INTERNATIONAL ATOMIC ENERGY AGENCY
UNITED NATIONS EDUCATIONAL, SCIENTIFIC AND CULTURAL ORGANIZATION
INTERNATIONAL CENTRE FOR THEORETICAL PHYSICS
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UNITED NATIONS INDUSTRIAL DEVELOPMENT ORGANIZATION

INTERNATIONAL CENTRE FOR SCIENCE AND HIGH TECHNOLOGY

SMR/760-47

"College on Atmospheric Boundary Layer and Air Pollution Modelling"
16 May - 3 June 1994

"Lagrangian Particle Models"

F. DESIATO
Agenzia Nazionale per la Protezione dell'Ambiente
A.N.P.A. (EX-ENEA/DISP)
Rome, Italy

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

LAGRANGIAN PARTICLE MODELS

$$U = U_A + U'$$

U'

k-theory: $U' = -\frac{K}{C}\nabla C$

Monte-Carlo:

$$U'(t+\Delta t) = U'(t)R(\Delta t) + U''(t)$$

$$R(\Delta t) = \overline{U'(t)U'(t+\Delta t)} / \overline{U'^2}$$

$$T_L = \lim_{t\to\infty} \int_0^t R(t)\,dt$$

$$\sigma_{U''} = \sigma_{U'}\left[1 - R^2(\Delta t)\right]^{1/2}$$

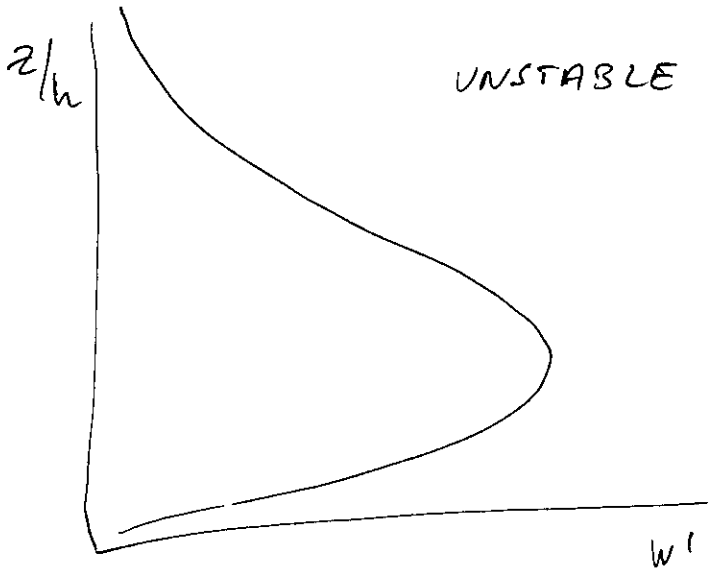
$$R(\Delta t) = \exp(-\Delta t/T_L)$$

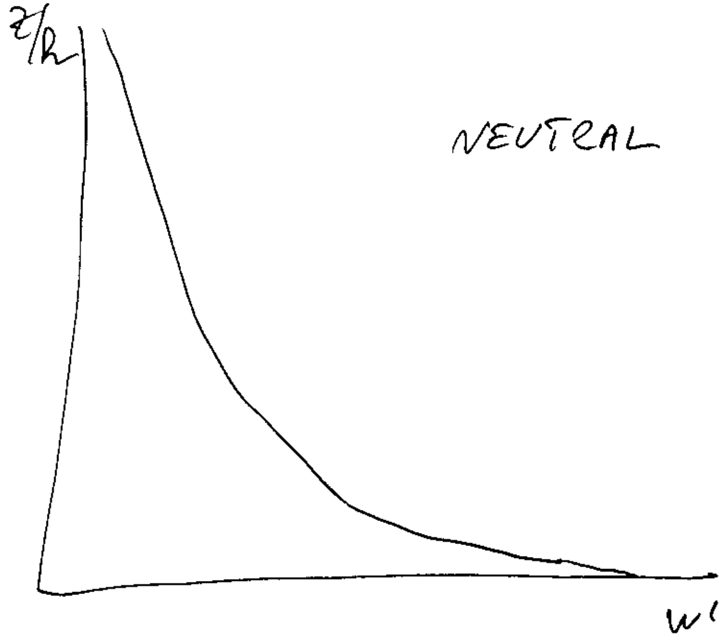
$$U'(t+\Delta t) = e^{-\Delta t/T_L} U' + (1-R^2)^{1/2}\sigma_{U'}\, r$$

DRIFT VELOCITY (additional term for w')

$$\left(1 - e^{\frac{-\Delta t}{T_L}}\right) T_L \, \partial\sigma_w^2/\partial z$$

$$\sigma_U, T_L \quad f(z, h, L, U_*, W_*, z_0)$$





A R I E S
(Atmospheric Release Impact Evaluation System)

is an integrated hardware/software system for the evaluation of atmospheric dispersion at different space and time scales.
Two versions of ARIES have been realized:

ARIES-I for the real-time evaluation of the consequences of accidental releases.
Platform: cluster of VAX 6300 and 6400 - VMS
Telephone link with the Italian Weather Service

ARIES-W for the previsional or post-facto analysis concerning routine emissions.
Platform: ALPHA 3000 Workstation - OSF.

The two systems share several components:
models, environmental data banks, user interface.

ARIES-I
(Atmospheric Release Impact Evaluation System-Improved)

AIM:
to provide a technical support for real-time evaluation of the consequences of accidental releases in the atmosphere.

BY MEANS OF:
integration of atmospheric dispersion modelling techniques with environmental data base.

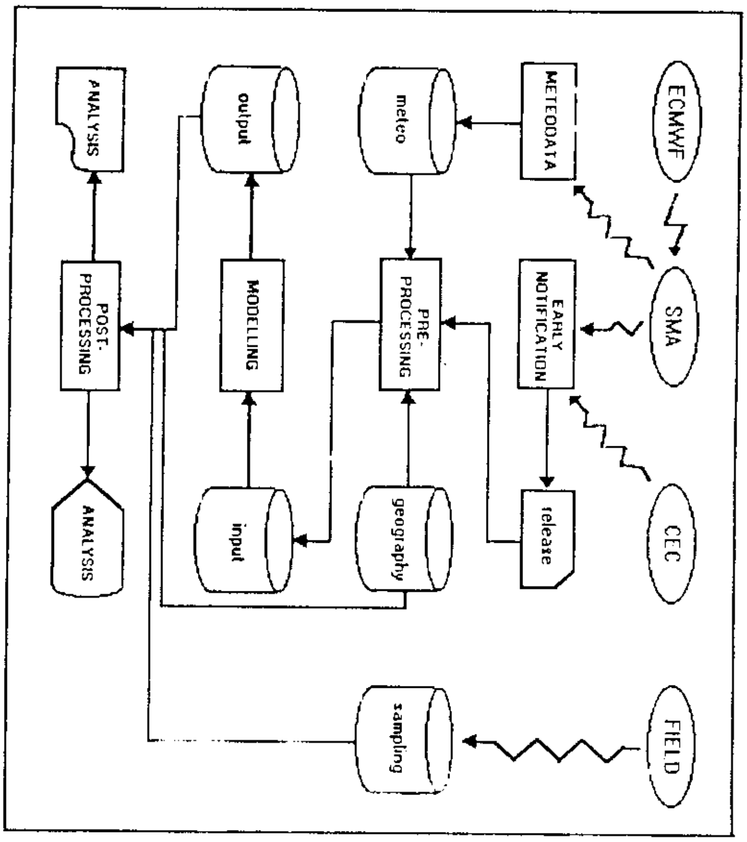


Fig. 1 - Functional model evaluation scheme in ARIES-I

ARIES-I

FEATURES

- Pollution episodes everywhere on the European territory, with different space and time scales, can be considered.
- Flexibility with respect to the type and the number of data available in real-time.
- Several functions of input and output processing can be carried out automatically.
- Model components and data banks can be updated or implemented without altering the system structure.

ARIES-I nodels

Forecasting

* Long range

APOLLO
(Atmospheric POLlutant LOng range dispersion)

Nowcasting

* Local scale, flat terrain

SPADE
(Sequential Puff for Atmospheric Dispersion Evaluation)

* Local and meso scale, complex terrain

CONDOR
(3-d mass-consistent diagnostic wind field model, by Moussiopoulos and Flassak)
ARCO
(Atmospheric Release in COmplex Terrain)

APOLLO
(Atmospheric POLlutant LOng range dispersion)

AIM: Real time estimate of the atmospheric dispersion of stable or first order decaying pollutants at distances up to some thousands of km from one point source.

