

REMOTE SENSING FOR FOREST RESOURCE MANAGEMENT:  
CCRS ADVANCES IN ELECTRO-OPTICAL AND RADAR IMAGING SYSTEMS

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Commission Number VII/Joint Session of IUFRO and ISPRS

ABSTRACT

Remotely sensed data are being used increasingly in Canada for forest resource management. Airborne and satellite systems are providing information for forestry requirements in a digital format that can be interfaced efficiently and cost-effectively to computer-based management systems. The Canada Centre for Remote Sensing (CCRS) has been active in the development and evaluation of new remote sensing systems and in the parallel development of processing algorithms and applications. In the area of electro-optical sensors, the MEIS airborne multispectral imager has improved radiometric sensitivity, geometric fidelity and stereo capability. It has demonstrated the value of such systems for insect and disease damage assessment and has shown potential for forest inventory mapping and update. This has led to plans within the government agencies and industry to implement a MEIS-based system for operational forest surveys. The new airborne synthetic aperture radar system (C- and X-band) of CCRS provides a unique facility for research into applications of radar imagery. It has acquired high-quality data for forestry pilot projects throughout Canada, leading to an improved understanding and evaluation of radar imagery for forestry applications. This airborne radar facility is playing a major role in the development of radar applications preparatory to the satellite-based systems such as ERS-1 and RADARSAT.

INTRODUCTION

The information requirements for forest resource management fall into four major areas related to reconnaissance survey, forest inventory, forest change and forest protection. Forest managers in Canada and world-wide are turning increasingly to digital forest inventories and digital geographic information systems to help their management of the forest resources; remotely sensed data are being used more and more as the source of such information, (Ahern and Leckie, 1987). While remote sensing in the form of aerial photography has provided information for many years, satellite sensors have allowed information to be provided over wider areas than possible with aerial photography. As the capabilities of the satellite sensors have improved, the types of information provided have expanded, and developments in data processing and interpretation have allowed more information to be extracted. Recent research and development towards improved forest surveys have employed airborne digital sensors, with responses in the visible and infrared regimes (electro-optical), and in the

microwave (radar). Such airborne sensors offer higher performance than possible with satellite sensors, in terms of spatial, spectral and radiometric resolutions. Projects with the electro-optical linear array imager MEIS II have demonstrated the potential of such systems for forest inventory and forest damage assessment, and this had led to initiatives to implement a MEIS-based imager for operational forest surveys.

Less use has been made of radar imagery for forestry applications, but this is likely to change with the launch of the satellite-based systems such as ERS-1 and RADARSAT in the 1990's. Preliminary investigations using airborne radar data have been carried out over the last few years, and are beginning to show the potential of radar imagery for resource management. In order to develop the necessary understanding of the interaction of the radar with the features of interest, Canada has implemented a radar data development program, which includes a comprehensive series of research and development projects to evaluate radar imagery and to develop the associated data processing, methodologies and interpretive techniques. A major component of this program is the CCRS airborne synthetic aperture radar (SAR) facility which includes two imaging digital radars operating at C-band and X-band frequencies. This unique facility has been acquiring radar imagery for a range of application projects, including a number of forestry-oriented studies, and is playing an important role in the evaluation of remotely sensed radar imagery for operational forestry applications.

## SENSOR DEVELOPMENTS

### MEIS Linear Array Imager

The MEIS (Multi-Detector Electro-optical Imaging Sensor) is an airborne multispectral linear array imager that was developed by the Canada Centre for Remote Sensing as part of a multi-year Canadian research and development initiative to develop and evaluate array imager technology for remote sensing applications (Zwick et al, 1978; Neville et al, 1983). The MEIS II has been the primary sensor in the CCRS airborne electro-optical facility since 1983 and is characterised by high spatial, spectral and radiometric resolution that is superior to that provided by remote sensing satellite sensors. It has acquired imagery for close to 60 remote sensing missions per year, for application research and development projects and for sensor evaluation (Till et al, 1986). The system has been described elsewhere (Neville et al, 1983; McColl et al, 1984); it is a multispectral linear array imager with six channels looking nadir and two channels looking fore and aft to provide continuous fore-aft stereo imagery. Its development has been accompanied by the implementation of data processing techniques to provide geometrically corrected imagery referenced to standard coordinates (Gibson et al, 1987).

Although the MEIS was developed as part of the research program of the CCRS, it has generated considerable interest in the capability of such imagers for operational resource management. Data acquisition services with the MEIS II are now being offered by Canadian industry on a commercial basis; as a result of the interest that has developed in the forestry resource management community, in the mapping community and in the Canadian industry, requirements have been generated for an advanced linear array imager for

forestry and mapping applications. Such a digital multispectral imager is seen as a major new tool in the survey and mapping industry.

