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VALIDATION OF THE SNOW ANALYSIS IN CANARI / ALADIN

Final report based on the work done in METEO-FRANCE during the time

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by

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VALIDATION OF THE SNOW ANALYSIS IN CANARI/ALADIN

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INTRODUCTION

The results of the snow analysis could be used in a NWP model to determine better the surface fluxes , as well as a diagnostic tool for nowcasting purposes. There are not many publications on the analyses of the snow depth. We would refer to Tada (2000), where a comparison between 3 operational objective snow analyses schemes (in CMC, DWD and JMA) has been presented.
In DWD the scheme is based on the method of weighted average of the observations (Tada(2000), Buchhold(2000)) , while in CMC and JMA the snow analyses schemes are based on the Optimal Interpolation (OI) method (Tada(2000), Brasnett(1999)).The snow analysis scheme in CMC takes into account the vertical separation of the points .
In MeteoFrance/CNRM/GMAP an OI snow analyses scheme has been developed but it has not been updated for some years. The necessity of using the snow analysis not only as input for the forecast models but also as a diagnostic tool initiated a work of update and validation of the snow analysis scheme within the ALADIN project.
The first part of the work on the snow analyses in ALADIN/CANARI has been done in February -March 2000 . The main effort at that time was put to reinitialize and update the statistical model and the observation operator in the snow analysis scheme and to get proper and coherent outputs from the different routines in CANARI. The validation has been done mainly within the frame of a single-obs experiment with ALADIN-FRANCE, CY22T1AL12 libraries. During this stage it has been found that the snow observation operator applied for calculating the difference (obs - an) for the historical file after the analysis drives to misleading results:the postprocessed value of the snow was 0 instead of the analysed non-zero value. For that reason the routine for postprocessing of the snow has been modified and the model equivalent of the snow quantity in the observation point has been taken as it is in the guess field. The results have been presented in L.Gaytandjieva et al (2000).
Since 18th of September 2000 the work on the snow analysis goes on , the purpose of this second stage of the work is to study the snow observation operator and the results of the snow analysis within the frame of a full set of observations .The experiments have been done with ARPEGE/ALADIN limited area model (ALADIN-FRANCE and ALADIN-BG) , CY22T2(T199L31)AL13 libraries. The validation of the results of the snow analysis has been done by studying the distribution of the increments (analyses - guess) and by comparisson of the analysis field with the reported values at the

observation points. As far as that is a first attempt to evaluate the snow analysis , the conclusions about the quality of the analysis could be based on the consistent determination of the areas with snow cover. Here we could refer to Buchhold (2000), where is written that " .. it is less important to determine the exact snow depth, but to decide which areas are actually covered by snow."

The report will present :

- the basic ideas of the snow analysis in the frame of CANARI,
- the description of the experiments with the snow analysis scheme and the obtained results,
- conclusions drawn on the basis of the obtained results.

SECTION I. Basic ideas of snow analysis in the frame of CANARI

The first experiments with the snow analysis scheme have been made with the following assumptions :

- the analysed variable is the **snow quantity [kg.m^{-2}]**;
- the variable is locally continuous, the correlation function of the variable is locally homogeneous and isotropic and the statistical structure for the other surface elements analysed in CANARI, could be applied for the snow analysis as well;
- the horizontal correlation function is **exp (-1/2*(r/d)^2)** with **r** being the horizontal distance between any 2 points with characteristic length **d** (V. Cassé (1998)) ; the value of d has been set to **50 000 [m]**
- the horizontal correlation function is defined only between points with snow observations, i.e. the snow analysis is performed only on the base of snow observations;
- the **rms observation error** is equal to the **rms guess error** with value set to **5 [kg.m^{-2}]** (or 5 mm liquid water equivalent of the snow quantity).

The guess field is the snow quantity taken from the 6 hour coupling ARPEGE file.
The model equivalent of the snow observation at the observation points (the vertical snow observation operator) is defined in Urban (1996).
The basic idea in that paper is that when there are significant differences between the real and the model orography, the best estimate of the observations located near the ground can not be obtained with an observation operator, based on simple interpolation-extrapolation . An alternative approach is to parameterize the probability distribution of a physical process and take the expectation to obtain the relevant quantities .

That idea has been realized by :
- assuming a reasonable joint distribution of (x,x_o) (x_o - the vector of the observed quantity, x - the state vector of the model variables) with some justification due to the physical processes involved;

- computation of the conditional mean $E(x_o|x)$, being the best nonlinear estimate of x_o knowing x in the rms sense, to define the observation operator $Hx - x_o$.

As far as the model does not have the same orography as the reality, there are problems in postprocessing of x to x_o when the parameters x_o are measured at the surface. That is why the observation operator H is split into $H = H_h H_v$ with:

- H_h - the horizontal part of the observation operator, which interpolates all the model variables x to a set of quantities x_h at the vertical of x_o ;
- $H_v(x_h) = E(x_o| x_h)$ - the vertical part of the observation operator, computed as the conditional mean

A very brief presentation of the theory of the snow obs operator is given in Attachment I
Here we will present only the final form of the equation on which the formulation of the snow observation operator is based :

$$E(x_o | x_h) = P_1\left[T_0 - T_{cl}(A)\right] I_{T_0 > T_{cl}(A)} + P_2\left[x_h - S_{cl}(G)/\sigma(G)\right]\left[T_0 - T(x)\right] I_{T_0 > T(x)}$$

where :

P_1 = constant > 0 with dimension $[kg.m^{-2}.K^{-1}]$
P2 = constant >0 with dimension $[K^{-1}]$
G - a portion of the surface corresponding to the real orography and representative of the area of validity of the model value x_h with measure $\sigma(G)$
A - a small portion of the real surface around the obs. point with surface measure $\sigma(A)$
S_{cl} (G) - climatology constant
T_0 - the temperature thresholt above which snow depth can not exist;
$T_{cl}(A)$ - climatology of the surface temperature at the observation area A.
T(x) - surface temperature obs operator computed at point x of the real orography

As it is shown in the Attachment 1 ,to take into account the impact of the difference between the real and the model orography , $T_{cl}(A)$ and T(x) are defined by :

$$T_{cl}(A) = T^*_{cl}(A) + \lambda[z(A) - z(G)]$$

$$T(x) = T^*(G) + \lambda^*[z(A) - z(G)]$$

T^*_{cl} (A) - the climatology of the surface temperature ;

$T^*(G)$ - the model surface temperature

λ - the standard vertical temperature gradient;

λ^* - the computed vertical temperature gradient;

$z(A)$, $z(G)$ - the mean altitudes of the observation area A and area G resp.

The coded form of the equation for the snow obs operator is:

PXPP(JROF,1,1) = ZPXPP1 + ZPXPP2

with :
a) **ZPXPP1 = P_1 * max (0, TR - ZTCLIMA)**
That term represents the impact of the postprocessed surface temperature climatology ZTCLIMA on the model equivalent of the snow at the obs point JROF for TR > ZTCLIMA (**TR = 276 [K]** is the code equivalent of T_0) ;
ZTCLIMA = ZCCLITS(JROF) + RDTDZ1*(PALTI(JROF) - POROG(JROF)) / RG
is the obs operator for postprocessing of surface temperature climatology , which modifies the surface temperature climatology ZCCLITS(JROF) with respect to the difference between the real (PALTI) and model (POROG) orography at the observation point JROF;
RDTDZ1 = -6.5E-03 [$K.m^{-1}$] - the standard vertical temperature gradient ;
P_1 = 1/2 [$kg.m^{-2}.K^{-1}$]

b) **ZPXPP2 = P2 * max (0,TR - ZTOBS) * (ZSNS (JROF) - ZCCLISN(JROF))**
That term represents the impact of the postprocessed model temperature ZTOBS and the snow climatology on the model equivalent of snow at the obs point JROF (for ZTOBS has been put the condition TR > ZTOBS for the same reason as for ZTCLIMA)
The surface temperature obs operator
ZTOBS = PTF5(JROF,NFLEVG) + ZDTDZ * (PALTI (JROF) - POROG(JROF)) /RG
modifies the temperature PTF5(JROF,NFLEVG) at the last model level (NFLEVG=31) with respect to the difference between the real and model orography at the observation point (for ZTOBS has been put the condition TR > ZTOBS for the same reason as for ZTCLIMA)
ZDTDZ is the calculated vertical model temperature gradient, ZSNS and ZCCLISN are the model (or analysis) value and the climatology of the snow quantity at the observation point JROF ; **P_2 = 1/3 [K^{-1}]**

SECTION II. SINGLE-OBS EXPERIMENTS WITH ALADIN-FRANCE

With the snow obs operator and the parameters of the statistical model described above we have performed on the vpp5000 for 2000/03/01/00 UTC two experiments introducing perturbation of 10 [$kg.m^{-2}$] snow quantity in observation points on different altitudes:

- TLS case - the perturbed point is Toulouse with mean altitute 100 [m]

That case has been considered as a test for the snow obs operator routine when there is no snow in climatology and in the guess field , but there is a perturbed non-zero value at the observation point

- IT case - the perturbed point is situated in NE part of Italy (synop station 16022) with mean altitude 2129 [m] ;

Thas case has been considered as a test of the ability of the scheme to perform snow analysis in conditions close to reality , when there is snow both in the climatology and the guess fields.

For both experiments the input cmafoc files have been produced by Mandalay from an ascii file for each case.

The results of the single obs experiments for both cases are presented on Table 1 and Fig.II.1 - Fig.II. 6.

Table 1 represents the values of the input and output variables in the snow obs operator routine . The analyses of the table shows that:

- practically there is no impact of the modification of the temperature on the last model level with respect to the difference between the real and the model orography at the observation point;
- the postprocessing of the surface temperature climatology with respect to the difference between the real and the model orography leads to a decrease of the value in IT case and an increase of the value in TLS case;
- the obs operator applied to the guess value of the snow quantity (to get the observation departure (OBS - GUESS)) leads to increase of its value, mainly due to the term which takes into account the modification of the surface temperature climatology ;
- the obs operator applied to the analysed snow quantity (to get the difference (OBS - AN) at the obs point) leads to:
    - an adequate value of the postprocessed snow for IT case ;
    - a wrong value of the postprocessed snow for TLS case . The reason for such a behaviour of the observation operator is the condition that there should be no snow when the temperature is higher than TR.

The conclusion that could be drawn from Table 1 is :

- the observation operator based on the formula (5) performs good postprocessing in the IT case for computing both differences (OBS - GUESS and OBS - AN) .

- the postprocessing with the same obs operator leads to wrong results when there is a snow quantity at the observation point, but the temperatures ZTCLIMA and ZTOBS are higher than the temperature threshold TR. That property of the snow obs operator could be useful for rejection of bad data during the QC of the snow. But the formula should be modified to allow postprocessing of the snow amount when there is a snow in the analysis field

The orography of ALADIN-FRANCE is presented on Fig.II.1. On Fig.II. 2 - Fig.II. 3 the climatological files of the snow quantity for February and March are shown (the clim files have been produced by one year of assimilation with truncation T79)
The guess snow field for 2000/03/01/00 is presented on Fig.II.4
The increments (AN - GUESS) fields are presented on Fig.II.5 for IT case and on Fig.II.6 for TLS case .
As it could be seen, the impact of the single obs is well pronounced over an area of order of the characteristic length of the snow analysis (Fig.II.5 - Fig.II.6)
The distribution of the increments for both cases shows that:

- the max value of the increments is the one expected when the observation error is set to be equal to the guess error.
- there are two types of paterns: isotropic patterns around the perturbed points and paterns of non-zero increments over the Alps;

That isotropic pattern in IT case means that the statistical model of the snow should be studied and the definition of the structure function should be reconsidered to account for the surrounding orography. As for the non-zero increments over the Alps, they have been found to be of order of 10E-05 [kg.m^{-2}] and could be considered as a noise
The conclusions drawn on the basis of the figures could be summarized as:

- the single obs experiments have shown the expected distribution of the increments when the observation error is set to be equal to the guess error;
- the statistical model of snow should be studied and perhaps a vertical component in the structure function should be taken into account.

SECTION III. Experiments with ALADIN -BG

The experiments with ALADIN-BG have been done for the period 17 - 21 February 2000 when there was significant snow amount (quantity) over the large part of the domain .
The orography of ALADIN-BG is presented on Fig.III.1, the clim files for February and March are presented on Fig.III.2-Fig.III.3. It is seen that there is almost no snow in both clim files.
The input cmafoc files for that experiments have been derived from the operational data base (OBD). It has turned out that:

- in the data base (OBD) the archived variable is the snow depth in [m] and to performe analysis with those data it has been necessary to modify the routine castro.F90;
- there are very few observations with snow in 00 and 12 UTC;the observations with snow are reported mainly at 06 and 18 UTC.

For that reason all our experiments have been done only for 06 and 18 UTC each day from the above mentioned period.
The control prints in ppobsn.F90 (the routine for postprocessing the snow quantity) have shown that there are significant differences between the real and model orography. On Fig.III.4 is presented the distribution of the difference dz = (alti - orog)/rg (in [m]) between the altitudes of 102 observation points and the model orography for 2000/02/17/06 Fig.III.5 presents the histogram of the distribution of dz within 50 m intervals.
It could be seen that for those sample of observations :

- the model orography is higher than the real one;
- there are several observation points with altitude much higher than the model orography (max value of dz ~1200 [m]).

That means that the postprocessing of the guess field and the statistical structure of the snow quantity should take into account the difference between the real and the model orography.

III.1 Experiments with $\mu(r) = \mu_h(r) = \exp(-1/2*(r/d)^2)$ for the snow analysis where $\mu_h(r)$ is the horizontal correlation function with characteristic length d

The first experiments over the new domain have been done with:

- modified ZPXPP2 term of the snow obs operator (modified ppobsn.F90 respectively):
    - instead of the temperature at last model level PTF5 , the model surface temperature PTSF5 has been used due to the fact that it represents better the temperature at the surface; that change required a modification of hop.F90 to include the PTSF5 in the input parameters when calling ppobsn.F90
    - instead of the calculated vertical model temperature gradient ZDTDZ , the standard lapse rate RDTDZ1 has been used to postprocess the model surface temperature at the observation point;
- correlation function $\mu_h(r)= \exp(-1/2*(r/d)^2)$, d=50 000 [m]

On Fig.III.6 - Fig.III.8 the guess, analysis and increments fields for 00021706 is presented .
The distribution of the increments field made us think that :
- due to the small value of the characteristic length d , not all observations have been taken into account in the analysis;
- the analysis scheme does not handle properly the zero values of the variable

To check that, two experiments have been performed with increased value of d (d=500 000 [m]) :
a) experiment with 2 stations in the input cmafoc file (13588 with Var = 0 and 15280 with Var = 68 $kg.m^{-2}$)
b) experiment with only one station in the cmafoc file (15280)
The increments for the two experiments are presented on Fig.III.9 - Fig.III.10 It is seen that the increments differ nontheless they look similar, which means that the analysis takes into account the station with the zero value
As we wanted to avoid the spot like features in the snow analysis, we decided to perform the experiments further on with increased value of d and fixed it to 100 000 [m]. The next experiment has been performed with data for 00021718. Guess field is presented on Fig.III.11, the increments field is on Fig.III.12 (contour interval 0.1 The 2 black spots in the SW corner correspond to the lakes on the Macedonia-Greece border, but to understand the reason for the strange patterns on the west part of the domain we made an experiment for which the min correlation has been put to 0 , instead of 0.1 (QCORMIN = 0)
The increments field is presented on Fig.III.13 and it could be seen that some of the patterns have been corrected.
In CANARI the search of the influencing stations is limited by the max number of observations for a given sector , different for the different kind of observations (for SY observations NMXGQA=10). As far as the observations with snow are less, this value of NMXGQA could be reached without any snow observation. We have performed an experiment with increased value of NMXGQA for SY (NMXGQA =50) and the analysis and increments fields are shown on Fig.III.14 - Fig.III.15. It is seen that the increments are smooth . The pattern in the north part of the domain is due to fact that there are observations with Var = 0 in that part but there is snow in the guess , which is removed by the analysis.
The results of all the experiments performed with a horizontal correlation function for the snow analysis have shown that the obtained increments are isotropic and do not represent the orography properly.

III.2 Experiments with vertical component in the correlation function for the snow analysis : $\mu (r , p) = \mu_h(r) * \mu_v(p)$

As far as the vertical correlation functions for the other meteorological variables in CANARI are functions of the pressure (lnP) , we have tried to apply the same statistical model for the snow correlation function and have performed some experiments with a vertical correlation of type $\mu_v (p) = 1 / (1 + P_p(dp_{ij})^2)$
where :
$dp_{ij} = \ln(p_j / p_i)$ - the difference between the pressures at the model and the obs points (cacova) and the pressures at the obs points (catrma)
P_p - a vertical characteristic parameter

III.2.1. Experiments with $\mu_v (p) = 1 / (1 + P_p (dp_{ij})^2)$

For those experiments we have modified the routines cacova.F90 and catrma.F90 so the correlation function between the grid point and the observations and between the observations to be of type:

$\mu (r , p) = \mu_h(r) * \mu_v(p)$ with $\mu_v (p) = 1 / (1 + P_p (dp_{ij})^2)$; $dp_{ij}=\ln(p_j /p_i)$;

P_p - a vertical characteristic parameter

The experiments have been done for 00021718 with different values of the vertical characteristic parameter P_p (200,300,400). On Fig.III.16-Fig.III.17 the increments fields for $P_p = 300$ are presented (the contour intervals for the two figures are different).

The comparisson with Fig.III.15 shows that instead of isotropic area in the northern part of the domain there is a well pronounced area of increments over the Karpats.Over the western mountaineous part the increments better represent the orography of the area.

III.2.2. Experiments with $\mu_v (p) = \exp(-1/2*(dp_{ij} / P_c)^2)$, where P_c is a vertical characteristic parameter

The experiments with vertical correlation function of type

$\mu_v (p) = \exp(-1/2*(dp_{ij} / P_c)^2)$

have been performed after modification of the modules and the routines listed in Attachement IV.

As it could be seen from Fig.III.18 the both vertical correlation functions decrease in the same way up to 1000 m difference between the real and the model orography, after that the exponential function decreases faster which is an advantage in the case of snow analysis.

The experiments for 00021718 have been performed with $P_c = 0.05$ and different values of the rms guess error. At the beginning of the validation of the snow analysis scheme , when we introduced perturbations in single_obs points, we set the rms of guess error to be equal to the rms of observation error to have analysed value in the middle between the guess and the observation. But this assumption is not fare for the real observations - we could assume that the rms of the model (guess) error is higher than the rms of the obs error

On Fig.III.19 - Fig.III.20 are presented the increments fields for REF_S_SN =5 and REF_S_SN = 10 . It is seen that with REF_S_SN = 10 we have more realistic pattern of the increments.