METHOD: Lagrangian particle
Particles are tracked by a three-dimensional wind field to which turbulent motions are superimposed.

INPUT:

. topography
. roughness
. 3-D wind field
. geopotential
. precipitation
. vertical temperature profiles

OUTPUT:

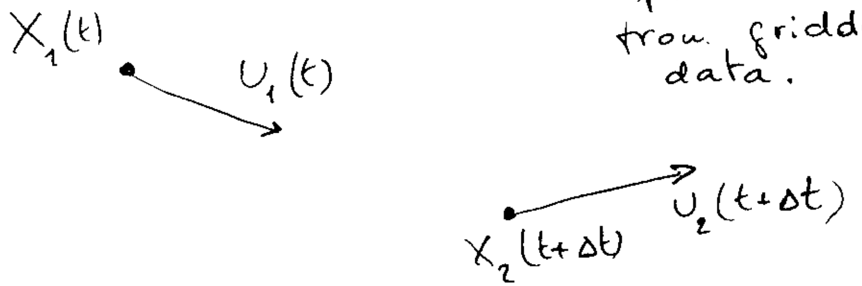
. instantaneous air concentration
. time-integrated air concentration
. dry deposition
. wet deposition

Time and space resolution of all input and output data are flexible.

Particle trajectory

(Reap)

U_1, U_2 interpolated in space and time from gridded data.



first guess:

$$X_2(t+\Delta t) = X_1(t) + U_1(t)\Delta t$$

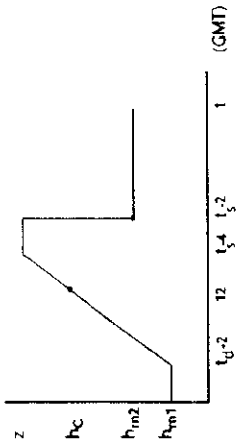
$$X_2^i(t+\Delta t) = X_1(t) + 0.5\left[U_1(t) + U_2^i(t+\Delta t)\right] \cdot \Delta t$$

iterated until

$$|X_2^i - X_2^{i-1}| < \varepsilon$$

Mixing Layer

- Mechanical mixing depth
  $h_m = .25 u_*/f$
  $u_* = kV_s / \ln(z_s/z_0)$
- Convective mixing depth h_c computed from 12 GMT temperature soundings.



t_d = local dawn GMT time
t_s = local sunset GMT time

U_*, L
are derived from
U, z_0, T, cloud cover
with the 'energy budget'
method (Van Ulden and Holtslag)

$T_{L_y} = 10^4\, s$ (Gifford)

$T_{L_z} = f(u_*, h, L)$

$\sigma_v, \sigma_w = f(u_*, h, z)$

GRID - FREE CONCENTRATION CALCULATION

('Kernel' method)

$$c(r,t) = \frac{\Delta(r)}{\ell^3} \sum_{i=1}^{n} m_i W(r_i - r, \ell)$$

$r_i - r$ = vector distance of particle i from receptor

m_i = particle mass

ℓ = smoothing length

$\Delta(r)$ = boundary correction

Gaussian kernel:

$$W = \frac{1}{(2\pi)^{3/2}} \exp\left(-\frac{1}{2} \frac{|r_i - r|^2}{\ell^2}\right)$$

ℓ should be a function of the mean interparticle separation around r.

. AIR CONCENTRATION

For particle with

$$z_m(x,y) < z_s(x,y) + h(x,y)$$

$$C_n(i,j) = \sum_m \frac{q_{n,m}}{2\pi h(i,j)\, \sigma_m^2} \cdot \exp\left[\frac{-(x_m - x_i)^2}{2\sigma_m^2}\right] \cdot \exp\left[\frac{-(y_m - y_i)^2}{2\sigma_m^2}\right]$$

. DRY DEPOSITION

$$D_{\Delta t}(i,j) = C(i,j).V_d.\Delta t$$

. WET DEPOSITION

$$w_{\Delta t}(i,j) = \sum_{m} \frac{\Lambda q_m}{2\pi\sigma_m^2} \exp\left[\frac{-(x_m-x_i)^2}{2\sigma_m^2}\right] \cdot \exp\left[\frac{-(y_m-y_i)^2}{2\sigma_m^2}\right] \cdot \Delta t$$

$$\Lambda = WP^{-8}(i,j)$$

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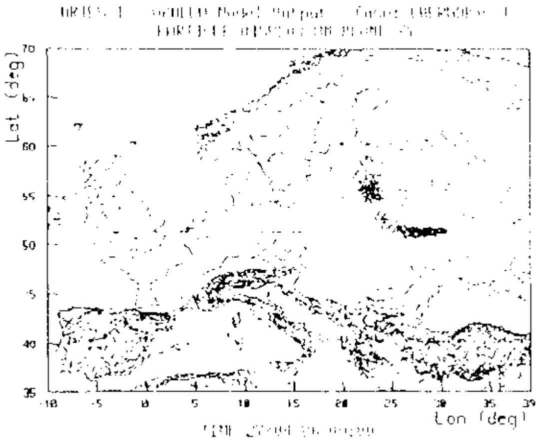
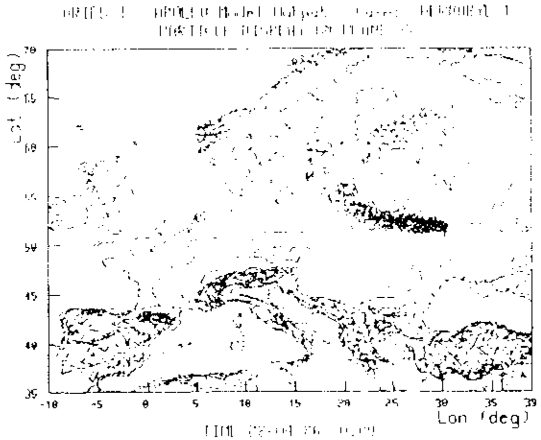
. PARTICLE DEPLETION BY:

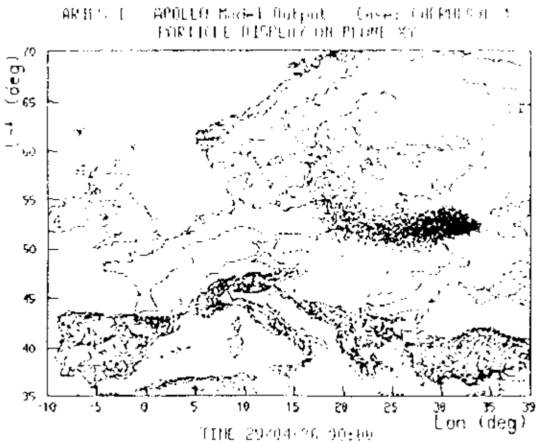
- Radioactive decay or first order chemical reaction

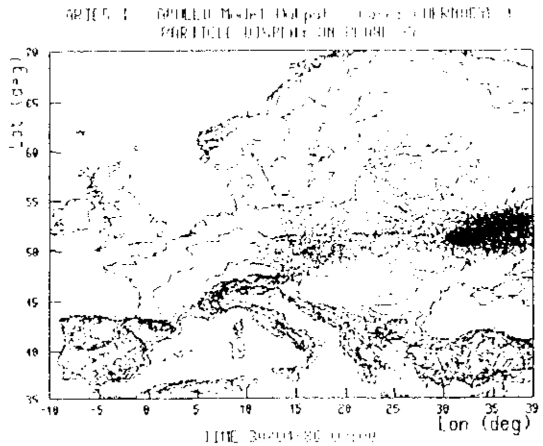
- Scavenging by dry deposition

- Scavenging by wet deposition

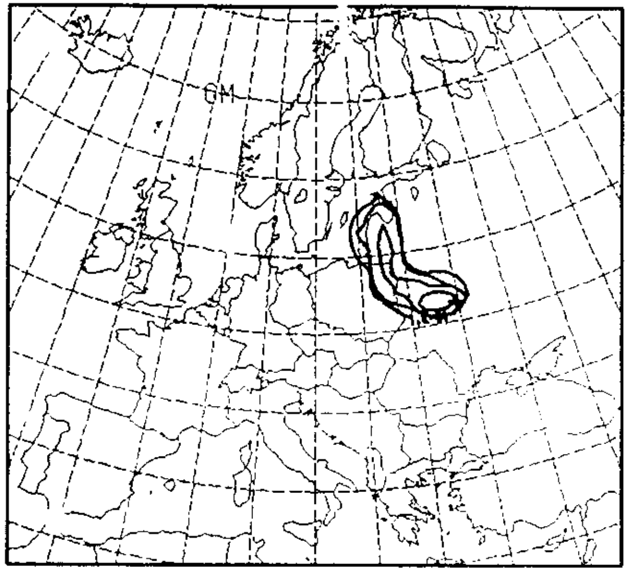

APOLLO Model Output
Lat (deg)
Lon (deg)


