Warren L. Flock

ELECTROMAGNETICS AND THE ENVIRONMENT: Remote Sensing and Telecommunications

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This volume differs from most environmental literature in the attention it gives to the environmental role of electromagnetic radiation, and it is rather unusual among literature treating technical topics in the attention it gives to the environment. The material is aimed at persons with interests in remote sensing of the environment, radar, telecommunications, or solar energy; those interested in applications of electromagnetic theory; and those with potential or established interests in the environment itself.

The title, *Electromagnetics and the Environment*, was chosen in recognition of the role of electromagnetic radiation in the environment and in our lives. The subtitle, *Remote Sensing and Telecommunications*, indicates specifically two of the principal topics that are considered to fall under the heading of the title. A third important aspect considered is solar energy, with emphasis on the effects of the propagation medium (the atmosphere) and on the availability of the resource at ground level. Other aspects of solar energy, such as flat-plate and concentrating collectors, are considered briefly as well. Important features of climate depend on the balance between incoming solar radiation and outgoing infrared radiation, which balance may be affected by man's activities. Also there is concern that the climate may be changing adversely at present because of poorly understood factors of natural origin. Such topics are complex and difficult to analyze but are discussed qualitatively in sections of Chapters 1, 3, and 5. The atmosphere is important to all the subjects considered and affects radiation of a given frequency in the same way regardless of whether the radiation is a feature of natural processes or is used for remote sensing or telecommunications or for providing energy for man's needs.

PREFACE

The electromagnetic aspects of remote sensing and telecommunications receive emphasis. It has been necessary, except for the inherent, inevitable overlap that occurs, to omit or minimize the interesting and important subjects of information theory and data processing. Furthermore, not all applications of remote sensing could be covered; subsurface sensing and extraterrestrial sensing have been omitted, and a number of individuals may find that some topic of interest to them is missing or does not receive proper attention. Certain major topics are treated in sufficient detail, however, to be useful to engineers and scientists in industry and to be suitable for a one-semester or longer upper-division engineering or science course. By providing both overall breadth and depth in certain areas, it is believed that this volume is suitable for different types of readers, including those who wish to concentrate on breadth and those who wish to devote effort to quantitative topics in some depth. Some persons interested in the environment, remote sensing, or telecommunications but lacking a strong technical background, for example, may wish to concentrate on the less technical sections and accept as fact the conclusions of the more highly technical sections. The electrical engineer or physicist will have had, or will want, the kind of background provided in a beginning, conventional course on electromagnetic fields and will give considerable attention to the technical material. This volume is suitable also for the important case of the person who is not an engineer or physical scientist, and does not plan to become one, but wishes to have an exposure to technical topics and wants an understanding of the language and techniques of remote sensing and telecommunications.

The material is an outgrowth of an undergraduate course entitled Environmental Electromagnetics that was developed for electrical engineering students. The course has the purpose of serving as an elective course in the electromagnetic fields area. As such it includes basic subject matter on atmospheric effects on electromagnetic waves, thermal radiation, and applications and extensions of material in introductory courses on electromagnetic fields. Any topic involving electromagnetic radiation, including radiation at optical frequencies, is considered to fall in the area of electromagnetic fields. The course is intended to provide experience with interdisciplinary applications of electromagnetic theory and with environmental and resource problems, rather than to serve as another pure conventional electromagnetics course emphasizing boundary value problems. The material of portions of Chapters 2, 3, and 4 has also been used in a course in an interdisciplinary program in telecommunications. Problems are included in the text for class use and for those who wish to obtain experience in applying the concepts presented. Cited references are listed at the end of each chapter, and an additional short bibliography of selected publications on remote sensing is placed at the end of the volume. Whereas the body of the text tends to emphasize technical principles and gives considerable attention to remote sensing of the atmosphere, a number of treatments of remote sensing omit the atmosphere and emphasize applications to the land, of interest to geographers, geologists, biologists, and many other users of remote sensing. The bibliography at the end of this volume is oriented in the latter direction.

