Interim Report R&D Project 207

Assessment of Snow Cover Change

Remote Sensing Unit
Department of Geography
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R&D Project 207/8/N

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ASSESSMENT OF SNOW COVER CHANGE

by

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30 November 1992

NRA

National Rivers Authority
Northumbria Region

M E M O R A N D U M

To: See Below

From: Dave Archer, Neil Smith

Date: 18 December 1992

Our Ref: NS/AJG

R & D Project 0207 - Remote Sensing of Snow by Satellite

Please find enclosed a copy of an Interim Report, entitled "Assessment of Snow Cover Change" (207/8/N), for your information.

If you have any comments please contact Dave Archer at the address below.

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Alison Gray

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1. INTRODUCTION

1.1 Objectives

This Interim Report aims to report work done during Phase II of the NRA/RSU study on satellite monitoring of snow, with special reference to the utilisation of NOAA-HRPT data in conjunction with GIS. The emphasis of this Interim Report lies in developing and testing methods to determine snow cover changes between successive AVHRR images as a basis for assessing changes in snow cover area and depth.

The specific objectives are:

(1) To describe the melting/accumulating state of the snowpack based upon satellite derived temperature information, used on a daily basis.

(2) To assess changes in snow cover area by comparison of snow classification results between successive AVHRR images with respect to selected NRA regions and catchments.

(3) To assess changes in snow depth through comparison of snow depth categorisations between different AVHRR images for selected catchments and NRA regions.

(4) To demonstrate the application of GIS in carrying out comparisons between different images for selected catchment basins and in assessing the effects of different factors such as forestry.

(5) To address the importance of error analysis in change detection exercises.

1.2 Background

The work addressed in this Interim Report is a continuation of the NRA project entitled "Remote Sensing of Snow by Satellite" (See also Bailey *et al.* 1991; Bailey and Xu 1992; Greenhill *et al.* 1992; and Beaumont *et al.* 1992). Seven objectives were proposed for Phase II of the project. This Interim Report concerns work done to meet the requirement for achieving one of the seven objectives, i.e., assessment of snow cover change. It is mainly focussed upon the analysis of different snowpacks from sequential NOAA-AVHRR images during periods of snow accumulation, stability and ablation for snow events during winter 1990/91. Attempts are also being made to study images for snow events in early 1992; results from the comparisons will be incorporated in the Final Report. Analysis of changes in snow cover area and depth between successive satellite images were carried out for selected basins. As reported in Bailey and Xu (1992), the areas selected have been in Northumbria based upon the availability of different data sets for snow study. Ground-based snow information has been obtained from this NRA region and the snow survey reports published by the UK Meteorological Office for comparison with imagery analysis.

1.3 Context to the present study

Information on changes in snow cover area and depth forms an important basis for calculating input to flood forecasting models. Snow hydrology has been traditionally a neglected part of the hydrological cycle. Both in terms of logistical problems and sporadic occurrence, ground based studies have not been popular and operational experience is limited. Nevertheless, several UK NRA Regions have rudimentary networks of snow depth/water equivalent measurement stations which currently provide information on which to base flow predictions. These data are complemented by data from the annual snow survey reports by the UK Meteorological Office. The combined ground data sets are used to calibrate results from satellite remote sensing analysis.

As demonstrated by Lucas (1989), snow melt or accumulation can be estimated using AVHRR information. Zones of snow melt or accumulation can be defined with daily AVHRR images or can be located through multi-temporal comparison of digital image values. However, the division of a snowpack into melt or accumulation zones, based upon the actual visible or near infrared spectral response alone may at times be subject to error, particularly in a UK environment. It is argued that the day-to-day variations in the normalisation of the visible/near infrared difference provide an indication of both the regions of the image where *melt*, *accumulation* or *stabilisation of the snowpack* are evident, and possibly even the *rates of snow melt*. However, differences in vegetation response within relatively snow free areas between images compared can give rise to the mis-identification of melting or accumulating snow. This problem may be exacerbated by mis-registration of image pixels. Therefore, discrepancies may result from variations in vegetation response, or from shadows and sub-pixel cloud. In the case of vegetation response, use of a detailed GIS data-base including several vegetation/land cover categories would help reduce the risk of pixel misclassification and associated errors in snow change detection. However, general capabilities of the existing model are thought sufficiently good for applications at large basin and NRA regional levels.

The method used in this study has been the post-classification comparison for change detection. This is the method which requires the comparison of independently produced classified images. Comparisons between different images have been made on analysis of changes in snow cover area and snow depth for selected basins in NRA Northumbria. Analysis of changes in snow water equivalent cannot be performed at this stage by the use of AVHRR images; this topic will be addressed in a subsequent Interim Report, concerning the utilisation of data from the passive microwave DMSP SSM/I instrument.

2. MONITORING CHANGES IN SNOW COVER

2.1 General considerations

As described by Bailey and Xu (1992), AVHRR images from NOAA-9, NOAA-10, NOAA-11 and NOAA-12 satellites have been obtained for the snow events during winter 1990/91. A series of programs have been developed and modified for calibration and mapping of these images (see Figure 2.1 in Bailey and Xu 1992). After calibration and navigation, AVHRR images have been used for snow area classification and mapping by going through procedures constructed in Bailey and Xu (1992: Figure 3.1). Subsequently, snow depth categorisation and depth value assignment can be carried out on the identified snow areas using AVHRR visible band-1 and the first principal component of AVHRR band-3 and band-4. The performance of the depth categorisation has been compared with ground survey data. The accuracy of snow area classification has also been confirmed through comparison with Landsat TM image classification. The output of snow area and snow depth classifications have been stored in GIS as different thematic overlays for retrieval and manipulation at a later stage. Catchment boundaries and NRA regional boundaries can be located using the stored overlays in the GIS for the selection of different area boundaries of interest to the end user.

To monitor changes in snow area and snow depth, the classification results for different images can be retrieved and compared within an appropriate GIS. This method holds promise because data from two dates are separately classified, thereby minimising the problem of normalising for atmospheric and sensor differences between two dates. By properly coding the classification results for time t_1 and t_2, change maps can be produced showing a complete matrix of changes in snow area and snow depth, indicating snow melting or accumulating zones. The GIS functions within the ERDAS system (e.g. **ALGEBRA** or **INDEX**) can be used to achieve this.

2.2 Changes in snow cover areas

The project team has recently acquired AVHRR images for snow events during winter 1990/91 and the available NRA regional boundary, products showing changes in snow area have been derived for NRA Northumbria region. Work has been carried out for different snow occasions to show changes in snow cover area with integration between imagery analysis and GIS. On completion of the digitisation of NRA regional boundaries, detailed studies of snow cover change in selected regions can be performed. Initial assessments of snow cover changes have been made for NRA Northumbria.

2.2.1 Snow melt/accumulation estimates using daily temperature information

AVHRR pixels with a temperature below 0°C suggest an accumulating or more stable snowpack. Surfaces warmer than 1°C are generally considered to represent snowpacks undergoing extensive snow melt. There is an uncertain zone of snow melt/accumulation within the 0-1°C temperature range. In this study, pixel temperatures are measured by the atmospherically corrected AVHRR band 6 which is derived from the calibrated AVHRR band-4 and band-5.

Plate 2.1 shows the zones of snow melt/accumulating using the temperature information extracted from the calibrated NOAA AVHRR band-6 for NRA Northumbria on 16 January 1991. In the image, it is clearly seen that most of the snow accumulating areas (represented in yellow) are these situated in the hills and uplands while areas undergoing extensive snow melt (red colour) are mainly located at lower altitudes. The uncertain zone of snow melt/accumulating (those in blue) appears as a narrow transitional zone of high altitude to low altitude areas.

