CHAPTER 2

APPLICATIONS OF ACTIVE MICROWAVE IMAGERY

Active Microwave Users Working Group

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INTRODUCTION

The objectives of the Active Microwave Imagery Applications Panel were as follows.

1. To review and critique the applications potential of active microwave image data

2. To review the findings of the Microwave Applications Task Force

3. To prioritize potential active microwave applications that are considered "payoff applications" by users such as resource managers and planners

The Applications Panel members were selected from the academic community, Federal Government, and private industry. Although some members have had previous experience with active microwave, they consider themselves as nonexperts who are inclined to view the potential for active microwave applications in a different light and with significantly different priorities than their counterparts at the workshop who are radar technologists. However, each Applications Panel member is an expert in one or more of the Earth resources disciplines and has had considerable experience in applying other forms of remote-sensing data. Panel members do represent the users who will determine the eventual success or failure of the active microwave program in Earth resources application.

Early in the workshop, the Applications Panel received a detailed briefing on microwave technology from Professor R. K. Moore, University of Kansas. The panel chairman provided an extensive library of radar and microwave literature, much of it applications oriented. Members also received a formal briefing on Seasat and entered into numerous discussions with other workshop members who were available for technical discussions. Likewise, application experts from the panel were called upon to consult with other workshop panels regarding the relevancy and priority of active microwave applications in various Earth resources disciplines.

Among the many recent documents on microwave reviewed by the Applications Panel, two were of special interest: the "Active Microwave Workshop Report" and "Applications Review for a Space Program Imaging Radar (SPIR)" (refs. 2-1 and 2-2, respectively). Also reviewed were numerous documents related to the active microwave research program stimulated by the Jet Propulsion Laboratory Symposium, May 1976.

Concurrently with the discussions of active microwave applications, the panel worked in four subpanel groups to discuss the following subjects.

1. Use of imaging radar to improve the data collection/analysis process

2. Unique data collection tasks for radar that other systems will not perform

3. Data reduction concepts

4. System and vehicle parameters: aircraft and spacecraft

The first task for the Applications Panel was to survey the aforementioned literature and document all potential microwave applications and any special data requirements noted - i.e., microwave parameters. This information was accumulated on form AP-1, "Active Microwave Applications Survey" (sample copy included in appendix).

Each of the 200 potential applications recorded on the AP-1 forms was prioritized on a scale of 1 to 6 (see appendix), denoting priority and feasibility; e.g., scale factor 1 rated high priority and high feasibility. Panel members then transferred all of the 25 scale factor 1 application tasks to form AP-2, "Application Matrix Master," and grouped them into 7 major application or discipline areas (see appendix). The resulting focus on the "high payoff" application tasks was accomplished, according to instructions received by the panel from the workshop chairman.

The Applications Panel determined seven major areas for high-payoff applications with a well-coordinated active microwave program including field measurements, aircraft, and spacecraft. Within each major discipline area, a number of specific activities were indicated, many of which are common among major areas. Specific tasks such as inventory, monitoring, and assessment appear to be the most important application roles in the future.

Whereas it is not certain that all 25 application tasks will eventually be satisfied from space-derived data, some could currently be successfully accomplished in the near future from aircraft platforms, achievement being predicated on the availability of suitable active microwave aircraft systems.

NATURAL VEGETATION

Currently, 6.27 Mm^2 (1.55 billion acres), approximately 67 percent of the Nation's land area, are classified as natural vegetation, principally forest and rangeland (ref. 2-3). The remaining area is classified as inland water, cropland, improved pasture, and other lands - i.e., deserts, barrens, and land used as residential and industrial sites, roads, and airports and for miscellaneous other purposes.

Two-thirds of the natural vegetation area, approximately 4.5 Mm^2 (1.1 billion acres), are classified as rangeland and noncommercial forest (ref. 2-4). The rangeland includes natural grasslands, savannas, shrub lands, most deserts, tundra, coastal marshes, and wet meadows. The noncommercial forest includes ecosystems such as the pinyon-juniper forests of the Southwest that are incapable of producing crops of industrial wood because of poor site or other adverse conditions, and productive forested land withdrawn for parks, wildlife refuges, recreation areas, or other uses not compatible with timber production. Another 2.0 Mm^2 (0.5 billion acres) are classified as commercial forest land; i.e., land capable of producing more than 0.57 m^3 (20 ft^3) of industrial wood a year in natural stands and not withdrawn for other uses.

As a result of the large area and wide geographic distribution, the Nation's lands have a diversified natural vegetation cover ranging from moss, lichens, and short grasses through high shrubs and cacti, to the large trees of the Pacific coast such as redwood and Douglas fir. This diversified natural vegetation is classified into 34 ecosystems - 14 nonforested and 20 forested. The nonforested ecosystems are based on the natural plant communities of the United States as described by A. W. Kuchler (ref. 2-5). The forested ecosystems are based on the forest types used in the forest survey, conducted by the United States Forest Service (USFS).

Rangelands are highly variable. They occur from sea level to the highest mountains. Some are flat and smooth; others are steep, rough, and rocky. Rangelands may be dominated by short grasses only 7.6 to 10.2 cm (3 to 4 in.) tall, such as buffalo grass of the Great Plains, or by grasses 1.8 to 2.4 m (6 to 8 ft) tall, such as big bluestem in the tall-grass prairie. The vegetation includes such common and widespread shrubs as sagebrush and rabbit brush, literally thousands of species of flowering forbes and grasses, and even tall shrubs and some trees.

Rangeland resources are receiving increased levels of attention on regional, national, and international scales. Mounting pressures through legislative mandates and economic factors have resulted in a requirement for optimization of rangeland management and productivity. Legislated actions are required of agencies such as the USFS, Soil Conservation Service (SCS), and Bureau of Land Management (BLM) to inventory and monitor various aspects of rangeland resources. Economic factors such as the high cost of supplemental feeds on ranches and the feedlot finishing of cattle are pushing a heavier burden on rangeland production for cattle grazing.

Rangeland extents and jurisdictions are very large for Government and private landowners. Each manager in the BLM, for instance, is responsible for extensive areas averaging tens of hundreds of square kilometers (hundreds of thousands of acres) in size. For example, two adjoining district offices are located in Phoenix, Arizona, and Las Vegas, Nevada. Approximately 8093.7 km^2 (2 million acres) of Texas State-owned lands are managed under one man. Few managers and planners, however, have accurate knowledge relating to many of the aspects of rangeland that they are required to deal with. The competitive possible uses of rangelands and varying agency priorities complicate management objectives on all scales. Federal agencies must consider a number of resource system requirements in managing rangelands and providing livestock grazing permits. In addition to range, the areas requiring consideration are as follows.

1. Recreation and wilderness
2. Wildlife and fisheries
3. Timber
4. Land and water
5. Human and community development

Even ranchers must consider the interplay of wildlife and livestock because, in many cases, hunting leases bring more income than livestock sales.

Because of the huge areal extent and paucity of information, coupled with the management activities concerning rangelands, optimum utilization of information-gathering facilities is required. Three high-priority applications that require active microwave data as part of the data base collection activity have been singled out.