APOLLO Model Output
Lat (deg)
Lon (deg)


APOLLO Model Output
Lon (deg)

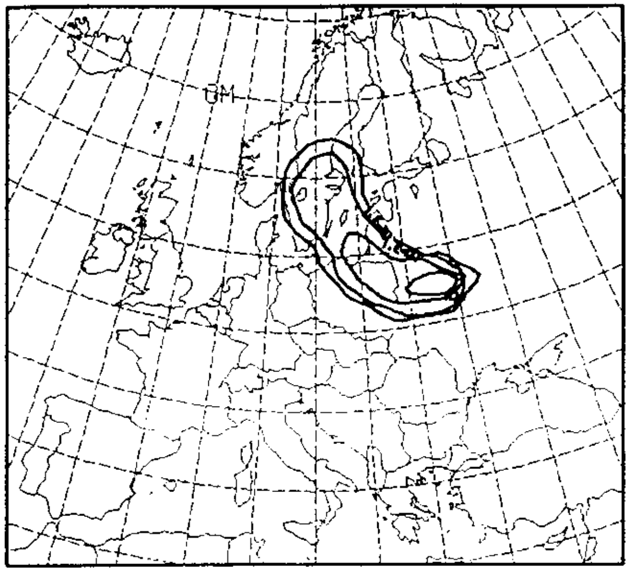

APOLLO Model Output
Lon (deg)

ARIES-I - APOLLO Model Output - Case: CHERNOBYL_1
C137 AIR CONCENTRATION (BQ/MC)



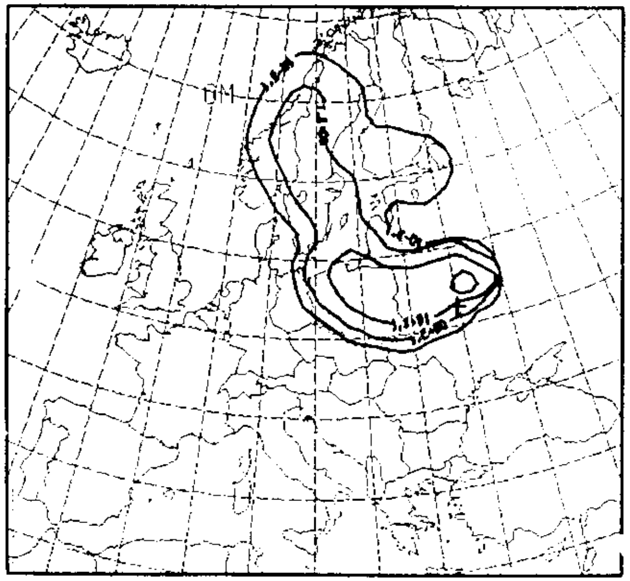
TIME 27/04/86 00:00

ARIES-I - APOLLO Model Output - Case: CHERNOBYL_1
C137 AIR CONCENTRATION (BQ/MC)



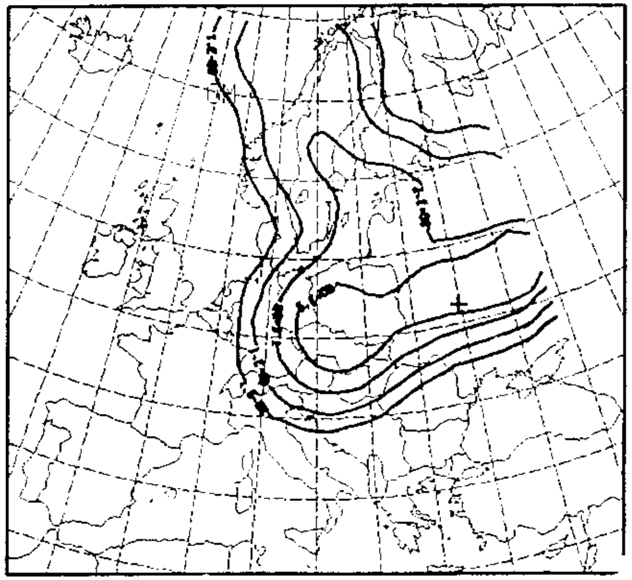
TIME 28/04/86 00:00

ARIES-I - APOLLO Model Output - Case: CHERNOBYL_1
C137 AIR CONCENTRATION (BQ/MC)



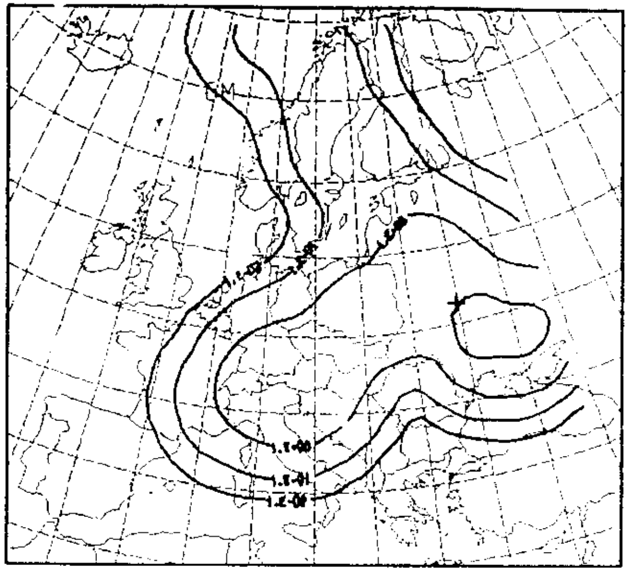
TIME 29/04/86 00:00

ARIES-I - APOLLO Model Output - Case: CHERNOBYL_1
C137 AIR CONCENTRATION (BQ/MC)



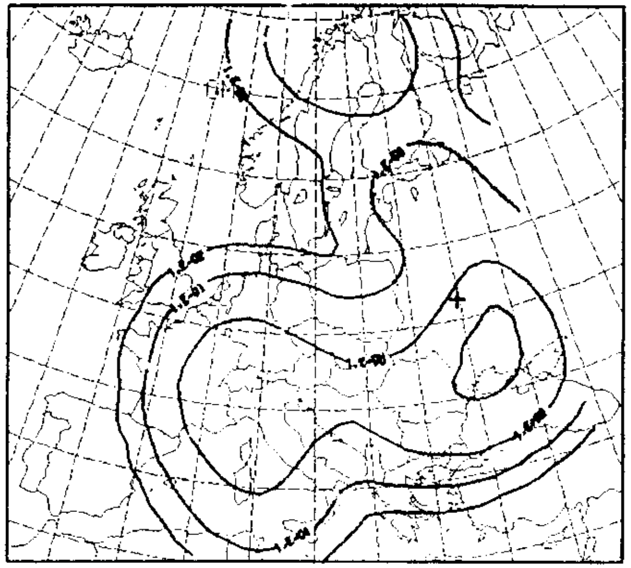
TIME 30/04/86 00:00

ARIES-I - APOLLO Model Output - Case: CHERNOBYL_1
C137 AIR CONCENTRATION (BQ/MC)



