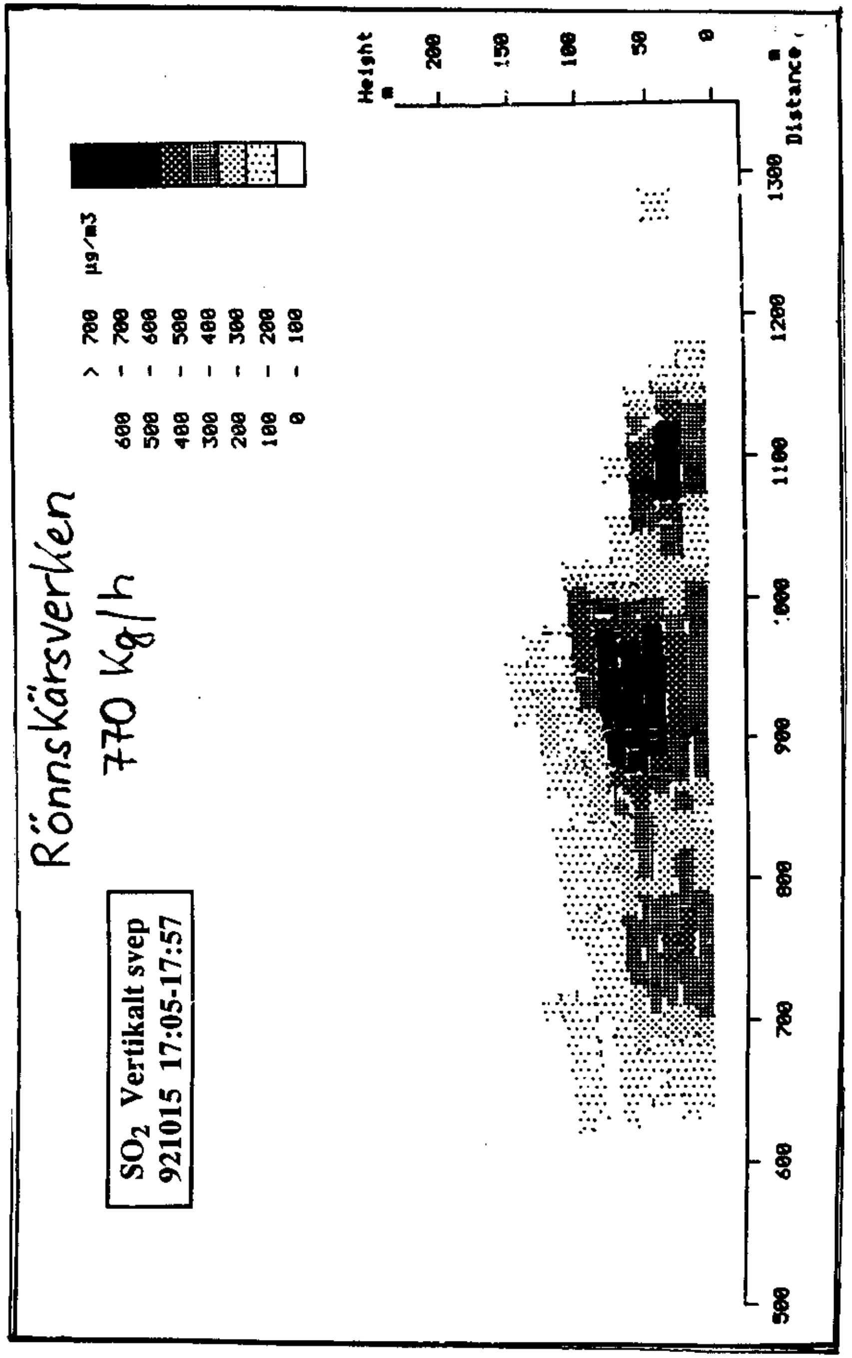
Figure 6





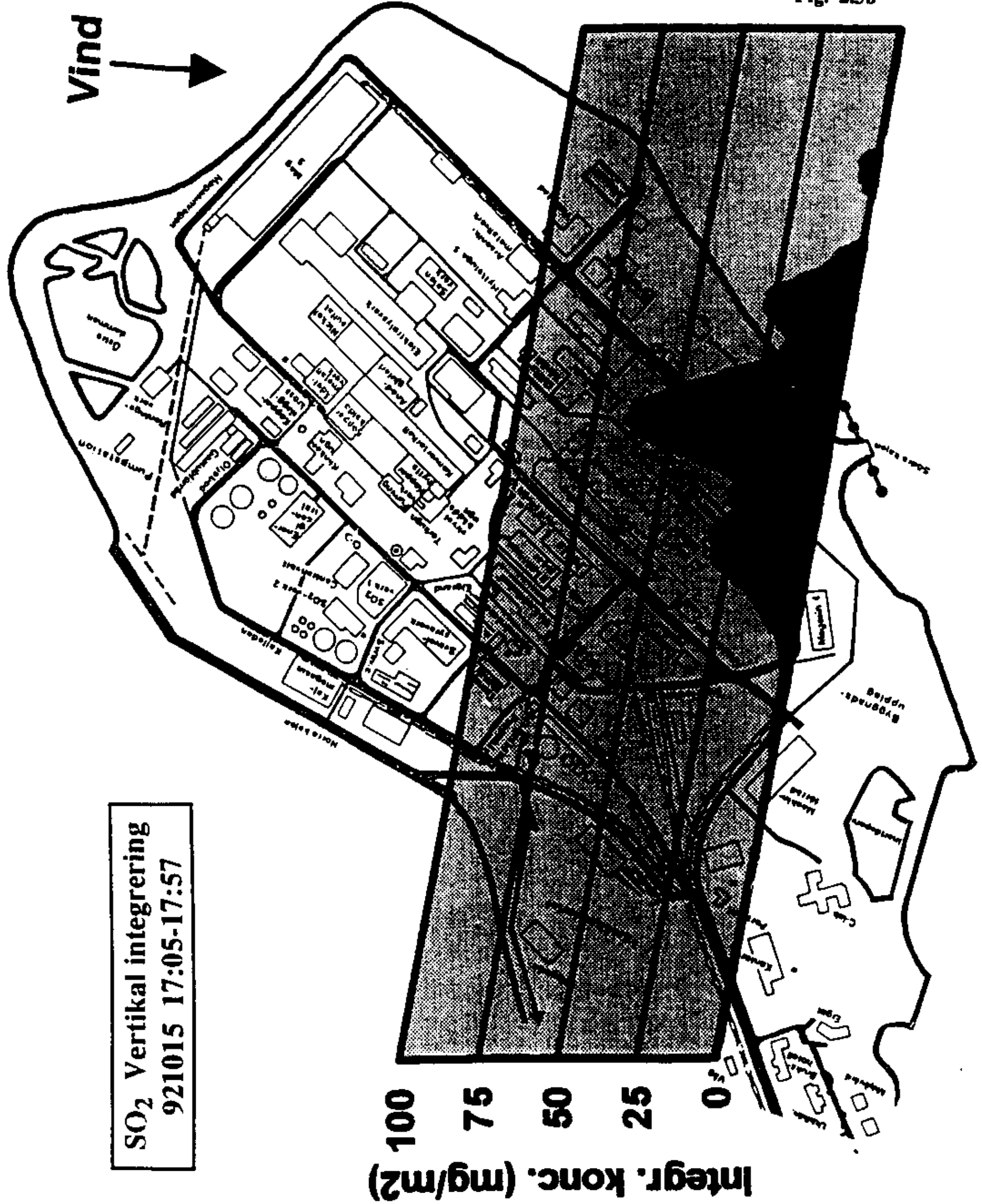
Edner et al., 1987

Figure 8



Rönnskärsverken
770 Kg/h
SO_2 Vertikalt svep
921015 17:05-17:57
> 700 µg/m3
600 - 700
500 - 600
400 - 500
300 - 400
200 - 300
100 - 200
0 - 100
Height m
200
150
100
50
0
Distance m
500
600
700
800
900
1000
1100
1200
1300

Fig. 2.3b



Vind
SO_2 Vertikal integrering
921015 17:05-17:57
Integr. konc. (mg/m2)
100
75
50
25
0

16

Fig. 4.1

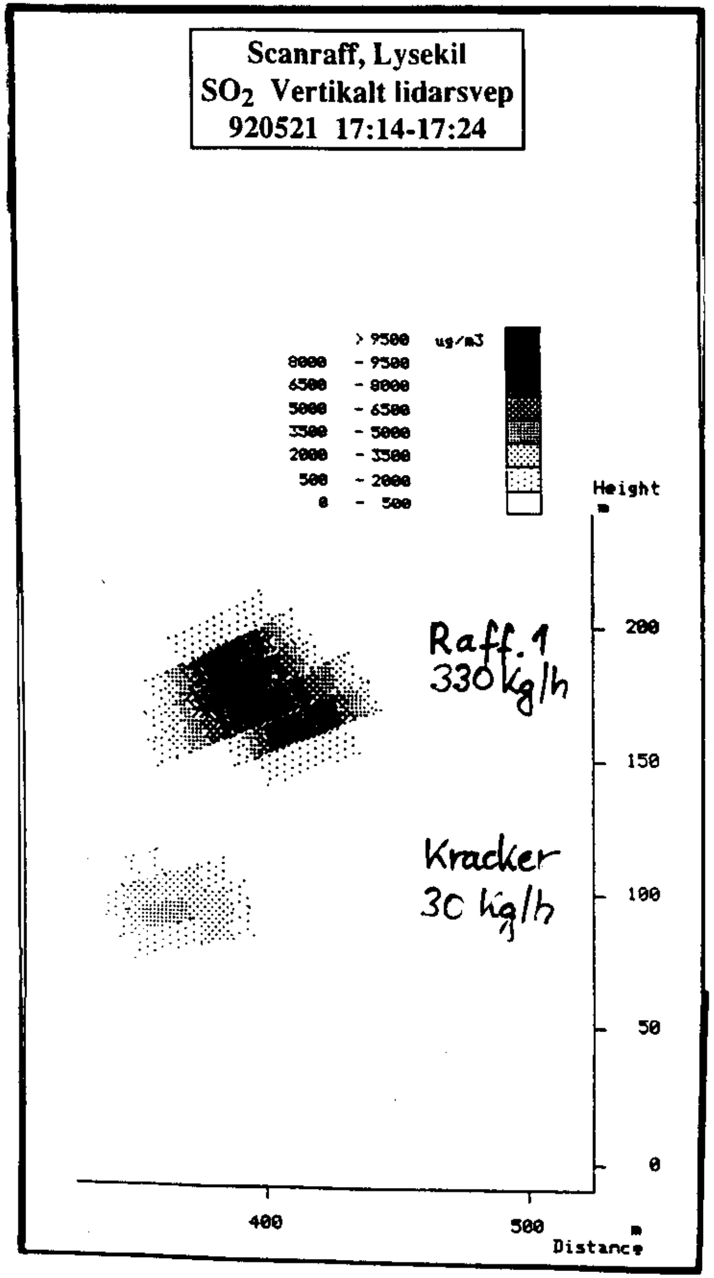


Figure 1

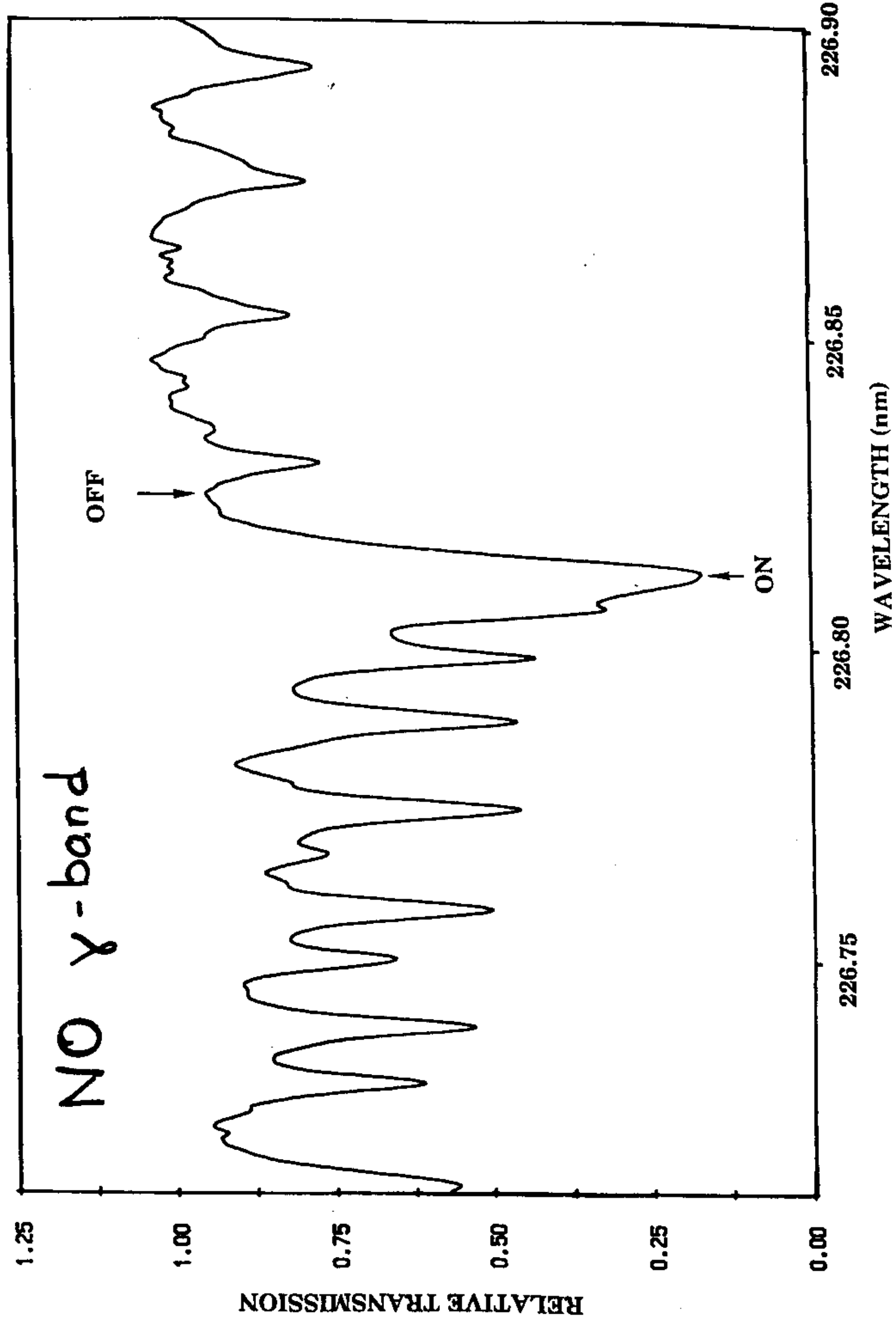
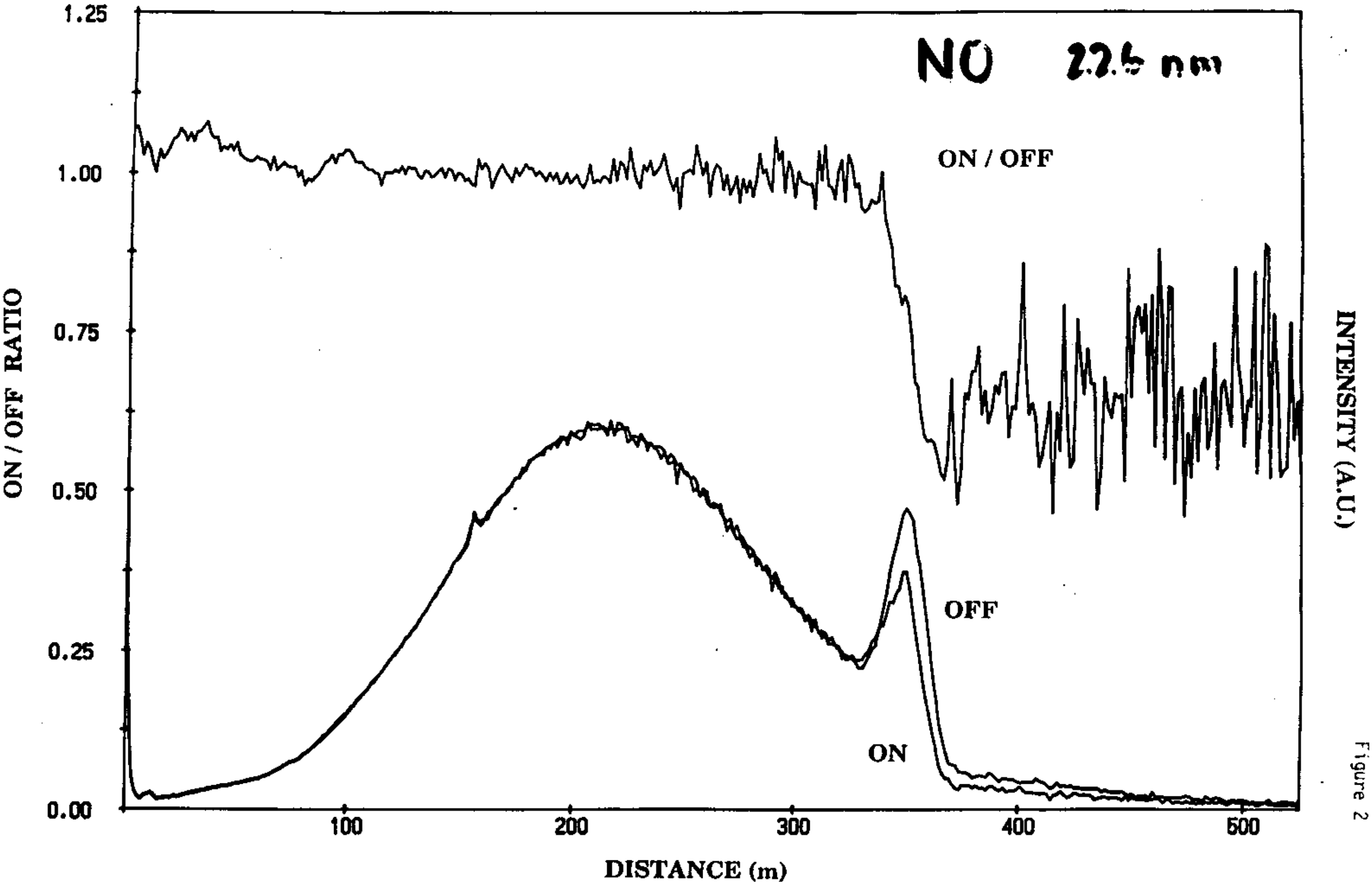
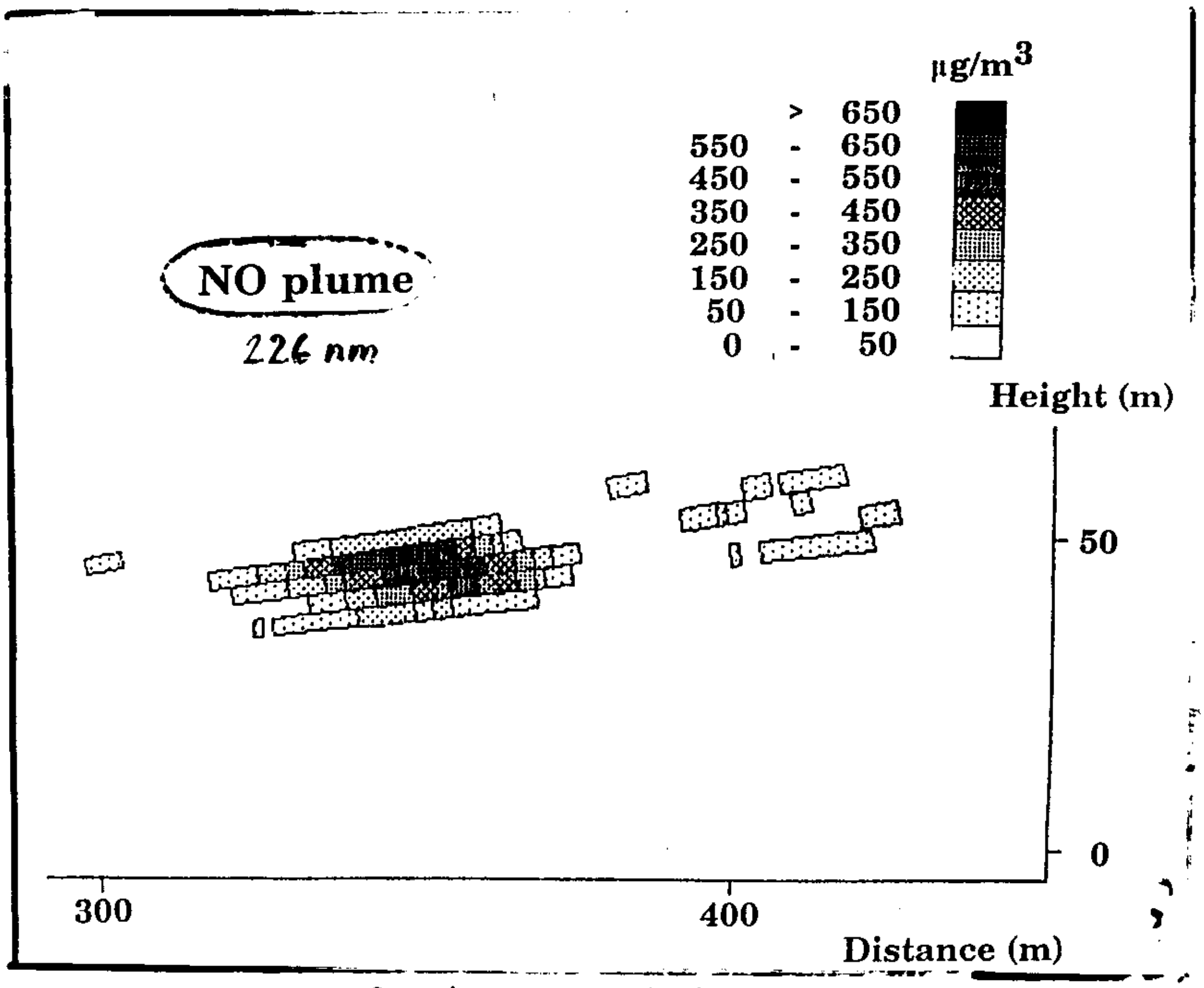