III.2.3. Experiment with $\mu (r, p) = \mu_h(r) * \mu_v(p)$, $\mu_v (p) = \exp(-1/2*(dp_{ij} / P_c)^2)$, $P_c = 0.05$; d = 100 000 [m], REF_S_SN = 10 for 00021818

The experiment for 00021818 have been performed with $P_c = 0.05$; d = 100 000 [m], and rms guess error REF_S_SN = 10. The results of the experiment are shown on Fig.III.21-Fig.III.24. The visualization is done with the new version of the plotting software Chagal. Here should be mentioned that there is some displacement of the observation points due to map problems and the observed values of the variable are at the height of the station, while the analysis is performed on the surface of the model. But it is seen that the analysis field is close to the observations and that there is an improvement of the guess field in the flat areas of the Aladin -BG domain.On Fig.III.25 -Fig.III.28 the same results are visualized by GraDS .The background field for Fig.III.27 -Fig.III.28 is the increments field (analysis-guess) and the values of OMN(Obs - An) and OMG (Obs - Guess) in the observation points are plotted.It is clearly seen that there is a coherence between the areas of big values of the increments field and the big values of OMG and OMN; it is seen that the values of OMN are less than the values of OMG

IV. CONCLUSIONS AND INTENSION FOR THE FUTURE WORK

The main results and conclusions drawn on the basis of performed experiments are:

- the snow analysis scheme in CANARI/ALADIN has been tested for full set of observations for a period of significant values of the snow quantity;
- the correlation function for the snow analysis has been modified and vertical component has been added
- the results obtained have shown that with that correlation function there is an improvement of the analysis field and good agreement with the observations ;
- the statistical model of the snow should be tuned

The intension for the future is :

- to study the impact of the new snow clim files (with ISBA files included) on the results of the snow analysis
- to modify the routine for the postprocessing of the snow amount so as to switch to simple interpolation when the condition for $T_0 > T(x)$ is not satisfied; to tune the parameters in the formula for the snow observation operator;to use screen-level temperature instead of surface temperature to obtain the model temperture at the obs point
- to try another formula for the snow observation operator ;

- to tune the parameters of the statistical model of the snow analysis ; if necessary, to define the vertical part of the correlation function as a function of distances in z , not in lnP
- to perform forecast and study the impact of the snow analysis on the forecast scores; to consider some coherence between analysed snow and the surface temperature fields (cacsts)
- to consider the possibility of QC of the snow data

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Attachment I

Formulae for snow obs-operator after Urban(1996)

Here we will present very briefly the theory, on which the formulation of the snow observation operator is based

Let x_h be any model surface variable and x_o - the corresponding observation at the observation point Q given by

$$x_o = \frac{1}{\sigma(A)} \int_A y(P)\, d\sigma(P) + w$$

with:

y(P) - the true value of the surface variable at point P ;

w - unbiased observation error, independent from the background x_h ;

A - a small portion of the real surface around Q; for the synoptic measurements it could be taken as the unique point Q;

σ - the surface measure

The conditional mean of x_o with respect to x_h is defined as:

$$E(x_o|x_h) = E[Z(A)/\sigma(A)|x_h] \qquad (1)$$

if a family Z of random variables indexed by all possible portions of the earth surface is defined by

$$Z(A) = \int_A y(P)d\sigma(P)$$

Let :

G be a portion of the surface corresponding to the real orography, containing Q and representative of the area of validity of the model value x_h ;

and

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if a family Z of random variables indexed by all possible portions of the earth surface is defined by

$$Z(A) = \int_A y(P)d\sigma(P)$$

Let :

G be a portion of the surface corresponding to the real orography, containing Q and representative of the area of validity of the model value x_h ;

and

$$x_h = \frac{1}{\sigma(G)} Z(G) + \eta \qquad (2)$$

η - an unbiased Gaussian error of variance τ^2, independent from x_h which is an assumption for x_h to be close to some spatial mean of y;

Then the expression (1) could be written as:

$$E(x_o | x_h) = E\left[\frac{1}{\sigma(A)} Z(A) | \frac{1}{\sigma(G)} Z(G) + \eta\right] \qquad (3)$$

The family Z of random variables is defined as a random measure, which is completely described by the covariance function μ and the family of probability measures

In case of postprocessing the snow depth (with discrete Poisson probability distribution), x_o is considered to be the observed snow depth, x_h - the snow depth from the model and Z - a random measure. To ensure that Z(G) would be positive, for any B (B - a subset of the real surface), all Z(B) are presented as

$$Z(B) = S_{cl}(B) + W(B)$$

In that case eq.(2) becomes

$$x_h = \frac{S_{cl}(G) + W(G) + \sigma(G)\eta}{\sigma(G)}$$

where:

$S_{cl}(G)$ is a climatological constant;

$W(G) + \sigma(G)\eta$ − a Poisson random variable with parameter $\mu(G) + \sigma(G)\xi^2$

The equation for $E(x_o | x_h)$ has been written in the form:

$$E(x_o | x_h) = S_{cl}(A)/\sigma(A) + \left[x_h - S_{cl}(G)/\sigma(G)\right]\frac{\mu(A)/\sigma(A)}{\mu(G)/\sigma(G)+\xi^2} \quad (4)$$

The numerical calculations with that formula have been done after some assumptions :

- for the measure μ:

$$\frac{d\mu}{d\sigma} = \delta\left[T_0 - T(x)\right]|_{T_0 > T(x)}$$

- for the snow climatology at the obs point

$$\frac{S_{cl}(A)}{\sigma(A)} = P_1\left[T_0 - T_{cl}(A)\right]|_{T_0 > T_{cl}(A)}$$

P_1 = constant > 0 with dimension [$kg.m^{-2}.K^{-1}$]

The eq.(4) is rewritten in the form:

$$E(x_o | x_h) = P_1\left[T_0 - T_{cl}(A)\right]|_{T_0 > T_{cl}(A)} + P_2\left[x_h - S_{cl}(G)/\sigma(G)\right]\left[T_0 - T(x)\right]|_{T_0 > T(x)} \quad (5)$$

where :

$$P_2 = \frac{\delta}{\mu(G)/\sigma G) + \xi^2} = \text{constant} > 0$$

with dimension [K^{-1}]

T_0 - the temperature thresholt above which snow depth can not exist;
$T_{cl}(A)$ - climatology of the surface temperature at the observation area A.
$T(x)$ - surface temperature obs operator computed at point x of the real orography

To take into account the impact of the difference between the real and the model orography , $T_{cl}(A)$ and $T(x)$ are defined by :

$$T_{cl}(A) = T^{*}_{cl}(A) + \lambda[z(A) - z(G)] \qquad (6)$$

$$T(x) = T^{*}(G) + \lambda^{*}[z(A) - z(G)] \qquad (7)$$

$T^{*}_{cl}(A)$ - the climatology of the surface temperature ;

$T^{*}(G)$ - the model surface temperature

λ - the standard vertical temperature gradient;

λ^{*} - the computed vertical temperature gradient;

$z(A)$, $z(G)$ - the mean altitudes of the observation area A and area G resp.

Attachment II

Single-obs experiments with Aladin-France

Contents

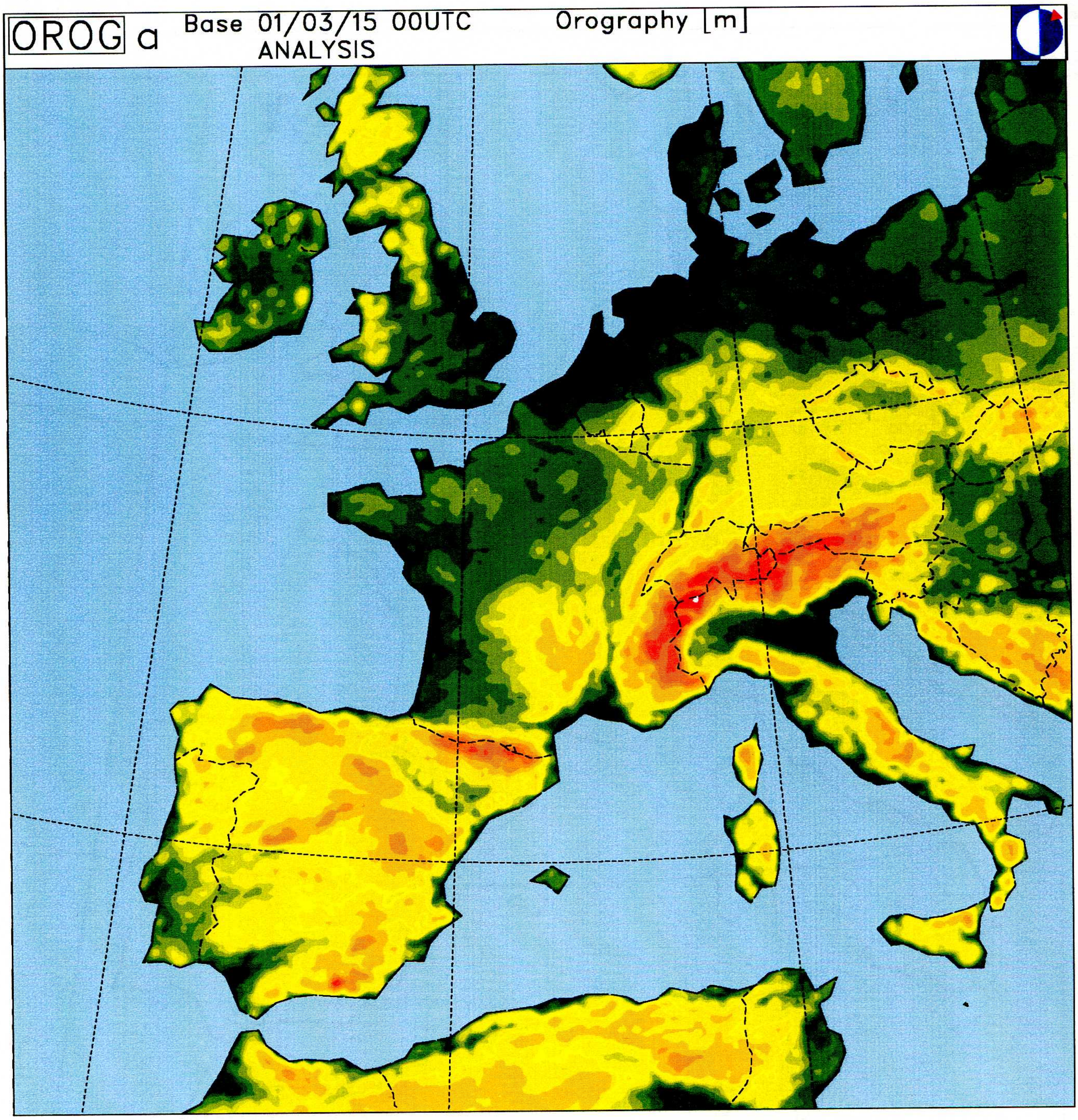
constants

RG= 9.806649999999999 [m/s**2]
RD= 287.0596736665907 [J/kg K] - specific constant for dry air
RDTDZ1= -6.5 E-03 [K/m] - the standard vertical temperature gradient below the tropopause
RTT= 273.16 [K] - the tripple point temperature
TR = RTT + 3.0 [K] - the temperature threshold above which snow depth can not exist

Analysed variable

snow quantity [kg/m2]**

	IT	TLS
Mean orography at the obs. point [J/kg] **PALTI** (JROF)	20878.357	980.665
Mean model orography at the obs.point [J/kg] **POROG** (JROF)	15574.019	2100.952
calculated vertical temperature gradients		
ZDTDP	4.701E-04	4.117E-04
ZDTDZ	-5.917E-08	-4.997E-08
Temperature of the last model level at the obs.point **PTF5**(JROF,**NFLEVG**)	**271.616**	**281.696**
Postprocessed temperature at the obs. point **ZTOBS** = **PTF5**(JROF,**NFLEVG**)+**ZDTDZ** * (**PALTI**(JROF)-**POROG**(JROF))/**RG**	**271.616**	**281.696**
Climatology of the surf temperatute at the obs.point **ZCCLITS**(JROF)	**271.501**	**281.945**
Postprocessed climatology of the surf temperature at the obs.point **ZTCLIMA** = **ZCCLITS**(JROF) + **RDTDZ** * (**PALTI**(JROF)-**POROG**(JROF))/**RG**	**267.985**	**282.688**
Climatology of the snow quantity at the obs.point **ZCCLISN**(JROF)	1.735E-03	0.000E+00
Guess (model) value of the snow quantity at the obs.point **ZSNS**(JROF)	**2.863E-02**	**0.000E+00**
Postprocessed value of the model snow quantity at the obs.point		
ZPXPP1 = **_HALF_*MAX(_ZERO_,TR - ZTCLIMA)**	**4.087**	**0.000E+00**
ZPXPP2 =(**ZSNS**(JROF) - **ZCCLISNS**(JROF))***MAX(_ZERO_,TR - ZTOBS)/3**	**4.073E-02**	**0.000E+00**
PXPP(JROF,1,1) = **ZPXPP1 + ZPXPP2**	**4.128**	**0.000E+00**
Analyses value of the snow quantity at the obs.point **ZSNS**(JROF)	**2.946**	**4.9577**
Postprocessed value of the analysed snow quantity at the obs.point		
ZPXPP1 = **_HALF_*MAX(_ZERO_,TR - ZTCLIMA)**	**4.087**	**0.000E+00**
ZPXPP2 =(**ZSNS**(JROF) - **ZCCLISNS**(JROF))***MAX(_ZERO_,TR - ZTOBS)/3**	**4.460**	**0.000E+00**
PXPP(JROF,1,1) = **ZPXPP1 + ZPXPP2**	**8.547**	**0.000E+00**



OROG a
Base 01/03/15 00UTC
ANALYSIS
Orography [m]

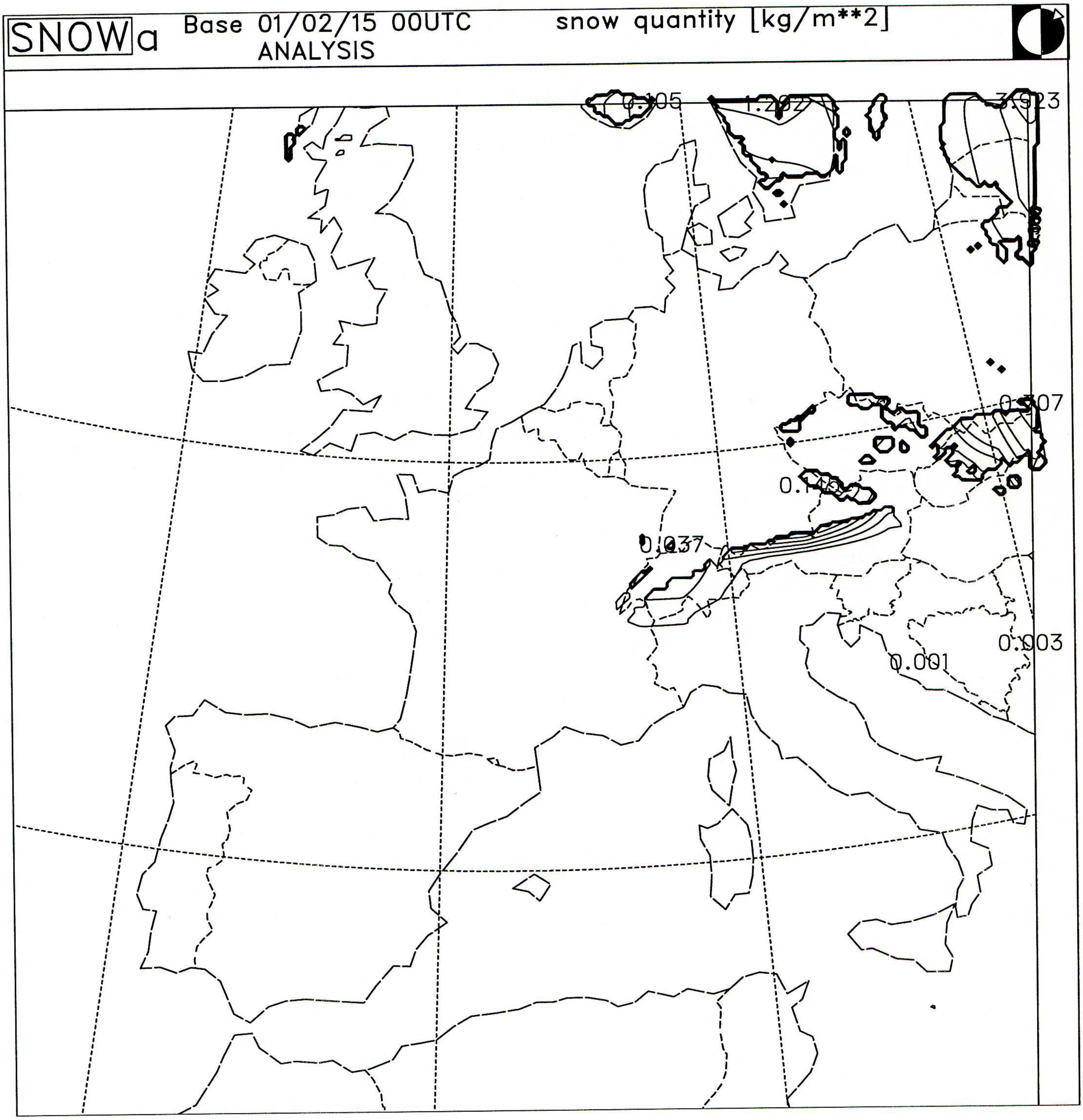

SNOW a
Base 01/02/15 00UTC
ANALYSIS
snow quantity [kg/m**2]
0.037
0.003
0.001

Fig. ii. 2

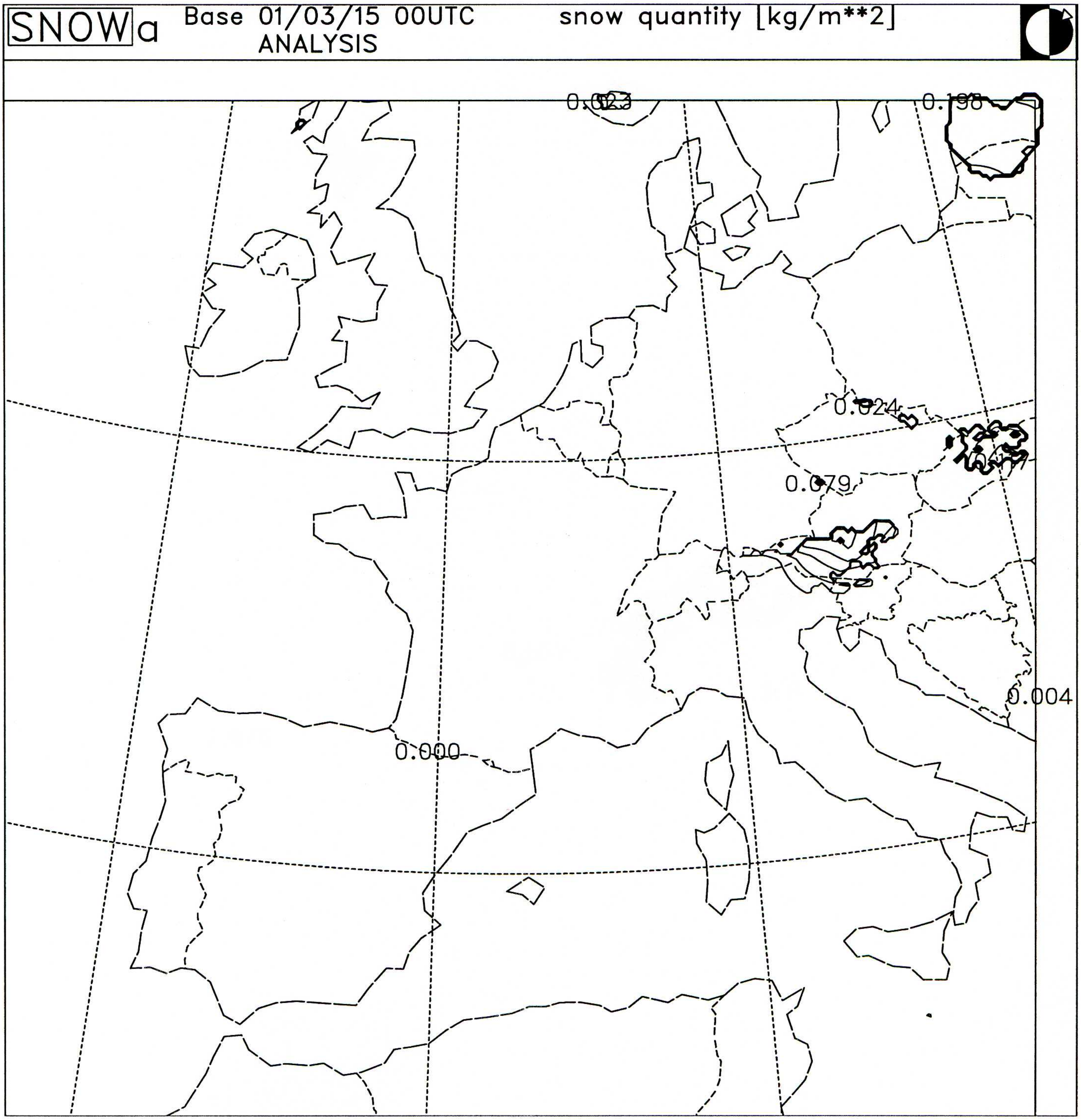
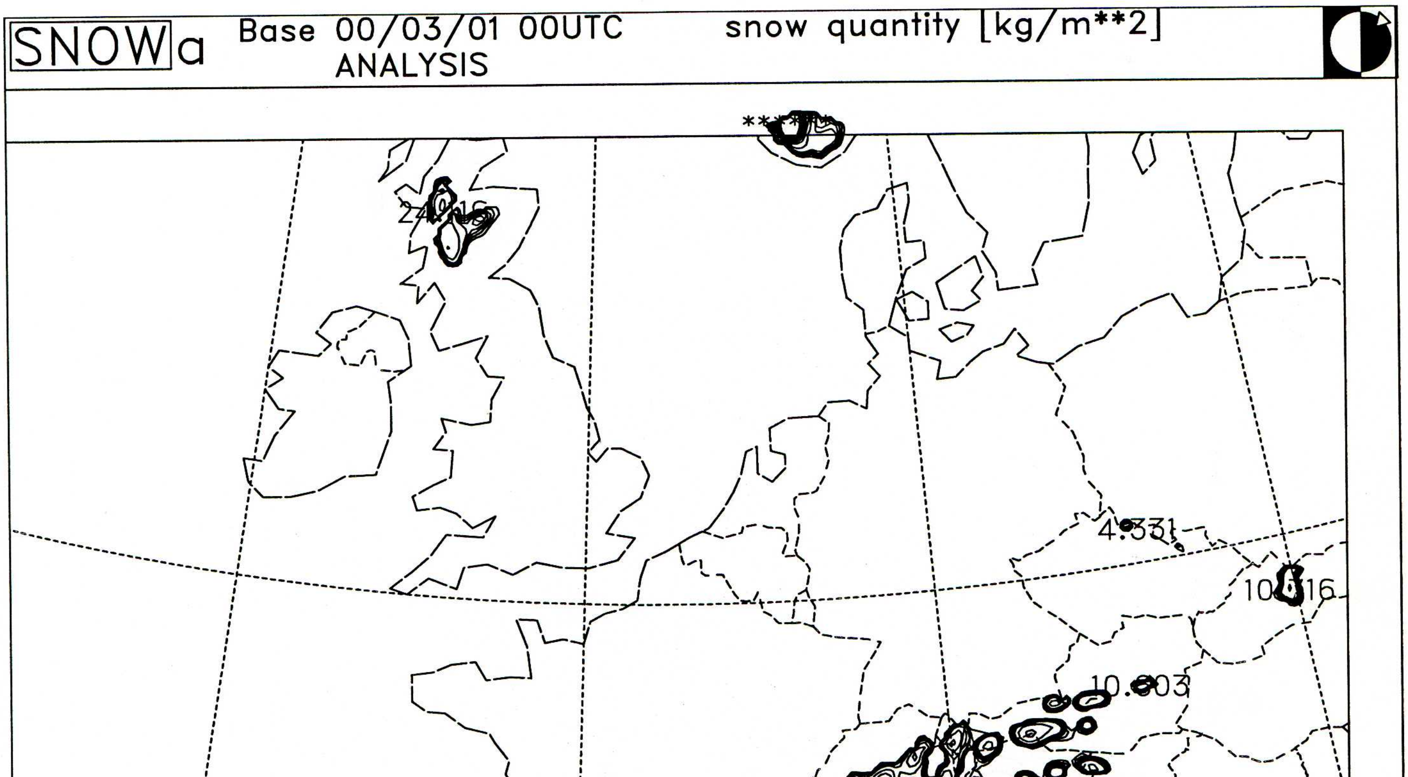

