Interim Report R&D Project 207

Scenarios for the Operational Implementation of Remote Sensing of Snow by Satellites

Remote Sensing Unit
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Scenarios for the Operational Implementation of Remote Sensing of Snow by Satellites for the NRA

by

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CONTENTS

LIST OF ABBREVIATIONS AND ACRONYMS

AVHRR	Advanced Very High Resolution Radiometer
BER	Bit Error Rate
BURL	Bradford University Research Ltd.
dB	Decibels
DCP	Data Collection Platforms
DMSP	Defense Meteorological Satellite Program
DSS	Department of Social Security
ERDAS	Earth Resources Data Analysis System
ERS	Environmental Remote Sensing
ESA	European Space Agency
ET	Evapo-Transpiration
G/T	Gain Temperature
GMS	Geostationary Meteorological Satellite (Japan)
GMT	Greenwich Mean Time
HRPT	High Resolution Picture Transmission
IBM	International Business Machines
ISDN	Integrated Services Digital Network
ISODATA	Iterative Self-Organising Data Analysis Technique
JANET	(UK) Joint Academic NETwork
LED	Light Emitting Diodes
MDD	Message Distribution Data
MOD	Ministry of Defense
NERC	Natural Environment Research Council
NOAA	National Oceanic and Atmospheric Administration
NRA	National Rivers Authority
PC AT	Personal Computer Advanced Technology
PDUS	Primary Data User's Station
RAE	Royal Aircraft Establishment
RAM	Random Access Memory
RSU	Remote Sensing Unit
S-VISSR	Super Visible & Infrared Spin Scan Radiometer
SMD	Soil Moisture Deficit
SPARC	Trade-name for present family of SUN Workstations
SUN	SUN Microsystems Inc.
TCP/IP	Transmission Control Protocol/Ethernet Protocol
TIROS-N	Television and InfraRed Observation Satellite
UK	United Kingdom
USA	United States of America
VAT	Value Added Tax
VDU	Visual Display Unit
VGA	Video Graphics Adapter

1 INTRODUCTION

1.1 The NRA Brief

Snow hydrology has been a relatively neglected part of the hydrological cycle. Although the climate of the British Isles is relatively mild for its latitudinal zone, the climatic average number of days with snow lying on the ground at 0900 GMT ranges from about 1.5 at sea level in the South-west Peninsula through about 6.0 in the London area and 25 in the central Pennines to about 55 in the Grampian Region of Scotland. In all areas of the British Isles snow poses a special threat through its potentially hazardous influence on river levels when melting, and has been responsible (wholly or in part), for many of the worst floods in the UK.

Until now snow monitoring in the UK has relied mainly on a voluntary network of snow observers whose reports are published annually in the Meteorological Office's "Snow Survey of Great Britain". Involving only about 160 stations, this system has proved inadequate to provide either a suitably complete view of this spatially often very discontinuous phenomenon, or all the types of information water authorities would most like (e.g. snow water equivalent measurements, which are made at only a few localities), or information quickly enough to be of use in water management, including hazard monitoring and flood prediction and control.

In 1988 the Department of the Environment (Water Directorate) contracted the Remote Sensing Unit, Department of Geography, University of Bristol to begin an investigation of the potential of satellite remote sensing for snow mapping and monitoring in the UK, a project adopted by the National Rivers Authority in 1990. This work programme is focussing on several objectives, including the following:

(a) Assessments of the utility of satellite remote sensing visible and infrared imagery for the determination of snow area, including considerations of classification accuracy, and spatial and temporal resolutions under different snow conditions and terrain (surface morphology and vegetation).

(b) Development and testing of procedures for the evaluation of snow depth by satellite remote sensing in the visible and infrared wavebands.

(c) Evaluations of the potential of satellite remote sensing in the passive microwave region of the electromagnetic spectrum for the assessment of snow water equivalent and other snow parameters even under conditions of continuous and persistent cloud cover.

(d) Investigations of the feasibility of establishing an operational system for snow monitoring by satellites to provide the NRA Regions with more, and more timely, information on snow than is presently available from conventional sources.

Results from (a), (b) and (c) above have been reported most recently by Bailey *et al.* (1991); initial results of (d) are provided in this present Report, which considers possible scenarios for the operational implementation by or for the NRA of the RSU's satellite-based snow algorithms. For present purposes, the main foci of attention are algorithms based on multispectral visible and/or infrared image data from US National Oceanic and Atmospheric Administration (NOAA) satellites, for these are themselves fully operational. Plate 1 illustrates both raw imagery (Plate 1a) from the AVHRR NOAA-Advanced Very High Resolution Radiometer, and processed products prepared by the Bristol methods.

These products include calibrated imagery which has been linearized and remapped to the British National Grid (Plate 1b), a 3-category snow area classification (Plate 1c) and a 5-

category snow depth classification (Plate 1d)

For the future, it should become possible soon to contemplate equally seriously a range of complementary products based on passive microwave image data from US Defense Meteorological Satellite Program (DMSP) satellites, whose Special Sensor Microwave Imagers (SSM/I) are state-of-the-art passive microwave sensors which are providing encouraging initial results relating to both snow area mapping and snow water equivalent estimation even under most types of clouds, though at a lower spatial resolution (c15 km *cf* 1 km with the AVHRR High Resolution Picture Transmission (HRPT) system). Data from this operational military satellite system are expected to become available to real-time civilian users in the UK soon (within 1-2 years) via a new receiver at West Freugh, Scotland. However, a detailed consideration of the possible consequences of this for the NRA would be premature at this point in time.

Finally, it must be noted that active microwave data from the European Space Agency (ESA) first Earth Resources Satellite (ERS-1) launched in the summer of 1991 is providing imagery of significance to the present R&D programme, but these data are very infrequent, and will be of value for the foreseeable future mainly for research purposes, e.g. helping to understand better the passive microwave data, and, perhaps, to better calibrated the SSM/I algorithms.