### C- and X-Band Synthetic Aperture Radars

The C-band SAR has been operating on the CCRS CV-580 aircraft since 1986 while the X-band SAR has been recently commissioned and is now collecting data for users (Livingstone et al, 1987; Livingstone et al, 1988). Both radars are dual-channel systems such that either H or V polarized radiation can be transmitted and both the like and the cross polarized radiation can be simultaneously received. The system features an onboard, 7-look, Real-Time SAR Processor (RTSP) and display with 6 or 20 m resolution in slant range and 6 or 10 m resolution in azimuth for the high and low resolution modes respectively. In both cases 4096 range pixels are displayed and recorded for one channel giving slant range swaths of 16.4 km and 61.5 km for high and low resolution respectively. The high resolution mode can be operated in the nadir (imaging to the nadir position) or narrow swath modes (near image edge at 45° incidence angle). The former mode is useful for simulating satellite radar geometry. Signal data, focussed in range but not in azimuth can be recorded for both channels on two separate high density digital tape recorders (HDDR), one for each frequency. A third HDDR is used to record the RTSP data for both radars.

Extensive use of digital technology has ensured that the radars can be well characterized, will operate linearly over a relatively wide dynamic range and, therefore, are calibratable. Real-time motion compensation based on data from an inertial reference system has also been implemented digitally. Future plans include polarimetric mode research and the addition of a second offset antenna to create an interferometric mode for estimation of terrain elevation.

## FORESTRY INFORMATION REQUIREMENTS

### Reconnaissance

Of the four major forestry categories for resource management, reconnaissance is needed to provide an overview of forest features on a broad scale, for example for forest discrimination of general forest types before detailed inventory, and for mapping of specific features such as forest ecosystems. In view of the broad coverage required, satellite data have proved effective in Canada for such reconnaissance information, and use has been made of the LANDSAT Multispectral Scanner and TM, and of the SPOT HRV.

### Forest Inventory and Change

In the area of forest inventory, the type of information required is generally related to the boundaries and composition of the forested areas, and may include the type of species, the age, the density and the height class. Since individual trees need to be observed, to judge species and height, etc., aerial photography at scales of 1:10 000 to 1:20 000 has been

used. Interpretation is generally performed by a skilled airphoto interpreter viewing the aerial photography in stereo. Because of the type of detail required, satellite sensors have not yet provided significant information in this area, since the resolution is too coarse and the species information too general (Cihlar, 1986).

However, advances in airborne electro-optical imaging systems promise to improve the inventory detail available. The spatial resolution of the MEIS II imager ranges from 0.5 m to 7 m, dependent on the altitude, and this is accompanied by a high radiometric resolution and a spectral resolution as narrow as 5 nm passband. Such performance is unlikely to be achieved with operational satellite sensors in the foreseeable future, and so is seen to provide a valuable complement to satellite data in forest information and management support systems. Figure 1 is an example of a juvenile stand in British Columbia imaged by the MEIS II with 1 m spatial resolution. This imagery was acquired as part of a pilot project in 1986 carried out by CCRS and the British Columbia Ministry of Forests to evaluate the use of MEIS for juvenile stand assessment, that is, an evaluation of the condition of coniferous plantations 5 to 10 years after planting. This image clearly shows which plantations have become well established, which are threatened