1. Rangeland inventory
2. Rangeland productivity
3. Rangeland improvement

Rangeland Inventory

The rangelands of the United States provide the renewable resource base for a multimillion dollar industry. Much of the rangeland area in the western United States is under Federal ownership and is the management responsibility of Federal agencies, particularly the BLM and the USFS. Grazing rights on thousands of square kilometers (millions of acres) of land are leased by these agencies to ranchers. However, adequate information concerning the condition of these rangelands is not widely available.

A key requirement for effective management is knowledge concerning the location, extent, and condition of the various rangeland areas throughout the United States. The Forest and Rangeland Renewable Resources Act of 1974 has mandated that such a rangeland inventory be conducted as a part of the 1979 assessment and updated at 10-year intervals thereafter. At present, the USFS does not have an established national rangeland inventory system as it does for timberland, with the forest survey. Because of the size of the area involved, space-acquired data appear to be one effective approach to meeting such a requirement and perhaps the only cost-effective method.

Before the condition of the rangeland areas can be effectively assessed, a basic rangeland inventory must be obtained. Because the SAR will provide data on moisture content and surface roughness characteristics of the target, it is anticipated that the SAR would provide a highly useful addition to the type of information that can be acquired from Landsat multispectral scanner (MSS) systems. Therefore, for a national rangeland inventory, the geometric correction and registration of MSS and SAR data will be necessary to provide the most effective data base for analysis.

Rangeland Productivity

As indicated in the discussion on rangeland inventory, there is a tremendous need for accurate, comprehensive information on the condition of the rangeland resources. The biomass available for grazing changes throughout the year, as a function of grazing intensity and weather conditions. Because of the sensitivity of radar systems to differences in total biomass and the moisture content of vegetation, such a system should have advantages for obtaining data useful in an assessment of rangeland productivity.

Because grazing permits are issued for varying numbers of cattle on the basis of the amount of vegetation available, ranchers often move their herds from one area to another throughout the year to prevent overgrazing of any one area; hence, there is a critical need for obtaining current data on a periodic basis. Such data should be obtained every 2 weeks during the summer and once per month during the remainder of the year. Also, a multistage sampling scheme should be established to monitor the condition and productivity of key areas; thereby, an effective and efficient subsampling system would be created for obtaining such information for compilation into a national statistical base.

Rangeland Improvement

Optimum management and utilization of rangeland resources requires improvement of those resources. Dollar investments in rangeland improvements, however, must be judicious because of the marginal return expectable. Improvements, consequently, must be limited to a few high-priority items - e.g., fertilization, rest rotation, and brush control.

In semiarid lands, brush control is the number one problem. Brush species (woody species) include mesquite and cedar, among others. Approximately 8093.7 km^2 (2 million acres) of State-owned lands in west Texas are now under a new flexible leasing program. The leaseholder is required to provide brush control on his leases when brush reaches a 30-percent canopy cover, to maintain good-quality range forage condition. The enforcement of the policy requires accurate determination of the brush cover percent on a semiannual basis. Other State and Federal agencies have, or will have, similar management information needs.

The unique capabilities of SAR systems in their high sensitivity to geomorphic properties of vegetation cover, land-cover texture, and plant moisture content will significantly improve the brush survey techniques being developed with visible/near-infrared sensors. Inclusion of SAR data with Landsat MSS data in a scene-registered, geometrically corrected format should provide a powerful multichannel, multisensor data set. Table 2-1 illustrates the user requirements for rangeland information as related to inventory, productivity, and improvement.

Forest Assessment

In contrast to the rangelands, which are nearly all in the West and Alaska, three-quarters of the area in the Nation's forest ecosystems classified as commercial timberlands are in the East.

The southern pine ecosystem, the source of more than one-fourth of the timber harvest in the United States, made up a little more than 14 percent of the Nation's commercial timberlands in 1970. Southern pines are concentrated on the Coastal Plain and Piedmont extending from New Jersey to Texas.

In the West, the bulk of the commercial timberland is softwood ecosystems. The Douglas fir and ponderosa pine systems make up approximately 6 percent of the total commercial timberland in the United States; and other western softwoods, 9 percent.

The ponderosa pine ecosystem occupies a large area in eastern Oregon and Washington and is the most extensive commercial forest type in California and the Rocky Mountains. In most ecosystems, and especially those in the West, there are substantial additional areas classified as noncommercial forest. For example, the total area in the ponderosa pine ecosystem is estimated to be 152 161.8 km^2 (37.6 million acres), or 38 849.8 km^2 (9.6 million acres) greater than the estimate of commercial area.

In examining the problem of measuring forest biomass productivity as a part of a forest assessment, the importance of at least one measurement requirement - losses from forest stress - should be considered in detail.

Stress detection in our Nation's wild lands and forests is a multiagency task, costing several millions of dollars each year in aerial and ground surveys. In the national forest system, the stress comes primarily from insects or disease; and its impact is evaluated by a count of killed or damaged trees.

TABLE 2-1.- USER REQUIREMENTS FOR RANGELAND INFORMATION AS RELATED TO INVENTORY, PRODUCTIVITY, AND IMPROVEMENT

User needs	Inventory	Productivity	Improvements
Justification	See text	See text	See text
User agencies	USFS, BLM, States	USFS, BLM, States	USFS, BLM, States
Importance	Very high priority	Very high priority	Very high priority
Time requirements	One every 10 years for entire United States; every 5 years for USFS and BLM lands (in early summer?)	Every 2 weeks in summer; monthly during rest of year	Semiannually
Area coverage	Entire western United States	Sample points within each strata defined in the inventory (sample data would come from locations throughout western United States)	Texas and other semiarid land areas
Measurement parameters	Location of rangeland type/ composition of species mixtures	Biomass of rangeland vegetation (density + height); moisture	Brush density (percent ground cover); 30-percent ground cover is maximum allowable in Texas lease situation
Data products	Maps of complete area coverage showing total rangeland area and individual types of range cover (species composition, mixtures); tables of areas of each rangeland type, by country or some TBD[a] designated geographic areas	Maps of sample sites and tabular display of biomass estimate for each site	Maps of entire area showing different brush density groupings
Cartographic products required	Yes	Yes	Yes

[a]To be determined.

Catastrophic outbreaks of forest insects, largely bark beetles and defoliators, continue to be the major cause of timber mortality, which annually equates to 23 597 372.2 m^3 (10 billion fbm). Forest management activities can play a major role in limiting these losses. Unfortunately, forest managers often do not have the information required to prevent serious losses and to utilize dead timber. The problem is not unique to the United States. The need for forest biomass productivity information is just as great in tropical forest ecosystems. To that end, microwave sensors are thought to be capable of contributing important and unique information to an all-source data base.

The overall aspects of the problem may be summarized as follows.

1. Problem definition - Measure forest biomass productivity. Investigate the use of SAR for identifying forest species and assessing stand composition, stand density, stand vigor, height/site quality, and soil moisture content.

a. Time requirements - Immediate need for global forest assessment.

b. Area coverage - 100-km^2 units and mapping to 0.1-km^2-minimum (10 ha minimum) land units.

c. Measurement parameters -

(1) Timber class boundaries.

(2) Timber stand height.

(3) Timber stand density.

(4) Dead and dying timber.

(5) Species identification.

(6) Soil moisture in plant root zone (2 m).