One way for an instructor to conduct a technical course based on the material of this volume but to give also an exposure to environmental and resource problems is to emphasize certain of the technical sections and the problems in class generally but to spend a few periods at least on Chapter 1, assign the chapter for reading, and call for as an assignment a critical review of a nontechnical environmental reference, or references, such as those listed for Chapter 1. Alternatively, Chapter 1 and other nontechnical sections and references could receive more emphasis in a less technical course. The engineering instructor may need to make a choice between emphasizing Chapters 3 and 4 or Chapters 5 and 6, with the technical portion of Chapter 2 being essential in either case.

Knowledge is commonly compartmentalized in our educational institutions, with practical justification to a certain extent. The compartmentalization is often artificial, however, and the solution of real-world problems often needs and is facilitated by an interdisciplinary approach. This volume draws strongly upon the area of electromagnetics but is devoted also to an interdisciplinary viewpoint.

I would like to express my appreciation to the many individuals whose work is reported here or who have provided information of value. These persons are too numerous to mention individually, but I do wish to give special thanks to colleagues associated with the International Union of Radio Science (URSI), the Institute of Electrical and Electronics Engineers (IEEE), the American Geophysical Union (AGU), the Geophysical Institute of the University of Alaska, the EROS Data Center of the U.S. Geological Survey, and Goodyear Aerospace Corp. Also I am particularly grateful to colleagues in Boulder, Colorado, who are with the Environmental Research Laboratories of the National Oceanic and Atmospheric Administration (NOAA), the Institute of Telecommunications Sciences (ITS), the National Bureau of Standards (NBS), the National Center for Atmospheric Research (NCAR), and the University of Colorado. In addition I appreciate the attentiveness and helpful questions of the students who have taken the course on which the material is based and the support of the Department of Electrical Engineering of the University of Colorado.

WARREN L. FLOCK

CONTENTS

1-1 ESSENTIAL NATURAL RESOURCES

Belatedly, in the late 1960's, the environment became a popular cause. The widespread concern that developed about the environment was overdue and most welcome to persons who had been concerned about conservation in earlier years when it was not so popular. By 1973 the energy crisis posed severe problems for the environmental movement but it still had momentum.

In the following pages we shall consider such well-known environmental topics as air pollution and energy and also the less familiar concepts of the electromagnetic spectrum as a natural resource and the environmental role of electromagnetic radiation. Remote sensing of the environment receives considerable emphasis; indeed all of the chapters contribute to that subject. The topics of the various chapters are also important, however, in their own right. The technical bases for remote sensing and those aspects of telecommunications considered here are similar, and for some purposes remote sensing might be considered to fall under the heading of telecommunications. In any case Chaps. 2, 3, and 4 are clearly applicable to both topics, and Chaps. 5 and 6 clearly apply to remote sensing. Before treating these topics, however, natural resources and the environment are discussed in general terms.

Concern over natural resources and the environment has been of at least two types—concern over the adequacy of natural resources for the survival of increasing numbers of persons and concern over the quality of the environment. In the first case one might question whether food, energy, and mineral resources will be adequate or not; in the second case one might ask

NATURAL RESOURCES AND THE ENVIRONMENT

1

whether the environment will be so crowded and ravaged that life will be no more than mediocre, if bearable, even though food and other supplies are adequate to support life. The two aspects cannot be completely separated, but one aspect or the other can be emphasized at a time. There are serious questions about the adequacy of food and energy resources, but the potential role of technology in alleviating shortages of essential resources seemed to many, until recently at least, to provide a basis for being less concerned about these than about the quality of the environment. The environmental movement has focused attention on the quality of environment, or on those aspects of environment which contribute to or detract from the quality of life. To many persons, the availability of natural, wild, scenic, and uncrowded areas is a highly desirable, if not essential, component of a high quality of life.