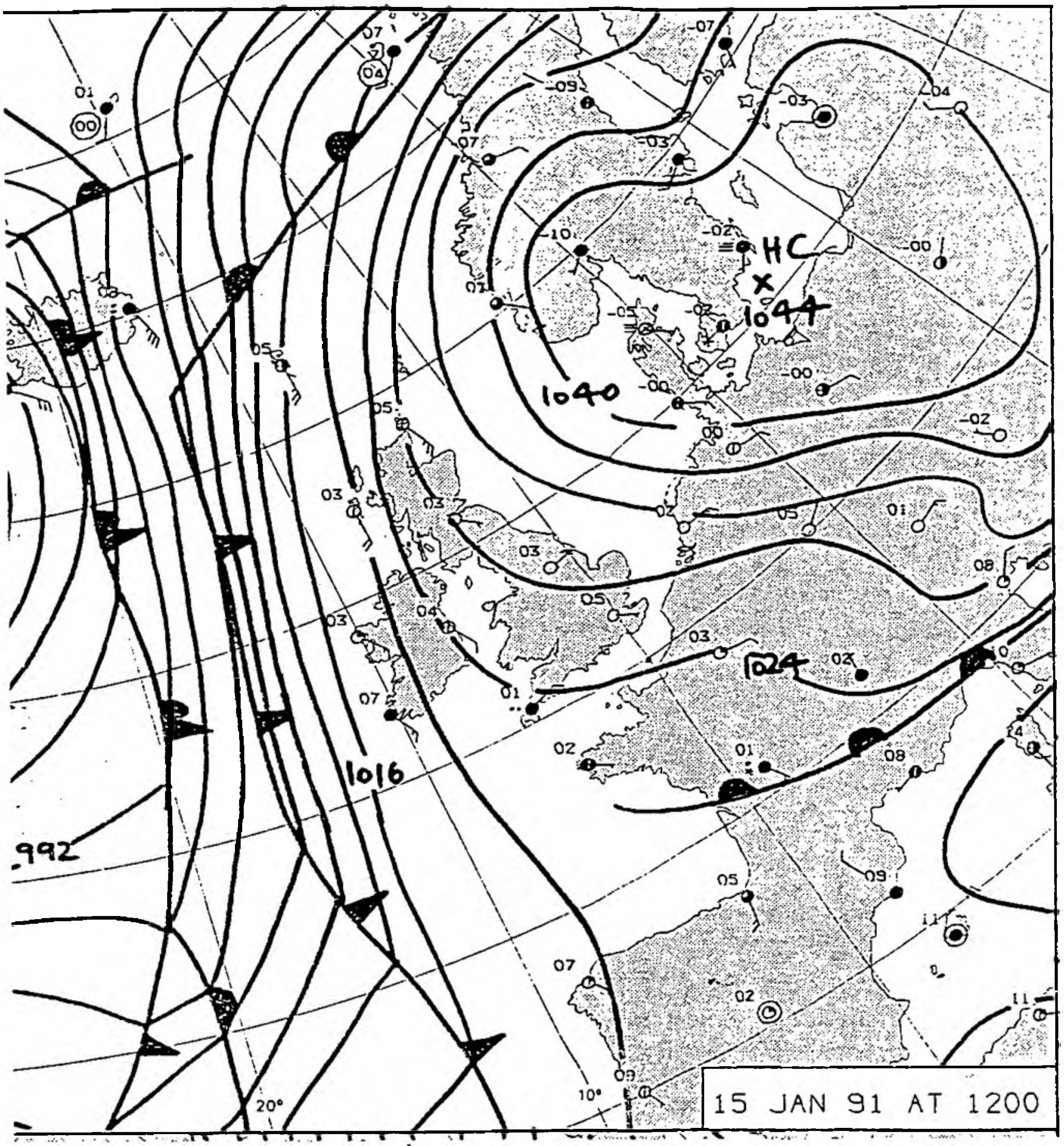


Figure 2.1 The synoptic situation on 15 January 1991 for 1200Z.

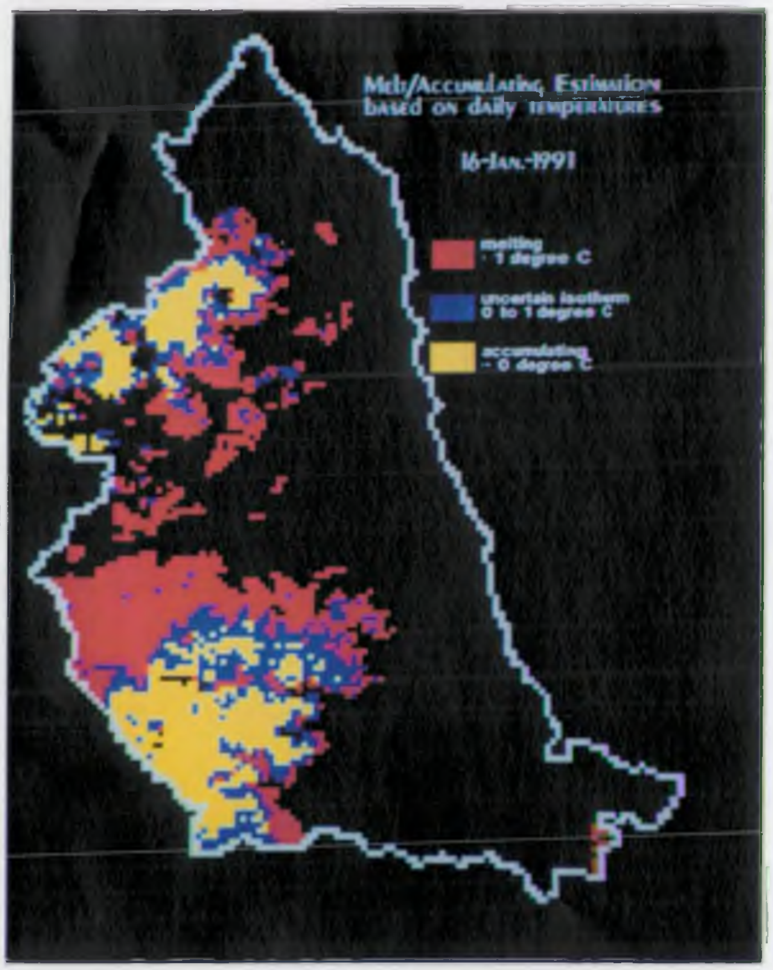


Plate 2.1 Zones of snow melt/accumulation using satellite derived temperature information on a daily basis (16 January 1991). Areas in red represent snow packs undergoing extensive melting with a temperature of > 1°C, these in yellow suggest accumulating /stable snowpack with temperature < 0°C, and blue colour shows the transitional zone of 0 - 1°C.

2.2.2 Snow area changes in largely cloud free areas

(1) Comparison of daily temperatures

Attempts have been made to express the changes in the snowpack between successive images by comparing the temperature band 6 values for the two successive days. If the temperature of the snowpack for the first day is higher than the following day, the snowpack is taken as stable or in its accumulating states. On the other hand, if the temperature for day 2 is higher than for day 1, the snowpack is likely to be in its melting states.

However, it is realised that the comparison of daily images may be complicated by the fact that the snowpack could have gone through several melting or refreezing processes in-between the period when two images were acquired. For example, snow may fall during the night when temperatures are below zero, but by mid-day the next day, an increased surface temperature might occur.

The comparison of daily temperatures may not be a straightforward issue. If the temperature for day 2 is greater than for day 1, this by itself is not enough to classify the snowpacks as being likely to be affected by the process of ablation. Clearly if the temperature was below 0°C on both days, no such conclusion could be drawn. Similarly if the temperature was above 0°C on both days, one could not assume a change from accumulation or stability to ablation. The absolute temperature information is needed to supplement the information about temperature change. For this reason, an alternative method is needed to provide information for snowpack comparison.

(2) Comparison of snow cover areas

One method is to compare the snow areas for two successive days. This is also known as post-classification comparison for change detection. Assuming that the two images with snow classification results were registered to the British National Grid accurately, the symmetric (*i.e. involving pixels with the same geographic reference for different images*) difference in snow or no-snow distribution between the two images would reflect changes in snowpacks. Therefore, if a pixel changed from no-snow on day 1 to snow on day 2, it might be the result of snow falling during the day. If snow is found for both days, it is assumed as stable snowpack. On the other hand, if snow is found in the first day but not the following day, snow ablation is assumed. Similarly, if different snow characteristics (e.g. complete and partial snow) are considered in the comparison, more change categories can be revealed. It is easy to carry out the comparison if both images used are cloud free for the selected area as in the following example.

Changes in snow cover area can be assessed by comparison of snow classifications between successive images. The first example has been for NRA Northumbria region from 15 January 1991 to 16 January 1991. Images for these two days over the Northumbria region are almost completely cloud free. The synoptic conditions during these days are illustrated in Figure 2.1. and Figure 2.2. Day-to-day changes in snow cover area were revealed in the comparisons and because of the confidence that can be placed in the registration system used, these areal changes can be regarded as accurate representation of reality. If only the snow and no-snow classes in the two images were used for comparison, zones of snow melting, stable snowpacks and increased snow areas could be generated consequently (Plate 2.2).

As can be seen in Plate 2.2, most snow areas in NRA Northumbria region remained snow covered between 15 January 1991 and 16 January 1991. Thus the change detection map revealed largely stable snowpacks (these in yellow) and most areas with snow cover changes between the two days were at the edges of snowpacks. Areas displayed in a sandy colour were classified as snow on the 15 January 1991 image but no-snow for the 16 January 1991 image, while blue represents areas which were classified as no-snow for 15