Figure 2

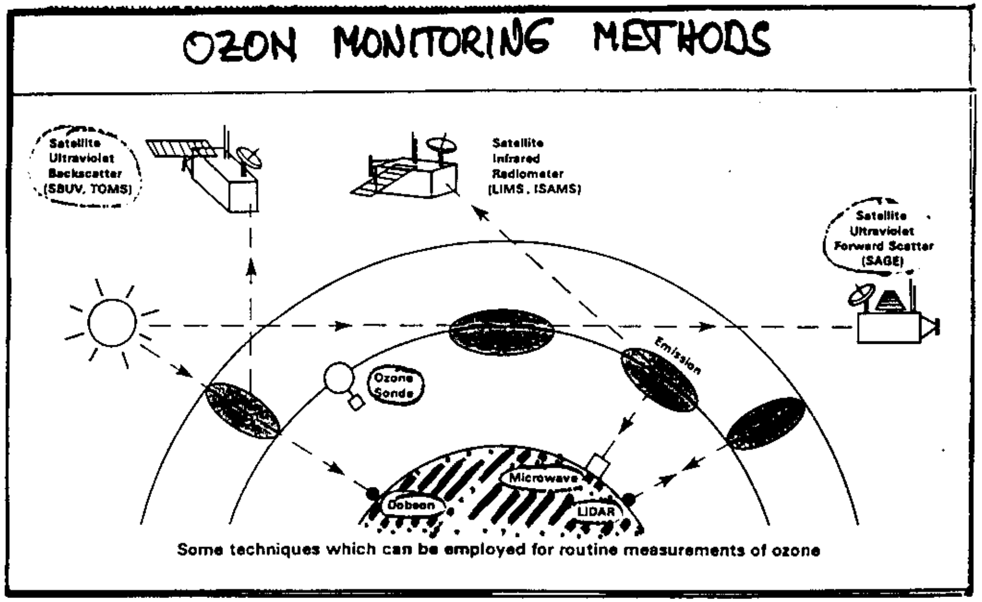


18



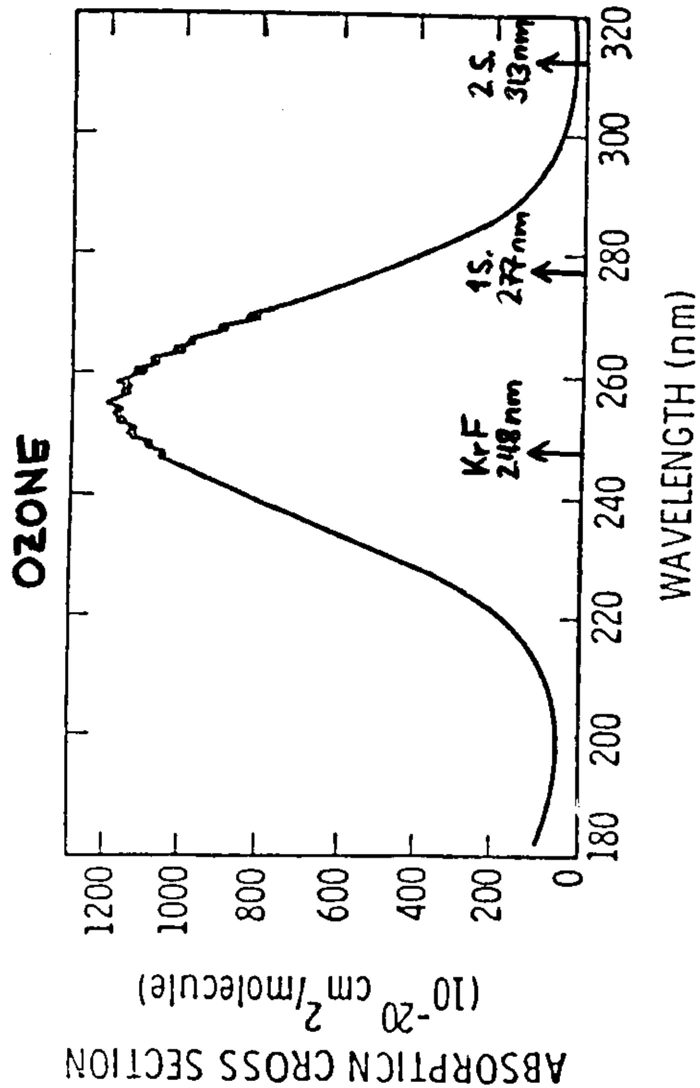
Edner, Sunesson, Svanberg, Opt. Lett. 13, 704 (1988).

Figure 6

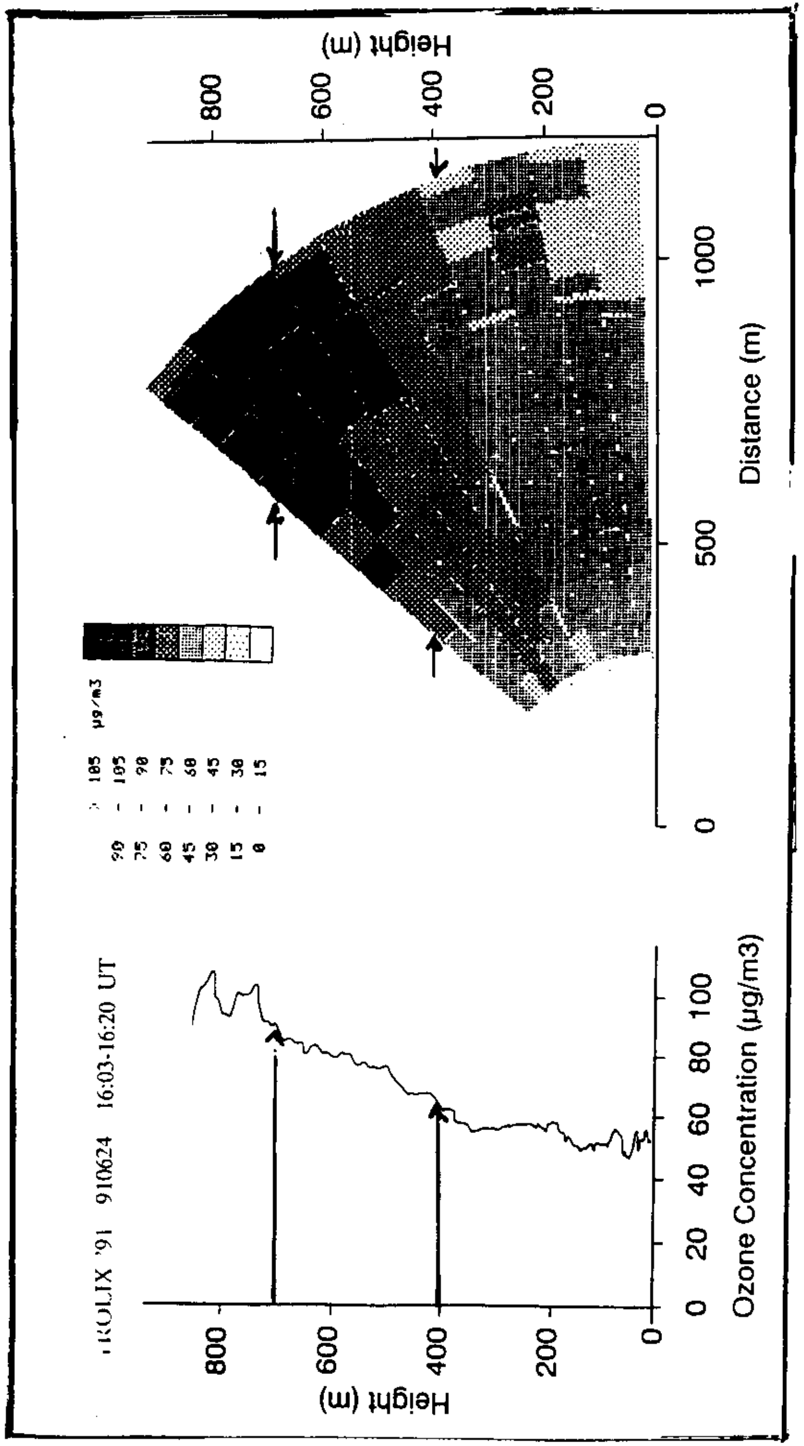


Some techniques which can be employed for routine measurements of ozone

British Ozon Report 1988



Absorption cross sections of ozone at 298 K in the region 180–320 nm.



ATOMIC MERCURY IN THE ATMOSPHERE

POLLUTANT:

- **CHLOR-ALKALI PLANTS**
- **COAL-FIRED POWER PLANTS**
- **REFUSE DEPOSITS**
- **CREMATORIES**

GEOPHYSICAL TRACER GAS:

- **ORE DEPOSITS**
- **GEOTHERMAL FIELDS**

} **exlo-ration?**

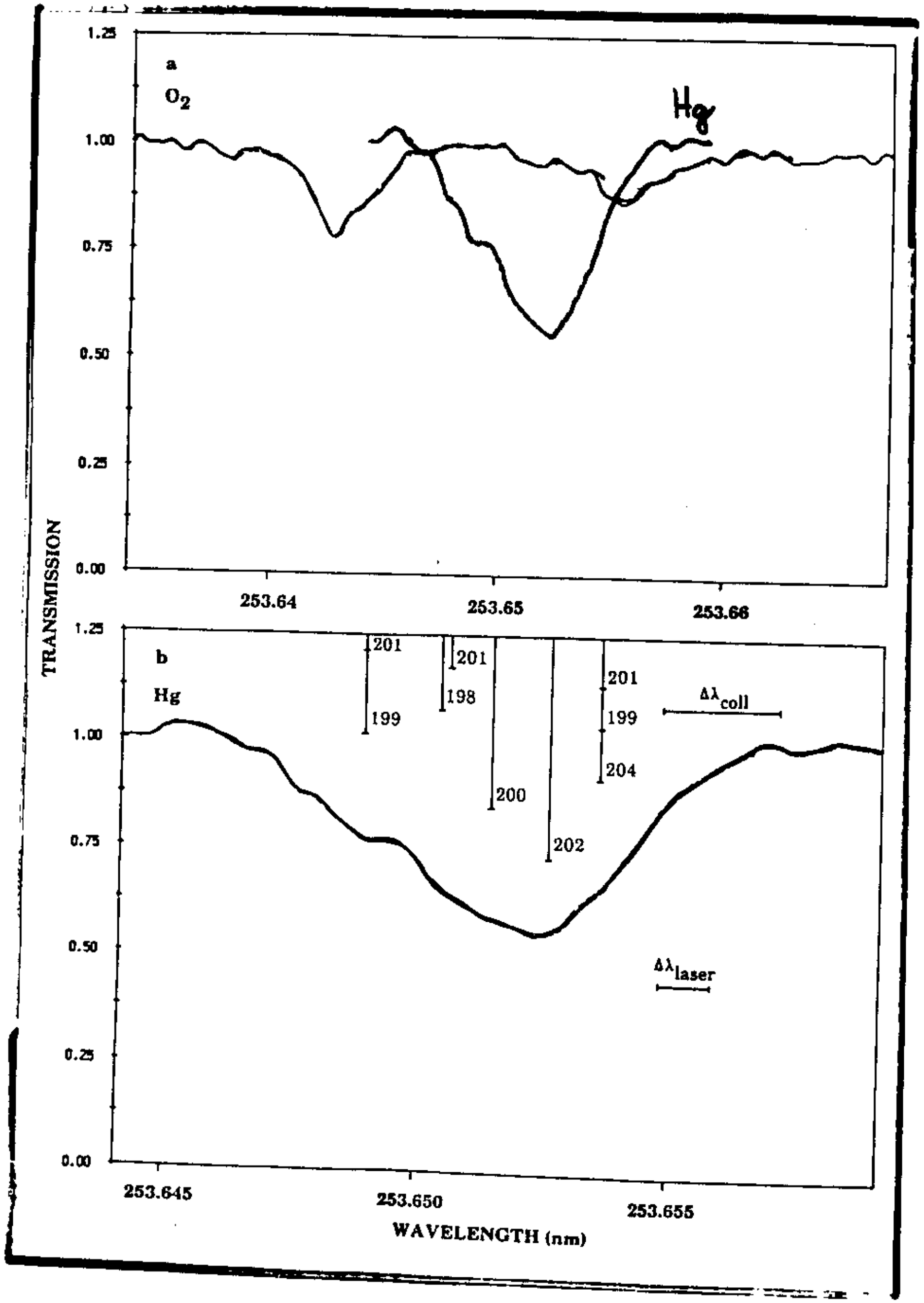
- **EARTHQUAKES**
- **VULCANO ERUPTIONS**

} **predic-tion ?**

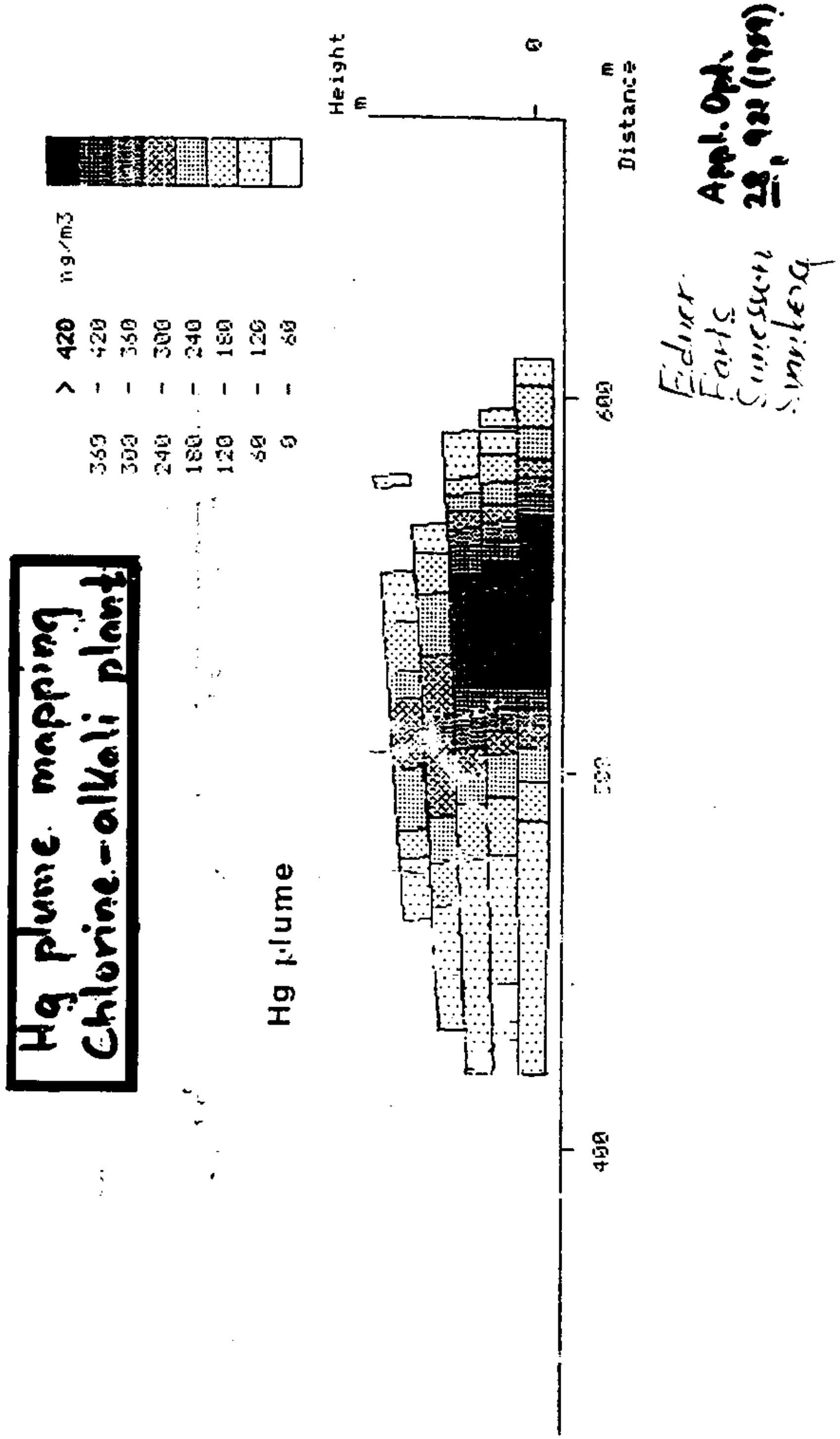
BACKGROUND CONCENTRATION:

~ 2 ng/m^3 ~ 0.2 ppt (1:10^{12})

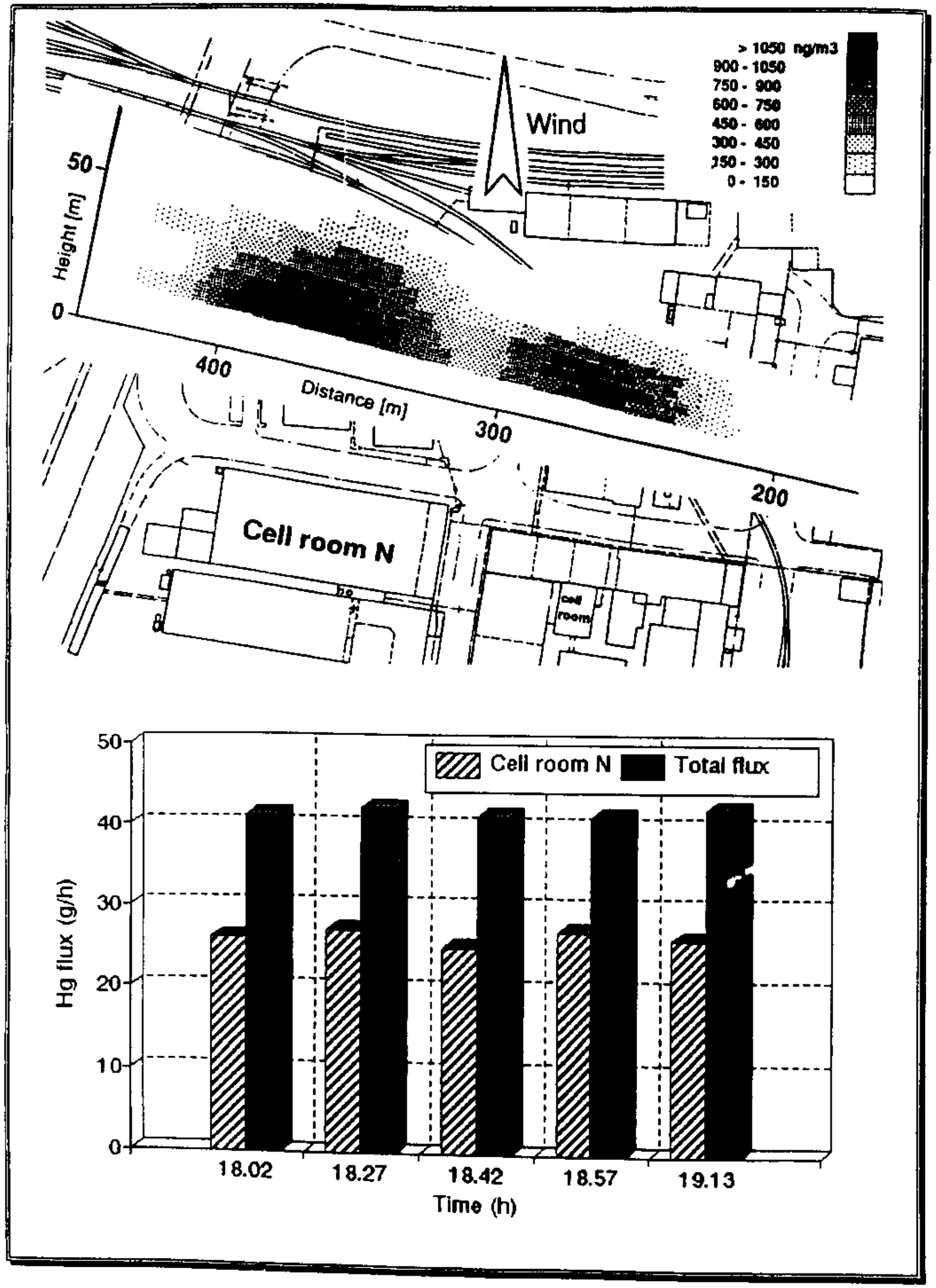
FIG. 4



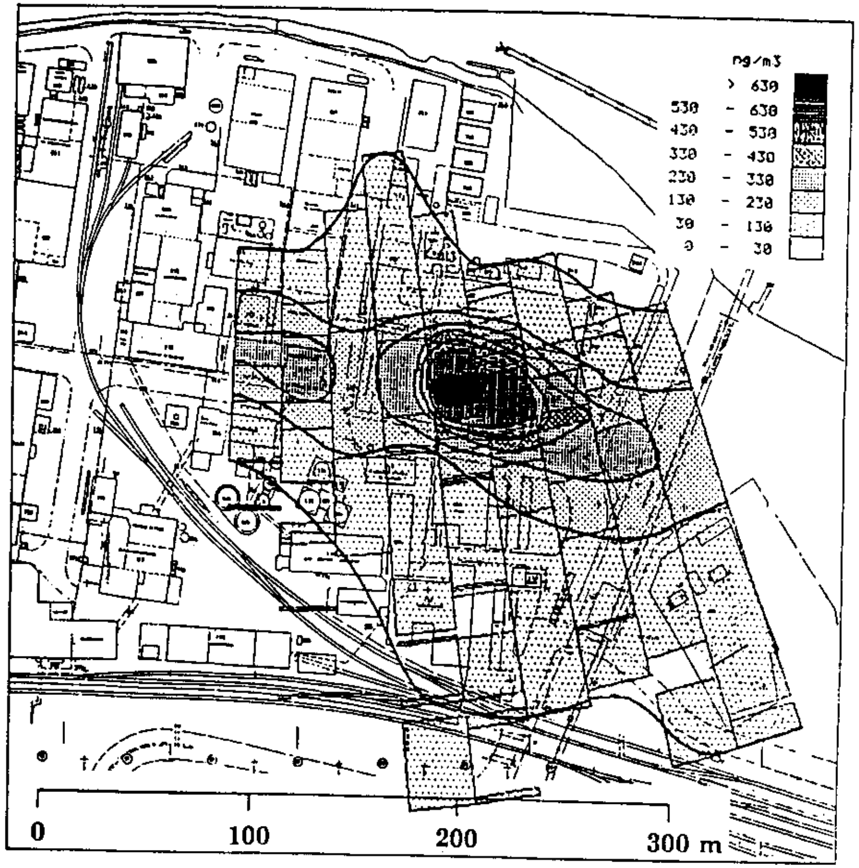
a
O_2
Hg
TRANSMISSION
1.25
1.00
0.75
0.50
0.25
0.00
253.64
253.65
253.66
b
Hg
201
199
201
198
200
202
201
199
204
$\Delta\lambda_{coll}$
$\Delta\lambda_{laser}$
253.645
253.650
253.655
WAVELENGTH (nm)

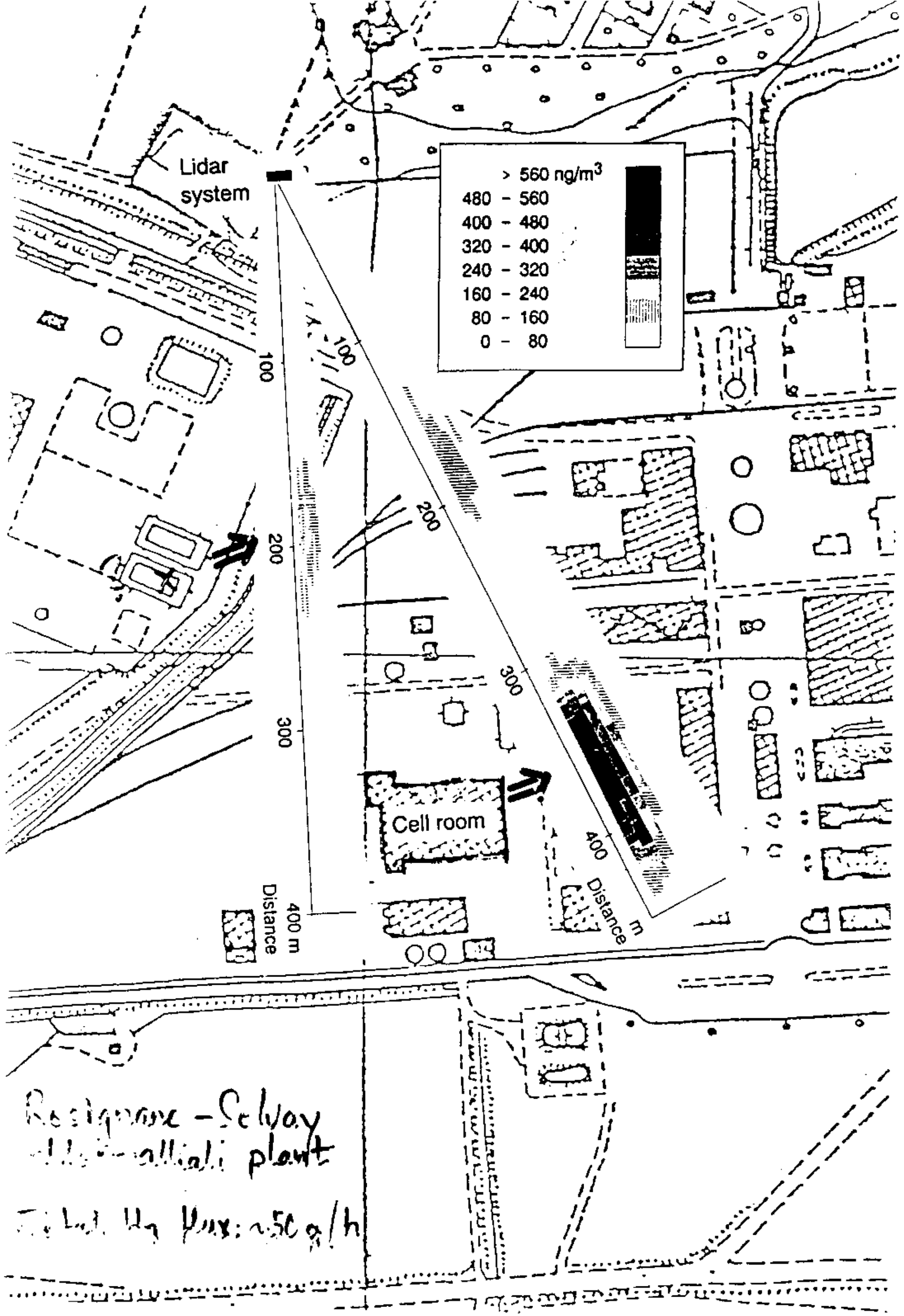


Hg plume mapping
Chlorine-alkali plant
Hg plume
ng/m3
> 420
360 - 420
300 - 360
240 - 300
180 - 240
120 - 180
60 - 120
0 - 60
Height m
Distance m
0
600
500
400
Appl. Opt. 28, 922 (1989)
Edner
Faris
Sunesson
Svanberg

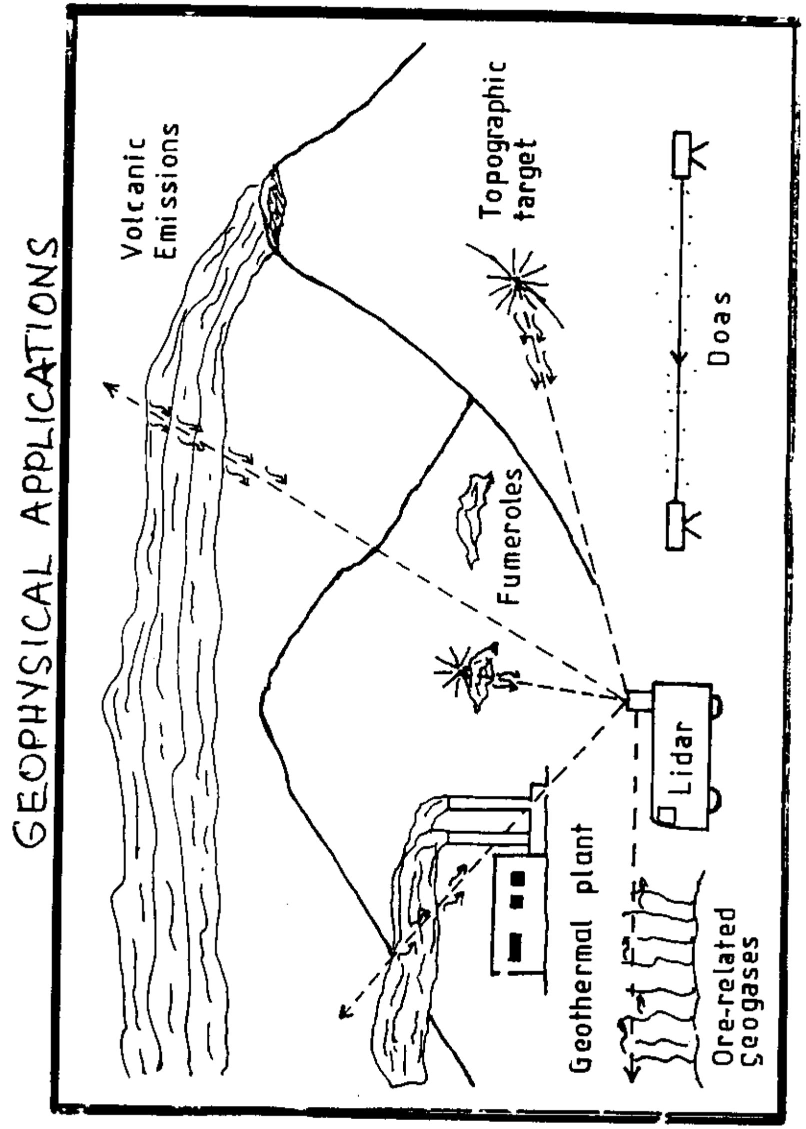


Horizontal Hg scan, chlorine-alkali plant





Lidar system
> 560 ng/m3
480 - 560
400 - 480
320 - 400
240 - 320
160 - 240
80 - 160
0 - 80
100
200
300
400 m
Distance
Distance m
Cell room
Rosignano-Solvay chlor-alkali plant
Tot. Hg flux: ≈50 g/h



GEOPHYSICAL APPLICATIONS
Volcanic Emissions
Topographic target
Doas
Fumeroles
Lidar
Geothermal plant
Ore-related Geogases

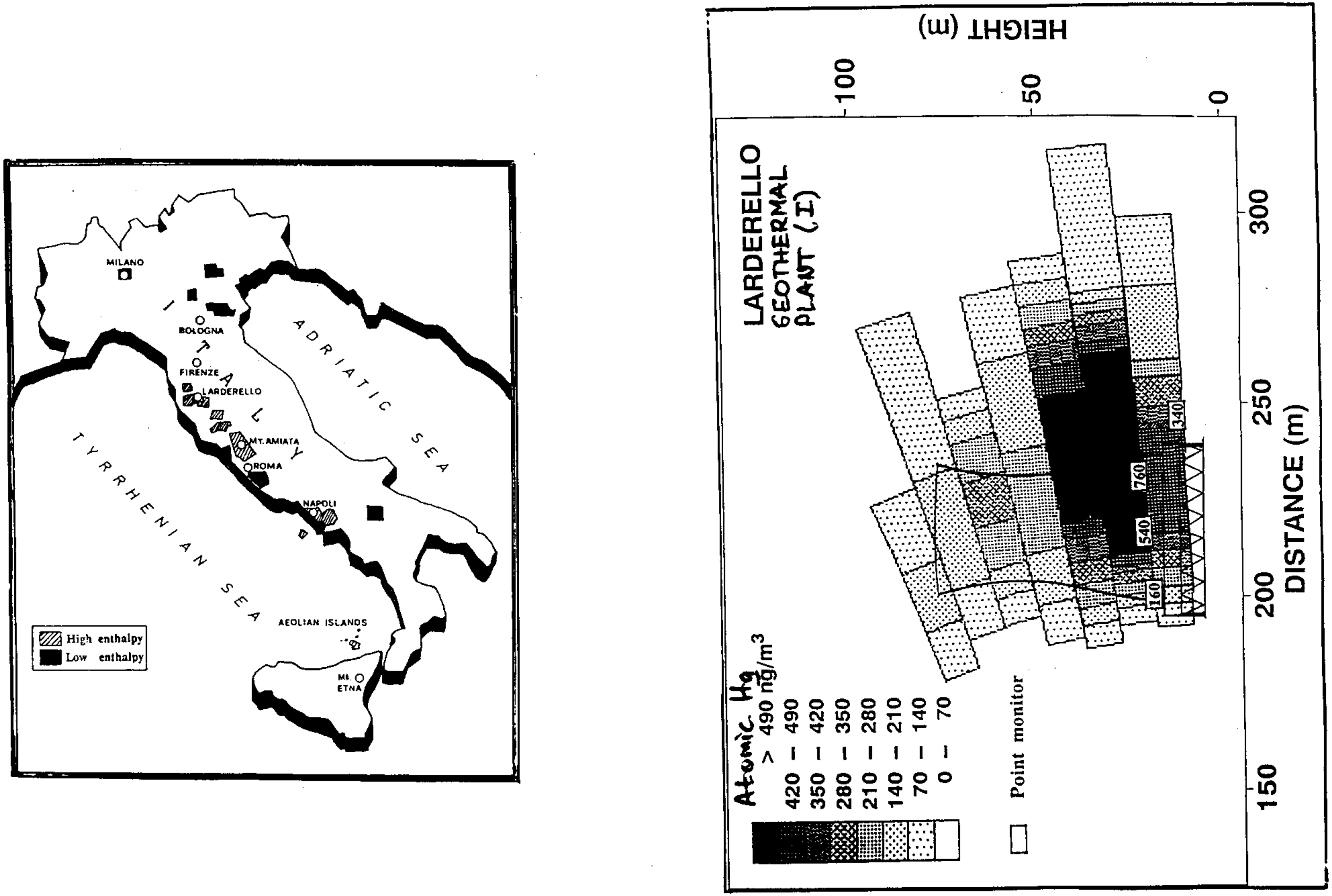

MILANO
BOLOGNA
FIRENZE
LARDERELLO
MT. AMIATA
ROMA
NAPOLI
AEOLIAN ISLANDS
Mt. ETNA
ITALY
ADRIATIC SEA
TYRRHENIAN SEA
High enthalpy
Low enthalpy
LARDERELLO
GEOTHERMAL
PLANT (I)
HEIGHT (m)
DISTANCE (m)
Atomic Hg
ng/m3
> 490
420 – 490
350 – 420
280 – 350
210 – 280
140 – 210
70 – 140
0 – 70
Point monitor
760
540
340
160