SNOW a
Base 01/03/15 00UTC
ANALYSIS
snow quantity [kg/m**2]
0.198
0.024
0.079
0.004
0.000

Fig. II.3



SNOWa
Base 00/03/01 00UTC
ANALYSIS
snow quantity [kg/m**2]
4.331
10.616
10.603
78
3.607
0.366
2.576
1.268
8.91

Fig. II. 4

SNOW a Base 00/03/01 00UTC snow quantity [kg/m**2]
ANALYSIS

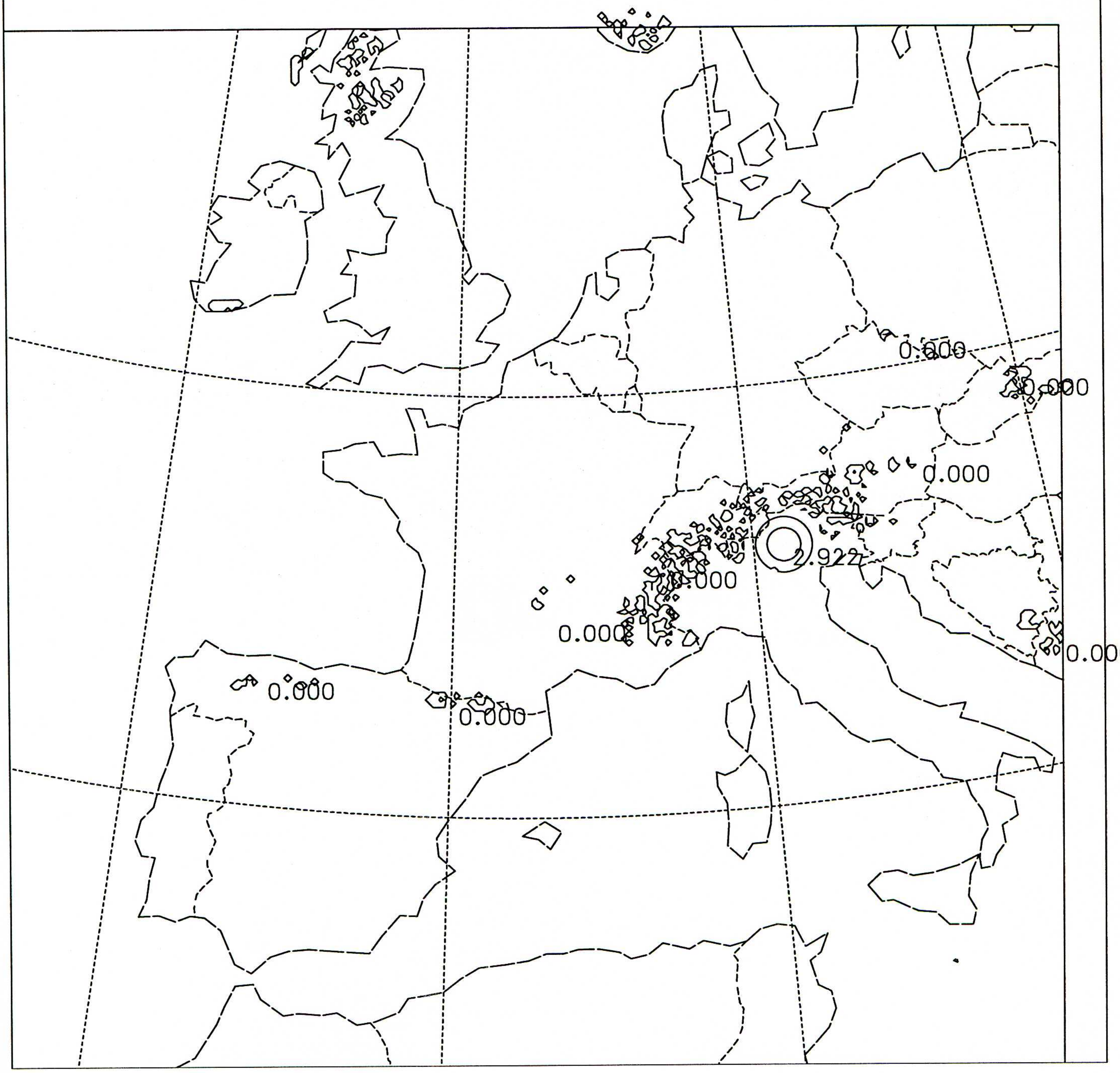


Fig. II.5

SNOW a Base 00/03/01 00UTC snow quantity [kg/m**2]
ANALYSIS

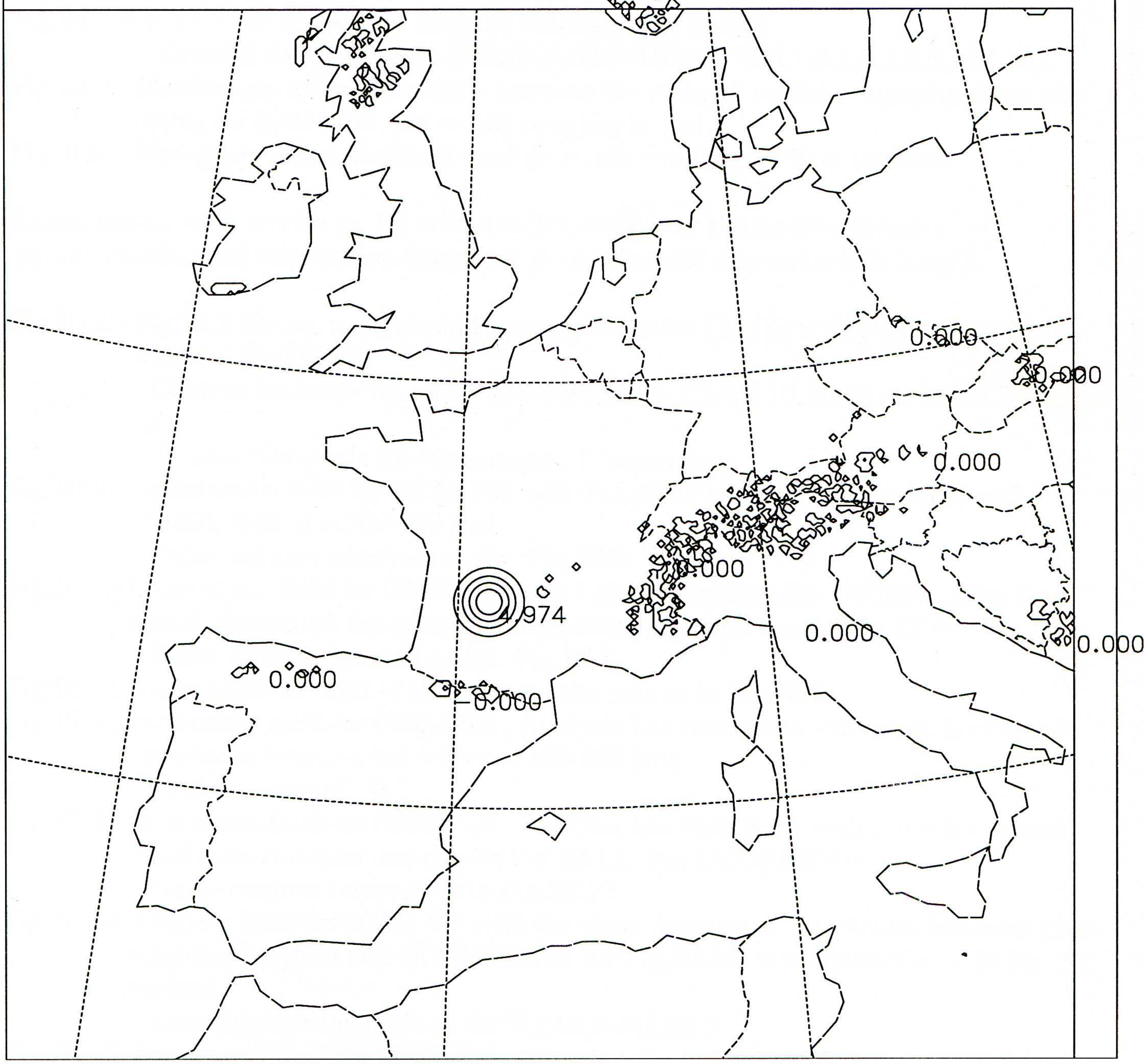


Fig. II.6

Attachment III

Experiments with Aladin-BG

Contents

Experiments with $\mu(r) = \mu_h(r) = \exp(-1/2*(r/d)^2)$ for the snow analysis; $\mu_h(r)$ - horizontal correlation function; d - horizontal characteristic length

Experiments with vertical component in the correlation function for the snow analysis : $\mu(r, p) = \mu_h(r) * \mu_v(p)$;

Experiments with $\mu_v(p) = 1 / (1 + P_p (dp_{ij})^2)$ where P_p is a vertical characteristic parameter, $dp_{ij} = \ln(p_j / p_i)$

Fig.III.16 Increments field for 00021718 corresponding to the analysis with $\mu(r, p)$, $\mu_v(p) = 1 / (1 + P_p (dp_{ij})^2)$, $P_p = 300$
Contour interval : 0.5

Fig.III.17 Same as Fig.III.16 but contour interval is 0.1

Experiments with $\mu_v(p) = \exp(-1/2*(dp_{ij} / P_c)^2)$, where P_c is a vertical characteristic parameter

Fig.III.18 Comparison between the two vertical correlation functions $\mu_v(p) = 1 / (1 + P_p (dp_{ij})^2)$ and $\mu_v(p) = \exp(-1/2*(dp_{ij} / P_c)^2)$ for a point at altitude 500 [m] and model orography $\subset$ [0, 3000] [m]

Fig.III.19 Increments field for 00021718 corresponding to the analysis with $\mu(r, p)$, $\mu_v(p) = \exp(-1/2*(dp_{ij} / P_c)^2)$, $P_c = 0.05$; d = 50 000 [m]
Contour interval : 0.5

Fig.III.20 Same as Fig.III.18 but for rms observation error **REF_S_SN = 10**

Experiments with $\mu(r, p) = \mu_h(r) * \mu_v(p)$, $\mu_v(p) = \exp(-1/2*(dp_{ij} / P_c)^2)$, $P_c = 0.05$; d = 100 000 [m], REF_S_SN = 10 for 00021818

Fig.III.21 Model orography [m] and the altitute of the observation points with snow quantity in the cmafoc file for 00021818 (the observations which have passed the QC against the guess)

Fig.III.22 Guess field for 00021818.Contour intervals :0.1,2,5,10,30,50,70

Fig.III.23 Analysis for 00021818. With red stars are visualized the values of snow quantity at the observation points , passed QC against guess
Same contour itervals as for Fig.III.21.

Fig.III.24 Increments field for 00021818

Fig.III.25-Fig.III.26 Guess and analysis for 00021818 with values of the snow quantity at the observation points. Visualization by GraDS

Fig.III.27-Fig.III.28 Increments field for 00021818 with values of the differences OMG (Obs-Guess). Visualization by GraDS

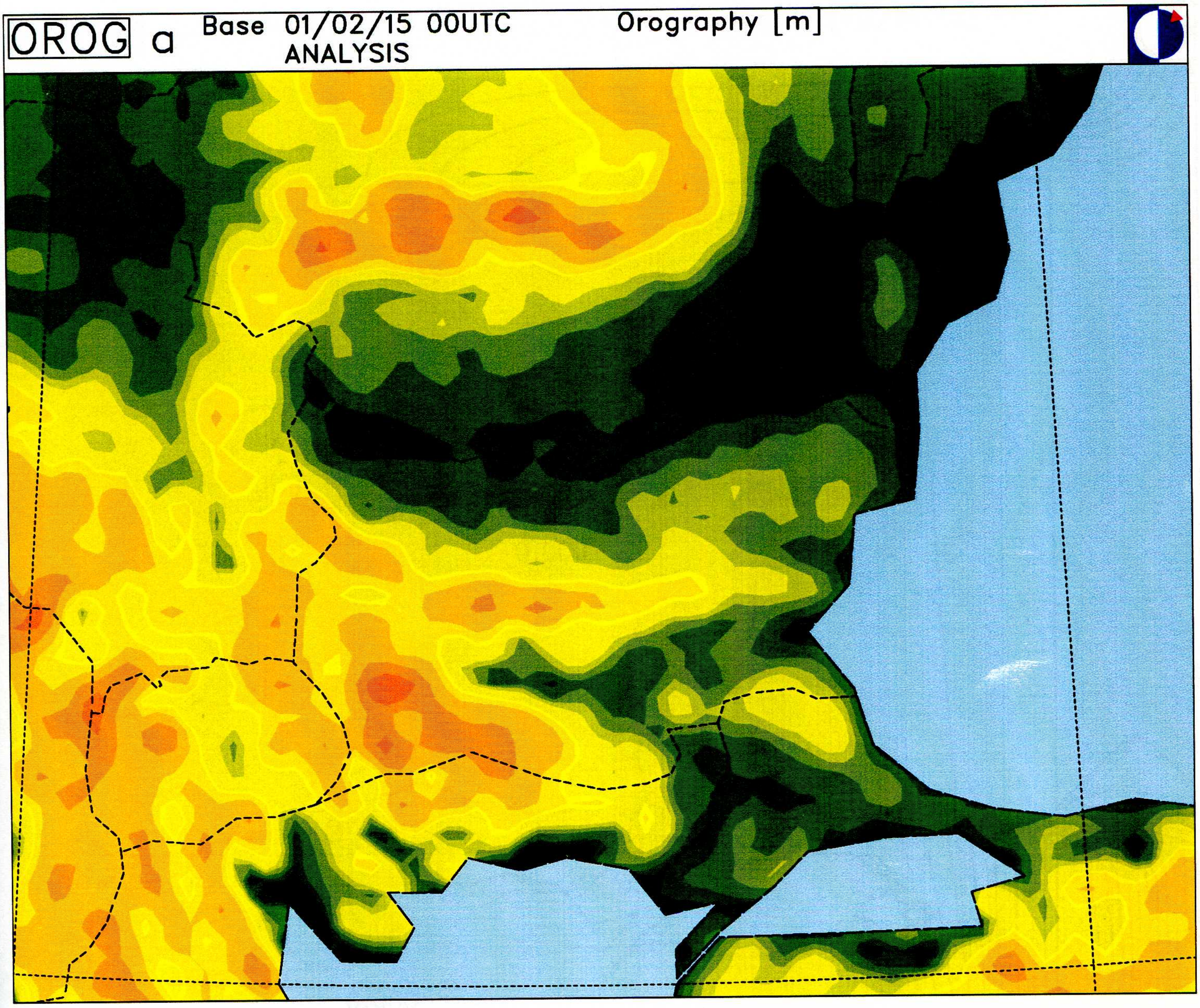


Fig. III-1

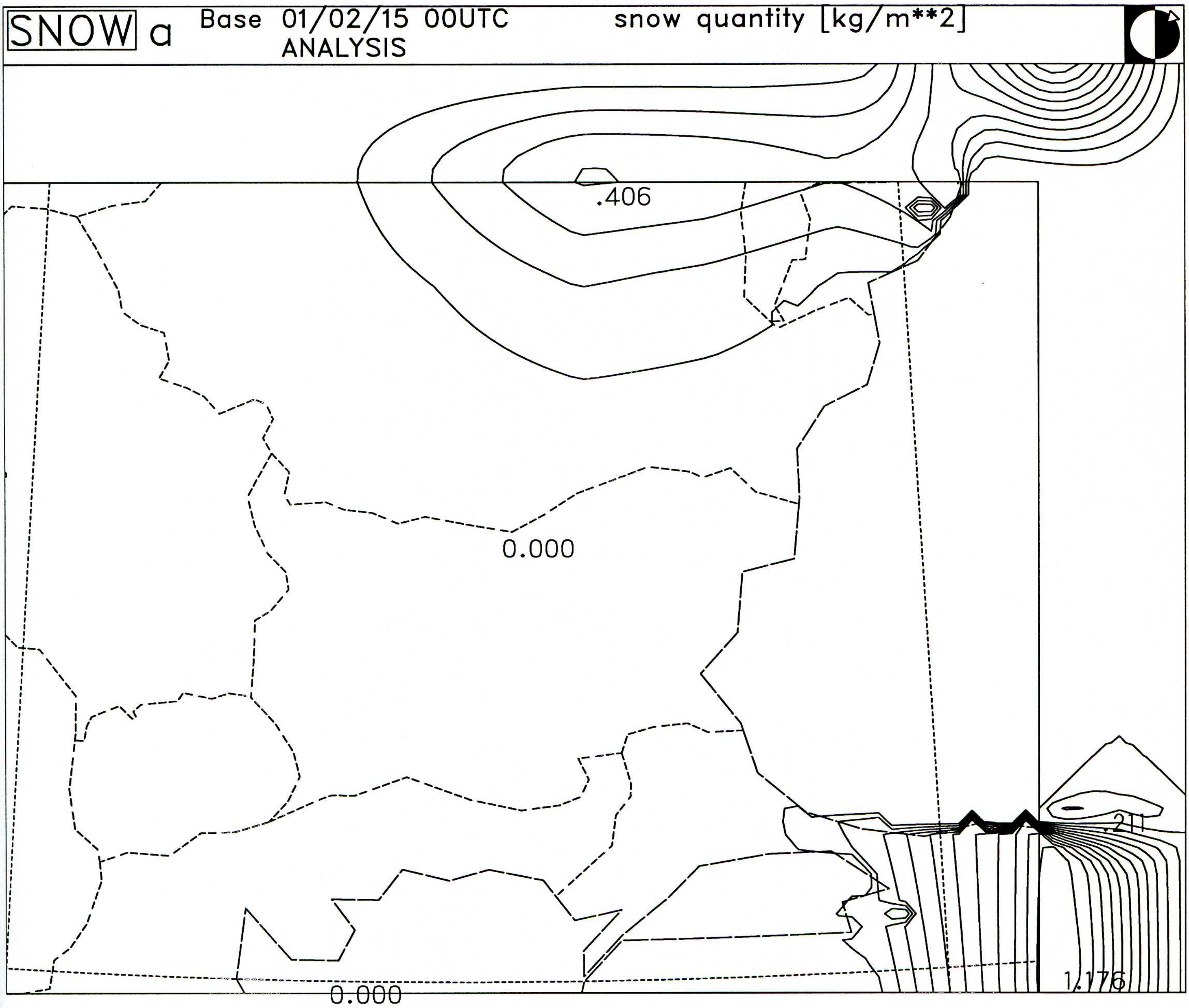

SNOW a
Base 01/02/15 00UTC
ANALYSIS
snow quantity [kg/m**2]
.406
0.000
.211
1.176
0.000

