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☐ ECONOMIC ANALYSES ☐ OPERATIONS RESEARCH ☐ POLICY STUDIES ☐ SYSTEMS ANALYSES ☐ TECHNOLOGY ASSESSMENT

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THE ECONOMIC VALUE OF REMOTE SENSING OF EARTH RESOURCES FROM SPACE: AN ERTS OVERVIEW AND THE VALUE OF CONTINUITY OF SERVICE

VOLUME VIII

ATMOSPHERE

Prepared for the
Office of the Administrator
National Aeronautics and Space Administration
Under Contract NASW-2580

October 31, 1974

NOTE OF TRANSMITTAL

This resource management area report is prepared for the Office of the Administrator, National Aeronautics and Space Administration, under Article I.C.1 of Contract NASW-2580. It provides backup material to the Summary, Volume I, and the Source Document, Volume II, of this report. The interested reader is referred to these documents for a summary of data presented herein and in the other resource management areas.

The data presented in this volume are based upon the best information available at the time of preparation and within the resource of this study. This includes a survey of existing studies plus Federal budgets and statutes. Throughout the analysis, a conservative viewpoint has been maintained. Nonetheless, there are, of course, uncertainties associated with any projection of future economic benefits, and these data should be used only with this understanding.

ECON acknowledges the contributions of Richard Miles and Gregg Fawkes who authored this volume.

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ABSTRACT

The imposition of the atmosphere between the earth and a resources satellite is often considered a disbenefit because cloud cover and air pollution limit observation of ground phenomena. Proper interpretation of the atmospheric data, however, will lead to substantial benefits. The reduction of the ground signal due to particulates and aerosols correlated with pollution concentrations will allow a replacement of some air pollution monitors and a substantial increase in ability to determine pollution sources, distribution and damage. The impact of man on weather as observed by ERTS-1 (Figure 1.3, Volume I) is without doubt more extensive than previously supposed; weather modification by poor land management, for example, is currently thought to be causing the Sahelian draught as it did the drought in the United States during the 1930's.

Benefits discussed in this section arise from air pollution and cloud observations correlated to ground stations. Although most weather observation is accomplished by satellites specifically designed for that purpose, the high resolution and ability to correlate weather with observed ground and ocean phenomena are capabilities unique to an earth resources satellite.

The estimate of total benefits falls into a range between 7.9 and 40.8 million dollars. These are mostly due to cost savings associated with air pollution monitoring by satellite, and social benefits due to more precise knowledge of the effects of pollution.

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1.0 INTRODUCTION AND OVERVIEW: ATMOSPHERE

The work contained in this section is an effort to identify the possible areas in which an earth resources satellite might impact understanding and control of atmospheric phenomena, to establish how such a satellite might be used, and to estimate possible economic benefits from an ideal satellite and the more limited ERTS satellite. Most of the resource management functions described have either little benefit or unquantifiable benefits. That is not to imply that they are unimportant: every one represents an area of current concern which may be impacted by satellite. Small or unquantifiable benefits only mean that in the current economic market, the value of such a function is small, irrelevant, or unappreciated. As satellite information becomes more dependable and more throughly interpreted, these benefits may expand.

The major quantifiable benefits fall into the category of air pollution largely because there is a substantial amount of activity in this area. Ten years ago, these benefits would also have had to be listed as unquantifiable since no substantial economic foundations had been laid. The hard numbers arise from the demonstrated capability of the ERTS satellite to measure aerosol and particulates. Such a capability means that already planned and existing aerosol and particulate monitoring stations may be unnecessary. Thus the estimate of between $1.5 million and $10.5 million is from the replacement of a large number of machines and personnel by a smaller more specialized group of data interpreters.

Soft benefits are attributed to anticipated results of demonstrated capabilities or anticipated but undeveloped capabilities which have a probable economic impact. Better interpretation of particulate pollution data and environmental damage lead to the large 5 to 27 million dollar figure. This comes from the increased ability of the society to adjust to more certain information. Similarly the approximately 1 million dollars from monitoring direct environmental effects and research reflect an estimate of other benefits of better data. For a summary of both the hard and soft benefits see Table 1.

Simple economic models are contained in RMF's 6.1.2 and 6.2.2. The first merely discusses the costs of maintaining pollution monitoring stations and how the satellite might affect them. The second is more general and develops the notion of the very real cost associated with the uncertainty of air pollution damage. This cost, for example, is already being felt as pressure mounts from automobile manufacturers and the energy crisis to relax clean air standards.

The assumption in this model is that the satellite will, in some way, better enable us to estimate air pollution costs. Various satellite images of pollution caused weather modifications and air turbidity indicate that this assumption is reasonable.

The Interplan, Dynatrend, and EarthSat* studies do not attack the air pollution problem with any depth. The first merely assumes a 50% reduction in pollution monitoring stations, apparently a randomly chosen number yielding a .35 million dollar benefit. Dynatrend argues that satellite sensors in conjunction with ground truth will be able to monitor regional air pollution, however they rather arbitrarily arrive at 5.5 million dollars as a benefit. EarthSat feels that no benefits are possible because of the low coverage frequency and low resolution. The ECON ERTS - B report agrees with the Dynatrend estimate of $5.5 million for pollution monitoring and does not establish values for reduction of pollution damage, improvement of control programs, etc.

The other resource management functions discussed in this section pertain mostly to weather related phenomena. The earth resources satellites are not specifically designed to observe weather or other atmospheric phenomena, however some of their capabilities will complement and extend these of other satellite systems. Weather prediction from a resources satellite is difficult because coverage is only once every 18 days and the field of view is limited. Cloud statistics taken repeatedly at the same time of day, however, may aid with our understanding of long term weather cycles and regional weather phenomena. Such information, combined with observations of ground conditions, may help with our understanding of the climatic changes that we already know are underway. Quantitative benefits for these functions cannot be derived since our ability to determine such information from space has not been demonstrated and earth based programs are just commencing.

1.1 Cartography, Thematic Maps and Visual Displays

The resources management functions listed in this section are various maps that might be produced by properly displaying satellite data. Cloud location and smoke and haze distribution are the most noticeable atmospheric features visible from ERTS. Location of sand and dust storms, such as from the

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* Dynatrend, "Final Report Evaluation of Benefits and Systems Features of Earth Resources Satellite Operational System (ERSOS)", Burlington, Mass., 1974.
EarthSat, "Case Study in Atmosphere", Beverly, Calif., 1974.
Review and Appraisal: Cost Benefit Analyses of Earth Resources Survey Satellite Systems, Document No. 7016R, March, 1971, Interplan Corporation, Santa Barbara, Calif.

Table 1 Magnitudes and Types of Net Annual Benefits by Resource Management Activity-Atmosphere

Resource Management Function	Benefits, $ millions (1973)		
	Equal Capability Benefits	Increased Capability Benefits	New Capability Benefits
6.1 Cartography, Thematic Maps and Visual Displays			
6.1.1 Cloud location			
6.1.2 Smoke and haze distribution	1.5-10.5		*
6.1.3 Sand and dust storm location			
6.1.4 Thermal map of atmosphere			
6.1.5 Noxious gas air pollution monitoring			
6.2 Statistical Services			
6.2.1 Cloud cover			
6.2.2 Air quality monitoring			(5-27)†
6.2.3 Weather forecasting			
6.2.4 Wind mapping			
6.3 Calendars			
6.4 Allocation			
6.5 Conservation			
6.5.1 CO_2 concentration and greenhouse effect monitoring			

Table 1 Magnitudes and Types of Net Annual Benefits by Resource Management Activity-Atmosphere (continued)

Resource Management Function	Benefits, $ millions (1973)		
	Equal Capability Benefits	Increased Capability Benefits	New Capability Benefits
6.5 Conservation (continued)			(.1-.3)
6.5.2 Monitor jet contrail water vapor condensation & carbon dioxide effects on weather & air			
6.6 Damage Prevention and Assessment			
6.6.1 Monitor effects of thermal & other pollution sources on weather			*
6.6.2 Monitor airborn pollution effects on the environment		(.25-.9)	*
6.6.3 Monitor effects of volcanic eruptions on air quality			
6.7 Unique Event Recognition and Early Warning			
6.7.1 Determine clear air turbulence location			
6.7.2 Provide severe storm warnings			
6.7.3 Monitor climatological changes			*
6.8 Research			
6.8.1 Research on effects of thermal sources on weather		*	
6.8.2 Research on air - sea interactions			
6.8.3 Research in dispersion of pollution in the atmosphere		(.1)	

Table 1 Magnitudes and Types of Net Annual Benefits by Resource Management Activity-Atmosphere (continued)

Resource Management Function	Benefits, $ Millions (1973) Equal Capability Benefits	Increased Capability Benefits	New Capability Benefits
6.8 Research (continued)			
6.8.4 Research on Weather phenomena			*
6.9 Administrative, Judicial and Legislative			
6.9.1 Control of particulate pollution	.01-.05		
6.9.2 Control of noxious gas sources			
6.9.3 Provide a data base for establishing appropriate air quality regulations		(.1-.2)	
Totals:			
Hard benefits documented in ECON Case Studies	1.51-10.55		
Soft benefits		(.45-1.2)	(5.1-27.3)

* Astricies indicate possibly significant, yet presently unquantifiable benefits

† Parentheses indicate soft numbers

Santa Ana wind as shown in Figures 1-4a and 1-4b of Volume 1, is a demonstrated capability but usually not as extensive or interesting as the others. A thermal map of the atmosphere and noxious gas observation are capabilities requiring sensors not currently flown on ERTS, however benefits would be large if these sensors were included.

1.2 Statistical Services

Single or repeated satellite observations added to existing information sources or interpreted alone provide several exciting capabilities listed in this section. The ability of ERTS to observe weather is limited because of its low coverage frequency, so weather related services have not been found to be of substantial interest. Air quality monitoring, on the other hand, with ERTS and other sources added together may yield large benefits. Distributions of pollutants observed from satellites and correlated with ground features will produce more extensive information than ground systems are capable of producing.

1.3 Damage Prevention and Assessment

The major airborne damage to the environment is through either direct or indirect effects of air pollution. ERTS pictures have shown pollution caused weather modification, and the deleterious nature of air pollution's effects on crops, health, and materials is well documented. The resource management functions contained in this section concentrate on observations of the interaction of man-made and naturally occuring air pollution on the environment.

1.4 Unique Event Recognition and Early Warning

A satellite's ability to relay synoptic views to those within the region or possibly affected by observed phenomena may save lives or structures. Severe storms are, of course, a dramatic example. Clear air turbulence is also important for aircraft. Climatologic changes, however, are perhaps the most important phenomena to be monitored, for the required social action may be substantial and slowly implemented. The ERTS satellite cannot dependably see clear air turbulence or storm. Climatologic changes, however, occur over periods long enough to be dependably sampled by an ERTS type system.

1.5 Research

Satellite data provide a new source for research on various atmospheric phenomena. Better understanding of the global environment will come from repeated analysis of synoptic data. Probably the most significant results will be in more accurate long range weather prediction. ERTS, however, is not particularly well suited for this function since many variables such as the thermal profile of the atmosphere are not observable. Pollution dispersion, however, is observable and has already been correlated with EPA models.

1.6 Administrative, Judicial, and Legislative

A satellite's ability to serve in an administrative role is determined first by its ability to observe, and then by the frequency of its observations. Naturally the same problem exists on the ground, so a satellite may simply complement a ground monitoring network. ERTS cannot observe noxious gases, but its ability to see smoke plumes and determine their sources has been demonstrated. The limited observation frequency, however, relegates this capability to a minor role. Perhaps more interesting will be the satellite's ability to determine what the effects and distribution of various pollutants are with a hope of establishing appropriate air quality regulations.

APPENDIX A:

DETAILED EXAMINATION OF BENEFITS BY RMF

Appendix A contains the detailed examination of each of the Resource Management Functions of this Resource Area. Firm benefit estimates verified by this report may be found in RMF's, 6.1.2 and 6.9.1. Benefits that can be attributable to an ERS system but not verified by this in depth study may be found in RMF's, 6.2.2, 6.5.2, 6.6.2, 6.8.3, and 6.9.3.

RMF No. 6.1.1

CLOUD LOCATION

Rationale for Benefits

Cloud location is a key parameter for weather forecasting on all levels. Regional, near real-time cloud images are used in short-range subjective weather forecasting. Ever since the original Tiros satellites, cloud imagery has proved an invaluable aid in this area. Synoptic cloud images, indicative of larger-scale atmospheric patterns, are used to improve the accuracy of longer-range forecasts. In addition, complete global cloud distribution data are necessary to establish the initial conditions for the development of, and use of models in numerical weather prediction.