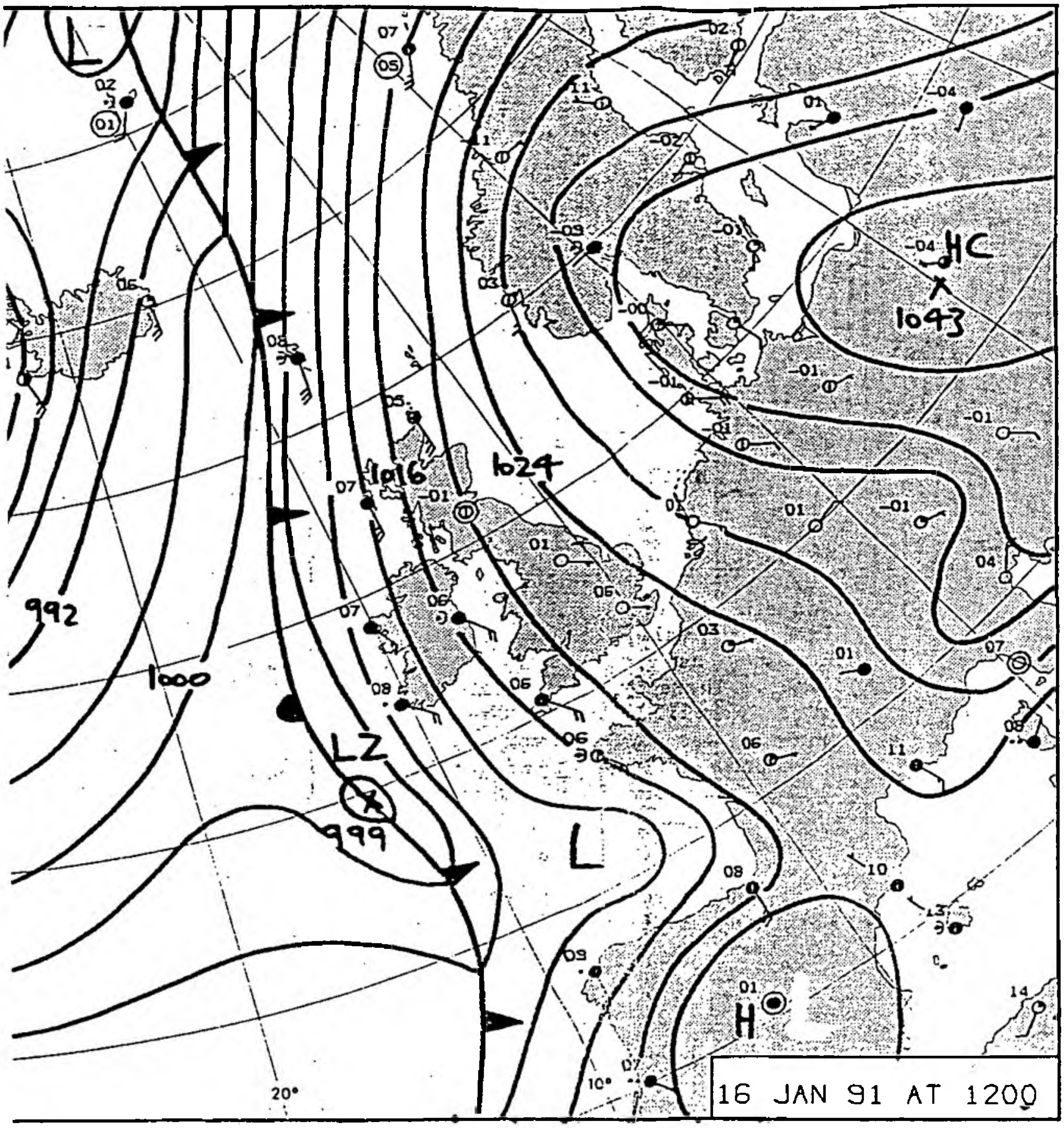


Figure 2.2 The synoptic situation on 16 January 1991 for 1200Z.

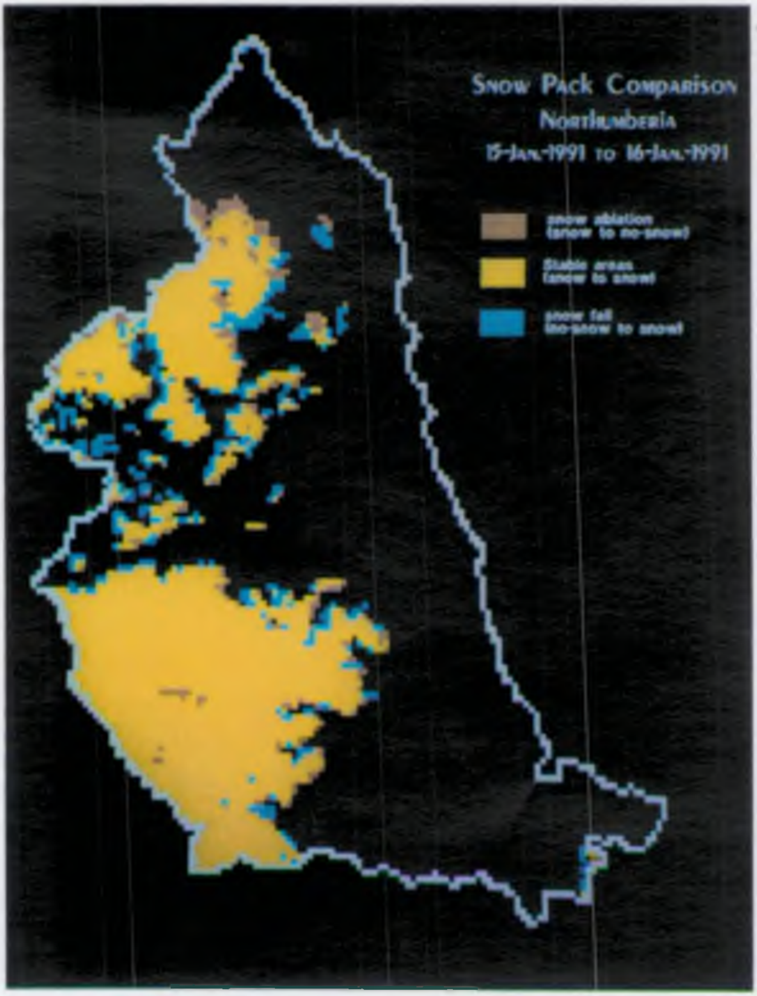


Plate 2.2 Snowpack comparison using snow classification images for 15 January 1991 and 16 January 1991. Only snow and no-snow classes in both images were used for comparison.

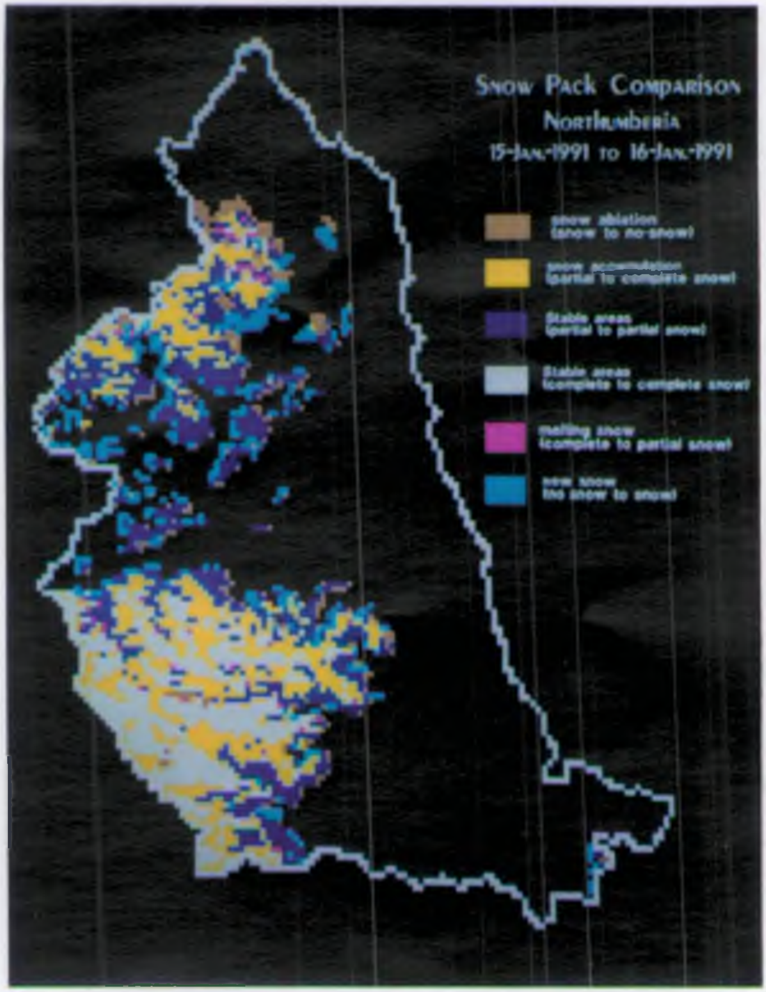


Plate 2.3 Snowpack comparison between 15 January 1991 and 16 January 1991, considering differences in partial and complete snowpacks.

January and snow for 16 January. Thus increased snow areas were found in these blue areas, which may be results of new falls of snow or snow redistribution in these localities.

However, if partial and complete snowpacks were considered during the comparison, the following categories could be established by comparison of characteristics of snowpacks (Plate 2.3):

snow ablation (snow to no-snow) - sand colour
snow melting (complete snow to partial snow) - magenta
stable snow I (partial snow to partial snow) - blue
stable snow II (complete snow to complete snow) - white
snow accumulation (partial snow to complete snow) - yellow
new snow fall (no-snow to snow) - cyan

Results of changes in snow cover area between 15 January 1991 and 16 January 1991 for selected catchments are shown in Plate 2.4 (a and b). Two catchments are selected for examples here. One is the catchment situated in the far north of Northumbria region with River Till running through. Most areas in this catchment are lowlands except the south-eastern part where snow and snow cover change have been mapped (see Plate 2.4-a). Another catchment selected is the big catchment across the middle of Northumbria region crossed by the River Tyne (Plate 2.4-b and -c). The western half of the catchment is largely covered by upland moors, where snow was seen on both 15 January and 16 January 1991. The land cover effects can be demonstrated in this case. Several forest areas cover the northern part of the catchment (see Plate 2.4-d). Thus most areas were covered by partial snow and many snow cover changes were found in these areas. Plate 2.4-c and Plate 2.4-d show the river courses and forestry distribution in the region together with NRA regional and catchment boundaries for geographical reference.