Fig. XII-2

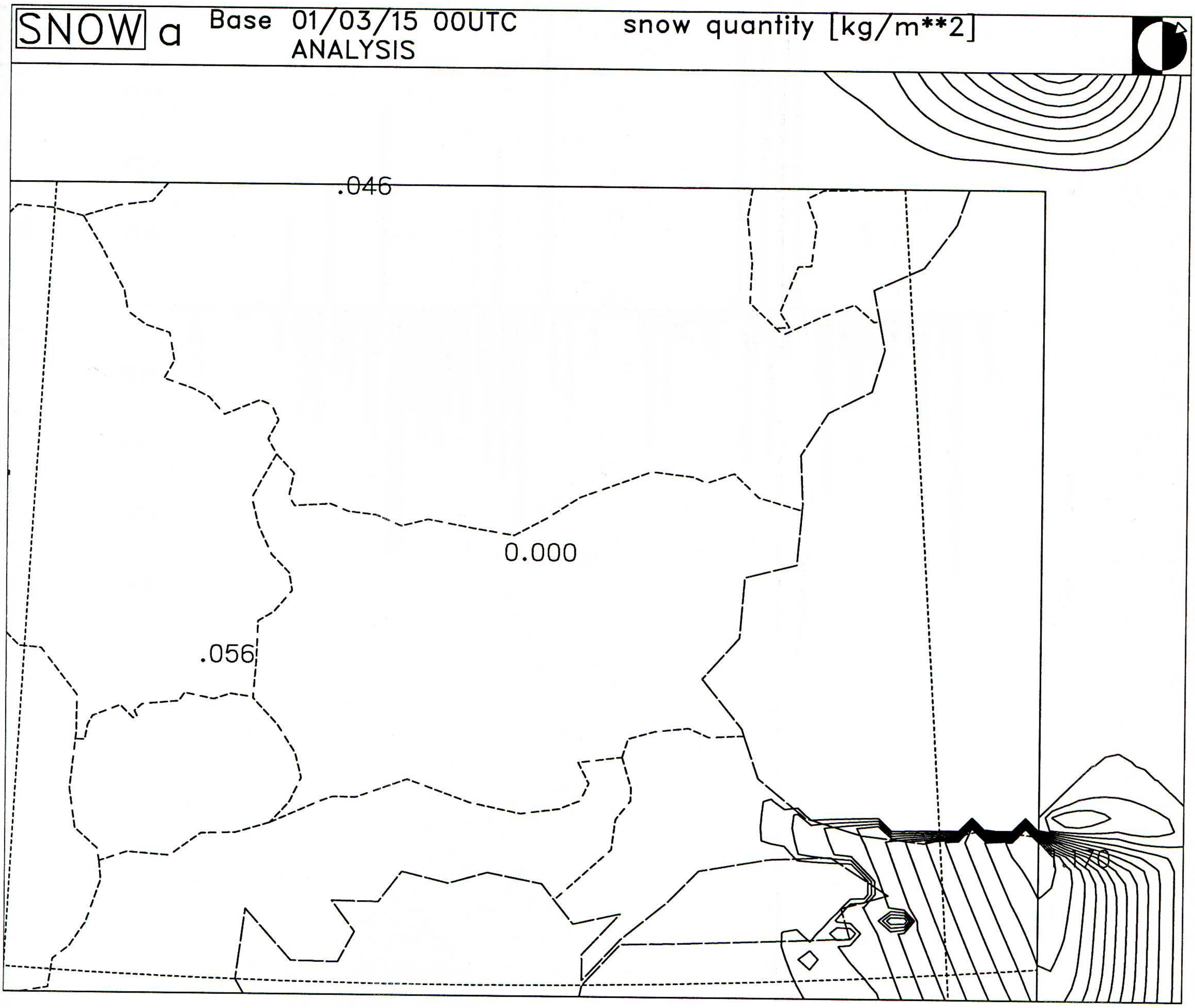

SNOW a
Base 01/03/15 00UTC
ANALYSIS
snow quantity [kg/m**2]
.046
0.000
.056

Fig. III-3

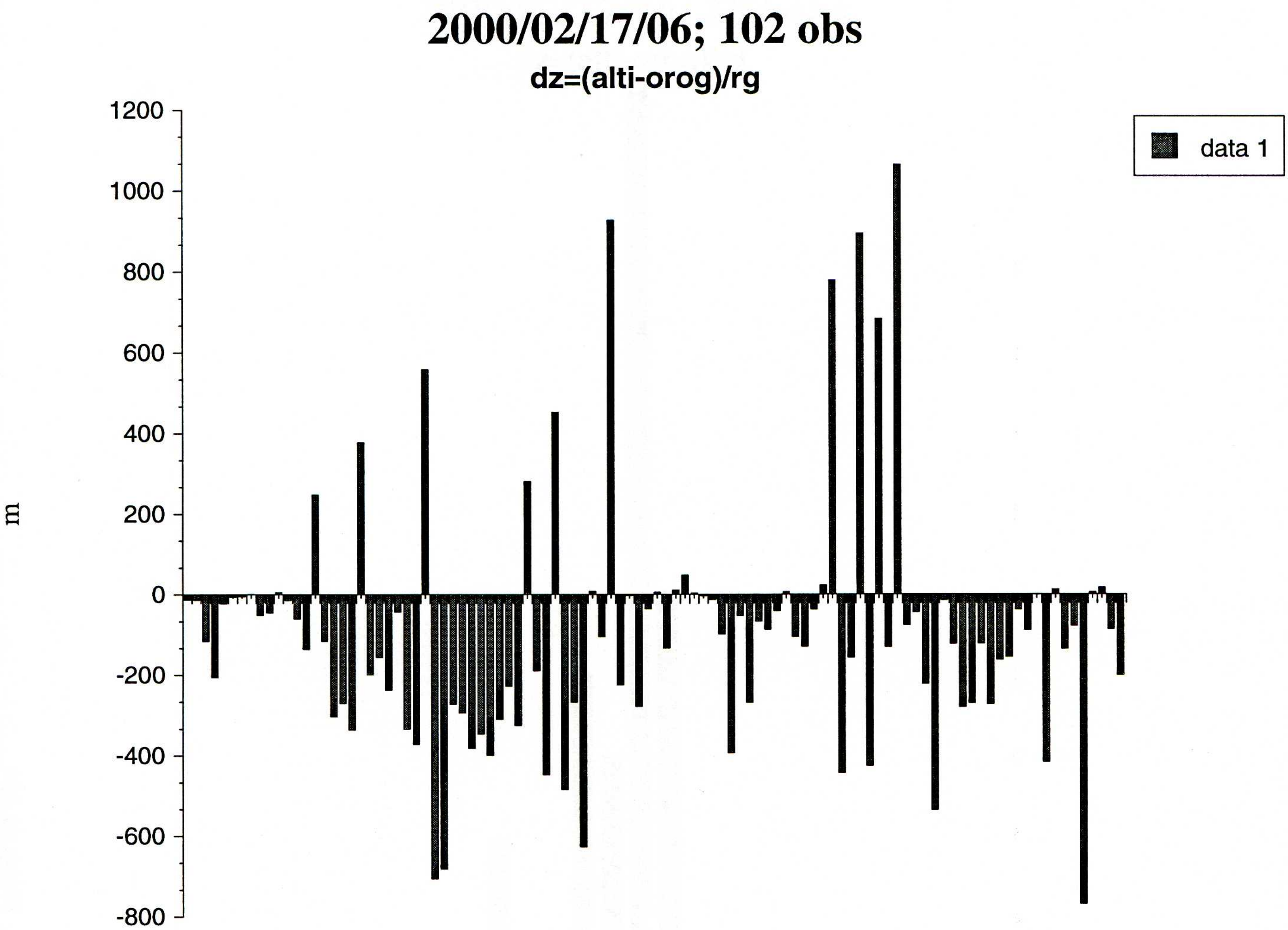

2000/02/17/06; 102 obs
dz=(alti-orog)/rg
1200
1000
800
600
400
200
0
-200
-400
-600
-800
m
data 1

Fig. III-4

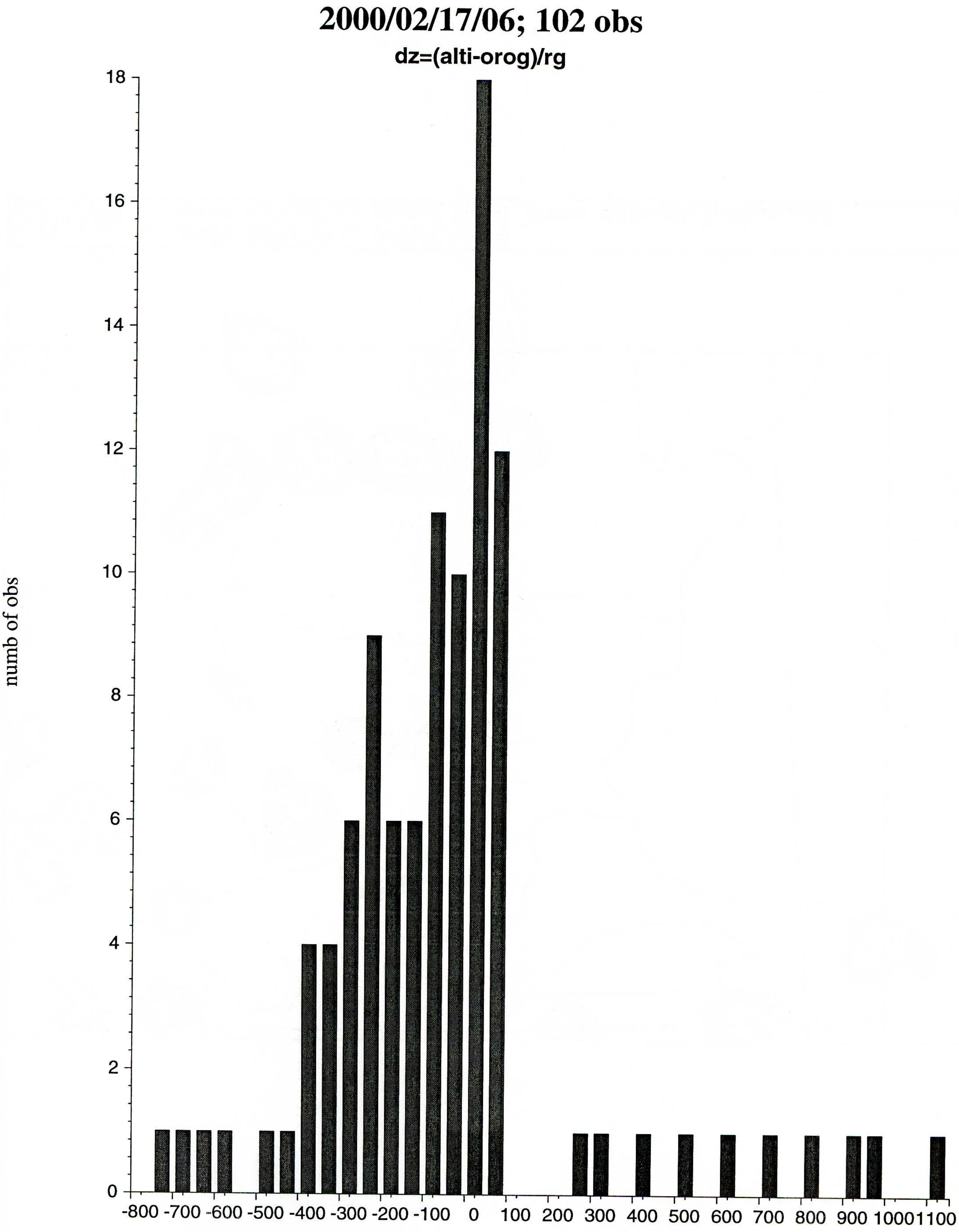

2000/02/17/06; 102 obs
dz=(alti-orog)/rg
numb of obs
18
16
14
12
10
8
6
4
2
0
-800 -700 -600 -500 -400 -300 -200 -100 0 100 200 300 400 500 600 700 800 900 10001100

Fig. III - 5

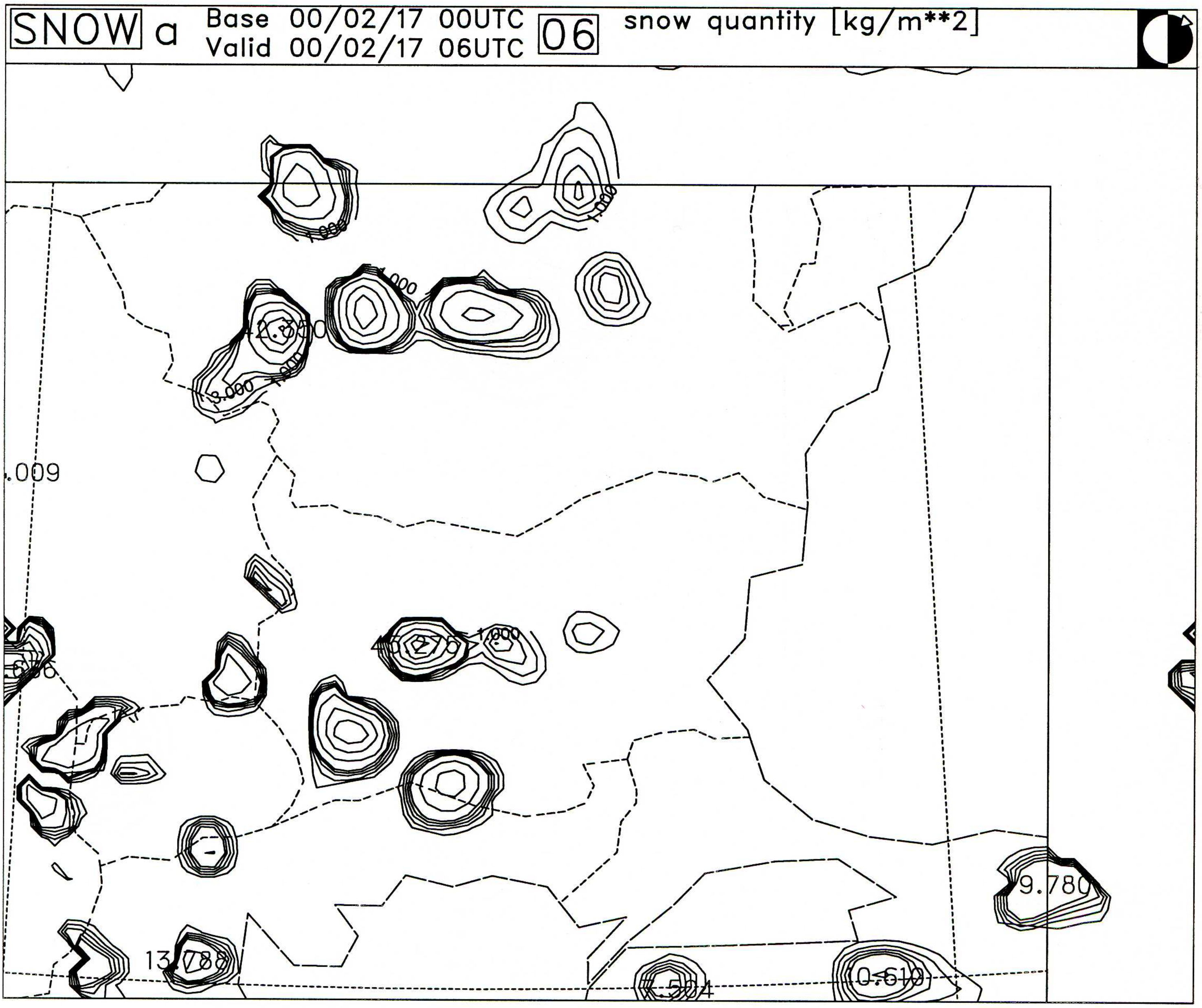

SNOW a
Base 00/02/17 00UTC
Valid 00/02/17 06UTC
06
snow quantity [kg/m**2]
1.000
1.000
1.000
1.000
3.000
1.000
.009
1.000
9.780
13.788
7.504
0.610