1.2 Setting The Scene

We have seen that the University of Bristol's snow algorithms are based on the use of multichannel AVHRR data from the NOAA series of satellites. The algorithms are to be applied over the England and Wales with the outputs distributed to the various NRA regions. To make this possible it is clear that the NRA should acquire either a NOAA AVHRR Receiver and Processing system or obtain data in real-time from an existing station. There are several potential suppliers of such a potentially suitable Receiver and Processing system . To name some :

(a) Dundee Satellite Systems - University of Dundee
(b) Bradford University Research Ltd. - Cranfield Institute of technology
(c) Dartcom Ltd - (British Aerospace)

The first two suppliers listed were selected for a detailed examination and visits to their premises arranged.

Dundee Satellite Systems (DSS) is the current NERC supported national AVHRR receiving and archiving station. DSS has a decade of experience of designing, manufacturing, exporting and installing on site reception systems for Meteosat PDUS, MDD and DCP, GMS S-VISSR and NOAA HRPT. They have installed systems in Africa, Antarctica, Australia, Austria, Bangladesh, Canada, Germany, Hawaii, Holland, Italy, Japan, Reunion Island, Singapore, Switzerland, U.K. and the U.S.A.

Bradford University Research Ltd (BURL) is a company registered under guarantee and established by the University of Bradford in 1979. BURL offers a wide range of reception and processing systems. From Meteosat it provides many receivers to collect Primary digital data and related DCP messages based around PC ATs (286/386/486). Its current user base for NOAA AVHRR consists of 10 sites in the UK, mainland Europe, Mexico and Africa.

Of all the potential suppliers, Dundee Satellite Systems is the only one to have extensive experience in the operation, installation and maintenance of NOAA receiving stations.

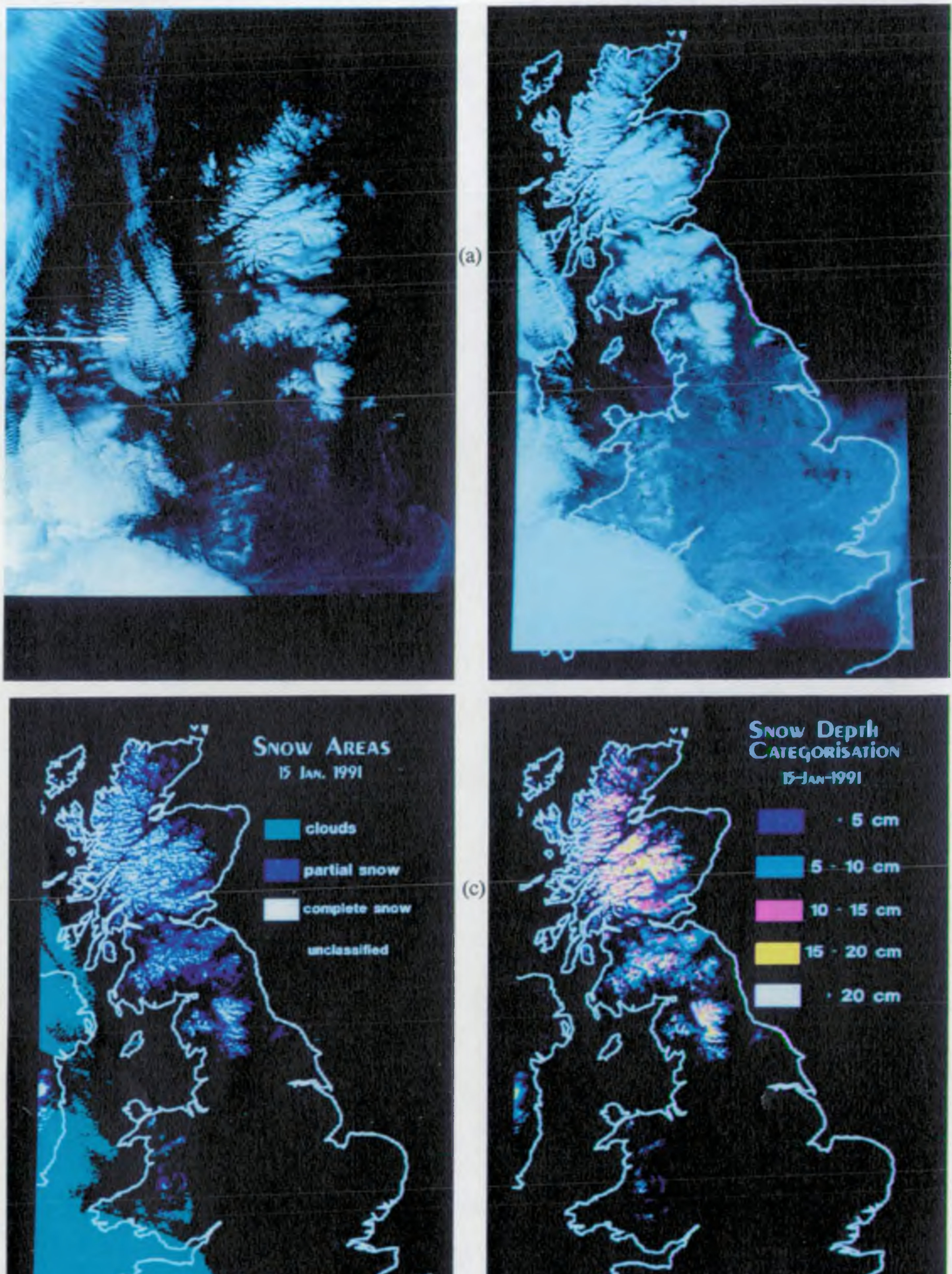

Plate 1 NOAA-AVHRR raw imagery (Plate 1a), and processed products (Plates 1b, 1c & 1d): for discussion, see text.