(7) Site quality.

d. Spatial resolution - 20 m except 100 m for soil moisture and site quality.

e. Revisit needs - 5- to 10-year intervals.

f. Priority - 1.

g. Justification - A rapid, global forest land inventory is needed to determine worldwide timber resources. The problem is global.

2. Present data collection methods - Aircraft photography and ground observations are currently being used. Manual methods are usually employed for photo interpretation and mensuration. Products are timber volume estimates and forest-type maps. Radar offers the potential of

digital data correlating to timber types, boundary delineations, biomass of standing vegetation, losses from stress, and site quality. Radar provides all-weather capability and an additional information source for inclusion with Landsat and thematic mapper data.

3. Energy-matter relationships - Microwave records geometric information, as well as scene reflectance of a radar signal. The signal is attenuated by the surface roughness and dielectric constant of scene components. Therefore, it is postulated that each timber/environmental unit will have a unique signature from reflected energy, providing information on timber stand characteristics and site quality.

4. Data needs -

a. Timing - Data are needed in 1 month or less from acquisition, and summer coverage is mandatory.

b. Products - Maps and area tables of vegetation types and site class boundaries, estimates of volume/biomass for each timber type mapped, species identification of timber classes, and cartographic map products.

c. Area - Estimate of each map class.

d. Collateral information - Ground and photo interpretation information for control and verification of radar data.

5. Candidate test sites - Nationwide forestry applications test sites representative of major forest ecosystems across the Nation are suggested.

a. St. Louis County, Minnesota.

b. Grand County, Colorado.

c. Jefferson County, Washington.

d. Kershaw County, South Carolina.

e. Clearwater-Coeur d'Alene National Forests.

f. Washington County, Missouri.

6. Ongoing research - Forestry applications program; University of California, Berkeley; Oregon State University; Texas A. & M. University; University of Idaho; and University of Minnesota.

7. Costs - Most timber volume and forest site information for selected areas is available from existing forest inventory. Correlation of radar data with existing data would be needed. Cost estimates to undertake the study are not available at this time. User interest would be very high for a rapid, automated system of global forest assessment, particularly if the method would require a minimum of ground data input because of the high field costs and the existence of denied-access areas such as the Union of Soviet Socialist Republics (U.S.S.R.).

8. Shuttle compatibility - A coordinated investigation plan could be prepared leading to experiments and application tasks on the initial Shuttle SAR flights. Test sites are established, and collateral ground-truth data are available.

Tropical Forest Inventory

In the same manner for which forest inventories are required in the temperate areas of the world, tropical forest inventory data are also required; thus, the forest inventory process is of global importance. The overall aspects of the problem may be summarized as follows.

1. Problem definition -

a. User needs - Many less-developed areas of the world contain large tracts of tropical forests. These areas provide the potential for vast quantities of forest products, as well as potential sites for other resource uses such as water supply, hydroelectric power generation, agricultural lands, and urban sites. Land and resource managers need information on tropical forest lands - timber species, volume, and areas involved - to develop these land areas and plan for management operations. Vast areas of tropical rain forests are totally obscured by clouds and haze for most of the year. As in the case of the recent Brazilian survey, the SAR can provide timely information on forest resources over vast remote regions where no cartographic control is available and only limited ground measurement is possible.

b. Time requirements - Data are needed as soon as agencies and responsibilities are assigned.

c. Area coverage - 1000 km^2, minimum area of interest.

d. Measurement parameters - Stand boundaries, location, tree stand height, density, species identification, and land-use information are needed.

e. Spatial resolution - 100 m.

f. Revisit needs - 10- to 15-year intervals.

2. Present data collection methods - Very few inventory data are being collected in tropical areas except for isolated areas in which conventional photo and ground techniques are being used where possible. Persistent cloud cover in tropical forest areas severely limits the use of conventional photographic systems for data collection.

3. Energy-matter relationships - Radar could provide a rapid data source in digital form for tropical forest inventory. Radar has unique properties of geometric and energy recording that could reveal information on location and biomass of tropical forests. Experience in the radar mapping of the Amazon project in the Brazilian Amazon Basin indicated the potential for gross-vegetation-type mapping in tropical forests and identification of certain high-interest vegetation communities for agricultural development.

4. Data needs -

a. Timing - Data are needed in 1 month or less from acquisition.

b. Products - Map of vegetation types showing boundaries and species identification, volume estimates, and associated land use.

c. Area - Minimum class sizes would be 1 km^2 (100 ha).

d. Collateral information - Ground-truth data for control and verification of radar data. Cartographic quality of maps is needed.

5. Candidate test sites - Eastern Bolivia, Taiwan, and northern Thailand.

6. Project support - Advisory personnel - Roger Hoffer, Robert N. Colwell, F. P. Weber, and Robert W. Brandt.

7. Costs - Not available.

8. User interest - Key interest to Food and Agriculture Organization, Rome, Italy.

9. Shuttle compatibility - Yes.

Present remote-sensing data used in the assessment of natural vegetation include those derived from aerial photography, the multispectral scanner, forward-looking infrared, and Landsat. Current analysis is based on algorithms such as the transformed-vegetation index (based on bands 7 and 5, Landsat MSS) and LARSYS[1] classification. Aerial photography interpreted by manual techniques is the mainstay of current remote-sensing application. Recently, advanced technology remote-sensing data have been demonstrated to be a useful base for resource managers and planners.

Imaging-radar data should be highly useful in a complementary - and in some cases, primary - role in conjunction with Landsat and photographic data. Unique properties of radar data include plant and soil moisture sensitivity, vegetation geomorphic property sensitivity, and surface roughness (texture) sensitivity.

The requirements for SAR data are completely compatible with the timing, resolution, areal coverage, and measurement parameter capabilities of the proposed spaceborne imaging radar (SIR) for the Shuttle.

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[1]Computer programs developed at the Laboratory for Applications of Remote Sensing (Purdue University).

CULTIVATED VEGETATION - CROP PRODUCTION ESTIMATES AND PLANT STRESS ASSESSMENT

The need for accurate crop production estimates is universally recognized as a fact of life on a global scale. Data concerning any stress factors that can alter production estimates during the growth and maturation of a given crop are likewise recognized as information of tremendous economic, social, and political importance. The present methods of collecting such data and disseminating information about crop production are reasonably accurate and inclusive for only a small portion of the world. The information is not, however, disseminated in anything like near real time. Active microwave sensors have the unique feature of all-weather capability and the ability to sense stress factors in crops. With present data-processing techniques, these data can be reduced to usable information that could be made available in a near-real-time system of the future.

There presently exists in the United States one method for estimating crop production. It is the Statistical Reporting Service's method of random sampling, with subsequent expansion of the data to produce a nationwide crop production estimate.

Another system is presently being developed and tested jointly by NASA, the National Oceanographic and Atmospheric Administration (NOAA), and the U.S. Department of Agriculture (USDA). This system is known as the Large Area Crop Inventory Experiment (LACIE). The LACIE system presently uses Landsat MSS data as the primary remote-sensing data input to identify wheat in the U.S. Great Plains area. In attempting to create a growth and productivity model for the LACIE, it was discovered that there is no reasonable method available today to estimate accurately the effect of stress during the growing season and the resulting adverse effect on crop production.