In addition to the qualitative information cloud images provide, certain quantitative information can be derived. For example, repetitive cloud images can be used to calculate wind speed and direction in the data sparse, but meteorologically important tropical areas. Cloud patterns have been used* to derive 500-mb geopotential heights, which are important in deriving the global pressure field for use in longer range weather prediction. In addition, cloud location maps contribute information on cloud sources (cities, mountains, particulate matter, jet contrails).

Federal Government Activities and Responsibilities

The Secretary of Commerce has charge of the forecasting of weather and the taking of such meteorological observations as may be necessary for the execution of this duty. **

All cloud imagery for operational meteorological forecasting is done by satellite under the administration of the National Environment Satellite Service (NESS) of the National Oceanic and Atmospheric Administration (NOAA) whose total FY 1974 budget in support of the Basic Environmental Services program (which includes weather forecasting) is $16,813,000. (See Appendix B)

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* Ronald E. Nagele and Christopher M. Hayden, The Use of Satellite-Observed Cloud Patterns in Northern-Hemisphere 500-mb Numerical Analysis, NASA Contractor Report, Washington, D.C., 1971.

** 15 U.S.C. 313

Functions of Remote Sensing

The only feasible method of producing cloud location maps is through the synoptic observation provided by remote sensing. These synoptic observations are used to provide information necessary for the current state of forecasting art as well as for the research required to improve forecasting capability.

There are two different scales of phenomena observed in cloud location maps: "synoptic-scale" phenomena including troughs, ridges, fronts and jet streams which may extend 1800-9000 km or more; and "meso-scale" phenomena, extending from 1 to several hundred kilometers.*

It is also important to study the interactions between the two scales of phenomena; this, too, is an area of meteorological understanding that can only be increased through remotely sensed data.

Scroggins, et. al.,* point out that, although there are no theories which relate cloud formation to meteorological variables such as pressure, temperature, experience indicates that such relationships exist. Consequently, remotely sensed synoptic cloud images will be important in increasing our understanding of meteorological phenomena and, as this occurs, such cloud images will become increasingly important forecasting tools themselves.

Economic and Technical Models for Estimating Benefits of Remote Sensed Data

It is difficult to estimate the value of remotely sensed cloud images because they represent an entirely new capability; without remote sensing the data would not exist, for it would be prohibitively expensive to collect the data through a system of in situ observations.

Within remote sensing, the only other approach that might compare with satellite imagery within the near future is radar; however, certain advances in applied radar technology

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* James R. Scroggins, et. al., An Investigation of Relationships Between Meso-and Synoptic-Scale Phenomena, NASA Contractor Report, NASA CR-2030, June 1972, p.1.

would be required to produce an operational system comparable to that using satellite imagery, and it appears clear that the cost of collecting and processing satellite data will always be lower than that of radar data. Hence, use of satellite imagery in this area represents the most cost-effective data collection method.

The economic value of the information derived will depend upon the extent to which the information contributes to more accurate weather forecasts and then upon the impact in specific industries and governmental activities of these more accurate forecasts. Both of these effects are largely indeterminable at this point in time.

Current ERTS Activities

None.

All of the satellite imagery in this area comes from other operational satellite systems, primarily the Improved Tiros Operational System (ITOS).

Estimate of ERTS Economic Capabilities

Although the Multispectral Scanner (MSS) of the ERTS system provides higher resolution images than currently available, there is a trade-off between resolution and coverage. The coverage provided by an ERTS system (even with two or three satellites) would not be adequate for the needs of meteorologists.

The ITOS program, on the other hand, provides very high-resolution day-and-night cloud-cover images, offering complete global coverage on a daily basis.

Annual Benefit: 0

RMF No. 6.1.2

SMOKE AND HAZE DISTRIBUTION

Rationale for Benefits

The level of particulate and aerosol content in the atmosphere affects aviation, public health, property, and the environment. About 40% of the harmful effects of pollution may be ascribed to total suspended particulates, (TSP), even though they account for only 15% of the total pollutants as is shown in Figure 1. Aerosol content affects visibility, and smoke and haze mixed with hydrocarbons and nitrogen oxides cause smog and with sulfur dioxide cause killer fogs. Location of particulate sources and haze is important for control of pollution, warning of potentially hazardous conditions, and air quality monitoring.

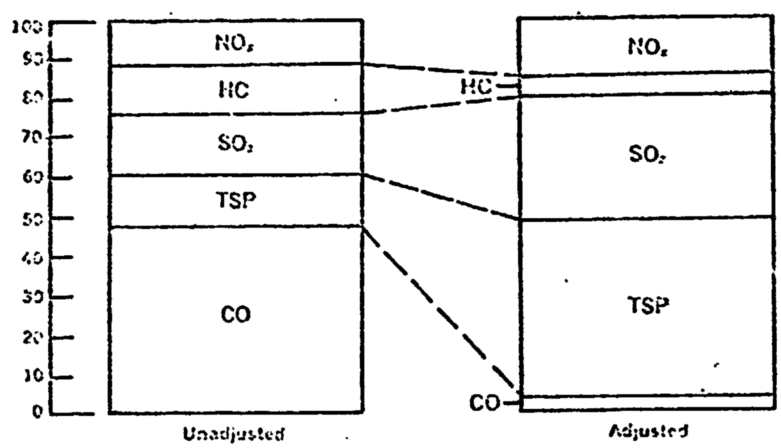

Figure 1. 1971 Air Pollution Emissions, Percentage by Pollutant, Unadjusted and Adjusted for Effect, (Ref: Council on Environmental Quality, "The Fourth Annual Report," - 1973 U.S. Government Printing Office, Washington, D.C., p. 270.)

RMF No. 6.1.2

Federal Government Activities and Responsibilities

The Environmental Protection Agency maintains two air monitoring systems located in predominantly urban areas, with one sampling station per city. The National Air Surveillance Network stations take data for a 24 hour period every 2 weeks, the Continuous Air Monitoring stations sample pollutants every 5 minutes. These stations are located in "roughly comparable sites" from city to city and are used to establish air quality trends representative of the entire city. In addition the EPA conducts a regional surveillance program for enforcement of air pollution standards. The 1974 budget for the monitoring systems is $1,694,000 and for enforcement is $8,597,400.

The National Oceanic and Atmospheric Administration maintains aircraft weather observation services and air stagnation advisory services, both of which are concerned, in part, with smoke and haze conditions. These services are budgeted at $565,000 and $1,365,000 respectively.

Non-Federal Activities

Each state, under the Clean Air Act, is required to submit to the EPA administration a plan for implementation, maintenance, and enforcement of the National Ambient Air Quality Standards within each Air Quality Control Region in the state. Most of these state implementation plans have been approved by EPA and are being implemented with full compliance expected by 1977. By 1977, an estimated 4412 particulate monitoring units are required to be in operation.

Functions of Remote Sensing

Particulate and aerosol content in the atmosphere can be remotely measured either by the loss of reflected light from the earth or by the backscattered sunlight from the atmosphere. Satellite information can be used to provide the spatial distribution of smoke and haze, while direct sensing systems on the ground yield quantitative information. The distribution of smoke plumes and wind circulation affects can be qualitatively recorded. Maps provided by the satellite will be useful in identifying areas of potential health hazards or limited visibility regions.

RMF No. 6.1.2

Economic and Technical Models for Estimating Benefits of Remote Sensed Data

Costs of current air pollution monitoring equipment are presented in Table 2. Total costs of equipment in a fully equipped pollution monitoring station range around $34,000 and typical manpower required to operate such a monitoring station is approximately 15*. Assuming an average salary of $9,000 such a facility would cost $126,000 per year for personnel. Building rent and maintenance plus equipment amortization and repair will add another $15,000/year. Yearly costs for operating such a facility, therefore, will be in the vicinity of $211,500. Operation of one of these facilities in each Air Quality Control Region requires 247 installations at a total cost of $52 million.

The state implementation plans, however, require 8646 monitoring instruments by 1977 in the 247 Air Quality Control Regions**. Total capital costs for these units will be around $16.5 million for noxious gas detectors and $5 million for particulate detectors. Costs associated with operating the machines are difficult to estimate, however it seems reasonable to assume that since 15 people are associated with 8 machines in the Trenton station, an average of approximately 2 people per machine at $9,000 each will cover operation, maintenance and housing. Total costs of the fully operational state implementation plans will, therefore, be approximately $155 million plus 5 year equipment amortization yielding about $159 million annually for pollution monitoring.

A satellite capable of quantitatively monitoring both particulate and noxious gas pollution with high resolution and continuous coverage would replace all these stations; that, however is unlikely. Satellites may be able to observe pollution distribution and, with the aid of ground stations derive the pollutant concentrations. Possible savings of an optimum system will accrue from the replacement of all but the control station in each Air Quality Control Region which will become

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* These figures are from an August 16, 1974 telephone conversation with Mr. Lewis of the Trention, N.J. air pollution monitoring facility. They are his estimates and must be considered only approximately correct.

** Environmental Protection Agency, The National Air Monitoring - Air Quality and Emissions Trends, Annual Report Vol. I (Aug. 1973) EPS-450/1-73-001-a, U.S. Government Printing Office, Washinton, D.C.

Table 2

Approximate Cost of Air Pollution Monitoring Equipment

Pollutant	Method of Monitoring	Cost Range, $
Particulates	Tape	1,500
Particulates	High Volume	800-1,000
SO_2	Continuous (Wet Method)	4,000 - 6,000
LO	Infrared	4,000 - 6,000
Hydrocarbons	Total **	2,500 - 3,500
Hydrocarbons	Non Methane	7,000 - 8,000
CO_2	Infrared	4,000 - 6,000
NO_x	Chemiluminescence	5,500 - 6,500
O_3	Chemiluminescence	6,500 - 7,500*

* Equipment measures oxides of nitrogen as well as ozone.

Source: These figures are from an August 16, 1974 telephone conversation with Mr. Lewis of the Trenton, N.J. air pollution monitoring facility. They are his estimates and must be considered only approximately correct.

** Total refers to a hydro carbon measuring device.

a calibration center. Thus benefits on the order of 122 million seem plausible with an ideal satellite monitoring system. The addition of two employees per station at $15,000 each to analyze the satellite data will cost an additional $7.4 million, so benefits on the order of $114 million might be available.

Current ERTS Activities

Numerous researchers are studying the use of ERTS imagery for locating and quantifying air pollution and aerosols*; others are studying the related problem of image degredation due to atmospheric effects**.

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* G.E. Copeland, "Remote Detection of Aerosol Pollution by ERTS, Paper E5, from Symposium on Significant Results Obtained from ERTS-1, NASA SP-327, U.S. Government Printing Office, Washington, D.C., P. 585.

W.A. Lyons, "Use of ERTS-1 Imagery in Air Pollution and Mesometeorological Studies Around the Great Lakes" Paper El, from Symposium on Significant Results Obtained from ERTS-1 NASA SP-327, U.S. Government Printing Office, Washington, D.C., P. 553.

M. Griggs, "Determination of the Aeorosol Content in the Atmosphere from ERTS-1 Data," from 9th International Symposium on Remote Sensing of the Environment, April 15-19, 1974, Willow Run Laboratories, Ann Arbor, Michigan.

E.L. Riky, S. Stryker and E. Ward, "Air Quality Indices from ERTS-1 Information, PR568," from Symposium on Significant Results Obtained from ERTS-1, NASA SP-327, U.S. Government Printing Office, Washington, D.C., P. 1533.

** R.S. Fraser, "Computed Atmospheric Effects on ERTS Observations," from Symposium on Significant Results Obtained from ERTS-1, NASA SP-327, U.S. Government Printing Office, Washington, D.C., P. 1567.

D.E. Pitts and A.E. Dillinger, "The Effect of Atmospheric Water Vapor on Automatic Classification of ERTS Data," from 9th International Symposium on Remote Sensing of the Environment, April 15-19, 1974, Willow Run Labs, Ann Arbor, Michigan, P. 49.

J. Potter, R. Hill, M. Shelton, "Effect of Atmospheric Haze and Sun Angle on Automatic Classification of ERTS-1 Data," from 9th International Symposium on Remote Sensing of the environment, April 15-19, 1975, Willow Run Labs, Ann Arbor, Michigan, P. 96.