2.2.3 Snow cover changes in partially cloud covered areas

For partially cloud covered images, change detection in snow cover should be carried out on the basis that cloudy areas should be excluded prior to the snowpack comparisons. That is, comparison should only be made on cloud free areas. This can be done using the "MASK" function in the ERDAS system. An example of the work done for partially cloud covered images was that for 11 February 1991 and 13 February 1991. Figure 2.3 and Figure 2.4 show the synoptic conditions for the two days. Plate 2.5-a demonstrates changes in snow cover area in NRA Northumbria region between 11 February and 13 February 1991. Results for selected catchments are shown in Plate 2.5-c and Plate 2.5-d.

According to the London Weather Centre's "Summaries of British Weather" the following has been reported:

On 11 February 1991, during the night snow showers affected eastern counties of England and Scotland and several inches fell in places... During the day eastern counties of England and Scotland continued to have snow showers well into the evening, and in some places the showers were heavy adding further to the snow cover... Some notable snow depths were 38 cm at Long Framlington (Northumberland),... reported at 0900 o'clock in the morning.

On 13 February 1991, most districts were cold, and the more eastern and south-eastern counties of England, where many places have 10 or more centimetres of snow on the ground, were very cold. Snow depth at 0900 GMT was 46 cm at Long Framlington, Northumberland.

Therefore, it is easy to see from Plate 2.5-a that most areas in Northumbria region except these concealed by cloud were covered by snow on these two days and the snowpack comparison presents an increased snow area or largely stable snowpacks. Areas coloured in cyan suggest changes from no-snow on 11 February to snow on the ground on 13

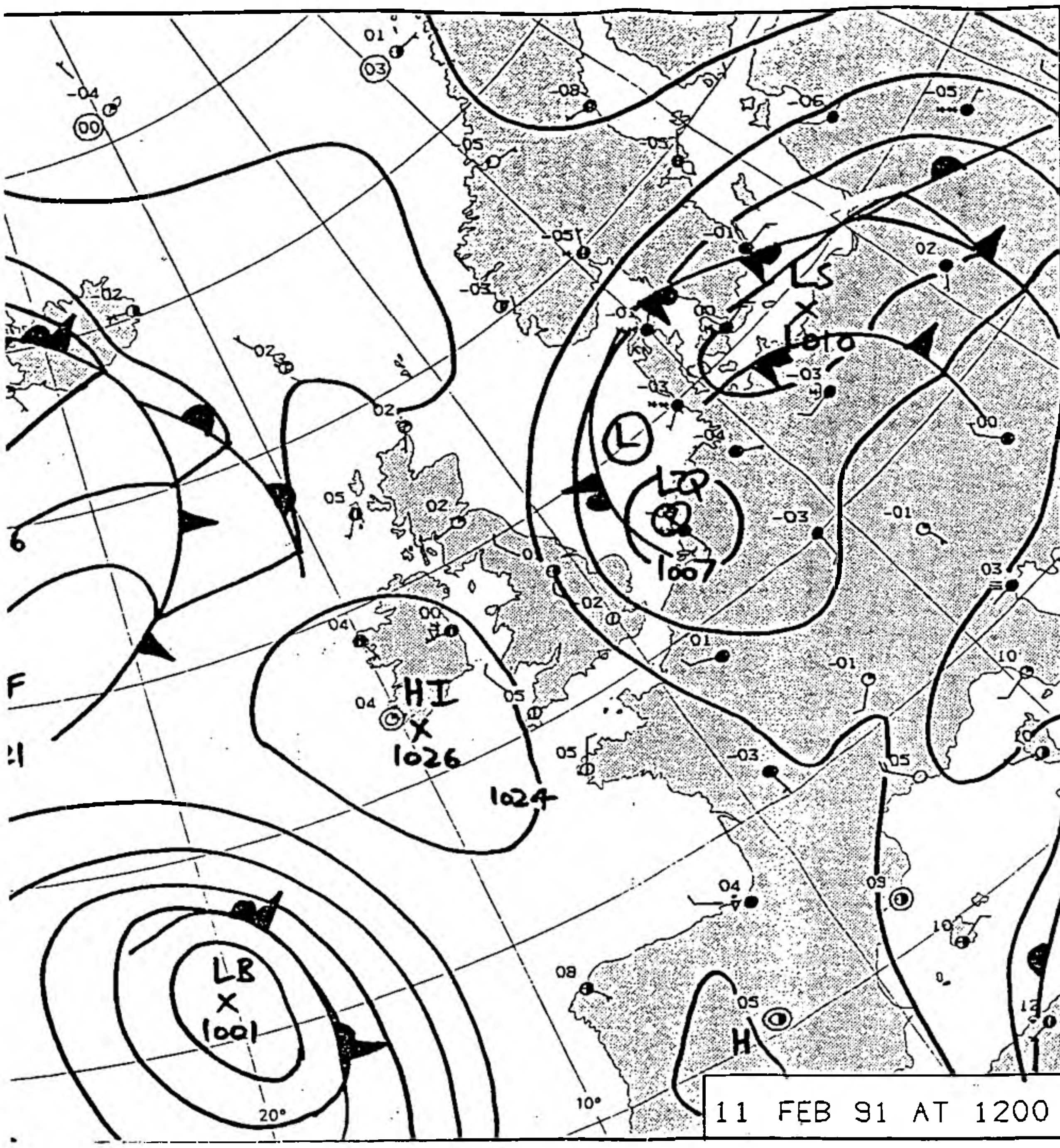


Figure 2.3 The synoptic situation on 11 February 1991 for 1200Z.

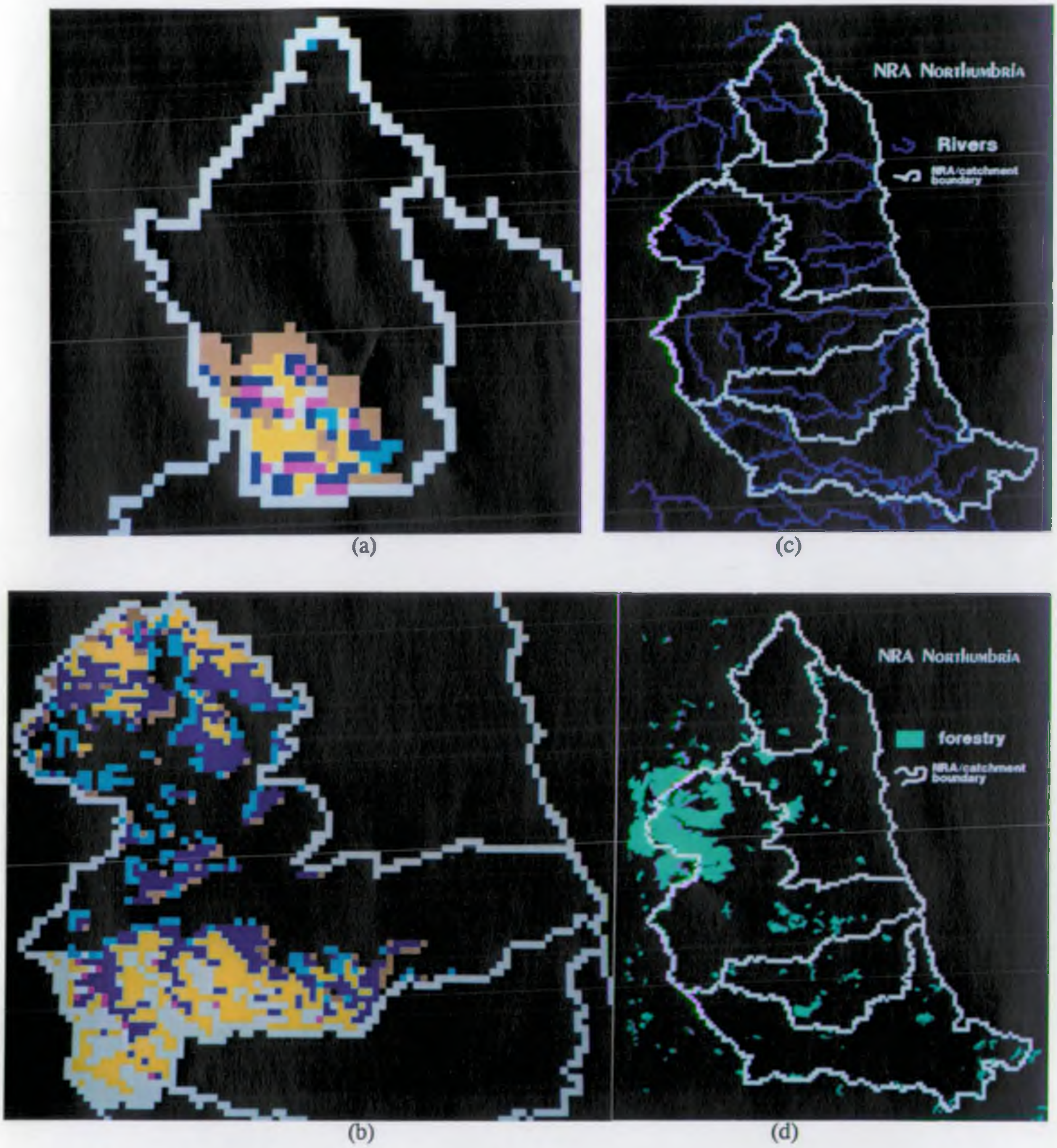


Plate 2.4 Changes in snow cover area in selected two catchments in NRA Northumbria region between 15 January 1991 and 16 January 1991. See Plate 2.3 for explanation of the colour schemes. (a) Details of snow area change in the catchment situated in the far north of the NRA region crossed by the River Till. (b) Details of snow area change in the catchment across the middle of the region. (c) NRA regional and catchment boundaries and river courses in the region. (d) NRA regional and catchment boundaries, together with forestry areas.