Bradford University Research Ltd (BURL) has many installations of Meteosat PDUS and has only recently entered the NOAA station marketplace. It was selected as being a technically innovative company who were offering a less conservative solution and at an apparently very attractive price.

The remaining companies are all attempting to enter the NOAA receiving station market at various levels. However, they are all at the research and development stages. It was considered that BURL would present the latest approaches to AVHRR reception while DSS would offer the experienced view.

The information gathered is presented in the following order:

Section 2: Hardware components.
Section 3: Software components.
Section 4: Supporting overheads.
Section 5: Operational Scenarios.
Section 6: Recommendations.

Each Section has been further subdivided to enable a convenient and detailed description to be made.

2 HARDWARE COMPONENTS

2.1 Antenna

An antenna dish is required to receive the satellite telemetry. Since the NOAA series of satellites are orbital rather than geostationary the antenna must be motorised and steered to point at the satellite as it tracks across the sky from horizon to horizon. For good quality data reception the ground station figure of merit G/T must exceed a certain minimum value where G is related to the antenna size and T depends on the sky and receiver noise. Minimum required G/T depends on the satellite transmitter power, data rate, antenna type, errors in elevation angle, imperfections in the receiver and acceptable bit error rate.

Calculation of the required G/T is subject to several uncertainties. For example, spacecraft manufacturers quote a nominal value for the transmitter power and worst case value. The difference is a massive 3.6 dB which is equivalent to doubling the size of antenna.

Another uncertainty is how much to allow for the receiver technology losses. These are difficult to measure, but a good receiver should be better than 1 db and a less good one may be over 3 dB.

For 0° antenna elevation, assuming nominal satellite transmitter power, 2 dB receiver technology losses and allowing a BER of 1 in 1 000 000, required G/T works out at -0.56 dB/°. If worst case transmitter power is used in the calculation, G/T becomes 3.04 dB/°. Dundee Satellite Systems state that the transmissions from TIROS-N through to NOAA 11 are well up to nominal power.

The value of T in a given ground station is also subject to uncertainties. Sky noise temperature can vary considerably, partly depending on solar activity. Also when the antenna elevation is reduced from 20° to 0°, system noise T can rise by as much as 2 dB because the antenna beam is viewing the relatively hot surface of the Earth.

Choice of antenna size and type is important. A balance must be struck between acceptable link margin (BER) and size and type of antenna which has a large effect on cost.

Dundee Satellite Systems can supply three sizes of dish antenna: 1.2 m, 1.8 m or 2.4 m: They recommend a 1.8 m dish antenna since this gives good reception from horizon to horizon with a margin of 3 - 4 dB.

Bradford University Research Ltd (BURL) decided upon a horn antenna rather than a dish, with the motor drive system based upon a heavy duty TV/security camera control. The ability to use a small aerial with a wide aerial beam width minimises the problems associated with aerial pointing and simplifies the mechanical design. At the required frequencies a horn aerial is about 30% more efficient than a dish of the same aperture so that the 65 x 65 cm square system is equal to a parabolic dish of 1.1 m diameter, i.e. a gain of about 22 dB. The aerial amplifiers have matched gains of 30 dB and noise temperatures of 35°K. The G/T of the system front end (for high elevations) is about 7 dB/degree.

2.2 Antenna Controller

The movements of the antenna or horn are controlled by a PC containing satellite track prediction software. Both BURL and DSS use an IBM 286/386 compatible for this purpose. DSS use a purpose built interface card to service the tracking antenna motors, shaft encoders, limit switches etc. DSS also offer a receiver Doppler option which enables automatic data reception for up to two weeks without the need to update the orbital model data during that period. DSS use a separate ingest computer to accept the incoming data stream whereas BURL use a single computer to act as the antenna controller and ingest the incoming data stream from the receiver. In this instance the antenna moves only between receiving scan lines. This approach has some obvious cost attractions and BURL can demonstrate its effectiveness.

2.3 Data Receiver

DSS supply a telemetry receiver in either a bench top or rackmount enclosure. This contains a down converter, phase demodulator, bit/frame synchronisers, remote/manual channel select and data output interface to the ingest computer. Front panels include: expanded scale S-meter, tuning indicator, carrier, clock and frame lock LEDs. Receiver options are : HRPT signal simulator which injects a signal into the phase demodulator for testing the demodulator, bit/frame synchronisers, computer interface and ingest software; rate of change of Doppler for measurement of time of closest approach of high elevation passes. Differential Doppler measurements are passed at one second intervals to the tracking PC for post pass processing.

The BURL receiver design is the result of a substantial investigation supported by the Natural Resources Institute and Department of Trade and Industry. The receiver contains wide band but high order transitional Gaussian filters (and no hard limiters are used as these would worsen performance near to threshold). The data clock is crystal locked and a 48 bit correlator used for line synchronisation. Overall performance is indicated by a voltage proportional to signal/noise (rather than signal) as this helps with tracking at low elevations and for orbits in the same direction as the sun.

2.4 Ingest Computer

BURL use any 286/386/486 IBM AT compatible computer fitted with sufficient memory (4 Mbytes minimum) to capture image data. The computer must also be equipped with the STB graphics board able to support an 800 x 600 x 256 colour level display (a super/enhanced VGA mode) as used by their image processing system. A maths coprocessor is also needed for use of the processing software, although such a coprocessor is not required for the capture of data. The interface card to the receiver is one of BURL's own design.

DSS may also use a standard IBM compatible, and systems have been developed which allow data to be ingested into Unix-based systems like SUN computers. Generally two types of standard interface cards are required. In those cases where the computer uses a DRQ-3B card or similar, a simple handshake circuit will suffice; in other cases a twin buffer memory arrangement is used. A Direct Memory Access card of Digital DR11-W type is then required. DR11-W emulator cards are available for use with fast IBM compatibles also.