Figure 1

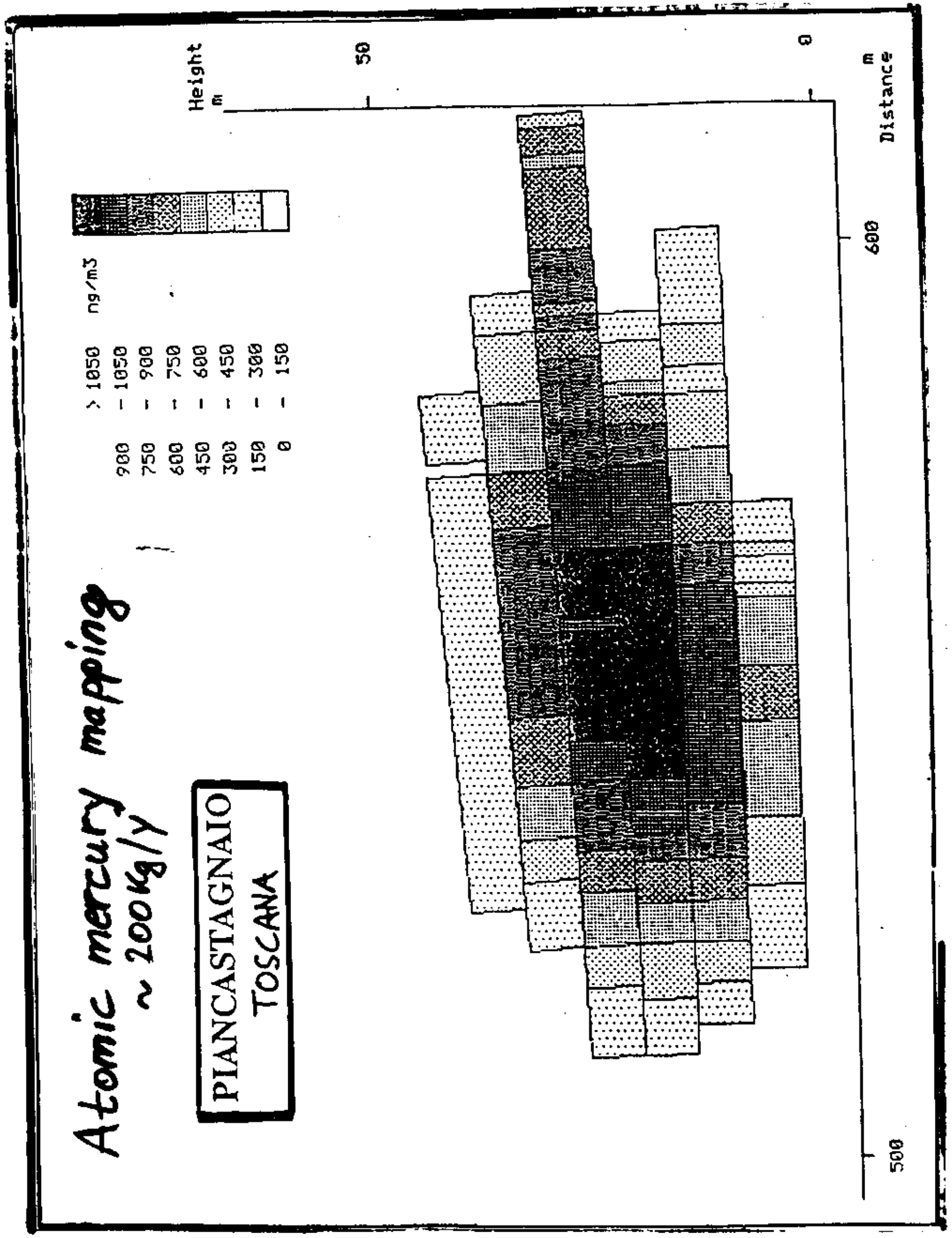


Fig. 4

Mercury mine

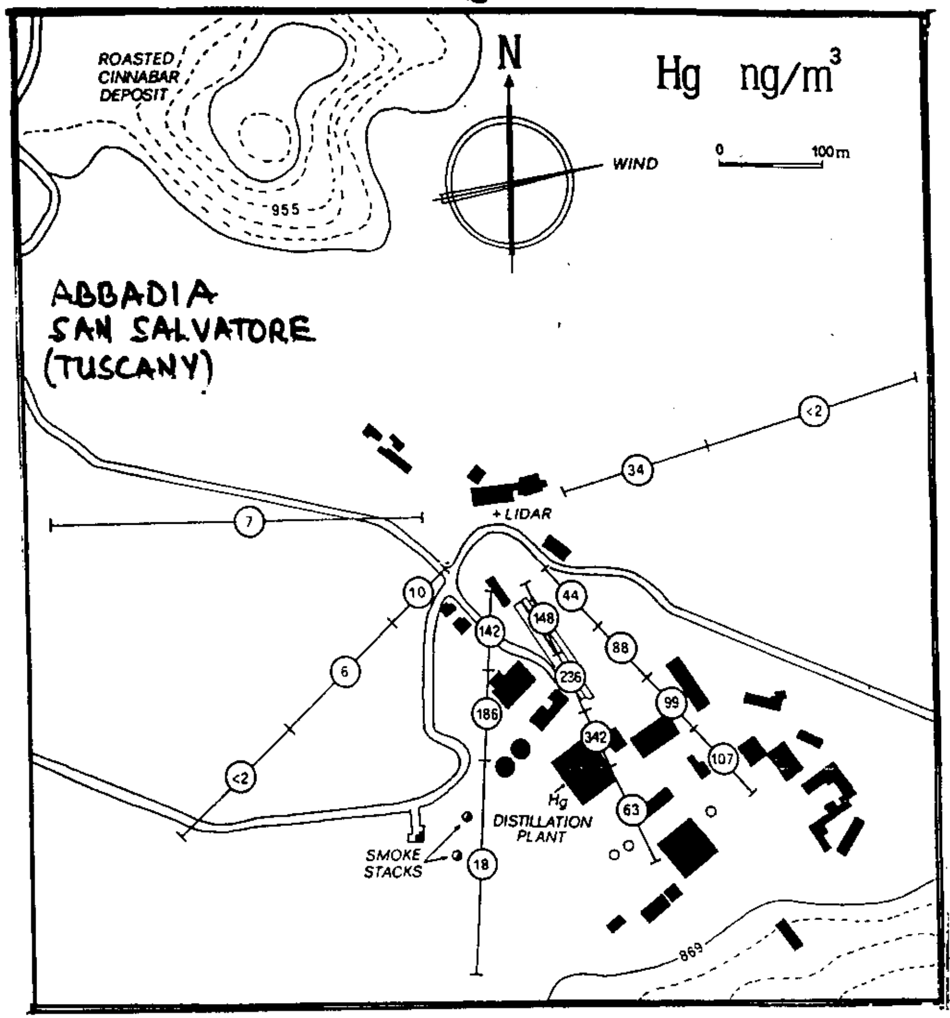


Figure 6

Figure 1.

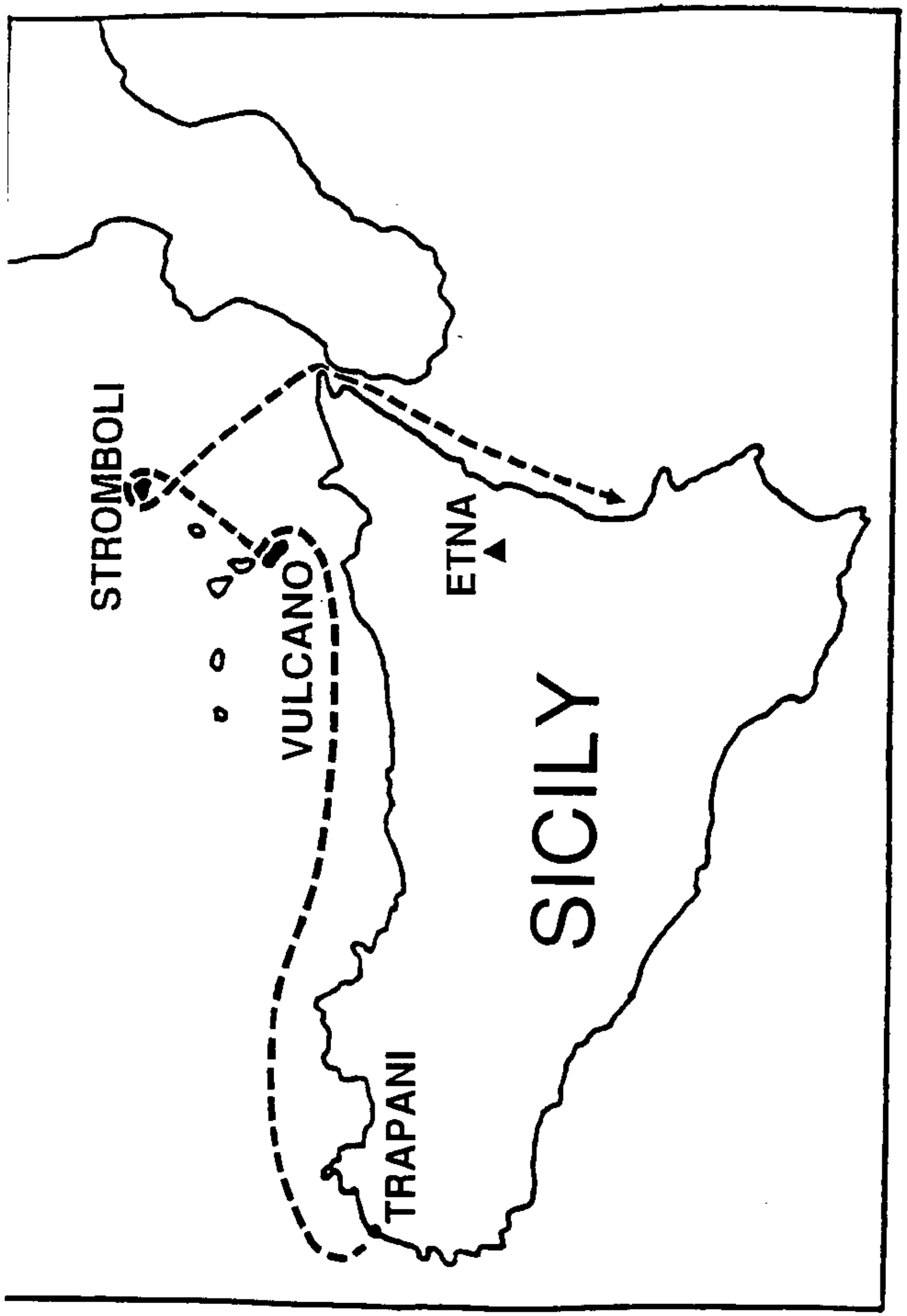
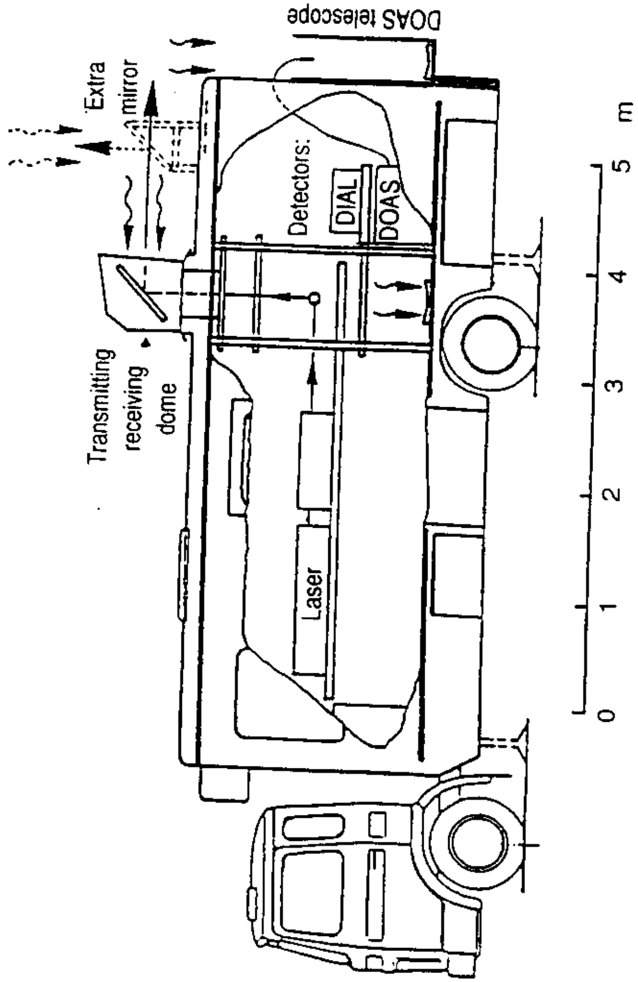
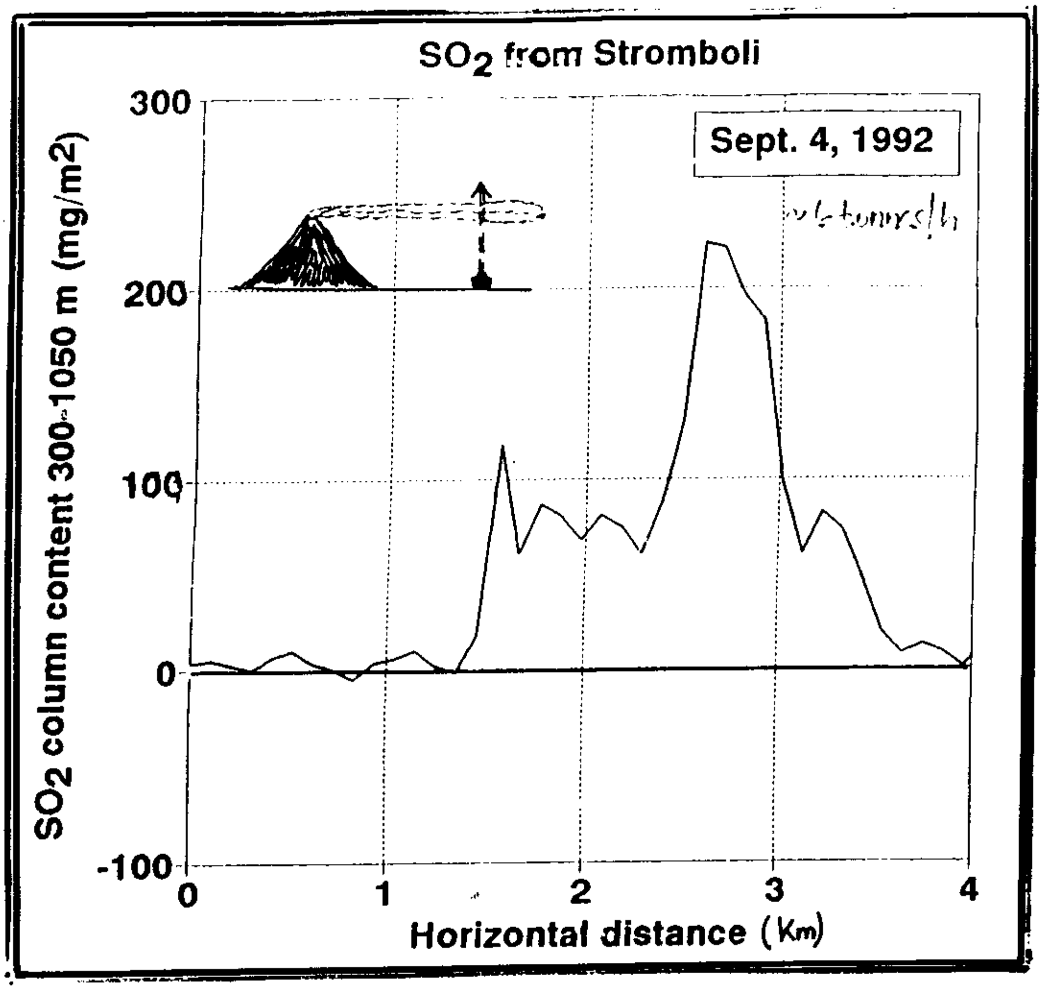
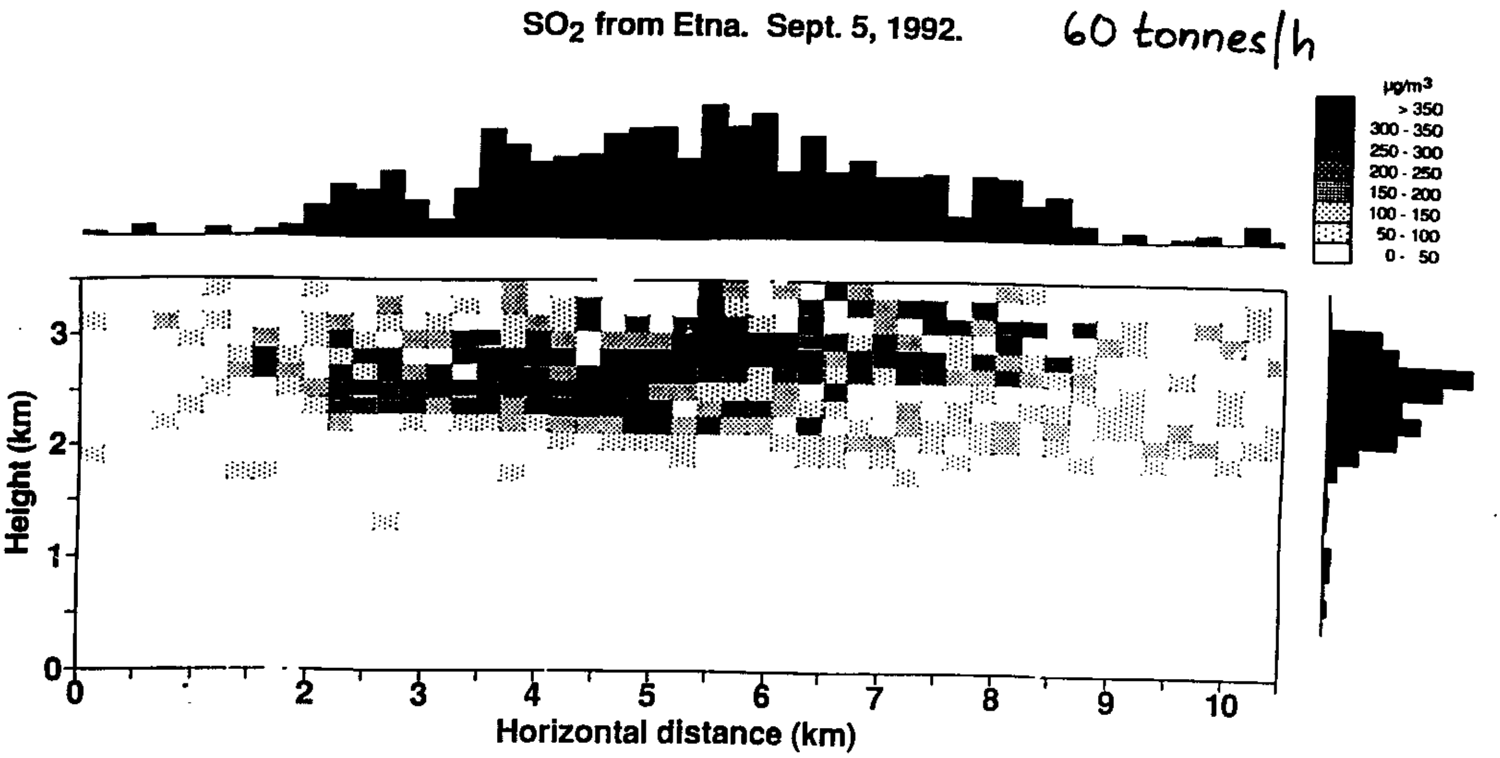