Fig. III-6

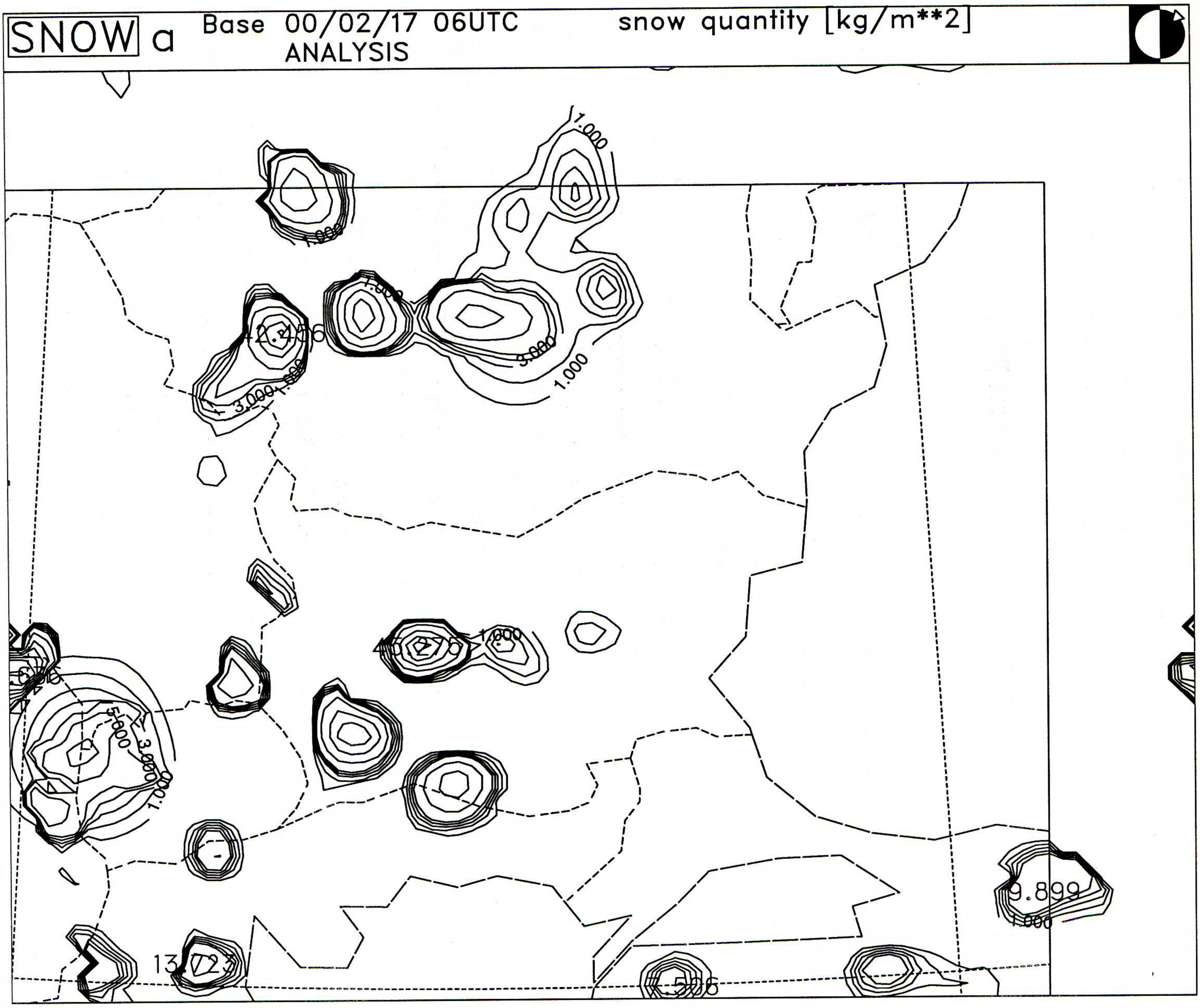

SNOW a
Base 00/02/17 06UTC
ANALYSIS
snow quantity [kg/m**2]
1.000
3.000
9.899

Fig. III-7

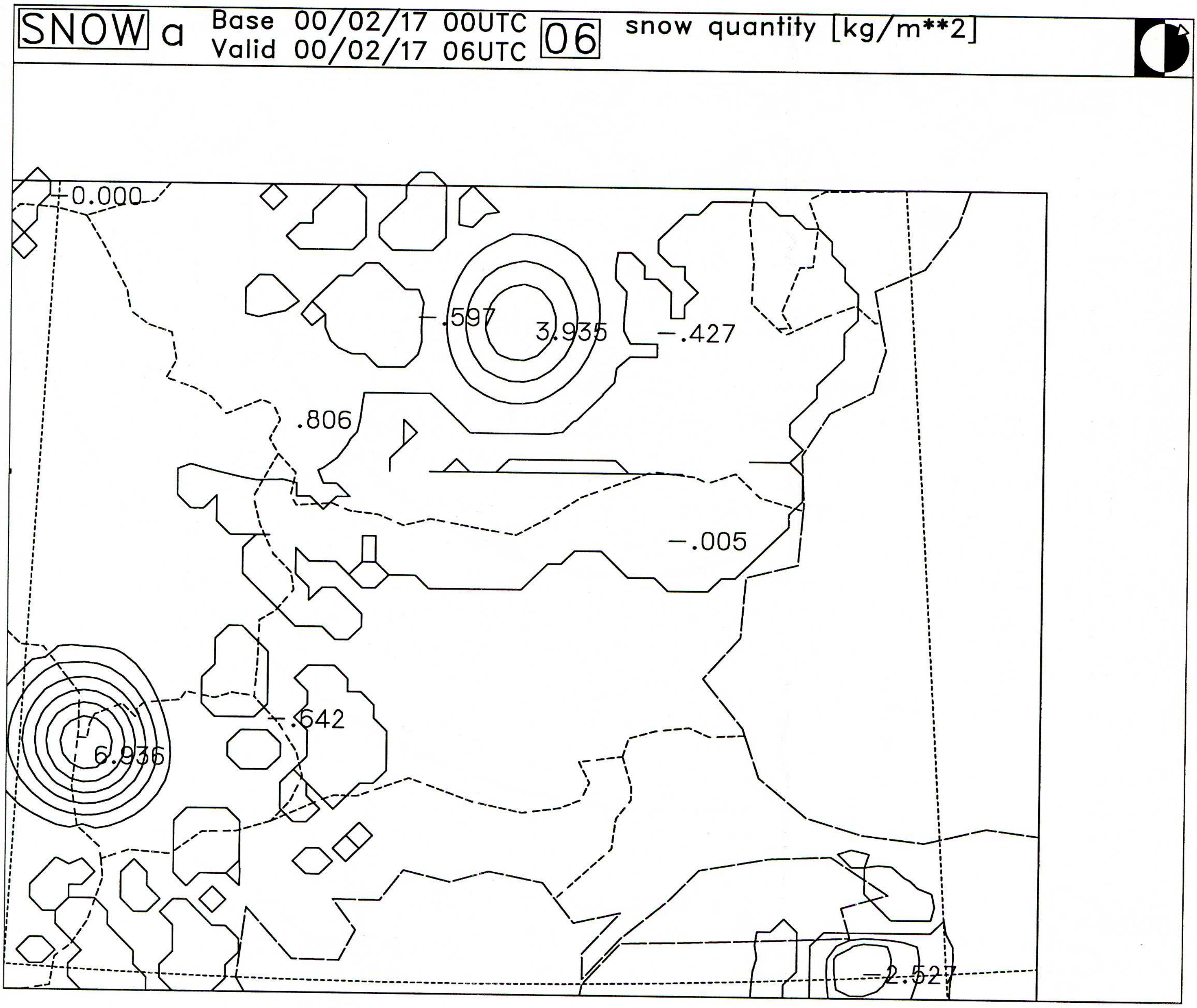
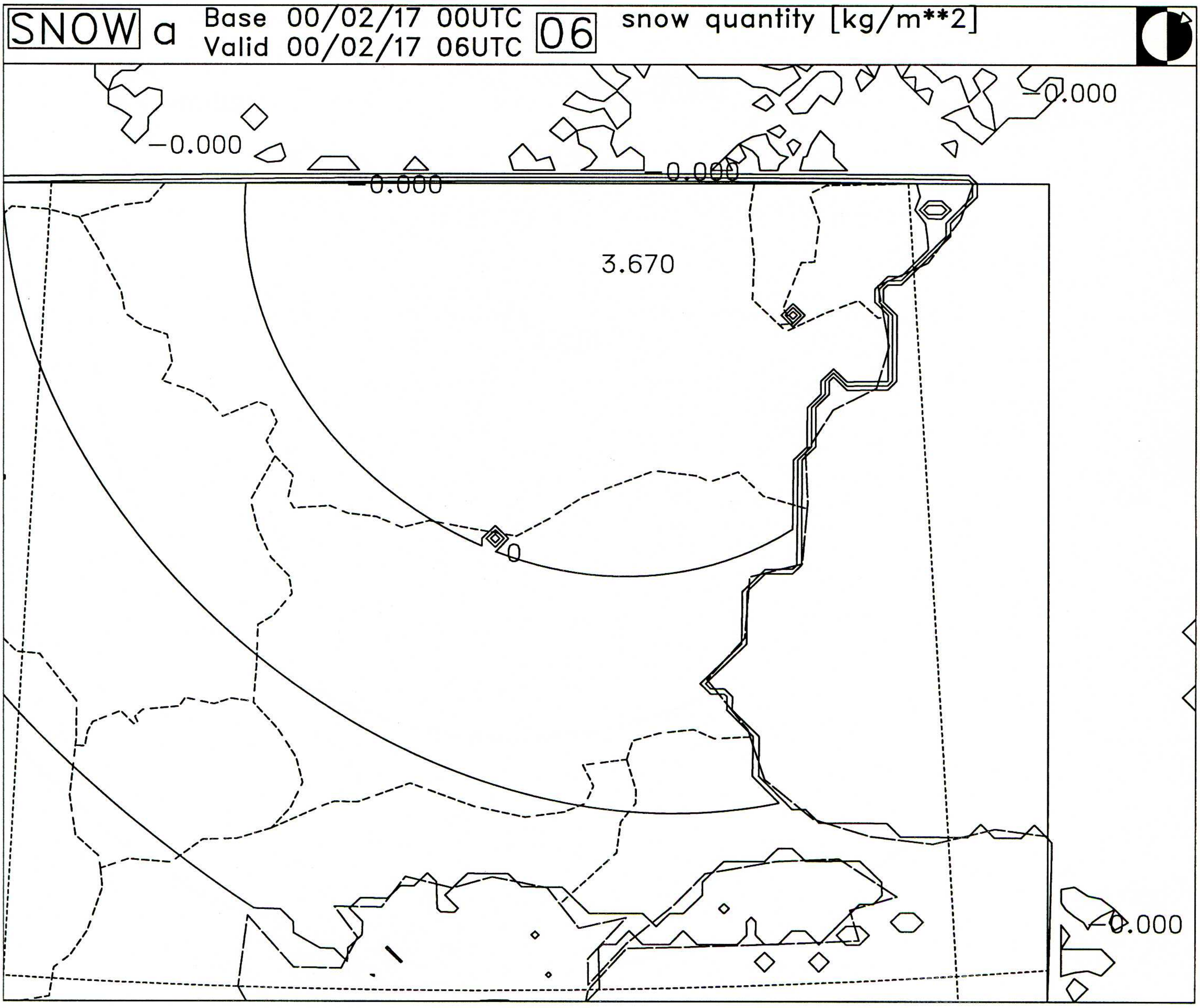

SNOW a
Base 00/02/17 00UTC
Valid 00/02/17 06UTC
06
snow quantity [kg/m**2]
0.000
.597
3.935
.427
.806
.005
.642
6.936
2.527

Fig. III-8



SNOW a
Base 00/02/17 00UTC
Valid 00/02/17 06UTC
06
snow quantity [kg/m**2]
-0.000
-0.000
-0.000
-0.000
3.670
0
-0.000

fig. III-9

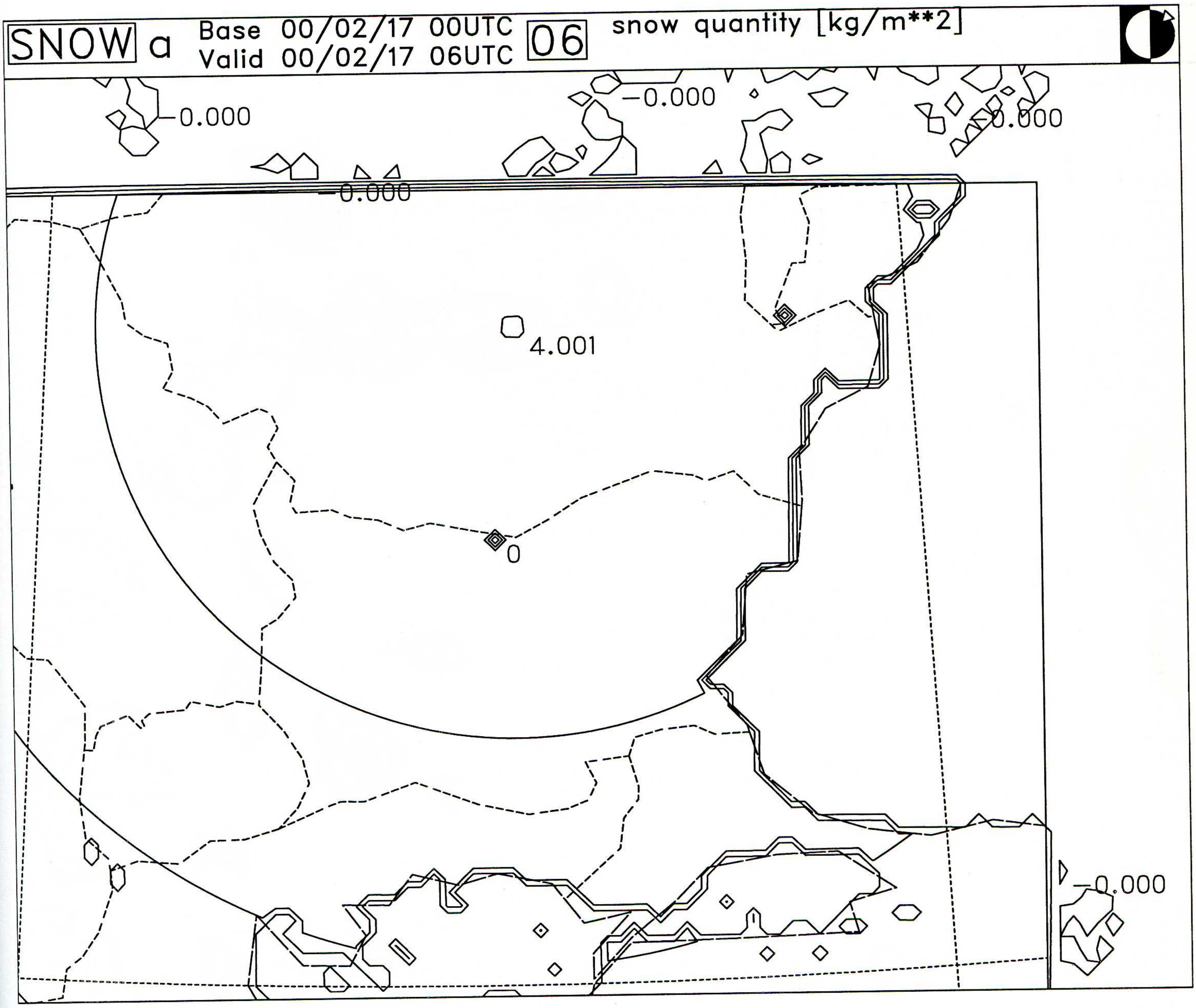

SNOW a
Base 00/02/17 00UTC
Valid 00/02/17 06UTC
06
snow quantity [kg/m**2]
-0.000
-0.000
-0.000
-0.000
4.001
0
-0.000

Fig. III.10

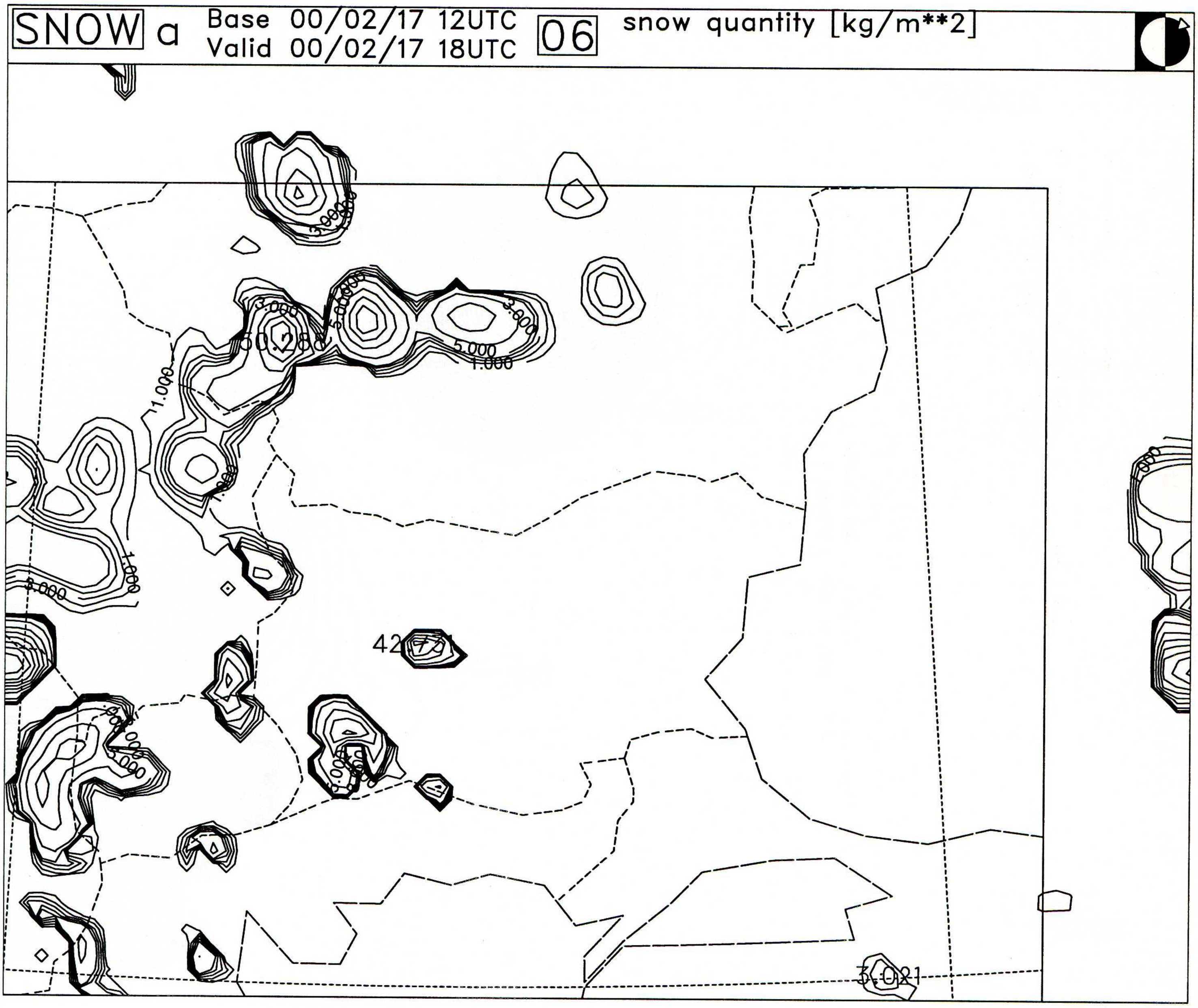
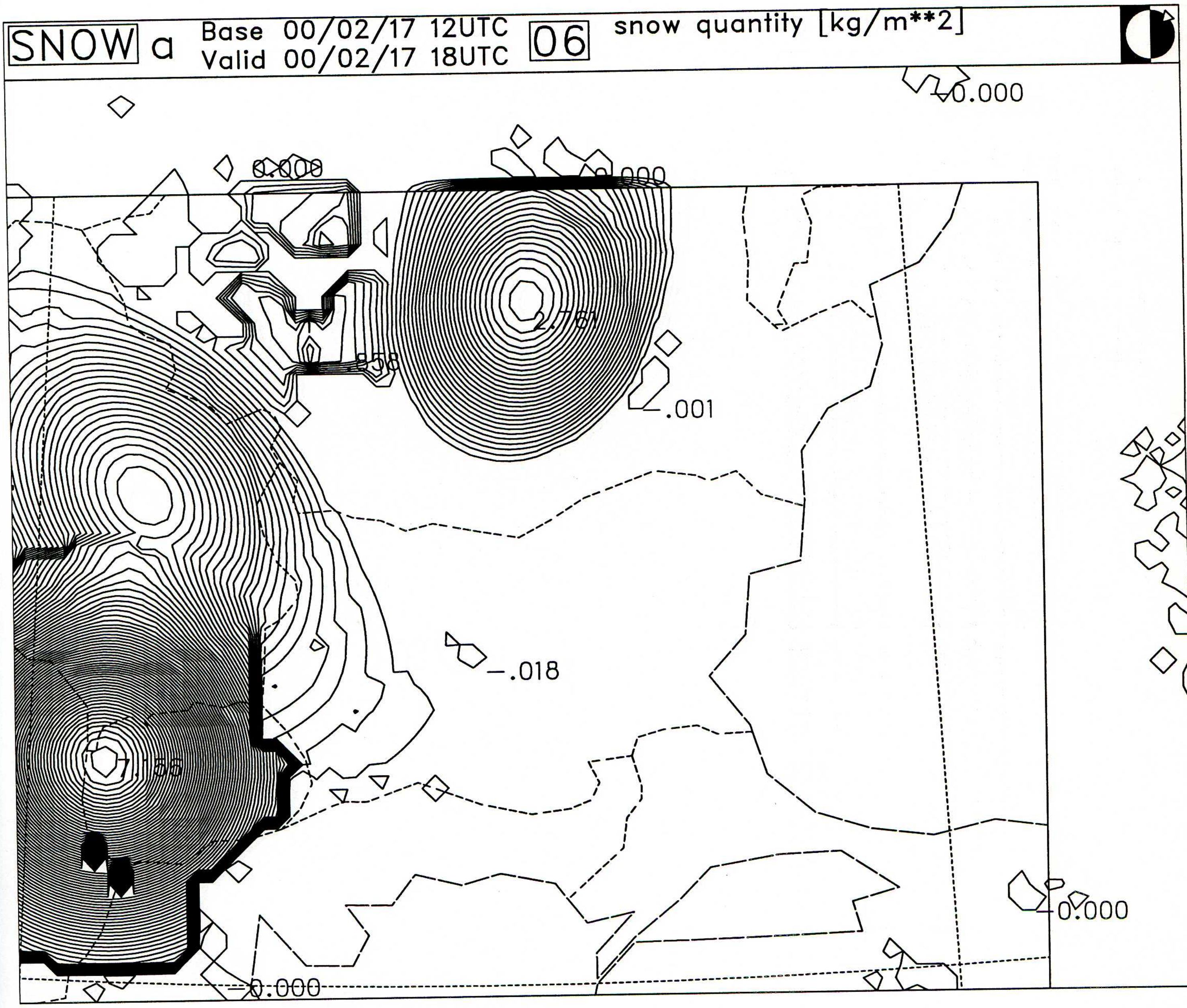

SNOW a
Base 00/02/17 12UTC
Valid 00/02/17 18UTC
06
snow quantity [kg/m**2]

Fig. III. 11



SNOW a
Base 00/02/17 12UTC
Valid 00/02/17 18UTC
06
snow quantity [kg/m**2]
0.000
0.000
0.000
2.761
.001
-.018
0.000
0.000

