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INVESTIGATION OF TRANSIENT EARTH RESOURCES PHENOMENA

Continuation Study

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NOTICE

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16. Abstract

Calculated sensitivity requirements for an earth resource satellite in a geostationary orbit are reported. Radiance levels at the satellite sensor were computed for twenty top-priority SEOS applications selected from a larger number described in a January 1974 ERIM report, "Earth Resources Applications of the Synchronous Earth Observatory Satellite (SEOS)." The observation requirements were reviewed and re-evaluated in terms of spectral band definition, spectral signatures of targets and backgrounds, observation time, and site location. With these data and an atmospheric attenuation and scattering model, the total radiances observed by the SEOS sensor were calculated as were the individual components contributed by the target, target variations, and the atmosphere.

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PREFACE

The monitoring of natural disasters and catastrophic events of a characteristically transient nature is clearly and uniquely suited to observation from a geosynchronous platform. In addition, many earth resource phenomena exhibit transient behavior on a time scale comparable to more the visible disaster events. Timing is critical. As the pressures on our environment and limited resources intensify, the need for immediate, intelligent, and informed management decisions is clear. A reliable system for collecting accurate and timely information—from a space platform—provides periodic revisit time unimpeded by schedule and transient delays associated with aircraft operations.

ERIM (the Environmental Research Institute of Michigan) teams, charged with the detailed investigation and documentation of potential mission objectives (applications) for a synchronous earth observatory satellite (SEOS), as well as the numerous user groups and earth-science experts contacted in the course of this study, are in complete agreement that geosynchronous observation capability represents a highly significant advance in earth resources management. The twenty applications listed in this report represent the highest-priority applications for which the SEOS is assumed to be an appropriate observation instrument. These twenty are a selection of the more than thirty reported in ERIM 103500-1-F, Earth Resources Applications of the Synchronous Earth Observatory Satellite (SEOS).

The work herein described was performed for NASA-Goddard Space Flight Center, Greenbelt, Maryland, under Contract NAS5-20021. For NASA-Goddard, Dr. Louis Walter/650 acted as technical monitor.

For ERIM, the work was accomplished under the leadership of Mr. Richard R. Legault, Director of the Infrared and Optics Division, and a Vice President of ERIM. Mr. D. S. Lowe served as Principal Investigator, and Dr. G. C. Goldman served as Program Manager. In addition, the following people contributed to this effort: W. Benjay, J. Colwell, J. Cook, R. Horvath, L. Istvan, W. Pillars, D. Rebel, N. Roller, B. Salmon, I. Sattinger, R. Turner, R. Vincent, and C. Wezernak.

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1
INTRODUCTION

For more than a decade, satellite-borne instruments—in programs such as TIROS, Nimbus and ATS—have been providing information about the earth and its atmosphere. Much of this information (derived from large-area synoptic views of remote and inaccessible areas and/or through the rapid assessment of dynamic events) would otherwise have been unavailable. Although much of the initial orbital effort was devoted to meteorological studies, the simultaneous observation of earth-surface features (augmented by an extensive aircraft- and ground-based measurement program) provided impetus for the investigation of earth resources applications. Imagery obtained during the manned Gemini and Apollo programs, and with the first low-orbiter satellite specifically devoted to earth resources applications (ERTS-1), clearly demonstrated the feasibility of orbital collection of such data.

To date, such programs have concentrated on low-altitude platforms providing repetitive coverage of much of the earth's surface (e.g., ERTS-1, once every 18 days). With such low-altitude satellites, however, the presence of intervening cloud cover can result in very long intervals between successive images of a specific area. For example, ERTS-1 was launched and began collecting data in July 1972, but an acceptably low cloud-cover image of the north-eastern quarter of Michigan's lower peninsula was not obtained until nearly one year later (in June 1973).

While current and planned programs will result in a number of such low-altitude orbital platforms, and one can postulate an appropriate observation sequence to partially alleviate these problems, there are many earth resources-related phenomena which exhibit such short-term temporal behavior as to require a prohibitively large number of low-altitude platforms. In such cases, the only practical approach appears to require the rapid-response, interactive capability of a geosynchronous satellite. For example, NOAA has noted that natural disasters constitute one of four key problems involved in monitoring the global environment [1]. Such disasters (summarized by NASA/GSFC, to include "hurricanes, tornadoes, forest fires, floods, frost and disease and insect crop damage" [2]) often involve temporal behavior requiring

1. NOAA, U. S. Basic Paper on Monitoring the Global Environment, Draft, 30 July 1971.

2. NASA/GSFC, A Plan for the Observation, Study, and Amelioration of Transient Environmental Phenomena, 18 August 1971.

critically timed and/or near-continuous observation. Though it has been demonstrated that remote observation can materially aid in reducing the harmful effects of such disasters, it must also be noted that critical timing is the key to appropriate preventive or corrective action.

The 1972 User Applications Panel of the Advanced Imagers and Scanners Working Group (NASA/GSFC) concluded that "some applications require a high frequency of observation, perhaps daily or even hourly, thus requiring development of geostationary observation capability" [3]. Many other studies and reports have reached similar conclusions [4-7]. Colvocoresses terms the potential value of a geostationary platform "enormous . . . offering a possible solution to the survey problem which is fundamental to resource management" [6].

Two previous studies, aimed at evaluating and documenting potential applications of an earth-synchronous satellite, have been performed for NASA's Goddard Spaceflight Center. The Space Sciences and Engineering Center of the University of Wisconsin evaluated meteorological applications [8], while the Environmental Research Institute of Michigan (ERIM) examined NASA's earth resources program to determine to what extent its effectiveness could be improved by the collection of selected earth-resources data from a geostationary platform [9]. The former study consisted of a four-month effort devoted primarily to defining those earth resources applications requiring critically timed observation.

The resulting model developed priorities for some 30 application areas to assess instrument and observation requirements and mission scenarios in the face of numerous competing, and sometimes conflicting, objectives (application areas). The model was developed and used to rank-order selected experiments according to three fundamental criteria:

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3. SP 335, Advanced Scanners and Imagery Systems for Earth Observation, 1972.

4. Booz-Allen, Surveillance from a 24-Hour Satellite, Applied Research Incorporated, Contract N00-14-67-C-0142, U.S. Navy, 1967.

5. USDI-EROS, Proposal for a High Resolution Earth Sensing Experiment from SEOS Stationary Orbit, Submitted to NASA, October 1969.

6. Colvocoresses, A. P., Surveying the Earth from 20,000 miles, Image Technology, 1970.

7. Doyle, F. J., Internal Memorandum: Synchronous Earth Observatory Satellite (SEOS), USDI-EROS, December, 1971.

8. Soumi, V. E., et al., Meteorological Users of the Synchronous Earth Observation Satellite, Space Sciences and Engineering Center, University of Wisconsin, Madison, July 1973.

9. Lowe, D. S. and J. J. Cook, et al., Earth Resources Applications of the Synchronous Earth Observatory Satellite (SEOS), NASA Report No. CR-ERIM 103500-1-F, Environmental Research Institute of Michigan, Ann Arbor, 1973.

(1) importance (or value) of the application
(2) ability of SEOS-based sensors to perform the experiment
(3) uniqueness of the required data collection to the SEOS capability

In addition, each application area was assigned a feasibility status according to whether the experiment is:

(1) based solely upon hypothesis
(2) based upon proven theory
(3) based upon laboratory measurement
(4) based upon field measurement
(5) based upon demonstrated measurement with remote sensors

Table 1 lists the resulting mission goal priorities (earth resources applications) which were used to establish tentative sensor and system requirements.

The earlier ERIM study reached the general conclusion that short-lived environmental phenomena (as well as other phenomena exhibiting significant variation during short periods of time) are quite common and often have severe impact on man and his environment. It further concluded that geosynchronous satellite systems can provide unique capabilities for monitoring transient conditions or dynamic phenomena. The freedom to select from a great variety of observational modes, with coverage ranging from selected small areas to those of near-hemispheric size, and with frequency of observation varying from "on-demand" to continuous, make earth-synchronous satellite systems ideally suited for certain earth resources applications.

The former ERIM study concentrated on specific phenomena and the consequent observables associated with a given application area and with user needs relative to the decision/action chain required for timely and effective management. The current study stresses a more detailed and quantitative evaluation of data and sensor requirements necessary to successfully accomplish the mission goals of the 20 highest-priority application areas (see Table 2).

In most applications, a particular phenomenon is detected on the basis of its unique spectral characteristics. To detect and observe this uniqueness, the sensor must be capable of detecting small differences in reflectance between the phenomenon being sought and its background. Thus, to measure the amount of phytoplankton in water, one must be able to observe quantitatively the differences in radiation upwelling from water with and without chlorophyll-containing phytoplankton. In the previous ERIM study, the minimum detectable change in reflectance was noted for each application along with desired spatial resolution and coverage. The prime objective of the present study is to determine how best to convert these scene properties into expected radiance levels at the SEOS sensor. In order to make this translation, one must define the wavelength and bandwidth of each channel as precisely as the state-of-the-art

TABLE 1. ORIGINAL LIST OF 32 POSSIBLE SEOS APPLICATIONS

SEOS Ability	Value	Unique SEOS Ability	Relative Priority		Feasibility
10	10	10	1000	Detecting Water-Suspended Solid Pollutants	5
8	10	10	800	Estuarine Dynamics and Pollution Dispersal	5
10	8	8	640	Monitoring Extent and Change of Snow Cover	5
10	5	10	500	Monitoring Volcanic Regions	5
10	6	8	480	Detecting Development and Movement of Colored Water Masses (Plankton)	5
5	10	9	450	Detecting Fish Location and Movement	3
6	9	8	432	Ocean Dynamics	5
6	7	10	420	Detection of Disease and Insect Damage to Forest Species	5
7	7	7	343	Forest Inventory and Valuation of Multiple-Use Management	4
6	7	8	336	Evaluation of Range Forage Resources and Grazing Pressure Assessment	3
5	8	8	320	Management of Irrigation	4
5	6	10	300	Detection and Monitoring Oil Pollution	5
8	4	9	288	Diurnal and Seasonal Variations for Lithologic Survey	4
4	9	8	288	Monitoring and Analysis of Lake Dynamics	3
4	7	10	280	Wildfire Monitoring	2
3	9	10	270	Flood Prediction, Survey, and Damage Assessment	3
6	6	7	252	Monitoring Water Erosion and Deposition	4
8	3	10	240	Diurnal and Seasonal Variations for Thematic Mapping	4
4	6	9	216	Monitoring and Prevention of Aeolian Soil Erosion	2
2	10	10	200	Detection of Disease and Insect Damage to Cultivated Crops	5
8	3	8	192	Determination of Optimum Crop Planting Dates	4
2	8	8	128	Earthquake Prediction	1
4	3	10	120	Exploration of Geothermal Sources	2
5	4	5	100	Monitoring Lake and Sea Ice for Navigation	5
2	4	10	80	Diurnal and Seasonal Variations for Geomorphological Survey	1
1	7	10	70	Wildfire Detection	3
6	1	9	54	Detection and Mapping of Shoal Areas	4
3	3	6	54	Phenological Classification of Agricultural Crop Types	2
1	6	8	48	Detecting and Monitoring Thermal Water Pollutants	5
1	5	9	45	Analysis of Undesirable Heat Islands in Urban Areas	1
1	5	8	40	Prediction of Landslides and Avalanches	1
3	2	2	12	Detecting and Monitoring Iceberg Hazards	4

permits, the target locations, the time of observation, and the atmospheric viewing condition. Specifically, available spectral signatures (hence, spectral-band requirements) and atmospheric transmission data were evaluated for the purpose of defining optimum sensor band-placement and the compromises required by sensor-mission commonality. Also evaluated were radiance and noise-equivalent levels required for monitoring observables associated with critical applications.

As a secondary objective, this study estimated the coverage requirements of an operational SEOS. In the earlier ERIM study, these were defined as the ones required to demonstrate that SEOS could reliably perform the operation defined by each application. Thus, rather than scan large areas, small, selected sites were defined for observing specific phenomena. For example, a demonstration in detecting and monitoring forest fires was limited to a single state in a fire-prone season. Operationally, one would want more frequent coverage over a larger area and time span. Accordingly, observation requirements for an operational SEOS sensor were also defined for purposes of sensor design.

Figure 1 outlines the approach and scope of the current study. First, disciplinary teams, involved in the original ERIM study and thoroughly familiar with user needs and data requirements in the various earth-science areas, performed literature surveys and detailed analyses aimed at a thorough documentation of the observables and spectral signatures associated with each of the top 20 application areas. This information was correlated with atmospheric transmission data (for each disciplinary application), and the requirements of various mission goals were compared and correlated to determine optimum band selection and priority assignment. Similarly, these disciplinary teams selected application-demonstration and operational test sites and evaluated both in terms of observational requirements, both diurnal and seasonal. This information, along with the resulting observational geometry, spectral band identifications, and atmospheric transmission data, was used in calculating radiance and noise-equivalent-power levels. Finally, these calculations were used to provide a quantitative feedback helpful in determining the feasibility of both application goals and mission scenarios.

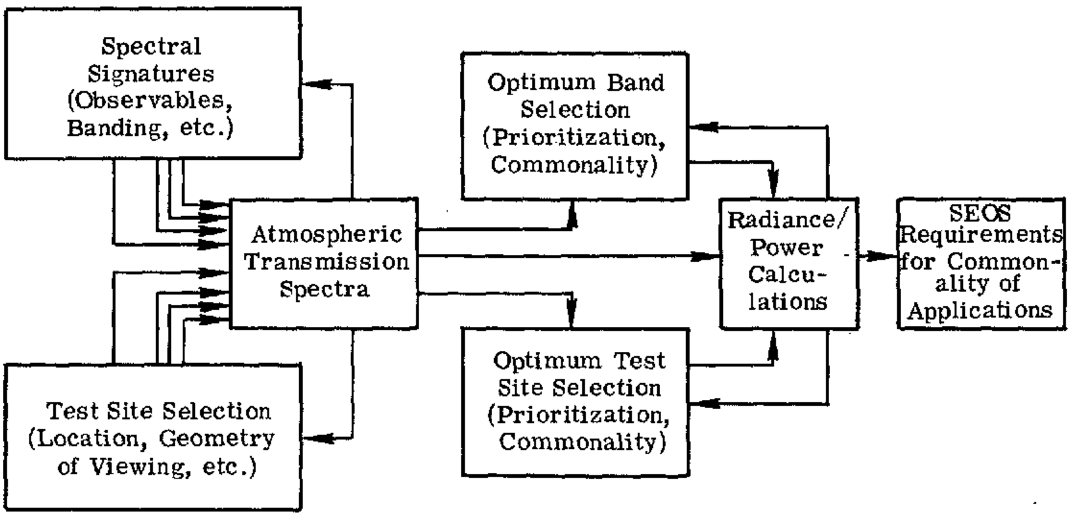

FIGURE 1. SCOPE AND METHOD OF TRANSIENT EARTH RESOURCES PHENOMENA INVESTIGATION

2
DESCRIPTION OF APPLICATIONS AND REQUIREMENTS

The applications for SEOS investigated and reported here are the 20 with the highest priority listed in Earth Resource Applications of the Synchronous Earth Observatory Satellite [9]. These 20 applications are listed in Table 2. As can be seen by a brief perusal of this list, the applications vary considerably in scope, subject matter, and requirements.

Overall, the list may be divided into four main subgroups: water-oriented, geology-oriented, vegetation-oriented, and miscellaneous. Of course there is some overlapping among these subgroups. However, for simplicity, each of the applications has been placed in one of the subgroups; the wavelength bands needed by each subgroup are also discussed.

2.1 WATER-ORIENTED APPLICATIONS

Those applications falling under the water-oriented category are:

1. Detection and Monitoring of Water-Suspended Solid Pollutants
2. Estuarian Dynamics and Pollution Dispersal
5. Detection and Monitoring Development and Movement of Colored Water Masses (Plankton)
6. Detecting and Monitoring Fish Location and Movement
7. Ocean Dynamics
12. Detecting and Monitoring Oil Pollution
14. Monitoring and Analysis of Lake Dynamics

To study the dynamic properties of natural waters by remote sensing, many non-water properties must be used. These include suspended organic and inorganic matter as well as surface temperature.

In order to make an optimum choice of spectral bands for assessment of suspended organic matter, the spectral reflectance of chlorophyll and general plant pigment must be evaluated. Parametric curves by Yentsch (Figure 2 [10]) and Ramsey (Figure 3 [11]) indicate that optimum results can be achieved by using a band from 0.42-0.46 μm to accentuate the high reflectance values for low phytoplankton concentration; 0.47-0.52 μm to yield a stable reflectance value independent of phytoplankton concentration; and a band from 0.56-0.60 μm to both achieve good negative correlation with the first 0.42-0.46 μm band and provide increasing reflectance as the

10. Yentsch, C. S., The Influence of Plankton Segments on the Color of Sea Water, Deep Sea Research, 7, 1960, pp. 1-9.

11. Ramsey, R. C., Study of the Remote Measurement of Ocean Color, Final Report to NASA, TRW-NASA-1658, 1968.

TABLE 2. SEOS APPLICATIONS FOR CONTINUOUS STUDY.
Listing is in order of priority.

Priority	
1	Detecting and Monitoring of Water-Suspended Solid Pollutants
2	Estuarine Dynamics and Pollution Dispersal
3	Monitoring Extent, Distribution and Change of Snow Cover
4	Monitoring Volcanic Regions
5	Detecting and Monitoring Development and Movement of Colored Water (Plankton)
6	Detecting and Monitoring Fish Location and Movement
7	Ocean Dynamics
8	Detection and Assessment of Disease and Insect Damage to Forest Species
9	Forest Inventory and Valuation for Multiple-Use Management
10	Evaluation of Range Forage Resources and Grazing Pressure Assessment
11	Management of Irrigation
12	Detecting and Monitoring Oil Pollution
13	Diurnal and Seasonal Variations for Lithologic Survey
14	Monitoring and Analysis of Lake Dynamics
15	Wildfire Monitoring
16	Flood Prediction, Survey, and Damage Assessment
17	Monitoring Water Erosion and Deposition
18	Diurnal and Seasonal Variations for Thematic Mapping
19	Monitoring and Prevention of Aeolian Soil Erosion
20	Detection and Assessment of Disease and Insect Damage to Cultivated Crops

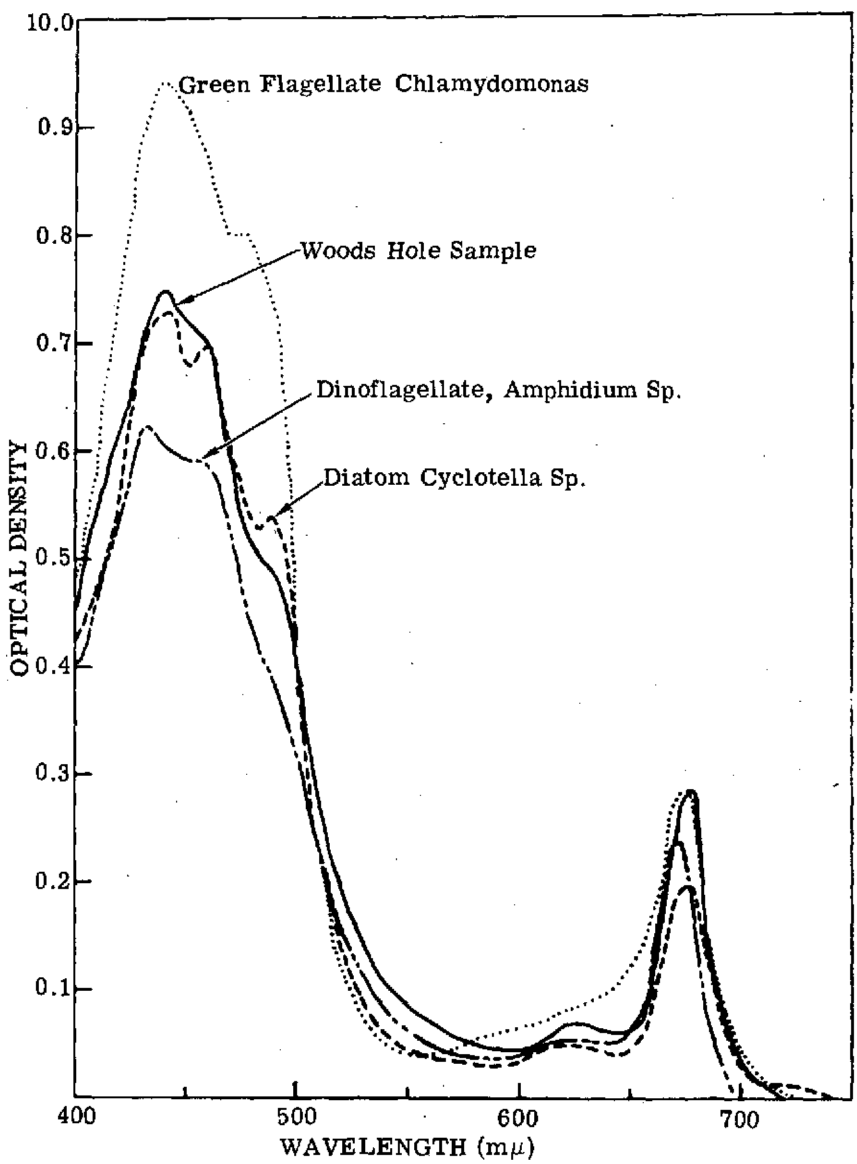

FIGURE 2. PIGMENT SPECTRA OF LIVING PHYTOPLANKTON

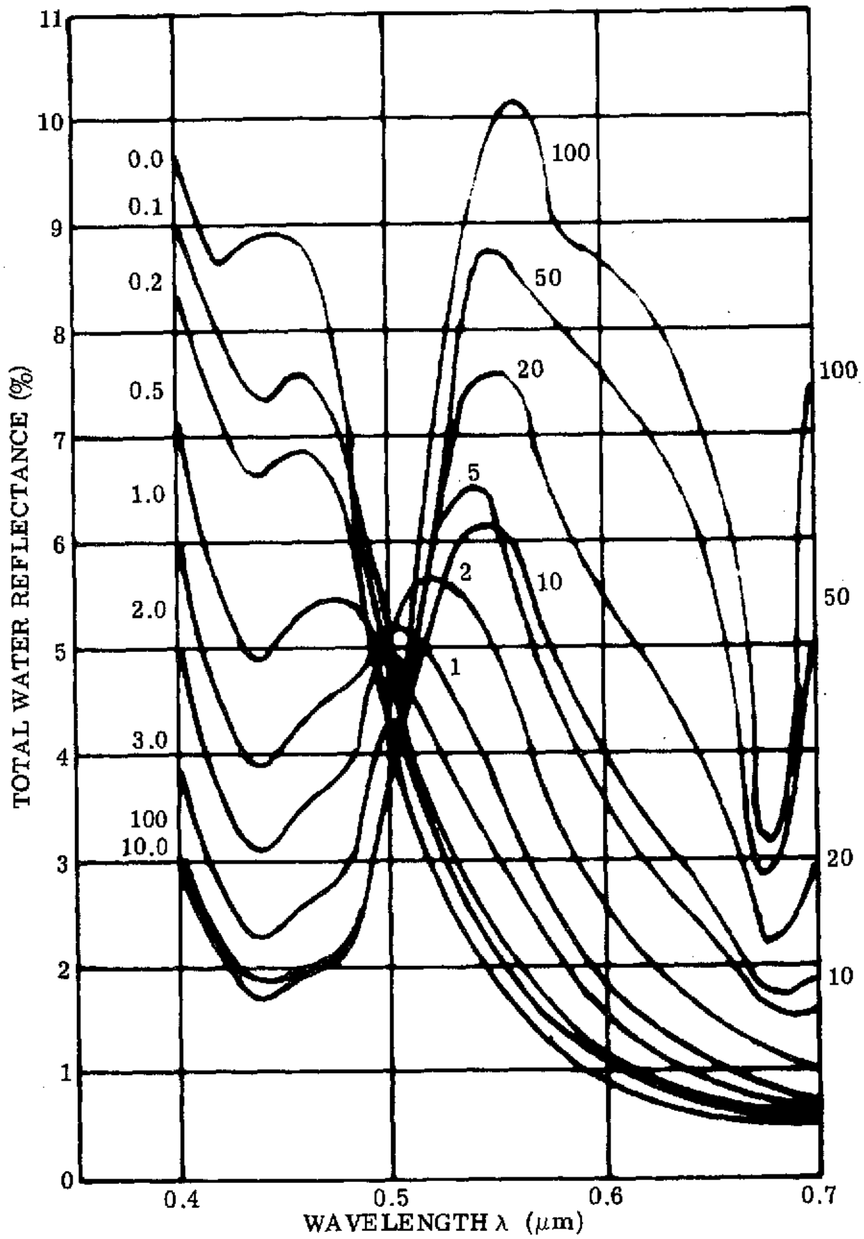

FIGURE 3. CALCULATED SPECTRAL REFLECTANCE OF DEEP OCEAN WITH VARYING AMOUNTS OF CHLOROPHYLL (mg/m^3)

concentration increases. A near-IR band, such as from 0.70-0.73 μm, is especially helpful for identifying near-surface phenomena because of the very poor penetration of water at this wavelength [12, 13]. Blooms such as the red tide are most easily seen in the 0.56-0.60 μm range [14].

The easiest way to deal with suspended inorganic matter is to locate the maximum penetration depth of the light into the water. Narrow bands beginning at 0.47μm are used in this case. A band from 0.47-0.52 μm yields maximum penetration in the clearest water. As the amount of suspended inorganic matter increases, the maximum penetration band shifts toward the longer wavelengths (Figure 4) so that for the average coastal water, 0.53-0.57 μm is optimum [15].

For the more severe coastal cases, 0.56-0.60 μm and 0.60-0.65 μm are needed. This latter band, in combination with the one at 0.47-0.52 μm,assists in making gross quantitative statements as to mean particle size [16]. Bands of increasing wavelength such as 0.60-0.65, 0.65-0.69 and 0.70-0.73 μm yield information about the depth of water because water transmittance decreases as wavelength increases. Further information regarding suspended material can be found in these bands as the material inhibits maximum light penetration. The 0.70-0.73 μm band cannot be extended toward 0.8μm for quantitative evaluation of either suspended organic or inorganic matter; such extension takes the band into a region of rapidly decreasing light penetration into the water.

For salinity and water-surface roughness measurements, microwave sensors are most useful. As the wavelength increases, the sensitivity to salinity increases up to about 30cm. Beyond 30cm, the microwave system also loses sensitivity to surface roughness [17]. Surface roughness determinations may also be made using radar at the X-band (10cm) range.

Measurements of two other phenomena may be of value in the fisheries application: bioluminescence and fish oil. These have, however, a low priority at this time in view of insufficient

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12. Sherman, J. W., Remote Sensing Oceanography, Vol. I, International Workshop on Earth Resources Survey Systems, Ann Arbor, 1971.

13. Sherman, J. W., Oceans, Streams, and Water Resources, American Society of Photogrammetry Symposium Proceedings, 1973.

14. White, P. G., High Altitude Remote Spectroscopy of the Ocean, Proceedings of the Society of Photo-Optical Instrumentation Engineers, Vol. 27, 1971.

15. Polcyn, F. C. and R. A. Rollin, Remote Sensing Techniques for the Location and Measurements of Shallow-Water Features, Willow Run Laboratories of the Institute of Science and Technology, The University of Michigan, Ann Arbor, 1969.

16. Williams, J., Problems of Ambiguity Involved with the Utilization of the Mie Theory in Particle Size Determination, Tech. Rep. No. 49, Chesapeake Bay Institute, The Johns Hopkins University, 1968.

17. Hanson, K. J., Remote Sensing of the Troposphere, USDC-NOAA TDS-8859, 1972.

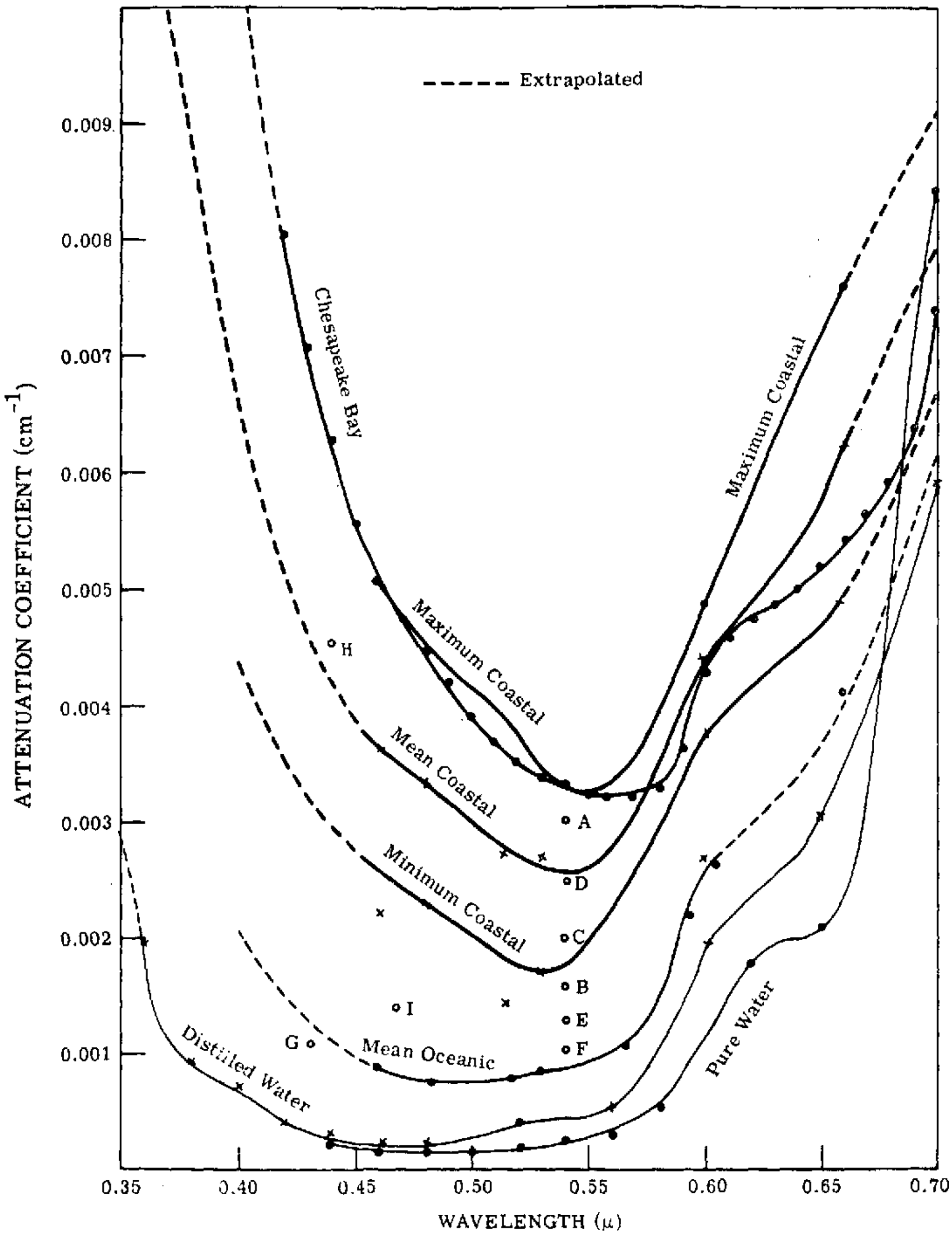

FIGURE 4. ATTENUATION COEFFICIENT VERSUS WAVELENGTH FOR PURE WATER AND SEA WATER [15]

evidence that these measurements are feasible from spaceborne sensors. Fish oil observations would require an active laser scanner system recording in the peak wavelength region of the specific fish oil fluorescence. Detection of fish schools using bioluminescence displays of plankton excited by the swimming fish would require a low-light-level imaging system with peak sensitivity at about 0.48μm [12].

To detect and monitor occurrences of on-water oil pollution, the increased reflectance of oil over that of water is used in the short wavelength region. Ideally, ultraviolet bands should be employed, but atmospheric considerations prohibit this choice. The acceptable choices remaining are a number of short wavelength bands up to 0.70μm [18]. Night-time detection and monitoring may be accomplished with thermal bands which distinguish the variation in emissivity of surrounding water as compared to that of the oil.

The mid-IR band from 2.05-2.35 μm shows sea ice and ice movements in good detail to assist in water dynamics studies.

2.2. VEGETATION-ORIENTED APPLICATIONS

Those applications considered as vegetation oriented are:

8. Detection and Assessment of Disease and Insect Damage to Forest Species
9. Forest Inventory and Valuation of Multiple-Use Management
10. Evaluation of Range Forage Resources and Grazing Pressure Assessment
11. Management of Irrigation
16. Flood Prediction, Survey and Damage Assessment
17. Monitoring Water Erosion and Deposition
18. Diurnal and Seasonal Variations for Thematic Mapping
19. Monitoring and Prevention of Aeolian Soil Erosion
20. Detection and Assessment of Disease and Insect Damage to Cultivated Crops

The optimum spectral bands to be used in monitoring certain properties of our vegetation resources (crop-type, disease, potential yield, biomass) are determined by many parameters, only one of which is hemispherical leaf reflectance [19]. Other parameters of interest include vegetation canopy structure, percent vegetation cover, leaf-area index, background reflectance, solar zenith angle, and shadow.

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18. Horvath, R., W. L. Morgan, and S. R. Stewart, Optical Remote Sensing of Oil Slicks: Signature Analysis and Systems Evaluation, for the U. S. Coast Guard Office of Research and Development, by Willow Run Laboratories of the Institute of Science and Technology, The University of Michigan, 1971.