Some of the resources essential to life in a modern society are air, water, food, energy, minerals, and forest products. Of these essential resources much attention has been focused on food for obvious reasons. The Reverend Thomas R. Malthus in 1798 raised the discouraging prospect that the human race would run out of food, and ever since then writers have argued either that Malthus was wrong or that he was right. Since his time much has been accomplished in increasing food production by the application of machinery, fertilizers, pesticides, and plant breeding. The Rockefeller and Ford Foundation programs for increasing wheat and rice production were so highly successful that the term Green Revolution was coined for the leap forward in food production that was under way by about 1966. Highly optimistic statements about the ability to feed the peoples of the world were made at that time. By about 1974, however, the great optimism engendered in some quarters about food resources by the Green Revolution lessened, and the actual and potential role of adverse climatic conditions on food production began to attract more attention. Lester Brown [16, 17] has been an informative and prolific writer about food and related matters, and a thought-provoking treatment of food and climate has been presented by Stephen Schneider [77]. *Science* magazine has been a good source of information on food [2], and a study of research on food and nutrition has been made by the National Academy of Science [67]. Some developments and considerations concerning food and climate are now outlined briefly.

In 1972 the U.S.S.R. experienced a severe drought, the monsoon was delayed by several weeks in India, the Sahelian drought continued in Africa, and the Midwest of the United States experienced floods. As a result world food production fell in 1972 for the first time in two decades. Two years later, 1974 was a year of productivity decline in North America. Corn production in the United States was especially hard hit by drought and early frost and was down 20% from the trend in 1974 [74]. It was the 1972 drought in the U.S.S.R. that led to the large Soviet grain purchases from the United States and Canada that contributed to dramatic increases in the cost of wheat and other foods. The agricultural problems of 1972 and 1974 drew attention to the importance of climate and to uncertainty about future climatic trends.

Another unfavorable event in 1972 was the failure of the anchovy fishery off the coast of Peru, due to the invasion of the cold upwelling waters off Peru by the warm current, El Niño, from the north. Recovery of the anchovy fishery has been slow. More intensive development of the world's fisheries has been often mentioned as one of the means of feeding the growing world population, but the production of food from the sea, after increasing by roughly 5% per year from 1950 to 1970, dropped in 1970 and continued to fall for three consecutive years [16], presumably due to overfishing and pollution as well.

The formerly large reserves of grains in the United States became small by about 1974, due to the demands upon them and because of a Department of Agriculture policy that government should get out of the food business. Memory of the depressing effect on prices of food surpluses and stores in the past was a factor in forming attitudes. The world reserves in terms of days of grain consumption decreased from 105 in 1961 to 35 in 1975 [77]. The 1961 figure included about 31 days as the grain equivalent of idled U.S. cropland, but the idled cropland had dropped to zero by 1974. Replenishment of the reserves has been advocated by a number of writers [16, 60, 74, 77]. Since the low point of 1974, inventories of grain increased, however, from the lowest point in 25 years in 1974 to the highest values in 14 years in 1977, in spite of the drought that occurred in large portions of the United States. Thus the immediate crisis in grain supplies eased, but the low market prices for wheat and corn received by farmers in 1977, problems of food distribution, and uncertainties of climate were such that hunger and the threat of future food shortages remained. Careful planning and strenuous efforts are needed if food supplies are to be adequate for all hungry peoples in the future.

North America has come to dominate exportable grain production to essentially the same extent that the Middle East dominates with respect to oil exports. In the 1930's North America exported only a moderate amount of grain, and Eastern Europe and the U.S.S.R., Africa, Asia, and Latin America also exported. By the mid-1970's, exports from North America had risen sharply, while all the other areas mentioned had increasingly become deficit areas, though to a lesser extent for Latin America where Argentina is a wheat producing area [17] (Table 1-1). Figure 1-1 is included to suggest the agricultural technology and fertile productive land of the United States and to illustrate also land as a potential object for remote sensing.

Part of the Great Plains of North America is subject to drought that tends to recur about every 22 years. The Dust Bowl of the 1930's was a well-known result of the occurrence of severe drought in the area. A factor that is pertinent to considerations of the food resources of the world is that nearly

Table 1-1 World Grain Trade (Million Metric Tons).