K.L. Coulson and R.L. Walraven, "Investigation of Atmospheric Effects in Image Transfer," from Univer. of California Annual Progress Report for NASA Grant NGL 05-003-404 (1 May 1972) Chapter 9.

R.H. Rogers, "A Technique for Correcting ERTS Data for Solar and Atmospheric Effects," Paper 13, Symposium on Significant Results Obtained from ERTS-1, NASA SP-327, U.S. Government Printing Office, Washington, D.C., P. 1115

RMF No. 6.1.2

Estimate of ERTS Economic Benefits

MSS channels 4 and 5 have been shown by Griggs to yield aerosol content to within ± 10%, and studies of imagery in East Virginia indicate that smoke plume geometries may be identified (see RMF 6.8.3). The synoptic view afforded by ERTS will provide a capability for quantifying the level of particulates throughout a region. This capability may alleviate the need for some of the state operated monitoring stations, since only one ground station would be needed in each region to calibrate the ERTS photo. Of the 8646 monitors proposed to be operational in 1977, about 5200 will measure particulate concentrations; the others measure SO_2, oxidants, and CO. If ERTS data can be used to reduce future need for these units, a subsequent benefit can be inferred. Replacement of all the units seems unreasonable since at least one per region will be needed to calibrate the data. The ERTS capability is currently not equal in sensitivity to the units, thus a 10-20% replacement seems reasonable. This reduction will save the cost of purchasing and operating 500 to 1000 particulate sampling machines. Assuming an average cost of $1200 per machine (see Table 2), a capital cost savings of $600,000 to $1,200,000 may be realized, yielding $120,000 to $240,000 per year if the equipment is amortized over 5 years.

A more substantial savings will occur in the decrease in labor required to run these machines. Since the particulate monitors constitute about 60% of the required pollution control monitoring devices, the personnel required to operate them must be considered non-peripheral. If we assume that each machine requires the equivalent of two people for operation, maintenance, and housing, then, the reduction of 500 to 1000 machines reduces cost by the equivalent of 1000 to 2000 employees. The ERTS data, however, must be interpreted; so the reduction in labor force is offset by an increase in personnel in the remaining stations. Assuming an additional two highly trained people in each of the 250 air quality control regions, a total reduction of 1000 to 2000 employees at $9,000 a year offset by an increase of 500 at $15,000 per year yields cost savings between $1,500,000 and $10,500,000.

The ERTS capability extends beyond replacing units. The synoptic view will provide more extensive information than will be available from localized stations. An example of this is the ozone episode in Milwaukee on July 17-18, 1973. The ERTS photo showed a "lake breeze convergent zone from Chicago northwards which channeled pollutants into Wisconsin." Similar information showing pollution distribution would be extremely difficult to obtain from ground. The 18 day observation cycle limits this benefit, however enough evidence is already available from ERTS-1 to assure its value. This information should substantially increase the value of existing observation sites. Possibilities of source identification are reasonable, however, the low observation frequency and predictable overfly times may frustrate any sole dependence on ERTS data for routine monitoring of local sources. A benefit on the order of several million dollars due to the increased capability seems reasonable, however due to the uncertainty of this number it cannot be included specifically in this report.

Annual Benefit:

Equal Capability: $1.5 to 10.5 million

New Capability: Possibly substantial but unquantified

RMF No. 6.1.3

SAND AND DUST STORM LOCATION

Rationale for Benefits

Observations of sand and dust storms, particularly on a global scale, lead to identification of severe erosion, wastelands, deserts, and mismanagement of crops, rangelands, and forests. The frequency of such events show severe surface wind conditions and climatological variations. (See RMF No. 6.7.3) Movement of sand dunes in arid regions and the resulting possible threat to populated areas may also be observed.

Federal Government Activities and Responsibilities

There are several Federal agencies involved to some extent with land management and erosion reduction policies; the most important of these are the Soil Conservation Service of the Department of Agriculture* and the Bureau of Land Management of the Department of Interior.

Also, the National Oceanic and Atmospheric Administration (NOAA) of the Department of Commerce is responsible for the monitoring of climatic change.**

Non Federal Activities

Most of the land management decisions connected with this RMF occur at the state level.

Functions of Remote Sensing

Remote sensing provides two unique advantages in the creation of sand and dust storm maps. First, remote sensing techniques can provide "instantaneous" images of such sand and dust storms for a given moment in time. Repetition of these images over time will generate information on the severity, frequency, and sources of these storms. Secondly, the synoptic view provided by remote sensing will produce information on the

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* The impact on agriculture of reduction of erosion and wind damage through ERTS imagery is discussed in detail in RMF No. 1.5.1.

** At present this program does not include the monitoring of the effects of climatic change of which this RMF is an example, but maintains a series of baseline climate monitoring stations.

extent and sources of sand and dust storms that was previously unavailable because of the size of these phenomena.

Economic and Technical Models for Estimating Benefits of Remote Sensed Data

Obviously, it is not possible to reduce the winds that drive sand and dust storms, but, to the extent that images of these storms can be used to identify bad land management techniques, economic benefits of two types can be realized. First, rangeland that is poorly managed can be identified, and the valuation of the restored forage yield can be calculated as the benefit. Second, improved land management practices will reduce the amount of loose sand and dust accessible to winds, and the reduced cost of damage associated with sand and dust storms.*

Current ERTS Activities

Leonard W. Bowden, et al of the University of California, Riverside used ERTS-1 imagery to identify dust plumes in the Mojave Desert associated with the Santa Ana wind condition.** These investigators, on examining the sites which the ERTS images had indicated were the sources of the dust plumes, found that these areas were subject to intensive use by off-road vehicles loosening the soil and making it more subject to removal by winds.

Estimate of ERTS Economic Capabilities

The benefits to be accrued in this area involve improved land management decisions which are dealt with in detail in Volumes III and IV (Intensive and Extensive Uses of Living Resources respectively); hence; they will not be recounted here.

Annual Benefit: 0

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* Damage includes accelerated erosion, sand pitting of glass in homes and vehicles, and structural damage to trailers, power lines, dwellings and other facilities.

** "Satellite Photograph Presents First Comprehensive View of Local Wind: The Santa Ana," Science, 7 June, 1974, pp. 1077-1078.

A montage of ERTS imagery showing the Santa Ana may be found in Volume I of this report: figures 1-3a and 1-3b.

RMP No. 6.1.4

THERMAL MAP OF ATMOSPHERE

Rationale for Benefits

Data needed for weather forecasting are determined by the desired accuracy and lead time of the forecast. Forecasting farther ahead than the current 1-2 day capability will require knowledge of the temperature profile of the atmosphere over the entire United States, the surrounding oceans and, in the limit, the whole earth. The thermal data are useful for both long-range and local weather predictions.

Thermal inversion layers and thermal sources associated with cities, plowed fields, and bodies of water will cause air stagnation or local updrafts and may lead to hazardous conditions and environmental modification. Identification and location of such phenomena will probably be as important as weather forecasting.

Federal Government Activities and Responsibilities

The Secretary of Commerce is directed to take "such meteorological observations as may be necessary to establish and record the climatic conditions of the United States [and forecast the weather] . . ."*

Functions of Remote Sensing

Thermal probing of the atmosphere is currently done with weather balloons and ground and ship based microwave devices. These yield the thermal profile at a specific location and, in the case of balloons, at infrequent intervals. Infrared and microwave radiometers mounted on satellites will determine the atmospheric temperature profiles from the temperature dependent emissions of atmospheric constituents. The view provided by a satellite will be vastly superior to current sampling techniques, yielding a three-dimensional map of the atmospheric temperature distribution. From ground based observations, it would be virtually impossible to create such a map.

Economic and Technical Models for Estimating Benefits of Remote Sensed Data

As with all information which is useful in meteorological prediction, the primary value of complete three-

* 15 USC 313 - Passed 1 October 1890.

dimensional sounding of the atmosphere is determined by the economic benefit resulting from the improvement in forecasting brought about by the information. In this case, benefits would accrue to industries and governmental agencies able to take advantage of improved long-range weather forecasts.

Secondary benefits are derived by cost savings in data collection; however, since remote sensing is the only means available to collect this information, it is not possible to compare the costs of remote sensing to the costs of any other approach.

Finally, it is impossible to determine at this point what the economic impact will be of information relating to thermal sources and inadvertent weather modification. (See RMF 6.6.1)

Current ERTS Activities

None. ERTS-1 does not have a thermal IR band sensor.

Estimate of ERTS Economic Capabilities

There is no sensor in the ERTS package capable of measuring the thermal profile of the atmosphere. Sensors are, however, being flown on the ITOS Satellite and will provide a vertical temperature profile from ground to 100,000 ft. twice a day.

Annual Benefit: 0

RMF No. 6.1.5

NOXIOUS GAS AIR POLLUTION MONITORING

Rationale for Benefits

Noxious gas pollutant mapping will aid with public health programs, enforcement of pollution control laws, evaluation of environmental effects of pollution, and statistical studies of pollution dispersion and variation. The impact of such mappings will be primarily to help the Environmental Protection Agency, state and local agencies to enforce the Clean Air Act, monitor ambient air quality, and establish new standards. Other agencies, however, will strongly benefit from the information for such activities as siting of health care facilities and pollution producing sources.

Federal Governmental Activities and Responsibilities

The Environmental Protection Agency air monitoring system is summarized in RMF 6.1.2. In addition to particulates, this system monitors sulfur dioxide, oxidants, and carbon monoxide. Some stations also monitor carbon dioxide and oxides of nitrogen. The United States is broken into 247 air quality control regions, each of which may have several monitoring stations. These AQCR's are state run but report their data to the National Aerometric Data Bank where ambient air quality is assessed.

Non-Federal Activities

The primary responsibility for implementation of the air quality standards falls to the states under the guidance and control of the Environmental Protection Agency.

Functions of Remote Sensing

Satellite observation of noxious gases may provide a pollution density and distribution map. Such a map, combined with the governed information from the already existing pollution monitoring stations, will be useful for ambient air quality surveys and source identification. Such information will enable the Environmental Protection Agency, state and local agencies to better characterize pollutant distributions. The resolution and observation frequency of the satellite will determine its effectiveness as a point source monitor, however coordination with ground on site inspections may lead to better enforcement even with a less than optimum system.

RMF No. 6.1.5

Economic and Technical Models for Estimating Benefits of Remote Sensed Data

A discussion of possible economic benefits is included in RMF 6.1.2.

Current ERTS Activities

There is no current ERTS oriented research on transparent noxious gases since the satellite has no sensors that can see them.

Estimate of ERTS Economic Capabilities

The ERTS system is currently incapable of directly observing noxious gases. There may be some method of correlating plant damage with local noxious pollution concentration, however that will depend heavily on plant types and will probably be useless in populated areas. Benefits associated with particulate and aerosol observations are discussed in RMF 6.1.2.

The "Measurement of Air Pollution from Satellites" (MAPS) sensor package in Nimbus G will map global distributions of CO, SO_2, NO_2, CH_4, NH_3, and aerosols to within ±10% accuracy to establish global background values, to track pollution movement, and determine regional air quality. The ground resolution however, is not high enough to replace local monitoring systems.

Annual Benefit: 0

RMF No. 6.2.1

CLOUD STATISTICS

Rationale for Benefits

The most important use for cloud statistics is in developing more accurate and longer-range numerical weather prediction techniques; one of the key parameters necessary for such techniques is the three dimensional global distribution of clouds.*

Such clouds statistics (location, amount, height, etc.) developed over time would be useful in monitoring climatic change and inadvertent weather modifications. (See RMF 6.6.1). This information will also help in the planning of earth observation satellite missions.

Federal Government Activities and Responsibilities

(See RMF No. 6.1.1).

Functions of Remote Sensing

Accurate and complete information concerning clouds is not possible without remote sensing. In addition to the visual imaging of clouds, research is being conducted on the use of radar and passive microwave sensing techniques for clouds. Also, a method has been devised for inferring cloud information from infrared data** even though clouds are opaque to infrared radiation.

Economic and Technical Models for Estimating Benefits of Remote Sensed Data

To the extent that cloud statistics contribute to the improvement of weather forecasting, benefits accrue to impacted industries and governmental agencies.

Estimate of ERTS Economic Capabilities

ERTS data are not sufficiently complete to be an aid in numerical weather prediction. (See RMF 6.1.1 - Estimate of ERTS Economic Capabilities.)

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* Useful Applications of Earth Oriented Satellites--Meteorology, National Academy of Sciences, 1969.