19. Colwell, J., Vegetation Canopy Reflectance, J. Remote Sensing of Environment (In Press).

Three reasonably distinct types of information are potentially available from leaf hemispherical reflectance [20]. In the visible spectrum (especially the blue and the red), reflectance is largely a function of the amount and quality of pigment present (generally chlorophyll). Information is available between approximately 0.75 and 1.1μm (near-IR) where the reflectance is largely a function of the internal cellular structure of the leaf, while between approximately 1.3 and 2.8μm the leaf reflectance is largely determined by the amount of water in the leaf.

Percent of vegetation cover is a characteristic frequently important in differentiating vegetation classes [21]. The spectral bands in which percent differences in vegetation cover can be most easily differentiated are those in which the contrast between leaf reflectance and background reflectance is the greatest. The amount of shadow in the canopy frequently increases with increases in percent of vegetation cover. Thus, differences in percent vegetation cover are enhanced by the amount of shadow in spectral regions where the background reflectance is greater than the leaf reflectance, and are somewhat masked in the spectral regions where the leaf reflectance is greater than the background reflectance. The contrast between leaf reflectance and background reflectance is frequently greatest in the red spectral region and in the near-IR spectral region. The red spectral region is generally more sensitive to changes in percent cover than is the near-IR because here background reflectance is generally greater than leaf reflectance, whereas in the near-IR this return is less than leaf reflectance.

Most leaves are characterized by high reflectance, high transmittance, and low absorption in the near-IR [22]. Under these conditions, multiple layers of leaves produce a greater total reflectance than a single leaf. It is therefore possible, using near-IR reflectance, to distinguish between vegetation classes having identical percent vegetation cover and hemispherical leaf reflectance but a different leaf-area index.

Vegetation canopy reflectance is much more affected by a change in leaf reflectance when leaf reflectance and transmittance are positively correlated than when these parameters are negatively correlated [23]. Leaf hemispherical reflectance and transmittance tend to be positively correlated in the blue, red, and mid-IR, and negatively correlated in the near-IR.

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20. Knipling, E. B., Physical and Physiological Basis for the Reflectance of Visible and Near-Infrared Radiation from Vegetation, J. Remote Sensing of Environment, Vol. 1, 1970, pp. 155-59.

21. Colwell, J., Bidirectional Spectral Reflectance of Grass Canopies for Determination of Above Ground Standing Biomass, Ph. D. Dissertation, School of Natural Resources, The Universith of Michigan, Ann Arbor, 1973.

22. Gausman, H. W., et al., Reflectance Transmittance, and Absorptance of Light of Leaves for 11 Plant Genera with Different Leaf Mesophyll Arrangements, Texas A & M University Technical Monograph No. 7, 1970.

23. Colwell, J., Grass Canopy Bidirectional Spectral Reflectance, Proceedings of the Ninth International Symposium on Remote Sensing of Environment, Environmental Research Institute of Michigan, Ann Arbor [In Press].

A red spectral band (0.65-0.69 μm) may be the single most useful spectral band for monitoring vegetation resources. For all-green vegetation, the red band is generally quite sensitive to changes in percent cover, as explained previously, and to some extent it is sensitive to differences in vegetation canopy structure. In addition, the red spectral band is quite sensitive to senescent (browning) vegetation.

The blue spectral region probably has nearly as much information associated with it. However, atmospheric problems and a generally smaller vegetation/soil contrast make it less useful, especially in earth observation from satellites.

The green spectral region (0.53-0.57 μm) seems to behave in some ways like the red and blue (sensitive to pigments) and in some respects like the mid- or near-IR (sensitive to cell-air interface and moisture content). When the vegetation is all green, the green spectral region is somewhat sensitive to percent vegetation cover. It generally has low vegetation/soil contrast, however. As vegetation ages, green reflectance has been found to increase, decrease, or stay about the same [20, 21]. An increase in reflectance may be attributable to less chlorophyll pigment (although chlorophyll does not absorb very effectively in this spectral region), an increase in cell/air interfaces, or a decrease in leaf moisture content. In leaves that turn color (yellow or red), green reflectance has been found to decrease [24]. This may be from absorption by other pigments such as carotene and anthocyanin. Difficulty in interpreting the causes of leaf reflectance in the green spectral region, plus generally low vegetation/soil contrast, suggest that leaf reflectance is most useful for monitoring vegetation that turns color (reflectance then becomes dominated by pigments other than chlorophyll).

The near-IR spectral region (0.78-0.82 μm) is generally sensitive to changes in amount of cell-air interface. Near-IR reflectance has been found in some cases to <u>increase</u> when <u>mature</u> foliage is stressed, and to <u>decrease</u> when the foliage <u>develops</u> under stress [25]. Near-IR reflectance is generally sensitive to changes in percent vegetation cover. Its uniquely useful property, however, is that it is sensitive to multiple layers of vegetation (because of high leaf transmittance) and hence is reasonably sensitive to leaf-area index. An additional important property is that the reflectance and transmittance are generally negatively correlated. This phenomena makes vegetation-canopy reflectance reasonably independent of leaf hemispherical

24. Olson, C. E. and R. E. Good, Seasonal Changes in Light Reflectance from Forest Vegetation, Photogrammetric Engineering, 1962, pp. 107-114.

25. Olson, C. E., Early Remote Detection of Physiologic Stress in Forest Stands, Proceedings of the Second Workshop on Aerial Color Photography in the Plant Sciences, University of Florida, Gainesville, 1969, pp. 37-52.

reflectance—which is a particularly valuable trait for assessment of total rangeland biomass [21]. This band is limited on the short wavelength end by the rapidly decreasing reflectance below 0.76μm, and at the long wavelength end by the strong atmospheric absorption starting at about 0.83μm.

The mid-IR spectral range (2.05-2.35 μm) is sensitive to the amount of water present in leaves. This parameter may not be correlated with the amount of cell/air space, so it provides additional information. In addition, leaf reflectance and transmittance are generally positively correlated in the mid-IR, so small changes in leaf hemispherical reflectance are more likely to be seen in canopy reflectance. There are some difficulties in using this spectral region, however. The vegetation/soil contrast is often small and may even reverse itself. In addition, interpretation is made more difficult by fluctuations in surface soil moisture. One's choice of the best mid-IR spectral band to use may thus hinge on atmospheric conditions and available solar power.

The thermal IR spectral region is of dubious value in assessing vegetation. Individual leaves stressed in the laboratory have been shown to have higher than normal temperatures; but in field situations convective cooling by winds tends to lessen temperature differences. When canopies exhibit apparent thermal anomalies, the underlying reason is frequently not actually higher leaf temperatures, but instead some other property (e.g., leaf density or leaf geometry) producing sensed reflective anomalies [26]. In addition, atmospheric and spatial resolution limitations of thermal sensors in satellites suggest that such sensors should be given a fairly low priority for vegetation analyses.

Determination of soil moisture is an important aspect of at least two of the tasks considered in this section. The 1cm microwave data are suggested for this purpose [27]. Ancillary data needed to most accurately analyze the microwave data include: (1) vegetation conditions as inferred from visible, near-IR and mid-IR data, and (2) soil conditions as determined by radar (surface roughness) and thermal-IR (temperature, composition, and texture).

2.3 GEOLOGY-ORIENTED APPLICATIONS

These applications are considered to be geology-oriented:

4. Monitoring Volcanic Regions
13. Diurnal and Seasonal Variations in Lithologic Survey
18. Diurnal and Seasonal Variations for Thematic Mapping

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26. Cook, J., Natural and Stress-Related Temperature Variation in Quercus Macrocarpa and Its Significance for Thermal Remote Sensing, School of Natural Resources, Ph. D. Dissertation, The University of Michigan, Ann Arbor, 1974.

27. Sibley, T. G., Microwave Emission and Scattering from Vegetated Terrain, Remote Sensing Center, Texas A & M University, College Station, 1973.

Two types of radiometric investigative procedure are available for geological mapping. The first type identifies rocks and minerals by their spectral signatures. The second procedure bases identification on thermal inertia properties. Of course, to maximize the identification probability, both methods can be employed in combination.

Spectral signatures in the reflecting regions of the spectrum may be used to identify iron oxide by comparing the signals from the various visible bands to that of the 0.60-0.65 μm band [28]. This is effective with ferric iron as its presence tends to dominate the rock color (red). Also useful in identifying ferric iron is an absorption band at 0.86-0.89 μm, with relative maximums of reflectance on both sides of this band. Ferrous iron, however, has an absorption band in the region near 1μm (0.95-1.10 μm band) to further aid in species discrimination [29].

With calcareous rocks, another identification signature is possible based on a characteristic carbonate molecular vibration between 1.9-2.5 μm (2.05-2.35 μm band). Such vibrations may, however, be inhibited by argillaceous or carbonaceous material. Also, most limestone spectra show a rapid and steady decrease in reflectance from the red to the blue portion of the spectrum [28].

The relative percent of silicon dioxide in the rocks is a further important parameter in their identification. Excitation from incident radiation in the reststrahlen bands produces an emissivity variation in the rocks. To detect this, the two thermal bands (8.3-9.4 and 10.3-11.3 μm) can be observed for a difference in apparent temperature. As the percent of silicon dioxide varies, the emissivity of the rock changes as a function of wavelength. Therefore, in the presence of silicon dioxide, one of these bands will indicate a different temperature (emissivity) with respect to the other [30, 31].

The second type of investigative procedure for geological applications entails evaluation of the thermal inertia of materials. In this procedure, which is highly adaptable to a stationary satellite, target areas are observed frequently during one day, with such observations repeated seasonally. As the sun rises, terrestrial materials absorb the incident solar radiation and heat up.

28. Salmon, B. C., and R. K. Vincent, Surface Compositional Mapping in the Wind River Range and Basin, Wyoming, by Multispectral Techniques Applied to ERTS-1 Data, Ninth International Symposium on Remote Sensing of Environment, Environmental Research Institute of Michigan, April 1974, Ann Arbor [In Press].

29. Salisbury, J. W. and G. R. Hunt, Remote Sensing of Rock Type in the Visible and Near-Infrared, Ninth International Symposium on Remote Sensing of Environment, Environmental Research Institute of Michigan, April 1974, Ann Arbor [In Press].

30. Vincent, R. K., A Thermal Infrared Ratio Imaging Method for Mapping Compositional Variations among Silicate Rock Types, Ph.D. thesis, Department of Geology and Mineralogy, The University of Michigan, Ann Arbor, 1973.

31. Vincent, R. K., Mapping Exposed Silicate Rock Types and Exposed Ferric and Ferrous Compounds From a Space Platform, EREP Investigation 444M, Environmental Research Institute of Michigan, Ann Arbor, 1973.

At 300°K, the absorbed radiation at high sun angles is about three times greater than the emitted radiation. The heating and cooling of a surface is affected by the radiation balance and the thermal properties of the material. Though sunlight is the prime cause of diurnal variation in the surface temperature of the earth, variations in thermal inertia produce the most significant temperature differences among terrestrial features and materials. Thus, for example, as asphalt roof, because of its insulation from the earth, undergoes a much larger diurnal excursion in temperature than an asphalt road. Figure 5 [32] shows this diurnal variation for materials of differing thermal inertia; Lowe showed the comparable variation for a number of natural and man-made features [33].

For monitoring volcanic areas to predict the onset of their activity, a few bands in the visible portion of the spectrum are used for simple observation, while the thermal bands supply pre- and post-dawn ground-temperature measurements. Before erupting, volcanos have been known to exhibit surface temperature increases in the vicinity of the crater.

2.4 MISCELLANEOUS APPLICATIONS

Two other applications fall outside of the three categories previously discussed. They are:

3. Monitoring Extent, Distribution and Change of Snow Cover
15. Wildfire Monitoring

For snow cover determinations, the spectral region from 0.70-0.73 μm is used because of its ability to distinguish snow and ice surfaces from the surrounding terrain. Also, a range of reflectance variations from frost to wet snow are observable in this band to help determine snow type [34].

The spectral interval of 2.05-2.35 μm is particularly useful in determining melting and fresh snow. Wet snow can also be separated from wet soil in this band. In addition, thermal bands are important for snow temperature determination and hence melting conditions.

The monitoring of wildfires takes a band from 3.6-4.1 μm as this is the location of maximum emitted energy from a fire at 600°C. Longer wavelength thermal bands are required for temperature/area calculations. A vegetation mapping band at about 0.78-0.82 μm is helpful in determining the extent of the forest region and fire damage.

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32. Pohn, H. A., T. W. Offield, and K. Watson, Geologic Material Discrimination from Nimbus Satellite Data, Fourth Annual Earth Resources Program Review, Manned Spacecraft Center, Houston, 1972.

33. Lowe, D. S. et al., Multispectral Data Collection Program, Proceedings of the Third Symposium on Remote Sensing of the Environment, Willow Run Laboratories of the Institute of Science and Technology, The University of Michigan, 1964.

34. Mellor, M., Optical Measurements on Snow, Research Report 164, Cold Regions Research and Engineering Laboratory, pp. 8-11.

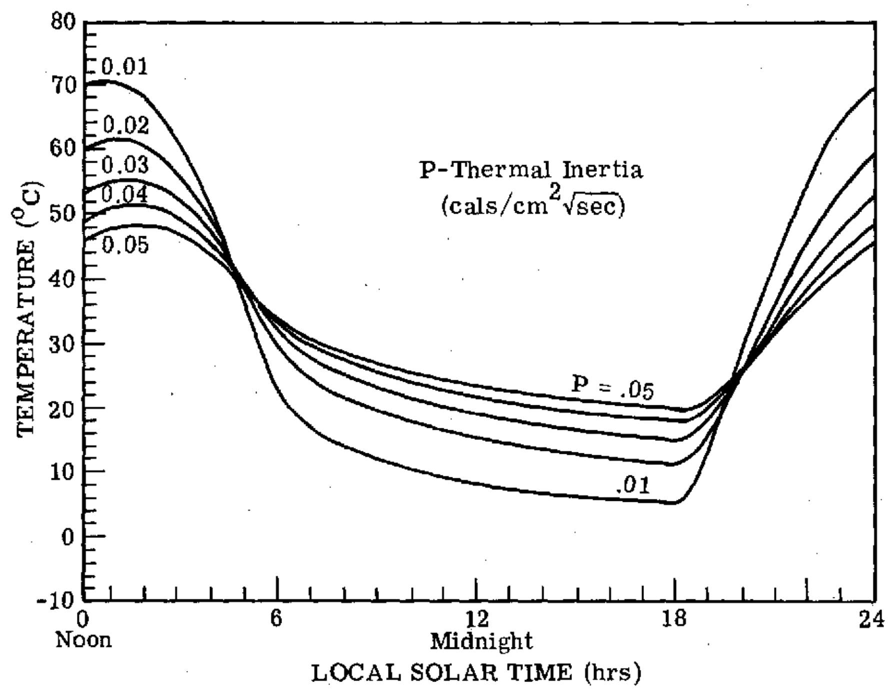

FIGURE 5. DIURNAL TEMPERATURE VARIATIONS OF MATERIALS WITH DIFFERENT THERMAL INERTIAS [32]

3
BANDS CHOSEN FOR SEOS APPLICATIONS

3.1 BAND DESCRIPTION AND SUMMARY

The previous section discusses particular band placements required for the various applications. Band placements for each application are given in Appendix A, along with all other observational requirements. This section tabulates the band requirements for the 20 selected applications.

The visible region is covered by seven bands having bandwidths of about 0.05 μm each. These are needed for water, geology, and vegetation applications.

The near-IR region is covered by five bands from 0.70 to 1.10 μm with bandwidths of from 0.03 to 0.15 μm. This region is used primarily by vegetation and geology applications, although some water applications use the shortest wavelength band in this region.

In mid-IR range, two bands from 2.05 to 4.1 μm are required. The bandwidths vary from 0.30 to 0.50 μm, and the primary users are the vegetation applications, followed by geology. Of course, the wildfire application (No. 15) makes primary use of the 3.6-4.1 μm band for mapping high temperatures.

Almost all of the applications requested thermal bands for various reasons. There are four such from 8.3 to 12.9 μm. Three of these are needed to correct for atmospheric effects. The particular choice of these bands is discussed in Section 3.2.

Long wavelength bands (1 to 30 cm) are suggested for salinity, soil-moisture content, as well as surface (both land and water) roughness. These bands are in the microwave region.

Table 3 gives the total listing of these bands for SEOS applications. This list is the result of an iterative compromise for all the applications and probably displays the best state-of-the-art choices. The large number of relatively narrow bands results from the large number of applications being satisfied by SEOS.

3.2 CHOICE OF THERMAL BANDS

Atmospheric transmission variability and corrections are usually based on climatological data. Corrections for atmospheric attenuation must relate to both time and place and can become costly. This report endorses the use of multiple thermal bands to provide atmospheric corrections and a visible band to ascertain the presence or absence of clouds in the field of view.

TABLE 3. BANDS CHOSEN FOR ALL SEOS APPLICATIONS

Band Number	Wavelength Limits (μm)	Major Users
I	0.42-0.46	Water, Geology
II	0.45-0.50	Water, Geology
III	0.47-0.52	Water, Geology
IV	0.53-0.57	Water, Geology, Vegetation
V	0.56-0.60	Water
VI	0.60-0.65	Water, Geology
VII	0.65-0.69	All
VIII	0.70-0.73	Water, Geology
IX	0.78-0.82	Vegetation, Geology
X	0.85-0.89	Geology
XI	0.89-0.95	Geology
XII	0.95-1.10	Geology
XIII	2.05-2.35	Vegetation, Geology
XIV	3.6-4.1	Wildfire, Geology
XV	8.3-9.4	Geology
XVI	10.3-11.3	All
XVII	11.3-12.0	All
XVIII	12.0-12.9	All
XIX	1cm (Microwave)	Vegetation
XX	30cm (Microwave)	Water
XXI	10cm (Radar)	Water, Vegetation

Such remote temperature measurements have been reported by Prabhakara et al. [35] and also by Anding and Kauth [36].

Using a reasonable model of the atmospheric attenuation, one can find a relative value of the extinction coefficient for each thermal band. For an extinction coefficient of zero, the observed radiance would correspond to the true surface radiance. If the apparent brightness temperature is plotted against the extinction coefficient, a curve can be drawn through the points (one point for each thermal band) and extrapolated to the zero extinction coefficient. Zero extinction corresponds to the surface brightness temperature.

By calibrating periodically on the surface temperature of sea water, accuracies to within $1^{\circ}K$ can be attained, depending on the number of thermal bands and the method used to draw the curve through the points.

Because of the variability of the atmospheric attenuation at each wavelength and the unknown emissivity of normal ground surfaces, each point (corresponding to a brightness temperature and a wavelength-extinction coefficient) is actually an area. Using the sea surface (whose emissivity is well known and does not vary significantly from unity), a curve can be drawn through the areas to give a true surface temperature. If only one thermal band were used, an infinite number of curves could be drawn. As the number of bands is increased, the number of possible curves decreases and the true parametric line is approached. Prabhakara et al. [35], using three thermal bands and a straight line curve, reduced the error to within $1^{\circ}K$.

Because this method is highly accurate for water surface temperature determinations, we can—by making the necessary atmospheric corrections using a significant water body in the field of view—make land-surface temperature measurements to a better level of accuracy than previously attained.

The bands recommended in this report are: 10.3-11.3 μm, 11.3-12.0 μm, and 12.0-12.9 μm. These bands avoid the strong ozone and water-vapor absorption regions.

The band from 8.3-9.4 μm, essential for geologic applications, could be used as a third thermal band in place of the 12.0-12.9 μm band. The ozone absorption on the longer wavelength side of the 8.3-9.4 μm band, however, causes considerable variation in transmission with time and location.

To determine the relative importance of each candidate spectral band, we asked ERIM, ERTS and EREP investigators to identify what they considered to be the relative importance of

35. Prabhakara, C., B. J. Conrath, and V. G. Kunde, Estimation of Sea Surface Temperature from Remote Measurements in the 11-13 μm Window Region, Goddard Space Flight Center Report No. X-651-72-358, 1972.

36. Anding, D. and R. Kauth, Estimation of Sea Surface Temperature from Space, Remote Sensing of the Environment, Vol. I, No. 4, New York, 1970, pp. 217-20.

each band for each application. It was assumed that each of the bands requested for each application is important. (Though, as is well known, not all of the bands are of equal importance.) The most important bands were defined as those without which the application demonstration could not be successful. In some cases, of course, they truly determine whether or not the demonstration for a particular application can in fact be carried out at all. These bands, all deemed absolutely necessary, were given a priority rating of 1.

Occupying the next level on the priority scale are those bands which are very necessary. These were defined as not having the GO/NO-GO status of the Priority 1 bands but nonetheless essential in contributing a great deal of needed information either by themselves or as further verification of information obtained by the Priority 1 bands. These bands have a priority rating of 2.

Included in the third set of bands are those which yield very helpful information—again usually used to complement the information from the higher-priority bands. This set carries a priority rating of 3.

The least important bands are those with a priority rating of 4. These bands, as secondary discriminators of information, either serve in retrieving backup information or provide information which is of secondary importance for a particular application.

Table 4 names, by application number, the SEOS tasks requiring each band and shows the priority accorded each band. The table, a modified histogram, lists the bands along the abscissa and gives, along the ordinate, the number of applications requiring each band. Within the axes, application numbers from Table 2 appear. If for a particular band application, the priority rating is 1, the application number stands alone. If the priority rating is 2, the application number is marked with a single asterisk. If the priority rating is 3, two asterisks are set next to the application number. Three asterisks denote priority 4—the lowest.

Some conclusions can be drawn from this table. Five bands, including two visible bands and three longer wavelength thermal bands, were chosen for almost all applications. It also should be pointed out that the respondents felt band VII is mandatory for more than two-thirds of the applications. Bands X, XII, XIV and XV were least-requested among all the visible and IR bands. And of these four, bands XIV and XV have priority 1 for applications 13, 15, and 18. The blue and blue-green bands (bands I-III) are frequently requested; however, atmospheric conditions may strongly prohibit their incorporation. The importance of the microwave choices may insure usage, despite some associated engineering difficulty.

TABLE 4. BANDS AND PRIORITIES FOR SEOS APPLICATIONS

WAVELENGTH Bands (μm)

NUMBER OF SEOS APPLICATIONS REQUESTING EACH BAND	I (0.42-0.46)	II (0.45-0.50)	III (0.47-0.52)	IV (0.53-0.57)	V (0.56-0.60)	VI (0.60-0.65)	VII (0.65-0.69)	VIII (0.70-0.73)	IX (0.78-0.82)	X (0.85-0.89)	XI (0.89-0.95)	XII (0.95-1.10)	XIII (2.05-2.35)	XIV (3.6-4.1)	XV (8.3-9.4)	XVI (10.3-11.3)	XVII (11.3-12.0)	XVIII (12.0-12.9)	XIX to XXI (Misc.)
1	2	17	12	1	1	1	1	1	10	13*	13	13*	13	15	13	2	2	2	19
2	6	5*	14	2	2	2	2	3	18	18*	16	18*	16		18	4	4	4	
3	14	13**	17	6	7	5	4	5	20		18		17			6	6	6	microwave (1cm)
4	17	18**	1*	7	12	6	5	7	8*		17*		18			7	7	7	
5	13**		2*	12	13	7	6	11	9*				3*			13	14	13	
6	18**		6*	14	18	13	7	2*	15*				7*			14	15	14	2
7			7*	16	5*	14	8	6*	19*				10*			15	18	15	6
8			4**	9*	6*		9	14*	13**				11*			18	12*	18	7*
9			13**	13*	14*		10	13**					20*			12*	13*	12*	
10			18**	15*	4**		12	18**					8**			3**	3**	3**	microwave (30cm)
11				17*			14						9**			11**	11**	11**	
12				18*			16						19***			16**	16**	16**	
13				20**			18									17**	17**	17**	7*
14				8***			20									20**	20**	20**	19**
15				11***			13*									19***	19***	19***	radar (10cm)
16							15*												
17							17*												
18							19*												

The numbers within the axes are the SEOS application numbers. Those with no asterisk are 1st Priority for that application. Those with one asterisk are of 2nd priority, etc.

4
OBSERVATION SITES

For each application various specified locations in the Western Hemisphere will be used to verify the SEOS feasibility. These locations, called Demonstration Sites, are relatively small areas in which adequate ground truth is usually provided; they are also chosen to verify certain observational limitations such as time of day and day of year.

Once SEOS has proven its capability and effectiveness, an operational system is in order. The coverage requirements of such a system, may, of course, differ significantly from those of the demonstration system. Accordingly, the temporal and spatial coverage requirements for operational systems must be called out at this time.

The following subsections define the area coverage, frequency, and time of observation for both the demonstration model and the operational mode of SEOS.

4.1 DEMONSTRATION SITES AND OBSERVATION REQUIREMENTS

The location of each of the demonstration sites along with its respective observation times is given in Table 5 as well as in the Application Summaries collectively included as an appendix to this report.

Figure 6 shows the demonstration site locations. Each site is identified by its application number.

Figures 7 through 19 display, by location, the required observation times. Each figure covers a specific local solar time of day ranging from 0400 to 2000 hours. Remember that a specified time —say 0900 —represents many different true times because each figure covers several time zones.

On each figure, the observation requirements are labeled next to the sites. The month or months of observation are abbreviated. If more than two consecutive months are called for, they are indicated. The name of a month indicates that observation is desirable in the time slot from the middle of the immediately previous month to the middle of the named month (i.e., "May" indicates observation from 16 April through 15 May). More precise information is called out in the Application Descriptions in an appendix to this report. If no month is indicated, observation is assumed to be necessary all year.

To specify particular days of the month, an Arabic numeral is used following the month indicator. If the observation requirements are weekly, semi-weekly, or every two days, the symbols used are w, w/2, or w/4 respectively; for monthly, we use (m), and for semi-monthly (m/2). Again, if no Arabic numeral or symbol is used, observations are assumed to be daily.

TABLE 5. LOCATIONS AND OBSERVATIONAL REQUIREMENTS FOR THE DEMONSTRATION SITES

SEOS Application	Location(s)	Observational Requirements
1.	Western Lake Erie Chesapeake Bay Northern Gulf of Mexico-Mississippi Delta	Daily at noon; also 0900 and 1500 hr on 15th of each month
2.	Delaware Bay San Francisco Bay System Galveston Bay	Three obs./hr for one hr centered at high-, low- and mid-tide. Obs. are to take place during spring, neap, and mid-amplitude tide as well as high-, low- and mid-river flow. Two to three such sets to be obtained at each site.
3.	Sierra Nevada, California Thunder Creek, Wash and Ore.	0400, 1200, 1500, 1700 on 1st and 15th of month from Oct. through March, and every 4th day in April, May and June
4.	Fuego Aqua Pocaya Izalco San Cristobal Cerro Negro Telica	0400 and 0800 on 15th of each month; in addition, 1/week if active
5.	Lake Erie Tampa Bay	Solar noon daily; also 0900 and 1500 if algae bloom occurs
6.	Mississippi Sound and offshore waters Northern Gulf of Calif.	Solar noon daily plus 0600, 0900, 1500; also 1800 during the local fishing season (15 April-30 Sept. for these sites)
7.	Northern Gulf of Mexico	0900, 1200, 1500 daily
8.	Grand Teton Nat. Park Umatilla Nat. Park	Solar noon, 1/wk in June, July, Aug. Solar noon, 1/wk in June, July, Aug.
9.	Ottawa Nat. Forest Manistee Nat. Forest	Solar noon, 1/wk from mid-Sept to mid-Nov.
10.	Tucson, Ariz. Weslaco, Texas Pawnee Co., Colo Cottonwood, S.D.	Solar noon every other day: April to Aug., Sept. noon every other day: 15 March to 15 May noon every other day: 15 April to 15 June noon every other day: 15 April to 15 June
11.	Columbia River Basin, Wash. Glenn and Butte Co., Calif. Maricopa Co., Ariz. Holt Co., Nebraska	0400, 1200, 1500, 1/week, May thru Aug.
12.	Mississippi River Houston Ship Channel Northern Gulf of Mexico	Solar noon daily; but 1/hr if oil spill occurs
13.	White Sands, New Mex.	0530, 0800, 1300, 1930 on 15th of Feb., May, Aug., and Nov.

TABLE 5. LOCATIONS AND OBSERVATIONAL REQUIREMENTS FOR THE DEMONSTRATION SITES (Concluded)

SEOS Application	Locations(s)	Observational Requirements
14.	Western Basin of L. Erie Southern Lake Michigan	Solar noon daily, April through Nov.
15.	NW U.S. (Wash, Ore, Idaho and W. Mont.) Southern Calif.	If fire occurs: 0400, 1200, 2000 from 1 June to 1 Nov. 0400, 1200, 2000 from 1 May to 1 Aug.
16.	Mississippi R. and major tributaries Cent. Calif and Bay Area L. Erie Shore of Mich and Ohio L. Mich. shore from L. St. Claire to Saginaw Bay Atlantic coast of Georgia, N. and S. Carolina Entire Florida Coast Ala., Miss., La, and Tex. coasts.	At least once per day if flooding occurs
17.	Same as Appl. 16, plus all Great Lakes Basins and U.S. Coastal Shores	At least 1/day if flooding occurs
18.	College Station, Texas Lafayette, Indiana Lansing, Michigan Maricopa Co., Arizona Central Atlantic Regional Ecological Test Site	0400, 0900, 1200, 1500, 1800 on the 15th of Jan., March, June, and Oct.
19.	Lamb Co., Texas Griggs Co., N.D.	Solar noon, 1/week from June through Aug.
20.	Saskatoon, Saskatchewan, Can. Whitman Co., Wash. Burke Co., N.D. Hill Co., Montana Garden City, Kansas	Solar noon every other day from: 15 June - 1 Aug. 15 April - 15 July 15 June - 1 Aug. 1 May - 1 Aug. 15 April - 1 June