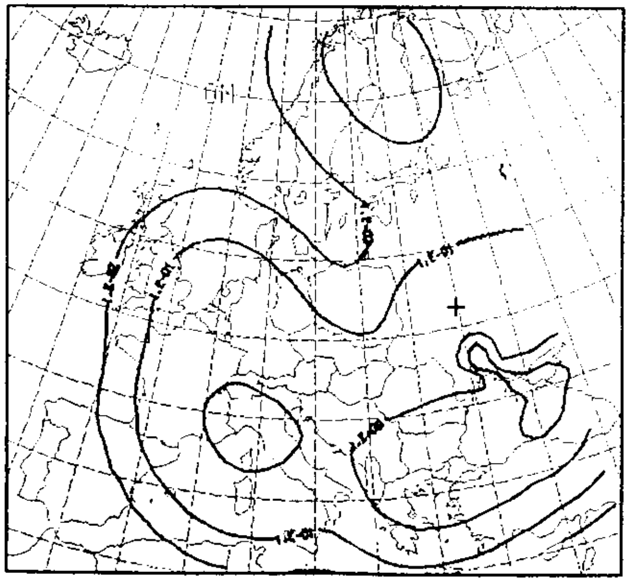
TIME 01/05/86 00:00

ARIES-I - APOLLO Model Output - Case: CHERNOBYL_1
C137 AIR CONCENTRATION (BQ/MC)



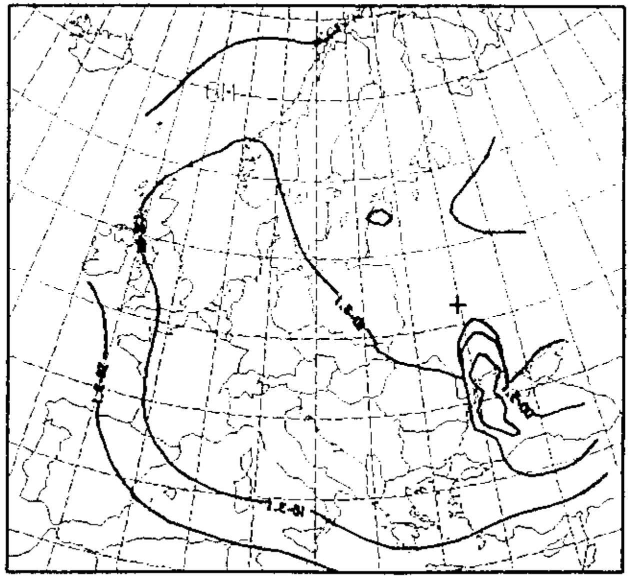
TIME 02/05/86 00:00

ARIES-I - APOLLO Model Output - Case: CHERNOBYL_1
C137 AIR CONCENTRATION (BQ/MC)



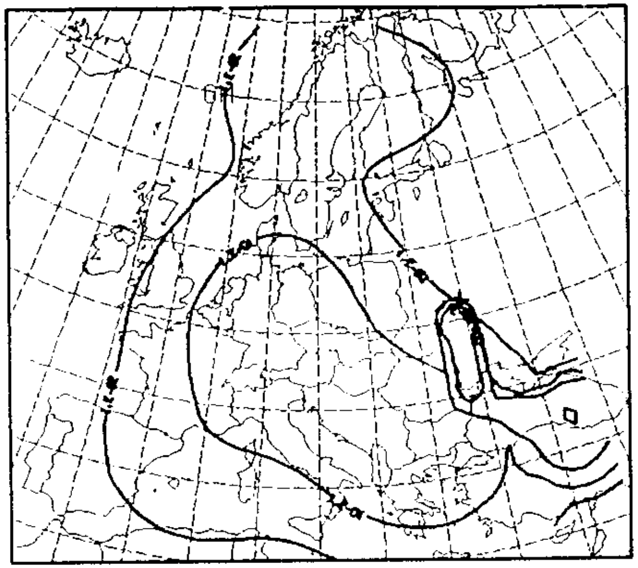
TIME 03/05/86 00:00

ARIES-I - APOLLO Model Output - Case: CHERNOBYL_1
C137 AIR CONCENTRATION (BQ/MC)



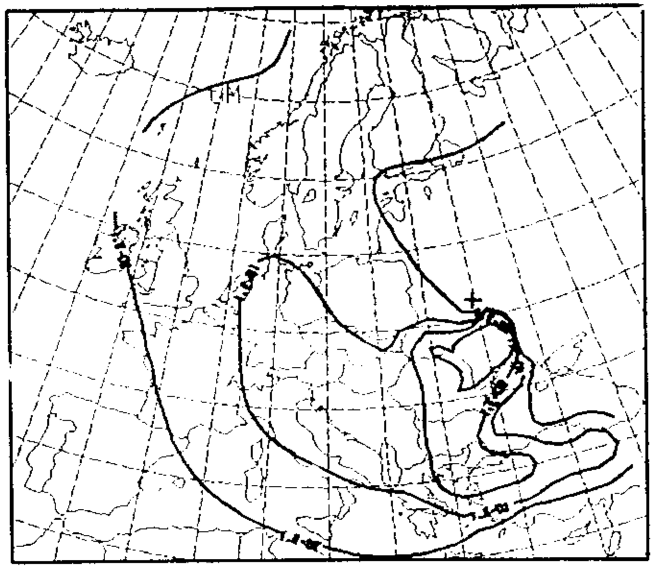
TIME 04/05/86 00:00

ARIES-I - APOLLO Model Output - Case: CHERNOBYL_1
C137 AIR CONCENTRATION (BQ/MC)



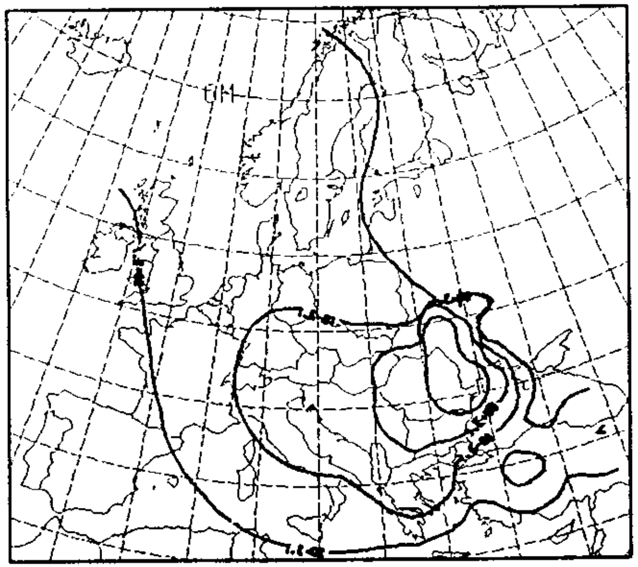
TIME 05/05/86 00:00

ARIES-I - APOLLO Model Output - Case: CHERNOBYL_1
C137 AIR CONCENTRATION (BQ/MC)



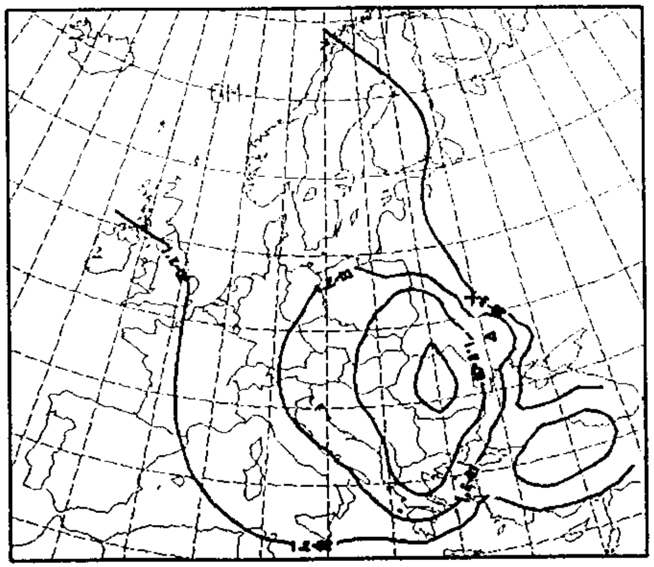
TIME 06/05/86 00:00

ARIES-I - APOLLO Model Output - Case: CHERNOBYL_1
C137 AIR CONCENTRATION (BQ/MC)