** P. Krishna Rao, Estimating Cloud Amount and Height from Satellite Infrared Radiation Data, ESSA, July 1970.

RMF No. 6.2.1

ERTS data may have a marginal value in helping to develop a data base for climatic and weather modification studies; however, the sun synchronous orbit limits ERTS observations to a single time of day.

Annual Benefit: 0

RMF No. 6.2.2

AIR QUALITY MONITORING

Rationale for Benefits

A sophisticated system to monitor the quality of the air throughout the United States is necessary for enforcement of pollution regulations, establishment of pollution standards, determination of trends, and accumulation of other statistics. The system must be sophisticated enough to monitor concentrations of noxious gases on the order of .01 parts per million and particulates as low as micrograms per cubic meter. It must be extensive enough to determine the distribution of these pollutants and, if possible, the location of their sources. A determination of the air quality up to high altitude is important in order to assess the effects of jet traffic, natural phenomena, and nuclear devices. Data as extensive as this currently is not available, however, any increase in information will enable statisticians to better determine the effects of pollution on our environment and that itself will be a substantial benefit. Additional benefits obviously accrue in enforcement and determination of standards.

Federal Government Activities and Responsibilities

The Federal mandate for air quality monitoring is established by the Clean Air Act of 1970* and consists mostly of monitoring and evaluating State enforcement programs. Air quality information is supplied by the states to the Environmental Protection Agency and verified by an independent National Air Sampling System. $1,694,500 was budgeted in 1974 for ambient air quality monitoring by the Environmental Protection Agency, however $51,518,000 was used to support state and local programs. The National Oceanic and Atmospheric Administration is also interested in air pollution and issues an Air Stagnation Advisory when weather conditions enhance the probability of air pollution. (See Appendix B)

Non-Federal Activities

Most of the responsibility for atmospheric quality falls to state and local agencies with the Environmental Protection Agency acting as an overseer and providing financial assistance.

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* 42 USC 1857 et. seq. - Passed 31 December 1970.

RMF No. 6.2.2

Functions of Remote Sensing

The gas sampling network maintained by the Environmental Protection Agency's Office of Air Programs has some two hundred stations throughout the continent. These stations measure ambient air quality and enable the EPA to generate national statistics. Disclaimers, however, must be included because the relationship of the pollution at the sampling site to that of the surrounding vicinity varies and is generally unknown.

A satellite equipped with sensors capable of observing pollution concentration can be coupled with existing ground sampling stations to produce a quantitative pollution distribution map. A similar map would not be practical from ground based sensors since wind fluctuations will distribute pollution in a variety of directions thereby necessitating many sampling stations, all synchronized and cross calibrated.

The possibility of detecting high altitude pollution particularly along jet ways is exciting and so far has been found to be very difficult from ground bases. Measurement of emissivities from high altitude ozone, carbon dioxide, and water vapor will yield profiles of the concentration of these combustion produced gases. A three-dimensional map of air pollution from satellite data combined with ground and air measurements if possible would very substantially improve our understanding of the environment and effects of pollutants on it.

Economic and Technical Models for Estimating Benefits of Remote Sensed Data

Uncertainties in the measurement of damage due to air pollution cost money. Obviously, if air pollution caused no economic or social damage, control would not be necessary. Similarly, slight damage does not justify costly control. Decisions on the proper level of control must be based on estimates of the cost of air pollution. Such decisions are facilitated by the graph such as Figure 2 on which is plotted the cost of pollution with 90% certainty limits and the cost of control versus the level of pollution. The most economical point at which to operate is where the sum of the two is a minimum. Uncertainty in the estimates of the cost of pollution produces an uncertainty in the minimum total cost point. One can visualize the cost of this uncertainty by assuming that there is a true cost of pollution point which defines the lowest overall social cost. Operating to either side of this

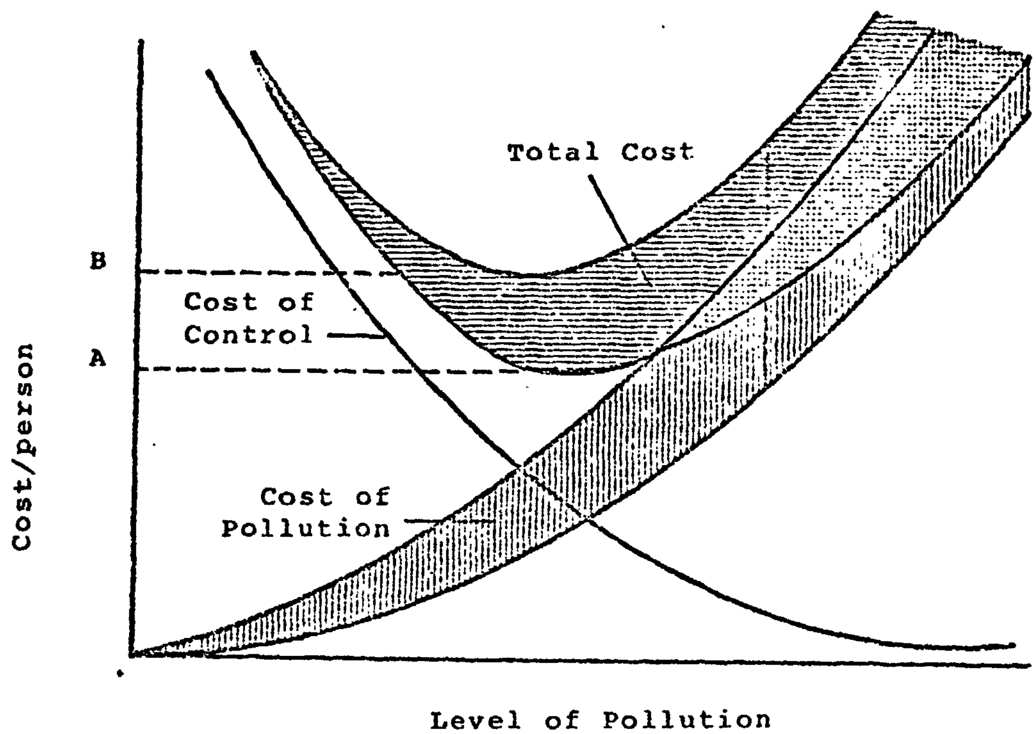

Figure 2 Diagramatic Representation of the Cost of Air Pollution

point will increase the total cost and, the greater the uncertainty, the greater the probability that the operating point will not be correct.

Referring again to Figure 2, one notes that the total cost uncertainty is determined by the 90% confidence limits in the cost of pollution at the cross-over points. The total cost limits are labeled A and B on the cost per person axis of the figure. Thus, one must extrapolate back from current pollution costs and uncertainties and current control costs to the cross-over region and use the values there. A unit area probability distribution function $f(x)$ along the annual cost/person axis will have 90% of its total area between point A and point B. The peak of this curve $(x=\bar{x})$ will be the most probable cost and will delineate the best operation point. The cost associated with points other than the best point will be the difference between the incorrect point and

and $\bar{x}$ times the probability of selecting that point, or

$$\text{cost} = \left| x-\bar{x} \right| \; f(x)$$

The total cost of uncertainty, then will be

$$\text{cost of uncertainty} = \int_{-\infty}^{\infty} \left| x-\bar{x} \right| \; f(x) \, dx$$

The probability function $f(x)$ is most likely of the form

$$x^2 e^{-(x-\bar{x})^2/2\sigma^2}$$

or the like since it must approach zero as x approaches zero. However, estimates of pollution costs by the EPA assume that most likely value to be half way between the 90% confidence values, implying a symmetric distribution. A normal distribution is convenient, easily solvable, and a reasonable approximation.

$$f(x) = \frac{1}{\sigma\sqrt{2\pi}} \; e^{-(x-\bar{x})^2/2\sigma^2}$$

Then,

$$\frac{1}{\sigma\sqrt{2\pi}} \int_{-\infty}^{\infty} \left| x-\bar{x} \right| \; e^{-(x-\bar{x})^2/2\sigma^2} dx = \sqrt{2/\pi} \; \sigma$$

$$= \text{Cost of uncertainty}$$

The 90% confidence line is found from the value of $x-\bar{x} = \alpha$ which gives

$$\int_{\bar{x}-\alpha}^{\bar{x}+\alpha} f(x)dx = .9$$

from which one finds $\alpha = 1.64\sigma$. If the total interval between the 90% confidence lines is called $\Delta = 2\alpha$, then the total cost of uncertainty is

$$\text{Total cost} = \sqrt{2/\pi}\ \frac{1}{2}\ \frac{\Delta}{1.64} = .24\Delta$$

for a normally distributed curve.

Figures 3, 4, and 5 give nationwide cost estimates for pollution damage and control. These numbers are derived from the EPA study of the economic damage of air pollution* plus the report from the Council of Environmental Quality.** The graphs are approximate and are included here to demonstrate current uncertainty. Associating nationwide emissions with a cost per person assumes that emissions are proportional to population density. Obviously, this is not necessarily true, and as the EPA study points out, "benefit and 'burden' information should be related to specific pollutants (or group of pollutants when effects are synergistic) and to specific regions. Weather conditions, topography, climate, the mix of emission sources, and sensitivity of the exposed population vary over time and from location to location."*** Also not included here is a weighting factor to account for the increase in severity of equal pollution levels in populated as compared to unpopulated areas.

Nevertheless, these figures indicate estimates of the cost of uncertainty. For SO_2, the 90% interval between minima in the total cost curves is about $14/person yielding a cost of uncertainty of $3.4/person, or $.7 billion. Similarly, for particulates the interval is $11/person, yielding $2.6/person or about .55 billion as a cost of uncertainty, and for NO_x, $7/person yields $1.7/person or $.35 billion.

The costs included in the EPA study are only those that are considered quantifiable. Economic costs associated with the quality of life, aesthetics, and health of nonworking and retired citizens must be added in some quantitative way to get the real social costs of pollution. Since these are subjective costs, they have not been included, although any cost analysis should give them some weight. This added cost, of course,

* T.E. Waddell, "The Economic Damages of Air Pollution," U.S.E.P.A. Document number EPA-600/5-74-012 (May 1974).

** Council of Environmental Quality, "The Fourth Annual Report," U.S. Government Printing Office, Washington, D. C.

*** Op. cit., page 13.

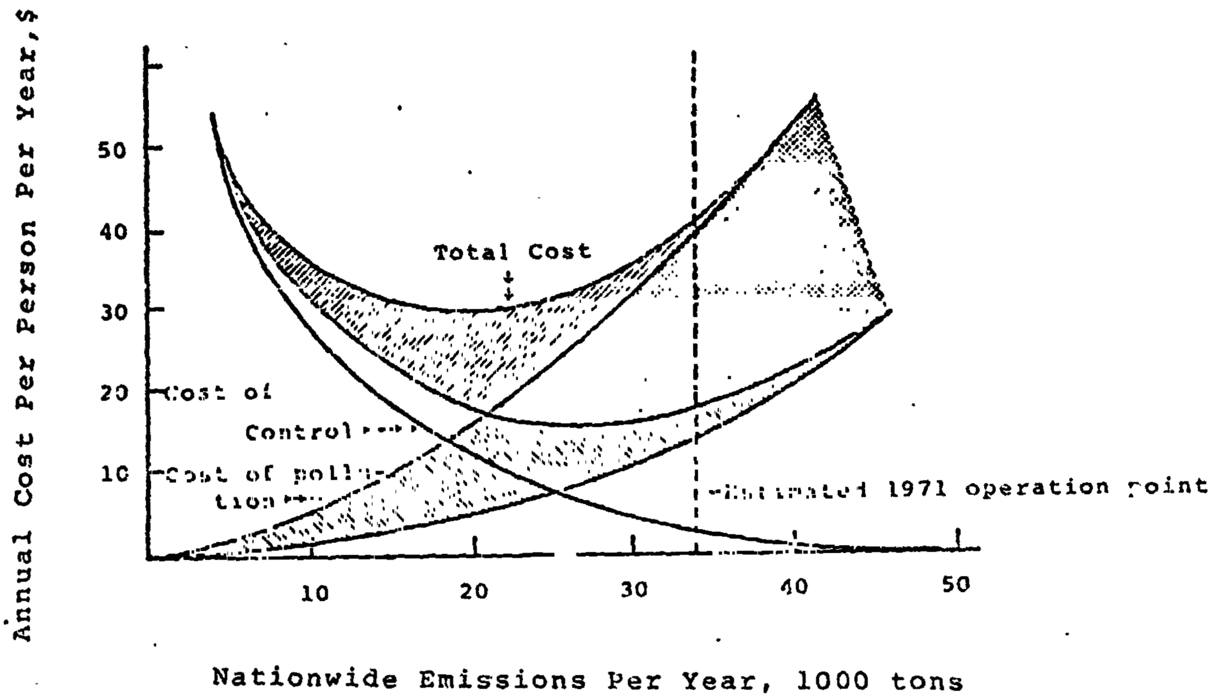

Figure 3 Annual Cost of SO_2 Pollution

Source: T.E. Waddell, "The Economic Dangers of Air Pollution," USEPA Document number EPA/5-74-012 (May 1974).
Council of Environmental Quality, "The Fourth Annual Report," U.S. Government Printing Office, Washington, D.C.