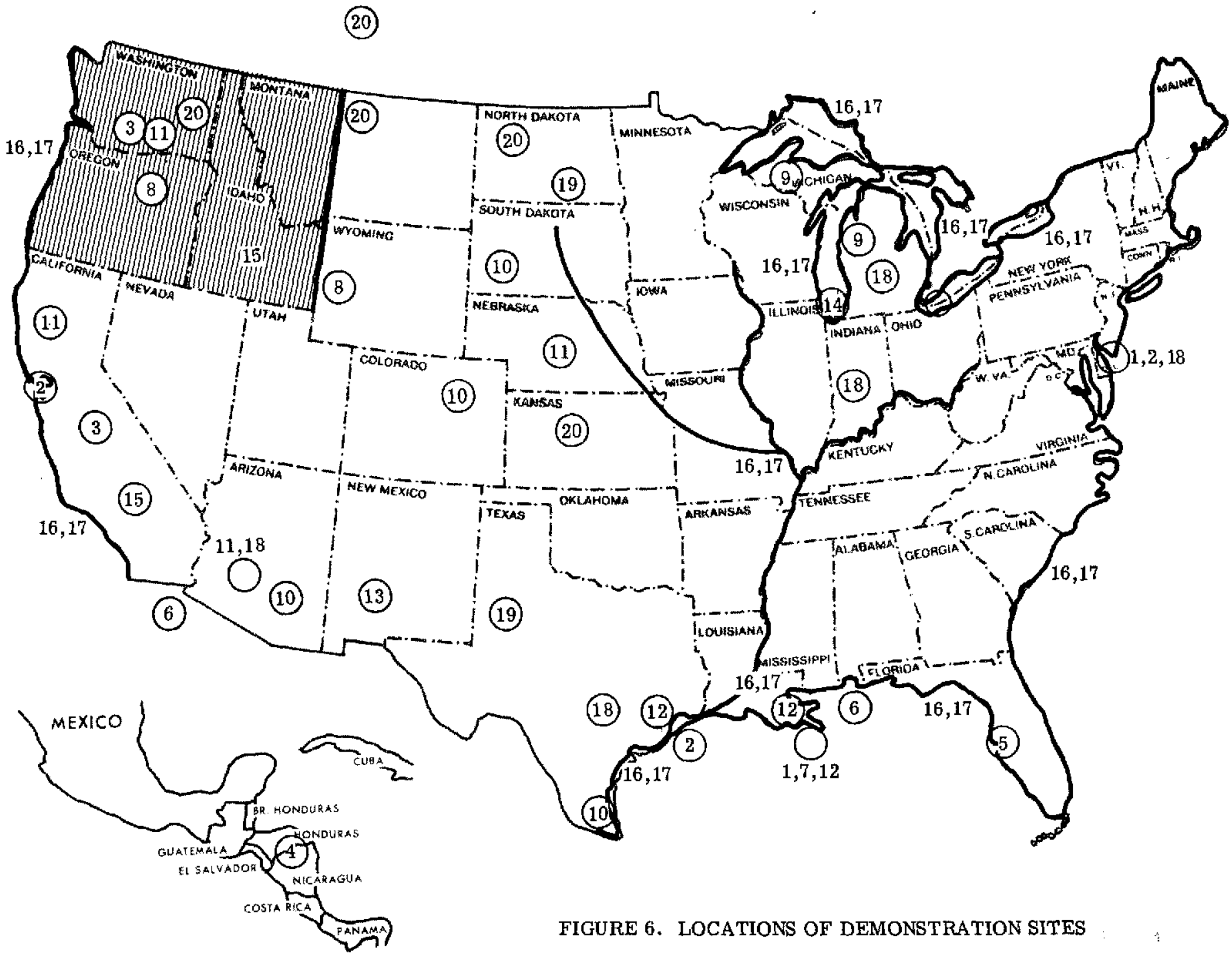

FIGURE 6. LOCATIONS OF DEMONSTRATION SITES

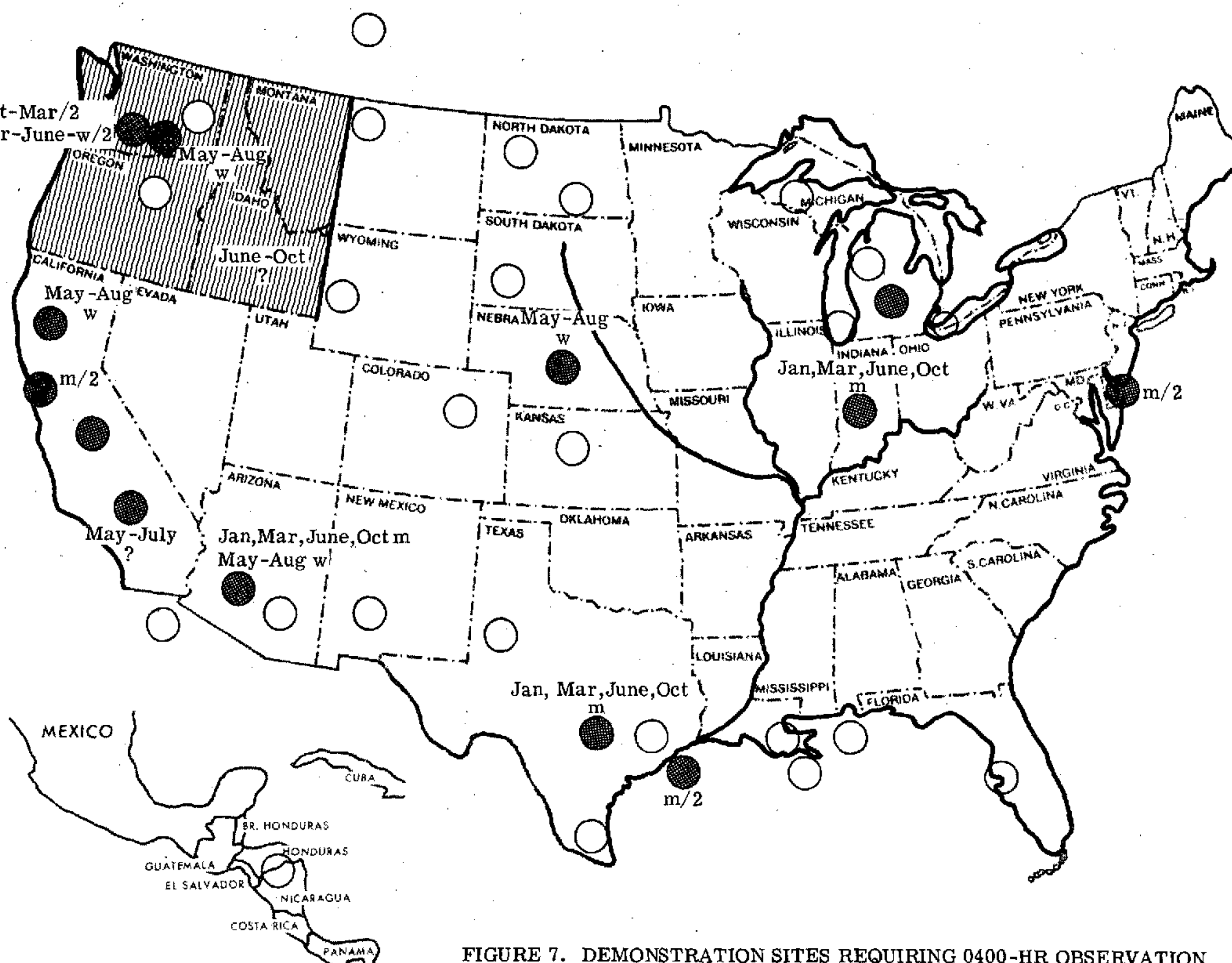

FIGURE 7. DEMONSTRATION SITES REQUIRING 0400-HR OBSERVATION
(indicated by cross-hatching of sites)

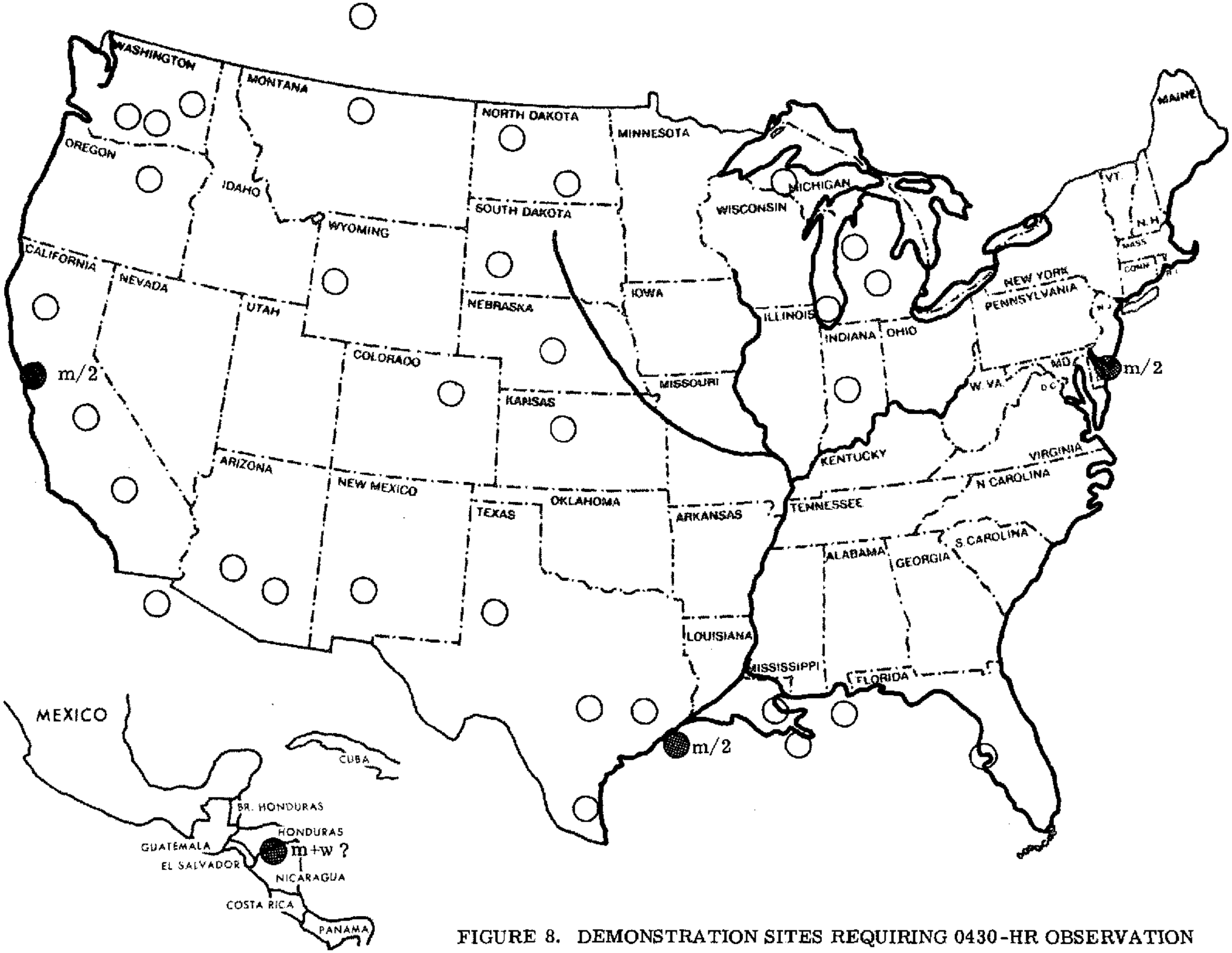

FIGURE 8. DEMONSTRATION SITES REQUIRING 0430-HR OBSERVATION
(indicated by cross-hatching of sites)

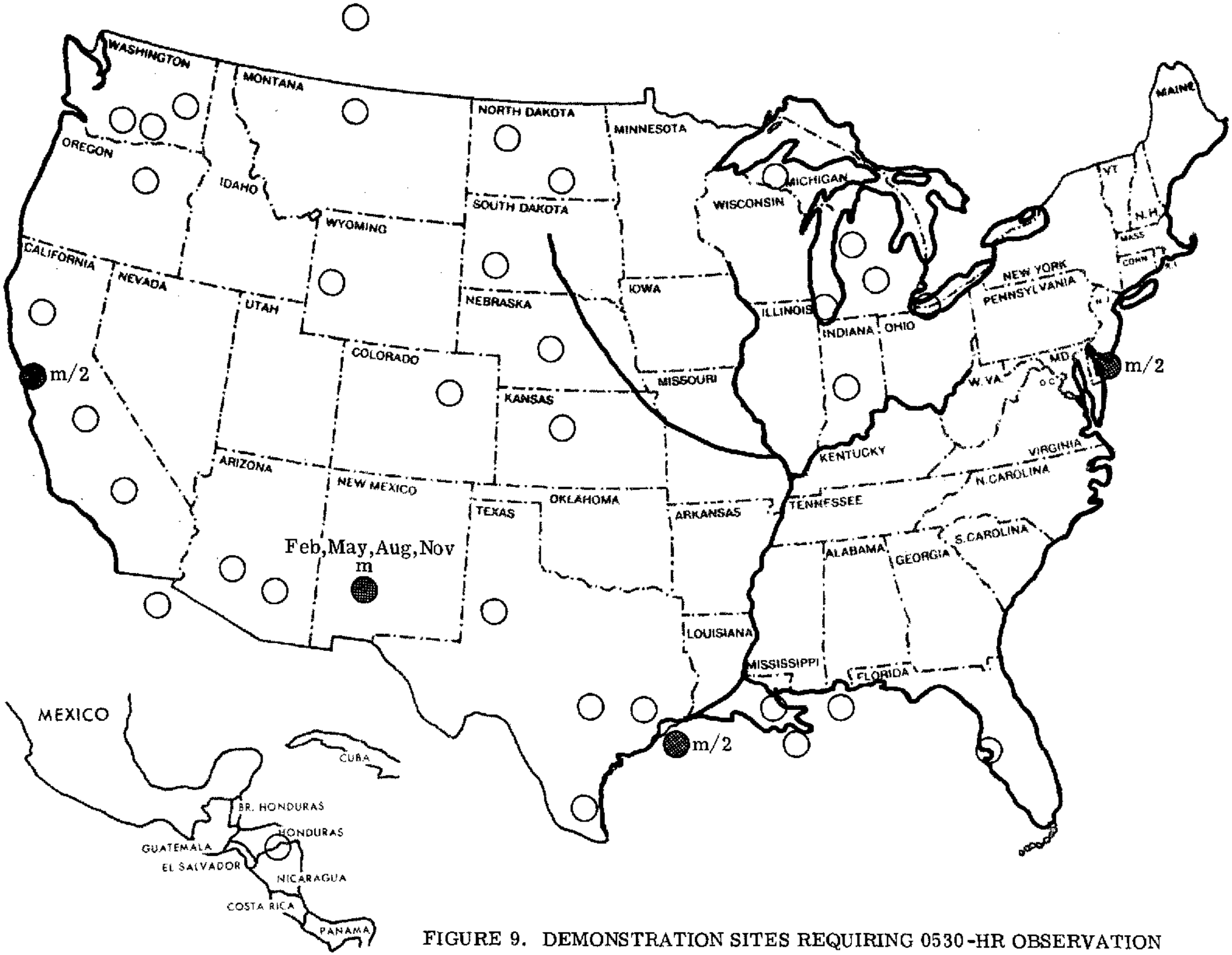

FIGURE 9. DEMONSTRATION SITES REQUIRING 0530-HR OBSERVATION
(indicated by cross-hatching of sites)

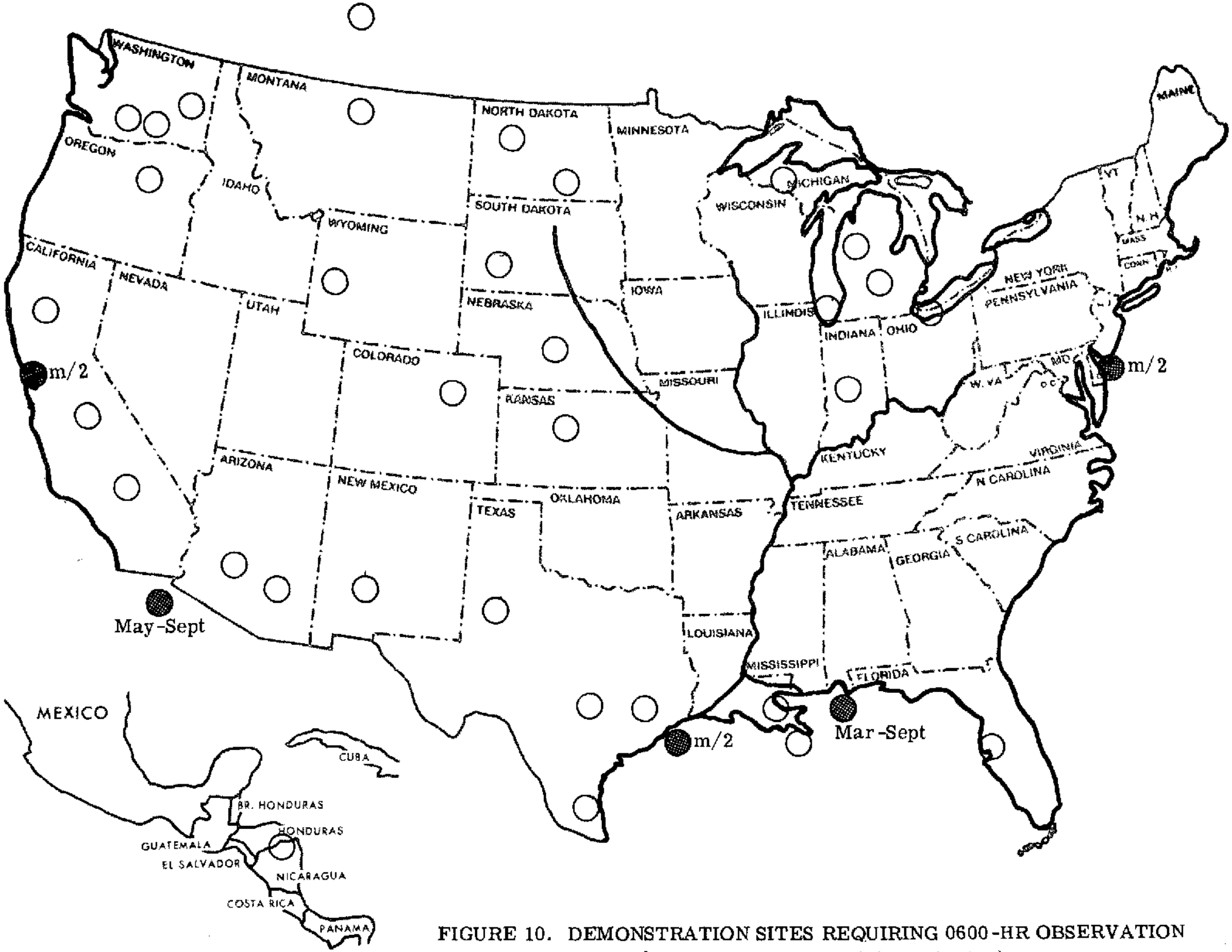

FIGURE 10. DEMONSTRATION SITES REQUIRING 0600-HR OBSERVATION
(indicated by cross-hatching of sites)