TIME 07/05/86 00:00

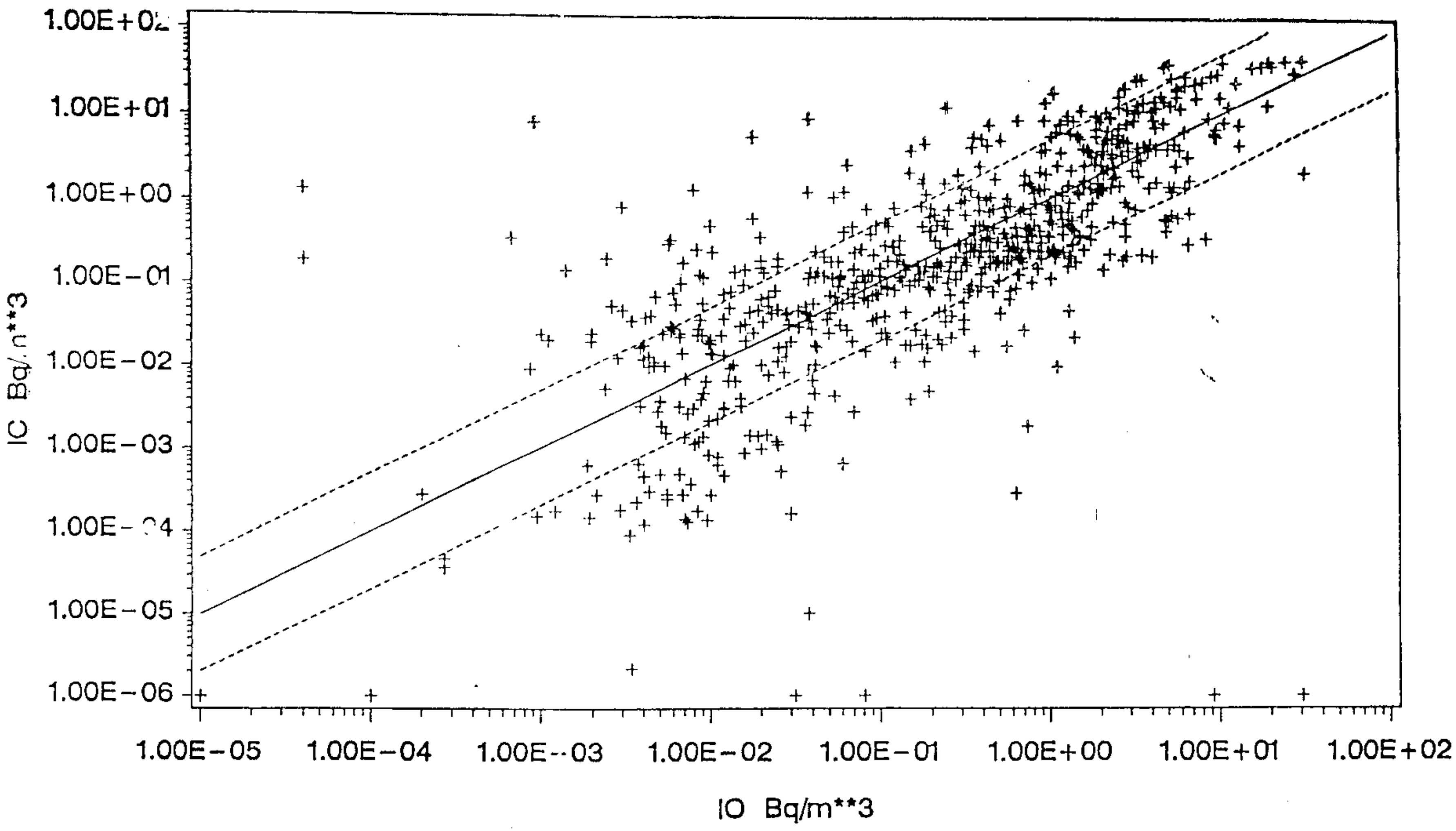
ARIES-I - APOLLO Model Output - Case: CHERNOBYL_1
C137 AIR CONCENTRATION (BQ/MC)



TIME 08/05/86 00:00

– Global Scatter Diagram – (model = mod5)

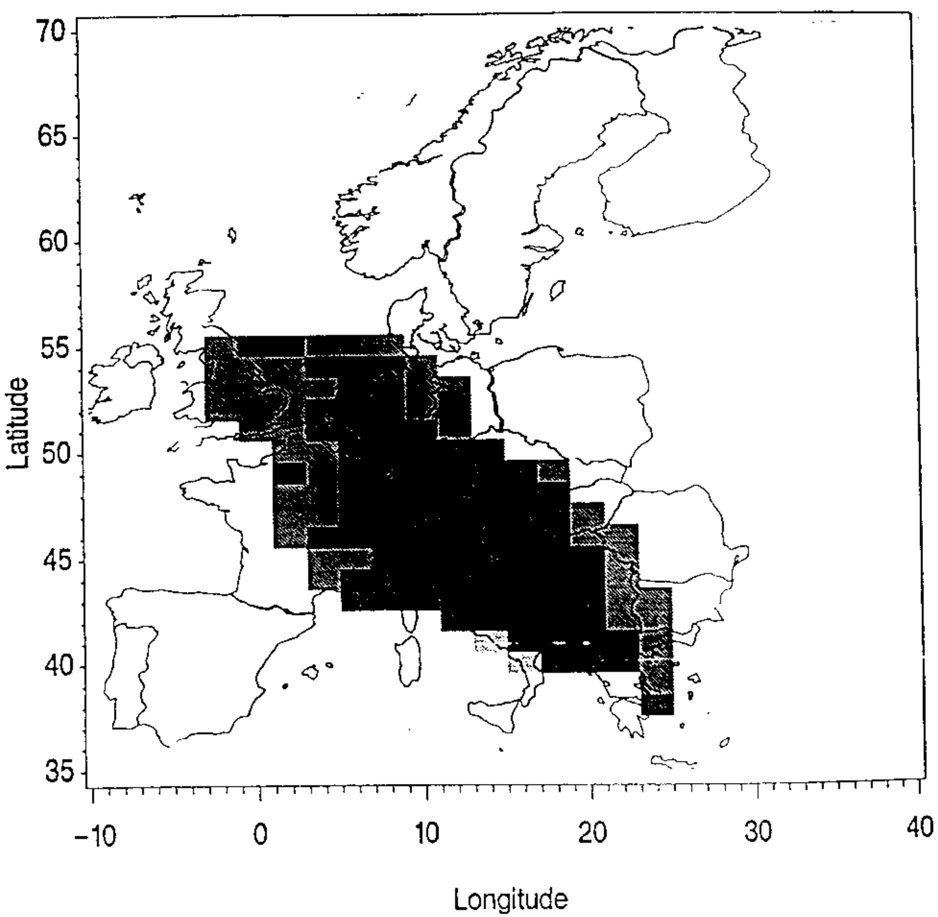
IO vs. IC (area A air concentration)



FA2 = 34 % FA5 = 69 % FOEX = 46 %

-Space Figure of Merit- (Model=mod5)

I-131 day = 86/05/02 (area A air concentration)



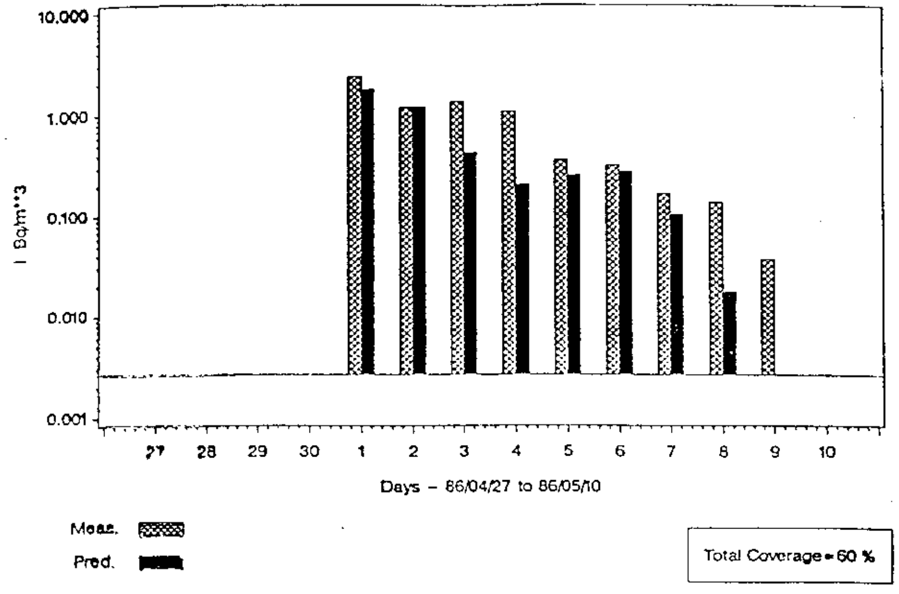
Coverage = 64 %

Significant level = 1 Bq/m**3

Light gray=meas. Medium gray=pred. Dark gray=overlap.