Fig. III.12

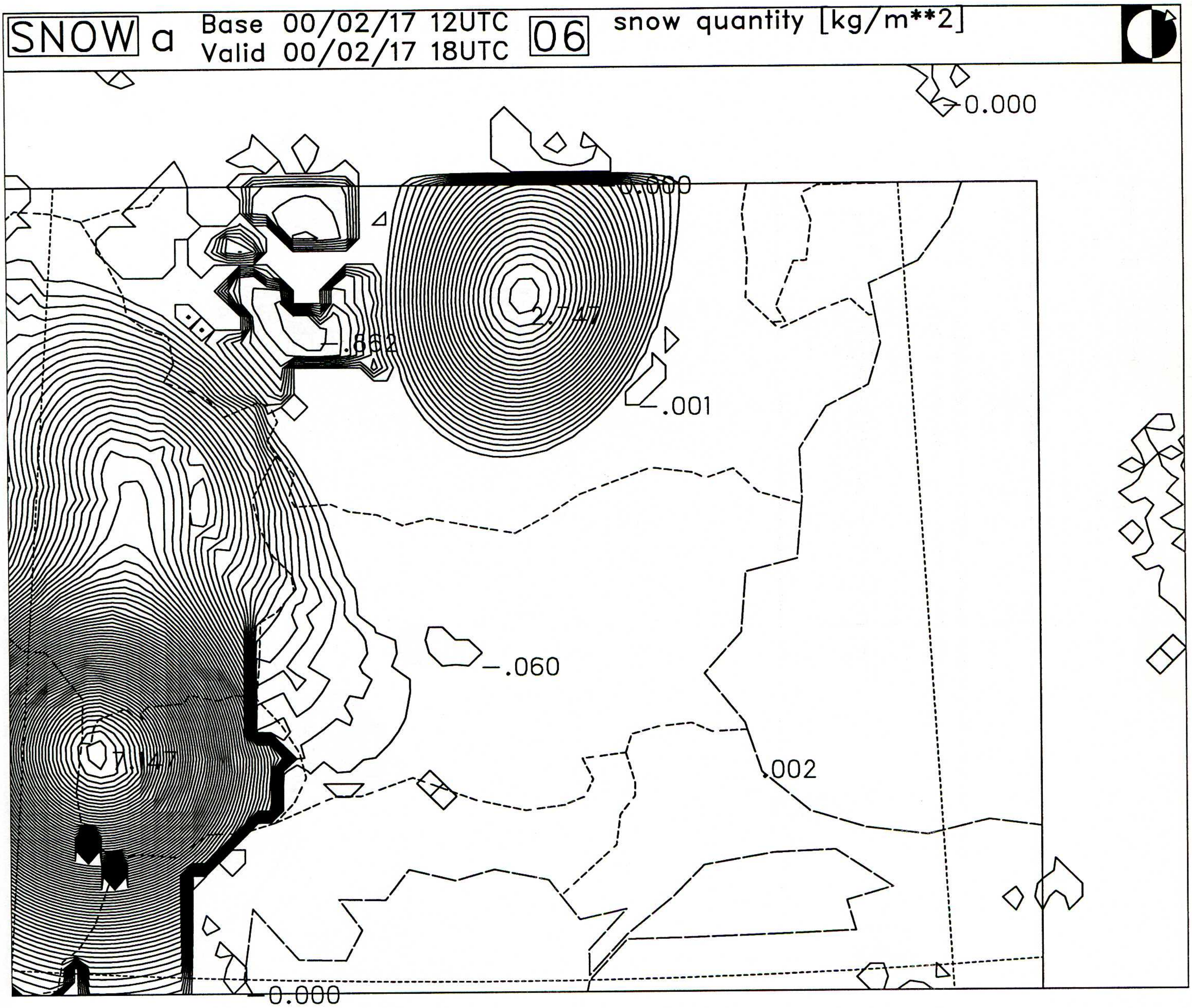
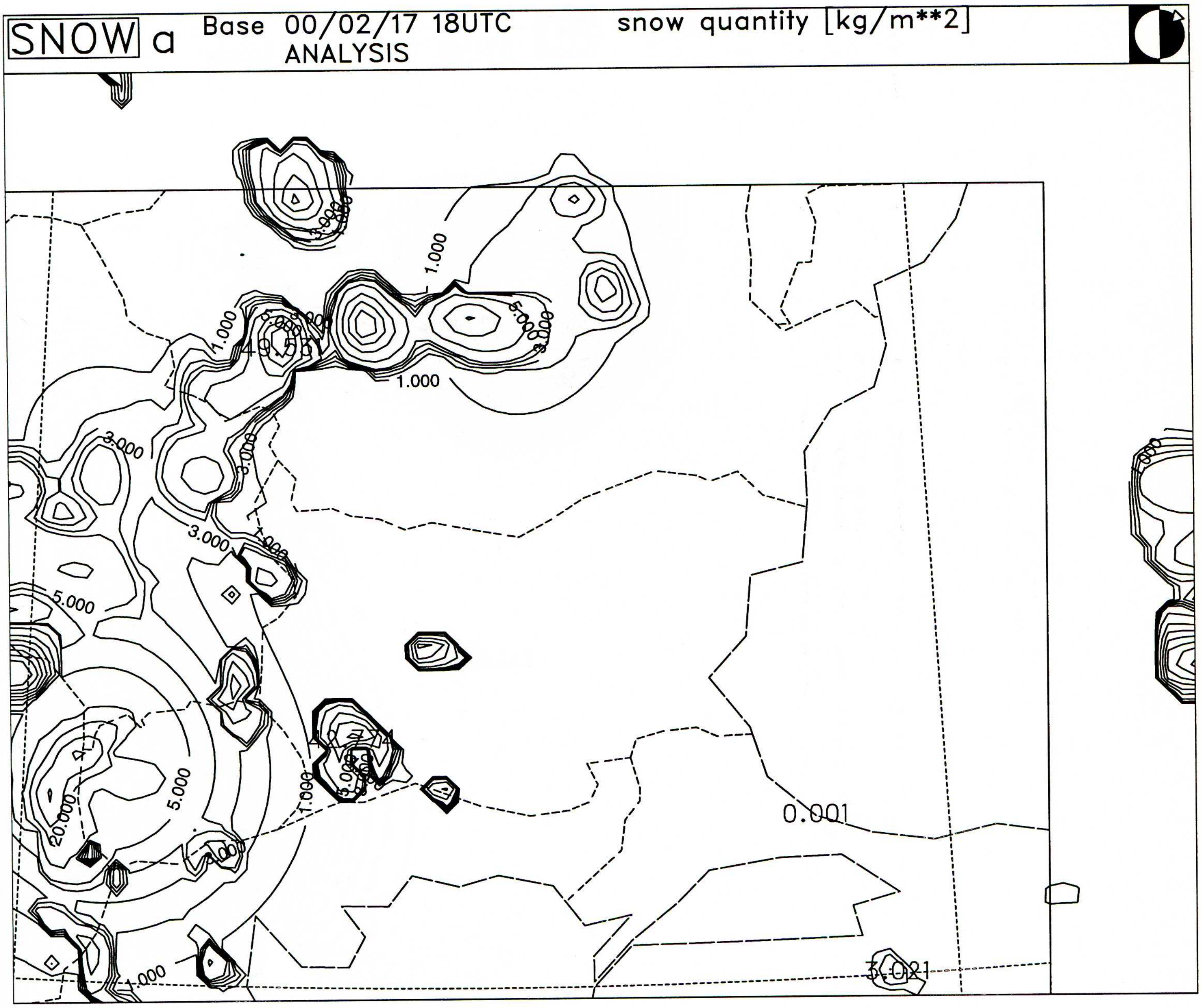
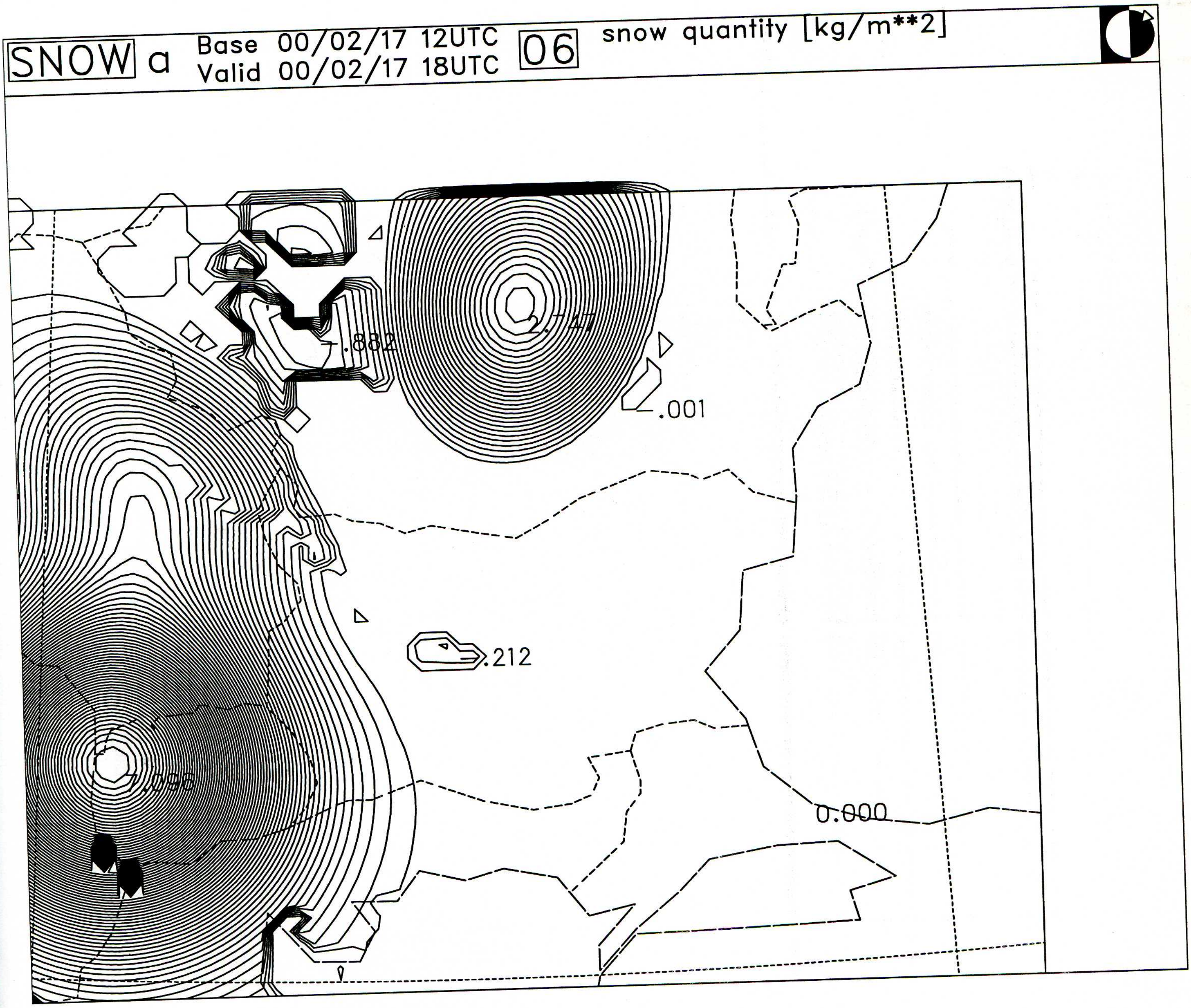

SNOW a
Base 00/02/17 12UTC
Valid 00/02/17 18UTC
06
snow quantity [kg/m**2]
0.000
0.000
2.747
.862
.001
.060
7.147
.002
0.000

Fig. III. 13



SNOW a
Base 00/02/17 18UTC
ANALYSIS
snow quantity [kg/m**2]
1.000
3.000
5.000
20.000
0.001

Fig. III.14



SNOW a
Base 00/02/17 12UTC
Valid 00/02/17 18UTC
06
snow quantity [kg/m**2]
.882
2.747
.001
.212
.096
0.000

Fig. III.15

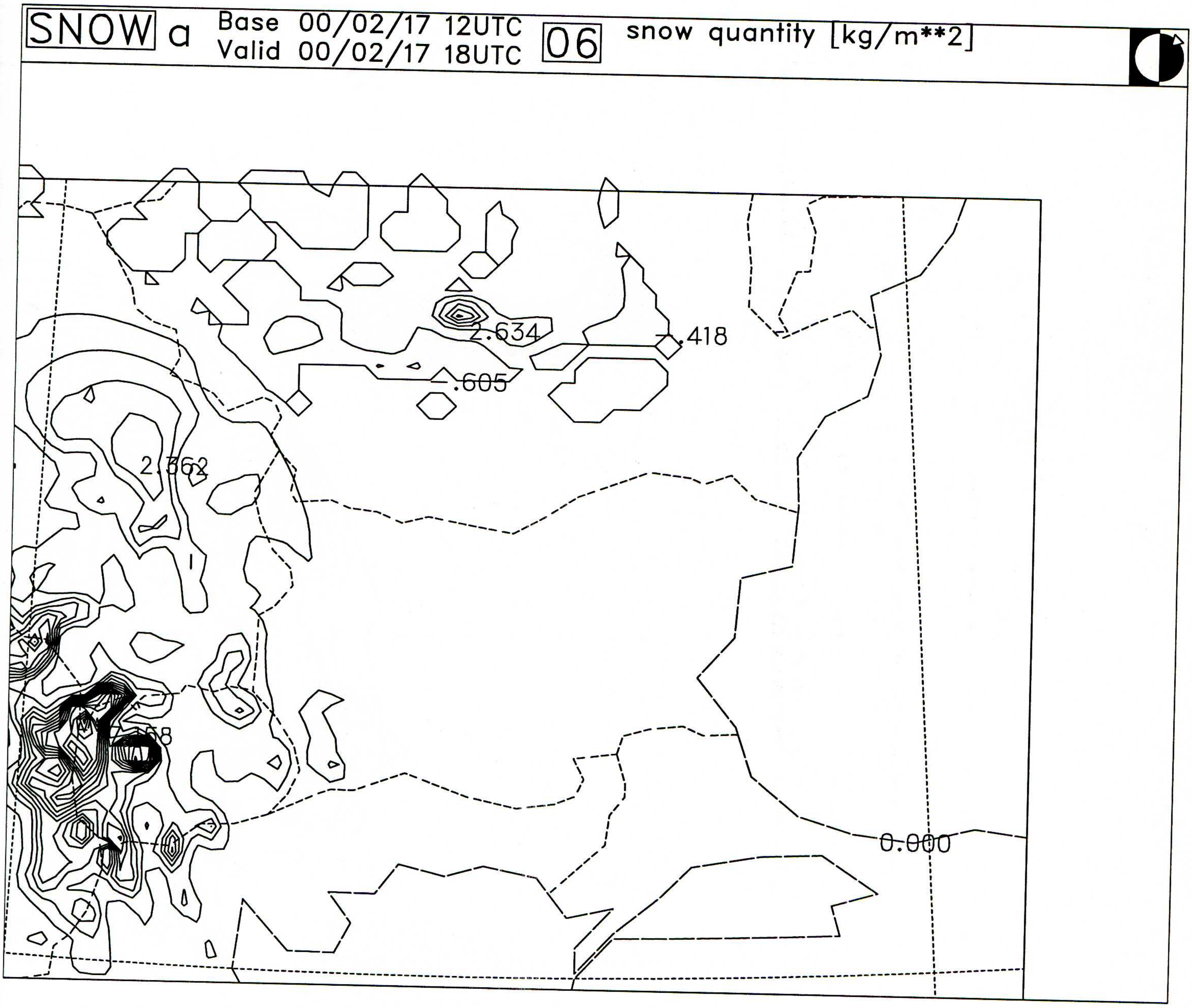

SNOW a
Base 00/02/17 12UTC
Valid 00/02/17 18UTC
06
snow quantity [kg/m**2]
2.634
.418
.605
2.362
0.000

Fig III 16

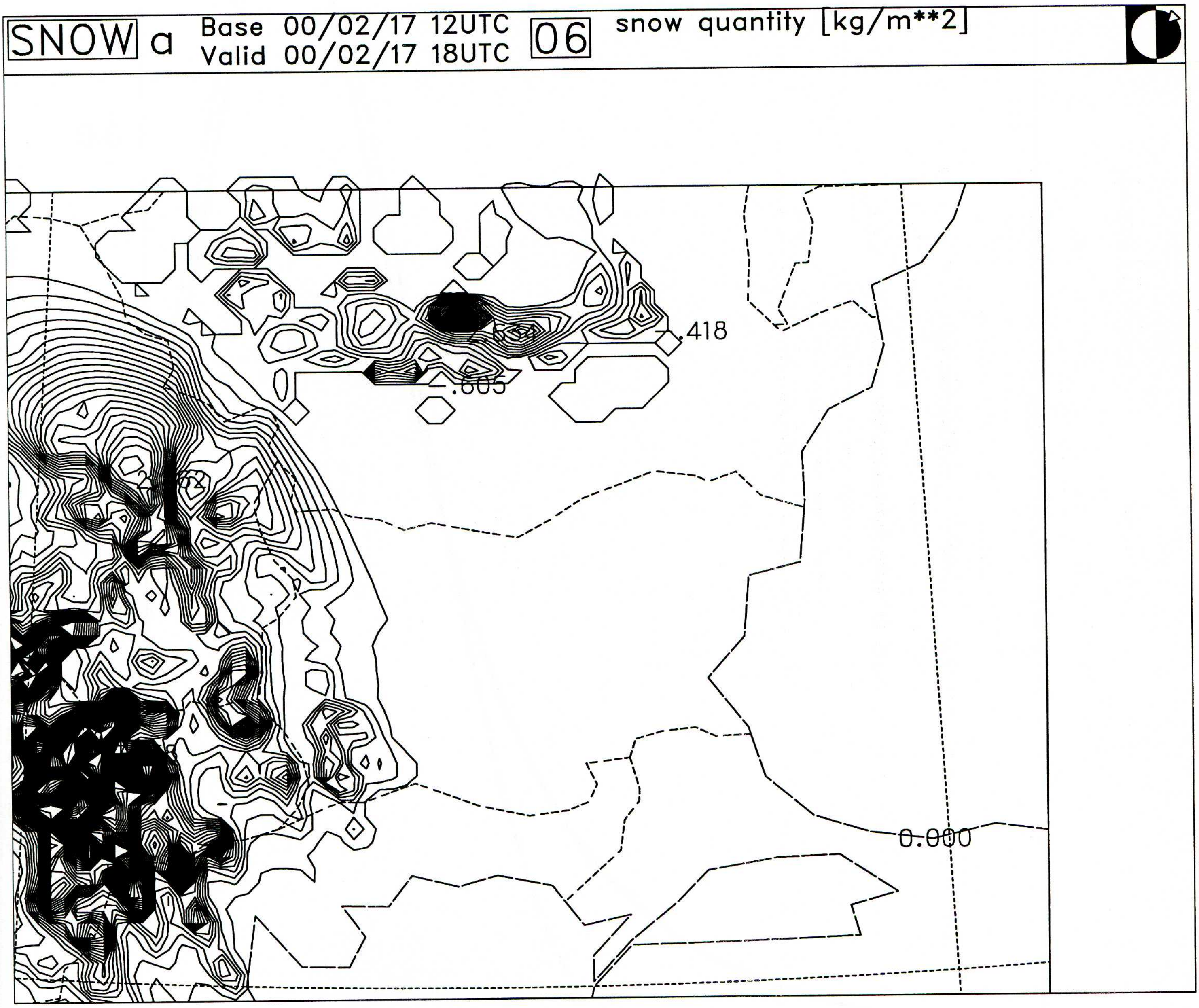

SNOW a
Base 00/02/17 12UTC
Valid 00/02/17 18UTC
06
snow quantity [kg/m**2]
.418
.605
0.000

Fig. III.17

Comparison of two vertical correlation functions

Altitude of observation is 500m

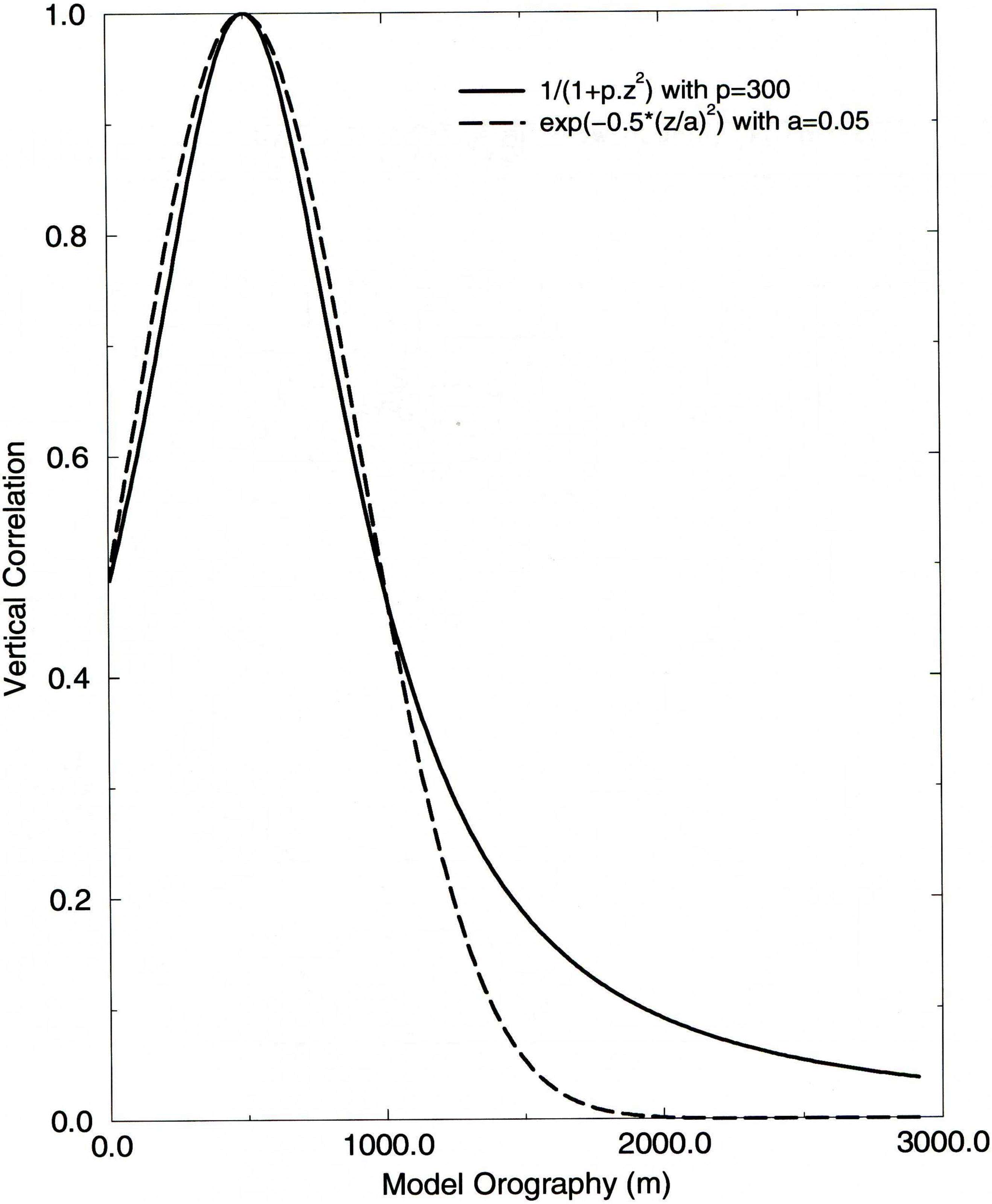
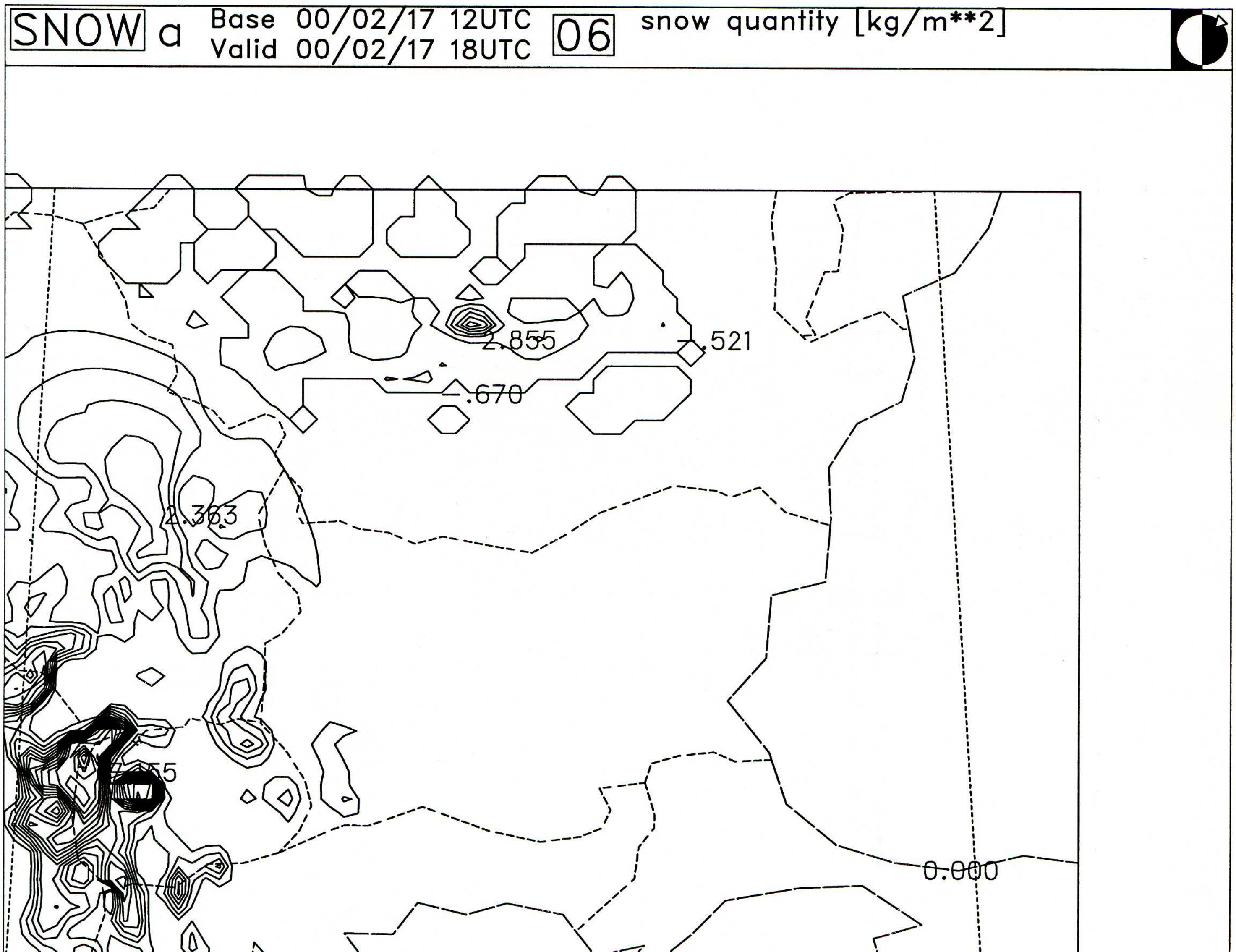