Active microwave sensors could be developed and deployed on orbital platforms such as the Shuttle to complement the Landsat MSS data as added channels of remotely sensed data. Microwave sensors also have the added capability to gather data in cloud-obscured areas that would be opaque to the MSS. These benefits of active microwave sensors would greatly enhance the prospect of monitoring worldwide agricultural crop production.

Active microwave systems not only possess the all-weather capability, but also are able to discern volumetric moisture content of plant biomass. This unique ability allows for the comparison of signatures of any given crop during the growing season and the determination of the degree of stress that has been introduced into the plant canopy. Stress may occur in the form of drought, disease, insect damage, or any one of many mechanically or physiologically induced vigor suppressors. By measuring (volumetrically) the above-ground moisture content of a crop, a direct relationship can be empirically determined between crop canopy moisture content and plant stress.

The data collection frequency required for this type of application would be on the order of once every 2 weeks. It is immediately evident that it would be impossible to monitor the entire area of any one crop every 2 weeks; so a well-defined and properly designed sampling system could be used to produce reliable data that would form the basis for accurate crop production estimates. Evidence is available to suggest that the combination of MSS and active microwave sensors may have a synergistic effect for the amount of information that may be extracted from a scene.

The output product could be in any format as needed by the user. Such products as maps, images, overlays for maps, tabular data, or any other similar product are possible for this system.

Candidate areas for research and development testing could be the LACIE test segments that are currently being used to develop the LACIE system techniques. Many data and experiences are being amassed as a result of this effort and would be invaluable in developing a viable test for the proposed system.

Project support should be forthcoming from organizations that have a direct interest in crop production. Farmers, ranchers, and their cooperative organizations, as well as State and Federal agricultural agencies, should be supportive of such an effort. Grain-marketing groups should have this information made available to them just as they now receive the monthly crop estimates.

The microwave sensors to be used in such a system should possess the following characteristics.

1. Resolution - 30 m

2. Frequency(ies) - X, C, L, and/or K band(s)

3. Polarization - like and cross

4. Look angle - 7° to 20° and 40° to 60° from vertical

This application of microwave sensing to crop production and plant stress assessment is well suited to the Shuttle operations of the 1980's. It is a practical and feasible proposal that has high user application in the time of diminishing food production and expanding world population.

WATER RESOURCES

The applications of active microwave imagery relevant to water resources are described in the following subsections.

Streamflow Forecast

Current studies show that hydroelectric power production can be increased in the Western States by 5 to 7 percent with a modest increase in the accuracy of streamflow forecasting for snowmelt-fed streams. This increased production can be accomplished by a reduction in the quantity of water "wasted" over the spillways of reservoirs as a result of poor streamflow forecasts.

The most significant increases in forecast accuracy can be obtained with the use of more accurate data or better information on all of the following six items.

1. Precipitation volume/unit area and extent

2. Areal extent of snow

3. Snow wetness (or relative ripeness and susceptibility to melt-producing factors)

4. Soil moisture index

5. Snow depth

6. Snow water content

The best estimates of streamflow will be obtained with a mix of ground-based and remote, noncontact methodology. Currently, the precipitation amount is only crudely estimated and is one of the most serious inadequacies in the current data-gathering systems applied in hydrology. This problem is global, and a solution to it is needed for all land-management activities; thus, it has a high priority. The present data collection method consists of catching precipitation in rain gages (cans) placed at very wide intervals in a watershed. From these few samples, inferences are drawn as to gross amounts distributed over entire mountain ranges. Active microwave sensors can provide an improvement on this method either by measurement of soil moisture content and distribution or by direct precipitation measurements. Data needs are for real-time data with constant, 100-percent coverage. This concept will require much research and could perhaps be tested with active microwave on board the Shuttle. The spaceborne meteorological radar concept being examined at the Goddard Space Flight Center (GSFC) is one possible approach.

Information on the areal extent of snow is needed by all agencies making forecasts on the basis of snowfields - the SCS, State water agencies, the U.S. Bureau of Reclamation (USBR), the U.S. Geological Survey (USGS), the U.S. Army Corps of Engineers (USACE), the National Weather Service, power companies, etc. The information is required to determine the snow/bare soil interface (freezing line) and the snow-covered area within each watershed. If this high-priority data need can be satisfied with the use of microwave sensors, the data can be used in the current information systems to enhance accuracy.

Currently, snowline information can be obtained by visual observation except during rainstorms, when data are urgently needed. The occurrence of such a storm is a critical phenomenon; and at that time, an imaging-microwave system becomes most needed, with the potential to penetrate cloud cover before and after rains and produce timely and accurate information. During storms, the rainfall pattern can be delineated by means of microwave images. Specifically, what is needed is the location of the snowline by map coordinates to within 20 m in the mountains and 100 m in the plains. Weekly coverage is needed, with a 24-hour delivery time to analysts.

The American River and San Joaquin River basins in the Sierra Nevada Mountain Range of California provide excellent test sites for this study. The American River basin is the location of the USBR weather modification tests, which are being conducted through 1983; and the San Joaquin River basin is the site of a snow project study by James L. Smith, Forest Service Experiment Station in Berkeley, California. The USFS studies encompass both watershed basins, and ground truth will be taken of some elements in both studies.

Snow wetness is a measure of the relative water-holding capacity of a snowpack. Currently, inferential data are obtained through measurement of a snowpack density. However, with a direct measure of wetness, the amount of new water from a melt or rain that a pack can hold before melting can be determined. No current remote-sensing method provides a capability for measuring snow wetness, but microwave sensors appear to offer a possible means. Research is now underway to confirm this potential. Weekly measurements are required during the snow season, with 24-hour data delivery. A stratified sampling scheme should be employed in a data collection system, and cartographic overlays would be required.

An excellent test site for studies of snow wetness with microwaves would be the USFS instrumented Central Sierra Snow Laboratory (CSSL), Soda Springs, California. There is an ongoing study to develop and test a profiling microwave wetness sensor at the CSSL, being conducted by Dr. W. I. Linlor of the NASA Ames Research Center (Moffett Field, California) and Dr. J. L. Smith of the USFS (P.O. Box 245, Berkeley, California). These two investigators are suggested as advisors. Current effort is coordinated with the State of California, the USACE, the USGS, and other interested agencies.

The soil under melting snow is a reservoir in which part of the snowmelt is stored, part is used by plants, and part is delivered to streams during the ensuing months. Lack of knowledge of this complex process is a global problem. There are no current quantitative data collected; only guesses are made. By measuring the water vapor in a cube of air including the surface of the area and vegetation on the slope, an estimate of evaporation/transportation can be made for different parts of a slope. This estimate can then be related to water movement within the soil and subsequent streamflow. Ultimately, an estimate of water left in the slope in the soil for subsequent addition to streamflow can be made.

Microwave technology is thought to offer a way to measure the aforementioned items, although little is known about the requirements for microwave parameters. Monthly, statistically stratified samples with identifiable sites on a cartographic base are needed to satisfy the user requirement. The Onion Creek experiment forest and the CSSL offer the best possibilities for research and development work on soil moisture index as related to active microwave remote sensing.