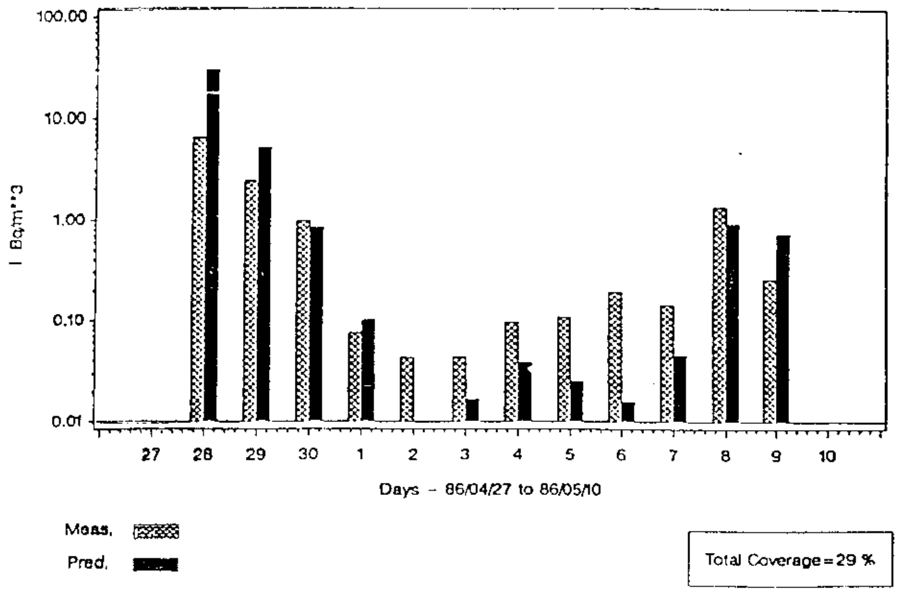
- Time evolution of daily average concentration -

I-131 locality = CASACCIA (Model = mod5)



- Time evolution of daily average concentration -

I-131 locality = STOCKHOLM (Model = mod5)



ARCO

Run a) $\sigma_u(z) = \sigma_u^M(z_1)\exp\left(-1/2(z-z_1)/h\right)$

T_L Hanna (1982)

Run b) σ_u as Run a)

$T_L = 750$ s (Neumann, 1978)

Run c) σ_v Hanna (1982)

$T_L = 750$ s

	CIC/Q Bias	CIC/Q NMSE	σy Bias	σy NMSE
Run a)	5.7	3.3	-1005	1.35
Run b)	0.5	0.6	- 607	0.50
Run c)	1.8	1.4	- 972	1.15

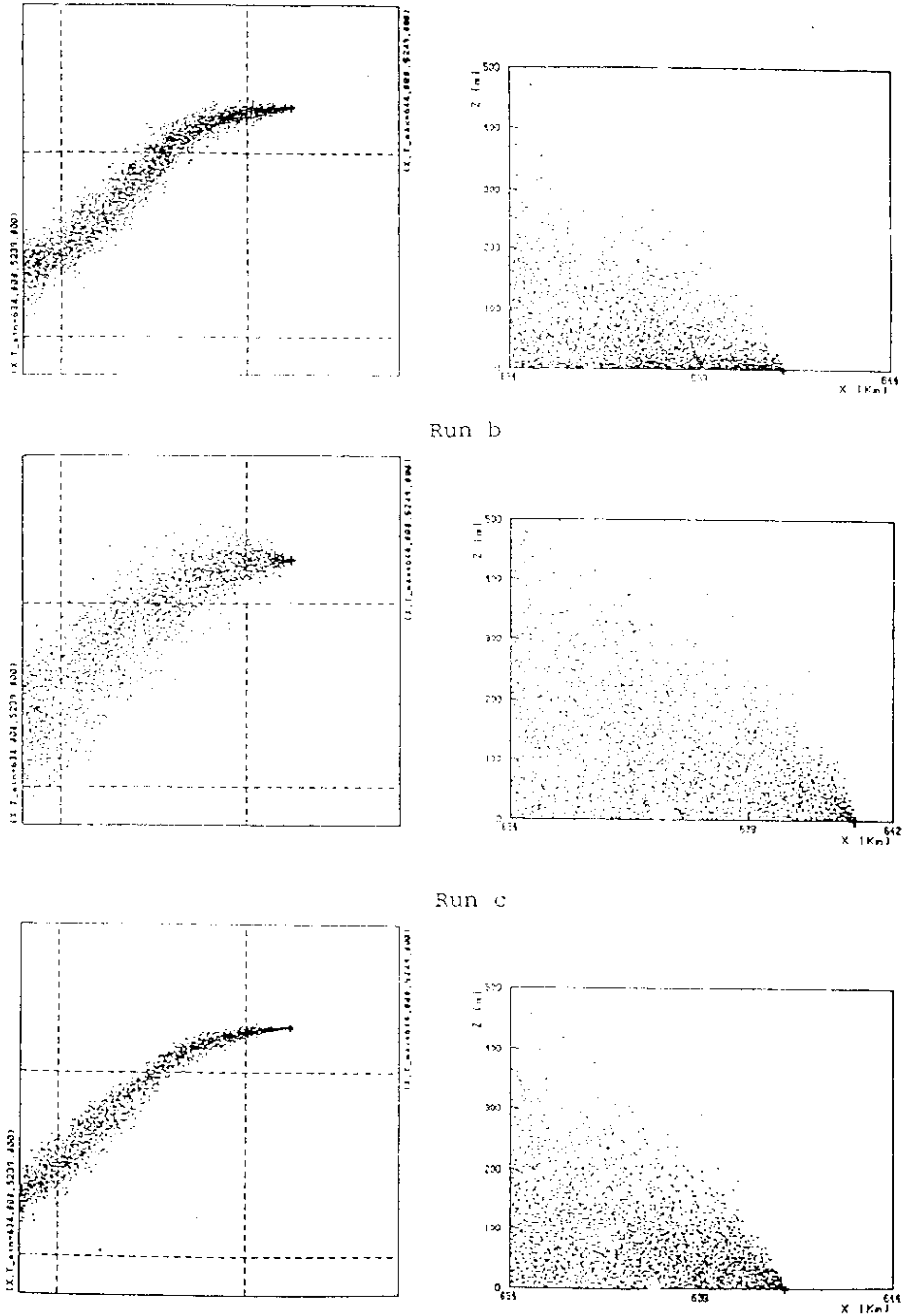


Fig. 2. Particle display on x-y (left) and x-z (right) planes, SIESTA experiment no. 1, 15/11/85, 12:00.