Generally speaking as much disk space that can be afforded should be obtained. Imagery is very consumptive of disk space, and the more disk space that is available eases the data transfer and archive load.

The complete AVHRR scan line containing all five channels consists of 20480 bytes (8 bits/byte) of data, and to that must be added 1500 bytes of ancillary data, calibration data, timing etc. The complete scan is therefore 21980 bytes in total. Each scan line covers 1.1 km of the Earth's surface along track, and 3000 km across track. If coverage of England and Wales is required then around 700 scan lines are needed. The amount of storage to contain a single swath of data is therefore nearly 15.5 Mbytes.

2.5 Data Processor

It is possible to use the ingest computer to process the data further and ultimately produce the desired application products. However this obviously depends on the amount of time given to each of its processing functions. The ingest computer cannot be used for any other processing function during the period of data reception. If the data receiving function is limited and all the operational processing is confined to one physical site then a single machine may be a good solution. However the single machine arrangement is potentially very restrictive. A better solution would be to use an entirely separate data processing machine linked to the ingest computer via a network line. This second machine could be any machine of suitable power. Both DSS and the Remote Sensing Unit at the University of Bristol use 8-bit colour, 16-Mbyte SUN Sparc workstations These machines have good Ethernet capabilities and are reasonably cheap and powerful. A typical SUN 8-bit colour IPC with a Gigabyte of disk space costs under £15K. It is conceivable that an IBM compatible PC 386/486 could be used, but additional memory would be required and the currently used software would need to be specially modified. The cost of this additional work could well exceed the cost difference between PC and workstation, say £5K.

2.6 Data Transmission

2.6.1 Between ingest computer and data processor

This is only required if a separate data processor is used. In this case the received data has to be transmitted between the ingest computer and the data processing machine. There are various methods of connection and the appropriate selection depends on the physical distance, quantity of data for transmission, time available and cost. If the ingest and data processors are physically close, for example, in the same building then a simple Ethernet connection would suffice. If on the other hand the two machines are on remote sites then there are two possible solutions. The first is to arrange for a linkage by private British Telecom or Mercury circuit. This might be appropriate if the connection time between the machines is high both during day and night, and over the entire year. In that case fixed 'Kilostream' or 'Megastream' lines offered by the two telecommunications companies could be used. The second possibility would be to use a standard digital circuit such as the British Telecom ISDN (Integrated Services Digital Network). This allows the user to send and receive high quality, high speed data via a simple digital connection across the public network. ISDN 2 provides two channels for voice and data and one channel for signalling. Information can be sent or received at speeds of 64-kbits/second, allowing large quantities of information to be sent quickly and accurately. At this rate of data transmission each scan line of AVHRR data can be sent in 2.75 seconds, and the entire swath of 22 megabytes in 45 minutes. If data transmission is limited to the winter months and to a single swath per day then this would appear to be the most economical solution of remote transmission. Currently the connection charge, exclusive of VAT, is £0.4K per connection together with a quarterly rental of £0.084K. Data call charges within the UK are normal telephone charges. Workstation suppliers such as SUN are moving quickly to provide ISDN connections as a standard feature of their machines, supplying also all the necessary software for remote digital communications. It will also be possible to give an ISDN capability to existing machines. The timescale for these developments is in the order of twelve to eighteen months from the date of this Report.

2.6.2 Between data processor and regional data consumers

Once products have been generated by the data processor as required they must be distributed to the various NRA Regions. Following a meeting of NRA representatives at the University of Bristol, Remote Sensing Unit on 8 August 1991 it became clear that the requirements for the Regions varied. Some Regions required a digital product as an input to existing numerical hydrological models, whilst others simply required either a printed numeric interpretation or its graphical equivalent. All these requirements can be met easily. In the first case, either a modem and analogue line or another ISDN line could be used. The amount of data to be transmitted would be small, in the order of 15000 bytes. In the second case hard copy of the output could be faxed to the appropriate Region. Either way, the time and cost is not a large factor.

3 SOFTWARE COMPONENTS

Software is required for the entire process from data reception to product generation. There is already sufficient software and experience to be able to make a reasonable estimate of the time required for it. It is thought that between 4 and 6 hours would be required from the time of initial satellite data reception to the distribution of results. A target time of 4 hours is probably feasible.

3.1 Data Acquisition

In order to position the satellite data acquisition antenna prior to data capture details of the satellite orbit are required. A program can then be used to calculate the coordinates of the satellite and hence control signals for the aerial to initialize it to point towards the expected start position of the overflight. The important parameters for each satellite overflight are :

1. The equatorial crossing position in degrees.
2. The direction of satellite motion, i.e. ascending or descending.
3. The time and position when the satellite first appears over the local radio reception horizon.
4. The maximum elevation the path takes.
5. Which side of the reception station the satellite passes i.e. east or west.

One problem is that with orbiting satellites all the orbital parameters are variable - patterns of transmissions from no two days' are the same: different areas are viewed from each overpass. Prediction times can drift by a few seconds per day, so unless regular and accurate loggings are made day by day, and orbit by orbit, the system will degrade. NOAA supply regular orbital updates, and both DSS and BURL use these to stabilise their orbital models. The orbital model used by DSS has been refined over many years to allow for continuous operation. Using the Doppler option automatic data reception for up to two weeks is possible before the orbital model needs updating. However the BURL system is currently up-dated on a satellite flight by flight basis although BURL have plans to move to continuous operation.