RMF No. 6.2.2

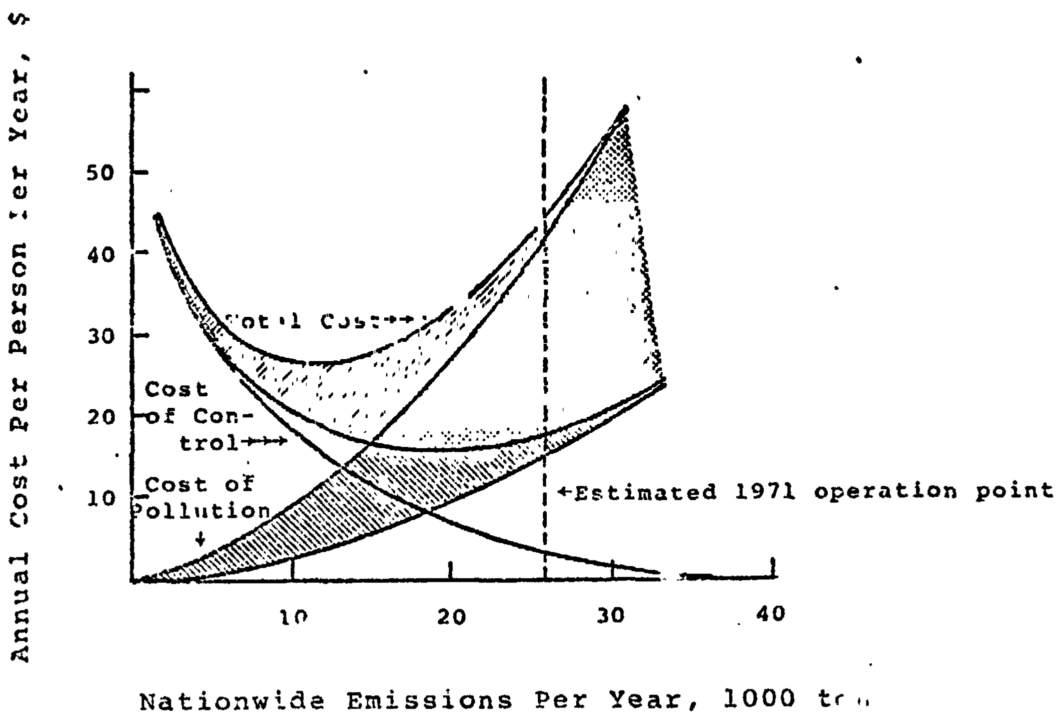

Figure 4 Annual Cost of Particulate Pollution

Source: T.E. Waddell, "The Economic Dangers of Air Pollution," USEPA Document number EPA/5-74-012 (May 1974).
Council of Environmental Quality, "The Fourth Annual Report," U.S. Government Printing Office, Washington, D.C.

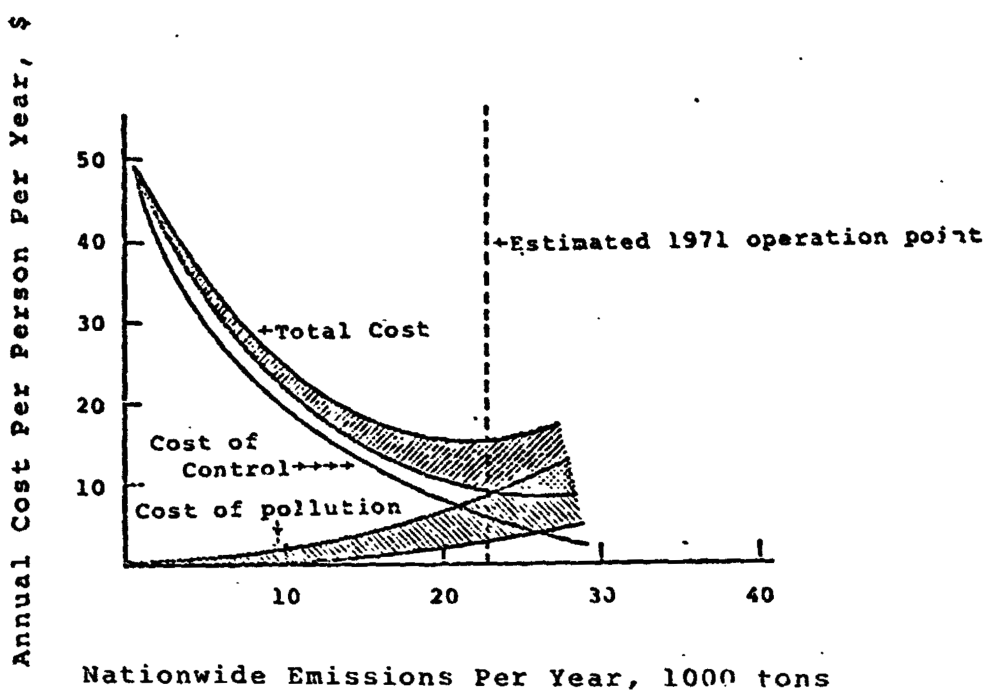

Figure 5 Annual Cost of NO_x Pollution

Source: T.E. Waddell, "The Economic Dangers of Air Pollution," USEPA Document number EPA/5-74-012 (May 1974).
Council of Environmental Quality, "The Fourth Annual Report," U.S. Government Printing Office, Washington, D.C.

increases the cost of uncertainty and makes the estimate here a lower bound. These uncertainties in the face of the energy crisis are serious and need to be resolved before decisions on such issues as how extensively to control sulfur and particulate emissions from coal are reached*

Current ERTS Activities

Fluctuations in the light levels detected by the four visible and near infrared MSS channels of the ERTS-1 Satellite are being correlated with the particulate and aerosol content of the atmosphere. E. Riley ** is currently developing an ERTS air quality monitoring system based on the "striking correlation" between ground observations and ERTS average grayness data. G. Copeland*** has used ERTS imagery to locate new particulate emission sources and is developing techniques to produce area wide isoplethic maps of particulates. W. Lyons**** has used ERTS images to explain a severe ozone episode in Milwaukee in July 1972.

Light interacts most strongly with particulates whose radii lie between .1 and 1 microns. Particles of this size are the most difficult to remove from emission sources and constitute the greatest health hazard. Optical bands MSS 4 and 5 are very well suited to monitoring of hazardous particulates. Relatively sophisticated signal level interpretation, however, will be necessary to retrieve this information from ERTS imagery.

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* An interesting discussion of the conflicts between environmental pollution and the energy crisis is contained in the article "Energy: Prospects for the Rest of the Century" by D.F. Othmer, Mechanical Engineering 96, 18 August 1974.

** E.L. Riley, "Air Quality Indices from ERTS-1 MSS Information, PR 568" Symposium on Significant Results Obtained from ERTS-1, from NASA SP-327, U.S. Government Printing Office, Washington, D.C., p. 1583.

*** R.S. Fraser, "Computed Atmospheric Effects on ERTS Observations," Symposium on Significant Results Obtained from ERTS-1, from NASA SP-327, U.S. Government Printing Office, Washington, D.C., P. 1567.

**** W.A. Lyons, "Use of ERTS-1 Imagery in Air Pollution and Mesometerological Studies Around the Great Lakes," Paper E1, Symposium on Significant Results Obtained from ERTS-1, NASA SP-327, U.S. Government Printing Office, Washington, D.C.

RMF No. 6.2.2

Estimate of ERTS Economic Capabilities

The ability of ERTS to observe particulate concentrations and delineate pollution-caused plant damage may substantially impact the economic model used to determine proper controls and emissions. ERTS benefits are not easily quantifiable because the capability to determine air quality is still being developed. If particulates can be measured to within 10% or so, then there will be large benefits. On the other hand, if only qualitative measurements such as now exist are possible, benefits will be more modest.

Research mentioned in the previous section indicates that there is a very good possibility that particulates may be measured accurately. Research by the U. S. Department of Health, Education and Welfare* indicates that plants may be observed from satellites. Thus, indications are that potential benefits are high, however realistic estimates must be based on current capabilities.

The ERTS sensor system is not sensitive to sulfur oxides, oxides of nitrogen, ozone, or other transparent gases. Benefits then, will only come from better monitoring of particulate sources and distribution. From Figure 4 a cost of $.55 billion or $2.6/person is found due to uncertainty in the cost of particulate pollution. A reduction of uncertainty on the order of 1-5% would yield benefits of 2.5-13 cents per person per year, or $5 to 27 million.

Annual Benefit:

New Capability: ($5-27 million)

* W. Heck, F. Fox, C. Brandt, and J. Dunning, "Tobacco, a Sensitive Monitor for Photochemical Air Pollution," National Air Pollution Control Administration Publication No. AP-55.

RMF No. 6.2.3

WEATHER FORECASTING

Rationale for Benefits

In spite of the importance of the effects of weather on many of Man's activities and in spite of the amount of effort that has been devoted to understanding atmospheric phenomena, our ability to forecast the weather (particularly for more than two days in advance) is very limited. (See Table 3.)

There are two major areas of inquiry in weather forecasting: long-range (synoptic-scale) forecasting and short-range (meso- and micro-scale) forecasting. The two different areas are characterized by the different scale of phenomena observed and, to some extent, by the different types of information required; also, the different time frames indicate different potential benefits for each. For example, more accurate long-term (up to two months) forecasts would provide substantial benefits in agriculture in improving planning of planting and harvesting; whereas, improved short-term forecasts would facilitate planning in the construction industry and planning of maintenance and repair schedules in the transportation and utility industries.

Present technology is a long way from having either the capability to collect and process all the pertinent data or the understanding to use the information derived from the data effectively if it were available. However, as the two simple examples above might suggest, because so many aspects of human activity are affected by the weather even incremental improvements in different forecasting capabilities would yield substantial economic benefits in both the public and private sectors.

Federal Government Activities and Responsibilities

The National Weather Service (now part of the National Oceanic and Atmospheric Administration [NOAA] as a result of Reorganization Plan No. 4 of 1970) exercises the responsibility for weather forecasting and the taking and distribution of meteorological information which is mandated by 15 USC 313. This agency of the Federal Government is the primary source nationally for meteorological information and analysis. By program and amount (FY 1974 adjusted) NOAA's activities in weather forecasting are summarized in Table 4. (See Appendix B for more details).

There is enormous variety in the methods by which meteorological data are collected and the ways in which they are used. Examples of data collection methods include in situ

Table 3 Summary of Present Forecast Skills

Time	Pressure	Ceiling	Visibility	Precipitation	Temperature, °F
12 Hrs.	R=.90	SS=.5	SS=.5		
1 Day	R=.70	Forecast	Forecast	85% Correct	3.7 Error
36 Hrs.	R=.68	Climatology	Climatology	82% Correct	4.3 Error
2 Days	R=.65	↓	↓	SS=.50	4.7 Error
60 Hrs.	R=.61	↓	↓	SS=.45	5.3 Error
3 Days	R=.58	↓	↓	SS=.38	
4 Days	R=.45	↓	↓	SS=.29	
5 Days	R=.34	↓	↓	SS=.22	
6 Days	R=.15	↓	↓	SS=.15	
7 Days	R=0	↓	↓	SS=.10	
8 Days	↓	↓	↓	SS=.05	
9 Days	↓	↓	↓	SS=0	
10 Days	↓	↓	↓	Forecast Climatology	
11 Days	↓	↓	↓	↓	
12 Days	↓	↓	↓	↓	
13 Days	↓	↓	↓	↓	
14 Days	↓	↓	↓	↓	

R is the correlation coefficient between observed and forecast parameters
SS is the Skill Score (The "skill score" is used to indicate forecast performance referenced to change. They are positive for forecasts better than chance and negative for forecasts worse than change. A skill of 1.00 is the best possible.)
Error is the mean absolute error of maximum and minimum temperatures.