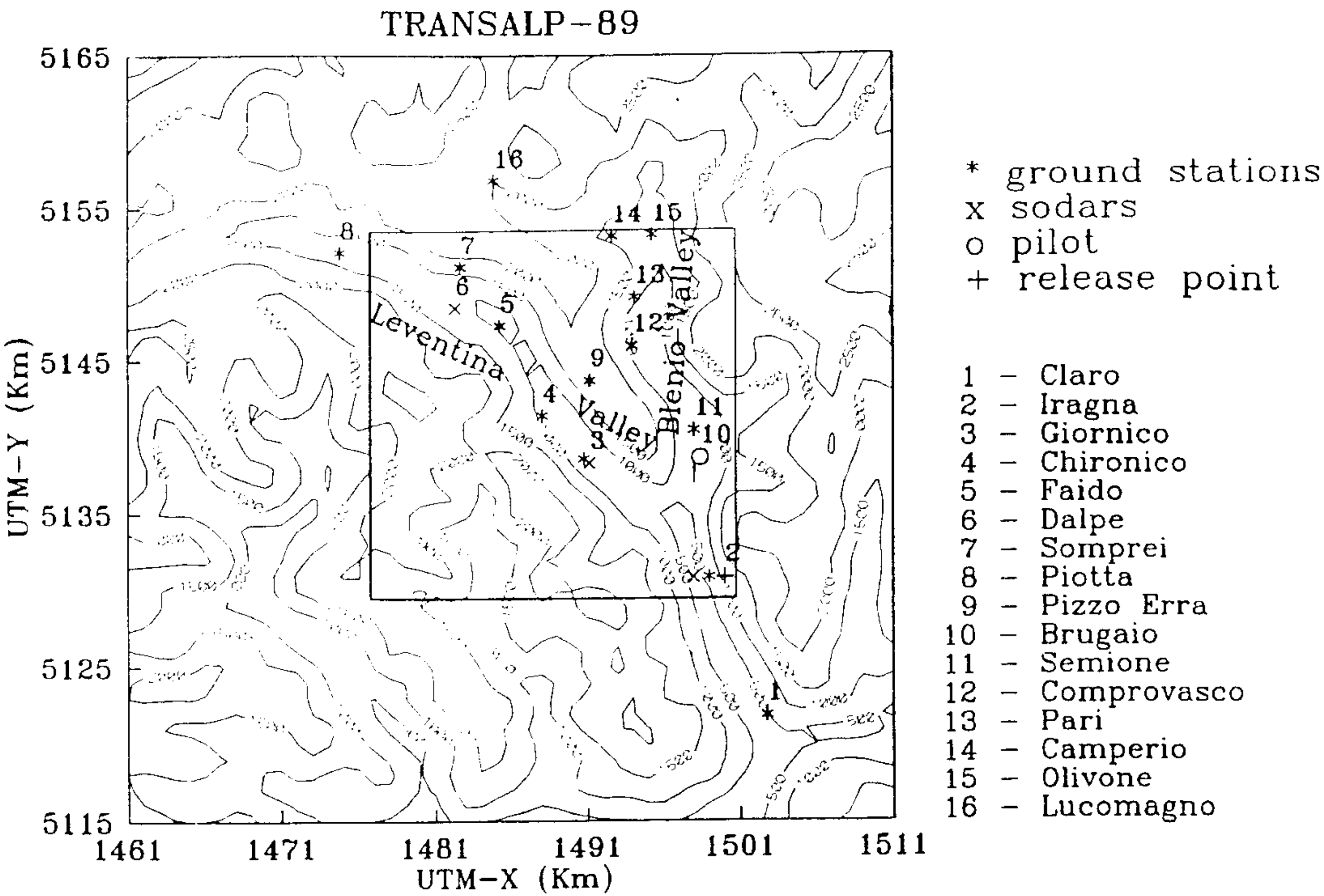
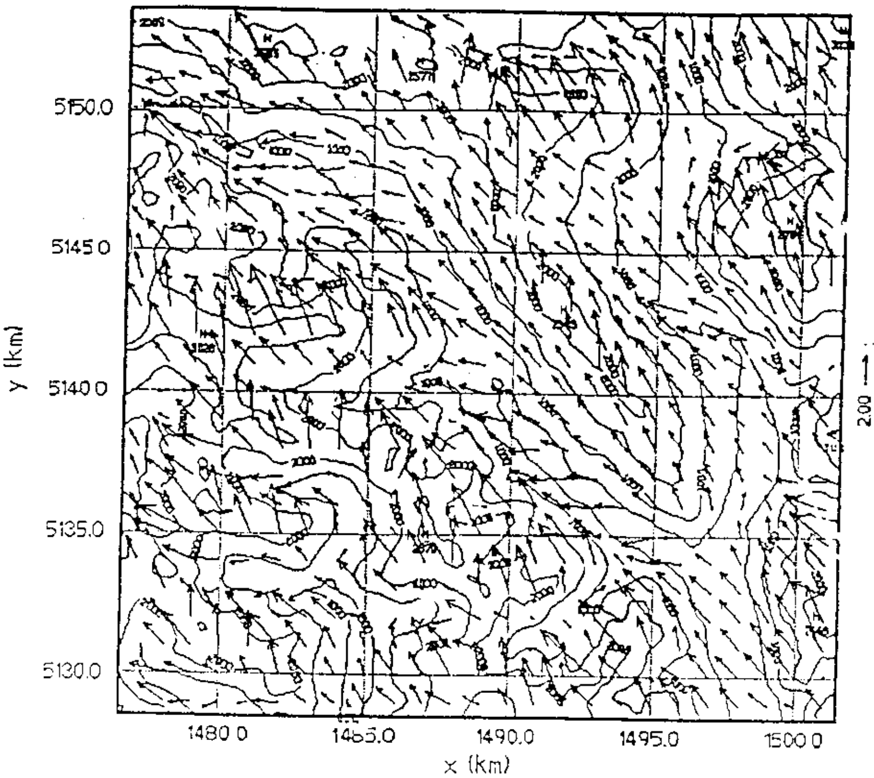
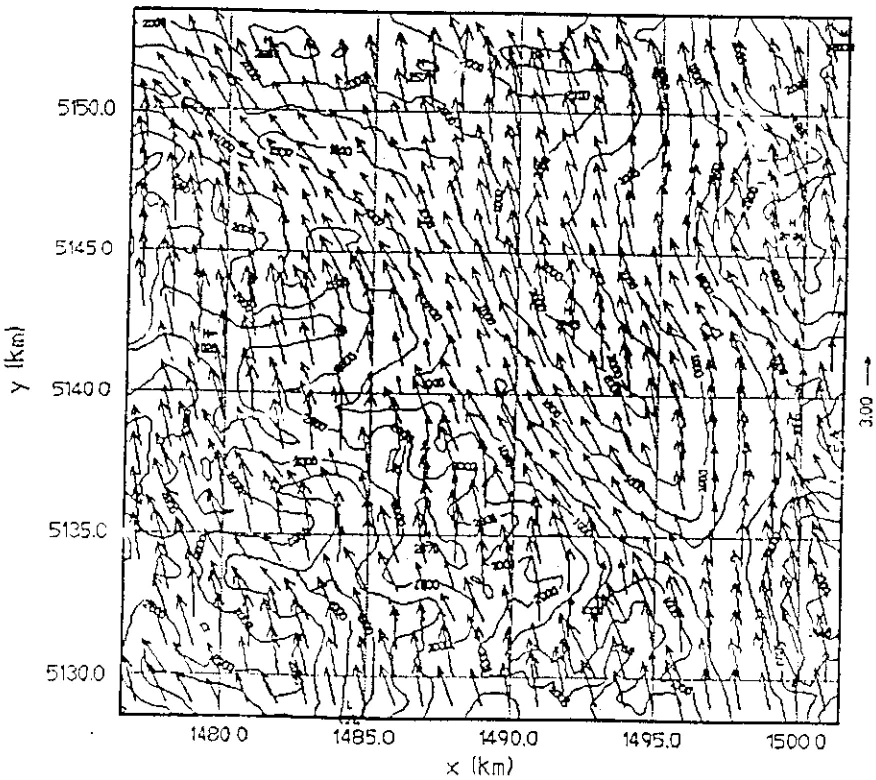

TRANSALP-89
5165
5155
5145
5135
5125
5115
1461
1471
1481
1491
1501
1511
UTM-X (Km)
UTM-Y (Km)
Leventina Valley
Blenio Valley
* ground stations
x sodars
o pilot
+ release point
1 – Claro
2 – Iragna
3 – Giornico
4 – Chironico
5 – Faido
6 – Dalpe
7 – Somprei
8 – Piotta
9 – Pizzo Erra
10 – Brugaio
11 – Semione
12 – Comprovasco
13 – Pari
14 – Camperio
15 – Olivone
16 – Lucomagno