Snow depth varies widely with area even within a climatic region, although snow density varies only slightly with area. If the depth can be measured, it can be correlated with the density obtained by onsite measurement, and this correlation can then be extended to broader areas. With these two measurements, one can compute the water content of the snow, a most important variable in streamflow forecasts, which are a global problem of high priority.

The present data collection method is manual inspection, either by ground observation of a snow course or by flying over vertical graduated posts and reading snow depth; this method cannot be used during inclement weather. Present methods provide only a very restricted sample. Imaging, calibrated radar is a potentially promising means of making large-scale samples available in all types of weather.

Because of the relationship of the data (one element to another), it is desirable to obtain snow depth, snow wetness, areal extent of snow, and snow water content from the same remote-sensing effort. Weekly data are required during the snow season, with 24-hour delivery. Statistically stratified samples are desired, located at the same points for each survey. Point data on snow depth must be presented on maps or by a listing of coordinate location. Any of the snow survey sites in California or the USDA SCS-administered sites in other Western States would be suitable test sites for active microwave studies.

All other snow inventory data are taken to get an estimate of snow water content. The current system consists of a mix of manual and remote ground measurement of depth and density of snow; and from this information, water content is estimated. Only a few samples are taken in an entire river basin; and from these data (and by correlation to historical snow water content versus streamflow data), estimates of future streamflow are made. Errors of estimate range from 10 to 25 percent. If a large sample inventory of snow can be obtained periodically for the entire watershed, a more accurate streamflow can be predicted. With information on snow water content, snow wetness, precipitation input for rainfall, and soil water storage, an estimate of streamflow can be made to a precision never before attained. Microwave sensors are a possible means whereby these parameters can be remotely measured, but the application of microwave sensors requires much supporting research.

Watershed Characteristics

The physical characteristics of a watershed are described in terms of topography and physiography, including vegetation cover. Specific measurements - slope angle and aspect, soil depth, type and extent of vegetation cover, and stream characteristics such as length, gradient, and area - are used to classify watersheds.

The great importance of accurately determining watershed characteristics is derived from the need to determine the rate at which snowmelt and rainwater are delivered to streams and, thence, downstream to reservoirs for man's use. Physical measurements are frequently used to create a watershed model that is applied to streamflow forecasts for flood prediction and reservoir management. The ideal model, correctly applied, minimizes unnecessary "spills" from reservoirs and, when interfaced with hydrologic data, optimizes water resource management and utilization.

Few of the major watersheds in the United States are accurately quantified in terms of the five major characteristics.

1. Stream length

2. Stream gradient

3. Area of watershed

4. Stream ordering

5. Classification, location, and area of vegetation cover type

The greatest inaccuracies and, in many cases, a total lack of understanding are associated with the mountain watersheds. Because many mountain watersheds are perpetually cloud covered, especially in southeast Alaska and the Pacific Northwest, microwave sensors are thought to be very promising as a means of providing remote-sensing data that will accurately describe and quantify watershed characteristics. The combination of imaging-radar data with registered multispectral scanner data can provide an even better remote-sensing data base for measuring the physical characteristics of watersheds.

Frozen-Lake Mapping (Alaska)

Moderate to large quantities of water are required throughout the year for development of petroleum reserves. In Arctic regions, the availability of water, potable or otherwise, becomes a significant limiting factor in exploration and exploitation.

Ground water generally is not available because of extensive permanently frozen soil. Major streams and lakes are sometimes suitable water sources in summer months, but there are few sources of data on the availability of water in the wintertime. Potential sources of water during the Arctic winters are deep lakes and moving rivers that do not become solidly frozen. The extent of Arctic petroleum resources precludes the conventional core drilling of thousands of lakes and rivers, which are potential sources of water.

It has been proposed by radar technologists that imaging microwave has great potential as a remote-sensing tool to provide inventory data on the existence and availability of water in the Arctic during the winter. The significant microwave parameters for mapping Arctic water sources are as follows.

Wavelengths: Multifrequency L-band (for thicker-ice-covered water), X-band (for delineation of ice- and snow-covered water)

Resolution: 30 m

Polarization: horizontal-horizontal (HH) and horizontal-vertical (HV)

Incident angle: 40°

Coverage: Monthly, December through April

Output product: Either a 1:250 000-scale map showing water source location, stratified by probability of existence, or a coordinate location listing, similarly stratified

The Shuttle imaging radar affords an excellent opportunity for investigating this application; however, feasibility studies with aircraft and perhaps Seasat-A are appropriate.

MINERAL AND ENERGY RESOURCES AND GEOLOGIC APPLICATIONS

The search for new sources of mineral and energy resources is a prime goal for a large number of users of remote-sensing data. The continued depletion of the United State's and the world's supply of these nonrenewable resources necessitates utilization of the most advanced exploration tools available for this search. Active microwave imagery will provide unique geologic information, including terrain data not otherwise available from existing remote-sensing systems.

The search for new mineral and energy resources is global in nature and includes both polar and tropical areas. The capability of active microwave sensors to "see" through clouds and plant canopy is especially useful. Although geologic features do not change rapidly with time, seasonal coverage is recommended because of the potential for surface variation indicators to infer structural and/or subsurface changes. This application is considered a number one priority of national significance.

The mineral and petroleum industries currently use Landsat-1 and -2 data and aircraft data, as well as the conventional means, for exploration purposes. Landsat-1 and -2 data do not have the necessary spatial resolution or stereo coverage desired by these industries, and they were not obtained with the use of optimum spectral bands. Hence, the existing Landsat systems have not had a great impact on solving the problem of the growing worldwide need for energy and mineral resources.

The Landsat multispectral sensor technology was developed before 1970; and, basically, this same technology will be used with Landsat-C in 1978 and the subsequent Landsat follow-on program. An active microwave system would, however, provide a different mix of information with all-weather, day/night sensing possibilities; high-resolution, calibrated, multichannel, multipolarization images; Landsat-compatible image data; and measurements of unique parameters not possible with infrared (IR) and visible sensors.

The kinds of surface features that need to be identified and mapped include linear and curvilinear structures, rock types, the composition of superficial material, underlying rock types, vegetation changes and boundaries, faults, and fractures. Sensing these features with active microwaves requires use of the following parameters.

Incident angle: $\approx 45^o$

Polarization: HH, HV, and vertical-vertical (VV)

Frequency: TBD

Resolution: $\approx$ 20 m

The principal data products that will be used by geologists should be Landsat-compatible imagery registered to geologic maps. Both the mineral industry and petroleum industry users have expressed a great need for stereo data products.

Proof-of-concept experiments can be demonstrated on the Shuttle flights utilizing the SIR. The operational use of active microwave for full exploration of its potential for mineral and petroleum exploration will require global and repetitive (seasonal) coverage. Initial data may be obtained from the radar flight (Seasat-modified) being proposed for the Shuttle Orbital Flight Test 2 (OFT-2). It is suggested that existing NASA expertise be used to closely coordinate the program being developed by the Geosat committee.

OCEANOGRAPHIC APPLICATIONS

Six high-priority application tasks were identified in the category of oceanography.

1. Ship navigation and routing
2. Navigation hazards
3. Pollution monitoring
4. Ocean engineering hazards
5. Commercial fishing intensity
6. Sea ice

Each task has global implications in the sense of multinational benefits to be derived from cost savings in shorter and safer merchant ship routing, more efficient deployment of fishing vessels, protection of the quality of the environment, and lower costs of outer-continental-shelf explorations.