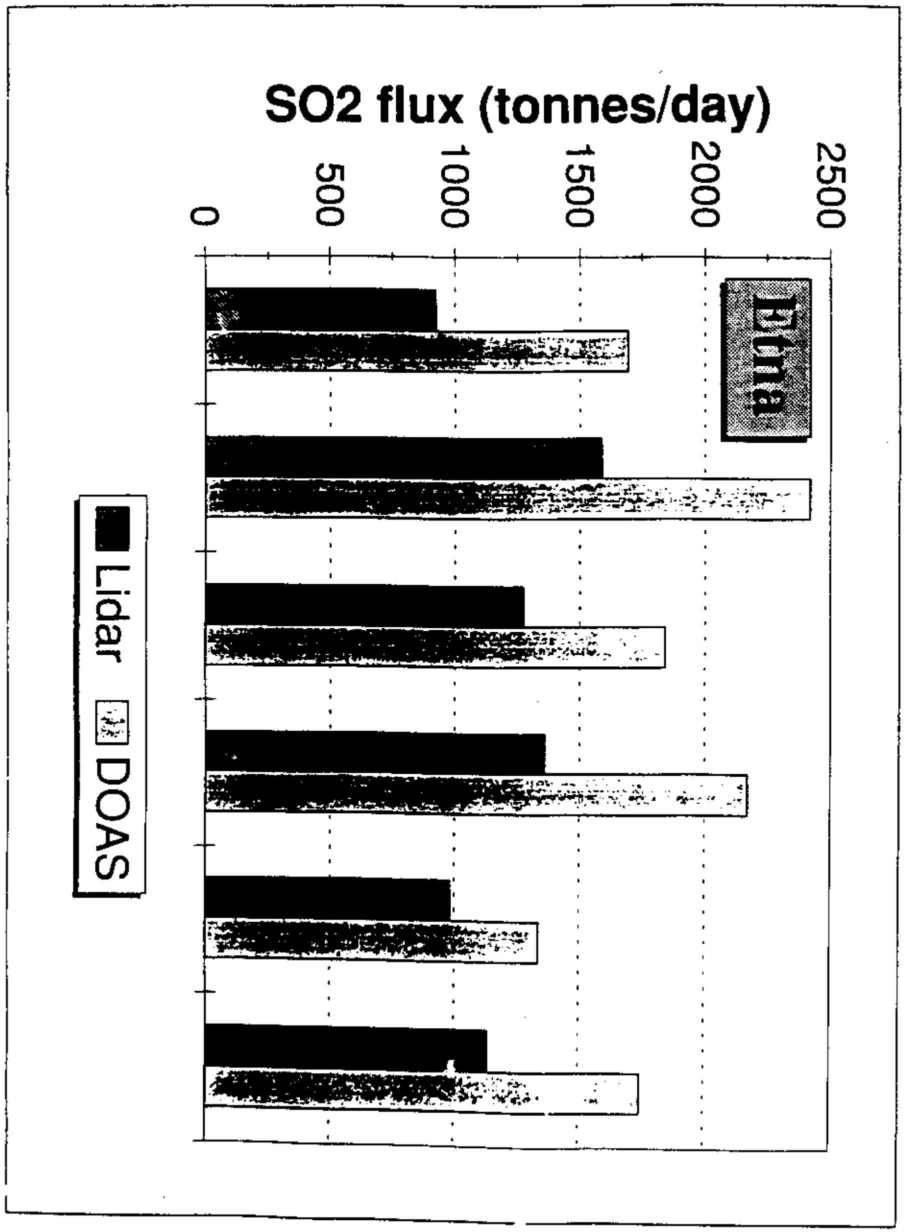
Figure 2.







Range-resolved DIAL measurements of the SO_2 plume from Etna.
Traverse under the plume with vertical measurement direction.



[redacted]

- source emission
- ambient air quality
- chemical transformation
- transport and dispersion

[redacted]

- temperature, pressure
- wind
- water vapour vertical profiles
- aerosols, boundary layer

[redacted]

- volcano emissions
- climatology

[redacted]

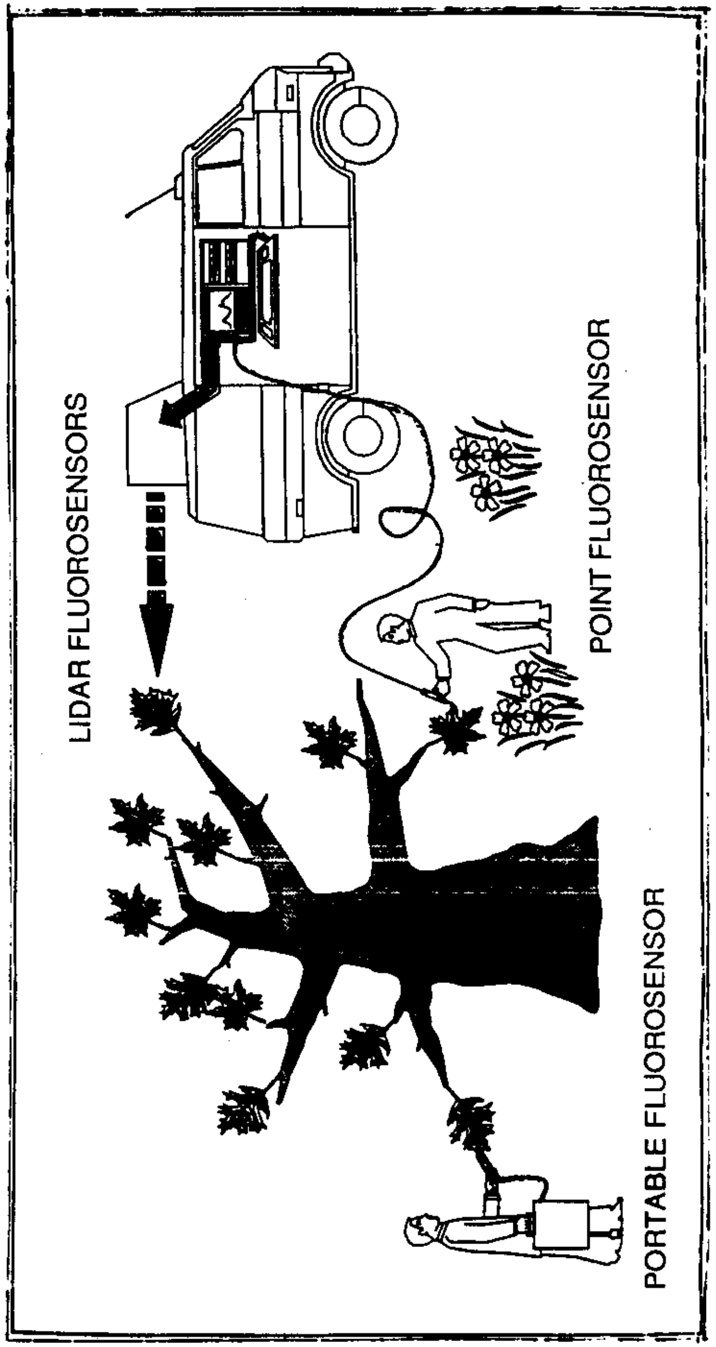
- tropospheric
- stratospheric ozone layer

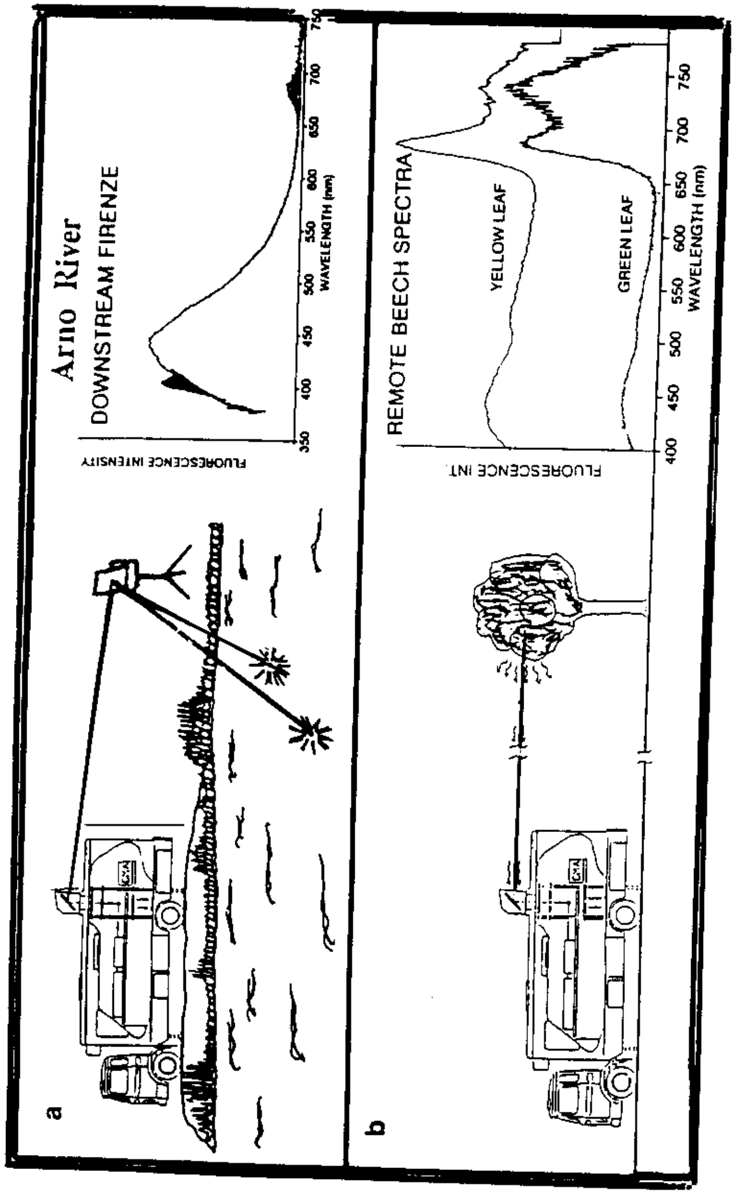
[redacted]

MOBILE DIAL SYSTEM SENSITIVITY AND RANGE

Visibility: 5 km   Measurement time: 1 min.

	Sens. (mg/m^2)	Range (km)
SO_2	10	3
NO_2	20	3
NO	3	0.5
O_3	5	3
Hg	0.002	1




a
Arno River
DOWNSTREAM FIRENZE
FLUORESCENCE INTENSITY
WAVELENGTH (nm)
b
REMOTE BEECH SPECTRA
YELLOW LEAF
GREEN LEAF
FLUORESCENCE INT.
WAVELENGTH (nm)

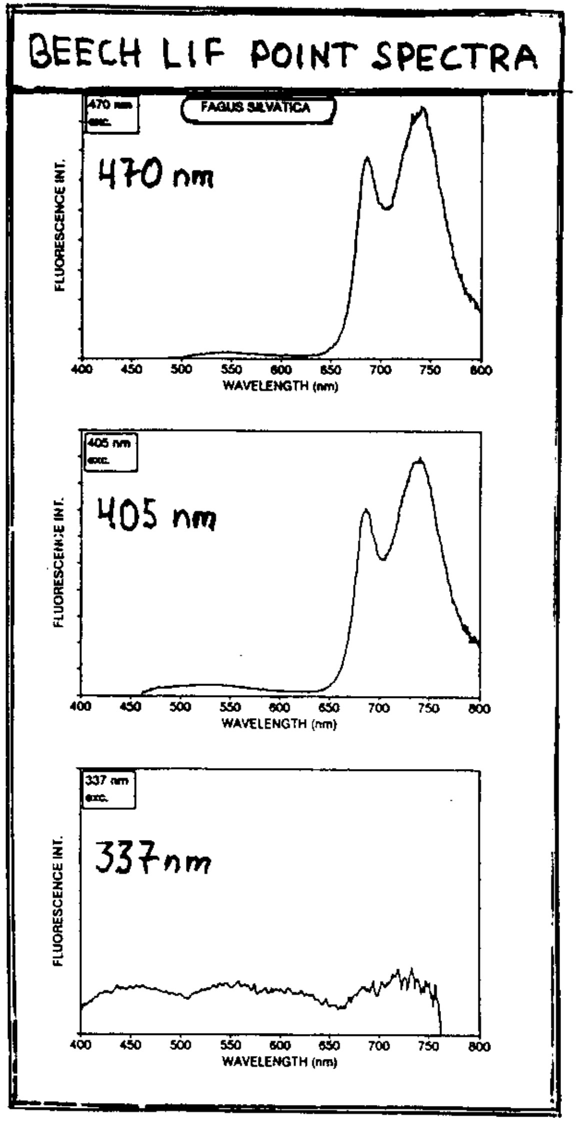
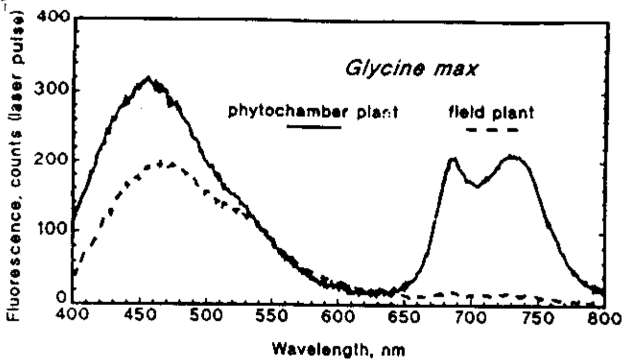
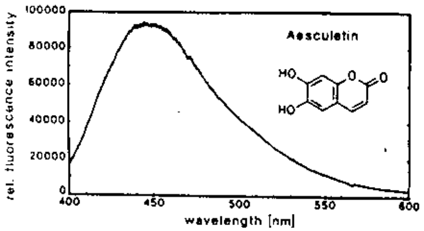
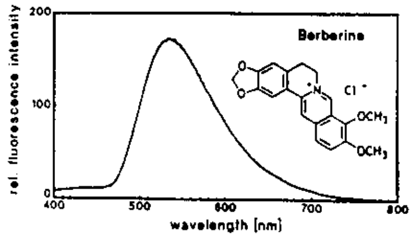
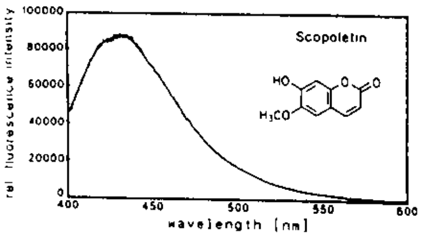

BEECH LIF POINT SPECTRA
FAGUS SILVATICA
470 nm exc.
470 nm
405 nm exc.
405 nm
337 nm exc.
337nm
FLUORESCENCE INT.
WAVELENGTH (nm)

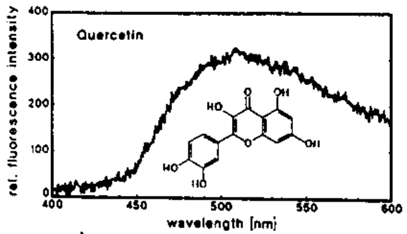
Figure 3.15

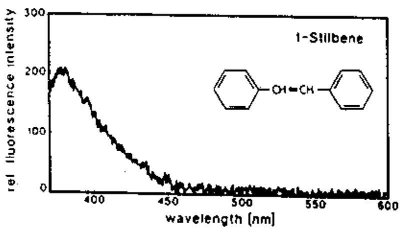


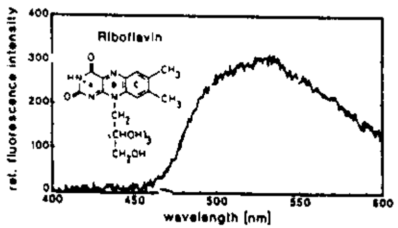


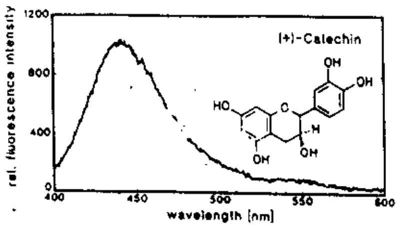


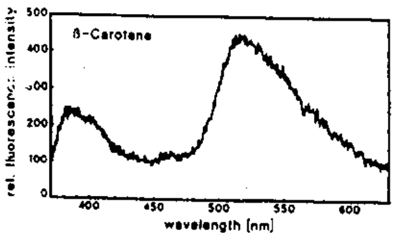




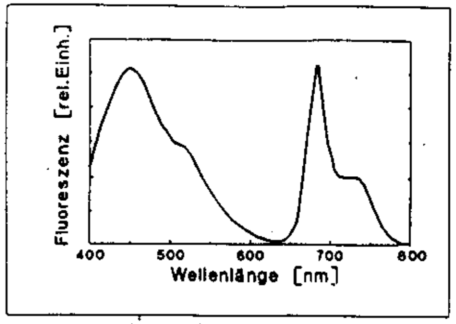




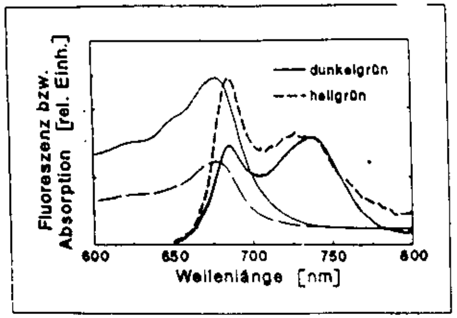




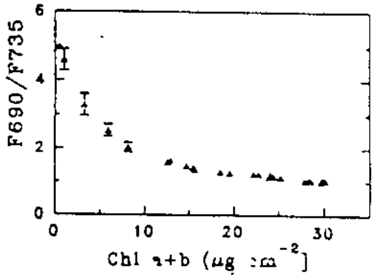
Lichtenthaler et al.