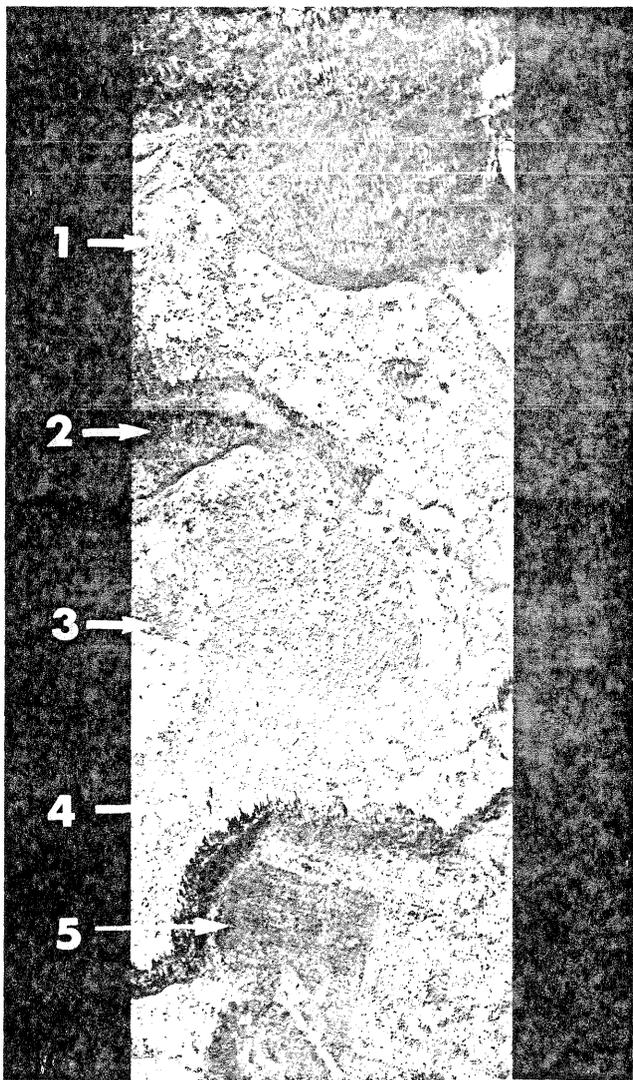


Figure 1:

MEIS II imagery of juvenile coniferous stands in British Columbia. Three of the MEIS channels, centered at 777 nm, 676 nm and 549 nm, were printed red, green and blue, and showed clear differentiation amongst the different conditions:

1. young plantation
2. mature conifer
3. brush competition
4. compacted soil
5. older plantation

by competition from brush and herbaceous species, and which areas are not regenerating because of compacted soil (Kneppeck and Ahern, 1987). Other inventory projects carried out with MEIS II have included studies of its capabilities to map clear-cuts and to identify tree species; Leckie and Dombrowski (1984) were able to use 1.2 m resolution MEIS imagery to highlight differences amongst several softwood species, while the ability of MEIS imagery to distinguish mixed hardwood and softwood stands is being evaluated (Hall, 1987). The MEIS imagery is available in stereo mode, for terrain profiling and stand relief applications, and can be corrected to cartographic coordinates for efficient input to forest inventories residing on Geographic Information systems.

Radar imagery, unlike electro-optical imagery offers the great advantage of being unaffected by cloud cover and by (sun) lighting conditions and so offers data timeliness which cannot always be guaranteed by visible and infrared sensors. Forestry related projects using the CCRS C-band SAR system have concentrated on potential inventory applications, and have covered a number of sites across Canada, for example inventory studies in Nova Scotia, monitoring of regeneration in Ontario and Quebec, clear cut mapping in Alberta and British Columbia, as well as biomass estimation in Alberta. Figure 2 shows an example of an area of cutovers and regeneration in Whitecourt, Alberta. This was imaged in 1987 with the narrow swath mode of the SAR, with a resolution of 6 m (azimuth) and demonstrates the discrimination of the SAR for different terrain features. Investigations of the mapping capabilities are underway; preliminary results indicate that the clear cut area is being measured satisfactorily but that improvements in the placement of the clear cut boundary will be required through, for example, improved interpretation experience. The advantages of multi-look imagery or multi-temporal acquisition are being considered.

### Forest Damage

The major sources of damage to the forests are forest fire and insect damage. Protection from fire is common in Canada while protection against insect attack is attempted in some circumstances. Generally, fire detection programs use visual observation from light aircraft on routine patrols, while in some areas detection in the thermal infrared is being used operationally as an effective fire mapping tool.

Insect damage surveys are used for assessing the amount of damage, the state of the insect infestation and the timber loss, for planning control and assessing the effectiveness of the control, and for planning harvesting. Again, visual observation by skilled "sketch mappers" in light aircraft has been used routinely to detect visually the damage. Recent research efforts in Canada have concentrated on the use of digital airborne sensors, with their potential for provision of similar information with greatly improved resolution and positional accuracy, and their potential for efficient interfaces to data bases. Pilot projects have been carried out to evaluate the MEIS imager for mapping spruce budworm defoliation and pinebeetle infestations. These have demonstrated the potential for routine insect damage surveys with such airborne imagers (Ahern et al, 1986; Murtha, 1987; Kneppeck and Ahern, 1987). Satellite imagery, with its poorer resolution, is not yet able to match the information content from these airborne sensors.



Figure 2:

SAR image of clear-cuts and mature coniferous stands, in Whitecourt, Alberta. This was acquired by the CCRS Airborne C-Band SAR in October, 1987, with 6 m resolution.

## CONCLUSION

Remotely sensed data from airborne and satellite systems are being used increasingly for forest resource management. The digital format of the imagery offers efficient interface to digital forest inventories, and the type and extent of the information provided have been expanding as the capabilities of the systems have improved. High performance electro-optical sensors and radar sensors are seen as major new tools in the management of the forests.

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