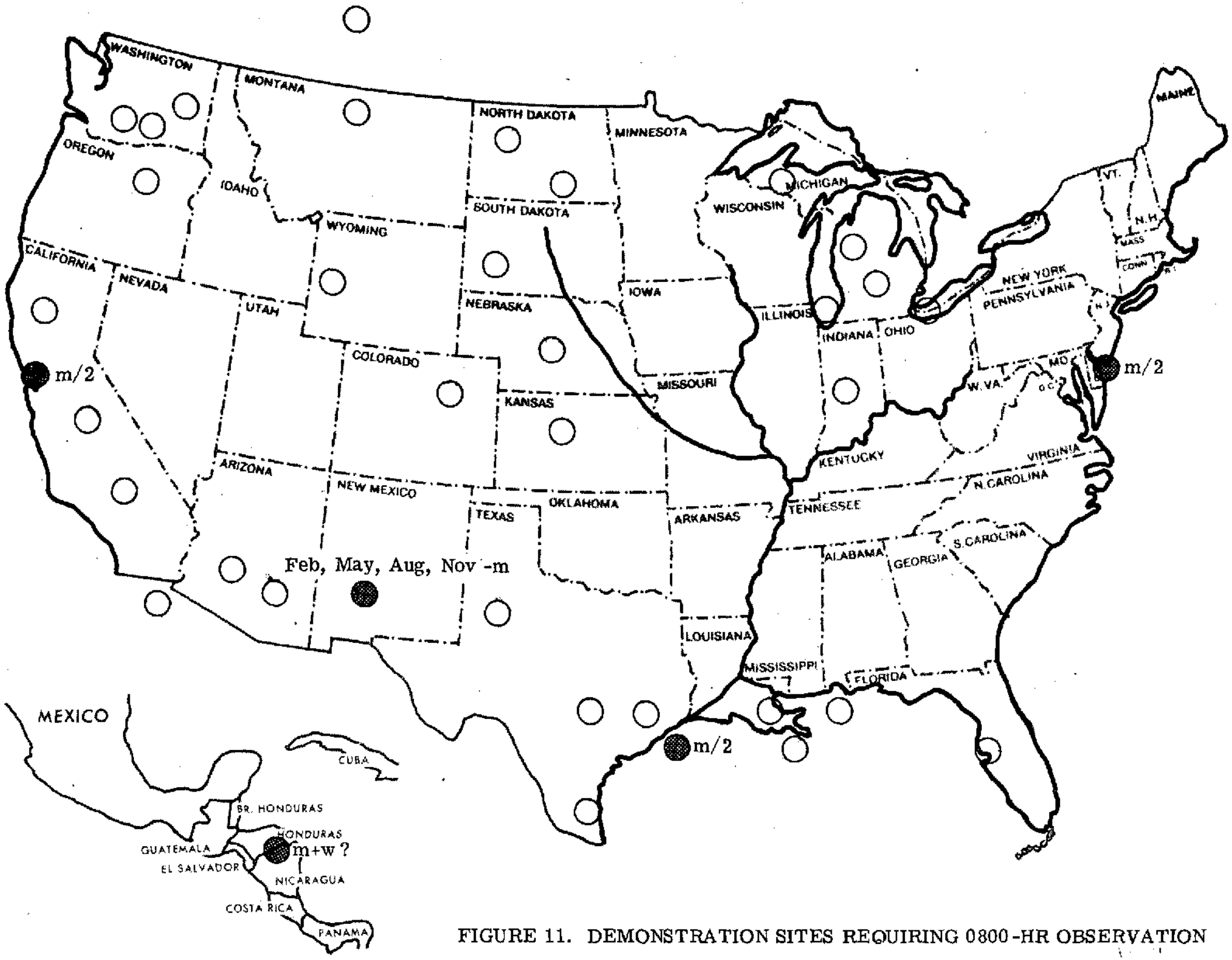

FIGURE 11. DEMONSTRATION SITES REQUIRING 0800-HR OBSERVATION

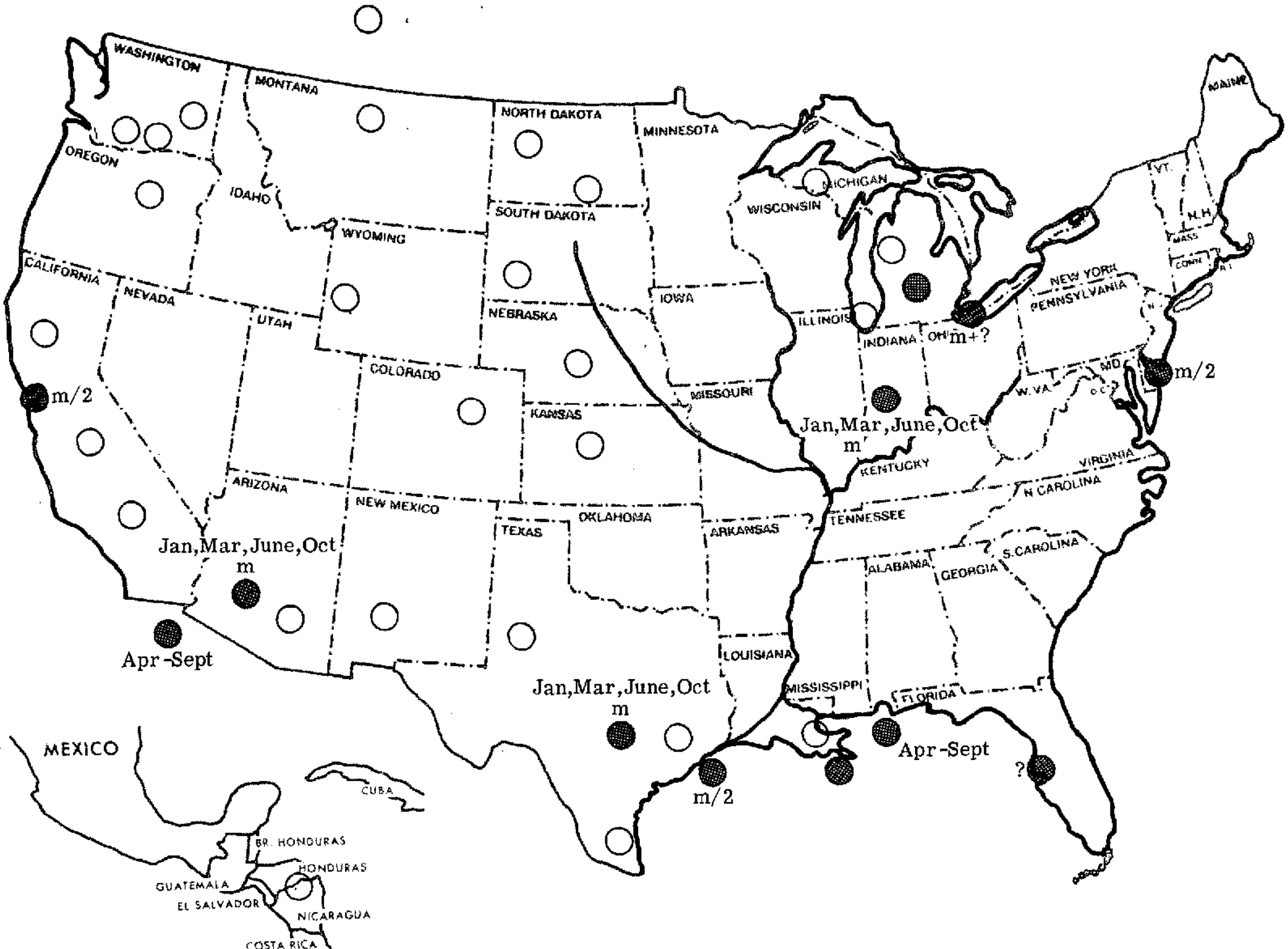

FIGURE 12. DEMONSTRATION SITES REQUIRING 0900-HR OBSERVATION

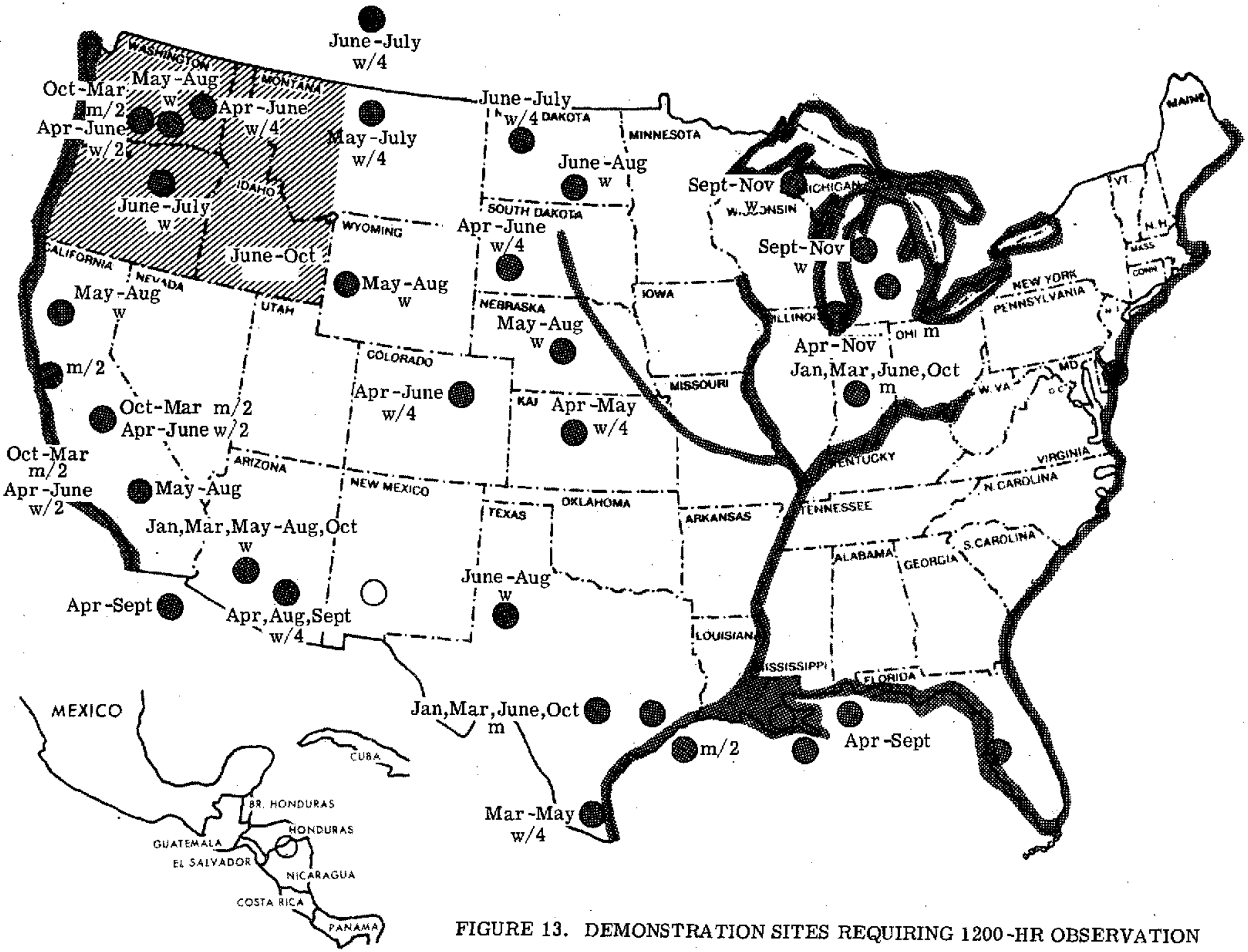

FIGURE 13. DEMONSTRATION SITES REQUIRING 1200-HR OBSERVATION

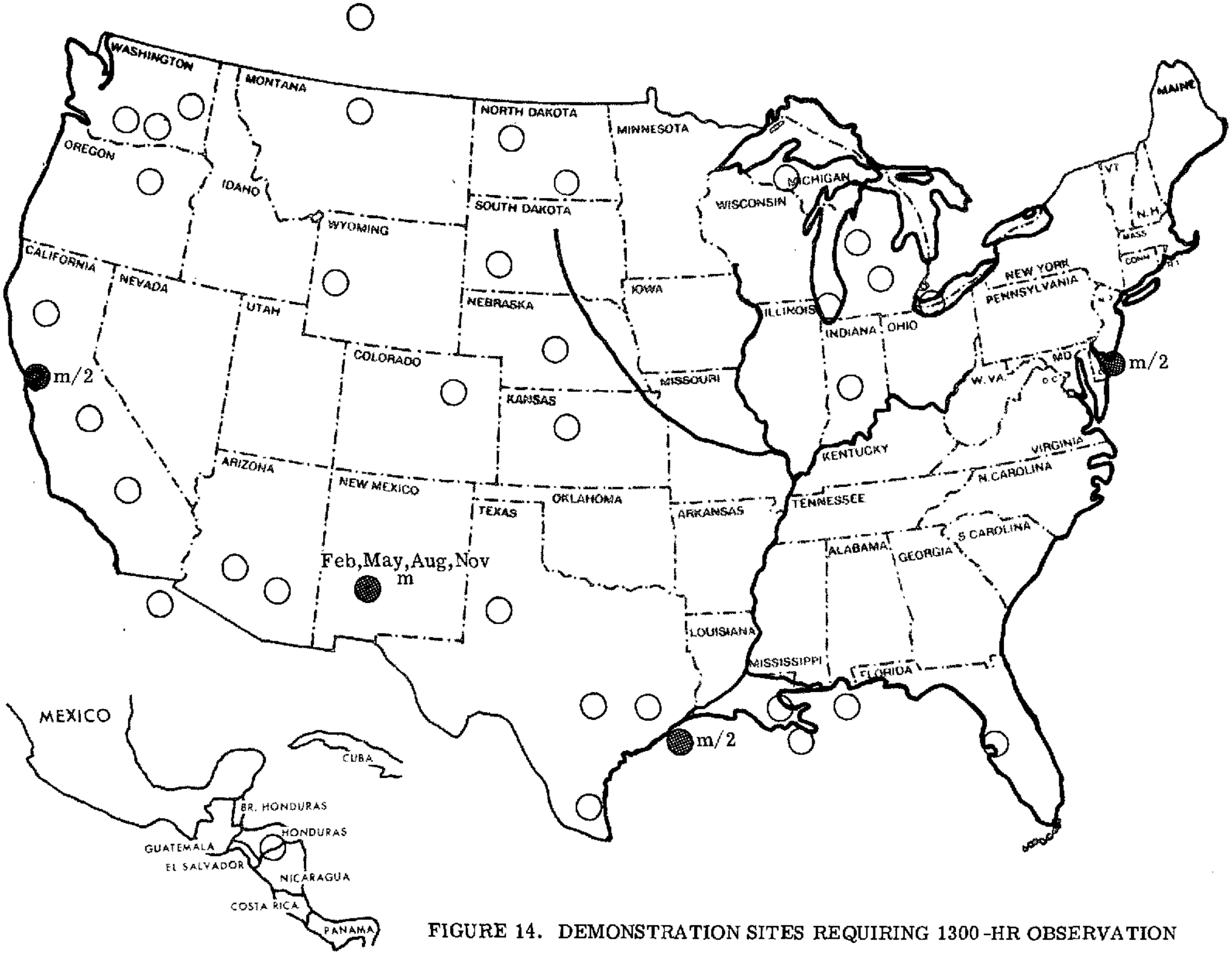

FIGURE 14. DEMONSTRATION SITES REQUIRING 1300-HR OBSERVATION

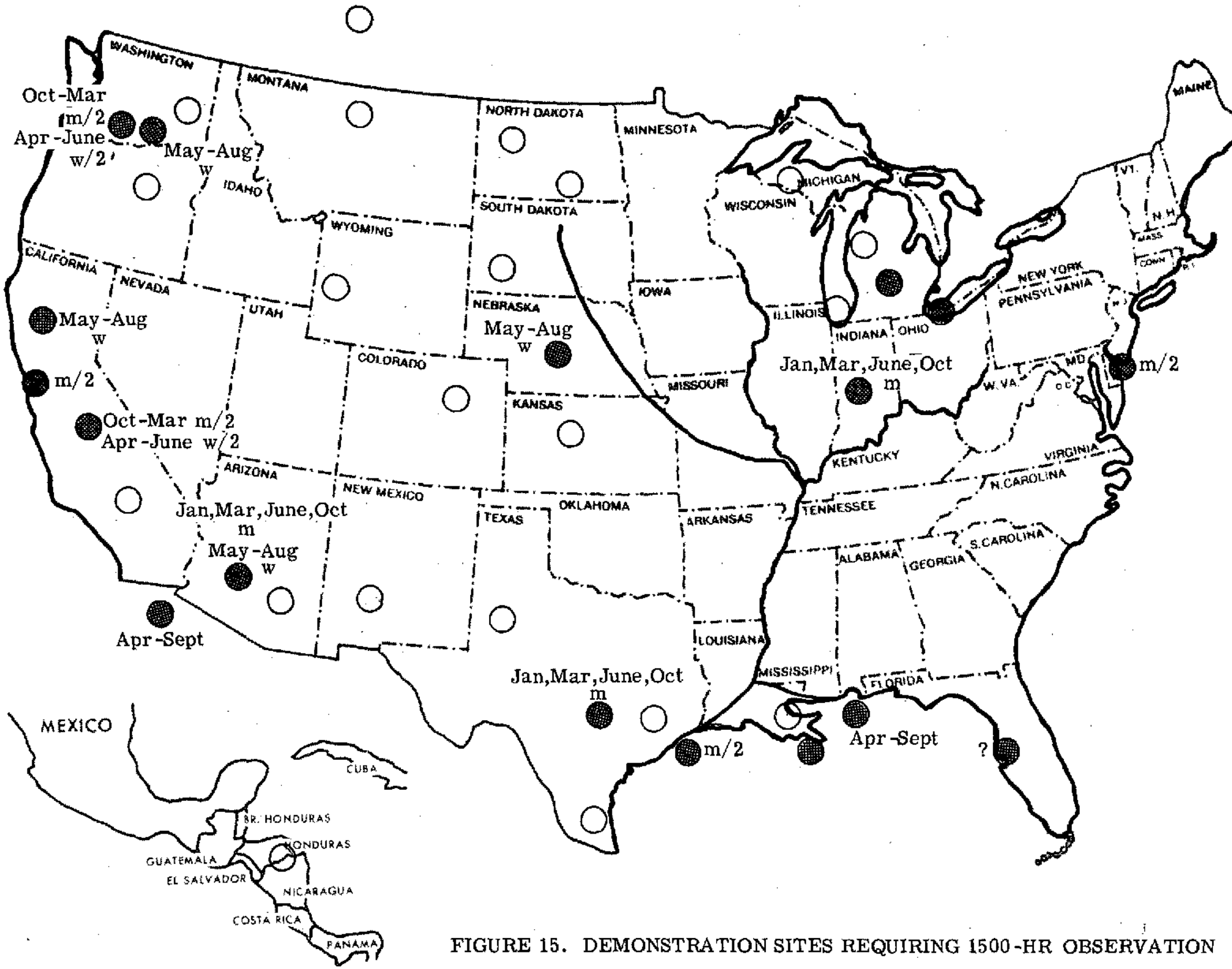

FIGURE 15. DEMONSTRATION SITES REQUIRING 1500-HR OBSERVATION

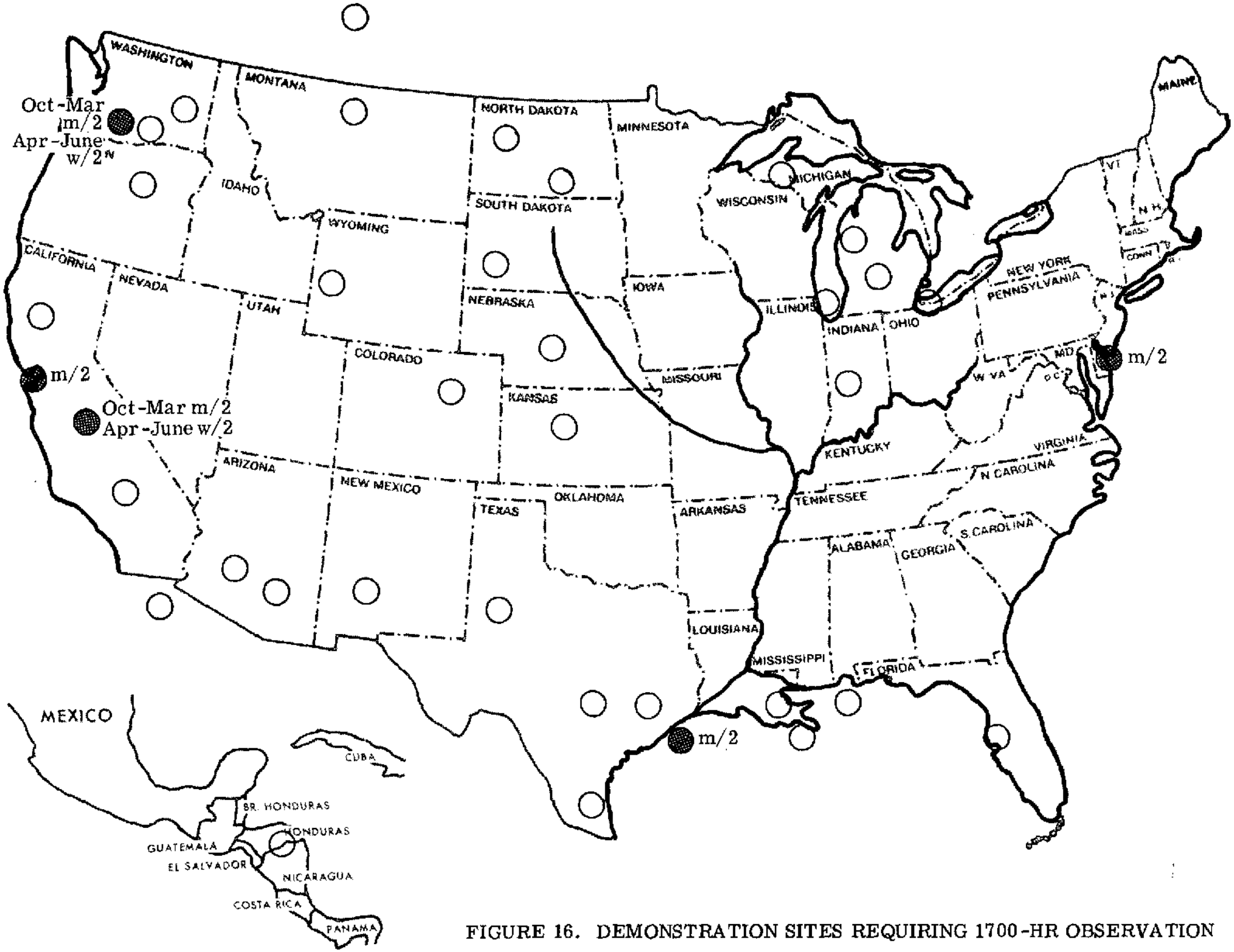

FIGURE 16. DEMONSTRATION SITES REQUIRING 1700-HR OBSERVATION

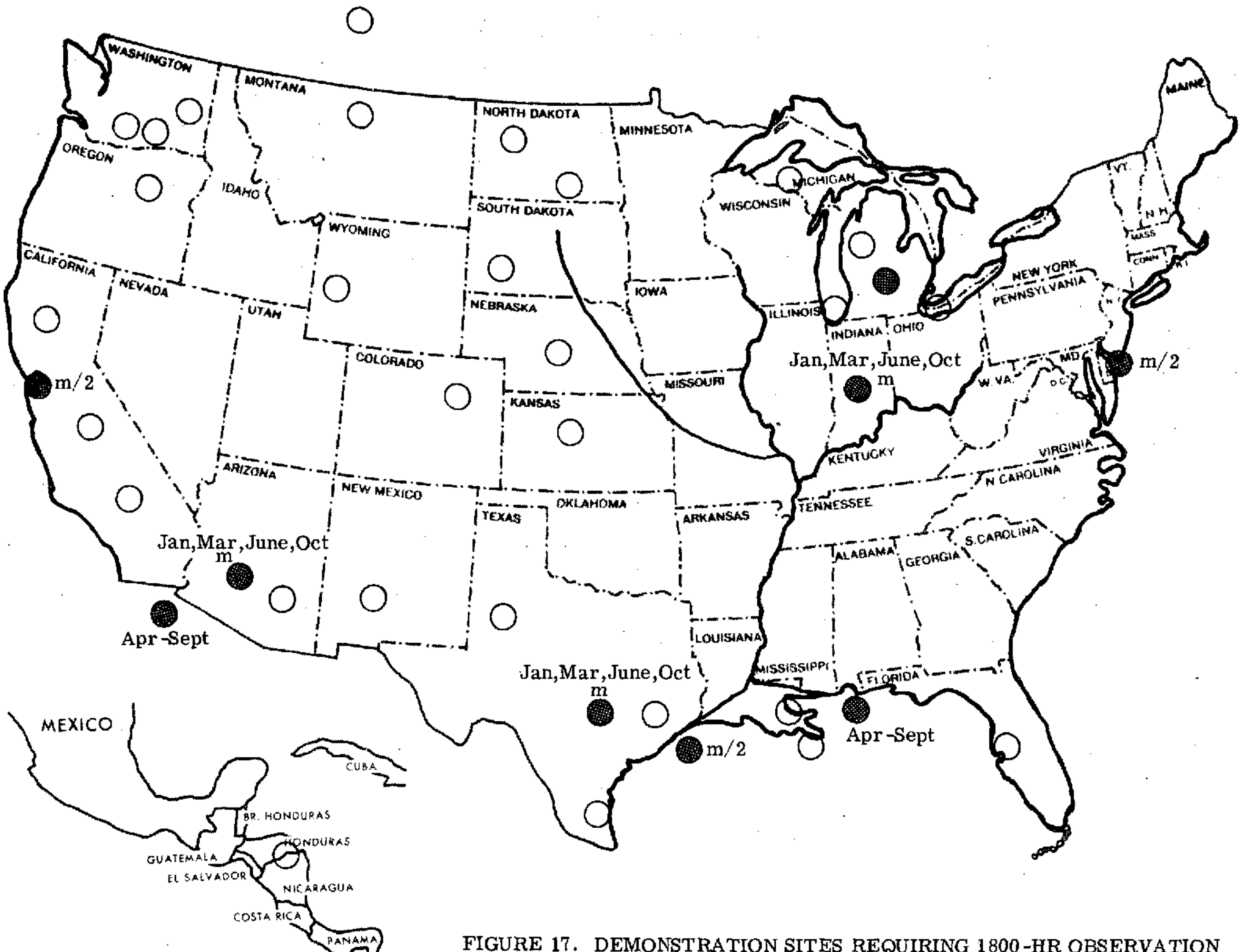

FIGURE 17. DEMONSTRATION SITES REQUIRING 1800-HR OBSERVATION

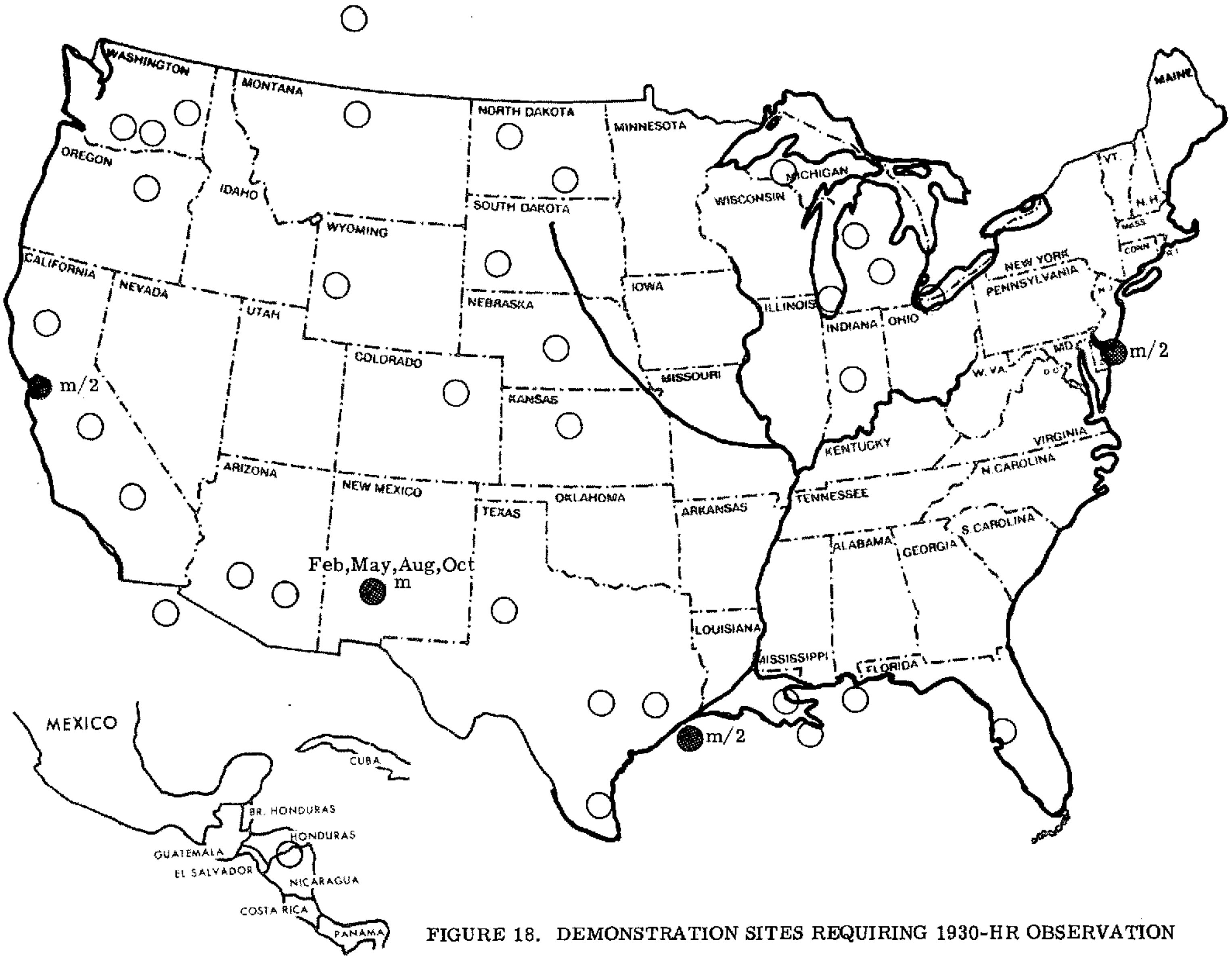

FIGURE 18. DEMONSTRATION SITES REQUIRING 1930-HR OBSERVATION

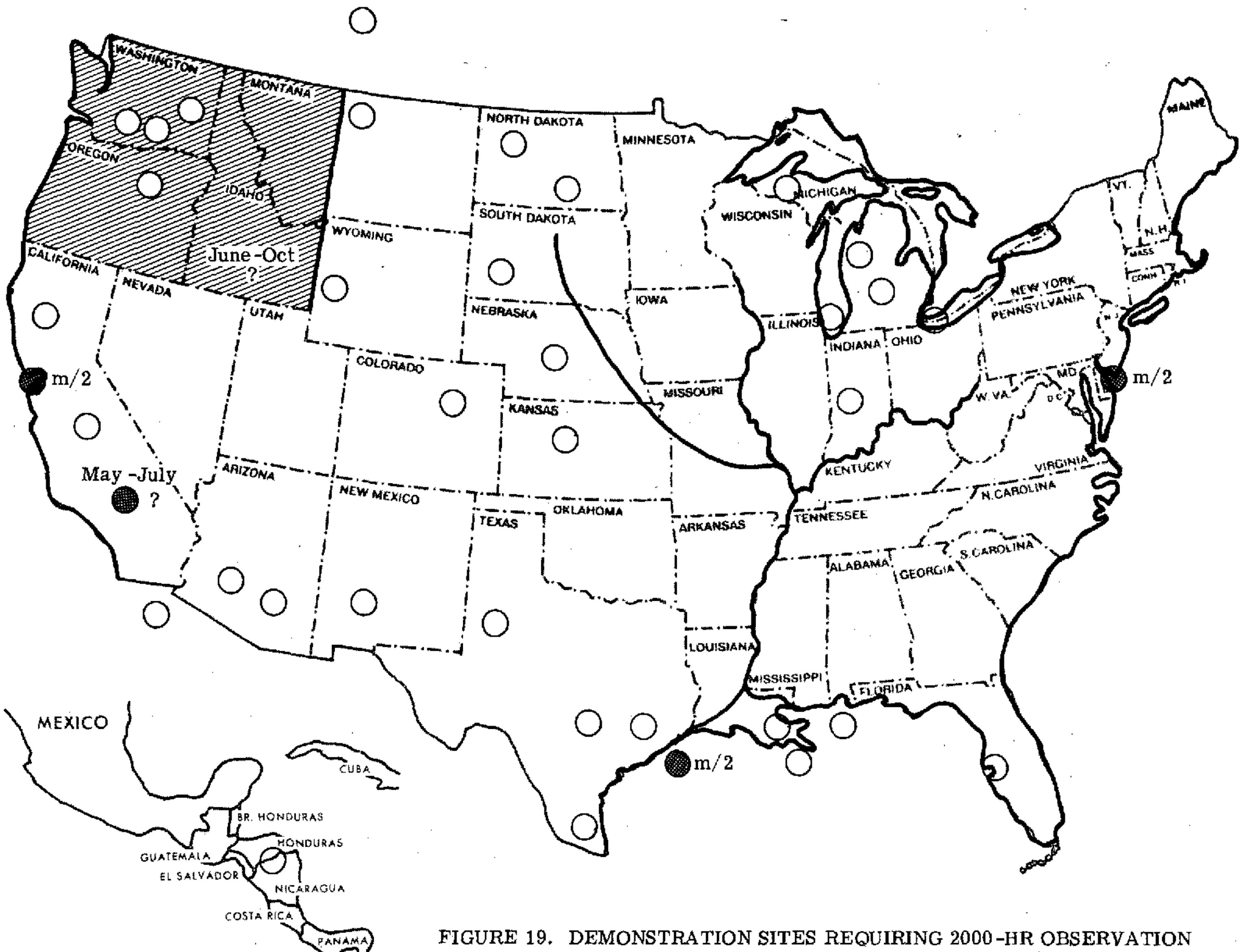

FIGURE 19. DEMONSTRATION SITES REQUIRING 2000-HR OBSERVATION

A question mark indicates that observations are to be made only if an unpredictable event (such as oil spill) occurs.

4.2 OPERATIONAL SITES

The Operational Sites are much larger in size than the Demonstration Sites, and cover a much greater fraction of the Western Hemisphere.

In most cases, the range of observation times is the same as that required for demonstration, but the frequency of coverage may differ. Where the requirements differ, the differences generally reflect the increase in site size and, therefore, enlarge the seasonal variance of the phenomena being observed.

Table 6 identifies the Operational Sites and gives the requirements for each of the applications being investigated. (These are further detailed in the Application Description appendix to this report.)

Figures 20 through 34 show the Operational Sites for each of the applications. The method of specifying data and frequency is the same as for the Demonstration Sites.

TABLE 6. LOCATION AND OBSERVATIONAL REQUIREMENTS FOR THE OPERATIONAL SITES

Application	Location	Observation Requirements
1.	All Oceanic and Major Lakes within SEOS range	Same as Demonstration Sites
2.	All Estuarine Systems within SEOS range	Same as Demonstration Sites
3.	Areas of significant Snow Cover in U.S. (N of 34 N)	Same as Demonstration Sites
4.		Same as Demonstration Sites
5.	All Water Areas within SEOS range	Same as Demonstration Sites
6.	All Oceanic Waters within SEOS range	Same as Demonstration Sites
7.	All Oceanic Waters within SEOS range	Same as Demonstration Sites
8.	Colorado, Wyoming, Montana, Idaho, Washington, Oregon, Calif., Minn., Mass., Conn., Maine	Same as Demonstration Sites
9.	Minn., Wisc., Mich., Penn., N.Y., Conn., N.H., Vt., Maine	Same as Demonstration Sites
10.	Eastern Half of N.M., Colo., Wy., Mont. Western Half of Okla., Kan., Neb., S.D., N.D., N. Texas, South Texas	See Application Summary Sheet No. 10 in Appen.
11.	Ariz., N.D., S.D., Neb., Kan., Okla., Tex.	Same as Demonstration Sites
12.	All Water Areas in SEOS range	Same as Demonstration Sites
13.	N.M., Tex., Ariz., Utah	Same as Demonstration Sites
14.	All Great Lakes and other large lakes in SEOS range	Same as Demonstration Sites
15.	U.S.	See Application Summary Sheet No. 15 in Appen.
16.	All Major River Basins and Coastal Areas in W. Hemisphere	Same as Demonstration Sites
17.	All Major River Basins and Coastal Areas in W. Hemisphere	Same as Demonstration Sites
18.	U.S.	Same as Demonstration Sites
19.	Central U.S.	Same as Demonstration Sites
20.	Crop Areas in West and Midwest U.S.	See Application Summary Sheet No. 20 in Appen.