Source: Scoggins, James R., et. al., An Investigation of Relationships Between Meso- and Synoptic-Scale Phenomena, NASA Contractor Report CR-2030, Washington, D.C., June 1972, p. A-30.

Table 4 Weather Forecasting Activities of the National Oceanic and Atmospheric Administration (NOAA)	
Program	FY 74 Budget, $*
Basic Environmental Services:	
Basic Observations	56,443,000
Basic Weather Analysis and Predictions	20,624,000
Environmental Satellite Services:	
Basic Environmental Services Support	16,813,000
Total	93,880,000

*These figures do not include some $56 million spent on the public issuance of weather forecasts and warnings and specialized weather forecasts such as those for agriculture and aviation.

Source: Office of Management and Budget, The Budget of the U.S. Government FY-1974, U. S. Government Printing Office, Washington, D. C.

observations by aircraft, radiosondes, buoys and ships and remote sensing by radar stations and satellites. This enormous bulk of data is analyzed by various sections of NOAA to provide, among other services, public and specialized weather forecasts and warnings.

Functions of Remote Sensing

Remote sensing, as a method for observing atmospheric effects, provides a number of specific advantages over in situ observations.* Remote sensing instruments can scan the atmosphere in two or three dimensions; they have better resolution in time and space than in situ measurements and are capable of measuring more sophisticated parameters; and because remotely sensed measurements are integrated over an area or volume, errors resulting from local perturbations are reduced. In addition, remote sensing systems do not disturb the atmosphere as do some in situ observation systems.

For the purposes of meteorological observation and analysis, remote sensed data collection by satellite has an inherent benefit because of the synoptic scale of observation. The scale of observation correlates conveniently with the scale of phenomena (see RMF 6.1.1 -- The Function of Remote Sensing) observed, reducing processing.

Economic and Technical Models for Estimating Benefits of Remote Sensed Data

There are two types of economic benefits to be accrued by use of remotely sensed data for meteorological purposes. The first type is the improved cost-effectiveness offered by remote sensing from providing more complete information at a reduced cost. The greater completeness of information results from the previously mentioned characteristic of remote sensing techniques to integrate measurement over an area or throughout a volume as opposed to the dispersed single point measurements of other methods. Also, reduced costs can be achieved because remote sensing techniques are inherently more susceptible to automation (i.e., reduction of manpower) and, although remote sensing techniques such as satellite or radar systems require large initial capital expenditures, the cost of employing such techniques compares quite favorably with systems utilizing simpler technologies requiring a larger labor force.

However, the modeling of such cost savings is very difficult. It is not possible to compare discrete systems for collecting the required data because for each parameter that must be measured (such as pressure, temperature, moisture, cloud cover, etc.) there are usually a number of different remote sensing methods each collecting all or part of the desired data with varying degrees of completeness or efficiency.

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* C. Gordon Little, "Remote Sensing of the Atmosphere," Atmospheric Technology, June 1973.

There is the additional complication of not being able to compare the values of similar sets of information when comparing remote sensing in this area to other approaches. Remotely sensed measurement of any parameter is more complete; in meterology greater completeness of information leads to better forecasts. The value of the improved forecast must then be measured by its impact on the private and public sectors.

Current ERTS Activities

No examinations have been conducted by the principal investigators toward the operational utilization of ERTS data for meteorological forecasting.

Estimate of ERTS Economic Capabilities

The internationally sponsored Global Atmospheric Research Program (GARP) has cited Ocean temperature as one of the variables required for models to provide 1-2 week weather forecasts.

A lower bound benefit has been calculated for thermal mapping of the ocean * by satellites based on a comparison of the cost of the use of high altitude aircraft versus satellites. (See RMF No. 7.1.2: Table 6 in Volume IX (Oceans) and accompanying discussion.)

The current ITOS satellites carry Very High Resolution Radiometers (VHRR) which monitor sea surface temperature on a global basis daily. The thermal IR band sensor which is to be flown on ERTS-C is expected to have a resolution approximately three times better than the ITOS sensors. However, the ERTS pattern of coverage would diminish the effect of this increased capability, especially for meteorological purposes.

For discussion of the observation of other meteorological parameters by an ERTS-like system see RMS No.'s 6.1.1, 6.1.4, 6.2.1, and 6.2.4.

Annual Benefit: 0

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* This estimate is just for the mapping of the Northern Pacific which is the area of most interest in predicting weather for the United States.

RMF No. 6.2.4

WIND MAPPING

Rationale for Benefits

The most important application for wind mapping lies in establishing part of the initial conditions for numerical weather prediction. With more precise and complete definition of this key meteorological parameter it will be possible to develop more accurate long-range predictive models.

Also, the development of wind statistics will become increasingly important as wind power is more carefully examined as an energy source.

Monitoring of upper tropospheric wind condition is important in aviation weather forecasting.

Accurate, real-time wind mapping will provide benefits in aircraft routing in terms of savings in fuel and time.

Federal Government Activities and Responsibilities

The Secretary of Commerce has responsibility for conventional weather forecasting (15 USC 313) and aviation weather forecasting (49 USC 1473). These responsibilities are carried out by the National Oceanic and Atmospheric Administration (NOAA) whose budget for basic weather observations is $56,443,000 (FY 1974 adjusted) and for aviation weather services is $18,213,000 (FY 1974 adjusted).

Functions of Remote Sensing

Remote sensing is vital in the area of wind mapping because it is not possible to implement a system of in situ observations (such as anemometers, data buoys, and radiosonders) that would provide data of the desired specificity for meteorological and commercial applications. Table 5 summarizes the current state of remotely sensed wind measurements. All the systems listed in the table are active systems examining various interactions such as frequency shift ("Doppler"), amplitude shift ("Scintillation"), and phase velocity shift ("Echo Correlation") of a generated electromagnetic or acoustic signal with the atmosphere. Recent research with microwave and laser radars has indicated that it will be possible to "interrogate" the clear atmosphere to measure such parameters as wind velocity and direction.

Table 5 Status of Wind Measurements

Parameter	Doppler			Scintillation			Echo Correlation		
	Microwave*	Acoustic†	Infrared	Microwave‡	Acoustic‡	Optical	Microwave*	Acoustic†	Optical
Mean Values									
Transverse				x	x	x		x	x
Longitudinal	x		F						
Vertical Profiles									
Horizontal Wind	x	x	F			F		x	x
Vertical Motion	x	x	F						
Turbulence	x	x	F						
Structure Constant (energy dissipation)		x							
Flux									
Momentum	x		F						
Energy	x		F						
2-D Coverage	x	F	F						
3-D Coverage	x		F						
Spectra of Turbulence	x		F						
Convergence/Divergence	x		F			x			
Vorticity	x	x	F		x				

*Requires precipitation or chaff †Not in rain or hail ‡Not in precipitation or cloud
x Already demonstrated F Expected in next 3-5 years

Source: C. Gordon Litte, "Remote Sensing of the Atmosphere," Atmosphere Technology, June 1973, p. 52

Passive systems are limited to observing the effects of winds such as cloud movement and fragmentation*, ozone**, or dust***.

Economic and Technical Models for Estimating Benefits of Remote Sensed Data

The benefit of remotely sensed data on winds results from its completeness. For example, the winds of the tropical areas have a considerable effect on the entire world's weather. Yet, these areas are notably data sparse. A remote sensing system providing frequent coverage of such areas would offer important data for the improvement of current numerical weather prediction methods.

Current ERTS Activities

(See footnotes on bottom of page.)

Estimate of ERTS Economic Capability

An ERTS-like system, with its high resolution, is capable of observing effects of winds (such as cloud movements); in addition, information can be inferred about wind altitude through cloud altitude. However, repetitive imaging is necessary over a fairly short period of time in order to derive wind information in this manner. The type of wind data which ERTS could collect over time would be of some use in the exploration of wind as a power source - it will provide wind data on a global basis for one particular time of day (9:00 a.m.). However, no large-scale research which could use this information exists at the moment.

Annual Benefit: 0

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* K. Tsuchiya and T. Kamiko, "Application of ERTS Data to the Detection of Thin Cirrus and Clear Air Turbulence," Paper E14B from Symposium on Significant Results Obtained from ERTS-1, NASA SP-327, U.S. Government Printing Office, Washington, D.C.

** C. Prablakara, E. Rodgers, and J. Steranka, "Observations of Jet Streams over the Northern and Southern Hemi-shpere, from Nimbus 3 IRIS Ozone Data," in preparation at Goddard Space Flight Center, Greenbelt, Md.

*** L. Bowden, J. Huning, C. Hutchinson, C. Johnson, "Satellite Photograph Presents First Comprehensive View of Local Wind: the Santa Ana," Science, June 7, 1974, pp. 1077-1078. (See Figure 1-3a and 1-3b of Volume I.)

RMF No. 6.5.1

CO_2 CONCENTRATION AND GREENHOUSE EFFECT MONITORING

Rationale for Benefits

The long-term heating of the earth's surface attributable to the trapping of heat by CO_2 may have immense impact on civilization. Substantial weather changes due to the increased evaporation from seas and land water masses may drastically affect agriculture and environment. Possible melting of part of the polar ice caps will raise the level of the oceans, severely affecting the coastal regions where the preponderance of the world's population resides.

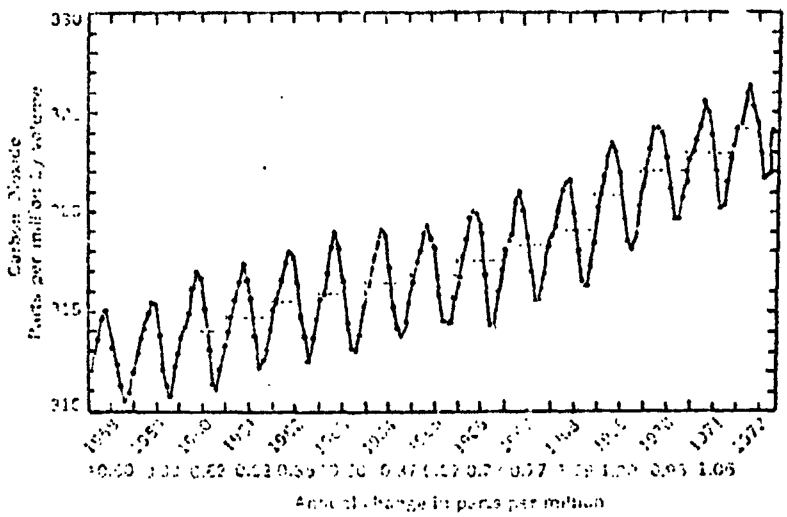
Federal Government Activities and Responsibilities

Research is currently performed by the National Oceanic and Atmospheric Administration's Environmental Research Laboratories. Four observatories in the Arctic, Antarctic, South Pacific, and Hawaii are currently monitoring carbon dioxide concentration.

Functions of Remote Sensing

Figure 6 shows the seasonal fluctuation and the global trend of the atmospheric content of carbon dioxide. It is apparent that over the past fifteen years the level of carbon dioxide has increased by about 4%, and the rate is constantly increasing. This growth is ascribed to increasing combustion and decreasing foliage. Regional variations of carbon dioxide have also been observed, with high concentrations in urban and industrial areas. Remote sensing of these concentrations, their long term variations and local distributions, can be accomplished by infrared detectors. Carbon dioxide is not yet identified as a pollutant, however, based on observations from such a satellite system, it may become one of the most hazardous pollutants. Currently localized observations limit knowledge of flow of carbon dioxide, particularly in the upper atmosphere where the recycling time is long. Such information is a benefit to the Environmental Protection Agency in setting standards and to society if future disasters can be avoided.

RMF No. 6.5.1



[1]Change based on less than 12 monthly measurements per year.
Source: Department of Commerce, National Oceanic and Atmoshperic Administration, based on data provided by C.D. Keeting, Scripps Institution of Oceanography, sponsored by the National Science Foundation.

Figure 6 Increase in Carbon Dioxide Concentrations at Mauna Loa Observatory

Estimate of ERTS Econrmic Capabilities

ERTS will not be capable of observing CO_2 since neither the sensors on board nor the thermal infrared scanner are sensitive to the CO_2 absorption or emmission bands. Benefits, therefore, are zero.