Fig. III. 18


SNOW a
Base 00/02/17 12UTC
Valid 00/02/17 18UTC
06
snow quantity [kg/m**2]
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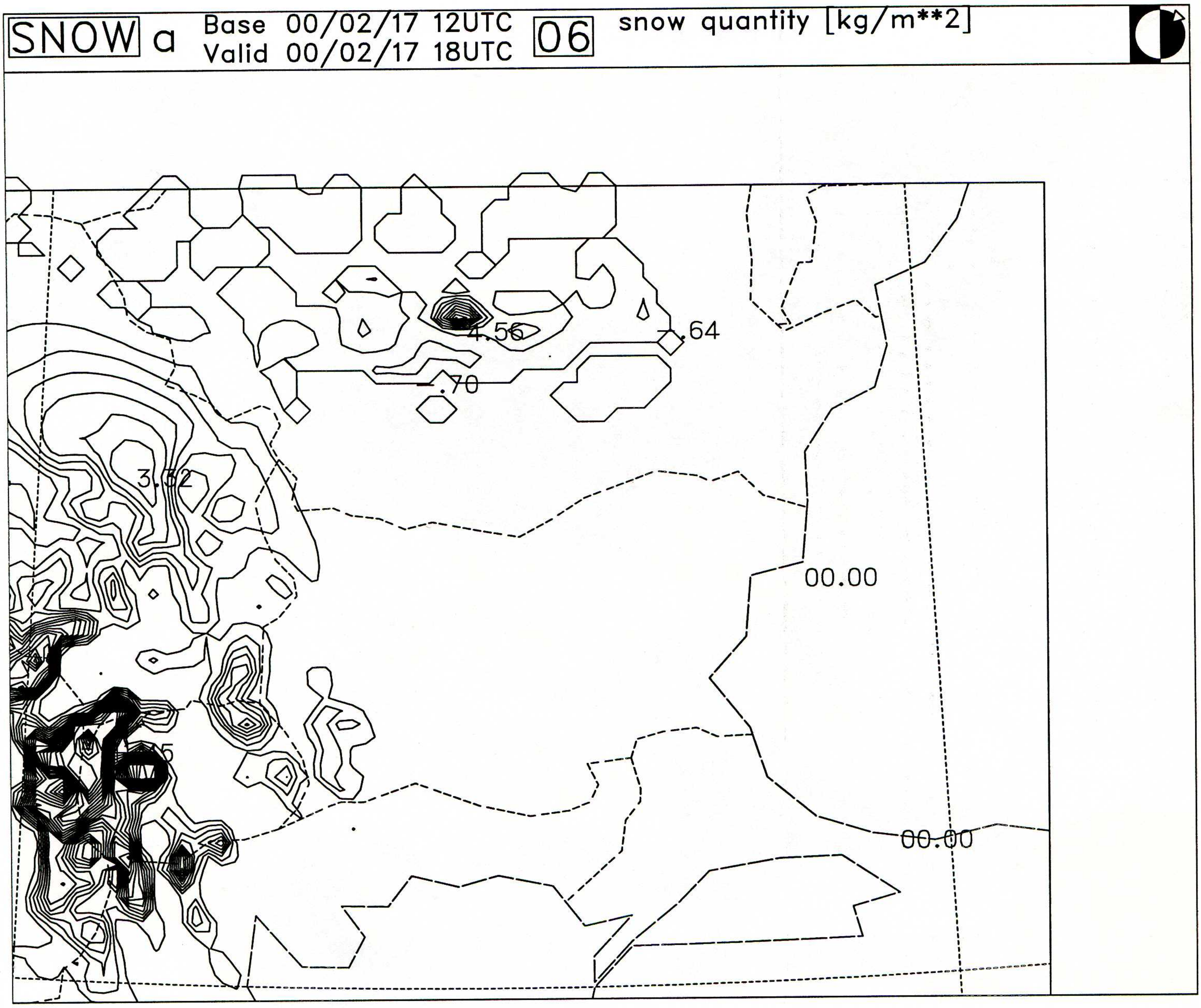
.521
.670
2.363
0.000

Fig. III.19


SNOW a
Base 00/02/17 12UTC
Valid 00/02/17 18UTC
06
snow quantity [kg/m**2]
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.64
.70
3.52
00.00
00.00

Fig. III.20

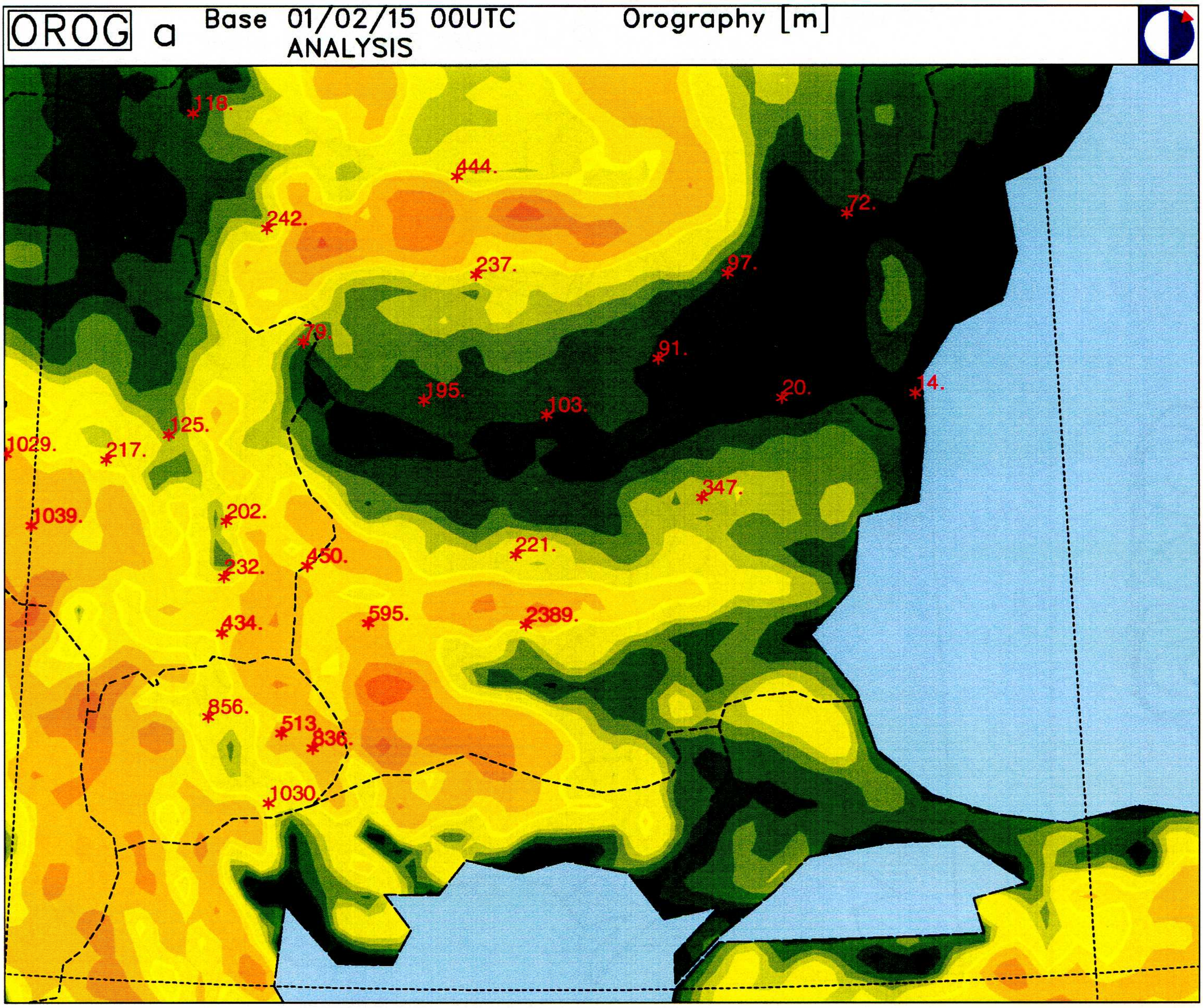

OROG
a
Base 01/02/15 00UTC
ANALYSIS
Orography [m]
118.
444.
72.
242.
97.
237.
79.
91.
195.
20.
14.
103.
125.
1029.
217.
347.
1039.
202.
221.
450.
232.
595.
2389.
434.
856.
513.
836.
1030.

Fig. III. 21

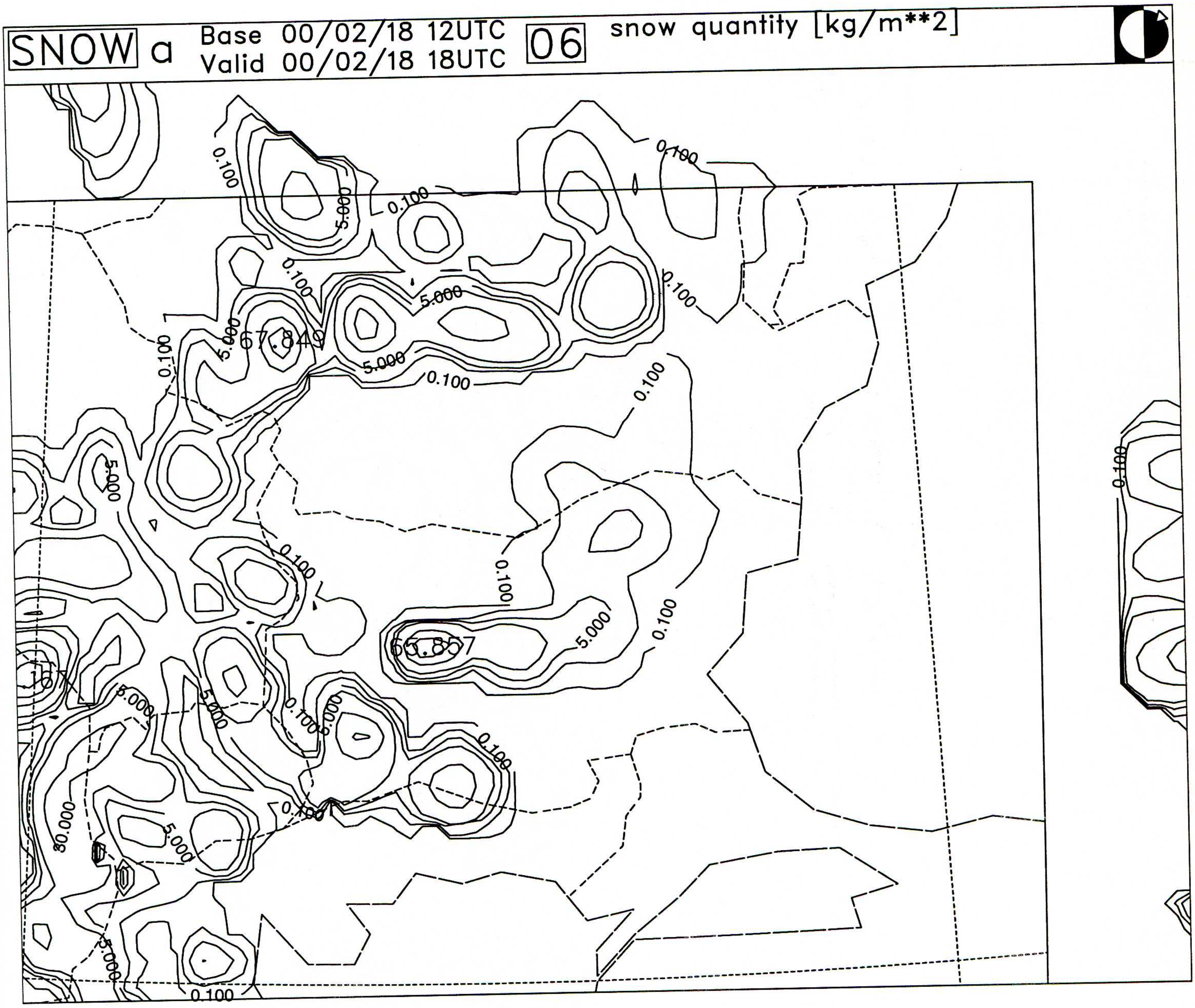

SNOW a
Base 00/02/18 12UTC
Valid 00/02/18 18UTC
06
snow quantity [kg/m**2]
0.100
5.000
67.849
65.857
30.000