3.2 Data Reception

This requires real-time software to capture the data stream from the receiver and transfer it to hard disk. DSS generally use a twin buffer memory arrangement. This method allows a full horizon to horizon swath to be captured without overflowing computer memory. The BURL system is primarily designed to collect data from a 'small' area of the total view seen by the satellite in its flyover. The definition of 'small' in this context is probably sufficient to collect the U.K. coverage, say 1000 scan lines. Data is collected into RAM in the computer and the amount which may be collected per pass is limited by the size of this memory. For 286 based PCs this limit is 16 Mbytes; for some 386/486 systems 32 Mbytes of memory is possible. Although data is captured into volatile memory it is immediately copied onto the hard disk just as soon as the capture process is complete so that data is not lost in the event of power failure.

3.3 Data Transmission

3.3.1 Between ingest computer and data processor

The computer supplier should provide a suite of networking software. This software should provide full data checking to ensure reliability of data transfer. For example SUN computers provide an Ethernet system based on the TCP/IP protocol. The AVHRR data transfer could be performed either by an operator or by a network process to accomplish the task of transfer automatically according to a schedule. If the distance for transmission is large, then Ethernet would no longer be used. In that case an ISDN line is used. It appears that SUN are shortly to incorporate an ISDN port as a standard feature. In that event apparently the TCP/IP protocol will be used over the ISDN line in the same transparent manner as an Ethernet connection.

3.3.2 **Between data processor and regional data consumers**

For those users who require digital products, a simple file transfer procedure using a modem to PC link is probably the simplest and cheapest solution. There are many proprietary packages to accomplish this; these are mostly very cheap or even free, using public domain software.

3.4 Image generation and linearization

The AVHRR multi-channel data is in the form of ten-bit interleaved values. Software is required to unpack these values and to create separate image files of the five channels. The ancillary data is stripped off and written to a secondary file for use by subsequent software modules. At this point the data, in the form of a swath containing 2048 pixels for each band, is 'as seen by the satellite'. Although the resolution remains constant at about 1.1 km along the track, the resolution worsens from the centre outwards along the swath so that the images are very distorted geometrically at their edges. This distortion is rectified by resampling the scan to maintain the 1.1 km resolution per pixel for the entire length of the scan. It should be noted that although this greatly increases the number of pixels in the scan line, it does not add extra data: the data resolution at the edges of the swath remain poor. This process of geometric correction is known as the 'linearization' of the data. In essence, it converts the data from being satellite-centred to being EARTH-centred. The Remote Sensing Unit, University of Bristol has software for this function. Other institutions could provide similar software.

3.5 Thermal and Visible Calibration

The 10-bit image values for each channel received from the satellite are all raw values. That is, the visible and thermal channels are expressed as sensor counts. This process is required to convert the visible channel to albedo, and the thermal channels to degrees Kelvin or Celsius. The NOAA series of satellites have an inbuilt calibration procedure. Essentially the AVHRR sensor views an on-board blackbody target of known temperature, and then also views the background space. The counts from these two reference views then permit the Earth-viewed counts to be calibrated. Associated data for this process are published by NOAA for each of its spacecraft while the on-board calibration data is transmitted along with the sensor data. The Remote Sensing Unit, University of Bristol, has software for this process also. Other institutions could provide similar software.

3.6 Data Extraction and Mapping

At this point the required data can be extracted from the swaths of each band. The area and projection of the required area is defined and a re-mapping is performed using the NOAA-supplied ephemeris data giving information on orbital parameters. The input data required are the satellite equatorial crossing time (GMT) and the equatorial crossing angle expressed as degrees WEST. These data form part of the data acquisition process, and accuracy at this point enables a more satisfactory navigation of the data to any given projection.

3.7 Geographic Registration

This mapping process is essentially navigation of the data values using satellite orbit and timing data, and is required because small errors of satellite height or timing all produce errors in the absolute location of data. This error can amount to a few pixels, usually as an along-track error, and is basically unavoidable. The solution for best possible registration is to visually shift the image onto a map reference overlay. This final step in the mapping process ensures that each image is geographically registered.

3.8 Product Algorithms

In the snow evaluation programs the calibrated and well-mapped NOAA AVHRR bands 1,3 and 4 are used in an unsupervised classification using the Iterative Self-Organising Data Analysis Technique (ISODATA). The statistically-clustered data, i.e., the resulting signatures of ISODATA, are further classified using a Maximum Likelihood Classification. The required information classes such as snow areas and clouds can then be identified and assigned by examining the spectral signature and spatial distribution of each cluster. Details of the principles behind the classification to distinguish snow from cloud cover and to define the snow area can be found in Lucas and Harrison (1989). AVHRR band 3 and 4 are primarily the snow/cloud discrimination channels while AVHRR band 1 describes the snowpack. The overlap in the spectral response of snow and cloud is characteristic of AVHRR band 1, but the spectral reflectance of cloud is much higher in calibrated AVHRR band 3 compared to calibrated AVHRR band 4.

3.9 Product Dissemination

The final step in the data processing is the partitioning of the product imagery according to the requirements of the regional NRA customers. One requirement is that there should be a single projection, since the product has already been mapped, but the output could be tailored to reflect local requirements, e.g. of scale and extent. The output would be converted into a form that could be transmitted easily over fax or simple modem line to the participating NRA regions as and when required. Figure 1 exemplifies types of maps which could be faxed to customers wishing to reserve visual displays of snow algorithm products. These could be tailored to individual regional needs e.g. through the addition of major rivers, catchment and sub-catchment boundaries, etc., and/or by summations of snow information for catchments, sub-catchments etc. as required. If customers required such information in numeric form, this could be transmitted by some agreed route, e.g. telephone line, computer network etc.