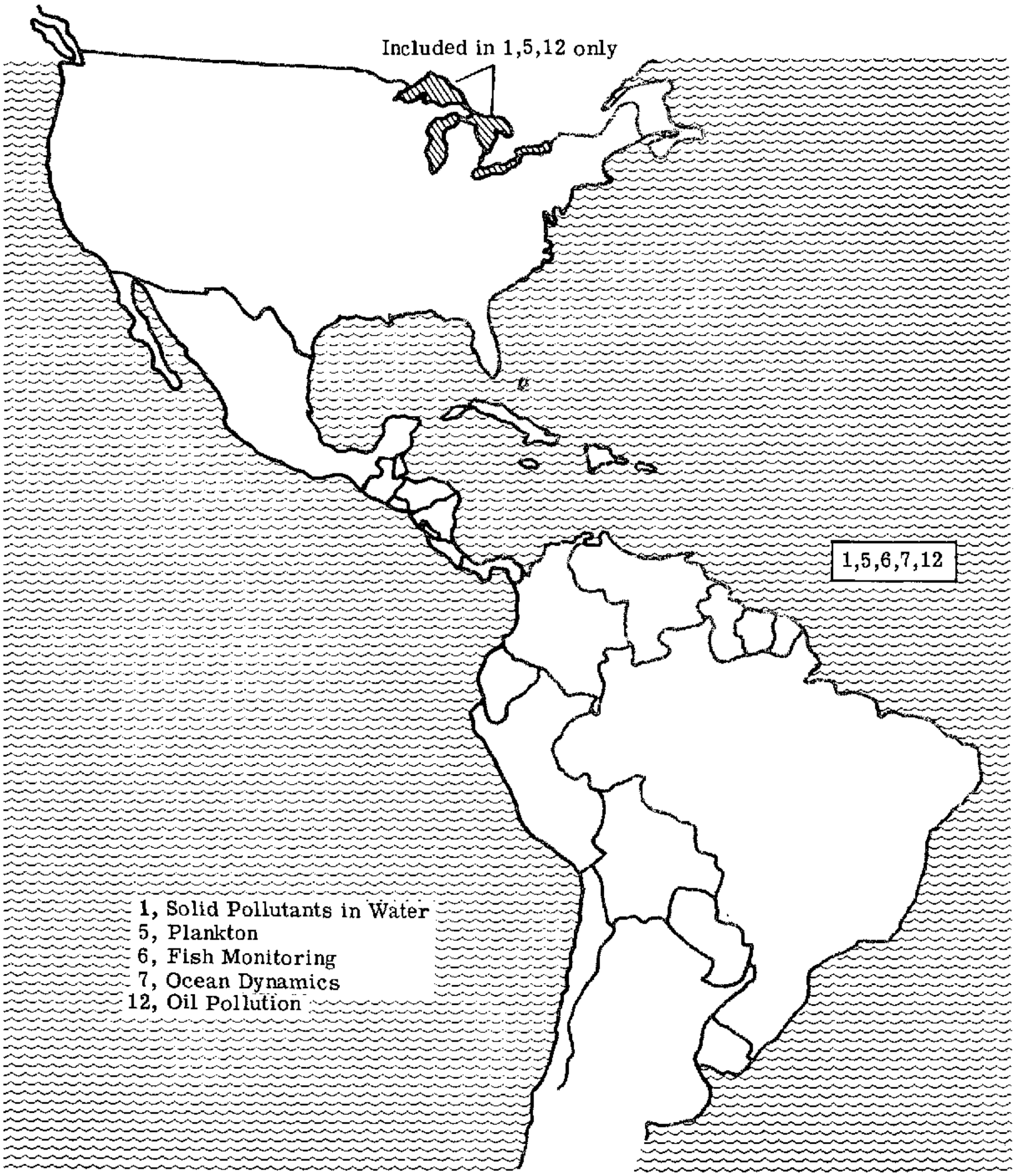

FIGURE 20. OPERATIONAL SITES FOR APPLICATIONS 1,5,6,7 AND 12

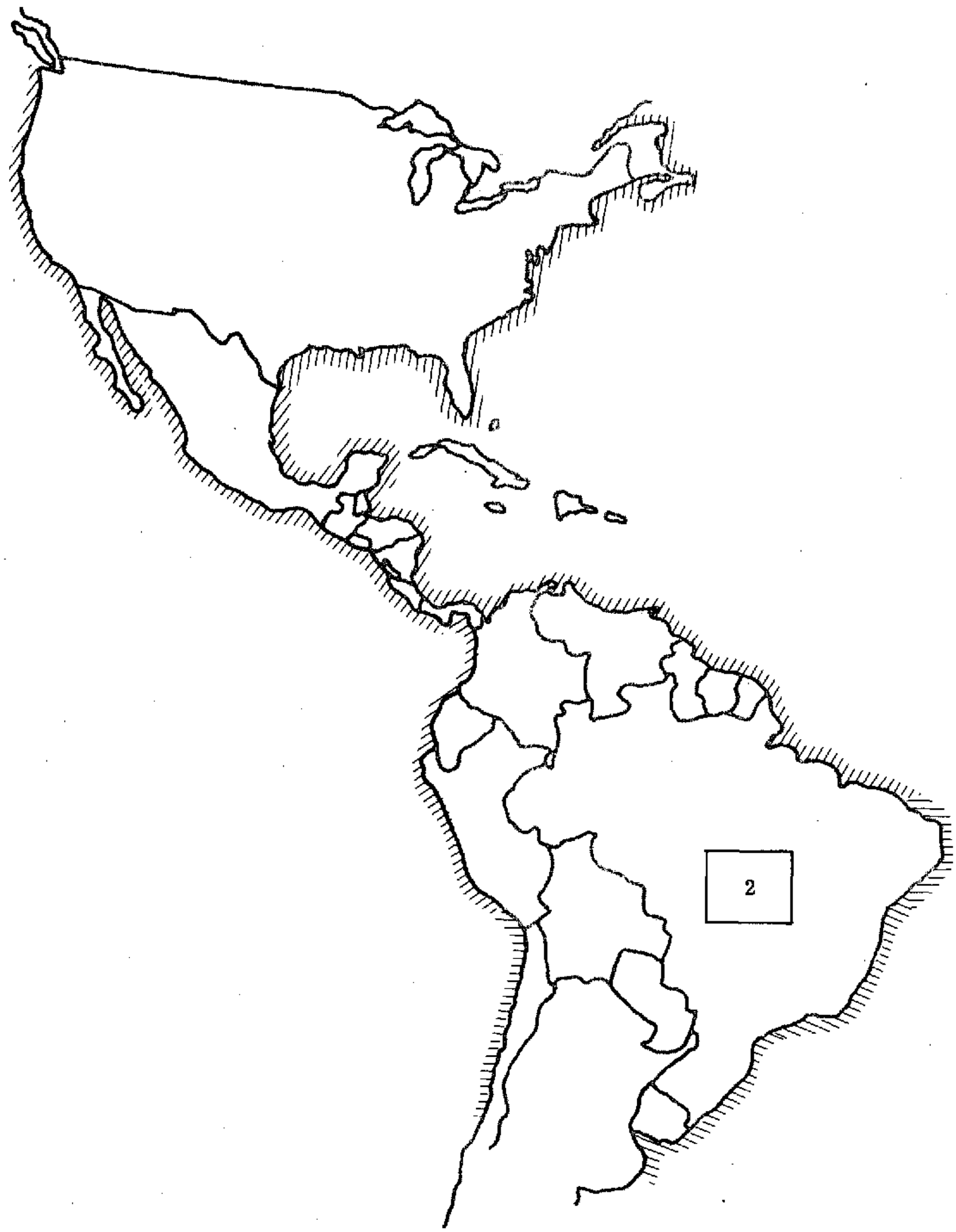

FIGURE 21. OPERATIONAL SITES FOR APPLICATION 2
Estuarine Dynamics

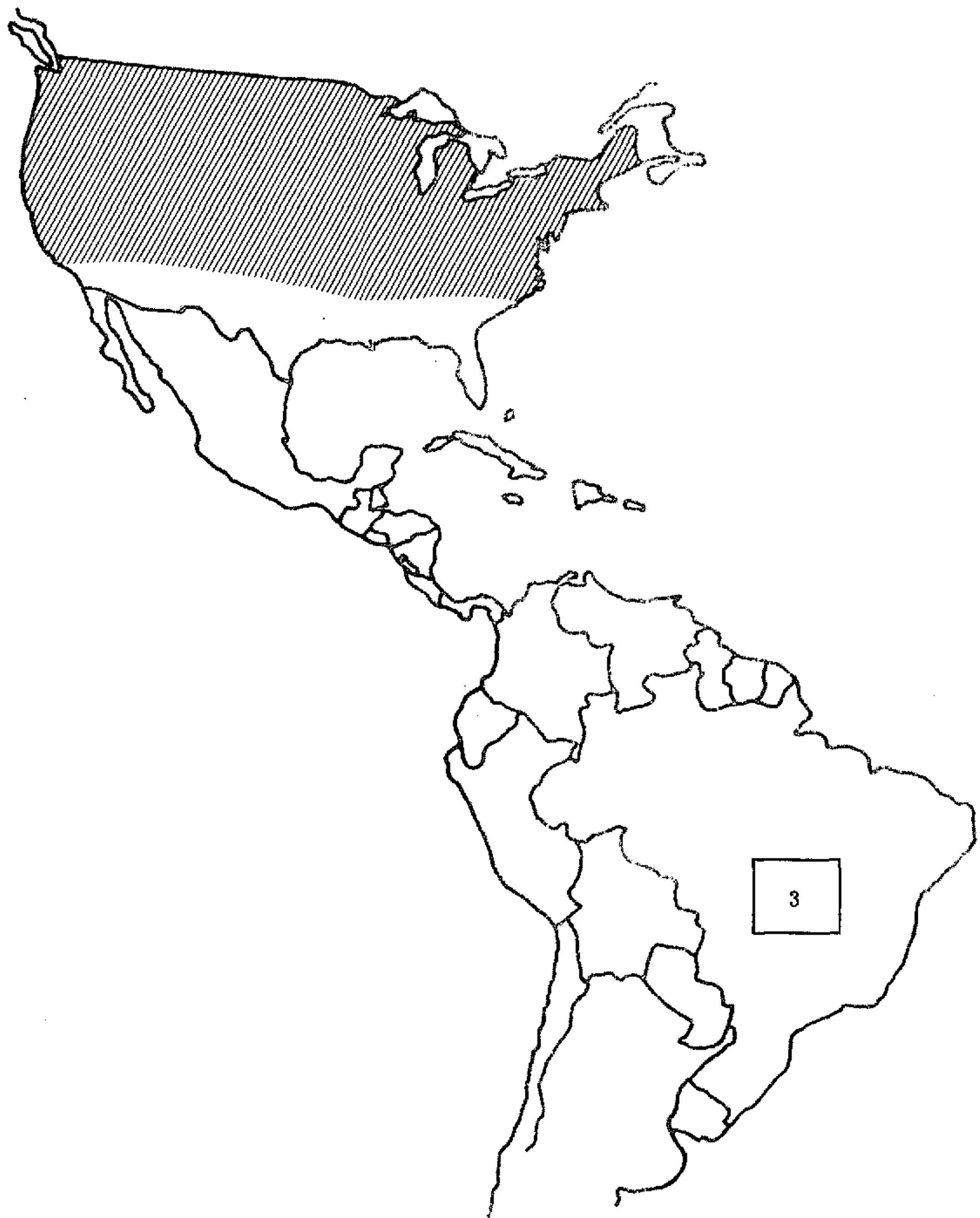

FIGURE 22. OPERATIONAL SITES FOR APPLICATION 3
Snow Cover

FIGURE 23. OPERATIONAL SITES FOR APPLICATION 4
Volcano Monitoring

FIGURE 24. OPERATIONAL SITES FOR APPLICATION 8
Forest Vigor Assessment

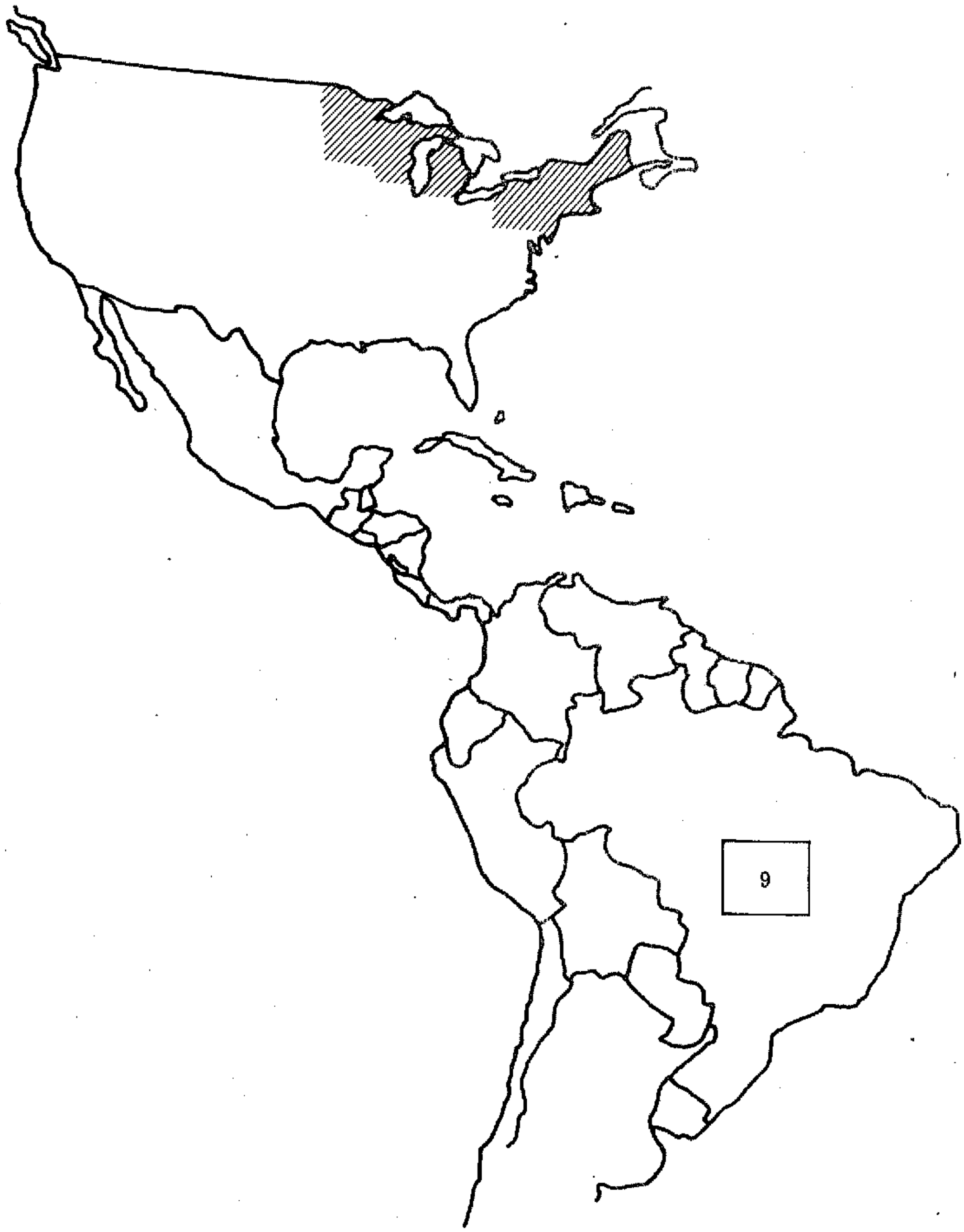

FIGURE 25. OPERATIONAL SITES FOR APPLICATION 9
Forest Inventory

FIGURE 26. OPERATIONAL SITES FOR APPLICATION 10
Range and Grazing Assessment

FIGURE 27. OPERATIONAL SITES FOR APPLICATION 11
Irrigation

FIGURE 28. OPERATIONAL SITES FOR APPLICATION 13
Lithologic Survey

FIGURE 29. OPERATIONAL SITES FOR APPLICATION 14
Lake Dynamics

FIGURE 30. OPERATIONAL SITES FOR APPLICATION 15
Wildfire Monitoring

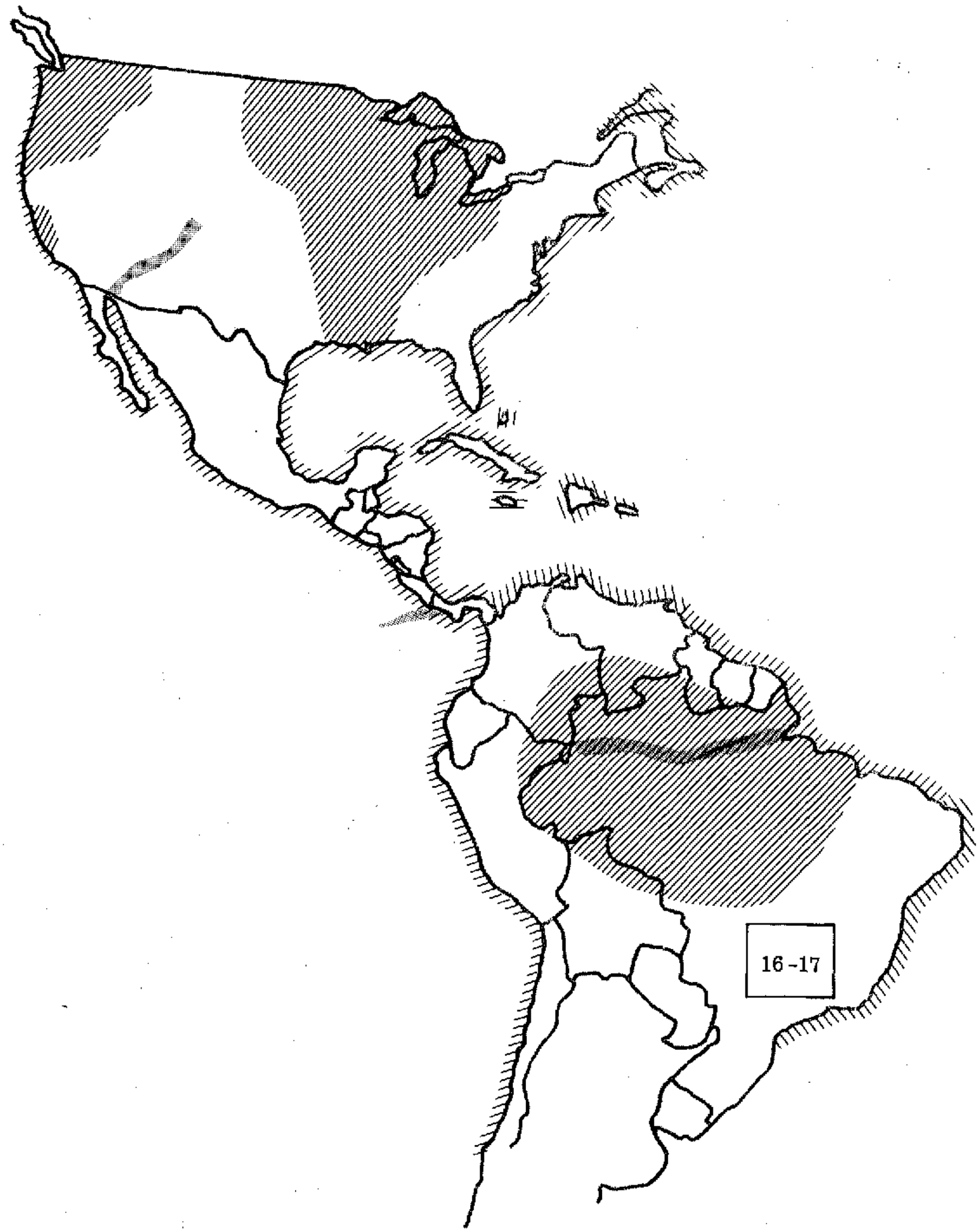

FIGURE 31. OPERATIONAL SITES FOR APPLICATIONS 16 AND 17
Flood Survey and Water Erosion

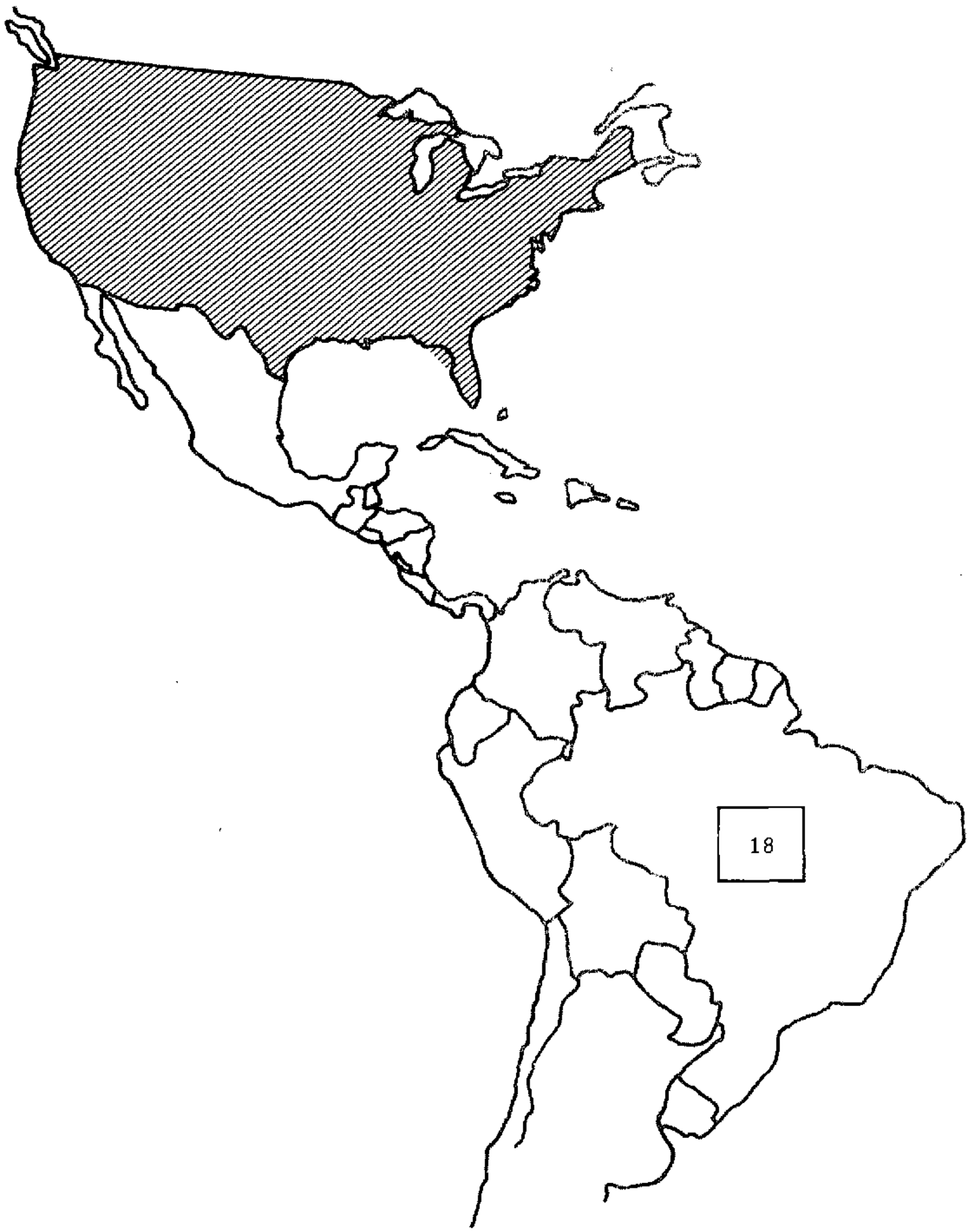

FIGURE 32. OPERATIONAL SITES FOR APPLICATION 18
Thematic Mapping

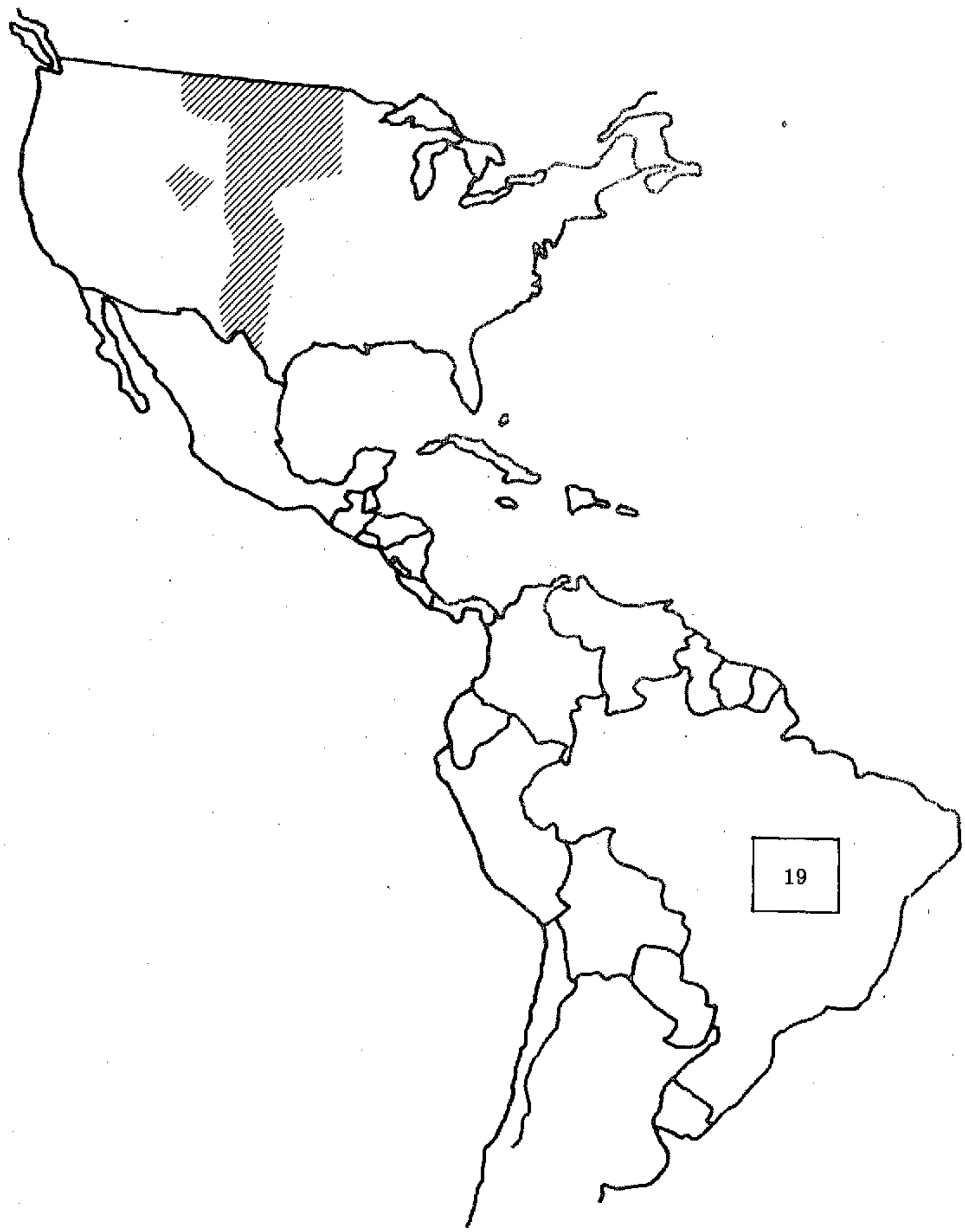

FIGURE 33. OPERATIONAL SITES FOR APPLICATION 19
Aeolian Soil Erosion

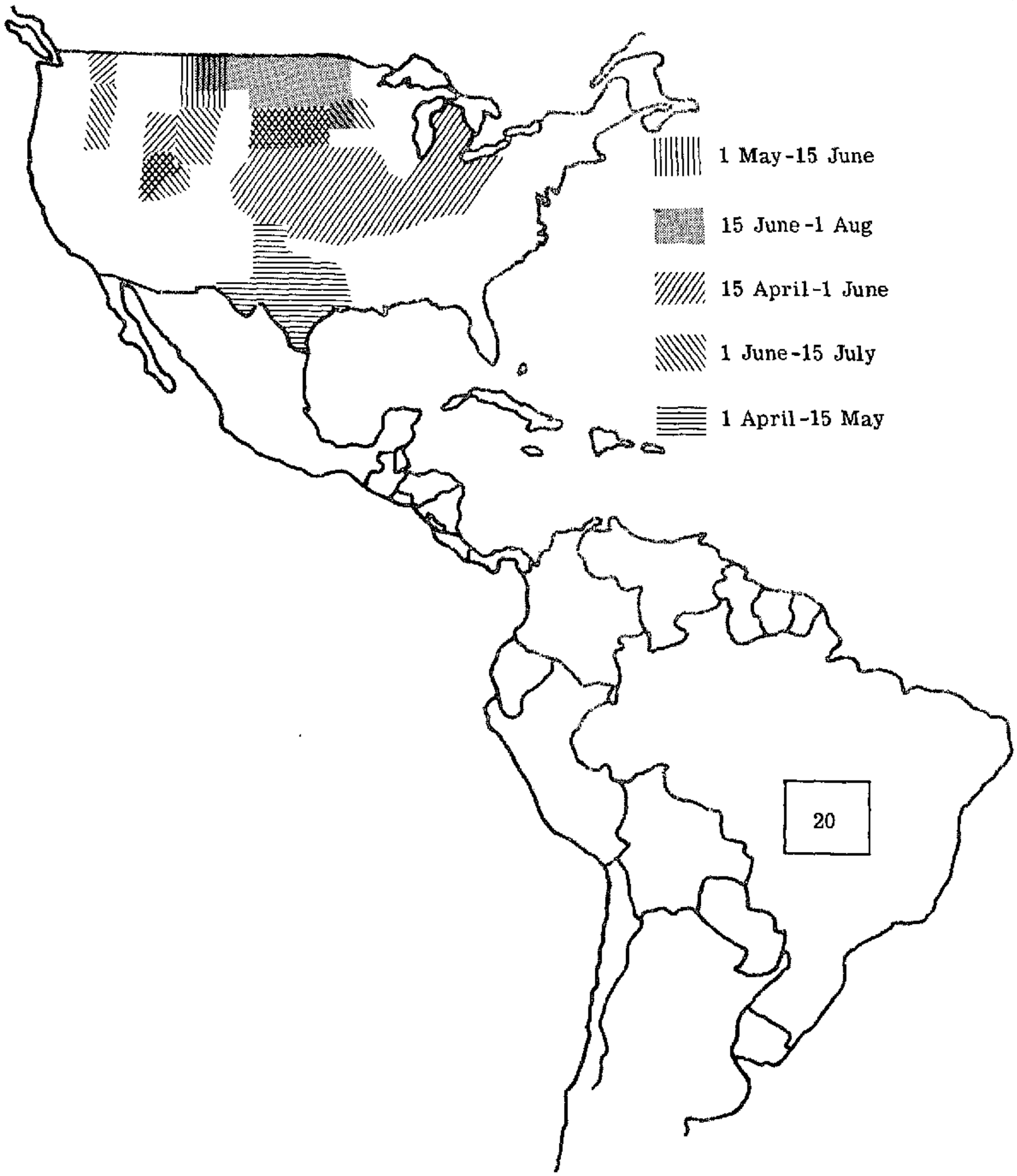

FIGURE 34. OPERATIONAL SITES FOR APPLICATION 20
Cultivated Crops

5
SENSOR REQUIREMENTS

After determining the observation bands, the minimum reflectance variation that should be observed in each band, the time of observation, and the site location, one can use these data to calculate the required radiometric sensitivity of the SEOS sensor. To perform these calculations, we used an atmospheric model and a computer program as described below.

5.1 DESCRIPTION OF ATMOSPHERIC MODEL AND COMPUTER PROGRAM TO CALCULATE RADIANCE LEVELS

The atmospheric radiative-transfer model used for the SEOS study is based upon a modified two-stream analysis and an aerosol model atmosphere. Input data comprise wavelength, solar zenith angle, nadir view angle, relative azimuthal angle between the solar plane and the view plane, target and background reflectance, horizontal visual range at the surface, and type of atmospheric haze. The effects of multiple scattering of radiation are accounted for, and absorption by ozone and particulates is also included. A model atmosphere relating spectral optical thickness to visibility has been developed by Elterman [37], and this model has been used in the analysis. The output consists of path radiance (L_P), i.e., the apparent spectral radiance along the line-of-sight path from sensor to target element which results from multiply-scattered radiation, and target spectral radiance (L_T), i.e., the surface radiance (L_o) attenuated by scattering and absorption. This composition can be expressed by the formula

$$L = L_o T + L_P \tag{1}$$

where L is total spectral radiance at the sensor, L_o is the surface radiance of the target, T is the spectral transmittance between target and sensor, and L_P is the apparent spectral path radiance. Equation (1) is quite general and applies to any kind of surface. If, however, we assume a perfectly diffuse (Lambertian) surface, then Eq. (1) becomes

$$L = \frac{\rho}{\pi} ET + L_P \tag{2}$$

where ρ is the spectral reflectance of a target and E is the downwelling spectral irradiance on the target (solar plus sky). The model assumes that the Earth's surface is spatially uniform and Lambertian, and the atmosphere is a plane-parallel medium with direct solar radiation incident on the top at some zenith angle Θ_o. It should be noted that for the SEOS viewing geometry, the error introduced by the assumption that the atmosphere is a plane-parallel

37. Elterman, L., Vertical Attenuation Model with Eight Surface Meteorological Ranges, 2 to 13 Kilometers, AFCRL Report No. 70-0200, Air Force Cambridge Research Laboratories, Bedford, 1970.

medium is very small. For a more complete description of the model, one should consult Turner [38-41] and Turner and Spencer [42].

Actual computer runs evaluated wavelengths from 0.42 to 1.73 μm with target and background having the same reflectances as called out and for each application. The visual range was 23 km—i.e., with a light haze condition assumed. For over-water applications, the atmosphere used was Derimendjian's Haze M for maritime particular sizes; for over-land applications the atmosphere was Derimendjian's type L for continental distributions; and for near-shore applications a mixture (50% each) was used [43]. This description of the atmosphere allows one to determine the polydisperse single-scattering phase function—a quantity of fundamental importance in atmospheric scattering work.

5.2 DEFINITION OF RADIANCE TERMS

The output of the model and the above program is the total radiance and the path radiance as observed at the SEOS sensor.

The total sensor radiance (L) is the radiance at the entrance to the satellite's optics. Per Eq. (1), it is the sum of the radiance from target ($L_T = L_0 T$) as well as the radiance of the path (L_p).

The reflectance of the target (ρ) is that percent of the incident solar energy being reflected by the target at a specific wavelength. In this case, we are referring to specific bands of wavelengths; therefore this report assumes that the target reflectance does not change significantly over the extent of the wavelength band we are using at that time, though of course such reflectance may vary considerably from band to band.

38. Turner, R. E., Remote Sensing in Hazy Atmospheres, Proceedings of ACSM/ASP Meeting, Washington, D.C., 1972.

39. Turner, R. E., Radiative Transfer in Model Atmospheres Scattering, Course Notes, Advanced Infrared Technology, Engineering Summer Conference, The University of Michigan, Ann Arbor, 1972.

40. Turner, R. E., Atmospheric Effects in Remote Sensing, Remote Sensing of Earth Resources, Volume II, The University of Tennessee Space Institute, Tullahoma, 1973.

41. Turner, R. E. Contaminated Atmospheres and Remote Sensing, Remote Sensing of Earth Resources, Vol. II, The University of Tennessee Space Institute, Tullahoma, 1974.

42. Turner, R. E. and M. M. Spencer, Atmospheric Model for Correction of Spacecraft Data, Proceedings of the Eighth International Symposium on Remote Sensing of the Environment, Willow Run Laboratories of the Institute of Science and Technology, The University of Michigan, Ann Arbor, 1972.

43. Derimendjian, D., Electromagnetic Scattering on Spherical Polydispersions, Elsevier, New York, 1969.

To determine the required sensor sensitivity, some value of minimum observable sensitivity must be given. This minimum sensitivity is called ($\Delta\rho$) and is defined as the smallest detectable percent of the incident solar energy necessary to adequately differentiate the observable parameter.

In order to avoid confusion, an example of ρ and $\Delta\rho$ will now be given. Assume that the incident solar energy striking the target has a magnitude of 100 units. If the average target reflectance at some wavelength band were 14% (ρ = 14%), 14 units of energy would be reflected from the target in that band and 86 units would be absorbed, etc. To determine if this target is, say, healthy or diseased vegetation, one must be able to see a difference of reflected energy from 12% to 16%. Hence, the required information from the target lies within ±2 units superimposed on a base of 14 units. Therefore $\Delta\rho$ = 2%.

Another measure of the sensor sensitivity incorporates all the above criteria into a single term, ΔL_T. This is the smallest variation in radiance from the target at the sensor entrance aperture that will allow us to observe the $\Delta\rho$. Therefore $\Delta L_T = (\Delta\rho/\rho)L_T$.

5.3 SATELLITE RADIANCE LEVELS

Using the aforementioned computer program, we determined radiance values for one Demonstration Site for each application. In each case every spectral band requested by each application was investigated as were the most and least favorable conditions for observing the site with respect to time of day and day of the year.

Parameters calculated were the total detector radiance (L), the detector radiance due only to the specific target (L_T) and the minimum required radiance variation from the target (ΔL_T).

Table 7 gives the Demonstration Site locations as well as dates (time of year) and times of day chosen for the calculations. As can be seen from this table, the most favorable conditions generally occurred at noon on 22 June, and many of the least favorable conditions occurred at 0900 hours on 22 December. In some cases, the applications actually called for more unfavorable times of day. In such cases, however, the observation bands are usually in the thermal region, and if by chance any visible energy is received, this is simply considered to be a bonus. Also, in some cases, the applications call for say 0600 hours all year. In these cases, visible energy may be received in the summer months, but not in the winter. For ease of interpretation, these cases were eliminated from our calculations.

Table 8 presents the results of the radiance calculations. Values are given for the most favorable conditions (L_{max}, L_{Tmax}, ΔL_{Tmax}) and the least favorable conditions (L_{min}, L_{Tmin}, ΔL_{Tmin}), as well as the $\Delta\rho$ for the application in that wavelength band. These results are tabulated by wavelength band and application. All radiance calculations were made assuming the satellite to be in stationary (synchronous) orbit positioned over a 0^oN by 100^oW site.

TABLE 7. DEMONSTRATION SITE LOCATIONS, DATES, AND TIMES CHOSEN FOR RADIANCE CALCULATIONS

Application Number	Demonstration Site and Latitude (°N)	Time of Day-Date Most Favorable Condition	Time of Day-Date Least Favorable Condition
1	W. Lake Erie - 41°46'	1200, June 22	0900, Dec 22
2	Delaware Bay - 39°	1200, June 22	0900, Dec 22
3	Cascade Mts., Wash. - 48°30'	1200, June 22	0900, Dec 22
4	Izalco - 13°49'	0800, June 22	0800, Dec 22
5	Lake Erie - 41°46'	1200, June 22	0900, Dec 22
6	Mississippi Sound - 30°15'	1200, June 22	1500, Apr 16
7	N. Gulf of Mexico 29°12'	1200, June 22	0900, Dec 22
8	Umatilla Forest - 43°37'	1200, June 22	1200, Aug 15
9	Ottawa Forest, Mich. - 46°30'	1200, Sept 15	1200, Nov 8
10	Pawnee Co., Colo. - 40°35'	1200, June 22	1200, Apr 15
11	Columbia R. Basin, Wash. - 46°	1200, June 22	1500, Aug 22
12	Houston Ship Channel - 29°45'	1200, June 22	0900, Dec 22
13	White Sands, N.M. - 33°	1300, May 15	0800, Nov 15
14	W. Lake Erie - 41°46'	1200, June 22	1200, Apr 1
15	Northwestern U.S.A.	1200, June 22	1200, Nov 1
16	W. Lake Erie Shore - 43°	1200, June 22	1200, Dec 22
17	W. Lake Erie Shore - 43°	1200, June 22	1200, Dec 22
18	Central Atlantic Regional Ecological Test Site - 38°34'	1200, June 22	0900, Jan 15
19	Griggs Co., N.D. - 47°27'	1200, June 22	1200, Aug 22
20	Hill Co., Mont. - 48°33'	1200, June 22	1200, May 1

TABLE 8. CALCULATED RADIANCE VALUES FOR MOST AND LEAST FAVORABLE CONDITIONS ENUMERATED IN TABLE 7

Band Number and Wavelength (μm)	Application No.	L_{max} ($\mu W/cm^2 \cdot sr$)	L_{Tmax} ($\mu W/cm^2 \cdot sr$)	ΔL_{Tmax} ($\mu W/cm^2 \cdot sr$)	L_{min} ($\mu W/cm^2 \cdot sr$)	L_{Tmin} ($\mu W/cm^2 \cdot sr$)	ΔL_{Tmin} ($\mu W/cm^2 \cdot sr$)	ρ (%)	Δρ (%)
Band I (0.42-0.46)	2	256	47	6	55	9	1	4	0.5
	6	256	63	8	69	17	2	4	0.5
	13	116	64	4	64	35	2	15	1
	14	377	56	5	309	46	4	6	0.5
	17	416	95	10	189	43	4	10	1
	18	375	118	12	85	27	3	10	1
Band II (0.45-0.50)	5	635	177	35	127	35	7	10	2
	13	519	354	18	286	195	10	20	1
	17	635	177	18	286	80	8	10	1
	18	1293	487	49	294	111	11	10	1
Band III (0.47-0.52)	1	1481	454	113	191	82	20	8	2
	2	597	137	15	108	25	3	4.5	0.5
	4	4172	3960	1485	569	540	202	40	15
	6	532	178	20	145	49	5	4.5	0.5
	7	663	309	77	120	56	14	8	2
	12	592	238	40	107	43	7	6	1
	13	380	216	11	208	119	6	20	1
	14	683	81	12	560	67	10	3.5	0.5
	17	835	233	23	380	106	11	10	1
	18	734	274	18	167	62	4	15	1
Band IV (0.53-0.57)	1	249	71	28	50	14	6	5	2
	2	222	80	9	44	16	2	4.5	0.5
	6	213	106	12	149	74	8	4.5	0.5
	7	225	118	47	46	24	10	5	2
	8	639	461	9	511	369	7	25	0.5
	9	272	87	43	238	76	3.8	10	0.5
	11	394	163	33	278	115	27	15	3
	12	225	118	24	46	24	5	5	1
	13	419	355	28	230	195	16	25	2
	14	206	28	7	165	23	6	2	0.5
	15	340	109	5	238	76	4	10	0.5
	16	639	461	18	288	208	8	25	1
	17	320	142	14	148	64	6	10	1
	18	319	177	18	80	44	4	10	1
	20	340	109	5.5	306	98	5	10	0.5
Band V (0.56-0.60)	1	285	60	30	57	12	6	4	2
	2	264	84	9	53	17	2	4.5	0.5
	4	1470	1200	450	331	270	101	40	15
	5	285	60	30	57	12	6	4	2
	6	247	112	12	198	90	10	4.5	0.5
	7	235	100	50	47	20	10	4	2
	12	260	125	25	52	25	5	5	1
	13	106	90	6	59	50	3	30	2
	14	247	22	7	198	18	6	1.5	0.5
	18	461	281	19	138	84	6	15	1

TABLE 8. CALCULATED RADIANCE VALUES FOR MOST AND LEAST FAVORABLE CONDITIONS ENUMERATED IN TABLE 7 (Continued)

Band Number and Wavelength (μm)	Application No.	L_{max} ($\mu W/cm^2 \cdot sr$)	L_{Tmax}	ΔL_{Tmax}	L_{min} ($\mu W/cm^2 \cdot sr$)	L_{Tmin}	ΔL_{Tmin}	ρ (%)	$\Delta\rho$ (%)
Band VI (0.60-0.65)	1	71	24	16	14	5	3	3	2
	2	46	8	4	9	2	1	1	0.5
	5	71	24	16	14	5	3	3	2
	6	41	13	6.5	29	9	4.5	1	0.5
	7	68	40	27	13	8	5	3	2
	13	297	280	16	163	154	9	35	2
	14	55	8	4	46	6	3	1	0.5
	18	138	100	5	34	25	2	10	0.5
Band VII (0.65-0.69)	1	99	26	26	20	5	5	2	2
	2	100	42	8	20	8	3	2.6	0.5
	4	1596	1560	585	159	156	58	40	15
	5	112	39	26	23	8	5	3	2
	6	86	42	8	61	30	6	2.6	0.5
	7	87	43	43	18	9	9	2	2
	8	580	507	84	464	406	67	30	0.5
	9	251	176	4.4	220	154	3.8	20	0.5
	10	169	117	7.3	150	104	6.5	8	0.5
	12	152	108	22	31	22	4	5	1
	13	546	520	26	300	286	14	40	2
	14	79	6.5	6.5	63	5	5	0.5	0.5
	15	315	220	5	220	154	4	20	0.5
	16	430	357	14	194	161	6	25	1
	17	203	130	13	92	58	6	10	.1
	18	383	325	8	96	81	2	20	0.5
	19	225	130	5	210	104	4	13	0.5
	20	135	40	3	122	36	2	8	0.5
Band VIII (0.70-0.73)	1	58	18	18	12	4	4	2	2
	2	43	11	5.5	8	2	1	1	0.5
	3	883	831	30	176	166	6	80	3
	5	103	63	20	21	13	4	7	2
	6	39	15	7.5	27	10	5	1	0.5
	7	54	30	30	11	6	6	2	2
	11	190	138	35	133	97	24	20	5
	13	374	360	18	206	198	10	40	2
	14	44	4.5	4.5	36	3.6	3.6	0.5	0.5
	18	257	225	11	64	56	3	20	1
Band IX (0.78-0.82)	8	668	633	63	535	506	51	50	0.5
	9	405	365	4.5	315	284	3.5	40	0.5
	10	480	456	8	427	405	7	30	0.5
	13	416	405	20	250	243	12	40	2
	15	449	405	5	315	284	3.5	40	0.5
	18	526	506	6	140	135	1.7	40	0.5
	19	196	152	5	158	122	4	15	0.5
	20	399	355	5	359	319	4.5	35	0.5

TABLE 8. CALCULATED RADIANCE VALUES FOR MOST AND LEAST FAVORABLE CONDITIONS ENUMERATED IN TABLE 7 (Continued)

Band Number and Wavelength (μm)	Application No.	L_{max} (μW/cm^2·sr)	L_{Tmax} (μW/cm^2·sr)	ΔL_{Tmax} (μW/cm^2·sr)	L_{min} (μW/cm^2·sr)	L_{Tmin} (μW/cm^2·sr)	ΔL_{Tmin} (μW/cm^2·sr)	ρ (%)	$\Delta\rho$ (%)
Band X									
(0.85-0.89)	13	445	372	19	245	205	10	40	2
	18	610	458	11	152	114	3	40	1
Band XI									
(0.89-0.95)	13	676	580	26	372	319	14	45	2
	16	441	237	10	218	119	5	25	1
	17	394	190	9	211	95	5	20	1
	18	835	635	16	209	159	4	40	1
Band XII									
(0.95-1.10)	13	1503	1324	53	826	728	29	50	2
	18	1675	1303	32	419	326	8	40	1
Band XIII									
(2.05-2.35)	3		93	9		19	2	30	3
	7		270	20		54	4	40	2
	8		101	2		81	1.6	25	0.5
	9		75	1.3		65	1.1	30	0.5
	10		114	2.1		101	2	25	0.5
	11		94	9		66	7	30	3
	13		142	8		78	4.5	35	2
	16		73	4		33	2	18	1
	17		73	4		33	2	18	1
	18		223	5.6		51	1.3	20	0.5
	19		125	9		100	7.5	40	0.5
	20		62	1.6		56	1.4	20	0.5
Band XIV									
(3.6-4.1)	15		120	10					
Band XV									
(8.3-9.4)	13		954	143		739	111		
	18		954	143		739	111		
Band XVI									
(10.3-11.3)	2		656	5					
	3		559	17					
	4		656	19					
	6		656	5					
	7		715	10					
	11		904	12					
	12		715	10					
	13		778	16					
	14		656	5					
	15		21,700	2060					
	16		656	98					
	17		656	98					
	18		778	16					
	19		778	11					
	20		833	11					

TABLE 8. CALCULATED RADIANCE VALUES FOR MOST AND LEAST FAVORABLE CONDITIONS ENUMERATED IN TABLE 7 (Concluded)

Band Number and Wavelength (μm)	Application No.	L_{max} (μW/cm²·sr)	L_{Tmax} (μW/cm²·sr)	ΔL_{Tmax} (μW/cm²·sr)	L_{min} (μW/cm²·sr)	L_{Tmin} (μW/cm²·sr)	ΔL_{Tmin} (μW/cm²·sr)	ρ (%)	Δρ (%)
Band XVII (11.3-12.0)									
	2		436	3					
	3		368	11					
	4		436	12					
	6		436	3					
	7		478	7					
	11		586	7					
	12		478	7					
	13		512	10					
	14		436	3					
	15		11,010	1040					
	16		446	76					
	17		446	76					
	18		512	10					
	19		512	7					
	20		586	7					
Band XVIII (12.0-12.9)									
	2		509	7					
	3		441	13					
	4		509	14					
	6		509	7					
	7		546	8					
	11		669	9					
	12		546	8					
	13		585	12					
	14		509	7					
	15		21,750	2060					
	16		509	76					
	17		509	76					
	18		585	12					
	19		585	7					
	20		626	8					

Figures 36 through 53 graphically display the data contained in Table 8. Figure 35 is a sample display showing how to read the others. As you will note on this figure, L, L_T, $\Delta\rho$, and ΔL_T are all shown. Each figure is for a single wavelength band, with the radiance values displayed for each application requesting that band.