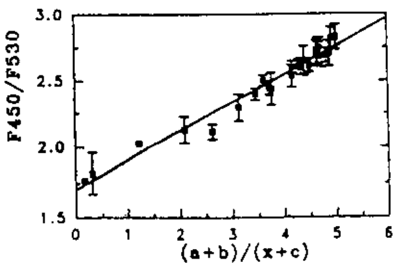
Lichtenthaler et al



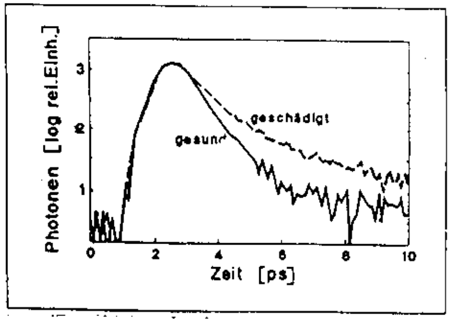
Buschmann et al.



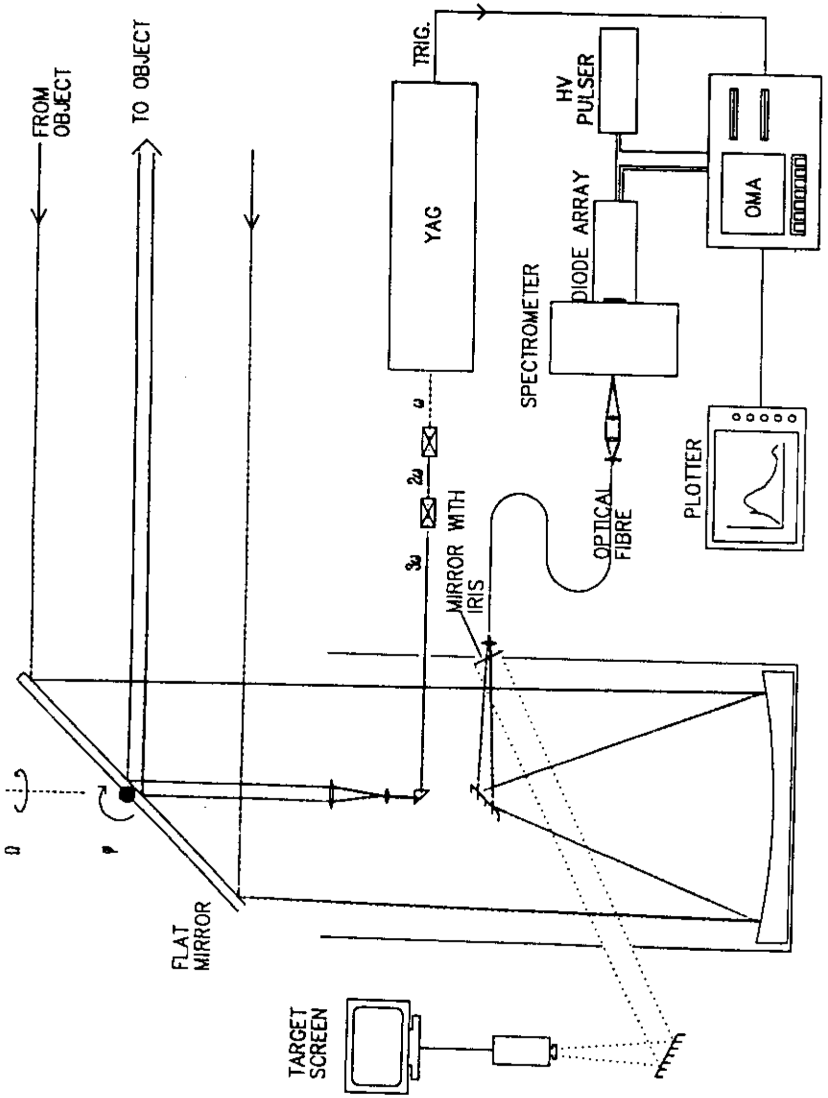
Lichtenthaler et al.

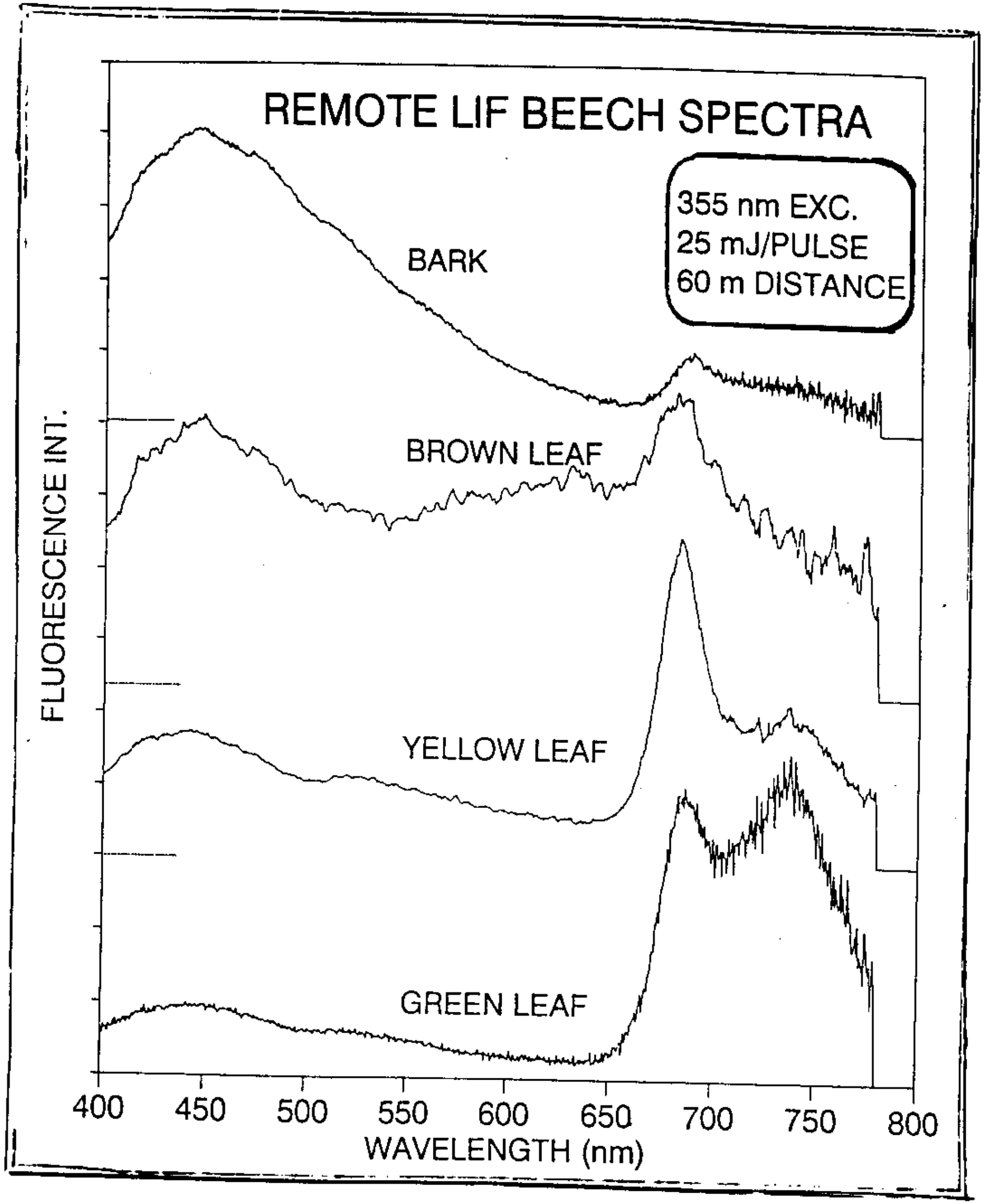


Lichtenthaler et al.

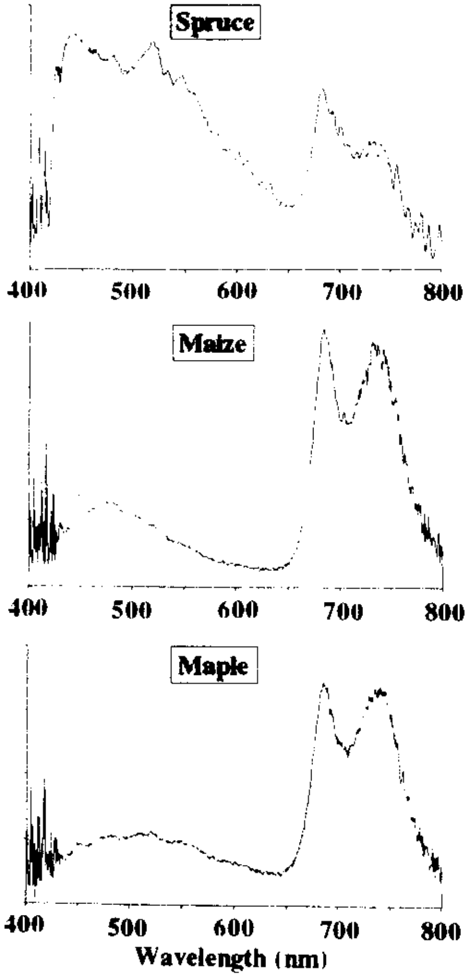


Schreckenberger et al.

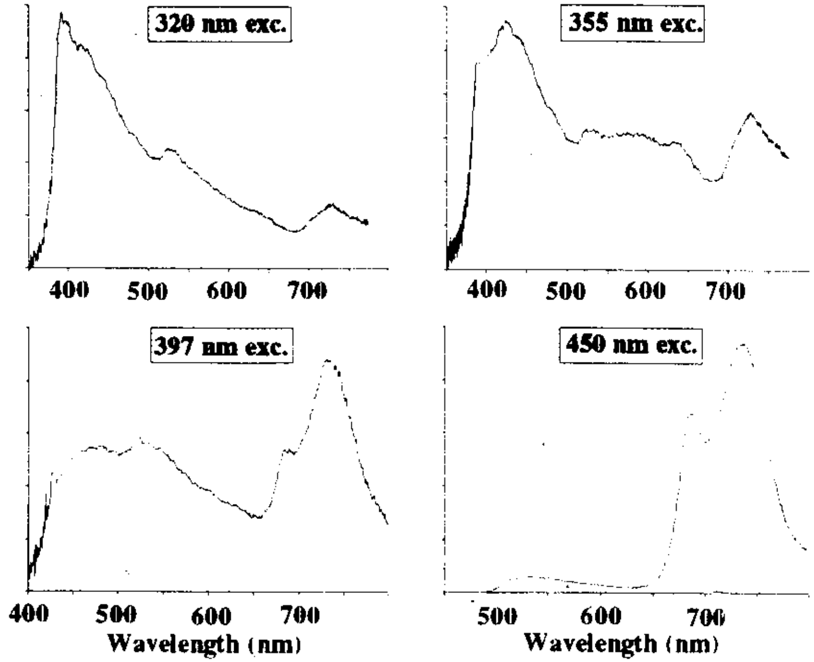

FROM OBJECT
TO OBJECT
TRIG.
YAG
HV PULSER
DIODE ARRAY
OMA
SPECTROMETER
PLOTTER
OPTICAL FIBRE
MIRROR WITH IRIS
ω
2ω
3ω
FLAT MIRROR
TARGET SCREEN

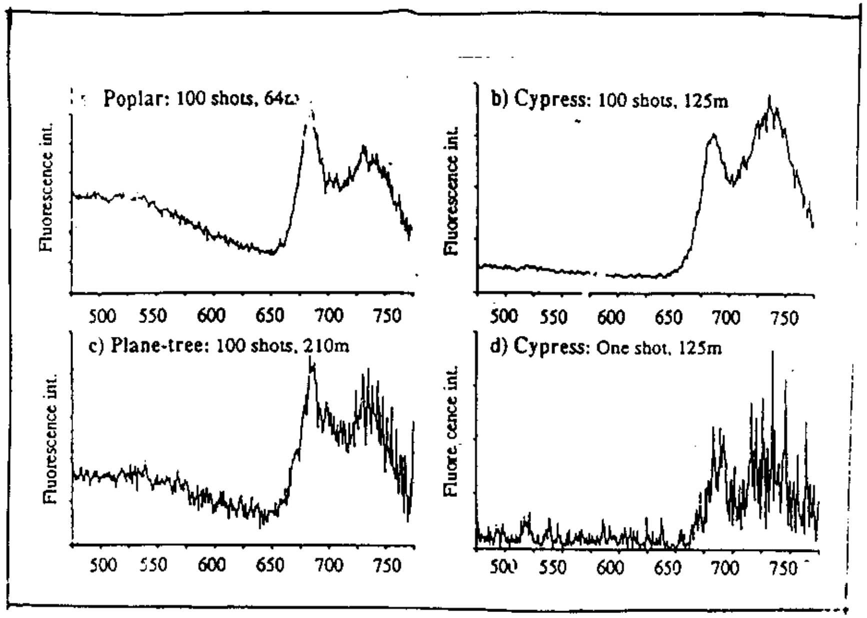

REMOTE LIF BEECH SPECTRA
355 nm EXC.
25 mJ/PULSE
60 m DISTANCE
BARK
BROWN LEAF
YELLOW LEAF
GREEN LEAF
FLUORESCENCE INT.
400
450
500
550
600
650
700
750
800
WAVELENGTH (nm)

[redacted]

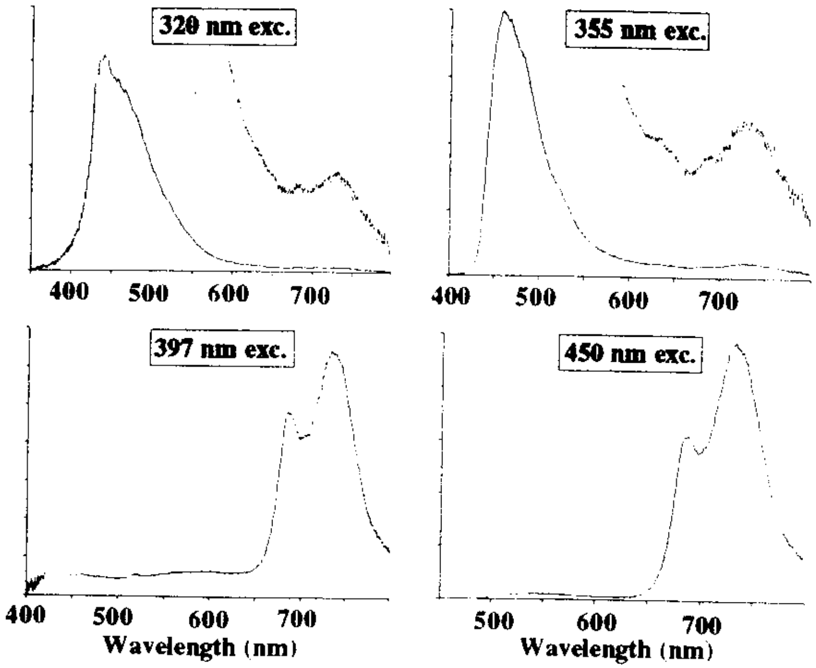


[redacted]

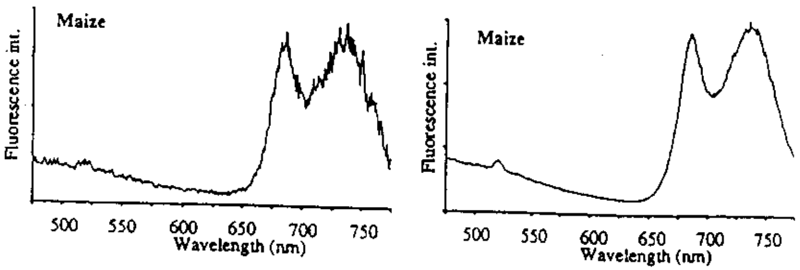


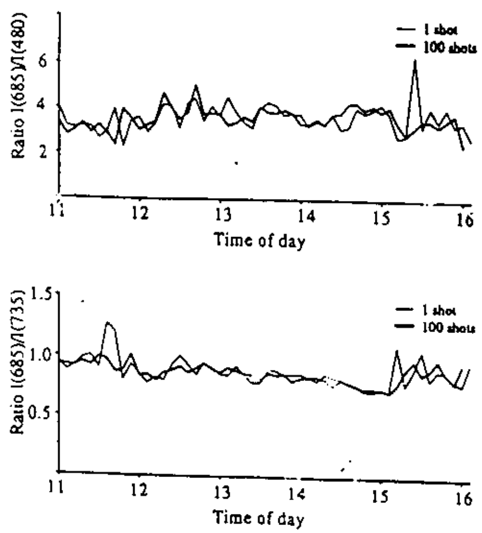

Poplar: 100 shots,
b) Cypress: 100 shots, 125m
c) Plane-tree: 100 shots, 210m
d) Cypress: One shot, 125m
Fluorescence int.
500 550 600 650 700 750

[redacted]

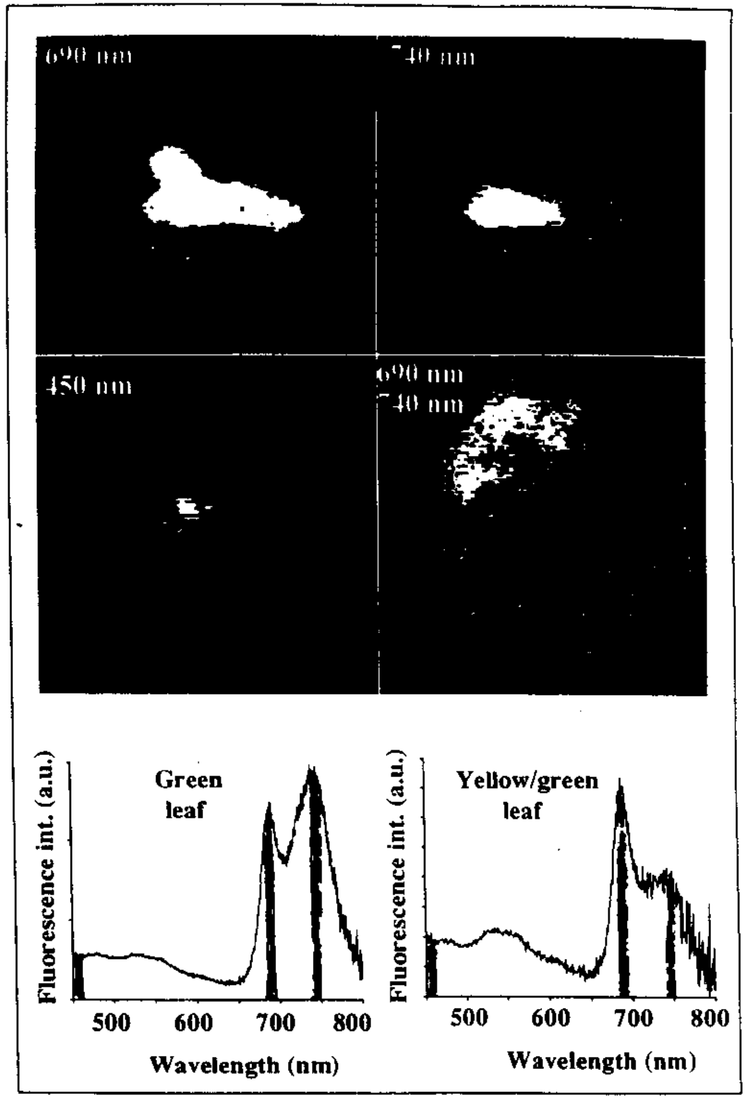

320 nm exc.
355 nm exc.
397 nm exc.
450 nm exc.
400 500 600 700
Wavelength (nm)