Fig. III.22

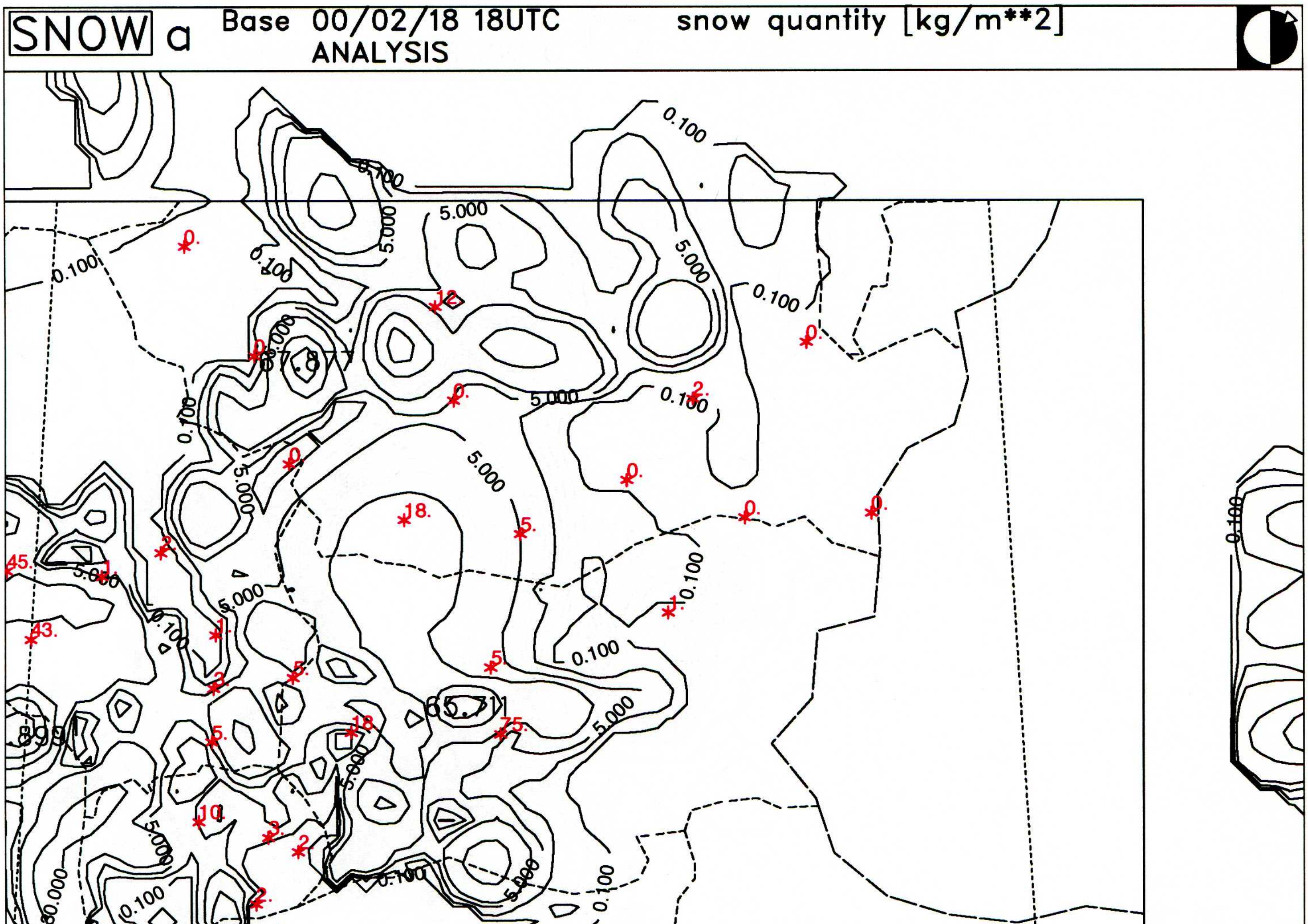

SNOW a
Base 00/02/18 18UTC
ANALYSIS
snow quantity [kg/m**2]
0.100
5.000
30.000

Fig. III, 23

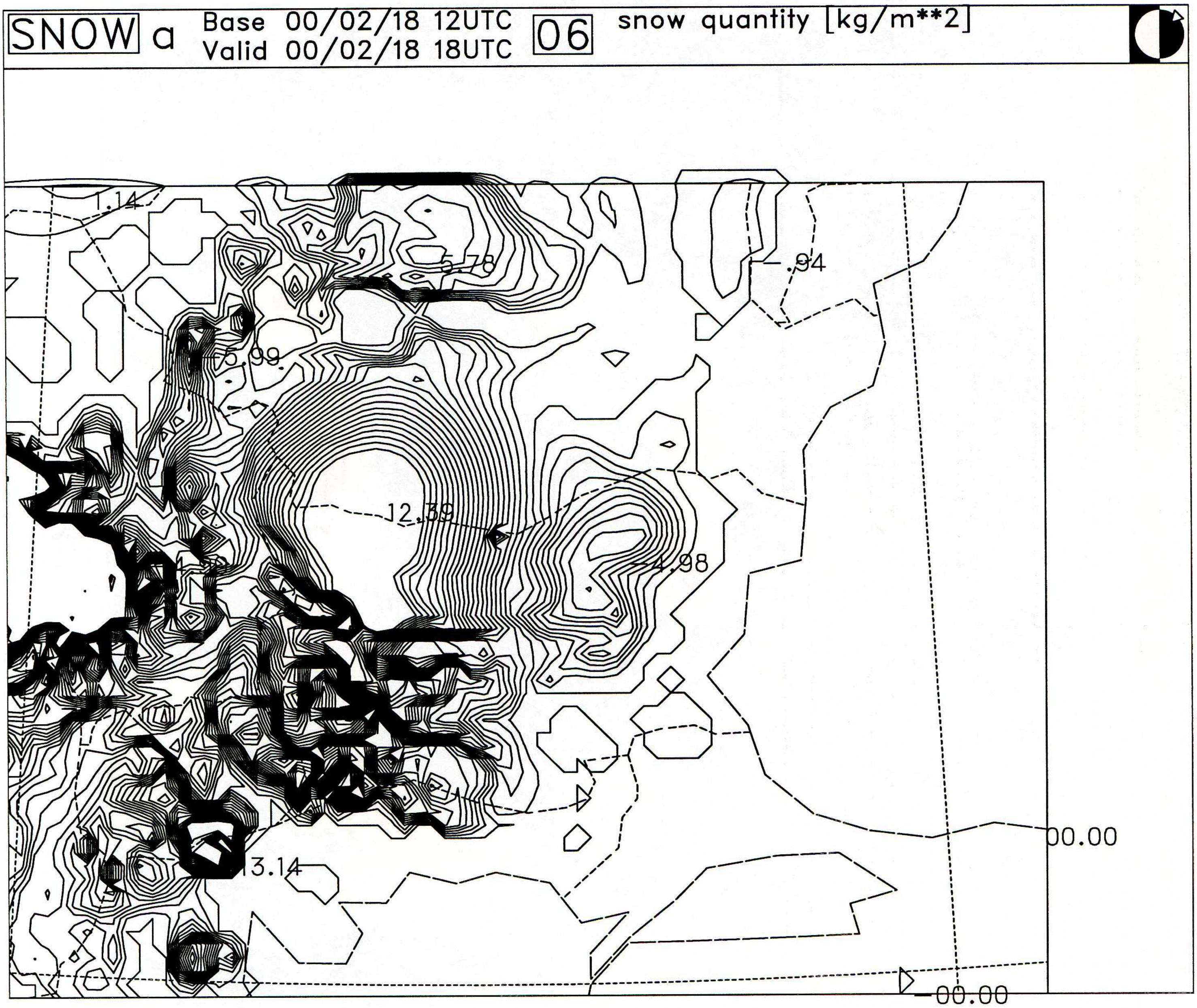
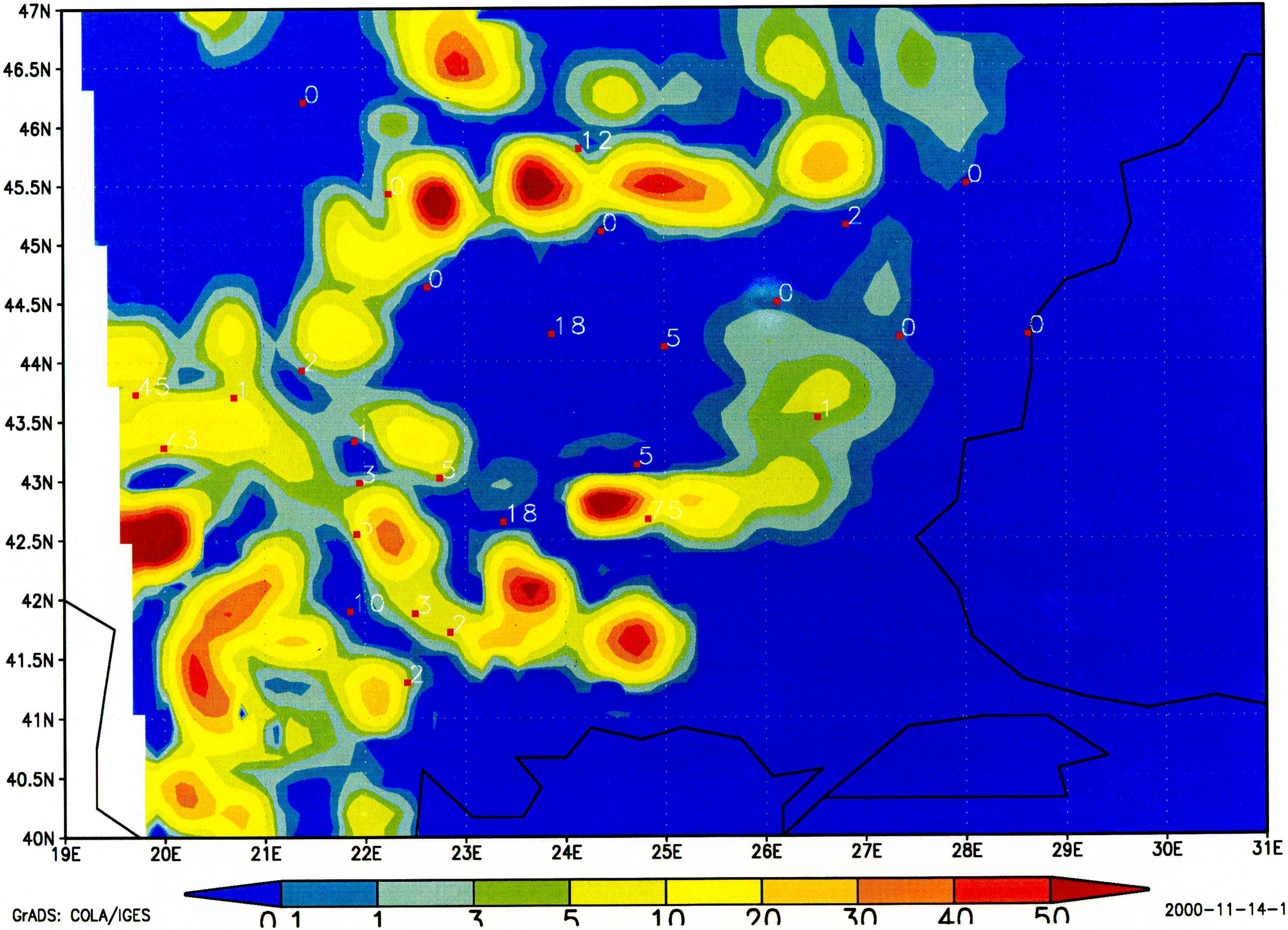

SNOW a
Base 00/02/18 12UTC
Valid 00/02/18 18UTC
06
snow quantity [kg/m**2]
1.14
5.78
.94
5.99
12.39
4.98
13.14
00.00
-00.00

Fig. III.24

SNOW



GrADS: COLA/IGES

2000-11-14-17:34

Fig. III, 25

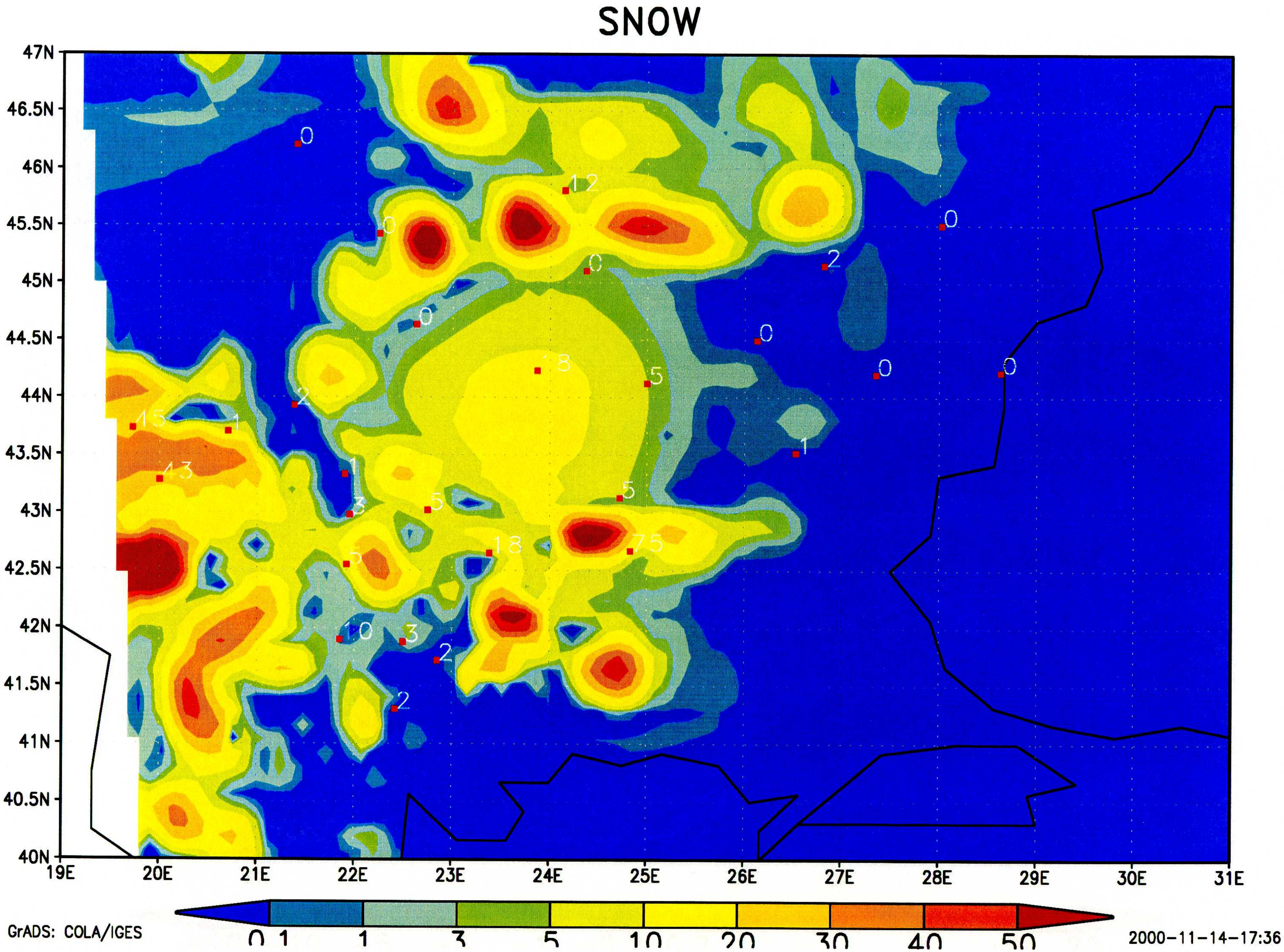

SNOW
47N
46.5N
46N
45.5N
45N
44.5N
44N
43.5N
43N
42.5N
42N
41.5N
41N
40.5N
40N
19E
20E
21E
22E
23E
24E
25E
26E
27E
28E
29E
30E
31E
0.1
1
3
5
10
20
30
40
50
GrADS: COLA/IGES
2000-11-14-17:36

Fig. III. 26

SNOW

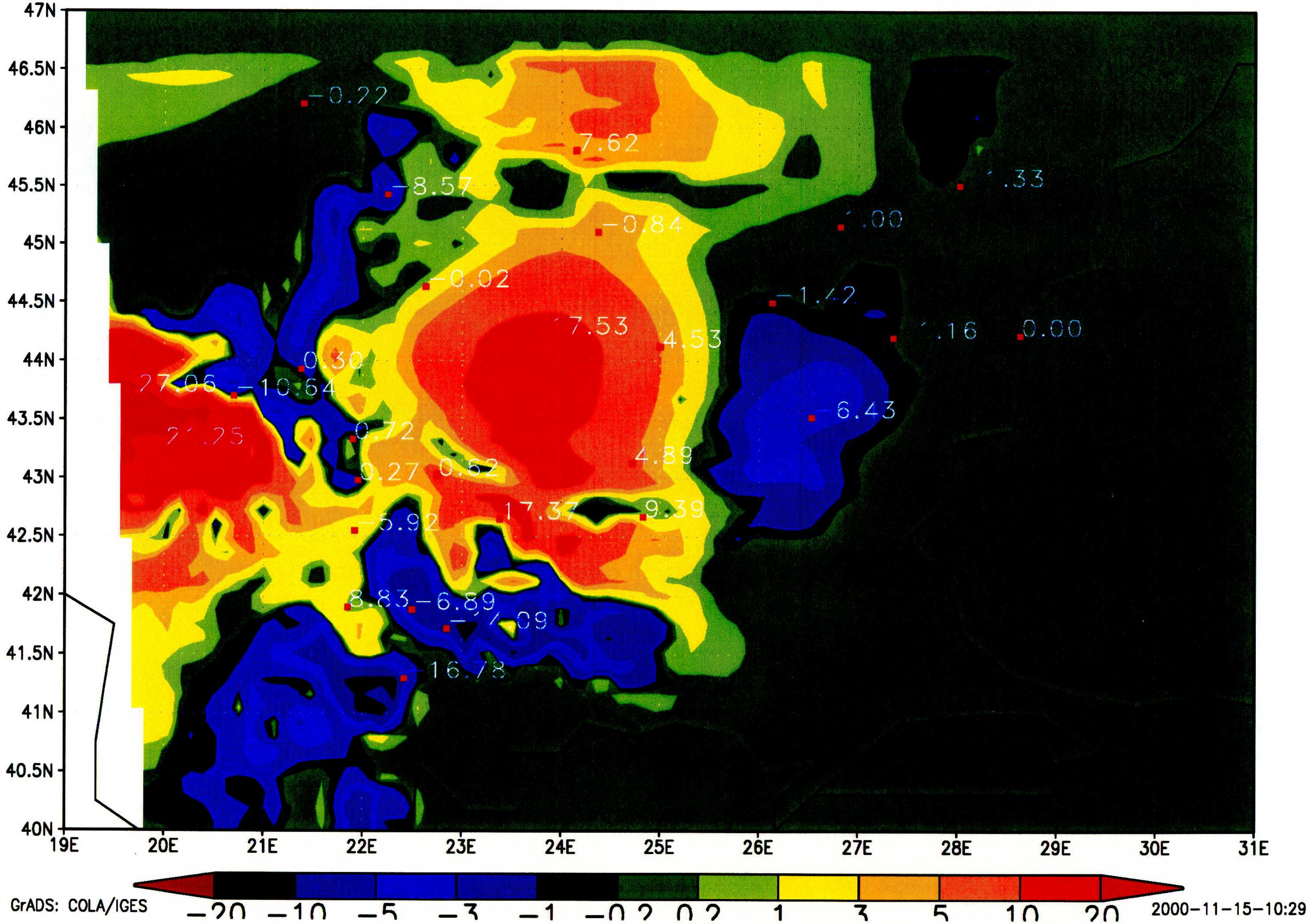


Fig. III.27

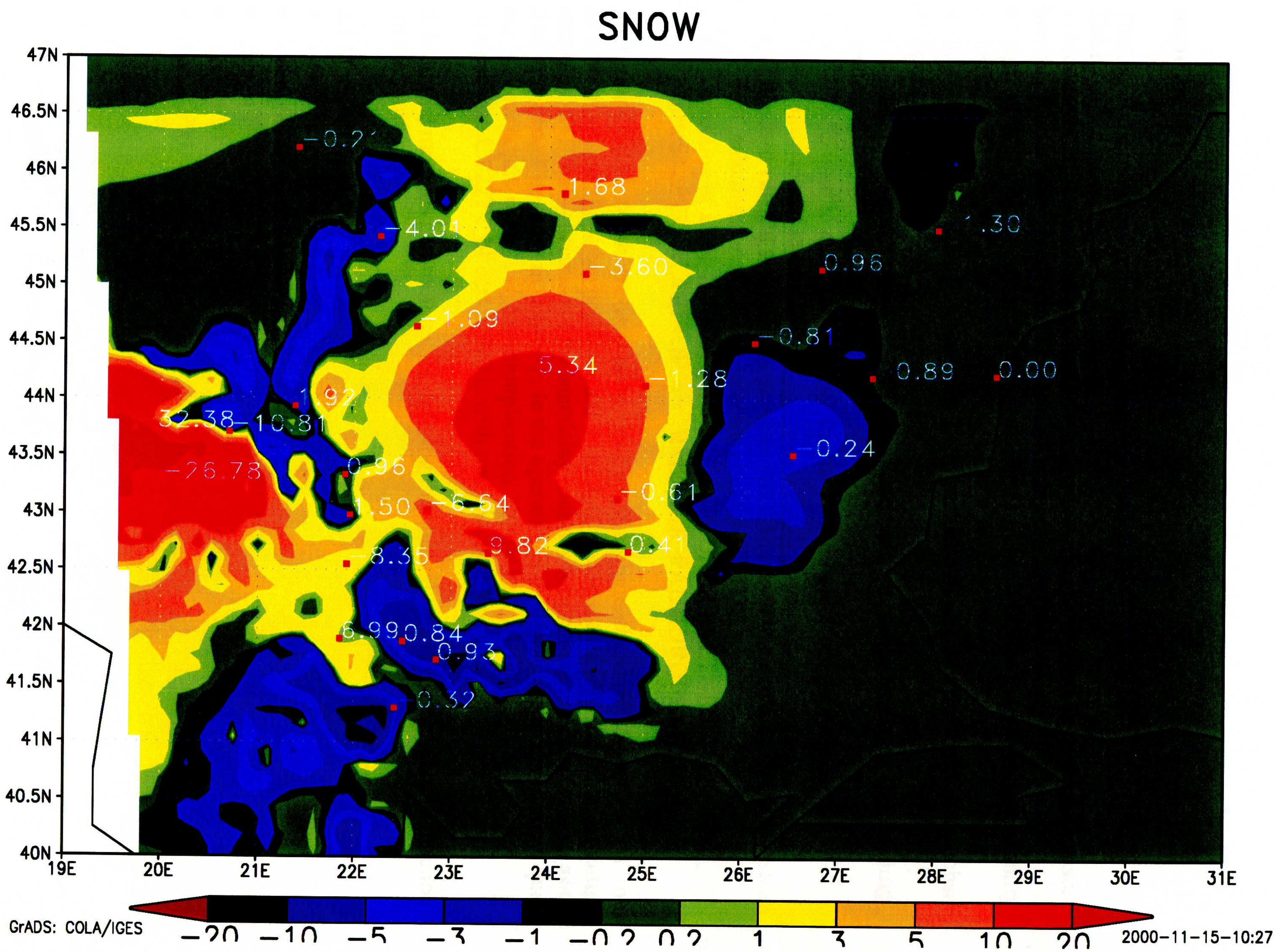

SNOW
47N
46.5N
46N
45.5N
45N
44.5N
44N
43.5N
43N
42.5N
42N
41.5N
41N
40.5N
40N
19E
20E
21E
22E
23E
24E
25E
26E
27E
28E
29E
30E
31E
-0.2
1.68
-4.01
-3.60
0.96
.30
-1.09
-0.81
5.34
-1.28
0.89
0.00
1.92
32.38
-10.81
-0.24
-26.78
0.96
-0.61
1.50
-6.64
9.82
0.41
-8.35
6.99
0.84
0.93
0.32
GrADS: COLA/IGES
-20 -10 -5 -3 -1 -0.2 0.2 1 3 5 10 20
2000-11-15-10:27

Fig. IV.28

Attachment IV

The list of the modified modules and routines taken from CY22T2_bf
The modified modules and routines are on kami: ~/canari/compile/tempo
1. Modified routines for performing snow analysis with cmafoc files from the data base, horizontal correlation function and modified snow obs.operator

- castro.F90 - multiplication of the snow depth [m] by 10000 to have the snow quantity in [kg.m^{-2}]
- hop.F90 - model surface temperature ZTS5 included as an input parameter for ppobsn
- ppobsn.F.90 :
  - model surface temperature PTSF5 included as an input parameter in the calling sentence;
  - PTSF5 used to calculate ZTOBS instead of the model temperature at the last model level PTF5
  - standard vertical temperature gradient RDTDZ1 used to calculate ZTOBS instead of calculated vertical temperature gradient ZDTDZ
  - correction of a bug in IF(PALTI(JROF==RMDI.OR.PALTI(JROF)>100000._ instead of IF(PALTI(JROF == RMDI .OR. PALTI(JROF) > 1000._

Special attention should be paid to castro.F90. If a single-obs would be performed from an ascii input file, the snow depth should be in [cm] and in castro.F90 should be a multiplication by 100 (that is because of the mandalay routines for creating cma file from an ascii file) to get snow quantity in [kgm^{-2}] . In the operational data base the archived snow quantity is snow depth in [m] , so the multiplication should be by 10 000 .
In clear case CY22T2_bf castro.F90 is with multiplication by 100.

2. Modified modules and routines for defining the vertical part of the correlation function for the snow

2.1 Modified modules:

- nam_canape.h
- qacoss.F90
- qacost.F90
- qaref.F90
- qastat.F90.

2.1 Modified routines:

- cabane.F90
- cacova.F90
- cainsu.F90
- canape.F90
- catrma.F90
- preint.F90 (if necessary).

2.2 Routines in ~/canari/compile/tempo which are non-modified but compiled because of qastat.h

- cabyio.F90
- carnak.F90
- caissedm.F90
- caissesm.F90
- cancer.F90.

3.Modules and routines on kami: ~/canari/compile/tempo/NCUSN
Those modules and routines are modified, but not compiled . They could be used in case NCURR would be replaced by NCUSN

- qaqeki.F90
- caffar.F90
- canada.F90
- casino.F90
- caviar.F90
- caviso.F90.

Compilation on kami: ~/canari/compile/mkal13m
~/canari/compile/loadal13m

Input data for full set experiments:

- observations: /cnrm2_a/mrpe/mrpe605/Snow/cmafoc_AAAAMMJJRR (2000021700-2000022118)
- guess : /cnrm2_a/mrpe/mrpe702/exp/JJ/ELSCFOPERALBC001 for analysis for 06 UTC
  /cnrm2_a/mrpe/mrpe702/exp12/JJ/ELSCFOPERALBC001 for analysis for 18 UTC
- clim files: /cnrm2_a/mrpe/mrpe702/clim/out/out/SELAMb_12_v$MM.

Namelists on kami : ~/Namel/E701/namel_aladin_surf_canape for experiments described in Section III
Script on kami: ~/canari/compile/script701_bg
Executable on kami: ~/canari/compile/tempo/al13_j98a.01.L9912.x.exe

If someone wants to redo the old experiments and derive the figures up to Fig.III.12, the namelist should be as ~/Namel/E701/namel and LMESSP=.F. in the script