The abscissa is the ΔL_T value. Distance along the abscissa shows the range of ΔL_T for each application (to better display the results, the abscissa is not linear). More accurate values can of course be found in Table 8. The ordinate is the application number, making the entire display a modified histogram.

Given within each box are the values of L and L_T for the most and least favorable conditions, as well as a value of the reflectance, $\Delta\rho$, for that application and wavelength band.

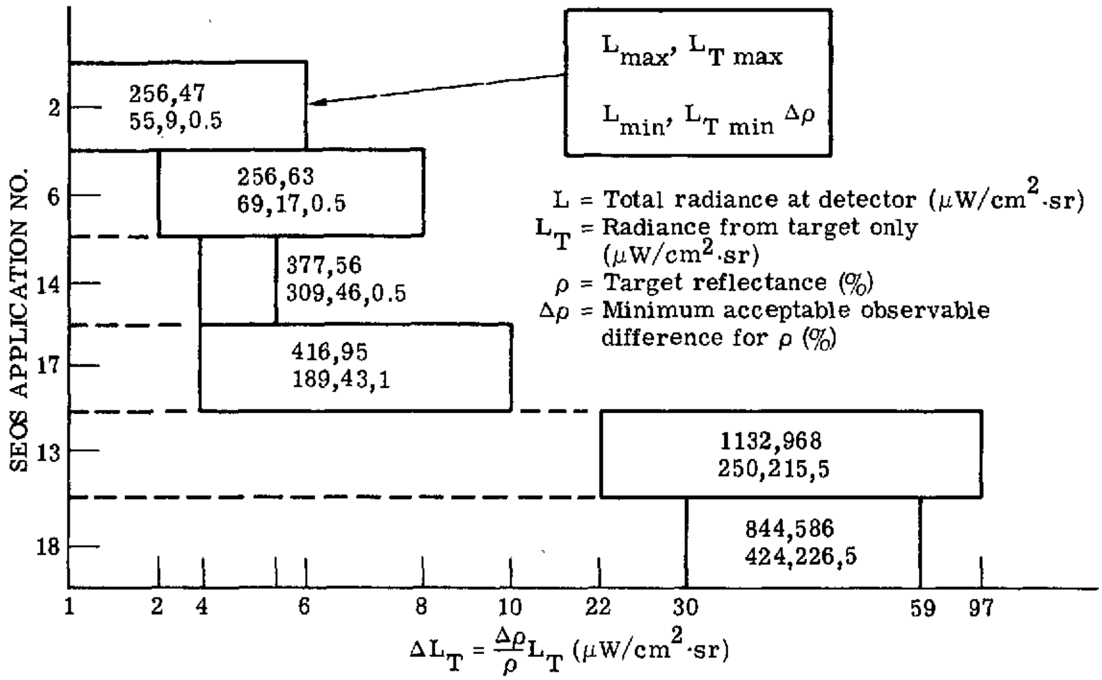

FIGURE 35. SAMPLE RADIANCE CHART

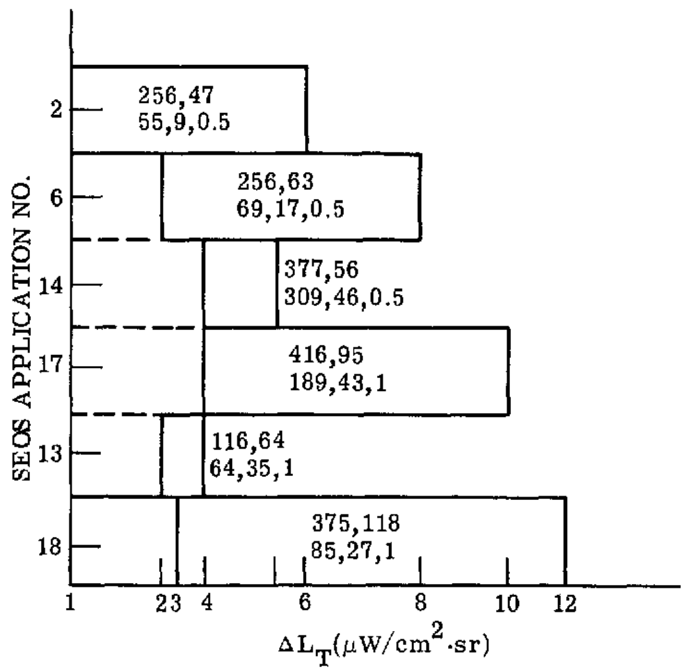

FIGURE 36. RADIANCE LEVELS FOR BAND I
(0.42-0.46 μm)

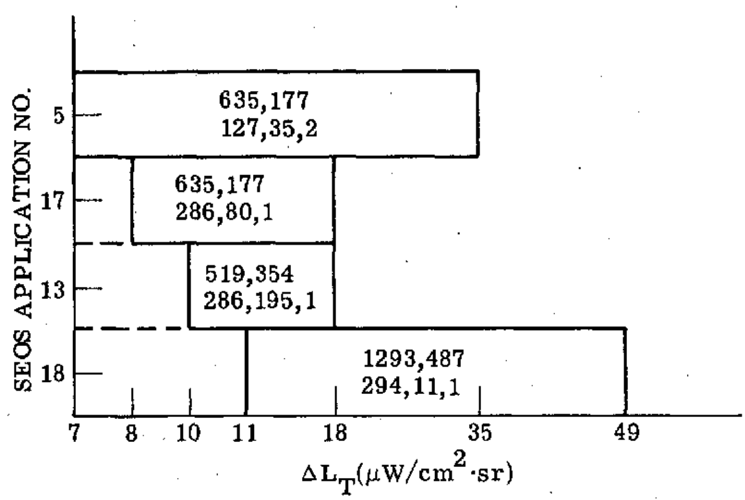

FIGURE 37. RADIANCE LEVELS FOR BAND II
(0.45-0.50 μm)

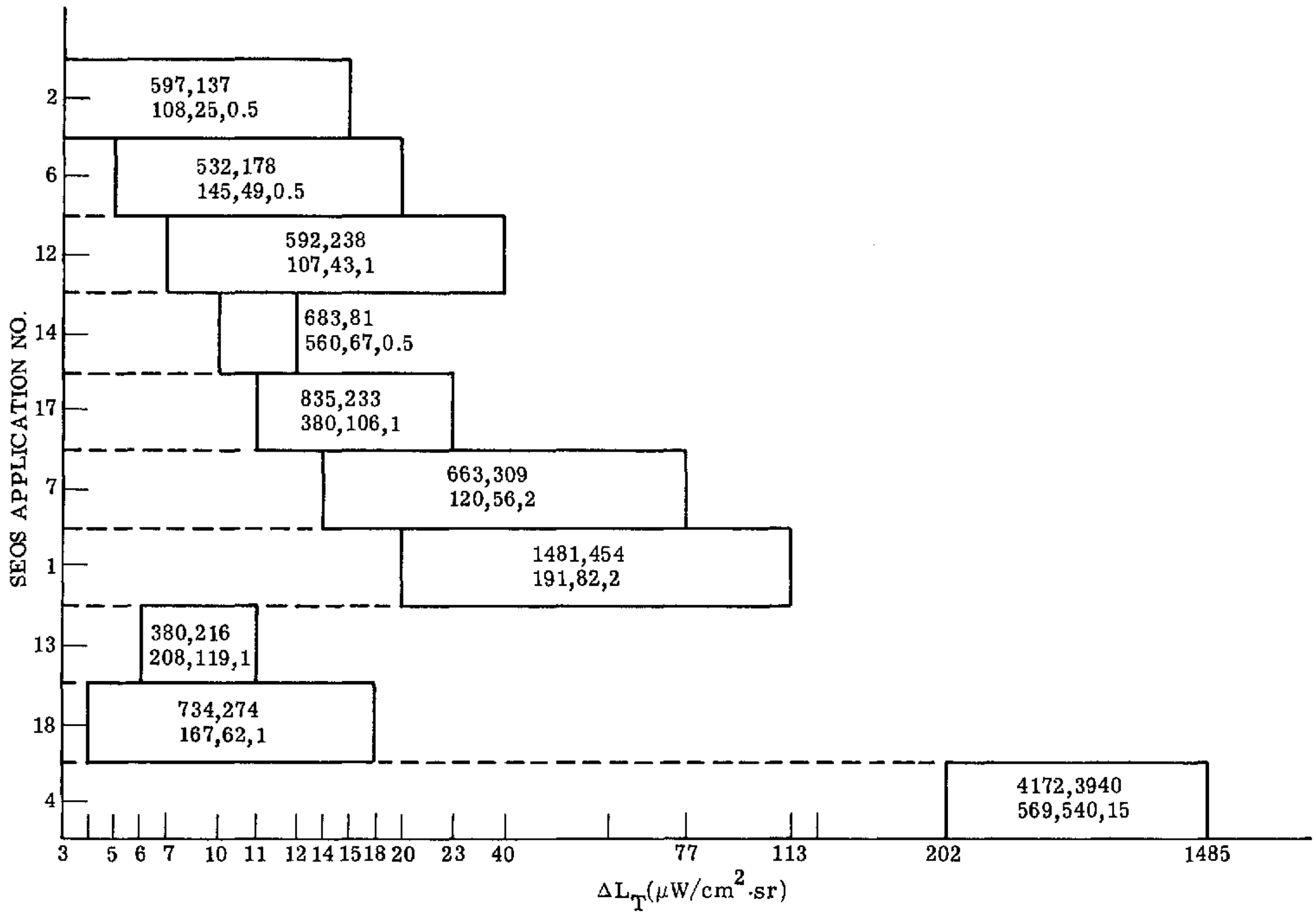

FIGURE 38. RADIANCE LEVELS FOR BAND III (0.47-0.52 μm)

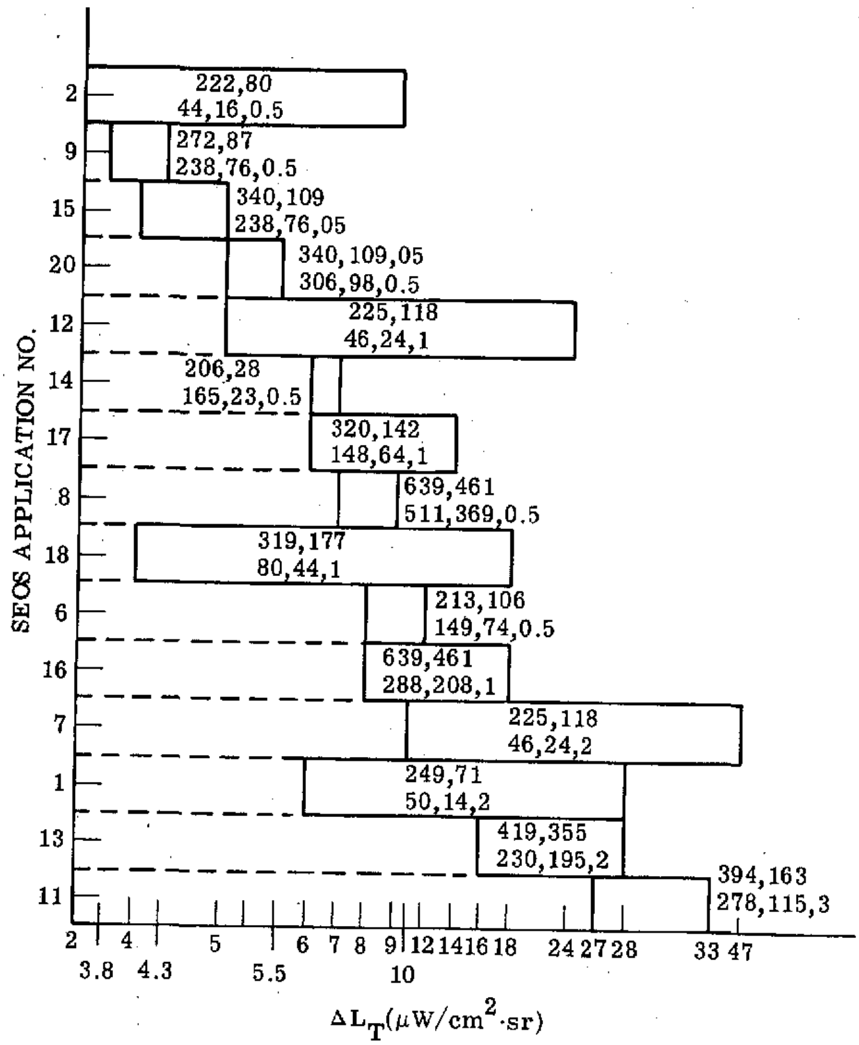

FIGURE 39. RADIANCE LEVELS FOR BAND IV (0.53-0.57 μm)

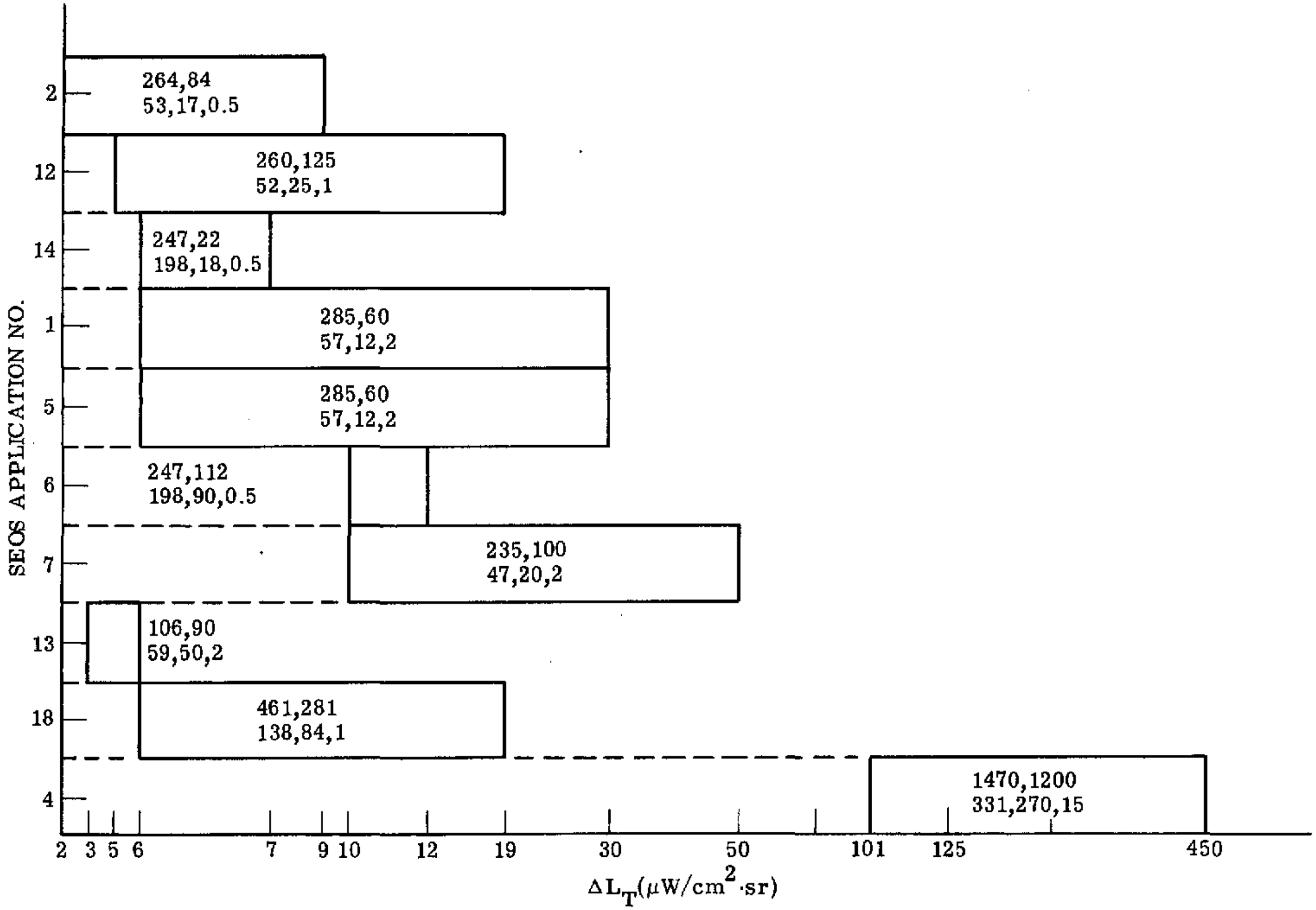

FIGURE 40. RADIANCE LEVELS FOR BAND V (0.56-0.60 μm)

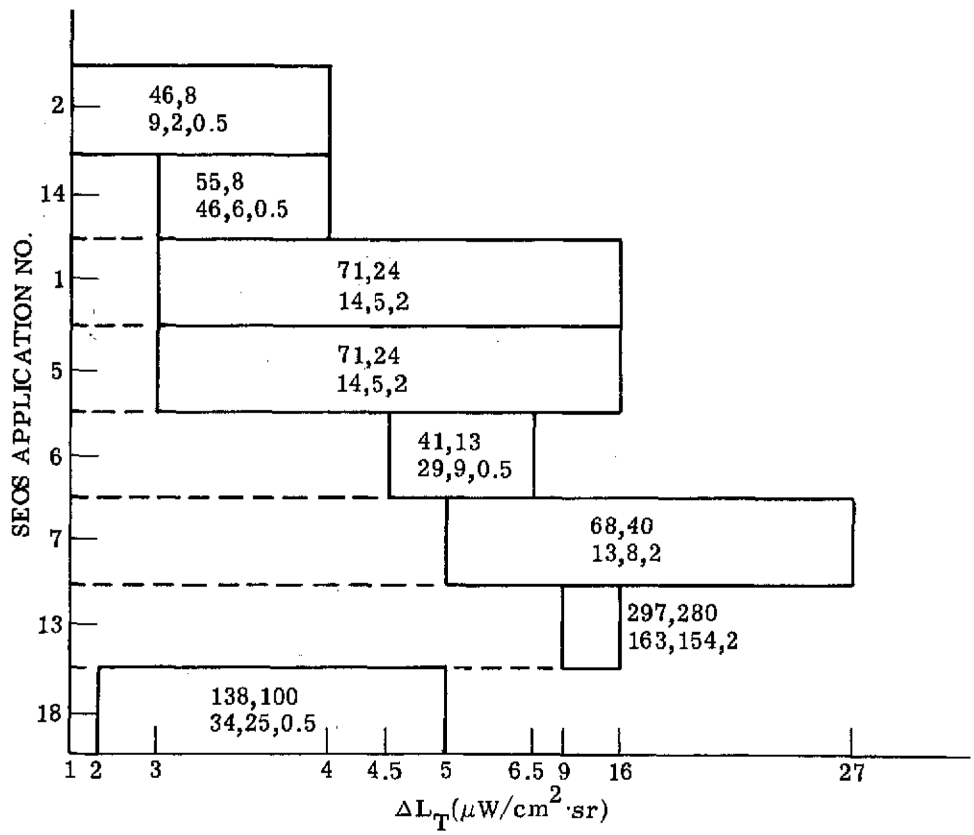

FIGURE 41. RADIANCE LEVELS FOR BAND VI (0.60-0.65 μm)

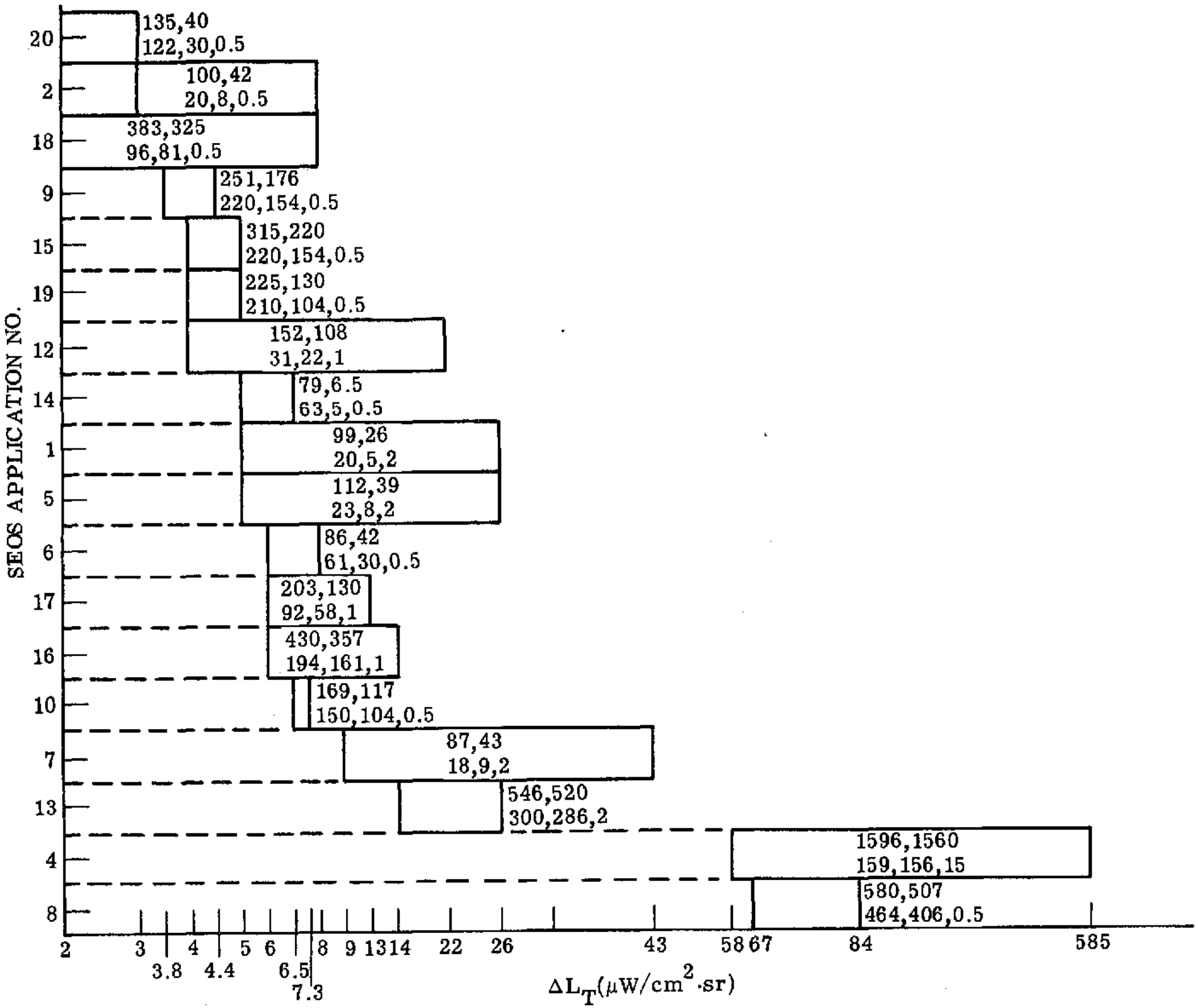

FIGURE 42. RADIANCE LEVELS FOR BAND VII (0.65-0.69 μm)

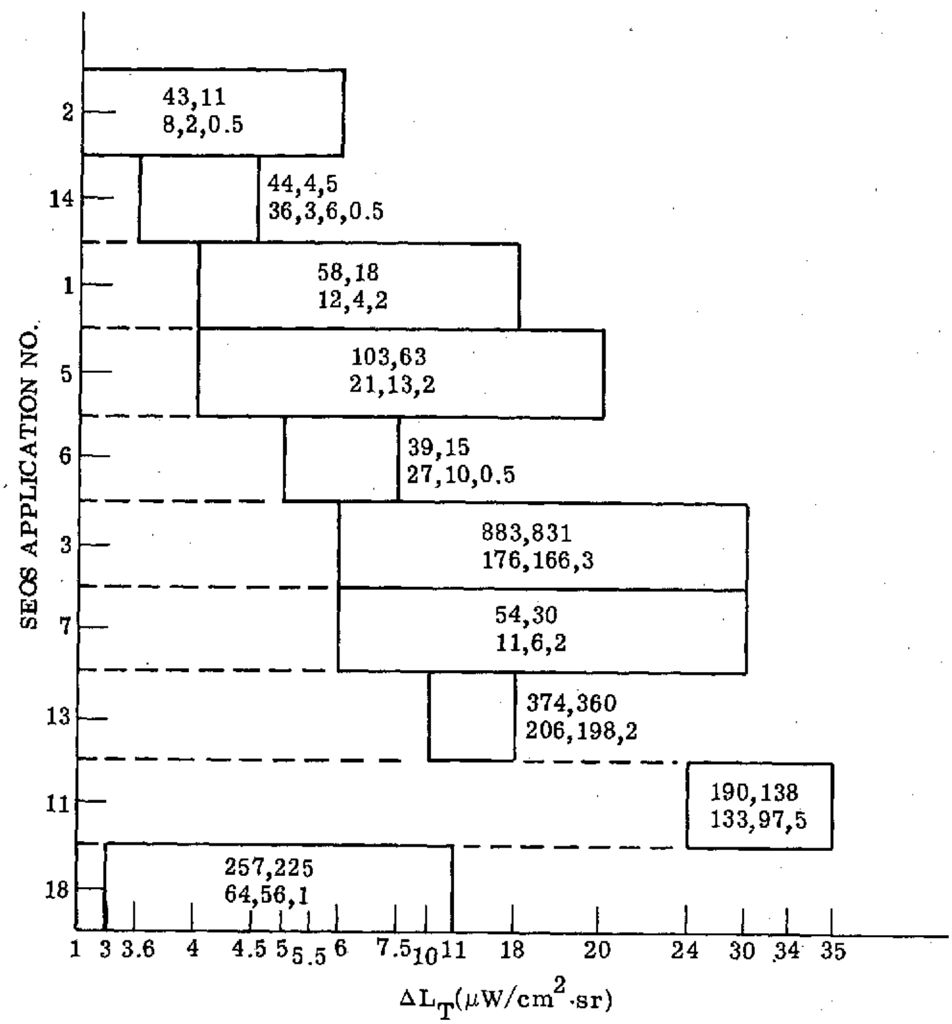

FIGURE 43. RADIANCE LEVELS FOR BAND VIII (0.70-0.73 μm)

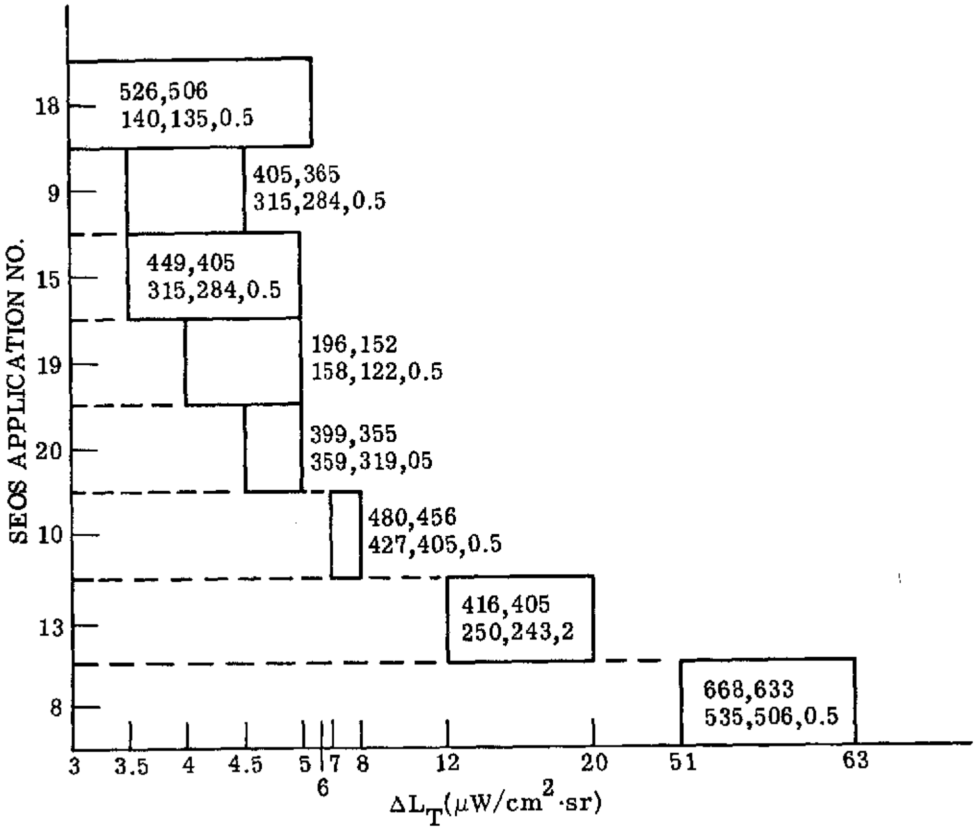

FIGURE 44. RADIANCE LEVELS FOR BAND IX (0.78-0.82 μm)

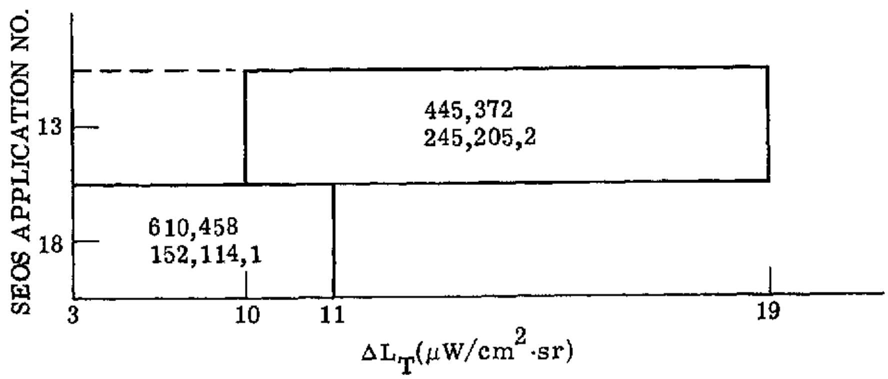

FIGURE 45. RADIANCE LEVELS FOR BAND X (0.85-0.89 μm)

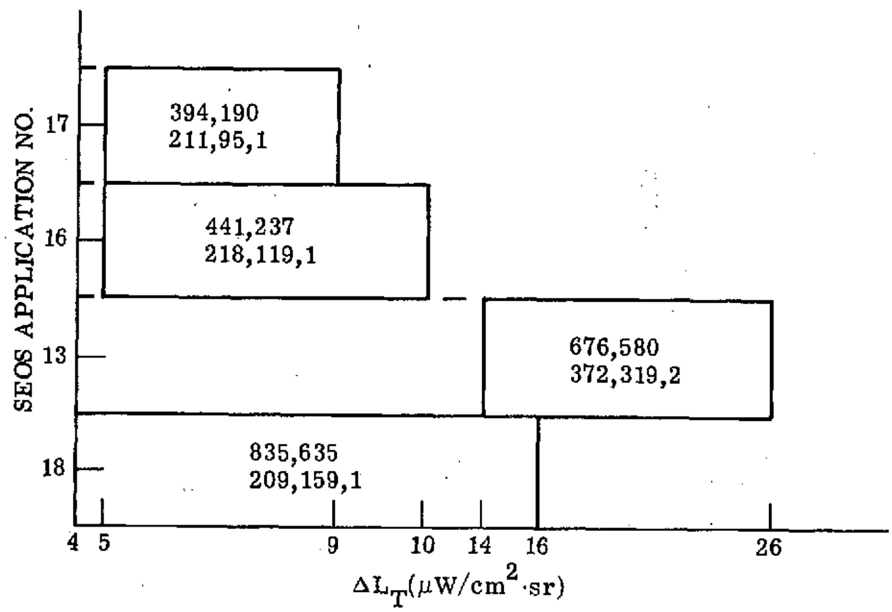

FIGURE 46. RADIANCE LEVELS FOR BAND XI (0.89-0.95 μm)