Figure 1



Wind direction and speed at z=10.0 m

Figure 5a



Wind direction and speed at z=190.1 m

Figure 5b

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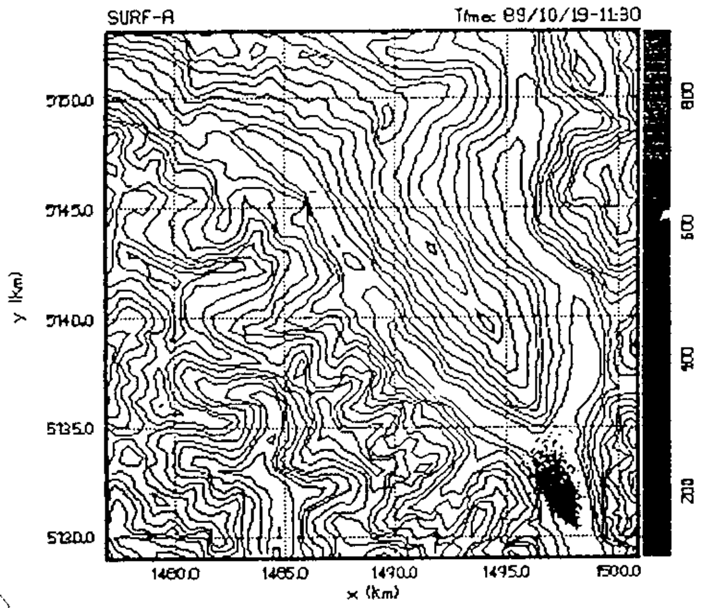
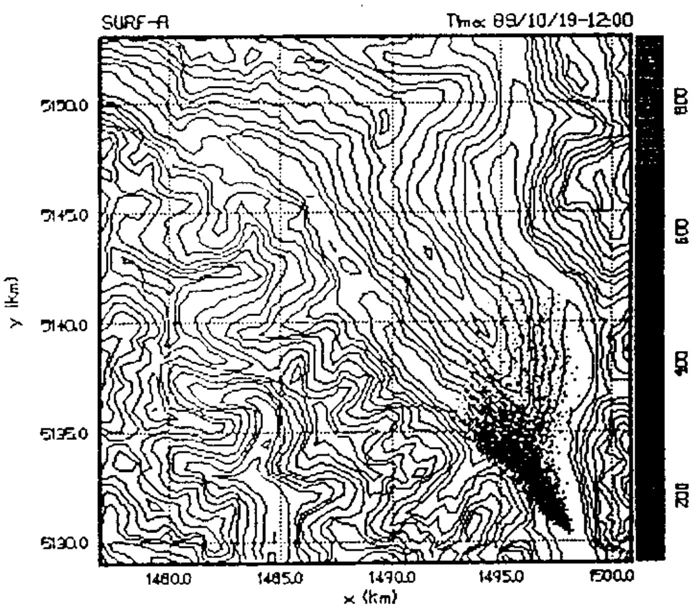
A R I E S - W - A r c o



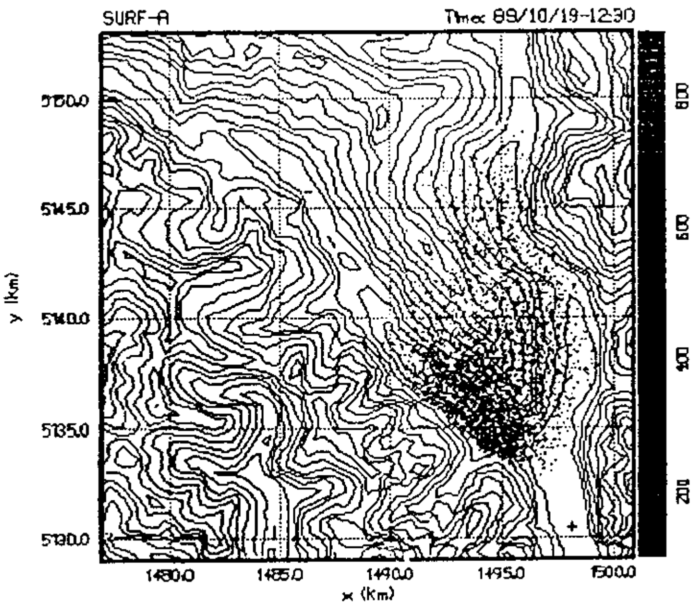
Particle display on plane XY

A R I E S - W - A r c o



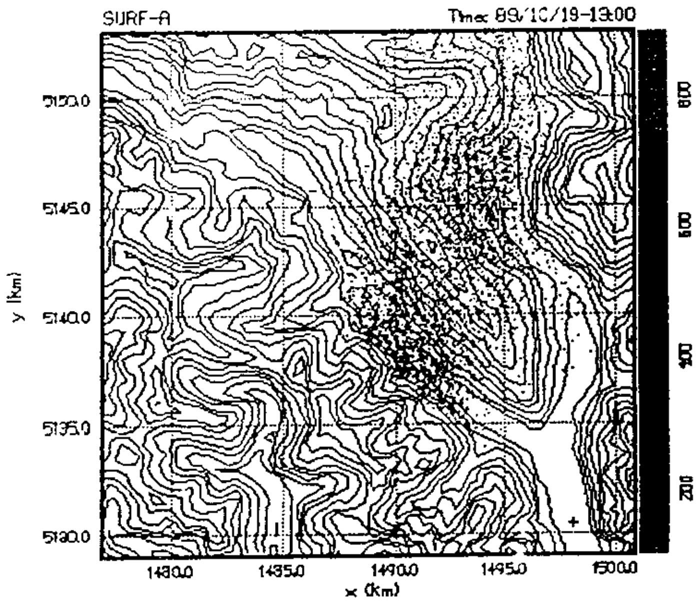
Particle display on plane XY

A R I E S - W - A r c o



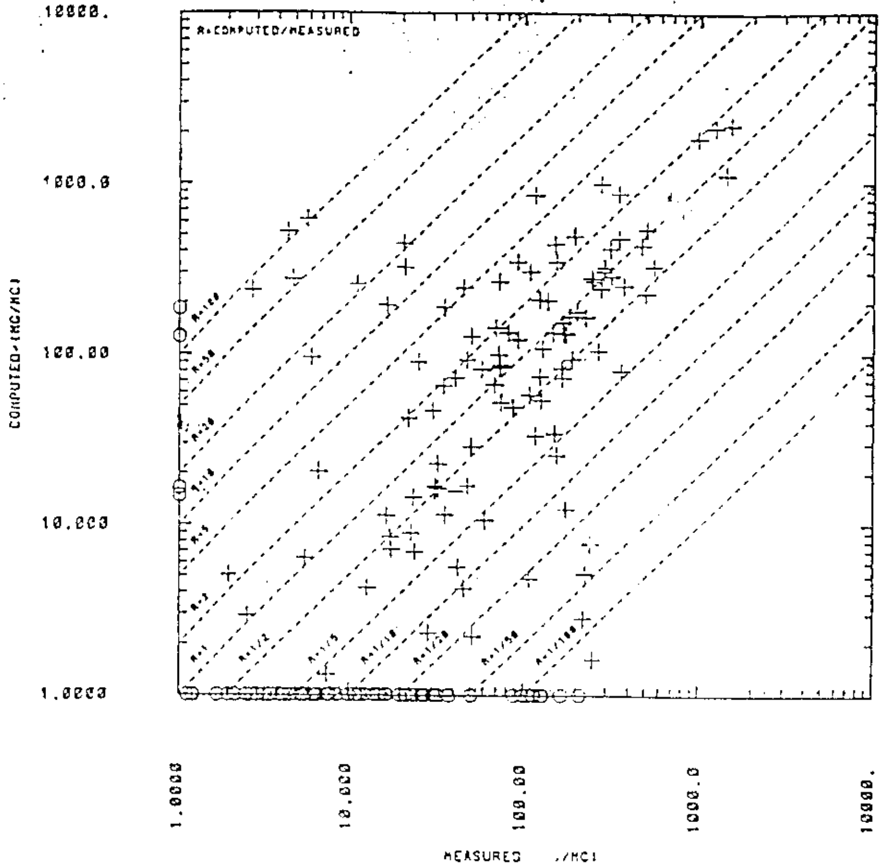
Particle display on plane XY

A R I E S - W - A r c o



Particle display on plane XY

1/2 hour concentr.



time-integrated concentr.

	Mean (ng/m³)	St.dev. (ng/m³)	Max (ng/m³)	Top_10 (ng/m³)	FB	NNR	CORRE
OBS.	664.6	733.0	3066.5	1511.6	-	-	-
ARCO	809.3	918.2	4672.4	1801.6	-0.127	0.381	0.87
SPRAY	633.7	679.3	3452.0	1425.2	0.048	0.795	0.67

maximum concentrat.

	Mean (ng/m³)	St.dev. (ng/m³)	Max (ng/m³)	Top_10 (ng/m³)	FB	NNR	CORRE
OBS.	303.7	347.5	1502.3	684.5	-	-	-
ARCO	458.0	480.3	2221.1	998.6	-0.405	0.370	0.88
SPRAY	303.8	298.8	1553.3	646.3	0.0002	0.855	0.70