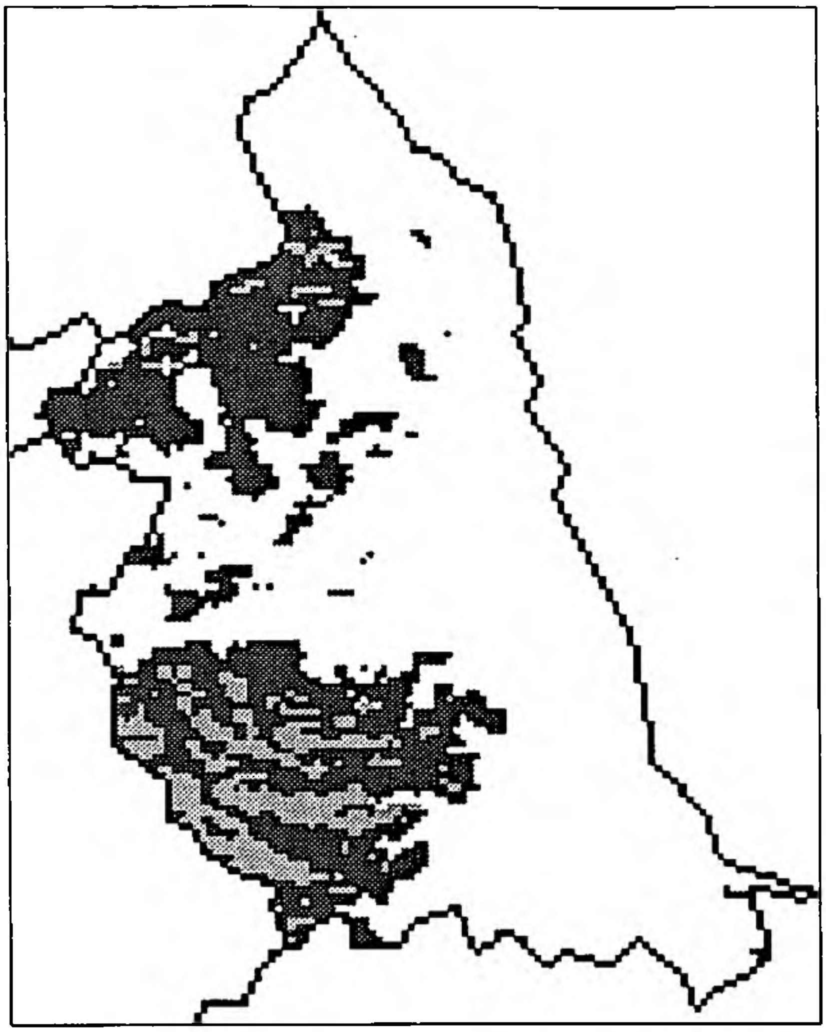

Figure 1 Example of possible paper product for dissemination by fax to NRA Regions: (a) snow cover categories.

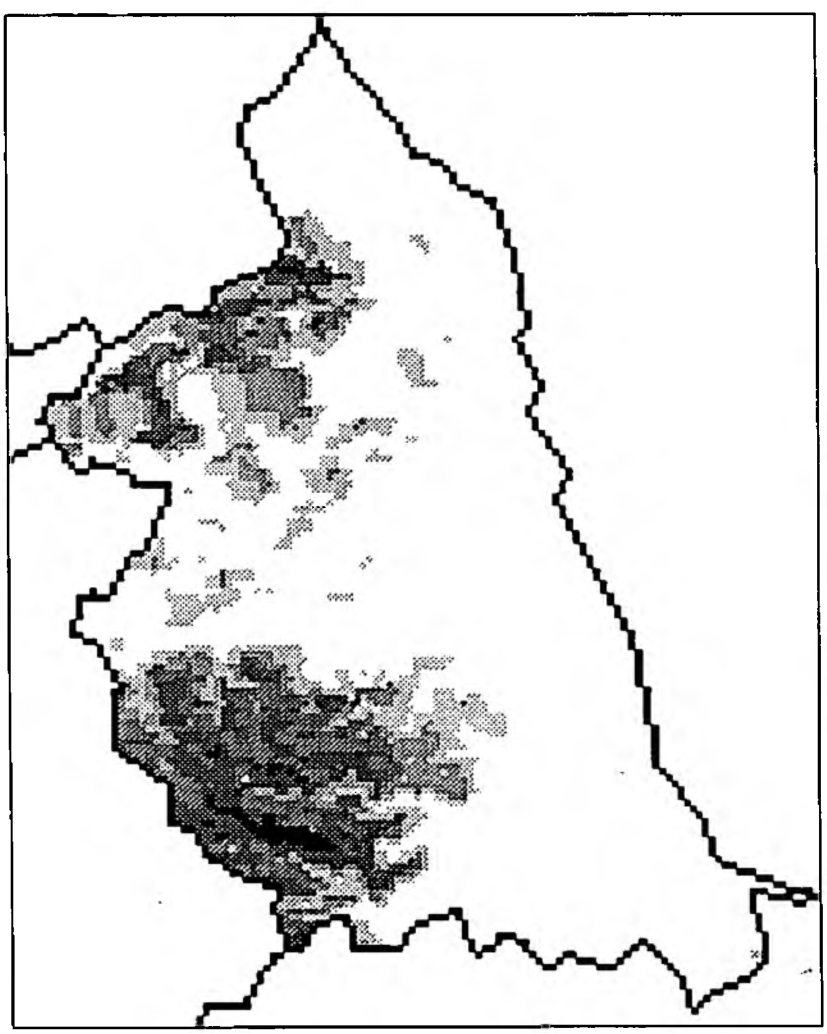

Figure 1 (cont.) Example of possible paper product for dissemination by fax to NRA Regions: (b) snow depth categories.

4 SUPPORTING COMPONENTS

4.1 Space Requirements

The amount of space required to house all the equipment (except the antenna) for data reception and processing is in the order of (35-40 m^2). The antenna should be sited externally as high as possible, with as wide and clear a horizon as possible.

4.2 Environmental Requirements

There are no specific environmental requirements for the NOAA AVHRR receiving station and its data processing. According to computer suppliers, the equipment required does not need air conditioning. Some noise is generated but normally this is within tolerable background limits. The lighting should be considered carefully to eliminate glare and reflections from the VDUs.