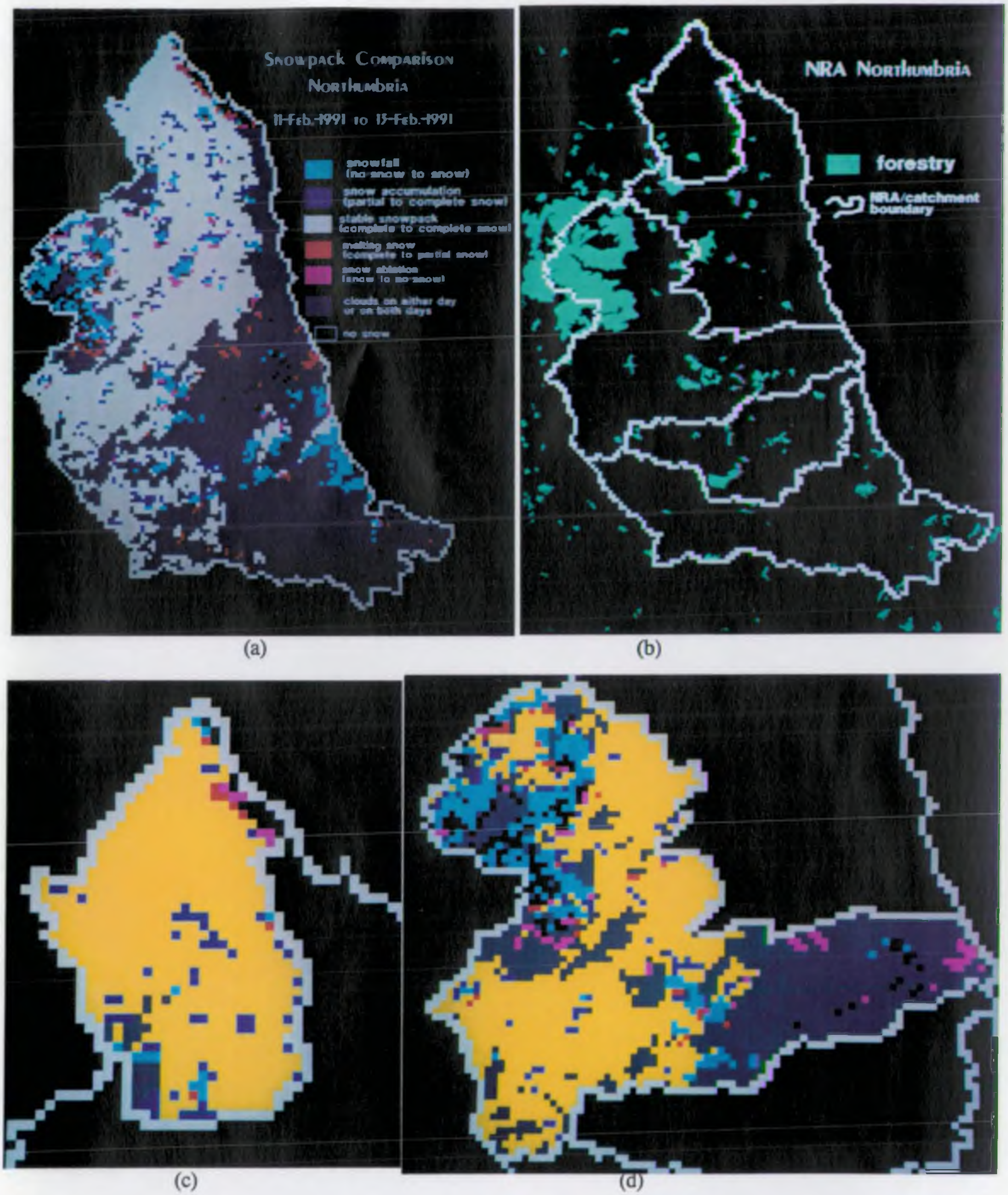


Plate 2.5 Snow cover changes in partially cloud covered areas from 11 February to 13 February 1991. (a) Snowpack comparison for NRA Northumbria region. (b) Forestry areas and regional and catchment boundaries. (c) Details of changes for selected northern catchment. (d) Details for the catchment across the middle of the region (same area as in Plate 2.4b). The colour schemes in (c) & (d) are as in (a) except where yellow has replaced white in order to distinguish the boundaries.

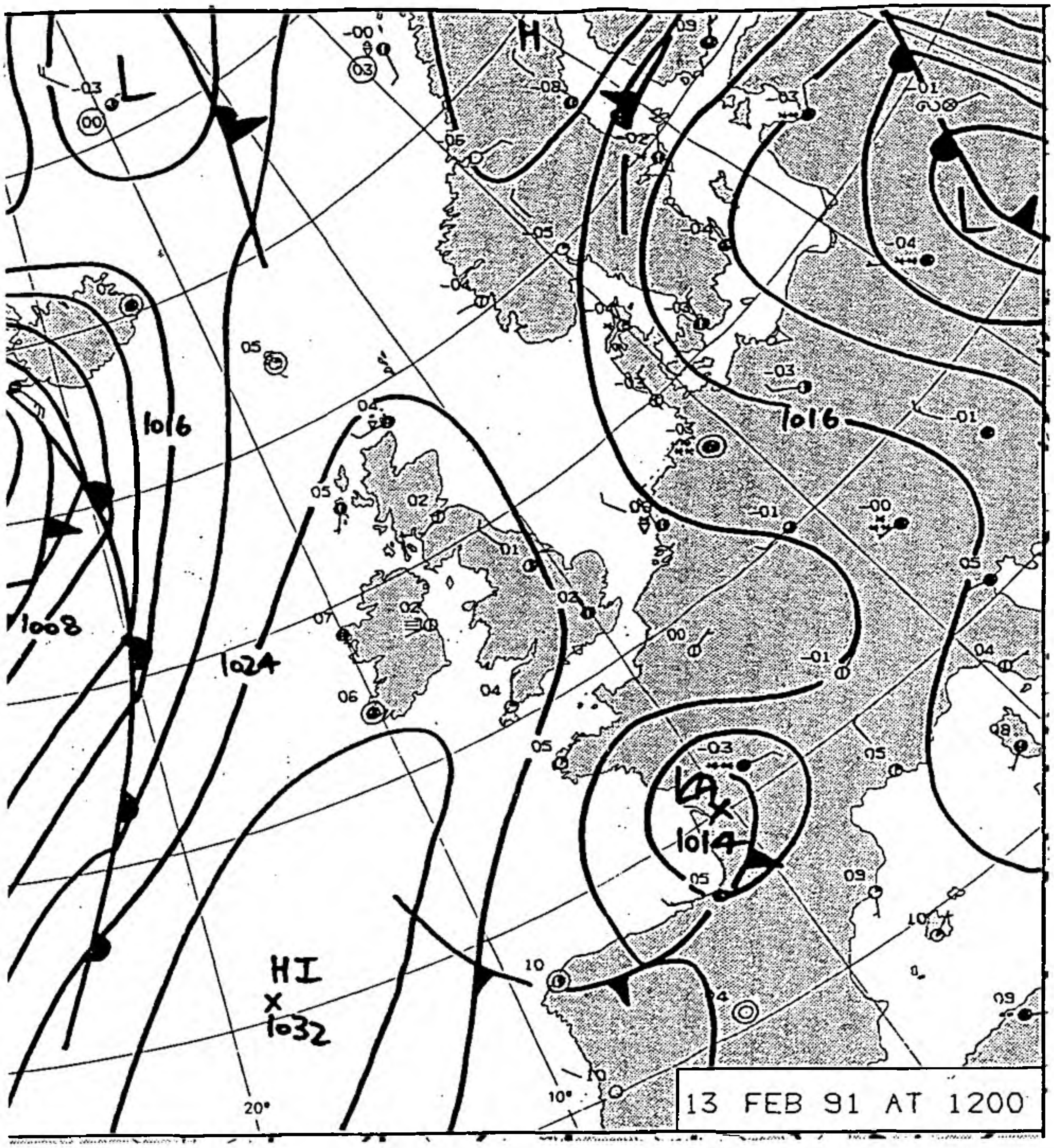


Figure 2.4 The synoptic situation on 13 February 1991 for 1200Z.

February, blue representing areas remained as partially snow covered and white showing areas covered by snow completely for both days. Plate 2.5-c and Plate 2.5-d are examples of detailed changes in snow areas for selected two catchment as in Plate 2.4-a and Plate 2.4-b. The geographical references of the catchments can be referred to in Plate 2.5-b. The yellow colour shown in Plate 2.5-c and Plate 2.5-d is equivalent to the white colour in Plate 2.5-a. Areas coloured in grey were concealed by cloud and snow area comparison was thus precluded in these areas.