1 shot 100 shots





Daily cycle



Maize at 40 m distance

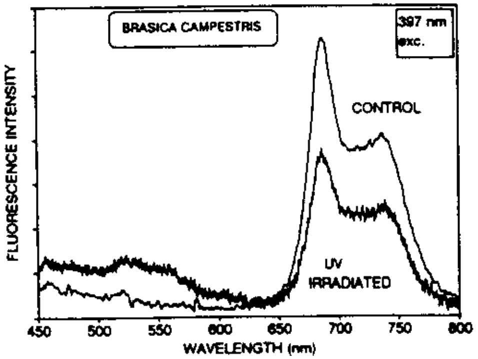
100 shots

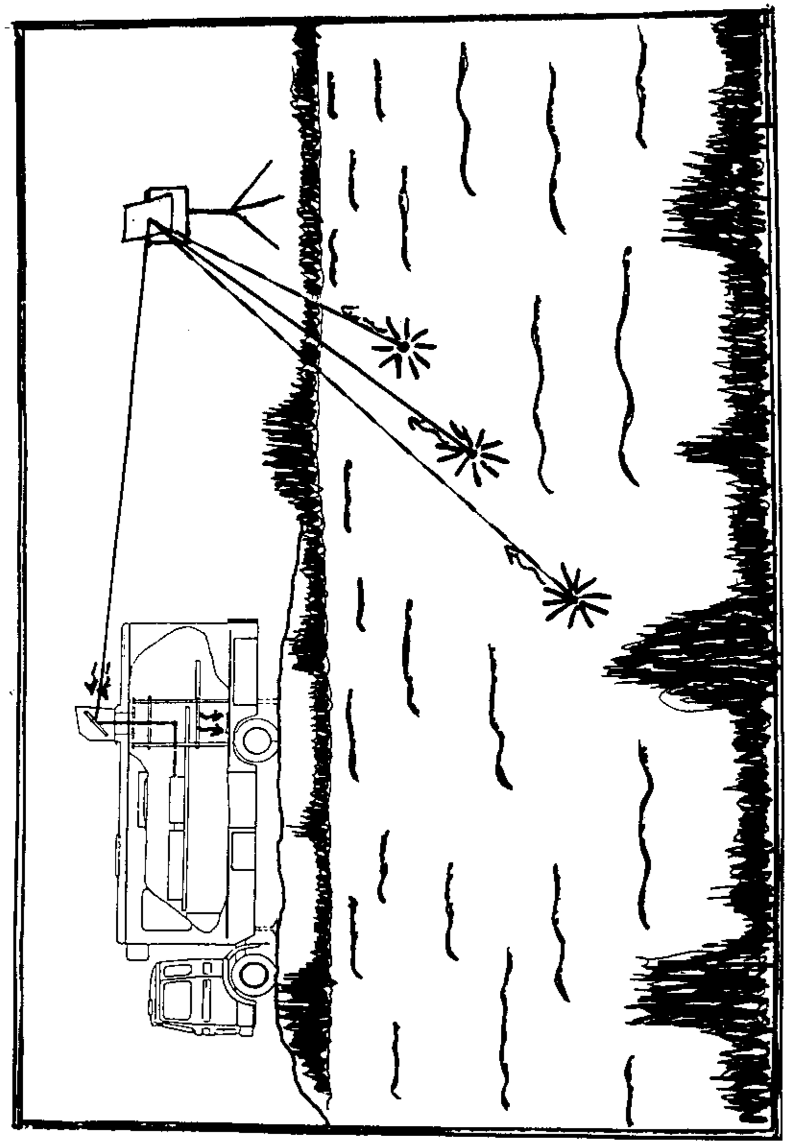
685 nm | blue

740 nm | red

Processed image I(685)/ blue

UV damaged cabbage leaf
(ozone hole simulation)





LASER-INDUCED FLUORESCENCE SPECTRA

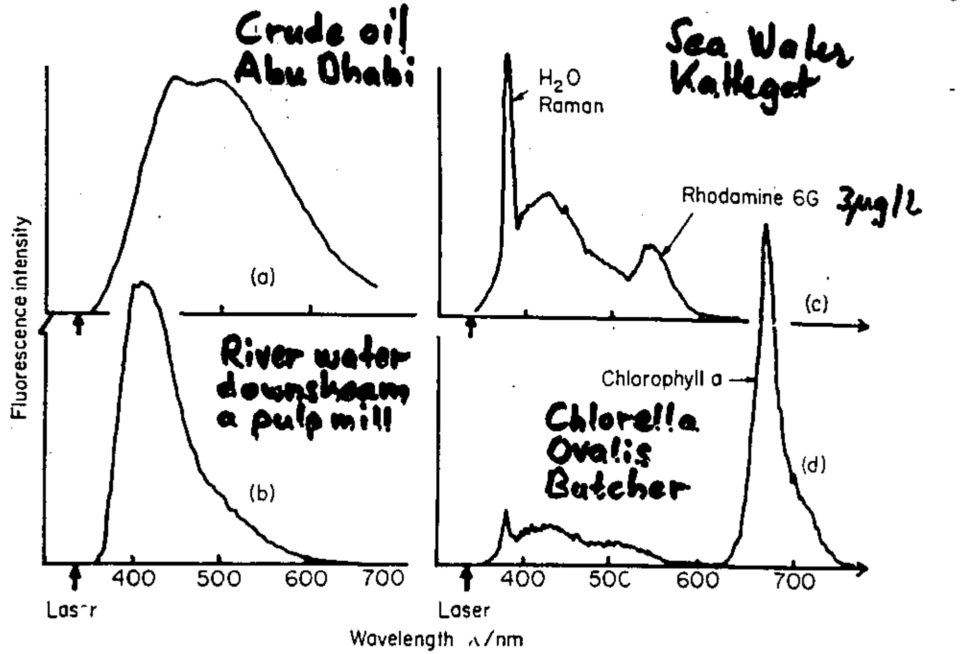
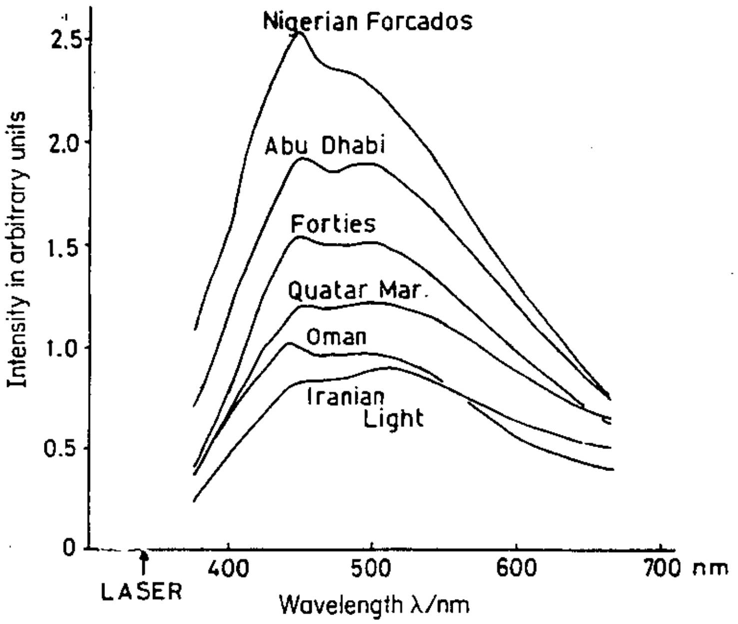


Fig. 3

CRUDE OILS



Celander et al.
1978

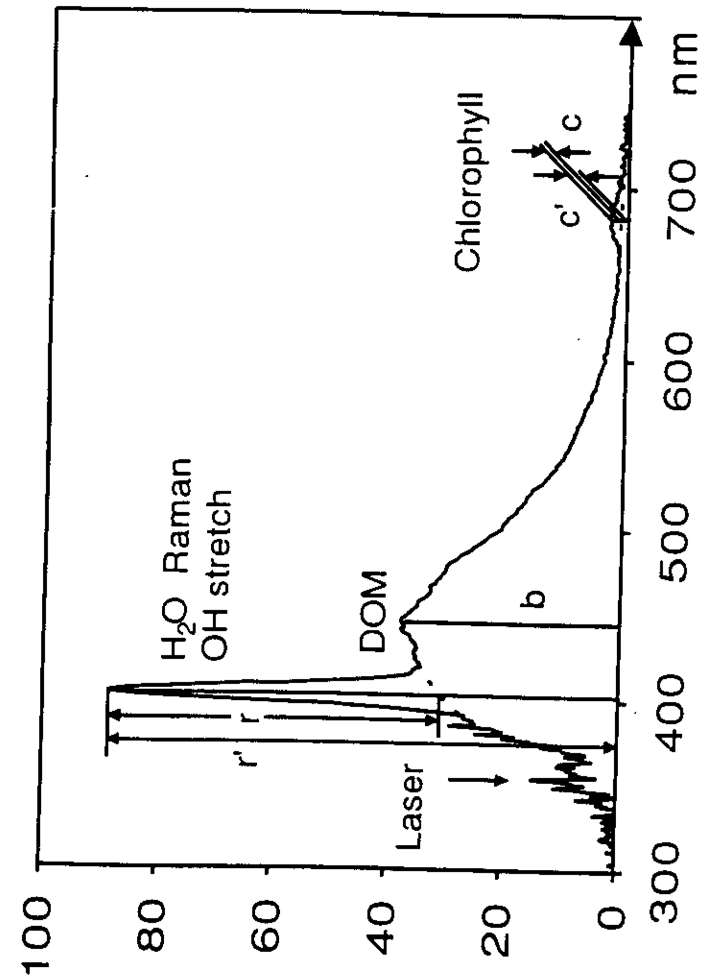
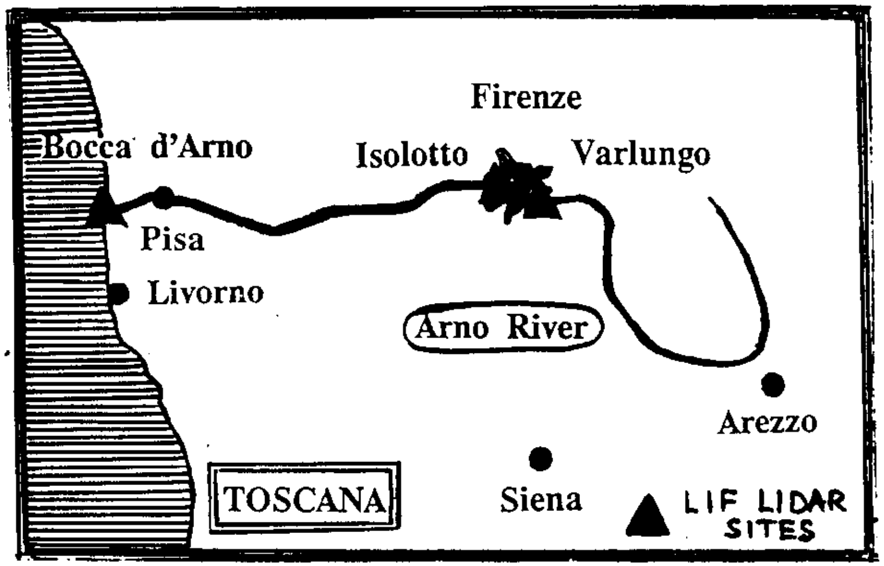
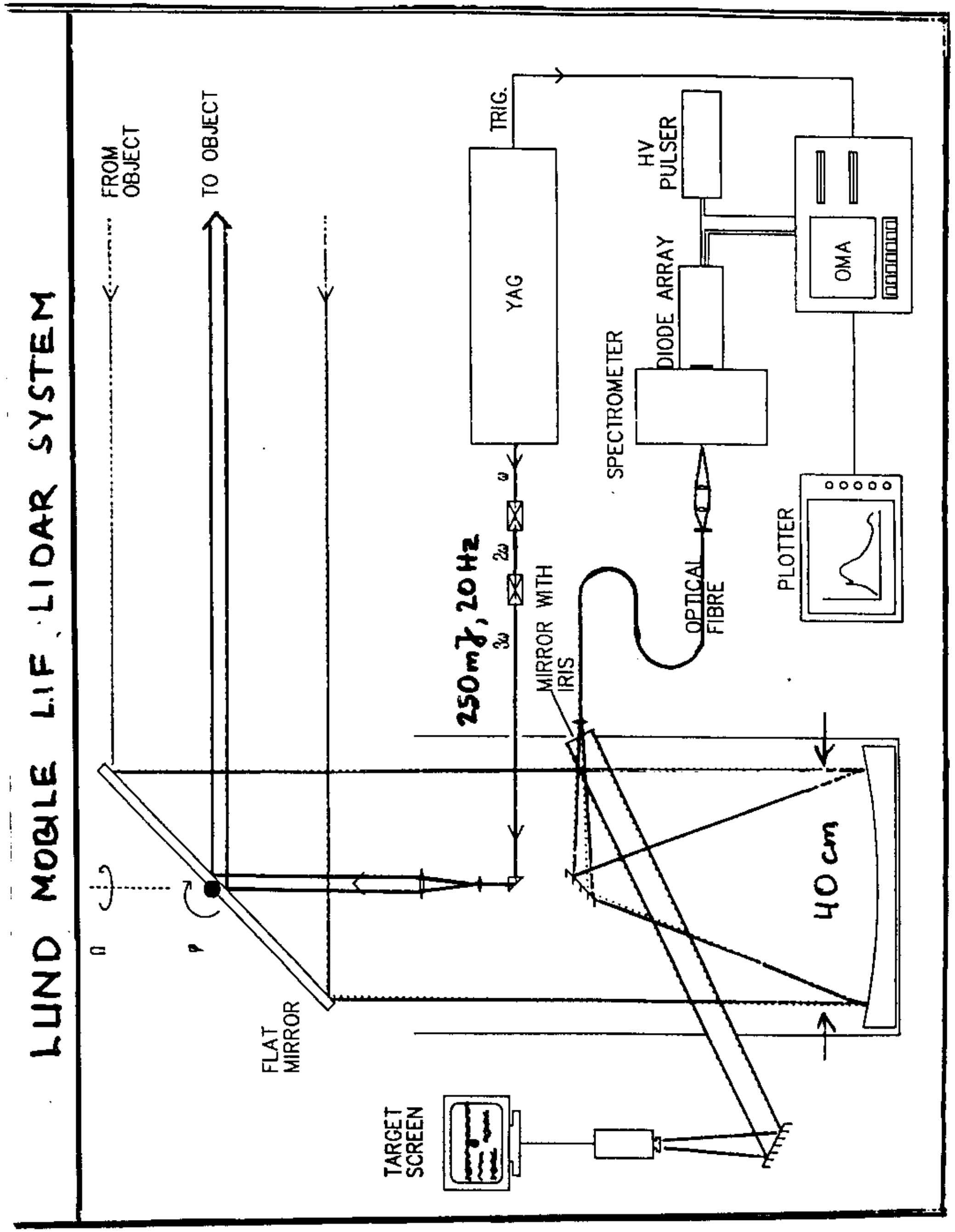
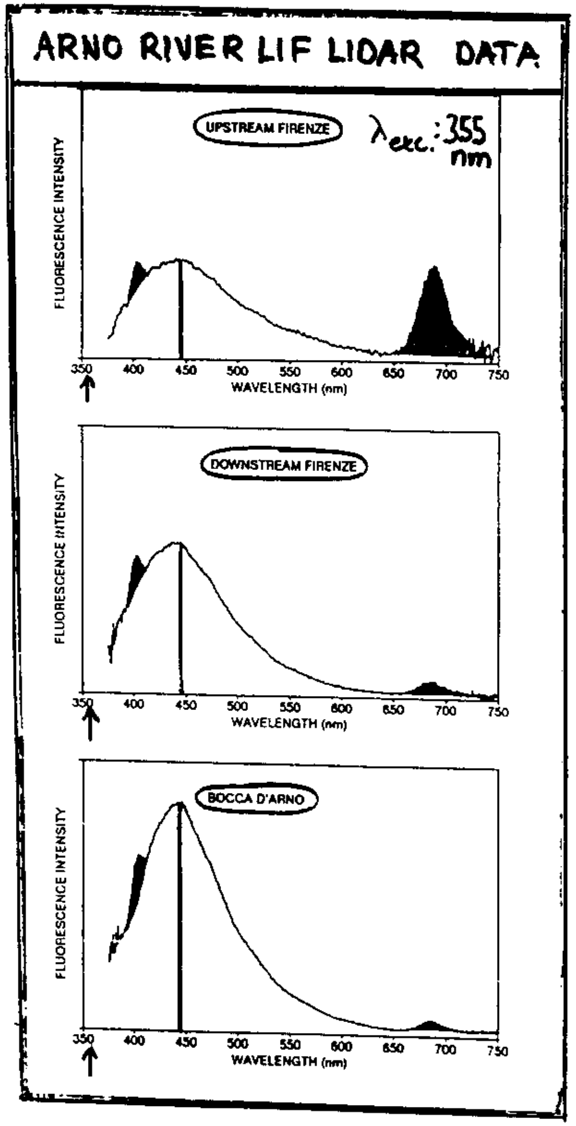
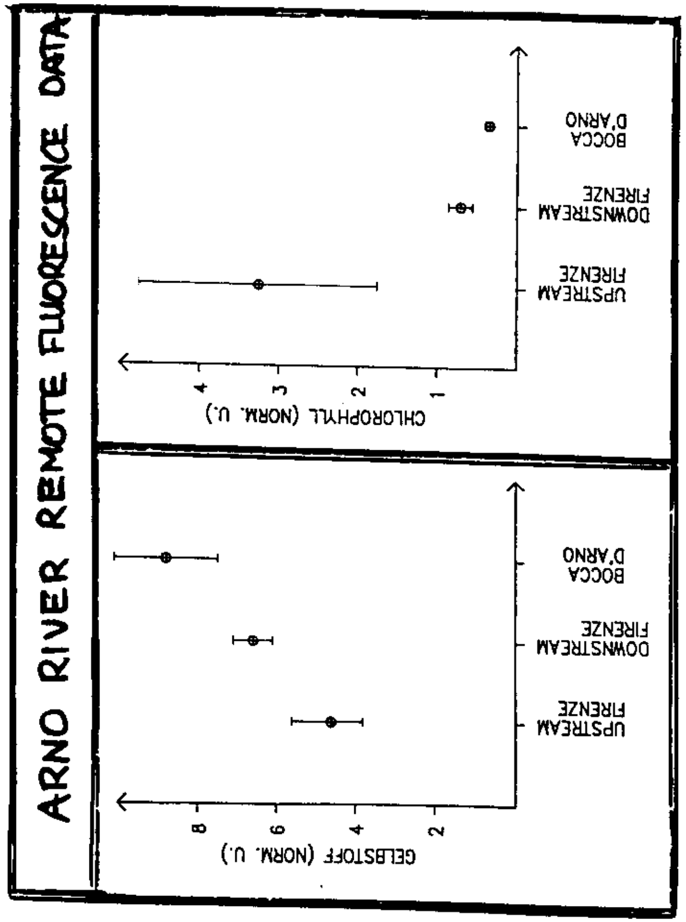