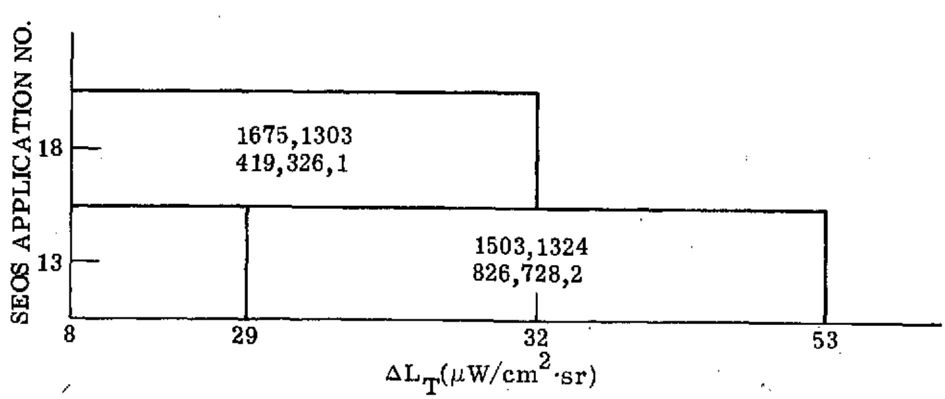

FIGURE 47. RADIANCE LEVELS FOR BAND XII (0.95-1.10 μm)

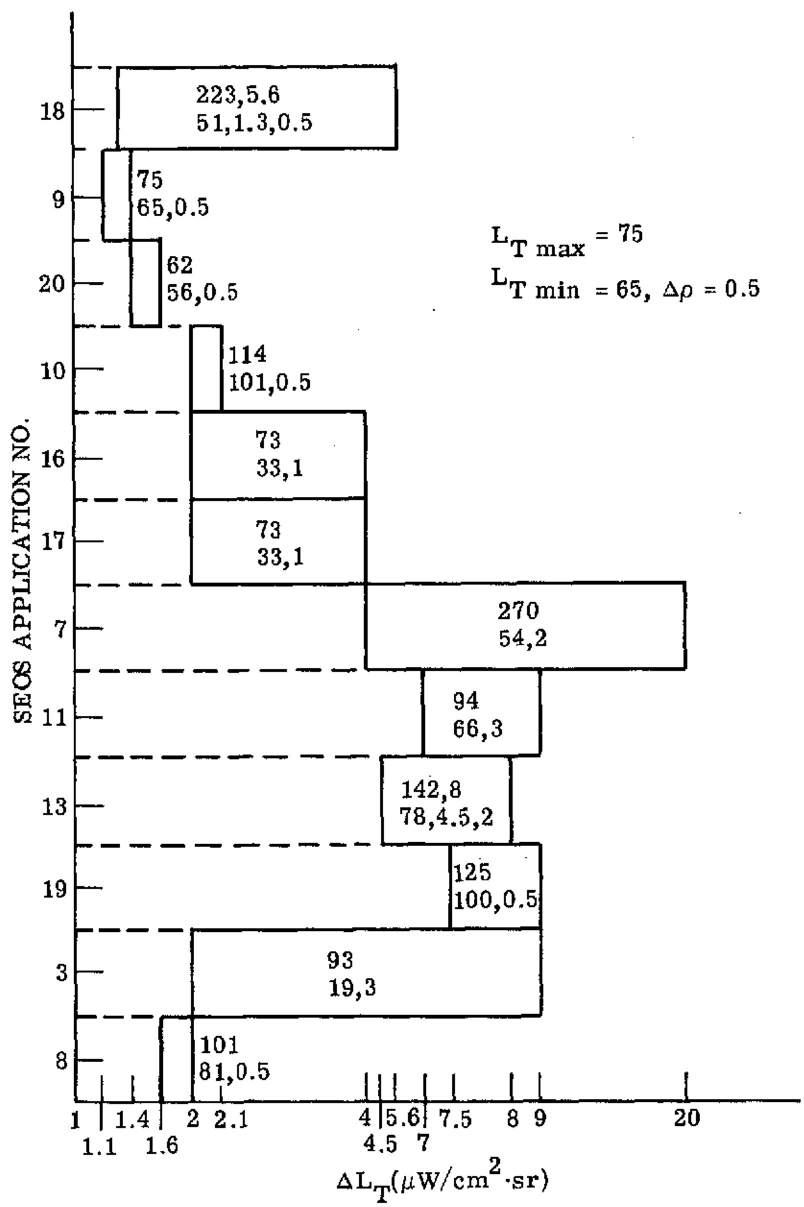

FIGURE 48. RADIANCE LEVELS FOR BAND XIII (2.05-2.35 μm)

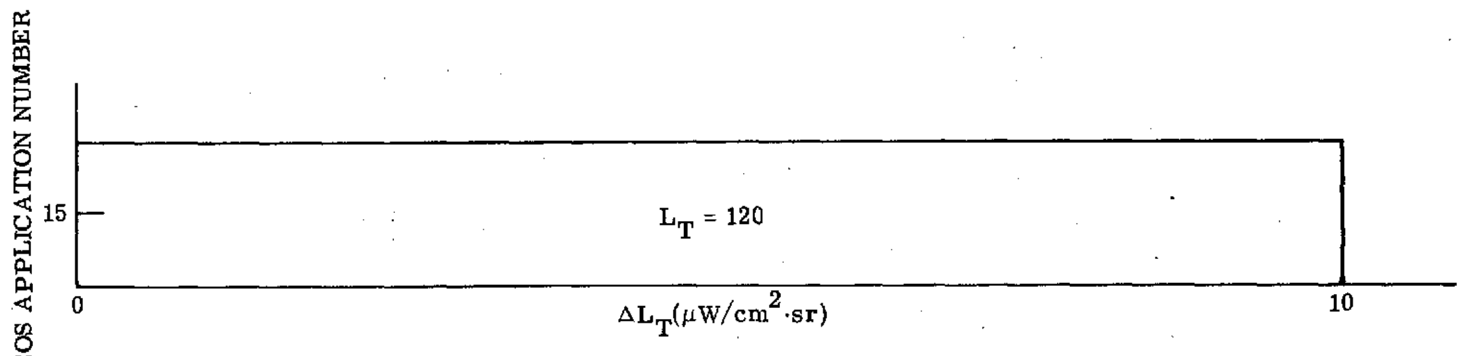

FIGURE 49. RADIANCE LEVELS FOR BAND XIV (3.6-4.1 μm)

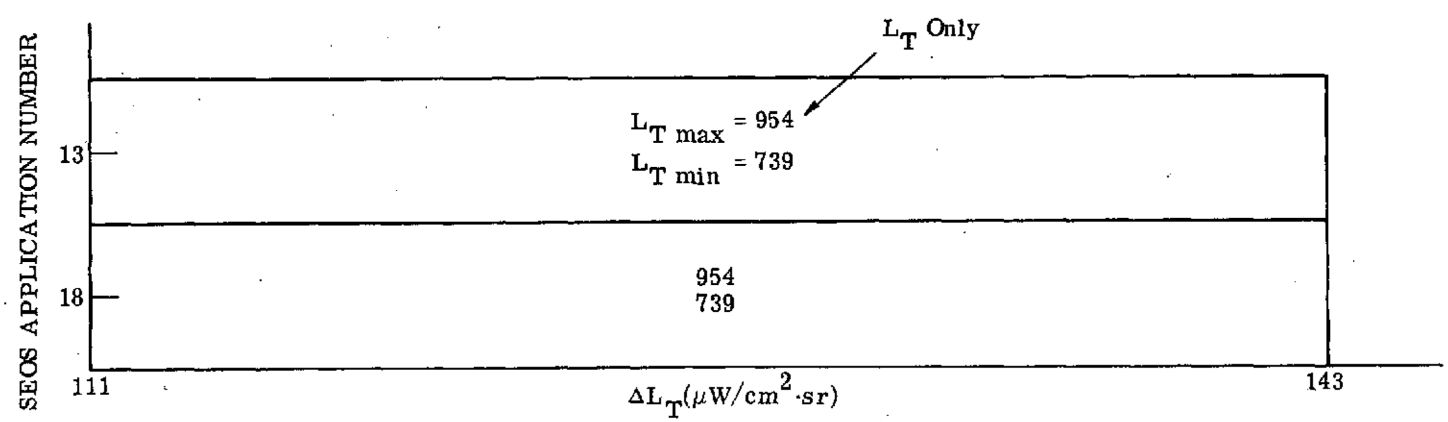

FIGURE 50. RADIANCE LEVELS FOR BAND XV (8.3-9.4 μm)

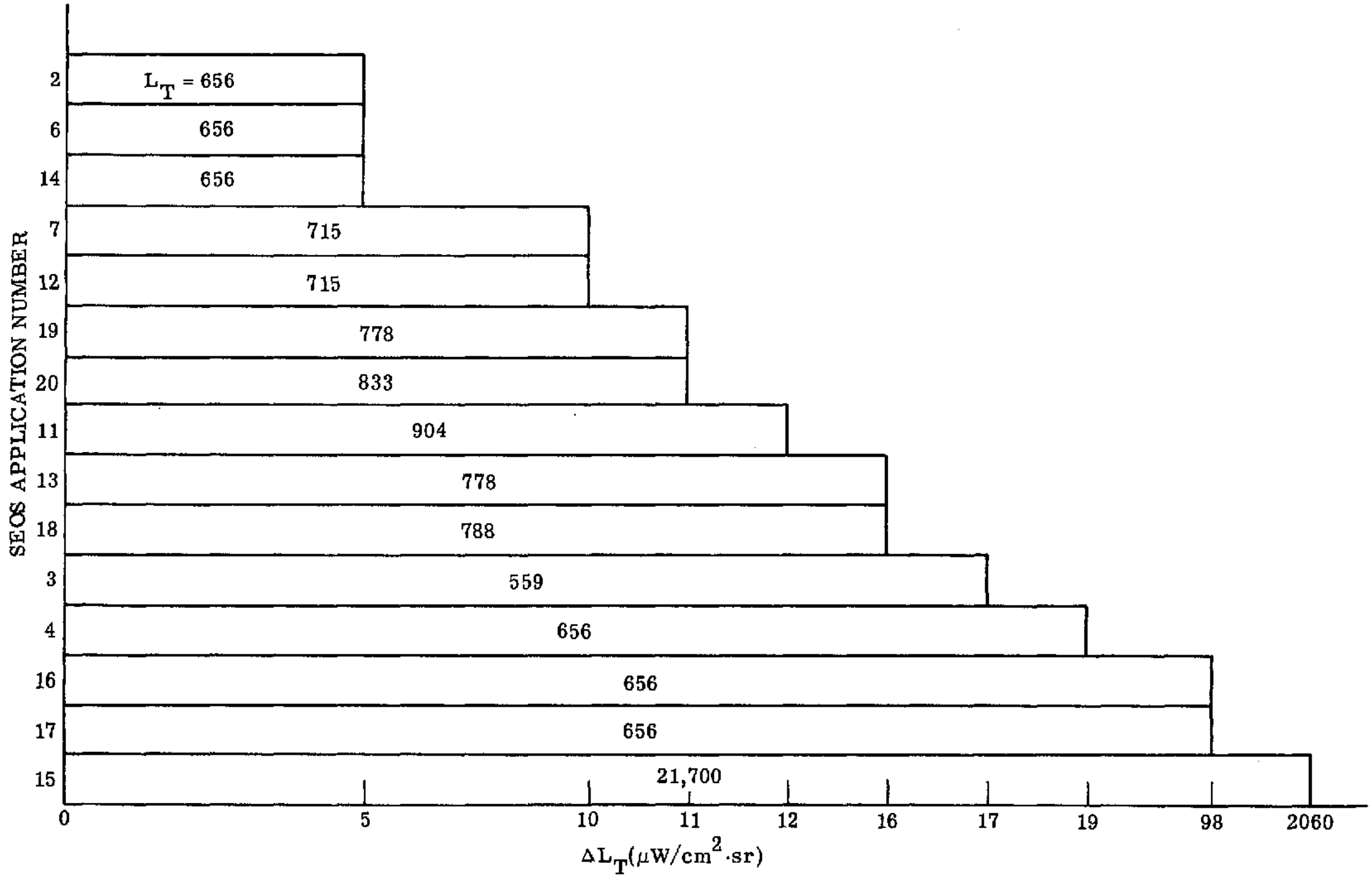

FIGURE 51. RADIANCE LEVELS FOR BAND XVI (10.3-11.3 μm)

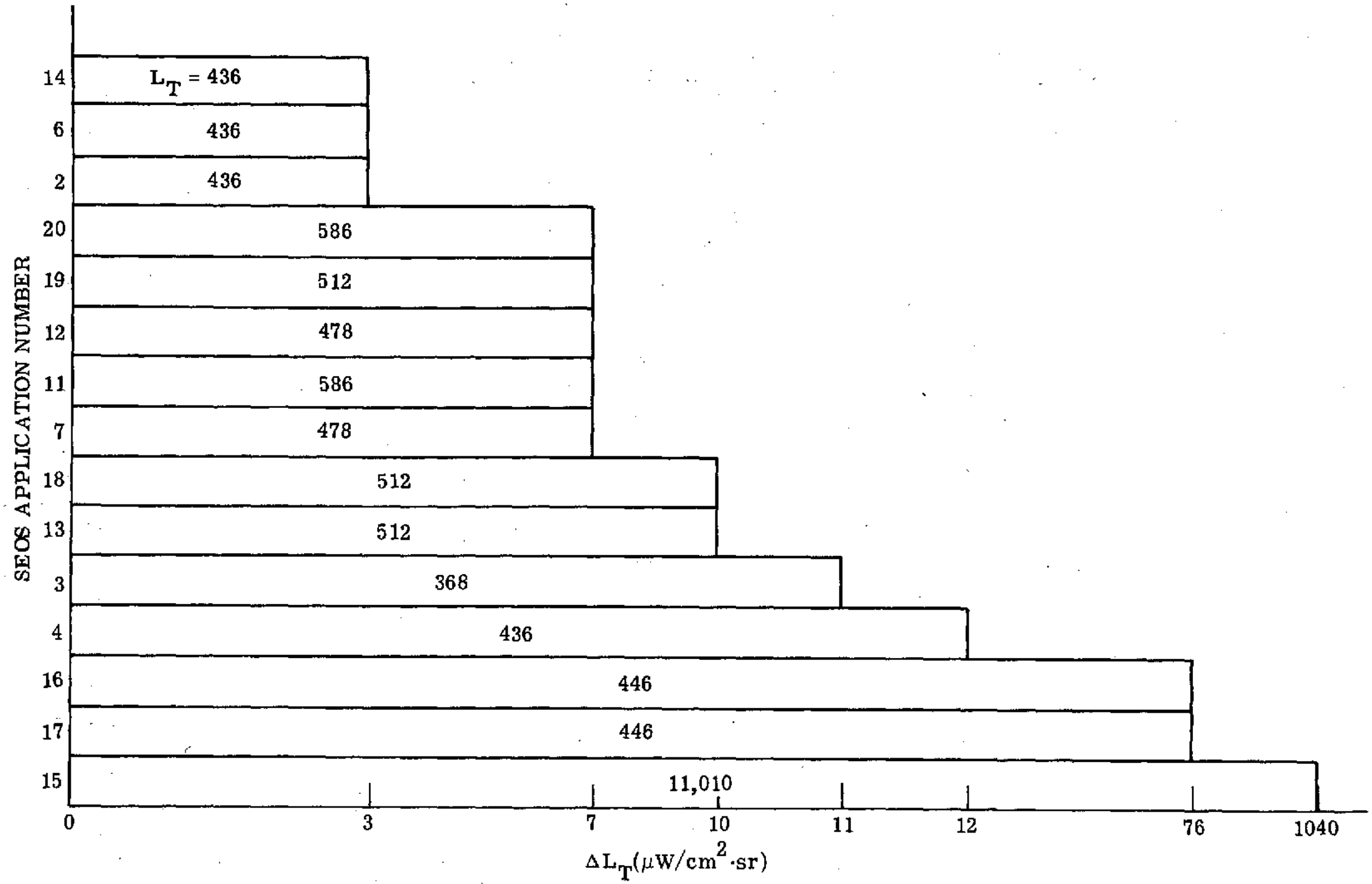

FIGURE 52. RADIANCE LEVELS FOR BAND XVII (11.3-12.0 μm)

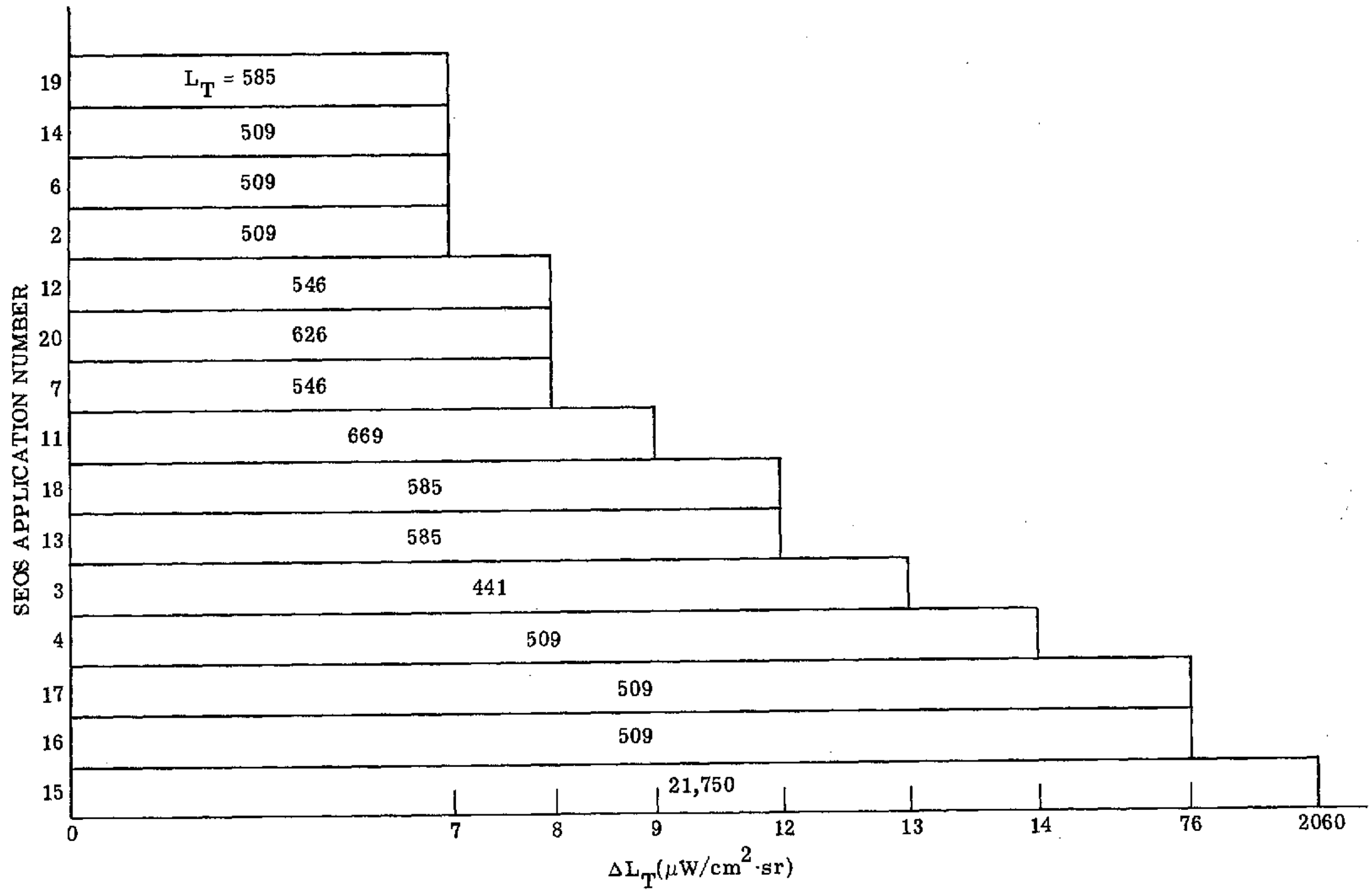

FIGURE 53. RADIANCE LEVELS FOR BAND XVIII (12.0-12.9 μm)

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Appendix
SEOS APPLICATION SUMMARY

Application and Application Number: Detecting and Monitoring of Water-Suspended Solid Pollutants - (No. 1)

User: EPA, U.S. PHS, USCG, NOAA, International Joint Commission of the Great Lakes, Delaware River Basin Commission, industrial concerns of most cities, USDI-BSFW, fisheries industry

Observables and Characteristics: Plumes of pollutants in water, identifiable through spectra yielding color differentiation

Demonstration Sites

Location and Size: Western Lake Erie (41°46'N, 83°W) 50 × 150 km; Chesapeake Bay (38°N, 76°W) 50 × 100 km; Northern Gulf of Mexico-Mississippi Delta (29°12'N, 89°W) 150 × 150 km

Observation Requirements: Daily at noon, plus 0900 and 1500 hrs on the 15th of each month (unless water is frozen over)

Operational Sites

Location and Size: All oceans and major lakes within SEOS range

Observation Requirements: Same as above

Sensor Requirements: *EIFOV - 20 m

Band	Priority	ρ_{min} (%)	ρ_{max} (%)	ρ_{ave} (%)	$\Delta\rho$ (%)	T_{min} (°C)	T_{max} (°C)	T_{ave} (°C)	ΔT (C°)
0.47-0.52	2	0.1	10	8	2				
0.53-0.57	1	0.1	8	5	2				
0.56-0.60	1	0.1	8	4	2				
0.60-0.65	1	0.1	7	3	2				
0.65-0.69	1	0.1	6	2	2				
0.70-0.73	1	0.1	6	2	2				

*EIFOV ≡ Effective Instantaneous Field of View

Data Requirements:

Format: Imagery and overlays, computer-compatible tapes

Time After Observation: 1 day

Ancillary Data: Sea state, wave height, wind direction and speed, water content, Secchi disc, sediment composition, water and air temperature

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Application and Application Number: Estuarine Dynamics and Pollution Dispersal - (No. 2)

User: BSFW, USACE, EPA, NOAA, BCF, FWS, water pollution control agencies, environmental quality councils, port authorities, regional planning agencies, municipalities, private industries, water resources councils, bureaus of outdoor recreation

Observables and Characteristics: Thermal and turbidity patterns, color, salinity, algal blooms, spectral reflectance of environmental parameters significant in estuarine circulation

Demonstration Sites

Location and Size: Galveston Bay (29°30'N, 94°50'W) 3700 km^2; San Francisco Bay System (37°40'N, 122°20'W) 3750 km^2; Delaware Bay (39°N, 75°10'W) 6760 km^2

Observation Requirements: Three observations per hour for one hour with center time at high-, low-, and mid-tide (both high to low, and low to high). These observations are to take place during spring, neap, and mid-amplitude tides, as well as during high-, and low-, and mid-river flow. Two to three such sets at each site

Operational Sites

Location and Size: All estuarine systems within SEOS range except perhaps fjords

Observation Requirements: Same as above

Sensor Requirements: EIFOV - 50 to 400 m

Band	Priority	ρ_{min} (%)	ρ_{max} (%)	ρ_{ave} (%)	$\Delta\rho$ (%)	T_{min} (°C)	T_{max} (°C)	T_{ave} (°C)	ΔT (C°)
0.42-0.46	1	1.5	6.5	4	0.5				
0.47-0.52	2	1.5	8	4.5	0.5				
0.53-0.57	1	1	8.5	4.5	0.5				
0.56-0.60	1	0.3	8.5	4.5	0.5				
0.60-0.65	1	0.15	6	1	0.5				
0.65-0.69	1	0.14	5	2.6	0.5				
0.70-0.73	2	0.1	4	1	0.5				
10.3-11.3	1					0	30	10	0.5
11.3-12.0	1					0	30	10	0.5
12.0-12.9	1					0	30	10	0.5
30cm	1 (microwave)								

Data Requirements:

Format: Imagery and computer-compatible tapes

Time After Observation: 2 hours for tapes; imagery somewhat later

Ancillary Data: All pertinent meteorologic, oceanographic, and hydrologic parameters

Application and Application Number: Monitoring Extent, Distribution, and Change of Snow Cover - (No. 3)

User: USDA, NOAA, USDI, municipal water utilities, power companies, local water resource planners, recreation site managers

Observables and Characteristics: Extent, distribution, and time rate of change of snow cover (albedo); soil moisture content (surface temperature variations); reservoir evaporation (surface temperature variations)

Demonstration Sites

Location and Size: Sierra Nevada Mountains, Calif. (37°40'N, 119°W) 5000 km^2; Thunder Creek, Cascade Range, Wash. (48°30'N, 120°W) 500 km^2

Observation Requirements: 0400, 1200, 1500, 1700 hrs on 1st and 15 of month from October through March; also on 4th, 8th, 12th, 16th, 20th, 24th, 28th of April, May and June

Operational Sites

Location and Size: Areas of significant snow cover throughout the U.S. (North of 34°N latitude)

Observation Requirements: Same as in block above

Sensor Requirements: EIFOV - 50 m for visible and near-IR; 400 m for thermal

Band	Priority	ρ_{min} (%)	ρ_{max} (%)	ρ_{ave} (%)	$\Delta\rho$ (%)	T_{min} (°C)	T_{max} (°C)	T_{ave} (°C)	ΔT (C°)
0.70-0.73	1	60	90	80	3				
2.05-2.35	2	5	55	30	3				
10.3-11.3	3					-30	0	0	2
11.3-12.0	3					-30	0	0	2
12.0-12.9	3					-30	0	0	2

Data Requirements:

Format: Imagery and computer-compatible tapes

Time After Observation: 2 days

Ancillary Data: Ground-based spot-checks of snow depth, equivalent water content, soil moisture

Application and Application Number: Monitoring Volcanic Regions - (No. 4)

User: USACE, USDI, local and regional planning agencies, state police departments, local and regional civil defense agencies

Observables and Characteristics: Temperature, temperature patterns, spatial and temporal changes in temperature of volcanic areas

Demonstration Sites

Location and Size: Fuego (14°28.9'N, 90°52.9'W) 160 km^2; Agua (14°28'N, 90°44.5'W) 160 km^2; Pocaya (14°23'N, 90°36.2'W) 160 km^2; Izalco (13°48.9'N, 89°38.1'W) 160 km^2; San Cristobal (12°24'N, 87°01'W) 160 km^2; Cerro Negro (12°31'N, 86°44'W) 160 km^2; Telica (12°36' N, 86°52'W) 160 km^2

Observation Requirements: 0430, 0800 hrs once per week if active; or 15th of month during all-year monitoring

Operational Sites

Location and Size: See Table A1 (following).

Observation Requirements: Same as given in block above

Sensor Requirements: EIFOV - 500 m

Band	Priority	ρ_{min} (%)	ρ_{max} (%)	ρ_{ave} (%)	$\Delta\rho$ (%)	T_{min}	T_{max}	T_{ave} (°C)	ΔT (C°)
0.47-0.52	3	5	70	40	15				
0.56-0.60	3	5	70	40	15				
0.65-0.69	1	5	70	40	15				
10.3-11.3	1							10	2
11.3-12.0	1							10	2
12.0-12.9	1							10	2

Data Requirements:

Format: Imagery and computer-compatible tapes

Time After Observation: less than one hour

Ancillary Data: Geographic location, winds, other related meteorological data, and ground thermometer readings all relayed by data collection platform (DCP)

TABLE A1. LIST OF VOLCANIC AREAS

Elevation (meters)	Place—Name	Location	
		Country	Coordinates
1995	Volcan de las Tres Virgenes	Mexico	27°28'N 112°35'W
375	Barcena		19°16'N 110°48'W
1100	Volcan Ceboruco		21°09'N 104°30'W
3960	Volcan de Colima		19°25'N 103°43'W
3170	Paricutin		19°29'N 102°15'W
1330	Jorullo		19°02'N 101°40'W
	Sierra de San Andrés		19°50'N 100°38'W
3120	Xitli		19°15'N 99°13'W
5452	Popocatépetl		19°01'N 98°37'W
5675	Pico de Orizaba		19°02'N 97°17'W
1550	Volcan de San Martin		18°35'N 95°10'W
1350	El Chichon		17°20'N 93°12'W
4030	Tacana		15°08'N 92°06'W
4210	Tajumulco	Guatemala	15°02.6'N 91°53.9'W
3768	Santa Maria		14°45.5'N 91°32.9'W
3179	Cerro Quemado		14°47.9'N 91°31.0'W
3533	Zuñil		14°42.8'N 91°28.5'W
3525	Atitlan		14°35.3'N 91°10.9'W
3153	Toliman		14°36.85'N 91°10.6'W
3960	Acatenango		14°30.2'N 90°52.4'W
3835	Fuego		14°28.9'N 90°52.9'W
	Agua		14°28.0'N 90°44.5'W
2544	Pacaya		14°23.0'N 90°36.2'W
1946	Tecuamburro		14°09.0'N 90°26.1'W
~1000	Ahuachapan	El Salvador	13°53'-13°57'N to 89°45'-89°50'W
2181	Santa Ana		13°51.2'N 89°37.8'W
1965	Izalco		13°48.9'N 89°38.1'W
1324	San Marcelino		13°48.4'N 89°34.6'W
1967	San Salvador		13°44.3'N 89°17.3'W
450	Islas Quemadas in Lake Ilopango		13°40.3'N 89°03.2'W
830	San Vincente		13°37.4'N 88°51.1'W
1603	Tecapa		13°29.8'N 88°30.2'W

TABLE A1. LIST OF VOLCANIC AREAS (Continued)

Elevation (meters)	Place — Name	Location: Country	Location: Coordinates
675	Chine Maca		13°30.6'-13°30.4'N to 88°21.7'-88°19.7'W
2132	San Miguel		13°26.2'N 88°13.3'W
	Conchagua		
1250	Cerro del Ocote		13°16.6'N 87°51.2'W
1170	Cerro del Bandera		13°17.0'N 87°50.0'W
550	Conchaguita		13°31.1'N 87°45.9'W
847	Cosegüina	Nicaragua	12°58'N 87°35'W
1781	ElViejo		12°42'N 87°01'W
1592	Chichigalpa		12°41'N 86°59'W
1040	Telica		12°36'N 86°52'W
1037	Santa Clara		12°34'N 86°49'W
140	Hervideros de San Jacinto & Tisate		12°34'N 86°49'W
490	Cerro Negro		12°31'N 86°44'W
1072	Las Pilas		12°29' N 86°41'W
1258	Momotombo		12°25'N 86°33'W
624	Masaya		11°57'N 86°09'W
1400	Mombacho		11°50'N 89°59'W
1557	Concepcion		11°32'N 85°39'W
1511	Orosi	Costa Rica	10°59'N 85°29'W
1895	Rincon de lu Vieja		10°50'N 85°21'W
2020	Miravalles		10°47'N 85°10'W
2722	Poas		10°11'N 84°13'W
2916	Barba		10°08'N 84°05'W
3432	Irazu		9°59'N 83°51'W
3328	Turrialba		10°02'N 83°45'W
3316	Mt. Baker	United States	48°47'10"N 121°49'00"W
4395	Mt. Rainier		46°52'N 121°45.5'W
2975	Mt. St. Helens		46°12'N 122°11'W
1822	Craters of the Moon		43°20'-43°30'N to 113°27'30"-113°35'W
2350	Glass Mountain		41°37'N 121°30'W

TABLE A1. LIST OF VOLCANIC AREAS (Continued)

Elevation (meters)	Place—Name	Location: Country	Location: Coordinates
	Little Glass Mountain		41°35'N 121°35'40"W
1908	Burnt Lava Flow		
1846	Paint Pot Crater		
4317	Mt. Shasta		41°24'N 122°11'W
2125	Cinder Cone		40°32'N 121°20'W
3186	Lassen Peak		40°29.5'N 121°30.5'W
1415	Steamboat Springs		39°22.5'N 119°43'W
1199	Coso Hot Springs		36°N 117°-47'W
2350	Yellowstone National Park		44°-45°N 110°-111°W
1495	Fernandina	Ecuador Archipelago de Colen (Galapagos)	0°22'S 91°33'W
1710	Volcan Wolf		0°01'N 91°21'W
1330	Volcan Darwin		0°11'S 91°17'W
1130	Volcan Alcedo		0°26'S 91°07'W
1490	Sierra Negra		0°50'S 91°10'W
1690	Cerro Azul		0°54'S 91°25'W
780	Pinta		0°35'N 90°45'W
343	Marchena		0°20'N 90°28'W
906	San Salvador		0°13'S 90°46'W
640	Santa Maria		1°18'S 90°27'W
205	Española		1°23'S 89°42'W
183	San Felix	Chile	26°16'S 80°07'W
915	El Yunque	Islas Juan Fernandez	33°39.5'S 78°51'W
~-100	[Submarine volcano]		33°37.3'S 78°47'W
?	[Submarine volcano]	176 km E of Isla Más a Tierra	33°34-40'S 76°49-51'W
5980	Tacora	Chile	17°43'S 69°47'W
6060	Guallatiri		18°25'S 69°06'W
5530	Isluga		19°09'S 68°50'W
5165	Irruputuncu		20°44'S 68°34'W
5310	Olca		20°56'S 68°31'W
5869	Oyahue		21°18'S 68°12'W
6159	San Pedro		21°53'S 68°24'W
4280	Hoyada de Los Geisers del Tatio		22°21'S 68°02'W

TABLE A1. LIST OF VOLCANIC AREAS (Continued)