It must be pointed out that there is potential to extrapolate snow areas beneath clouds when the Digital Terrain Models (DTM) are available for the required region. There are recognised relationships between snow cover and elevation, aspect and slope. Generally it is accepted that in mountainous regions, there is a location specific, linear relationship between snow accumulation and elevation while slope and aspect influence deposition of snow (US Army Corps of Engineers 1956). Thus snow areas concealed by cloud may be approximated by using snow-line altitude estimated in relation to its aspect and slope and assuming a similar accumulation of snow above the calculated snow-line in these obscured regions as on observed surfaces. Snow-line altitudes for different aspects can be established by comparison of these between cloud free areas and cloud covered areas in the same image.

Examples of snow area extrapolation beneath cloud through the use of DTM in the GIS can be found in Bailey *et al* (1991) and Bailey and Xu (1992), where DTM for a smaller area in Northumbria was used.

This problem of cloud constraints on assessments of snow cover changes will be further discussed in Section 3.

2.3 Changes in snow depth

One way of carrying out the detection of changes in snow depth is to use the NOAA-AVHRR Normalized Difference Vegetation Index (NDVI) (Lucas 1989) to describe snow depth or snow optical thickness. If the NDVI value for the first day is less than the following day, a reduction in snow depth or snow optical thickness is assumed, while a greater or identical NDVI value for the next day may indicate either increased or stable snow depths. By comparing NDVI values of images for 15 January 1991 and 16 January 1991 for snow areas in the NRA Northumbria region, it is shown that most areas were in snow accumulating state and had increased snow depths. However, this result is subject to differences in vegetation response for different days. Therefore, the post-classification comparison method is used for detecting changes in snow depths.

2.3.1 Snow depth changes from 15 January to 16 January 1991

Plate 2.6 and Plate 2.7 show the snow depth categorisation for the NRA Northumbria region on 15 January 1991 and 16 January 1991 respectively, with five depth categories for each image. The assumed depth values ranges were annotated on the plates. As mentioned in Section 2.2, AVHRR images for these two days are largely cloud free over the Northumbria region. Thus, the comparison of snow depth between these images could be carried out for the selected NRA region. By properly coding the GIS files which contain the snow depth groups and using the "**ALGEBRA**" function with the ERDAS system, changes in snow depth could be demonstrated both spatially and statistically for the region of interest (Plate 2.8). When a pixel was assigned to the same snow depth category for both of the two days, no change in the snow depth groups was identified; such pixels are shown in white colour in Plate 2.8. The blue colour in Plate 2.8 indicates an increased snow depth in the two days' comparison, possibly due to snow accumulation in these areas. That is, these pixels were assigned into a deeper snow depth category for 16 January 1991 than that for 15 January 1991. On the other hand, the magenta coloured areas in Plate 2.8 represent the decreased snow depths in the comparison, which might result from snow

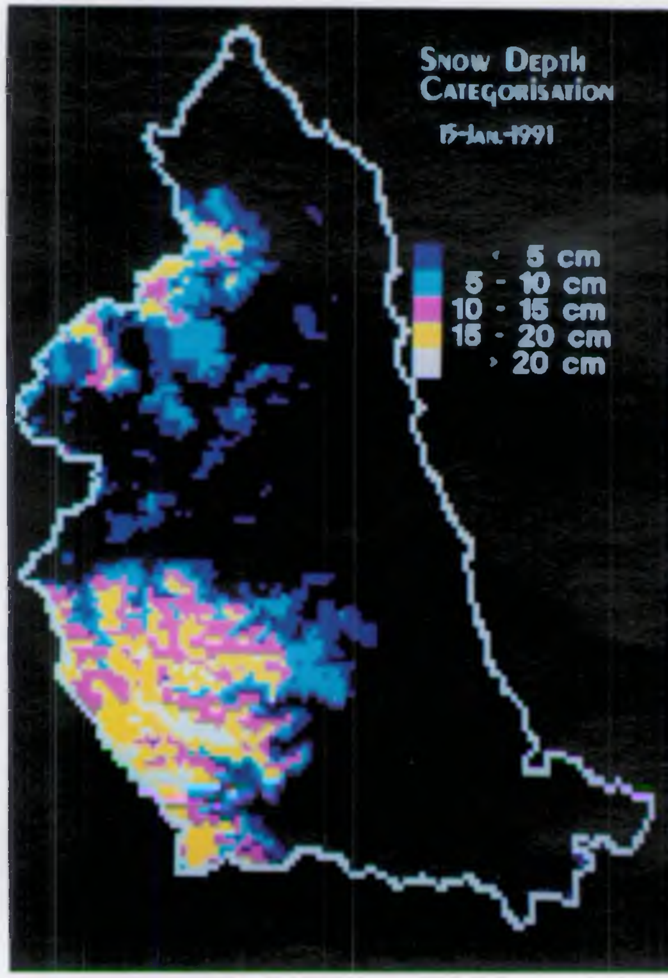


Plate 2.6 Snow depth categorisation for 15 January 1991 (Northumbria region).

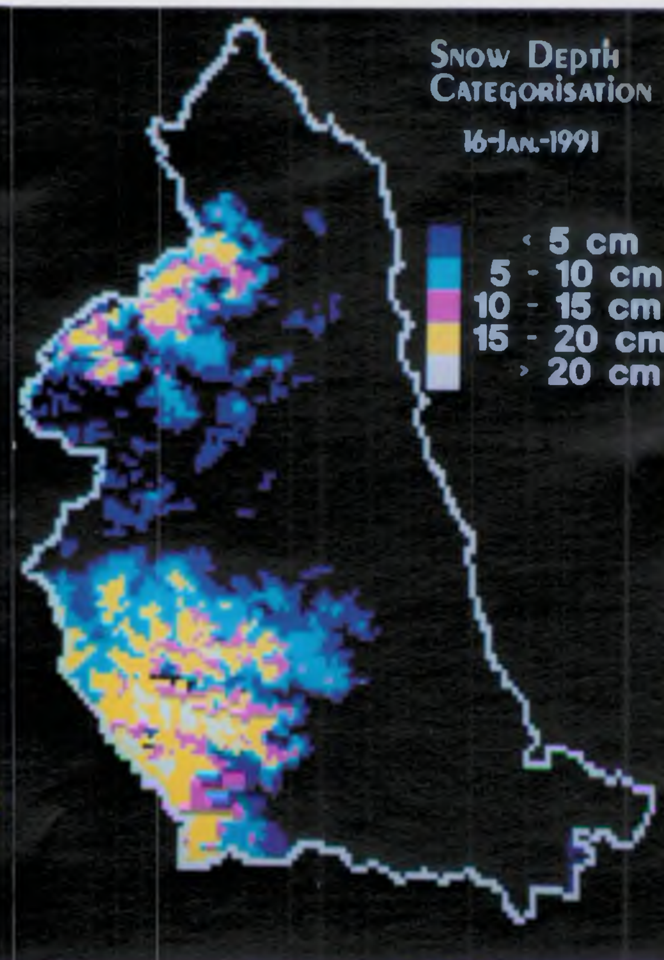


Plate 2.7 Snow depth categorisation for 16 January 1991 (Northumbria region)

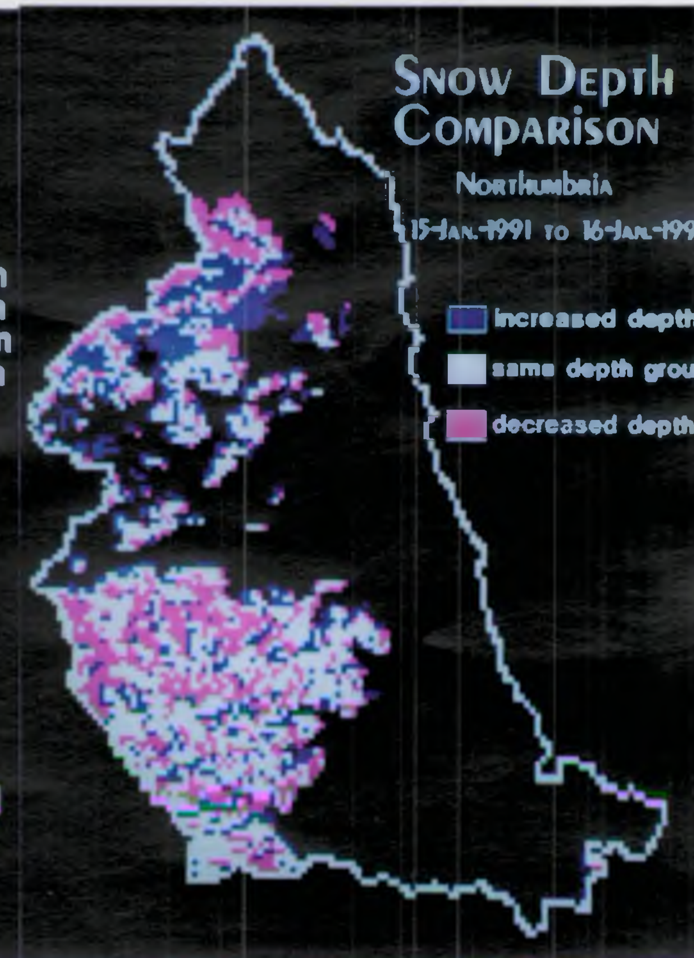


Plate 2.8 Snow depth comparison in NRA Northumbria region between 15 January 1991 and 16 January 1991.

melt. The statistics for these changes can be obtained by multiplying the pixel numbers in each category and the area each pixel represents (c. 1 km^2 in this case). Thus in the comparison of snow depth between 15 and 16 January 1991 over the NRA Northumbria region, 961 pixels (961 km^2) were in the increased snow depth category, 1431 pixels (1431 km^2) remained in the same snow depth category and 1039 pixels (1039 km^2) changed to less deep snow depth groups.