Fig. 4


Firenze
Bocca d'Arno
Isolotto
Varlungo
Pisa
Livorno
Arno River
Arezzo
TOSCANA
Siena
LIF LIDAR SITES

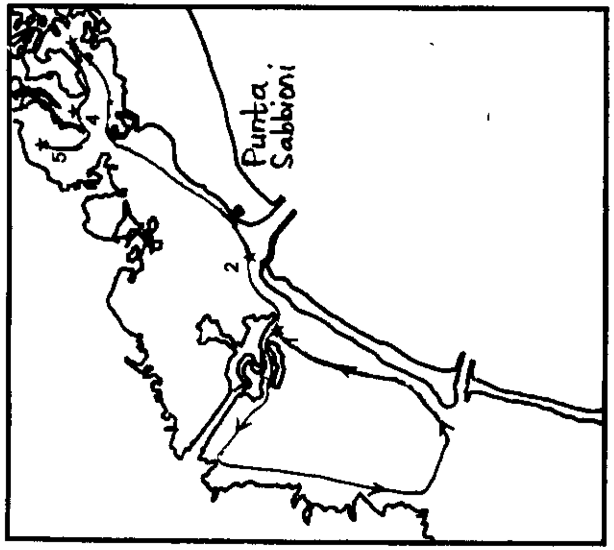

LUND MOBILE LIF LIDAR SYSTEM
FROM OBJECT
TO OBJECT
TRIG.
YAG
HV PULSER
DIODE ARRAY
OMA
SPECTROMETER
PLOTTER
OPTICAL FIBRE
MIRROR WITH IRIS
250 mJ, 20 Hz
ω
2ω
3ω
FLAT MIRROR
TARGET SCREEN
40 cm

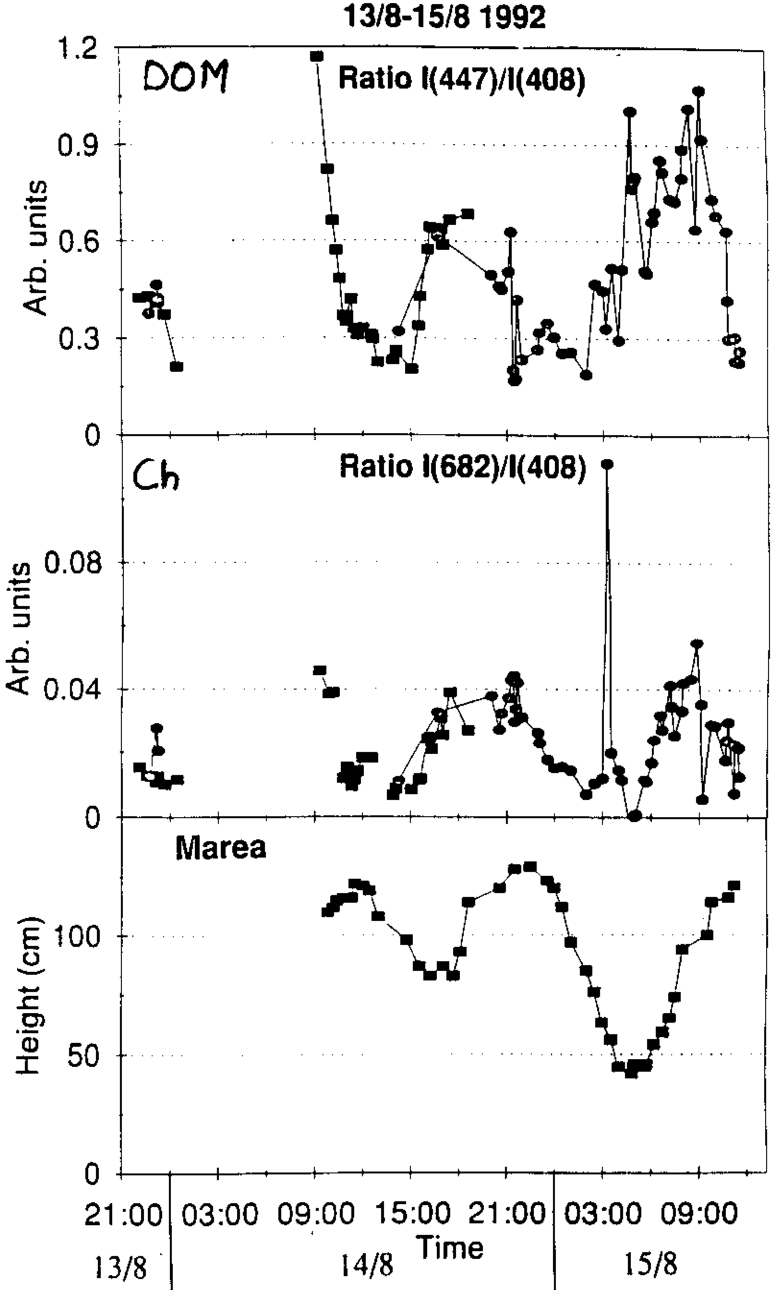

ARNO RIVER LIF LIDAR DATA
UPSTREAM FIRENZE
$\lambda_{exc.}$: 355 nm
DOWNSTREAM FIRENZE
BOCCA D'ARNO
FLUORESCENCE INTENSITY
WAVELENGTH (nm)
350 400 450 500 550 600 650 700 750

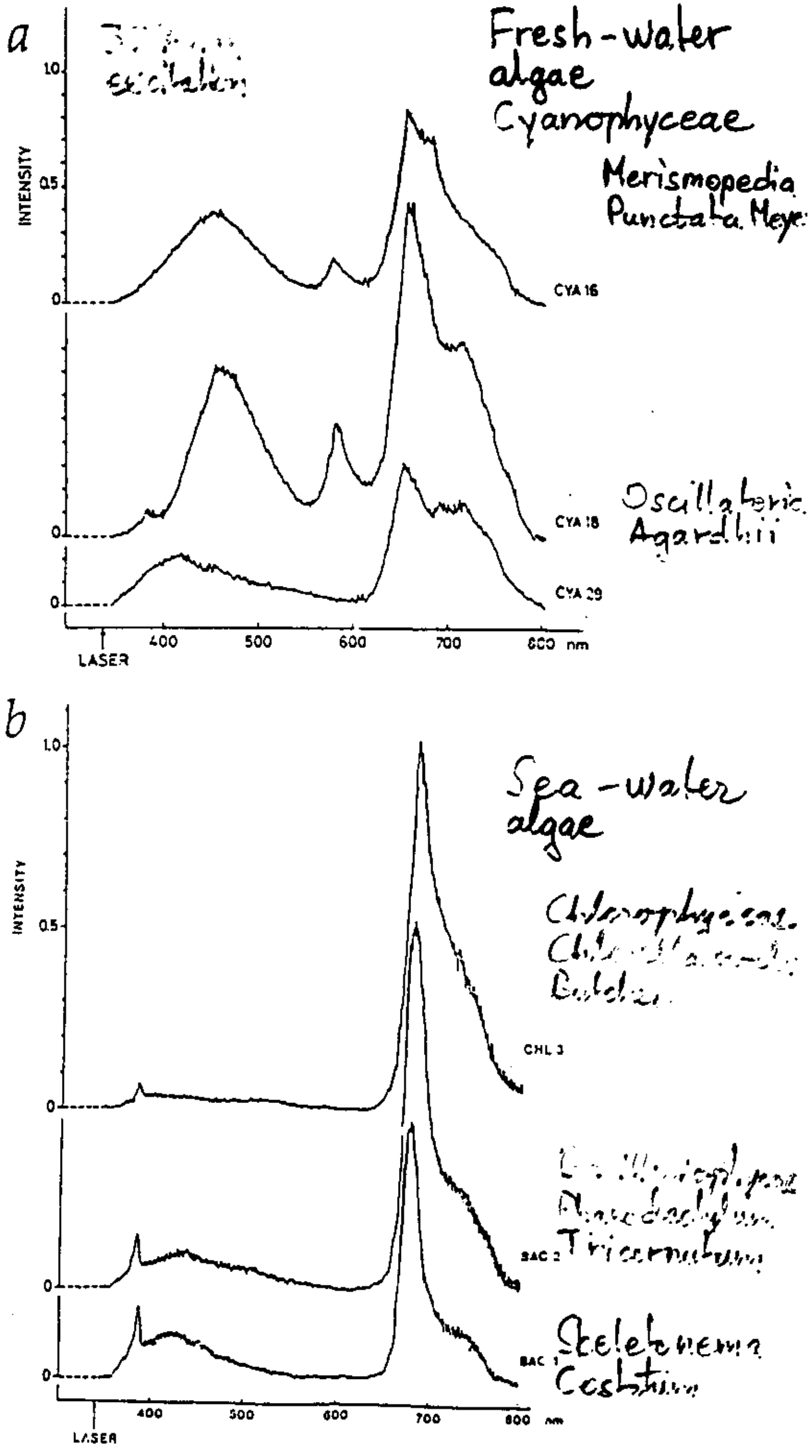

ARNO RIVER REMOTE FLUORESCENCE DATA
CHLOROPHYLL (NORM. U.)
GELBSTOFF (NORM. U.)
UPSTREAM FIRENZE
DOWNSTREAM FIRENZE
BOCCA D'ARNO

VENICE LAGOON CAMPAIGN ROUTE (July-August 1992)

IROE-CNR

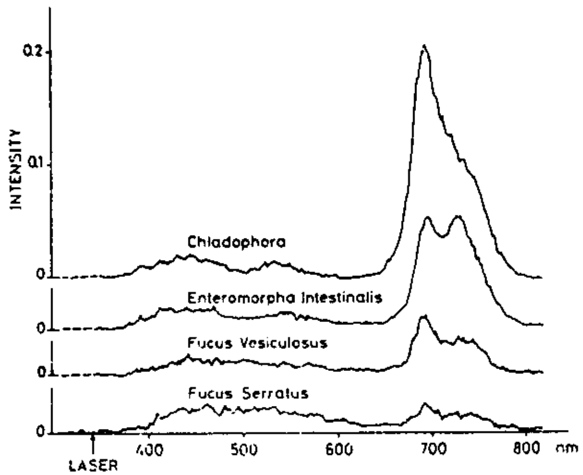






elander,
Fredriksson,
...lle,
...lung 1978

Benthic algae

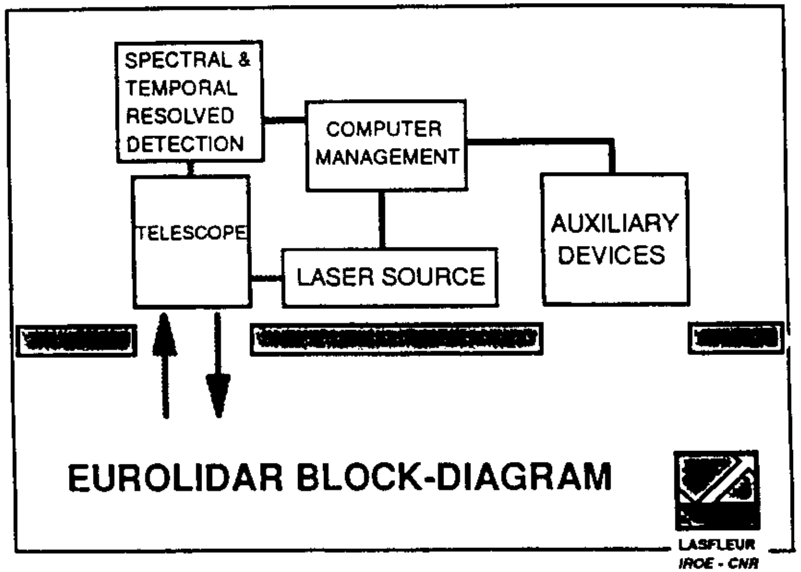


CTH 1976

LASFLEUR
EUREKA EU 380

AIRBORNE VEGETATION FLUORESCENCE SYSTEM

DORNIER D228, CASA 212



G. CECCHI CNR-IROE
P. MAZZINGHI CNR-IEQ
I. MOYA CNRS-LURE
K. GÜNTHER DLR
S. SVANBERG LTH

H: 300 m, v = 80 m/s
λ: 397 nm, ν = 100 Hz
ø: 40 cm

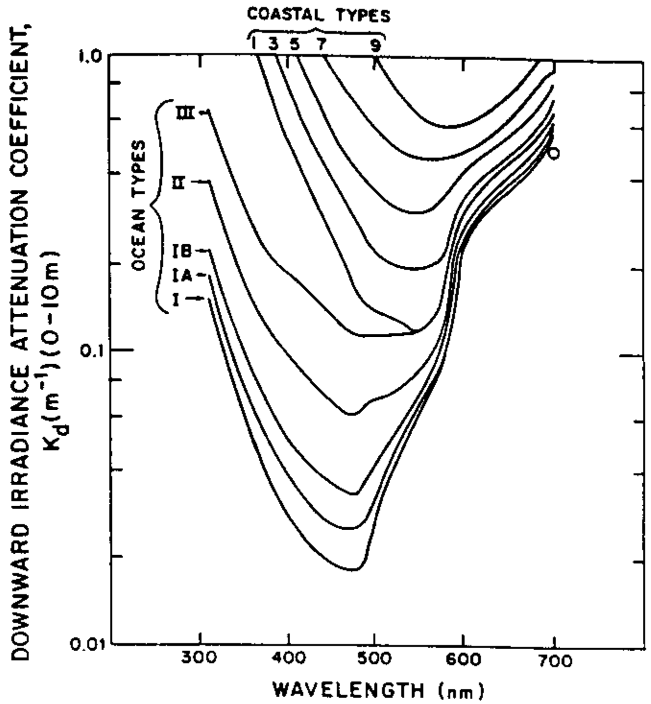
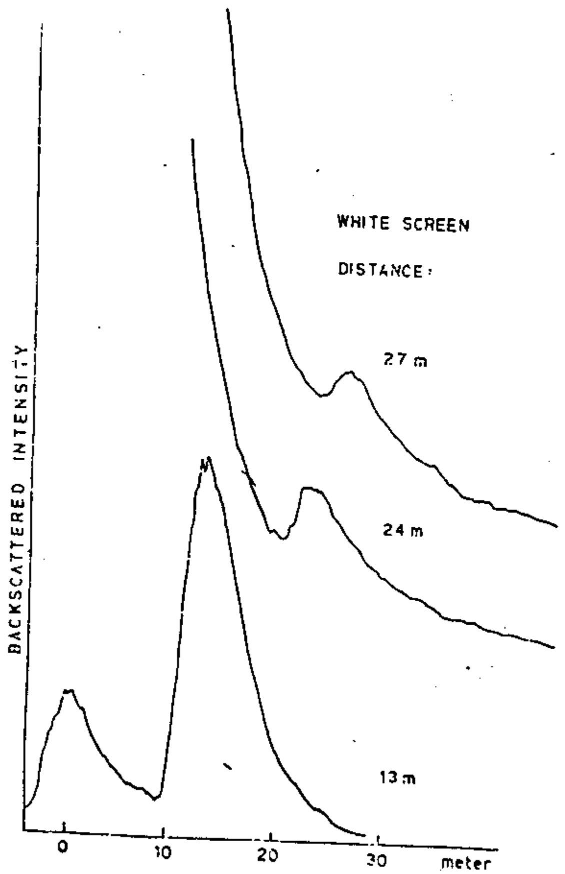


Fig. 6.54

UNDER-WATER LASER-RADAR RANGING



FISH ECHOES

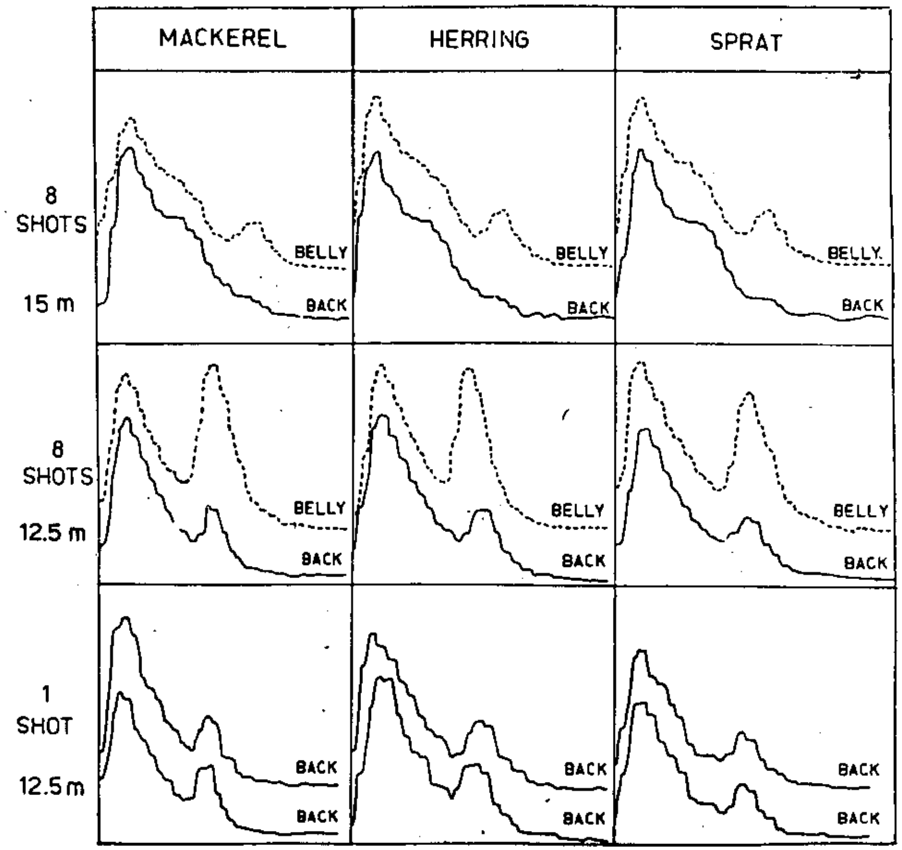


Fig. 15. Fish detection measurements for different depths and species.