Region	*1934–1938*	*1948–1952*	*1960*	*1970*	*1976**
North America	+ 5	+23	+39	+56	+94
Latin America	+ 9	+ 1	0	+ 4	− 3
Western Europe	−24	−22	−25	−30	−17
Eastern Europe, U.S.S.R.	+ 5	—	0	+ 1	−25
Africa	+ 1	0	− 2	− 5	−10
Asia	+ 2	− 6	−17	−34	−47
Australia, New Zealand	+ 5	+ 3	+ 6	+12	+ 8

*Preliminary. Plus sign indicates exports; minus sign, imports.
After L. Brown [17].

FIGURE 1-1. Farm land near Garnavillo, Iowa. (U.S. Department of Agriculture photograph by W. H. Lathrop.)

half of the present century has been unusually warm, in terms of climatic history. Peak average temperatures were reached around 1940 or 1945, and average temperatures declined following that time. The period from 1930 to 1960, for example, should not be regarded as a normal period but rather as the most abnormally warm period in 1000 years [19]. The variations of average temperature are not impressive in magnitude but are significant. From 1830 to 1930 the average temperature increased by about 1.7°C (3°F) near Philadelphia, while the drop from 1940 to 1975 was about 0.6°C (1°F) [84]. Superimposed on the general trend are decade-to-decade fluctuations of about 2.2°C (4°F). Cooling affects the higher latitudes most severely and results in shortened growing seasons and reduced productivity there. Because of its high-latitude location and the long period of records kept, Iceland has an especially useful record of climatic history. Based on reports of drift ice in earlier years, Bergthorsson constructed a 1000-year history of temperature in Iceland [20]. His results show alternating periods of relative warmth and cold—warmth from about 900 to 1200, cold from 1200 to 1400, warmth around 1500, cold from 1600 to 1900, and warmth in the first half of the present century. With respect to corn, wheat, and soybean production at lower latitudes, cooling itself is not so very harmful as somewhat lower temperatures and somewhat higher rainfall than normal tend to be optimum for these crops. Such conditions were generally present in North America from about 1955 to 1972. Further cooling could adversely affect food production in Canada and the U.S.S.R. significantly, but at lower latitudes weather variability (drought, floods, and changes in wind patterns) is a greater hazard [84]. It has been proposed, however, that cooling tends to be accompanied by "unusual" weather, greater weather variability, and failure of monsoons. Reid Bryson [20] of the University of Wisconsin is a leading proponent of this viewpoint. Whatever the explanation, the winter of 1976–1977 was characterized by unusual cold and severity in the eastern United States, mildness in Alaska, and drought in the western United States. Also the summer of 1977 was unusually warm in the eastern United States, and drought was widespread throughout the United States.

While the possibility that the earth may be returning to a more nearly normal, cool climatic period appears to pose a threat to food supplies, the steady buildup in CO_2 content of the atmosphere may cause the climate of the earth to become warmer. Some climatologists place considerable emphasis on this possibility and anticipate that this man-made change in climate will be greater in magnitude than natural fluctuations in the foreseeable future [55]. In any case it appears that change of climate is something mankind will have to deal with and that careful monitoring and analysis of climate are essential. The atmospheric CO_2 content is considered further in Sec. 3-4.

Energy resources are crucial resources because they can be used to supply most other resources. With unlimited energy, fresh water can be obtained from seawater, minerals can be extracted from low-grade ores and from the sea, and food can be produced. In 1972–1973 serious energy shortages were experienced in the United States for the first time, and much discussion has been devoted since to the energy crisis, especially since the Arab oil embargo of 1973–1974. With the end of the embargo and with some easing of the economic downturn that seemed to be triggered by the embargo and high prices for oil, the public's concern about energy apparently decreased. The trend toward buying smaller cars, for example, lessened, and General Motors found in early 1976 that a new compact model was not selling so well as expected. Energy is a major problem, however, and failure to take effective measures to solve the problem following the embargo made the problem worse. The dependence of the United States on imported oil increased, and it was reported that the United States imported more oil than it produced for the first time in the second week of March 1976. In 1977, President Carter presented a national policy for energy and provided a basis for hope that much-needed actions might finally be taken. It has become apparent that much of the prosperity of the United States and much of its productivity have been based in good part on extensive supplies of low-priced fuel, but such low-priced supplies cannot be expected to be available in the future. Some of the useful references on energy are those by Holdren and Herrera [52], the *Scientific American* [79], the AAAS [1, 3], Clark [25], the Ford Foundation [43], Krenz [59], and Lovins [62]. Among the approaches to the energy problem are attempting to increase supply and increasing efficiency of use. Krenz has emphasized increased efficiency of use and has pointed out that increasing efficiency has the same effect as increasing production but tends to require less capital. The subject of energy supply and demand has been discussed recently in terms of the use of "soft" and "hard" technology. Lovins is among those who have addressed the subject in these terms, and he has espoused soft technology (energy conservation, solar energy, and related measures and expanded use of coal, with individual facilities tending to be relatively small and widely dispersed) as contrasted to hard technology (such as breeder reactors and/or other large, centralized, complex facilities). Lovins has met criticism, and even some advocates of solar energy, for example, believe he has overstated the case for solar energy, but he has been effective in promoting discussion.