2.3.2 Snow depth changes from 11 February to 13 February 1991

As in Section 2.2.3 on snow area changes, changes in snow depth for the partially cloud covered images in NRA Northumbria region were detected by comparison of snow depth groups between 11 and 13 February 1991. Different from the comparison between 15 and 16 January 1991 as described in Section 2.3.1, the comparison between 11 and 13 February 1991 was carried out on areas where snow was identified on both images. Again, the "**MASK**"/"**ALGEBRA**" function can be used for the discrimination of these areas.

First of all, as described by Bailey and Xu (1992), snow depth classification was carried out for the snow areas established in the snow area classification using the AVHRR channel 1 and the first principal component of AVHRR channel 3 and channel 4. The ellipse diagrams and scatterplots of data file values for these pair bands are presented in Plate 2.9-a (11 February 1991) and Plate 2.9-b (13 February 1991). Fifteen potential clusters were generated for the re-assignment of snow depth categories. As a result, five depth categories were produced for the UK and can then be generated for a selected area via the use of GIS. Plate 2.10 and Plate 2.11 show the snow depth categorisation for NRA Northumbria on 11 February 1991 and 13 February 1991 respectively. Table 2.1 and Table 2.2 summarise the results of the image depth categorisation and snow depth data from the ground survey. The results of comparison of snow depth groups between 11 and 13 February 1991 for the NRA Northumbria region are presented in Plate 2.12. The statistics of these changes are as follows: 843 pixels (843 km^2) changed into deeper snow depth categories; 2239 pixels (2239 km^2) remained in the same snow depth groups; and 1048 pixels (1048 km^2) changed into shallower snow depth groups.

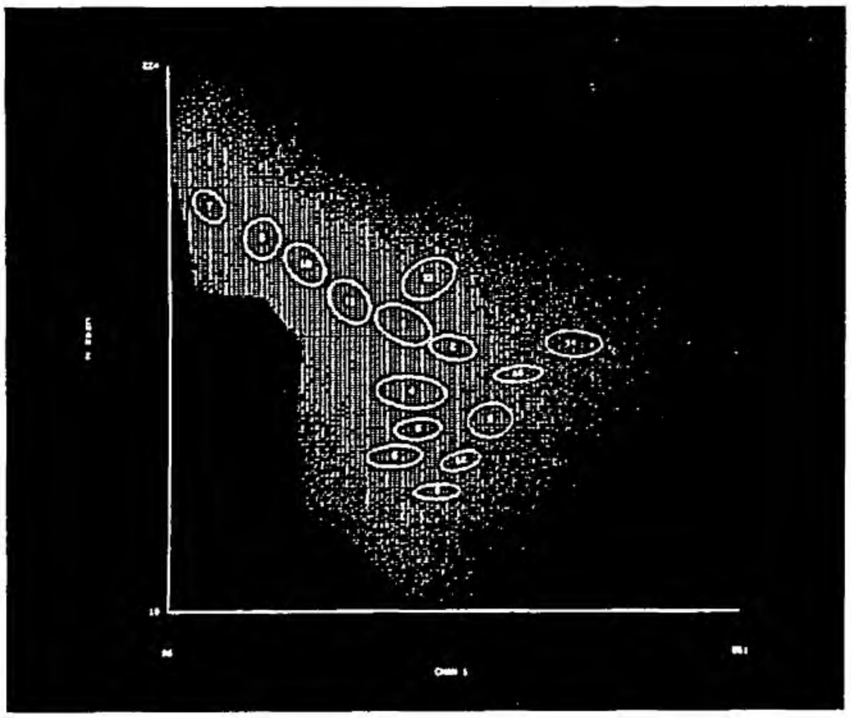
It is encouraging to note from Tables 2.1 and 2.2. that the modal classes of the satellite estimation image categories and the snow survey reports coincide in seven out of the ten cases. Considering the high spatial variability usually exhibited on the ground, this is a good result.

Table 2.1 Number of pixels in snow depth groups from image classification and ground surveys, UK, 11 February 1991.

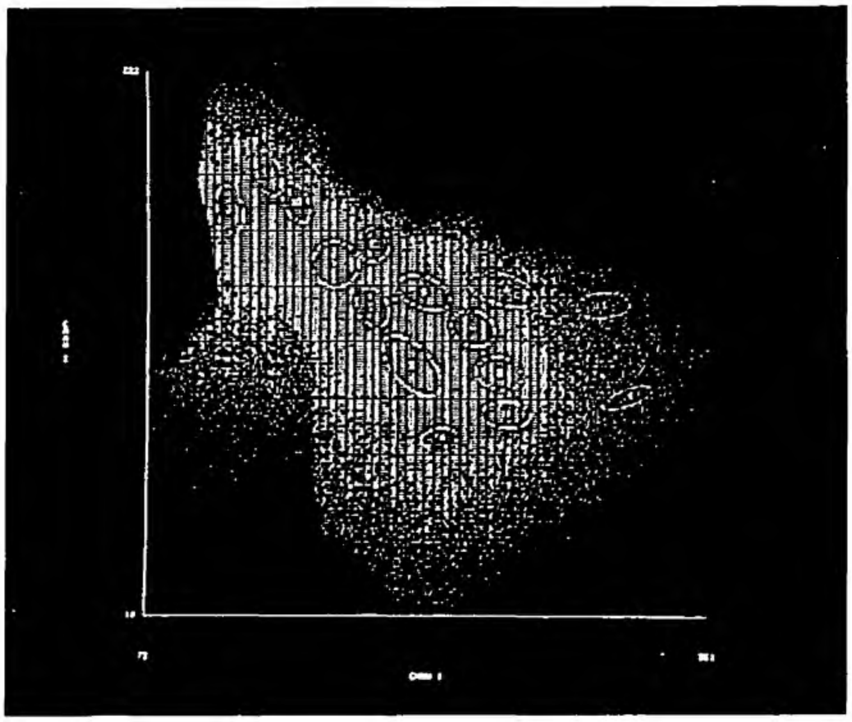
Snow survey reports	Image categories < 5 cm	5-10 cm	10-15 cm	15-20 cm	>20 cm
< 5 cm	**12**	4	4	1	0
5-10 cm	7	**17**	9	9	0
10-15 cm	4	9	**17**	5	0
15-20 cm	2	7	0	**2**	0
>20 cm	1	3	3	19	**4**

Table 2.2 Number of pixels in snow depth groups from image classification and ground surveys, UK, 13 February 1991.

Snow survey reports	Image categories < 5 cm	5-10 cm	10-15 cm	15-20 cm	>20 cm
< 5 cm	**10**	15	4	7	1
5-10 cm	5	**6**	4	11	1
10-15 cm	0	5	**6**	11	8
15-20 cm	1	1	3	**12**	8
>20 cm	2	2	2	14	**11**



(a)



(b)

Plate 2.9 Ellipse diagrams and scatterplots of data file values for AVHRR visible band-1 and the first principal component of AVHRR bands-3 and -4 with 15 potential classes in the signature data. (a) 11 February 1991. (b) 13 February 1991.

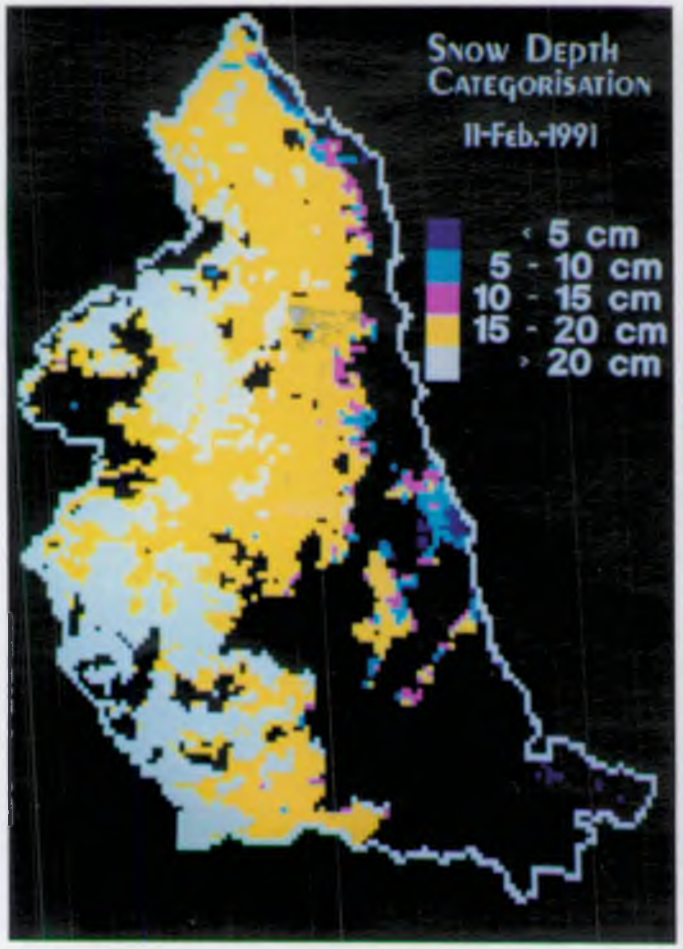


Plate 2.10 Snow depth categorisation for NRA Northumbria, 11 February 1991.