4.3 Manpower Requirements

Ultimately it might be possible to automate, in principle, the whole process entirely from data reception to product distribution. However this would represent a very ambitious aim. In the meantime the minimum manpower that should be considered initially would be one person with a good background in remote sensing and computing.

5 OPERATIONAL SCENARIOS

The key issues of data acquisition, processing and transmission, which are common to all possible operational scenarios (see Figure 2, can now be addressed in the form of operational scenarios.

5.1 Data Acquisition

From the previous text it is evident that there are two primary options if the NRA is to proceed with any form of operational testing of AVHRR snow cover and water equivalent algorithms: *either* the NRA must purchase its own receiving station *or* acquire the data it needs from existing receiving stations.

5.1.1 Via NRA NOAA satellite receiving station

Let us now consider the two possible suppliers for an NRA AVHRR receiving station.

The Dundee receiving station is clearly a well tried and conservatively engineered product. DSS have extensive experience in setting up and maintaining such systems. The purchase cost (ex VAT) for a system with a 1.8 m antenna, controller, receiver and ingest computer is in the order of £60-70K. The costs of further data processing and any transmission equipment would be additional to this figure. The advantage of this option is that the equipment is proven. DSS already use SUN workstations as their data processing machines, which would permit simple implementation of the existing Remote Sensing Unit, University of Bristol software. The involvement of NERC, and possibly ESA also, in the funding of DSS could prove to be an adverse factor: a new protocol for costs of data services by DSS is about to become public. Until it is, only estimates of possible costs can be made.

Meanwhile BURL offer a much lower cost package: the comparable package from BURL would cost in the order of £20-30K. However, it must be remembered that BURL does not yet offer a fully automatic system: the current system operates on a flight-by-flight basis only. BURL will no doubt continue to develop their system, and in time will be able to demonstrate its robustness. However, there would be a significant commercial risk in purchasing a system from BURL in the short-term future.

5.1.2 Data acquisition via data line

The alternative to purchasing a NOAA receiving station is to access the data over a data communications line from a currently operating NOAA receiving station. In this case there are two immediate possibilities, the Dundee NERC supported archiving station or the Royal Aircraft Establishment (RAE) station at Lasham. Either station would be capable of ISDN connection to provide immediate access to AVHRR data in virtually real time. Both stations currently export data using fixed Kilostream/Megastream lines to some of their existing customers. The choice of supplier would depend on normal commercial considerations, but one significant factor might be that Dundee and Bristol operate compatible computer systems.

A further point of interest is that AVHRR data is available from Dundee over the UK Joint Academic NETwork (JANET) using a file transfer facility. This facility allows access to AVHRR data immediately after its reception, enabling research projects located anywhere with connections to JANET access to near real time image data without the usual processing and postal delays. Currently, users of this service have online access to HRPT data for 24 hours after its reception. After this period the data is over written and must be ordered from the Dundee archive through the usual channels. It may be that the N

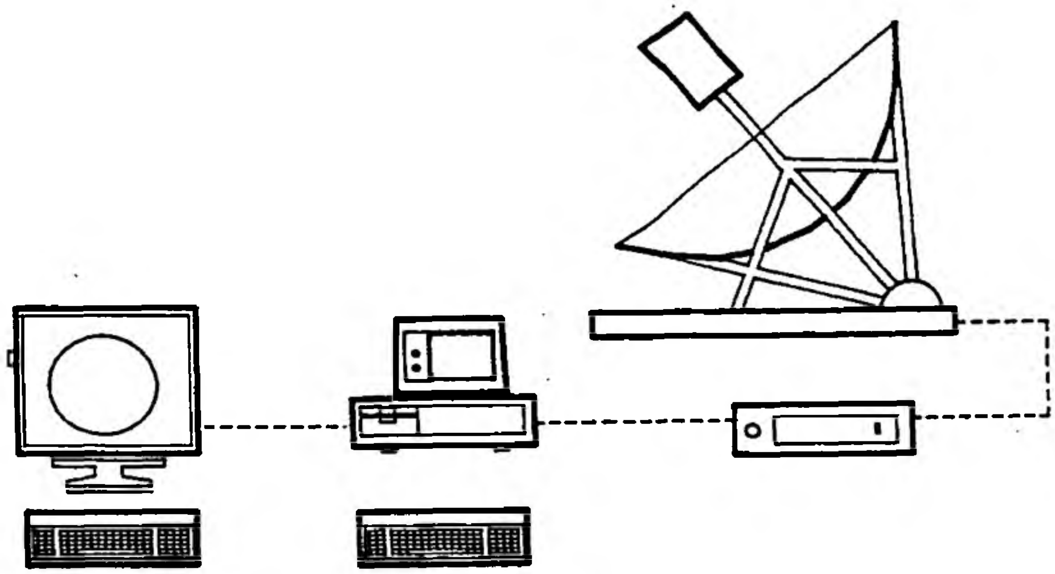

Figure 2 The essential components of all operational scenarios for data acquisition, processing and dissemination.

could come to some arrangement with Dundee to utilize the JANET network during a prototype phase.

5.2 Data Processing

There are two alternatives to the data processing requirement. First the NRA could purchase all the necessary computing equipment and software, obtain training from the University of Bristol, and proceed to operate a fully operational system. Second, the NRA could fund the operation and expertise externally. There would be some obvious benefits to this approach, particularly since the initial requirement for derived products might be for only 6 months of the year and any operational problems have yet to be resolved. However, it may be noted at this juncture that other uses of the system would by no means double the overall costs. For example, use of the system to provide improved evapotranspiration (ET) and soil moisture deficit (SMD) data in summer would add to the total costs relatively modestly, and should greatly improve the overall benefit/cost ratio. The current work of the University of Bristol has been to develop and demonstrate snow cover, depth and water equivalent algorithms. If these algorithms are to be used operationally the next logical step might be a system prototype phase where possible operational difficulties are resolved.