Elevation (meters)	Place—Name	Location	
		Country	Coordinates
5890	Putana		22°34'S 67°52'W
5641	Lascar		23°22'S 67°44'W
6723	Llullaillaco		24°43'S 68°33'W
5700	Lastarria		25°10'S 68°31'W
6885	Nevado Ojos del Salvado		27°07'S 68°32'W
5640	Tupungatito		33°24'S 69°48'W
5880	San José		33°48'S 69°55'W
4300	Tinguiririca		34°49'S 70°21'W
4090	Peteroa		35°15'S 70°34'W
3830	Descabezado Grande		35°35'S 70°45'W
3810	Cerro Azul		35°40'S 70°46'W
3050	Quizapu (the crater)		35°39'S 70'46'W
	Nevados de Chillan		36°50'S 71°25'W
3089			36°52'S 71°23'W
2985	Antuco		37°24'S 71°22'W
3010	Los Copahues		37°51'S 71°10'W
2822	Lonquimay		38°22'S 71°35'W
3124	Llaima		38°42'S 71°42'W
2840	Villarrica		39°25'S 71°57'W
2400	Riñihue		39°55'S 72°03'W
300	Nilahue		40°22'S 72°06'W
2240	Puyehue		40°35'S 72°08'W
2660	Osorno		41°06'S 72°30'W
2015	Calbuco		41°20'S 72°37'W
1050	Huequi		42°20'S 72°40'W
2470	Minchinmá Vida		42°48'S 72°27'W
2300	Corcovado		43°11'S 72°48'W
3380	Lautaro		49°01'S 73°33'W
1758	Monte Burney		52°20'S 73°24'W
5590	Mesa Nevada de Herveo	Colombia	5°18'N 75°28'W
5389	Ruiz		4°53'N 75°22'W
5215	Tolima		4°39'N 75°22'W
2750	Machin		~4°30'N 75°34'W (13 km SW of Tolima)

TABLE A1. LIST OF VOLCANIC AREAS (Continued)

Elevation (meters)	Place — Name	Location	
		Country	Coordinates
5750	Huila		3°00'N 75°59'W
4590	Puracé		2°22'N 76°23'W
4250	Doña Juana		1°31'N 76°56'W
4180	Galeras		1°13'N 77°18'W
4070	Azufral de Túquerres		1°05'N 77°41'W
4764	Cumbal		0°59'N 77°53'W
4470	Cerro Negro de Mayasquer		0°48'N 77°57'W
3485	Reventador	Ecuador	0°05'S 77°40'W
4787	Guagua Pichincha		0°15'S 78°36'W
5705	Antisana		0°30'S 78°08'W
3870	Sumaco		0°34'S 77°38'W
5897	Cotopaxi		0°50'S 78°26'W
5981	Quilotoa		0°52'S 78°55'W
	Llanganate		1°13'S 78°15'W
5016	Tungurahua		1°27'S 78°26'W
5230	Sangay		2°00'S 78°20'W
5825	El Misti	Peru	16°18'08"S 71°24'50"W
5672	Ubinas		16°21'18"S 70°55'11"W
4800	Huaynaputina		16°35'03"S 70°52'00"W
5806	Tutupaca		17°01'31"S 70°21'30"W
887	The Mountain	Island of Saba	17°38'N 63°14'W
601	The Quill	Isle de St. Eustatius (Statia)	17°29'N 62°57'W
1157	Mount Misery	Isle de St. Christopher (St. Kitts)	17°22'N 62°48'W
985	Nevis Peak	Isle of Nevis	17°09'N 62°35'W
914	Soufriere Hills	Isle of Montserrat	16°43'N 62°11'W
1467	La Soufrière de la Guadaloupe	Basseterre Guadaloupe	16°03'N 61°40'W
~7	(Submarine volcano near Marie Galante)	Guadaloupe-Marie Gal.	~16°08'N ~61°17'W
861	Morne Au Diable	Dominica	15°37'N 61°27'W

TABLE A1. LIST OF VOLCANIC AREAS (Concluded)

Elevation (meters)	Place — Name	Location	
		Country	Coordinates
1421	Morne Diablotins		15°30'N 61°25'W
792	Valley of Desolation		15°18'N 61°18'W
525	Morne Patates		
1397	Montagne Pelée	Isle of Martinique	14°49'N 61°10'W
	Hodder's Volcano	W of Isle of St. Lucia	~14°02'N ~61°04'W
777	Qualibou	Isle of St. Lucia	13°50'N 61°03'W
1178	Soufriere of St. Vincent	Isle of Saint Vincent	13°20'N 61°11'W
-192	Kick-'Em-Jenny	8 km N. of Isle of Grenada	12°18'N 61°38'W
840	Mount St. Catherine	Isle of Grenada	12°09'N 61°40'W

Application and Application Number: Detecting and Monitoring Development and Movement of Colored Water Masses (Plankton)-(No. 5)

User: EPA, FWQA, USDI-BSFW, NOAA, port authorities, health departments, state departments of natural resources, marine patrols, fishing industry, resort operators, recreation industry

Observables and Characteristics: Plankton concentrations, red tide; changes in spectral response in visible bands

Demonstration Sites

Location and Size: Lake Erie (41°46'N, 83°W) 50 km × 150 km; Tampa Bay, Fla. (27°40'N, 82°35'W) 50 km × 50 km

Observation Requirements: Daily at noon (if no ice); also 0900, 1500 if algae bloom occurs

Operational Sites

Location and Size: All water areas within SEOS range

Observation Requirements: Same as above

Sensor Requirements: EIFOV - 20 m

Band	Priority	ρ_{min} (%)	ρ_{max} (%)	ρ_{ave} (%)	$\Delta\rho$ (%)	T_{min}	T_{max}	T_{ave}	ΔT
0.45-0.50	2	2	13	10	0.1				
0.56-0.60	2	2	8	4	0.1				
0.60-0.65	1	2	6	3	0.1				
0.65-0.69	1	2	4	3	0.1				
0.70-0.73	1	2	10	7	0.1				

Data Requirements:

Format: Imagery and computer-compatible tapes

Time After Observation: 2 to 12 hours for control; 1 week for modeling

Ancillary Data: Algae and sediment samples, sea state, wind speed, and direction

Application and Application Number: Detecting and Monitoring Fish Location and Movement - (No. 6)

User: USDI-BSFW, national marine fisheries service, commercial and recreational fishing industries, state, national, and international management agencies

Observables and Characteristics: Sea surface conditions, temperature, color, turbidity, currents, salinity, depth, thermal emission, spectral reflectance

Demonstration Sites

Location and Size: Mississippi Sound and Offshore Waters (30°15'N, 89°W) 8685 km^2 Northern Gulf of California

Observation Requirements: Daily at noon, also 0600, 0900, 1500, 1800 from 15 April to 30 Sept.

Operational Sites

Location and Size: All ocean waters within SEOS range

Observation Requirements: Daily at noon; also 0600, 0900, 1500, 1800 during the local fishing season

Sensor Requirements: EIFOV - 20 m to 400 m

Band	Priority	ρ_{min} (%)	ρ_{max} (%)	ρ_{ave} (%)	$\Delta\rho$ (%)	T_{min} (°C)	T_{max} (°C)	T_{ave} (°C)	ΔT (C°)
0.42-0.46	1	1.5	6.5	4	0.5				
0.47-0.52	2	1.5	8	4.5	0.5				
0.53-0.57	1	1	8.5	4.5	0.5				
0.56-0.60	2	0.3	8.5	4.5	0.5				
0.60-0.65	1	0.15	6	1	0.5				
0.65-0.69	1	0.14	5	2.6	0.5				
0.70-0.73	2	0.1	4	1	0.5				
10.3-11.3	1					0	30	10	0.5
11.3-12.0	1					0	30	10	0.5
12.0-12.9	1					0	30	10	0.5
30cm	1 (microwave)								

Data Requirements:

Format: Computer-compatible tapes in real time. Imagery may be at a later time

Time After Observation: 2 hours or less

Ancillary Data: Meteorologic and oceanographic measurements

Application and Application Number: Ocean Dynamics - (No. 7)

User: NOAA, EPA, USN, USACE, UN, FAO, USCG, Dept. of Interior, International Oceanographic Commission, Dept. of Transportation

Observables and Characteristics: Ocean color and temperature, sun glitter, cloud patterns. Visible and thermal imagery

Demonstration Sites

Location and Size: Northern Gulf of Mexico (29°12'N, 89°W) 150 km × 150 km

Observation Requirements: Daily at 0900, 1200, 1500

Operational Sites

Location and size: Entire Ocean area within SEOS range

Observation Requirements: Same as in block above

Sensor Requirements: EIFOV - 100 m

Band	Priority	ρ_{min} (%)	ρ_{max} (%)	ρ_{ave} (%)	$\Delta\rho$ (%)	T_{min} (°C)	T_{max} (°C)	T_{ave} (°C)	ΔT (C°)
0.47-0.52	2	2	10	8	0.1				
0.53-0.57	1	2	8	5	0.1				
0.56-0.60	1	2	8	4	0.1				
0.60-0.65	1	2	6	3	0.1				
0.65-0.69	1	2	4	2	0.1				
0.70-0.73	1	2	10	2-7	0.1				
2.05-2.35	2	5	70	40	3				
10.3-11.3	1					2	35	15	1
11.3-12.0	1					2	35	15	1
12.0-12.9	1					2	35	15	1
30cm	2 (microwave)								
10cm	2 (radar)								

Data Requirements:

Format: Imagery-positives and negatives. Computer-compatible tapes

Time After Observation: 4 hr

Ancillary Data: Surface and airborne verification of anomaly-detection of sea state, meteorological data (during observations), and all water parameters

Application and Application Number: Detection and Assessment of Disease and Insect Damage To Forest Species - (No. 8)

User: U.S. Forest Service, state departments of natural resources, forest experiment stations, city foresters, forestry products industry, home and woodlot owners, veneer industry

Observables and Characteristics: Percent of vegetation cover (large-scale defoliation or foliage discoloration patterns due to insect or disease damage)

Demonstration Sites

Location and Size: (a) Grand Teton National Park (Mt. Pine Bark Beetle) (43°45'N, 110°48'W) 10×10^{10} m^2

(b) Umatilla National Forest (Douglas Fir Tussock Moth) (43°37'N, 118°40'W) 4×10^{10} m^2

Observation Requirements: (a) Solar noon on 1st, 8th, 15th, 22nd of June, July and August

(b) Solar noon on 1st, 8th, 15th, 22nd of June and July

Operational Sites

Location and Size: States of: Colorado, Wyoming, Montana, Idaho, Washington, Oregon, California, Minnesota, Massachusetts, Connecticut, Maine

Observation Requirements: Same as "(a)" above

Sensor Requirements: EIFOV - 300 m

Band	Priority	ρ_{min} (%)	ρ_{max} (%)	ρ_{ave} (%)	$\Delta\rho$ (%)	T_{min}	T_{max}	T_{ave}	ΔT
0.53-0.57	4	17	30	25	0.5				
0.65-0.69	1	22	44	30	0.5				
0.78-0.82	2	45	55	50	0.5				
2.05-2.35	3	10	30	25	0.5				

Data Requirements:

Format: Thematic maps of isodefoliation, overlays to show occurrence of reflushing, tabulated statistics on extent of defoliation change

Time After Observation: 1 month

Ancillary Data: Location of known defoliation sites, forest cover type maps

Application and Application Number: Forest Inventory and Valuation of Multiple-Use Management - (No. 9)

User: U.S. Forest Service, state departments of natural resources, National Park Service, forest products industry, natural resource departments of foreign governments, outdoor recreation industry, food and agriculture organizations

Observables and Characteristics: Phenological foliage reflectance patterns of northern forest tree species

Demonstration Sites

Location and Size: Ottawa National Forest (46°30'N, 89°W) 2.3×10^6 m^2; Manistee National Forest (44°30'N, 86°W) 2.3×10^6 m^2

Observation Requirements: Solar noon on 15th, 22nd of Sept; 1st, 8th, 15th, 22nd of October; and 1st, 8th of November

Operational Sites

Location and Size: States of Minnesota, Wisconsin, Michigan, Pennsylvania, New York, Connecticut, New Hampshire, Vermont, Maine

Observation Requirements: Same as above

Sensor Requirements: EIFOV - 500 m

Band	Priority	ρ_{min} (%)	ρ_{max} (%)	ρ_{ave} (%)	$\Delta\rho$ (%)	T_{min}	T_{max}	T_{ave}	ΔT
0.53-0.57	2	8	15	10	0.5				
0.65-0.69	1	5	30	20	0.5				
0.78-0.82	2	30	40	40	0.5				
2.05-2.35	3	25	35	30	0.5				

Data Requirements:

Format: Overlays of timber types by tone for a suitable map base—e.g., USGA quad. sheets; tabulated statistics for areas of these types.

Time After Observation: 6 months

Ancillary Data: Suitable map base; coordinates, time

Application and Application Number: Evaluation of Range Forage Resources and Grazing Pressure Assessment - (No. 10)

User: USDA-SRS, USFS, BLM, BIA, individual livestock owners and associations, local management agencies

Observables and Characteristics: Annual greening of forage resource, reflectance phenomena associated with amount of biomass produced and/or grazing intensity

Demonstration Sites

Location and Size: (a) Tucson, Arizona (32°14'N, 110°57'W 100 km^2; (b) Weslaco, Texas (26°09'N, 98°W 100 km^2; (c) Pawnee Co., Colo. (40°35'N, 105°06'W 100 km^2; (d) Cottonwood, S.D. (44°53'N, 98°30'W 100 km^2)

Observation Requirements: Noon every other day, (a) during April, August and September, (b) from 15 March to 15 May, (c) from 15 April to 15 June, (d) from 15 April to 15 June

Operational Sites

Location and Size: Eastern half of: (a) New Mexico, (b) Colorado, (c) Wyoming, (d) Montana Western half of: (e) Oklahoma, (f) Kansas, (g) Nebraska, (h) South Dakota, (i) North Dakota, (j) North Texas, (k) South Texas

Observation Requirements: Noon every other day, a, e, f, j, 1 April to 1 June; b, c g, h, 15 April to 15 June; k, 15 March to 15 May; e, i, 1 May to 1 July

Sensor Requirements: EIFOV - 100 m

Band	Priority	ρ_{min} (%)	ρ_{max} (%)	ρ_{ave} (%)	$\Delta\rho$ (%)	T_{min}	T_{max}	T_{ave}	ΔT
0.78-0.82	1	20	40	30	0.5				
0.65-0.69	1	4	12	8	0.5				
2.05-2.35	2	20	30	25	0.5				

Data Requirements:

Format: Computer-compatible tapes

Time After Observation: 1 day

Ancillary Data: Topographic maps, land ownership data, location of major vegetation types, clipped quadrants, ground photographs

Application and Application Number: Management of Irrigation - (No. 11)

User: USDI, USDA, local and regional water supply managers, commercial farmers

Observables and Characteristics: Soil moisture content, soil albedo, diurnal temperature excursion. Crop moisture stress and phenology: ground cover, crop vigor and maturation (from vegetation signatures).

Demonstration Sites

Location and Size: Columbia River Basin, Wash. (46°N, 120°W) 1000 km^2; Glenn and Butte Co., Calif. (39°43'N, 121°51'W) 1000 km^2; Maricopa Co., Ariz. (33°27'N, 112°04'W) 1000 km^2; Holt Co., Neb. (42°28'N, 98°38'W) 1000 km^2

Observation Requirements: 0400, 1200, 1500 hrs, on 1st, 8th, 15th, and 22nd of May, June, July, and August

Operational Sites

Location and Size: States of: Arizona, North Dakota, South Dakota, Nebraska, Kansas, Oklahoma, and Texas

Observation Requirements: Same as in block above

Sensor Requirements: EIFOV - 350 m

Band	Priority	ρ_{min} (%)	ρ_{max} (%)	ρ_{ave} (%)	$\Delta\rho$ (%)	T_{min} (°C)	T_{max} (°C)	T_{ave} (°C)	ΔT (C°)
0.53-0.57	4	12	18	15	3				
0.70-0.73	1	10	30	20	5				
2.05-2.35	2	15	45	30	3				
10.3-11.3	3					10	50	30	1
11.3-12.0	3					10	50	30	1
12.0-12.9	3					10	50	30	1

Data Requirements:

Format: Imagery and computer-compatible tapes. Maps of relative need.

Time After Observation: 2 days

Ancillary Data: Soil moisture, crop relative turgidity, transpiration rate, vegetation temperatures

Application and Application Number: Detecting and Monitoring Oil Pollution-(No. 12)

User: USCG, EPA, USACE, NOAA, major oil companies, citizen groups, port authorities, fishing industry

Observables and Characteristics: Oil films on water surfaces, observed as variations from ambient water temperature (i.e., thermal differences) or as variations in visible and NIR reflectance-spectral differences

Demonstration Sites

Location and Size: Mississippi River, (30°N, 90°05'W) 2500 km^2; Houston Ship Channel (29°45'N, 95°22'W) 2500 km^2; Northern Gulf of Mexico (29°16'N, 89°W) 22,500 km^2

Observation Requirements: Daily at noon; if oil spill occurs, then every hour

Operational Sites

Location and Size: All water areas in range of SEOS, with emphasis on U.S. Coastal and Inland shipping areas

Observation Requirements: Same as in block above

Sensor Requirements: EIFOV - 20 m

Band	Priority	ρ_{min} (%)	ρ_{max} (%)	ρ_{ave} (%)	$\Delta\rho$ (%)	T_{min} (°C)	T_{max} (°C)	T_{ave} (°C)	ΔT (C°)
0.53-0.57	1	0.1	12	5	1				
0.47-0.52	1	0.1	15	6	1				
0.56-0.60	1	0.1	10	5	1				
0.65-0.69	1	0.1	10	5	1				
10.3-11.3	2					2	35	15	1
11.3-12.0	2					2	35	15	1
12.0-12.9	2					2	35	15	1

Data Requirements:

Format: Imagery and computer-compatible tapes

Time After Observation: 4 hours

Ancillary Data: Geographic coordinates of detections. Field-checked signatures of SEOS alerts. Sea state, wind, oil sample type and thickness.

Application and Application Number: Diurnal and Seasonal Variations for Lithologic Survey - (No. 13)

User: USGS, USBM, foreign national geological surveys, mining industry, exploration companies

Observables and Characteristics: Reflectance and emission spectra characteristic of specific terrestrial materials; thermal patterns and spatial variations in thermal inertia

Demonstration Sites

Location and Size: White Sands, New Mexico (33°N, 106°30'W) 3600 km^2

Observation Requirements: 0530, 0800, 1300, 1930 hrs on 15th of February, May, August, November

Operational Sites

Location and Size: New Mexico, Texas, Arizona, Utah

Observation Requirements: Same as in block above

Sensor Requirements: EIFOV -

Band	Priority	ρ_{min} (%)	ρ_{max} (%)	ρ_{ave} (%)	$\Delta\rho$ (%)	T_{min} (°C)	T_{max} (°C)	T_{ave} (°C)	ΔT (C°)
0.42-0.46	3	5	80	15	1				
0.45-0.50	3	5	80	20	1				
0.47-0.52	3	5	80	20	1				
0.53-0.57	2	5	80	25	2				
0.56-0.60	1	5	80	30	2				
0.60-0.65	1	5	80	35	2				
0.65-0.69	2	5	80	40	2				
0.70-0.73	3	5	80	40	2				
0.78-0.82	3	5	80	40	2				
0.85-0.89	2	5	80	40	2				
0.89-0.95	1	5	80	45	2				
0.95-1.10	2	5	80	50	2				
2.05-2.35	1	5	80	35	25				
8.3-9.4	1					0	30	20	1.5
10.3-11.3	1					0	30	20	1.5
11.3-12.0	2					0	30	20	1.5
12.0-12.9	1					0	30	20	1.5

Data Requirements:

Format: Imagery and computer-compatible tapes

Time After Observation: 6 months

Ancillary Data: Weather reports, thermatic maps in existence for test area

Application and Application Number: Monitoring and Analysis of Lake Dynamics-(No. 14)

User: NOAA, USACE, EPA, Great Lakes Basin Commission, state departments of natural resources, various water resource commissions, fishing industry, lake region landowners and recreation industry

Observables and Characteristics: Color and temperature discontinuities identifiable in visible and thermal imagery. Position and movement of natural or artificially induced tracers.

Demonstration Sites

Location and Size: Western Basin of Lake Erie (41°46'N, 83°W) 6000 km^2; Southern Lake Michigan (43°N, 87°30'W) 11,500 km^2

Observation Requirements: Daily at noon from 1 April through 1 December

Operational Sites

Location and Size: All the Great Lakes and other large lakes within SEOS range

Observation Requirements: Same as in block above

Sensor Requirements: EIFOV - 50 to 400 m

Band	Priority	ρ_{min} (%)	ρ_{max} (%)	ρ_{ave} (%)	$\Delta\rho$ (%)	T_{min} (°C)	T_{max} (°C)	T_{ave} (°C)	ΔT (C°)
0.42-0.46	1	4.8	9	6	0.5				
0.47-0.52	1	2.5	4.5	3.5	0.5				
0.53-0.57	1	1.5	2.5	2	0.5				
0.56-0.60	2	1.3	1.8	1.5	0.5				
0.60-0.65	1	0.15	6	1	0.5				
0.65-0.69	1	0.6	1.7	0.5	0.5				
0.70-0.73	2	0.1	2	0.5	0.5				
10.3-11.3	1					0	30	10	0.5
11.3-12.0	1					0	30	10	0.5
12.0-12.9	1					0	30	10	0.5

Data Requirements:

Format: Imagery and computer-compatible tapes

Time After Observation: Not critical—6 months

Ancillary Data: Wind speed and direction, water content

Application and Application Number: Wildfire Monitoring-(No. 15)

User: USFS, BLM, BIA, NPS, Canadian Forestry Service, state departments of natural resources, timber companies

Observables and Characteristics: Smoke and heat, reflection and thermal emission, intensity and spatial pattern, fire parameter, and internal structure

Demonstration Sites

Location and Size: (a) Northwestern U.S. (Washington, Oregon, Idaho, Western Montana) 180 km^2; (b) Southern California 180 km^2

Observation Requirements: If forest fire occurs, then 0400, 1200, 2000 hrs for area (a) from 1 June to 1 November and for area (b) from 1 May to 1 August

Operational Sites

Location and Size: (a) Southeast U.S., (b) Northeast U.S., (c) Northwest U.S., (d) Southwest U.S.

Observation Requirements: Same as in block above, but during (a) September-May, (b) March-May and Oct-December, (c) June-October, (d) May-July

Sensor Requirements: EIFOV - 100 to 200 m for visible and NIR; 30 to 50 m for IR—center of fire; 800 m for IR—extent of fire and heat budget

Band	Priority	ρ_{min} (%)	ρ_{max} (%)	ρ_{ave} (%)	$\Delta\rho$ (°C)	T_{min} (°C)	T_{max} (°C)	T_{ave} (°C)	ΔT (C°)
0.53-0.57	2	8	15	10	0.5				
0.65-0.69	2	5	30	20	0.5				
0.78-0.82	2	30	40	40	0.5				
3.6-4.1	1					0	600	600	20
10.3-11.3	1					0	600	600	20
11.3-12.0	1					0	600	600	20
12.0-12.9	1					0	600	600	20

Data Requirements:

Format: Imagery, annotated maps, on-site TV display

Time After Observation: Instantaneous monitoring (about 5 minutes)

Ancillary Data: Fuel conditions, weather forecasts, meteorological conditions, local topography

Application and Application Number: Flood Prediction, Survey and Damage Assessment-(No. 16)

User: USACE, USDI, USDA, local and regional planning agencies, local and regional civil defense agencies, state police forces, state departments of natural resources, water resources boards, disaster relief agencies

Observables and Characteristics: Flood waters, extent, depth, rate of change, flooded lands, damaged areas

Demonstration Sites

Location and Size: Mississippi River and Major Tributaries (29°12' to 45°N, 80° to 102°W) 9000 km^2; Central California and Bay Area (38°N, 122°W) 9000 km^2; Lake Erie Shoreline of Michigan and Ohio (42°N, 82°W); Michigan Shoreline from Lake St. Claire to Saginaw Bay (43°N, 83°W); Atlantic Coast of Georgia, North Carolina, South Carolina (29°N, 80°W); Entire Florida Coast (28°N, 82°W); Alabama, Mississippi, Louisiana, Texas Coast (30°N, 95°W)

Observation Requirements: at least once daily when flooding occurs, if clouds permit

Operational Sites

Location and Size: All above areas plus major river basins in Central and South America. Also the Caribbean Islands

Observation Requirements: Same as in block above

Sensor Requirements: EIFOV - 100 m

Band	Priority	ρ_{min} (%)	ρ_{max} (%)	ρ_{ave} (%)	$\Delta\rho$ (%)	T_{min} (°C)	T_{max} (°C)	T_{ave} (°C)	ΔT (C°)
0.53-0.57	1	15	60	25	1				
0.65-0.69	1	15	60	25	1				
0.89-0.95	1	15	60	25	1				
2.05-2.35	1	15	20	18	1				
10.3-11.3	3					0	20	10	1°
11.3-12.0	3					0	20	10	1°
12.0-12.9	3					0	20	10	1°

Data Requirements:

Format: Imagery overlays, and computer-compatible tape

Time After Observation: 1 day for disaster-relief activities, 1 month for flood plain delineation

Ancillary Data: Time of observation, stream flow data, localized spot-checks of water depth and extent

Application and Application Number: Monitoring Water Erosion and Deposition-(No. 17)

User: USCG, USA, USACE, USDA, USDI, USDT, disaster relief agencies, highway departments, public health offices, state departments of natural and water resources

Observables and Characteristics: Damaged areas, sediment load in streams, channel changes, coastal changes, reservoir washouts, characteristics of water

Demonstration Sites

Location and Size: Same as Application No. 16 plus all of Great Lakes basin and coastal shores

Observation Requirements: When flood or storm occurs—as often as possible (up to maximum of 1/hr) when clouds permit, for period including event duration and several days after

Operational Sites

Location and Size: All above and major river basins in Central and South America, also Caribbean Islands

Observation Requirements: Same as in block above

Sensor Requirements: EIFOV - 100 m

Band	Priority	ρ_{min} (%)	ρ_{max} (%)	ρ_{ave} (%)	$\Delta\rho$ (%)	T_{min} (^oC)	T_{max} (^oC)	T_{ave} (^oC)	ΔT (C^o)
0.42-0.46	1	5	15	10	1				
0.45-0.50	1	5	15	10	1				
0.47-0.52	1	5	15	10	1				
0.53-0.57	2	5	20	10	1				
0.65-0.69	2	5	20	10	1				
0.89-0.95	2	15	30	20	1				
2.05-2.35	1	15	20	18	1				
10.3-11.3	3					0	20	10	1^o
11.3-12.0	3					0	20	10	1^o
12.0-12.9	3					0	20	10	1^o

Data Requirements:

Format: Imagery, overlays, computer-compatible tape

Time After Observation: 1 day

Ancillary Data: Weather, hydrographic, local gauges

Application and Application Number: Diurnal and Seasonal Variations for Thematic Mapping- (No. 18)

User: USGS, BLM, BOR, USDA, USFS, USDI, state departments of natural resources, state highway departments, timber companies, state and regional planning agencies, zoning and enforcement agencies, real estate development agencies

Observables and Characteristics: Diurnal temperature changes, critically timed observations of seasonal changes, observations under varying view angles and sun angles

Demonstration Sites

Location and Size: College Station, Texas, 30°40'N, 96°22'W; Lafayette, Indiana, 40°26'N, 86°53'W; Lansing, Michigan, 42°45'N, 84°35'W; Maricopa Co., Arizona, 33°27'N, 112°04'W; Central Atlantic Regional Ecological Test Site, 38°34'N, 76°07'W

Observation Requirements: 0400, 0900, 1200, 1500, 1800 hrs on 15th of January, March, June, October

Operational Sites

Location and Size: Continental U.S.

Observation Requirements: Same as in block above

Sensor Requirements: EIFOV -

Band	Priority	ρ_{min} (%)	ρ_{max} (%)	ρ_{ave} (%)	$\Delta\rho$ (%)	T_{min} (°C)	T_{max} (°C)	T_{ave} (°C)	ΔT (C°)
0.42-0.46	3	5	80	10	1				
0.45-0.50	3	5	80	10	1				
0.47-0.52	3	5	80	15	1				
0.53-0.57	2	5	80	10	1				
0.56-0.60	1	5	80	15	1				
0.60-0.65	1	5	80	10	0.5				
0.65-0.69	1	5	80	20	0.5				
0.70-0.73	3	5	80	20	1				
0.78-0.82	1	5	80	40	0.5				
0.85-0.89	2	5	80	40	1				
0.89-0.95	1	5	80	40	1				
0.95-1.10	2	5	80	40	1				
2.05-2.35	1	5	80	20	0.5				
8.3-9.4	1					0	30	20	1.5
10.3-11.3	1					0	30	20	1.5
11.3-12.0	1					0	30	20	1.5
12.0-12.9	1					0	30	20	1.5

Data Requirements:

Format: Imagery and computer-compatible tapes

Time After Observation: 1 month - not critical

Ancillary Data: Time of observation, view angles, ground-based spot checks

Application and Application Number: Monitoring and Prevention of Aeolian Soil Erosion-(No. 19)

User: USDA, USDI, Soil Conservation Service, farmers, agricultural cooperatives and associations, agricultural industry

Observables and Characteristics: Soil moisture, spectral-radar return, soil-moisture levels in dry periods

Demonstration Sites

Location and Size: Lamb Co., Texas, 33°56'N, 102°18'W 2.7×10^{10} m^2; Griggs Co., N. D., 47°27'N, 98°06'W 2.7×10^{10} m^2

Observation Requirements: Solar noon on 1st, 8th, 15th, 22nd of June, July, August

Operational Sites

Location and Size: Central U.S., including parts of Montana, Minnesota, North and South Dakota, Nebraska, Wyoming, Colorado, Kansas, Oklahoma, Texas, New Mexico

Observation Requirements: Same as in block above

Sensor Requirements: EIFOV - 500 m

Band	Priority	ρ_{min} (%)	ρ_{max} (%)	ρ_{ave} (%)	$\Delta\rho$ (%)	T_{min} (°C)	T_{max} (°C)	T_{ave} (°C)	ΔT (C°)
0.65-0.69	2	5	20	13	0.5				
0.78-0.82	2	8	25	15	0.5				
1.52-1.73	4	30	40	35	0.5				
or 2.05-2.35	4	35	45	40	0.5				
10.3-11.3	4					10	40	20	1
11.3-12.0	4					10	40	20	1
12.0-12.9	4					10	40	20	1
1cm	1 microwave								
10cm	3 radar								

Data Requirements:

Format: Imagery and computer-compatible tapes. Prevention thematic maps of soil moisture for affected region

Time After Observation: Prevention; 12 hr

Ancillary Data: Soil-type maps, topographic maps, weather information

Application and Application Number: Detection and Assessment of Disease and Insect Damage to Cultivated Crops - (No. 20)

User: USDA-SRS, USDA-ARS, state departments of agriculture, entomology, and pathology, extension services, farmers and intermediate elements of the food preparation and consumption industry

Observables and Characteristics: Percent vegetation cover, leaf area index, biomass, leaf geometry, leaf moisture, leaf reflectance, and temperature

Demonstration Sites

Location and Size: (a) Hill Co., Montana, 48°33'N, 109°41'W, 100 km^2; (b) Burke Co., N. Dakota, 48°47'N, 102°01'W, 100 km^2; (c) Whitman Co., Washington, 46°44'N, 117°12'W, 100 km^2; (d) Saskatoon, Canada, 52°12'N, 106°44'W, 100 km^2; (e) Garden City, Kansas, 37°57'N, 100°53'W, 100 km^2

Observation Requirements: Noon every other day, (a) 1 May to 1 August; (b) 15 June to 1 August; (c) 15 April to 15 July; (d) 15 June to 1 August; (e) 15 April to 1 June

Operational Sites

Location and Size: Winter Wheat: (a) Central Montana; (b) E. Washington, S.E. Idaho, N.W. Utah, S. South Dakota, Nebraska, E. Colorado, S. Iowa, Missouri, Kansas, S. Illinois, Indiana, Ohio, S. Michigan, N. Kentucky, N. Oklahoma; (c) S.W. Oklahoma, N. Texas; Spring Wheat: (d) N.E. Montana, North Dakota, N. South Dakota, W. Minnesota; (e) S.E. Washington, N.E. Oregon, W. Central Oregon, S.E. Oregon, N. Utah, W. Wyoming, S. South Dakota, N. and N.W. Nebraska, N.E. Colorado, S. Minnesota.

Observation Requirements: Noon every other day: (a) 1 May to 15 June; (b) 15 April to 1 June; (c) 1 April to 15 May; (d) 15 June to 1 August; (e) 1 June to 15 July

Sensor Requirements: EIFOV - 100 m

Band	Priority	ρ_{min} (%)	ρ_{max} (%)	ρ_{ave} (%)	$\Delta\rho$ (%)	T_{min} (°C)	T_{max} (°C)	T_{ave} (°C)	ΔT (°C)
0.65-0.69	1	4	12	8	0.5				
0.78-0.82	1	20	50	35	0.5				
0.53-0.57	3	5	15	10	0.5				
2.05-2.35	2	15	25	20	0.5				
or 1.52-1.73	2	20	40	30	0.5				
10.3-11.3	3					10	40	25	1
11.3-12.0	3					10	40	25	1
12.0-12.9	3					10	40	25	1

Data Requirements:

Format: Computer-compatible tapes

Time After Observation: 1 day

Ancillary Data: Crop ID/location and on-ground confirmation of pathogenic agent and test site, estimate of productivity, loss of correlation with altered reflectance

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