Water and land are closely related to food and energy. Water is needed for food production, and production of oil from shale in Colorado, for example, would require large amounts of water and contribute to a conflict between the use of water for producing food and for producing energy. Especially in the western United States, water has been transported for large distances, as from northern to southern California, to sustain populations without adequate local supplies. Such transport of water is justifiable to a point, but the concept of massive diversions from one area to another has been questioned and opposed increasingly in recent years [14,80]. A related matter is the controversy engendered in 1977 when President Carter sought to eliminate funds for a number of water projects on the basis that they were not cost effective and represented traditional pork-barrel politics.

One of the major problems concerning land use is that, as the need for food increases because of the growth of population, good agricultural land is being made unavailable because of residential and commercial construction and because of waterlogging and the accumulation of salts resulting from inadequate drainage [36]. Deforestation and overgrazing contribute to erosion, floods, silting of reservoirs and irrigation canals, and the conversion of productive land to desert (desertification). Such desertification has taken place extensively in northern and central Africa, and widespread application of slash-and-burn agriculture continues to take a toll of tropical forests in Latin America and elsewhere. Strip mining of coal and production of oil from shale threaten to seriously damage large areas of land, and much debate has taken place as to what requirements should be formulated for restoration of such land. Urban sprawl proliferates near cities, and wild and natural areas, including the U.S. National Parks, are under increasing pressure and abuse. While the use of fertilizers and pesticides has increased food production, it has contributed to eutrophication of lakes [12,75] and other adverse ecological effects [18]. The annual reports of the Council on Environmental Quality are valuable sources of information on environmental matters, including land use [31].

Warnings have been given from time to time of impending shortages of materials (nonenergy minerals, forest products, etc.), but the warnings have been countered by pointing out that the predictions of the past have often proved to be unduly pessimistic. Also the ability to work with lower-grade ores, to substitute new or more plentiful materials for previously employed materials, and to recycle materials can be pointed to. All of these measures have merit. The problem of incompatibility between mineral production and environmental quality, however, must be taken into account [23], and while we shall not run out of geologic resources, they will become more expensive [30]. A fundamental consideration is that processing lower-grade ores, substituting plentiful aluminum for steel, etc., require energy, and energy costs are increasing. Energy is a critical factor in considering the adequacy of mineral resources [30,47]. The AAAS has assembled a compendium on material resources [4].

Mankind lives in an environment permeated by electromagnetic radiation of natural and man-made origin. The electromagnetic radiation from the sun is the prime essential for life, and electromagnetic waves of man-made origin provide the basis for telecommunications. The concept of the electromagnetic spectrum as a natural resource is considered in Chap. 2.

General references on natural resources not already mentioned include Ehrlich and Ehrlich [39,40], *Resources and Man* (National Academy of Sciences–National Research Council) [66]; Brown et al. [15], and Huberty and Flock [53].

1-2 POPULATION AND ECONOMIC GROWTH

The present rapid increase in the world's population puts obviously corresponding pressures on the environment, and population is considered by many to be the basic overriding environmental problem. Of course the environment can be badly managed in sparsely settled areas. Also harmonious