6 SCENARIO SUMMARY

The price given below for each system is a considered estimate (ex VAT) rather than a firm quotation. Only direct costs to NRA are included; *any NRA in-house overheads and other associated costs are omitted, for the bases on which these might be evaluated are not known outside the NRA.* All scenarios assume a 6 month period in the main figure for snow cover/water equivalent monitoring. The figures in brackets indicate the costs for 12 month snow cover monitoring plus ET and soil moisture deficit.

SCENARIO I

NRA to purchase Dundee AVHRR receiving station and all associated data processing equipment.

Estimated capital costs

Dundee AVHRR receiving station		£70K	
SUN 8 bit colour SPARC workstation + disk		£15K	
Image processing software (basic ERDAS)		£15K	
Implementation of Bristol RSU algorithms		£15K	(£20K)
Extra hardware/software for data transmission to the regions.	Total	£6.5K £121.5K	

Estimated Revenue costs

Hardware maintenance.(10% capital cost)		£8K	
Software maintenance		£5K	(£6.67K)
Travel and subsistance		£1.5K	
Personnel (Staff, 1 person)		£12.5K	(£25K)
	Total	£27K	

SCENARIO II

NRA to purchase BURL AVHRR receiving station and all associated data processing equipment.

Estimated capital costs

Dundee AVHRR receiving station		£30k	
SUN 8 bit colour SPARC workstation + disk		£15K	
Image processing software (basic ERDAS)		£15K	
Implementation of Bristol RSU algorithms		£15K	(£20K)
Extra hardware/software for data transmission to the regions.	Total	£6.5K £81.5K	

Estimated Revenue costs

Hardware maintenance.(10% capital cost)		£4K	
Software maintenance		£5K	(£6.67K)
Travel and subsistance		£1.5K	
Personnel (Staff, 1 person)		£12.5K	(£25K)
	Total	£23.0K	

SCENARIO III

NRA to acquire AVHRR data by means of an ISDN line from either Dundee or Lasham. NRA to purchase and operate all associated data processing equipment to produce and disseminate the required snow cover and water equivalent products.

Estimated capital costs

ISDN line installation		£0.8K	
ISDN SUN upgrade (Dundee)		£2K	
SUN 8 bit colour SPARC workstation + disk		£15K	
Image processing software (basic ERDAS)		£15K	
Implementation of Bristol RSU algorithms		£15K	(£20K)
Extra hardware/software for data transmission		£6.5K	
to the regions.	Total	£54.3K	

Estimated Revenue costs

Hardware maintenance.(10% capital cost)		£1.5K	
Software maintenance		£5K	(6.6K)
Travel and subsistance		£1.5K	
Data access to Dundee or Lasham		£3.2K	(14.4K)
(based on a figure supplied by DSS)			
ISDN line rental		£0.4K	
ISDN line costs (45 minutes/day)		£1.2K	(5.3K)
(Based on Dundee - Bristol)			
Personnel (Staff 1 person)		£12.5K	(£25K)
	Total	£25.3K	

SCENARIO IV

NRA to acquire AVHRR data by means of an ISDN line from either Dundee or Lasham. NRA to use the facilities of the RSU, University of Bristol to produce and disseminate the required snow cover and water equivalent products.

Estimated capital costs

SUN 8 bit colour SPARC workstation + disk		£15K	
(SUN workstation to be either leased or purchased. If purchased the SUN remains the property of NRA)			
ISDN line installation		£0.8K	
ISDN SUN upgrade (Dundee)		£2K	
Implementation of Bristol RSU algorithms		£5K	(£10K)
Extra hardware/software for data transmission		£6.5K	
to the regions.	Total	£29.3K	

Estimated Revenue costs

Data access to Dundee or Lasham	£3.2K	(1.4K)
(based on a figure supplied by RAE, assumes 80 days of data at a cost of £40 per days data. Full NERC guidelines for costing are currently being formulated)		
Travel and subsistance	£1.5K	
Computer processing charge	£1K	(2K)
Software maintenance	£2K	(3.5K)

ISDN line rental	£0.4K	
ISDN line costs (45 minutes/day)	£1.2K	(5.3K)
(Based on Dundee - Bristol)		
Personnel and overheads (RSU Staff)	£33.3K	(£50K)
(Note that overheads have been included in this item)	Total	£39.4K

7 CONCLUDING RECOMMENDATIONS

1. We would recommend that the NRA not purchase a NOAA AVHRR receiver at this time. The technology is still improving and waiting another 1-2 years could prove cost effective. In that time the BURL system might become fully automatic and well proven.

2. We would recommend that the current work with the RSU University of Bristol be continued into an prototype stage to demonstrate its operational effectiveness. This would suggest an implementation of Scenario IV in the first instance.

3. It is possible that the NRA would want to will use other potential satellite algorithms for Evapotranspiration, Soil Moisture Deficit Measurement etc., with implications for data capture over longer periods of the year, but with arguably higher overall benefit/cost ratios.

4. It might be profitable to apply the algorithm(s) to Scotland as well as England and Wales, e.g. if snow products for Scotland could be supplied to other customers, with little impact on total costs.

5. Finally, it should be noted that future algorithms might require the acquisition of data from other satellites. For example the RSU is currently demonstrating the synergistic usefulness of passive microwave data from the American DMSP defence satellite. In the longer term this might emphasise the function of the NRA as a user of data rather than an acquirer of data.

6. Our considered view is that it might be more effective for NRA to leave the receiving and archiving of data together with its attendant problems to others, whilst commissioning products appropriate to its own needs, and perhaps marketing some which meet the need of others.

8 REFERENCES

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