Annual Benefit: 0

RMF No. 6.5.2

MONITOR JET CONTRAIL WATER VAPOR CONDENSATION AND CARBON DIOXIDE EFFECTS ON WEATHER AND AIR

Rationale for Benefits

High altitude clouds caused by jet traffic are daily observable, and introduce into the upper atmosphere condensed ice particles that reflect sunlight, causing somewhat of a decrease in light reaching earth. Jets also leave combustion residue, particularly carbon dioxide in the upper atomsphere where recirculation times are long. The flights of hundreds of jets per day over the United States and the world may be substantially affecting our environment. Information bearing on the long-term modification of the upper atmosphere plus trailing of higher concentrations of pollutants and condensation in jetways will impact decisions on new aircraft, air routes, and determine any necessity of control.

Federal Government Activities and Responsibilities

The Department of Transportation is currently completing a Climatic Impact Assessment Program to establish possible effects from supersonic transports operated by other countries as well as the United States.* According to testimony of Dr. Robert Cannon, then Assistant Secretary for Systems Development and Technology, before the U.S. House of Representative Appropriations Committee, "Conclusions ...may well turn out to indicate that the world could have a couple of serious problems with its climate if many hundreds of (supersonic) aircraft were allowed to fly with present engines and present fuels."** Results of a recently completed summary at Woods Hole, Mass. are to be presented to Congress in December 1974.

The National Oceanic and Atmospheric Administration budgeted $3,795,000 in 1974 for upper atmospheric and space research. Among their programs, this money was spent for

* A.J. Grobecker, "U.S.D.O.T. Research Program for Assessment of Stratopheric Pollution", presented at 24th International Astronautical Congress, Baku, USSR, 7-13 October 1973.

** U.S. House of Representatives Committee on Appropriations Hearings, Department of Transportation and Related Agencies Appropriations for 1975, part 2.

RMF No. 6.5.2

"research on the possible effects of the intoduction of man made pollutants into the stratosphere and upper atmosphere from supersonic aircraft and space shuttle vehicles."*

Functions of Remote Sensing

High altitude cirrus clouds formed by jet contrails can only be seen in their entirety from afar. Observations from the ground are limited to views of small regions compared to the global voyages of present and future jet aircraft. Satellite observation will cover the entire globe, and will be able to generate long-term statistics on average atmospheric ice, particulate, CO_2 and ozone concentration which can be correlated with regional and global variations. Such information is crucial for determining effects of the supersonic transports, and should be obtained before large fleets of such planes begin operating.

Current ERTS Activities

K. Tsuchiga has demonstrated that thin cirrus clouds of the type left by jet aircraft are observable from ERTS and are not observable from meterological satellites.** ERTS images often have contrails across them, so there appears to be little difficulty observing effects of jet traffic.

Estimate of ERTS Economic Capabilities

It has been estimated that contrails increase by 5 - 10% the cirrus cloud cover in the North America - Atlantic-European area. Surface temperature decrease under contrails has been estimated at .15°C. The carbon dioxide from jets will not be observable by ERTS, however, studies indicate that the dominant effect will be due to water vapor contrails.

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* U.S. House of Representatives Committee on Appropriations Hearings, Department of State, Justice, and Commerce, The Judiciary, and Related Agencies Appropriations for 1975, part 3.

** K. Tsuchiga, "Application of ERTS Data to the Detection of Thin Cirrus and Clear Air Turbulance", Paper E 14 B from Symposium on Significant Results Obtained from ERTS-1 NASA SP-377, U.S. Government Printing Office, Washington, D.C., p. 673.

RMF No. 6.5.2

Decisions concerning supersonic transports require information on the climatic impact of condensed vapor trails. The lack of such data led to the demise of the SST in the House Appropriations Committee hearings. The value of the data would have been large at the time since a $290 million dollar program was cancelled. Currently the data will be useful for assessing the environmental impact of jet traffic and future deliberations on new transports and decisions concerning foreign transports.

ERTS is limited in its value because of the low repetition rate which makes it difficult to determine the diffusion and persistence of all but north-south vapor trails. Experiments, however, could be run flying a plane north-south on a path photographed shortly after by the satellite. Benefits from such data may be extremely valuable; however, the future dollar value of this information is not quantifiable. Estimated benefits on the order of $100,000 to $300,000 are based on current efforts to obtain this information.

Annual Benefit:

New Capability: ($.1 - .3 million)

RMF No. 6.6.1

MONITOR EFFECTS OF THERMAL AND OTHER POLLUTION SOURCES ON WEATHER

Rationale for Benefits

Photographs from ERTS-1 demonstrate the role particulate pollution sources in Chicago are playing on the weather in Michigan.* These sources are clearly identifiable, their plumes extend over Lake Michigan and become clouds on the far side. Other unintentional man-made local weather effects include the thermal uprisings caused by cities and plowed areas and subsequent formation of clouds or haze. Inversion layers and stagnant air due to smoke and haze daily modify the weather in many cities. Very substantial weather alterations due to poor farming techniques and dust may be causing the deadly draught in the sub Sahara region of Africa in ways similar to those thought to have caused the severe draught in the United States during the 1930's. Studies of clouds caused by dust particles indicate that the particles act as condensation centers for water and ice.**

Federal Government Activities and Responsibilities

The National Oceanic and Atmospheric Administration operates a program of weather modification of severe storms, but does not concern itself with inadvertent weather modification. Project Metromax is currently underway to study the effects of pollution on the weather of St. Louis. Sponsorship is primarily under the auspices of the EPA and involves researchers from the University of Wyoming and Stanford Research Insitúte, among others. Total government expenditures in weather modifications are about $17 million distributed throughout various agencies.

Functions of Remote Sensing

The modification of weather due to pollution usually occurs on a meso to micro scale (less than 500km). Weather satellites are not capable of monitoring phenomena on such a small scale. Pollution densities are highest in populated areas, therefore, a large portion of the population of the

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* See Figure 1.3 of Volume I of this report.

** D.L. Veal, University of Wyoming. Private communication.

United States and world may be living in modified regions and may suffer from local conditions never seen by weather satellites. Analysis of pollution effects on weather from ground based observers suffers from too small a view; what is needed is a system capable of observing the source and the affected area. The earth resources satellite is well qualified for such observations and has indeed already identified previously unobserved phenomena, as has been mentioned.

Economic and Technical Models for Estimating Benefits of Remote Sensed Data

Damage due to inadvertent weather modification has only been observed recently. No models have been developed to assess possible social costs. Obviously long term unintentional modifications causing changes will have major economic and social impacts. These are specifically discussed in RMF 6.7.3.

Current ERTS Activities

ERTS activities in this area are incidental and involve the observation of pollution modified weather phenomena over Lake Michigan and some studies of the Sahel region of Africa.*

Estimate of ERTS Economic Capabilities

The ability of ERTS to observe weather phenomena, atmospheric smoke and haze, and ground conditions with relatively high resolution provides a previously unavailable capability of determining man's effect on the weather. Cloud cover and cloud location statistics on a micro and meso scale will be extremely useful in observing inadvertent weather modification. Local cloud formations due to thermal and particulate effluents have already been observed.

The economic impact of observations of weather modification is unclear. Increased rainfall may actually be a benefit; however, current theories are that man's major modification will cause a decrease in rainfall due to poor

* See Figure 1.5 of Volume I.

RMF No. 6.6.1

agricultural practices.

A discussion of long term weather modification is presented in RMF No. 6.7.3 under monitoring climatic changes. The major short term use of the ERTS capability in this area will be for statistical and legal activities. Benefits of a more substantial nature will most likely accrue as more statistics are recorded and weather deviations become apparent. Net benefits for the present, although possibly large, must be assumed to be unquantifiable for the purposes of this study.

Annual Benefit:

New Capability: Possibly substantial but unquantified

PMP No. 6.6.2

MONITOR AIRBORNE POLLUTION EFFECTS ON THE ENVIRONMENT

Rationale for Benefits

Numerous studies have documented and attempted to quantify damage to the environment due to air pollution. Total costs on the order of ten billion dollars per year generally are based on readily quantifiable disbenefits such as materials damage, lost productivity due to health, and vegetation damage. These estimates appear to be a conservative limit on damage since aesthetic damage, psychological damage and health damage to non productive (retired or unemployed) citizens have not been quantified. Evidence indicates that damage to vegetation may occur long before it becomes obvious. Tree rings, for example, show effects of pollution on growth years before foliage damage is observed.* Adverse effects of low pollution concentrations may be greater than previously estimated. ** Monitoring of ambient air quality, pollution drift, and environmental damage will be extremely important for setting air quality standards, assessing pollution-related damage, and protecting public health and welfare.

Federal Government Activities and Responsibilities

Under the auspices of the Clean Air Act (42 U.S.C. 1857) the Environmental Protection Agency budgeted $30,441,800 in 1974 for research and development work in processes and effects of air pollution.*** An increase of $9,044,200 was asked for 1975 to, among other activities, "expand studies of chemical and physical processes of atmosphere pollutants." On-going research on "ecological processes and effects involving meterological research regarding pollutant transport processes" will presumably continue.

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* H.C. Fritts, "Tree Rings and Climate" Scientific American, May, 1972, p.93.

** L.I. Moss (Pres. Sierra Club) Statements before EPA hearing on Significant Deteoriation, Washington, D.C., (Aug. 1973.)

*** U.S. House of Representatives Committee on Appropriations Hearings for the 93rd Congress, 2nd session, Agriculture-Environmental and Consumer Protection Appropriations for 1975, part 4.

RMF No. 6.6.2

The Agriculture Research Service currently conducts research on soil, water, and air pollution effects and methods to protect plants and animals from them. The 1974 budget allocates $13,250,000 to this activity, and the eff rt involves some 209 scientists. The authorization for this research is from the National Environmental Policy Acts of 1969 and 1970 (PL 91-190 and 91-148, S780 and Section 2 as amended in 42 U.S.C. 1857-19571).*

The Functions of Remote Sensing

The studies outlining the effects pollution has on the environment are done on a case-by-case scale, then extrapolated to the entire United States, leading to gross uncertainties. This is particularly true in the case of vegetation, where study of losses in Pennsylvania has been extrapolated to U. S. losses. Different regions, however, have different types of pollution. The distributed sources in the Los Angeles basin cause extensive hydrocarbon, nitrous oxides and carbon monoxide pollution which are quite different from Pennsylvania sulfur dioxide and particulate pollution. Effects of pollution also exhibit different symptoms, frequently they appear minor but affect large areas.

Remote sensing satellites have the capacity not only to view the entire earth, but they are particularly well suited to sensing widely distributed phenomena, such as usually will be the case with vegetation damage. Healthy vegetation in regions removed from pollution sources can be easily compared with affected vegetation. Pollution flow patterns can be monitored and correlated with vegetation vigor and stress. Even though the specific symptoms of pollution damage may be unknown, a satellite will be able to identify pollution-caused losses and may be able to detect pollution effects earlier than ground observations.

Economic and Technical Models for Estimating Benefits

Economic estimates of benefits attributable to satellite observation depend on the success of data reduction techniques in detecting air pollution and crop stress. Benefits are assumed to be cost savings in the area of identification of crop and vegetation damage. Benefits from the knowledge of pollution distribution will accrue in numerous ways but must be treated as a cost savings associated with higher productivity of labor

* U.S. House of Representatives Committee on Appropriations Hearings for the 93rd Congress, 2nd session, Agriculture-Environmental and Consumer Protection Appropriations for 1975, part. 4.

and marketable items.

Current ERTS Activities

Association of pollution with environmental damage is not an area that is heavily researched. Several studies, however, allude to pollution damage. N. Press's* work on metal damage to vegetation indicates pollution caused effects may be observed from space. Some air pollution occurs in rather well defined areas. Observation by aircraft may be of substantial import until a resources satellite with high enough resolution to observe urban foliage areas is developed.

Estimate of ERTS Economic Capabilities

Air pollution has been shown to damage numerous things including human health, vegetation, metals, paint, electrical contacts, rubber, textiles, animal health, and property. Among these, ERTS is limited to ob erving the damage to vegetation since that is the only extensive item in the above list. Pollution damage to other items may be inferred.

The extent of pollution damage to vegetation has not been directly measured, however, numerous studies particularly in California and Pennsylvania have concentrated on damage to selected regions. Air pollution may be affecting vegetation throughout the entire Northeast,**however, no synoptic scale observations have been made. A study by SRI*** determined probable plant damage from fuel usage, weather, and plant statistics on a county by county basis throughout the most populous areas. Dollar loss of all commercial crops grown in the United States was estimated at .5%

* N. P. Press, "Remote Sensing to Detect the Toxic Effect of Metals on Vegetation for Mineral Exploration," from 9th International Symposium on Remote Sensing of the Enviroment, Willow Run Labs, Ann Arbor, Michigan, p. 221.