Information useful for ship routing and safety is needed on a daily basis, especially along the major shipping lanes of the world. Specialized data are needed in Arctic waters regarding ice flows and icebergs because of increased shipping for exploration and transfer of oil. At the same time, monitoring for oil spills in environmentally sensitive locations is needed for protection of marine life and habitat.

In many of the new areas, microwave sensors show promise for providing much of the critical data required; e.g., exploration in the design of structures and placement of drilling platforms, and the location of new facilities for deep seaports and for building shore power plants. Information on wave forces - their duration, intensity, and frequency - is not sufficiently known.

Earlier experiments with aircraft and satellite sensors (Skylab, S193 and S194) have shown the feasibility and promise of achievement from future operational satellites with both passive and active microwave sensors. The penetration of cloud cover and the response of a microwave signal to sea state - the correlation between microwave signal response and wind profiles, capillary waves, and the detection of surface waves - have both been successfully demonstrated with microwave sensors. The suppression of backscattered signal due to oil films has also been successfully detected. Imaging radar of proper frequency and polarization on a satellite platform would provide a synoptic view, day or night, irrespective of cloud conditions, and at times during storms when the most severe wave forces are generated but for which few reliable data are available. These data would also be complementary to Landsat data in the mapping of currents, the tracking of pollution, and the detection and measurement of shipping hazards.

For data needs for each of the priority applications, resolutions in the 25- to 100-m range are required. A well-organized approach to determining frequencies, polarizations, and bandwidths is being determined by cooperative radar sensor working groups in aircraft and Seasat programs. (See ref. 2-1, ch. 3.) Imaging-radar sensors, in conjunction with radar altimeters, scatterometers, and passive microwave radiometers, are expected to provide most of the measurements required for successfully meeting the objectives of oceanographic applications.

In certain cases, data are needed daily. For the ocean engineering hazards, application users have defined data requirements as being needed on a 3-hour, 3-day basis (ref. 2-2, ch. 5). Candidate test sites for early experimentation would be the North Atlantic and North Pacific, the Atlantic coast, and the Gulf of Alaska. Project support and instrumentation are available from several research organizations and groups in various Government installations within the NOAA, the USGS, the Naval Research Laboratory (NRL), and NASA, as well as in several universities and private industries.

Continued research with aircraft sensors in support of the Seasat program will prove to be a decisive factor in the future definition of radar requirements. The Space Shuttle, with 3- to 5-day experimentation potential, could be used for proving satellite capability with a variety of sensor parameters in a sophisticated operational test. Coastal test sites could be defined, with ship and aircraft support organized to coincide with Space Shuttle overpasses.

The new 370.4-km (200 n. mi.) limit defined as national waters along U.S. coastlines brings new emphasis for improved capability in monitoring this resource area. Satellite sensors afford the best chance for a complete system capable of managing resources found in that continental shelf zone.

HAZARD SURVEYS

The monitoring of major disaster situations has been traditionally posed as a potential application for a Shuttle (or standby Shuttle) imaging-radar system. The analysis and prioritization of application areas have resulted in determining that events such as floods, hurricanes, etc., are of a very high national and worldwide priority for monitoring, and that the SAR has an extremely good potential for utility in these situations because of its nighttime and all-weather capability. Furthermore, the timely acquisition and display of such data can be of significant benefit. For the most part, however, an airborne SAR system with possibly a digital readout to a communications relay satellite system for timely processing at a central ground station can fulfill a majority of disaster-monitoring requirements. Even an onboard recording scheme with subsequent processing can meet a surprising number of crisis-oriented delivery schedules. For this reason, it is recommended that such application areas be given a low priority for Shuttle implementation in favor of the more Shuttle-unique applications discussed previously. Within the realm of understanding that all active microwave user applications will not be solved from space platforms, and for report completeness, a discussion of these disaster-situation radar requirements and conclusions is provided.

Flood Mapping

The effective monitoring of flood conditions can have a significant impact on evacuation strategies, watershed runoff model updates, flood models, relief and insurance grants, levee/dam design and implementation, and rehabilitation plans. The SAR imagery, with its all-weather, nighttime, and high-resolution capabilities, can provide the necessary input for monitoring this type of disaster.

Essential inputs to a comprehensive flood-monitoring program would include flood extent, flow patterns, erosion/accretion mapping, and debris tracking. All measurements could be obtained with X- and L-band radar imagery of 30-m resolution, although for small-debris tracking, a resolution of 10 to 15 m or better might be required. A generally low depression angle and 50-km swath are sufficient. The output imagery is desired in near real time (hourly) and would perhaps be displayed in both film and cathode ray tube (CRT) formats. Eventual output products would include thematic flood maps, forecasts as to flooding depths, and map overlays.

The basic requirements for flood mapping can be met with a high-flying-aircraft SAR system with digital readout. Timing considerations, especially for a Shuttle application, seem to preclude the use of a space platform. For additional flexibility of such a scheme, the possibility for timely multiple looks and multiple resolutions (low resolution over the flood extent, high resolution over selected sample areas) is included. Interactive image-processing techniques may be appropriate.

Hurricane Damage Assessment

Hurricane monitoring and damage assessment can be valuable for possible warning/evacuation schemes, seawall and levee system design and evaluation, Federal aid determination, insurance claims, and the update of hurricane models. Again, the SAR is particularly appropriate because of its all-weather and nighttime operating characteristics.

There are four primary measurements desired for this application: flood extent, vegetation wind damage, vegetation flood damage, and urban damage in general. Vegetation wind/flood damage assessments, as well as urban damage assessments for larger features, can be achieved with resolutions of 10 to 20 m, whereas flood extent can be determined with a 50-m resolution in most cases. For a flood extent determination, data over a 100-km swath will probably be required; whereas damage assessments will be determined over smaller regions, say 20-km swaths. A daily output of film, thematic maps, and map overlays rectified to ground coordinates is required.

A high-flying aircraft with SAR capability can meet the aforementioned measurement requirements. Such a platform, with the side-looking aspects of the radar system, would not necessarily be required to be flown in storms but, rather, could be flown alongside. Furthermore, variable resolution desired (low during storm, high afterwards) can easily be obtained.

Tornado Damage Assessment

Justification is similar to that for hurricane monitoring. However, an additional unique SAR characteristic is applicable in this case - the capability to detect the shallow trough of displaced soil that accompanies most tornado situations. The required measurements and output products are identical to those for hurricane monitoring with the exception of flood extent and flood damage.

Because of the generally localized nature of tornado activity, as well as the rapidity with which funnel clouds form and strike, an aircraft platform SAR is more appropriate to use than a satellite platform SAR. This method would enable high-resolution and limited-area coverage of affected areas in a timely manner consistent with relief and/or evaluation requirements.

Earthquake Prediction and Damage Assessment

The monitoring of earthquake activity and regions will facilitate appropriate land-use planning, aid, prediction, potential strain relief by water injection, and a significant saving of lives and property. The SAR is properly suited to many geologic applications such as fault detection and terrain analysis. It can, therefore, provide useful input to crustal-motion-monitoring schemes.