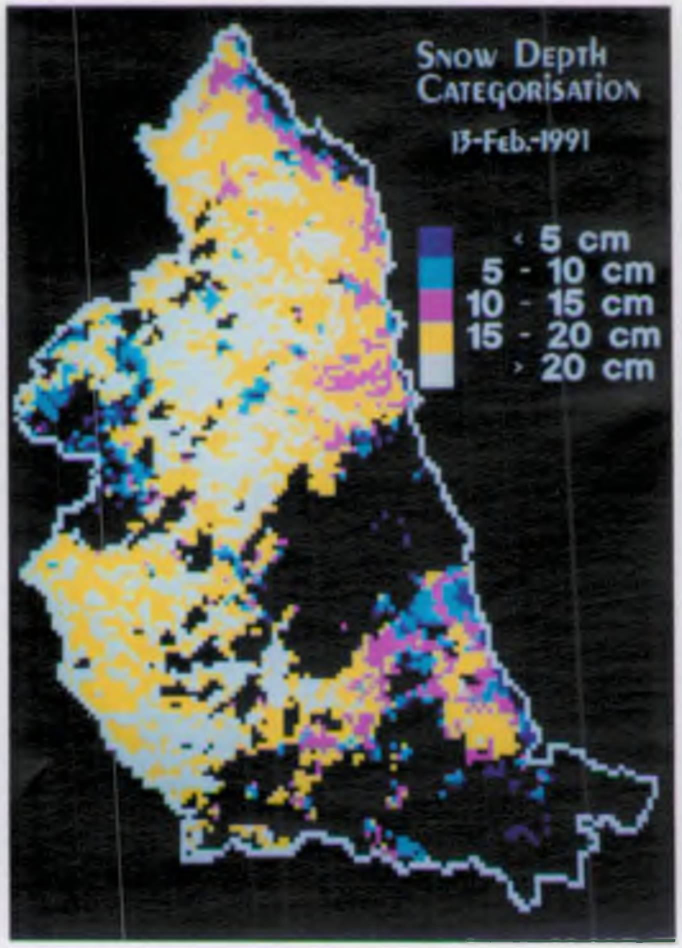


Plate 2.11 Snow depth categorisation for NRA Northumbria, 13 February 1991.

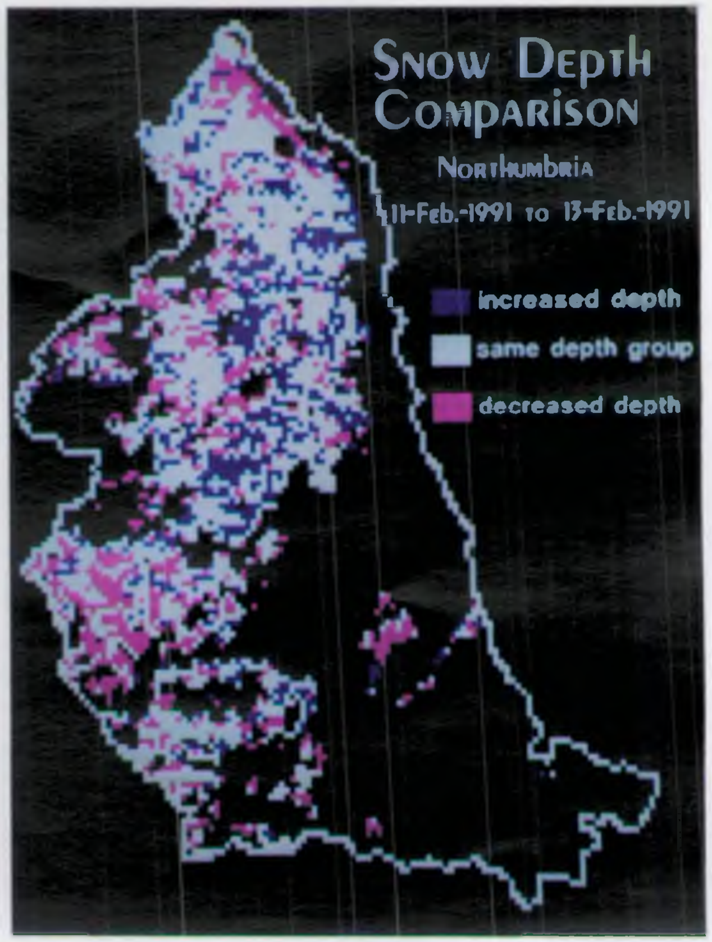


Plate 2.12 Snow depth comparison for NRA Northumbria region from 11 February 1991 to 13 February 1991.

3. DISCUSSION

3.1 Constraints of cloud cover in change detection exercises

Cloud cover imposes constraints on the use of AVHRR sensing of snow areas and properties. These problems are exacerbated when assessing snow cover changes, as areas concealed by clouds on either image have to be excluded for detection of changes in snow cover.

Application of GIS and DTMs would help to reduce the constraints by extrapolating snow areas beneath cloud (Bailey *et al* 1991; and Bailey and Xu 1992). It is important to identify snow areas under different conditions or with different snow depths and only by incorporating a large number of cases will it be possible to establish the value of such interpolation. Thus, efforts have been made to establish the relationships between snow depth and elevation or aspect. But more data are needed to perform extrapolation of snow depth beneath cloud and this will be limited by the availability of local DTMs.

Satellite image data from other spectral bands which are not limited by cloud cover are also being studied in the NRA/RSU project. In particular, passive microwave images are showing potential for assessment of snow area, depth and water equivalent and their changes in cloudy conditions. This work will be reported in a separate Interim Report.

3.2 Error analysis in the change product

It is necessary to recognise the importance of error analysis in the (snow) change detection exercise. Among different techniques for detecting changes from digital satellite images, the change map product of image classifications each generated from image data for a single date is likely to exhibit accuracies similar to the product of multiplying accuracies of each individual classification (Singh 1989). Hence it may produce erroneous change detections since any mis-classification on either date would give a false indication of change.

Also, error propagation may be attributed to several other aspects. For example, any mis-registration of the AVHRR image to the BNG would form an inherent problem for the comparison of the classification results. Differences in vegetation response may also complicate the snow cover change assessment. As shown in Plate 2.3 and Plate 2.4 where snow cover area change between 15 January 1991 and 16 January 1991 were presented, most apparent changes occurred in the forested areas. To a certain extent, these changes could be attributed to the forestry effects on the AVHRR visible reflectance and thus the snow identification in the image analysis. The assessment of land cover effects on snow redistribution and interpolation of snow area under forestry are not performed at this stage because of the existing difficulties and the requirements for further work (Bailey and Xu, 1992).

4. CONCLUSIONS

Methods to assess changes in snow cover area and snow depth have been developed and tested with the integration of AVHRR image analysis and GIS. Examples have been presented in this Report. Further examples are intended, drawn from the list in Table 4.1, upon which the work has already begun. Results confirm that the daily temperature information extrapolated from the atmospherically corrected AVHRR band 6 can be used to describe the melt/accumulating state of the snowpack. Changes in snow cover area and snow depth have been detected by post-classification comparisons for selected NRA regions and catchments. The application of GIS played an important role in carrying out comparisons between different images for selected catchment basins and in assessing the effects of different factors such as forestry. Finally the importance of error analysis in change detection exercises is stressed. The assessment of snow cover change will be implemented for calculating input to flood forecasting models.

Table 4.1 List of recently acquired AVHRR images for snow events during winter 1991/92

Tape ID	Date	Eqx. °West[a]	Eqx. Time[b]	Satellite Number
1109/14	17/12/91	337.94	13:21:03	11
1110/02	18/12/91	181.94	02:57:04	11
1110/09	19/12/91	182.98	07:44:35	12
1111/04	20/12/91	354.48	14:27:22	11
1111/09	21/12/91	351.48	14:15:29	11
1111/14	22/12/91	348.48	14:03:35	11
1112/05	23/12/91	345.48	13:51:41	11
1117/03	05/01/92	331.96	12:58:50	11
1117/09	06/01/92	354.45	14:28:56	11
1117/14	07/01/92	351.45	14:17:00	11
1118/05	08/01/92	348.44	14:05:06	11
1118/10	09/01/92	345.44	13:53:10	11
1119/01	10/01/92	342.43	13:41:13	11
1119/06	11/01/92	339.42	13:29:17	11
1119/11	12/01/92	336.41	13:17:20	11
1120/02	13/01/92	333.40	13:05:25	11
1120/08	14/01/92	355.89	14:35:29	11
1132/06	15/02/92	335.86	13:18:38	11
1132/11	16/02/92	332.83	13:06:39	11
1133/03	17/02/92	355.30	14:36:37	11
1133/08	18/02/92	352.27	14:24:37	11
1133/13	19/02/92	349.24	14:12:36	11
1143/05	14/03/92	352.83	14:29:29	11
1143/11	15/03/92	349.78	14:17:23	11
1144/03	16/03/92	346.74	14:05:21	11
1150/06	01/04/92	348.92	14:15:58	11
1150/11	02/04/92	345.87	14:03:53	11
1151/02	03/04/92	342.88	13:51:48	11
1151/07	04/04/92	339.82	13:39:41	11
1151/12	05/04/92	336.77	13:27:34	11

Note: a. Equatorial crossing angle expressed as degrees West
b. Equatorial crossing time (GMT).

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