Crustal motion detection, fault location, and terrain analysis are all required for earthquake monitoring/prediction schemes, whereas resource and urban damage assessments are required for actual disaster scope determination. For all five measurements, a resolution in the 10- to 20-m range and a maximum swath of 50 km are required. Repetitive and stereo data are a distinct requirement, and thematic displacement maps on a map overlay would be useful outputs. Measuring Earth crustal motion may be best accomplished by using corner reflectors placed at strategic points. To produce artifacts such as shadowing and overlay, multiple looks and perspectives best done by aircraft are required.

Forest and Range Fire Damage Assessment

Whereas some types of active microwave measurements - hourly burn determination, burn intensity, soil-type classification, and terrain-type classification - are primarily intended for subsequent damage assessment and planning, microwave sensors may make the greatest contribution in a related task. If microwave sensors can, as some radar technologists suggest, monitor vegetation moisture and fuel loading, these data will contribute to a very great need for this type of information over extensive areas of the West for fuels inventory and suppression preplanning.

LAND USE

For land-use applications in natural settings, remotely sensed data of all types are primarily needed to provide information on the existing types of ground cover that prevail throughout a management region. Such information is most useful in the form of maps and tabular data that characterize the extent, location, and boundaries of each recognizable category. Indeed, classification maps that address existing types of ground cover are the basic tools for a number of applications other than land use that also have important priorities. Knowledge of existing patterns of natural vegetation, water, barren ground categories (sand, rocks, snow, or ice), or human activities is a prerequisite to any decisionmaking process.

The land-use-planning aspect of environmental management joins many other applications in being based upon the recognition and classification of types of surface cover. Typically, agencies at all levels of Government conduct land-use-planning activities and are subject, in this respect, to varying degrees of pressure to develop plans for accommodating expanding population or resource exploitation or for quality-of-life factors. All planning activities involve making long-term commitments of allocating resources that have deep impacts on today's citizens, as well as on succeeding generations. Thus, the best possible information is needed to assist the planning process.

The quality of global information currently available to regional land-use planners typically supports category classification to only levels I and II. These classes are too broad for many land-use decisions, and planners constantly desire the capability of classifying cover to levels III and IV, levels which heretofore have been achieved only with the use of medium-scale aerial photography. The SAR capabilities, both from aircraft and spacecraft platforms, together with that of the thematic mapper, show strong evidence that level III and, in some cases, level IV classification will become possible on a regional basis in a cost-effective manner. The SAR data provided for all land-use applications must be corrected to a standard map base so that they can be effectively overlaid with Landsat MSS data.

In undeveloped or partially developed areas, the type of natural ground cover that typically predominates is vegetation. Not only are accurate, detailed vegetation maps of prime concern for agricultural and forestry applications (as aforementioned), but these maps are equally valuable for the determination of the many aspects that make up other development-related decisions. Barring the ability to sense beneath the soil surface or the canopy of vegetation, the density and mixture of naturally occurring vegetation are leading indicators of certain critical soil factors that influence certain kinds of cultural features. Potential limestone sink holes in Florida frequently produce clues in the surface vegetation, whereas the extent of grass, indicating shallow permafrost, in interior Alaska is related to the extent of dwarf black spruce stands. Conventional classification maps of natural vegetation prepared from the enhanced-resolution (10 to 30 m) data of the SAR coupled with MSS data from the thematic mapper would be a valuable, cost-beneficial tool for land-use planning.

Although international organizations such as the Food Agriculture Organization desire global information on land use on a more or less regular basis - e.g., a 5-year update - some areas are changing so rapidly that an update on new data is required on a yearly basis. This task clearly is a mission designed for spacecraft platforms, especially when the coverage per pass is decreased to compensate for achieving high spatial resolution. Together with the six or seven bands in the visible and IR wavelengths, the spaceborne SAR system, deployed for collecting land-use data, should employ cross-polarization data from two wavelengths.

Although obtaining total land-cover data is important globally, land-use planning and mapping of urban areas is critical. The core areas of cities, which include commercial and industrial areas, form integral components in the deployment of the limited resources for firefighting and police protection, for transportation and refuse services, and for tax-base projections for the frequently hard pressed administration of city governments. Presently, the extent and change in characteristics of urban areas are determined with aerial photography because of the limited spatial resolution capabilities of Landsat scanners. Analysis of data from two polarizations of X-band radar will make possible the differentiation of commercial centers from industrial areas. The radar data, with high contrast from corner-reflector effects of buildings and paved surfaces, should be an effective supplement to the data produced by shorter wavelength sensors. Coverage of metropolitan areas should be on a semiannual basis, with routine information extraction and delivery schedules.

The SAR data provide excellent information for mapping transportation networks, which are another important variable in land-use planning. Transportation services must be provided for commuters and for moving materials and products, without causing undue interference in the achievement of environmental values. The SAR data have proven to be a valuable form of remote-sensing data for gathering information on existing transportation capabilities, as well as for providing insight for developing transportation potential.

CONCLUDING REMARKS

The Applications Panel of the Active Microwave Users Workshop considered seven major areas in which a coordinated aircraft, spacecraft, and field measurements program should be directed in the future. Within each area a number of specific activities are indicated, many of which are common among major areas.

1. Natural vegetation
   a. Range improvement
   b. Range biomass productivity
   c. Range inventory
   d. Forest assessment
   e. Tropical forest inventory
2. Cultivated vegetation
   a. Crop productivity estimates
   b. Stress identification
3. Water resources
   a. Streamflow forecast
   b. Watershed chracteristics
   c. Frozen-lake mapping
4. Mineral-energy resources - mineral and petroleum exploration

5. Oceanography

   a. Ship navigation and routing

   b. Pollution monitoring

   c. Ocean engineering hazards

6. Hazard surveys

   a. Flood mapping

   b. Hurricane damage assessment

   c. Tornado damage assessment

   d. Forest and range fire damage assessment

   e. Landslide and Earth slippage assessment

   f. Earthquake prediction and damage assessment

7. Land use - determination of existing land cover other than vegetation

Specific tasks such as inventory, monitoring, and assessment seem to be the most important applications roles in the future. Owing to the focus of past microwave remote-sensing research and development, more specific knowledge exists for applications of geology, oceanography, and cultivated-crop assessments. However, the panel expressed a strong opinion that the greatest potential for microwave applications in the future is in the heretofore lightly explored areas of natural vegetation, hazard surveys, and land use. Each of these important areas is currently covered by other forms of remote-sensing activity, but in most cases microwave sensing can offer a considerable boost in contributing complementary data to help satisfy information needs.

Although the water resources area of investigation has received a moderate amount of attention in the past with respect to microwave investigation, the possibilities for using this technique for such applications as streamflow forecast and watershed modeling are essentially unexplored.

The Applications Panel was composed entirely of nonmicrowave experts who were inclined to view the potential for active microwave applications in a different light and with significantly different priorities than the radar technologists. However, each member is an expert in one or more Earth resources discipline fields and has had considerable experience in applying other forms of remote-sensing data. Panel members do represent the users who will determine the eventual success or failure of the active microwave program in Earth resources applications.

The Active Microwave Applications Panel believes that although it is not difficult to identify important and unique applications for active microwave, a significant commitment to a research and development program is needed now, far in advance of committing large sums of money to sophisticated space systems. Therefore, the strongest recommendation is for an immediate commitment by NASA of major funds for an imaging-microwave program supported by the development and utilization of a sophisticated airborne multifrequency active microwave imaging radar system for use in the Earth resources program.

It is recommended that an active microwave program be built around the aforementioned seven application areas, which show the most promise for early return on the research and development investment. Special attention must be given in structuring the microwave applications program to focus on the high-priority activities within each application area.

To one extent or another, it will be necessary within each application area to develop a coordinated program plan, including field measurements and a supporting aircraft data collection effort, leading to the definition of space experiments and, more importantly, characteristics of space hardware. It is recommended that a detailed investigation plan for active microwave activities be written to include the priority applications identified by this panel of users.

APPENDIX

APPLICATION SURVEY FORM AND MATRIX MASTER

The application survey form, form AP-1, is illustrated in figure 2-1. The application matrix master terms are defined as follows.

1. Application - Refers to the seven major application areas identified by the panel as potential areas for imaging-radar investigations

2. Measurement required - Refers to the specific active microwave measurement; e.g., moisture in the plant root zone to a depth of 3 m

3. Resolution - A spatial requirement of an active system related to a photographic interpretation requirement

4. Comments - Ancillary considerations; i.e., season or biowindow in which to observe a phenomenon

5. Radar priority versus technological feasibility - Scale of 1 to 6.

   1 = high priority - high feasibility

   2 = high priority - low feasibility

   3 = medium priority - high feasibility

   4 = medium priority - low feasibility

   5 = low priority - high feasibility

Form AP-1

Active microwave applications survey

Application:

Objective:

Advantages of microwave:

User interest:

Radar data required:

Coverage:

Resolution:

Frequency:

Polarization:

Look angle:

Other collateral data:

Output product:

Figure 2-1.- Sample copy of form AP-1.

6 = low priority - low feasibility

This scheme was used to arrive at the high-priority and high-potential-payoff applications. Because only applications that received a scale factor 1 rating were developed in detail by the panel, a column is not used in the application matrix master (form AP-2 (table 2-2)) to denote scale factor.

REFERENCES

2-1. Matthews, Richard E., ed.: Active Microwave Workshop Report. NASA SP-376, 1975.

2-2. Simonett, D. S., ed.: Applications Review for a Space Program Imaging Radar (SPIR). NASA CR-151182, 1976.

2-3. U.S. Department of Agriculture, Forest Service: The Outlook for Timber in the United States. Forest Resources Rep. No. 20, 1973.

2-4. U.S. Department of Agriculture, Forest Service: The Nation's Renewable Resources - an Assessment. 1975.

2-5. Kuchler, A. W.: Potential Natural Vegetation of the Conterminous United States. American Geographical Society, Special Publ. No. 36, 1964.

TABLE 2-2.- APPLICATION MATRIX MASTER

APPLICATION: Natural vegetation

APPLICATION TASK	MEASUREMENT REQUIRED	RESOLUTION (METERS)	COMMENTS
Range improvement	Brush density, location, and area Erosion patterns Bare soil vs. vegetation	30	Yearly
Range biomass productivity	Soil moisture index Biomass/density	100	Summer, biweekly Winter, monthly
Range inventory	Vegetation complex Vegetation quality Area of cover	100	Yearly
Forest assessment	Forest stand complex Canopy density Losses from stress (dead timber) Soil moisture in root zone	20 100	Annual Biannual
Tropical forest inventory	Location and extent of vegetation cover Potential agricultural production areas	100 30	10-yr intervals

APPLICATION: Cultivated vegetation

APPLICATION TASK	MEASUREMENT REQUIRED	RESOLUTION (METERS)	COMMENTS
Crop production estimates	Crop identification Growth stage Area determination Soil moistures Precipitation amount and extent	30	Biweekly data required during growing season
Stress reducing crop yield	Effect and extent of: Hail Drought Flood Freezing Insect/disease	20	Weekly data required during growing season

TABLE 2-2.- Continued

APPLICATION: Water resources

APPLICATION TASK	MEASUREMENT REQUIRED	RESOLUTION (METERS)	COMMENTS
Streamflow forecast	Precipitation volume/unit area times extent Areal extent of snow Snow wetness Soil moisture index Snow depth Snow water content	20, mountains 100, plains	Weekly measurements required
Watershed characteristics	Stream length and gradient Area of watershed Vegetation cover type by area Erosion: gully or stream bank	30 10	5-yr data interval acceptable Yearly measurement required
Frozen-lake mapping	Ice depth Availability of water under ice	70	Monthly during lake ice season

APPLICATION: *Mineral and energy resources and geologic features*

APPLICATION TASK	MEASUREMENT REQUIRED	RESOLUTION (METERS)	COMMENTS
Mineral exploration	Faults and fractures Rock-type boundaries Vegetation alteration Erosion features	30	Data required once annually depending on data quality
Energy resources exploration	Surface alteration Structural folds in faults Sedimentary basins	30	One-time data requirement

TABLE 2-2.- Continued

APPLICATION: Oceanography

APPLICATION TASK	MEASUREMENT REQUIRED	RESOLUTION (METERS)	COMMENTS
Ship navigation and routing	Sea state Wind velocity	95 to 100	Daily measurement
Navigation hazards	Location and tracking of icebergs and ice flows	50 to 100	Weekly tracking
Pollution monitoring	Oil spills and waste dumpings - detection, identification, direction/extent	50	Quick response to disasters and weekly monitoring
Ocean engineering hazard	Wave forces Current boundaries	10 to 30	3-day measurements with 3-hr forecasts for continental shelf explorations
Fishing intensity (commerical)	Numbered location of fishing vessels within legal zone	10	Weekly sampling
Sea ice	Map ice type Map land/ice boundary Map open water Map pressure ridges/leads	100	Weekly coverage required

Form AP-2

TABLE 2-2.- Continued

APPLICATION: Hazard surveys

APPLICATION TASK	MEASUREMENT REQUIRED	RESOLUTION (METERS)	COMMENTS
Flood mapping	Flood extent Flow patterns Debris monitoring Erosion/accretion	30	Quick response to phenomenon
Hurricane damage assessment	Flood extent Crop wind damage Crop flood damage Wind pattern measurement Urban damage	30	Quick response to phenomenon
Tornado damage assessment	Crop wind damage Urban wind damage Mapping and evaluation of extent of damage	20 to 30	Quick response to phenomenon
Forest and range fire damage assessment	Burn boundary determination Burn intensity Soil-type classification Terrain-type classification	30 to 50	Quick response to phenomenon
Landslide/Earth slippage	Terrain classification Fault location Slip/slide delineation	20 to 30	Quick response to phenomenon
Earthquake prediction/ damage assessment	Crustal movement Fault location Terrain analysis Resource damage assessment Urban damage assessment	10 to 30	Yearly monitoring with quick response to phenomenon May require corner reflections at critical points

TABLE 2-2.- Concluded

APPLICATION: Land use

APPLICATION TASK	MEASUREMENT REQUIRED	RESOLUTION (METERS)	COMMENTS
Land use (nonvegetation)	Existing land-cover map Urban change Residential Rural Extractive Transportation	30 to 50	Biannual; data also used for site selection studies and environmental input monitoring/ prediction