** U. S. Forest Service, Air Pollution Damages Trees, from Forest Service Northeastern Area, (1973), U. S. Government Printing Office, Washington, D.C.

*** H.M. Benedict, C.J. Miller, and R. E. Olson, "Economic Impact of Air Pollutants on Plants in the United States," prepared for Coordinating Research Council and EPA, document number PB 209 265 available from NTIS.

Losses to crops and ornamental plants due to oxidants were estimated by SRI to be $121,396,000 for the entire U.S. Those due to all pollutants were $131,936,000. The ERTS ability to observe the plants affected by pollutants does not in itself yield benefits, however, two major functions may be served. First, a correlation between pollution distribution and crop stress will produce an earlier identification of pollution related effects and a better estimate of pollution damage. Second, identification and observation will facilitate the selection of pollution resistant plant species in affected areas and the selection of sites for planting. The low resolution of ERTS and its questionable ability to observe plant vigor and stress limit observations to extensive areas like large single crop fields or forests that might be affected by regional rather than local pollution. Estimated benefits of about .2 to .7% of the U.S. plant losses (.25 to .9 million dollars) may be conservative if pollution damage is found to be as extensive as is feared by some.

Extrapolation of pollution effects on vegetation, particularly to vegetation affected by sulfur oxides and particulates, may aid with evaluation of pollution effects on non observable items such as human and animal health, residential property, materials, etc. Damage to all these is estimated to be between 6.1 and 18.5 billion dollars.* Since most damage occurs in highly populated areas, the observation by ERTS will probably have little benefit with regard to property and materials. There are, however, possibilities of saving human and animal facilities and pollution sensitive crops using ERTS or Nimbus G pollution distribution data. The estimate of between 1.6 and 7.6 billion dollars as an annual cost for air pollution damage to health from future earnings lost due to mortality and treatment neglects any value associated with non income individuals including homemakers and retired persons. For example, air pollution in New York City is estimated to cause the deaths of 28 people per day.** Benefits attributable to ERTS, however, are uncertain especially since Nimbus G will be capable of observing noxious gases as well as particulates.

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* T.E. Waddell, The Economic Damages of Air Pollution, U.S.E.P.A. Report number EPA 600/5-74-012 (May 1974).

** H. Schimmel, Annual Convention of the Air Pollution Association (1974), reported in The Sciences 14, 4 (July/Aug. 1974).

RMF No. 6.6.2

Annual Benefit:

Increased Capability: ($.25 to .9 million)

New Capability: Possibly substantial but not quantified.

RMF No. 6.6.3

MONITOR EFFECTS OF VOLCANIC ERUPTIONS ON AIR QUALITY

Rationale for Benefits

Severe volcanic eruptions spew particulates, sulfur dioxide, carbon dioxide, and numerous other pollutants into the upper atmosphere. The lack of circulation in the upper atmosphere may cause these particulates and gases to remain for weeks and diffuse around the world, as was observed in 1883 from Krakatoa. Other less active volcanoes, such as Mt. Baker in Washington, emit fumes which affect local surroundings. Observation of these natural phenomena provide a unique opportunity to assess how the environment responds to large perturbations. The time to recover will indicate the persistence of upper atmosphere pollution from jets, nuclear devices and other man-made sources.

Federal Government Activities and Responsibilities

The National Oceanic and Atmospheric Administration monitors solar radiation at the Mauna Loa observatory and is able to observe the attenuation of the sun by the dust in the atmosphere.

Functions of Remote Sensing

Volcanic eruptions constitute the most substantial short term atmospheric modification. Figure 7 is a plot of the variation in solar radiation due to particulates in the upper atmosphere from the eruption of Mt. Agung in early

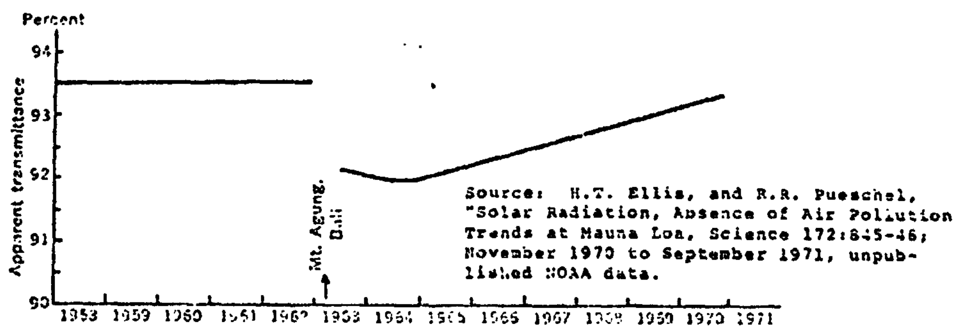

Figure 7 Transmittal of Normal Incidence Solar Radiation at Mauna Loa

1963. The variation is large, and the recovery time long. Similar plots of gas concentration in the upper atmosphere due to such eruptions will indicate the time required to recovery, which may be longer since particulates settle out faster than gases.

Satellite data taken at intervals after an eruption will show the diffusion of gases and particulates as well as the concentration and recovery time. Ground data do not give diffusion or circulation information.

Current ERTS Activities

Current research on measurement of atmospheric haze and aerosols is listed under RMF 6.1.2.

Estimate of ERTS Economic Capabilities

ERTS can determine aerosol and particulate content in the atmosphere most easily over uniform backgrounds such as the ocean. Following an eruption, ERTS data could be analyzed to track the concentration and dispersion of dust around the earth. Economic benefits associated with this capability, however, must be considered negligable.

Annual Benefit: 0

RMF No. 6.7.1.

DETERMINE CLEAR AIR TURBULENCE LOCATION

Rationale for Benefits

Although the possibility of dependably locating clear air turbulence is remote, the benefits are significant. Commercial and military aircraft are constantly threatened by turbulence, and route themselves to avoid high probability areas. Fuel and time are expended, even when the probability of clear air turbulence is low. Identification of regions of turbulence would save on routing of airplanes and lower the accident probability. Benefits to the military in terms of equipment damage and personal injury prevention as well as lower fuel expenses and time to destination could be substantial. Commercial aviation also stands to gain in cost savings from fuel loss, equipment damage, as well as personal injury.

Federal Government Activities and Responsibilities

The Secretary of Commerce is directed (49 USC 1463) to "make such observations...and establish such meteorological offices and stations, as are necessary...or ascertaining, in advance, information concerning probable weather conditions...(in order to promote safety and efficiency in air navigation)"; hence, clearly a mandate exists to pursue investigation of such threats to safety as clear air turbulence. The total budget (FY 1974 adjusted) of the National Oceanic and Atmospheric Administration (NOAA) for aviation weather services is $18,213,000. NOAA is currently researching the use of remote sensing for detection of clear air turbulence at its WAVE Propagation Laboratory.* Funding for this area of research in FY 1974 is $1,470,000.

In addition, the Air Force is conducting its own research into ways to locate and/or predict clear air turbulence.

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* V.E. Derr, Remote Sensing of the Troposphere, Wave Propagation Lab NOAA and Electrical Engineering Dept. U. of Colorado, 15 Aug. 1972.

RMF 6.7.1.

Function of Remote Sensing

The current state of knowledge concerning clear air turbulence (CAT) indicates that thin cirrus clouds, sometimes occur nearby. Only remote sensing systems capable of observing objects of low reflectivity are able to detect thin cirrus clouds.

The presence of thin cirrus clouds has been used to detect the core of the jet stream, and it has been observed that CAT occurs in proximity to the jet stream.* Therefore, it is hoped that passive remote sensing techniques able to detect thin cirrus clouds will lead to predictions of areas that may have CAT.

As has been pointed out by R.S. Lawrence,** many experimenters have attempted to use both passive and active remote sensing to locate clear air turbulence with little or no success. Present plans to use a satellite borne laser for scintillation detection may produce some results, however most scientists are skeptical.

Economic and Technical Models for Estimating Benefits of Remote Sensed Data

The costs connected with not being able to specifically locate or predict the location of CAT include fuel and time loss, equipment damage and personal injury. To whatever extent a remote sensing system provides better information which reduces these costs, it provides a clear economic benefit.

Current ERTS Activities

Kiyoshi Fuchiya, Japan Meteorological Agency, Tokyo, Japan
Toshiro Kamiko, Tokyo International Air Weather Service, Tokyo, Japan.

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* Kiyoshi Fuchiya, Toshiro Kamiko, "Application of ERTS Data to the Detection of Thin Cirrus and Clear Air Turbulence," from Symposium on Significant Results Obtained from the Earth Resources Technology Satellite-1, NASA, 1973, U.S. Government Printing Office, Washington D.C.

** Ibid., Section 25.2.5.

RMF No. 6.7.1

Estimate of ERTS Economic Capability

Fuchiya and Kamiko state that data with the quality of ERTS data available in real time would be useful in predicting the area of CAT. However, the brevity of time span and the small horizontal scale combined with ERTS's projected polar orbit suggest strongly that no economic benefit will be realized by an ERTS-like ERS system in this area.

Annual Benefit: 0

RMP No. 6.7.2

PROVIDE SEVERE STORM WARNINGS

Rationale for Benefits

Local conditions leading to tornadoes, cyclones, hurricanes and severe thunderstorms can be remotely identified. Combined with weather satellite information and ground observations, this information would be useful for warnings to populated areas and routing of aircraft. Storm conditions at sea where ground truth is difficult to obtain would be important for aircraft, and to some degree for ships. Improved monitoring of storms will increase knowledge of storm origins and dynamics, leading eventually to more dependable prediction and storm modification. Earlier and more accurate warnings of severe storms will reduce loss of life and property damage.

Federal Government Activities and Responsibilities

The Secretary of Commerce is responsible (15 USC 313) for issuing storm warnings. In pursuance of this the National Oceanic and Atmospheric Administration (NOAA) spends $5,563,000 (FY 1974 adjusted) annually for hurricane and tornado warning services including warning preparation and dissemination, research, and community preparedness services.

Functions of Remote Sensing

Severe local storms are mesocale phenomena which are related to synoptic systems.* One researcher** who has studied the relationship between the two scales of phenomena has shown that the conditions necessary for the development of severe storms are conditional instability, low level moisture, a lifting mechanism, and a favorable distribution of strong winds and wind shears. The more completely and efficiently remote sensing can monitor these conditions, the more dependable and timely will the severe storm warnings be.

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* James R. Scroggins, et. al. An Investigation of Relationships Between Meso-and Synoptic Scale Phenomena, NASA, Contractor Report CR-2030, Washington, D.C., June 1972.

** R.C. Miller, Notes on Analysis and Severe-Storm Forecasting Procedures of the Military Weather Warning Center, 1967.

RMF 6.7.2

Remote sensing is also important for tracking larger-scale severe storms such as hurricanes in the data-sparse areas over oceans in order to predict their landfall and to issue appropriate warnings.

Economic and Technical Models for Estimating Benfits of Remote Sensed Data

Two types of benefits occur in this area. One results from increased dependability of storm warnings; this reduces the cost of preparing for "false alarms."* The other benefit would occur from increasing the lead time in warnings by more accurately assessing storm conditions before the storms actually occur. Over time this increased warning will reduce loss of life and property connected with severe storms.

Estimates of ERTS Economic Capabilities

In order to obtain economic benefits from more accurate or earlier severe storm warnings, near continuous monitoring is necessary. ERTS will not provide this; such information will be provided more efficiently by the Geostationary Operational Satellite System, which is intended to provide a near continuous capability to detect, locate and track hurricanes and severe local storms.

Annual Benefit: 0

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* It has been estimated that it costs the city of Miami on the order of about $2 million to prepare for a hurricane. (Rand Corporation, study).

RMF No. 6.7.3

MONITOR CLIMATOLOGICAL CHANGES

Rationale for Benefits

Climatic changes are obviously occurring, yet it is difficult to observe them except in the most drastic of circumstances such as the apparent 8 miles per year southward motion of the Sahara Desert. Short and long term trends need to be identified at an early stage so that response in the form of improved irrigation, crop selection, and public facilities can be initiated before crises conditions occur. This is particularly important if the climatic changes can be traced to man's effects on the environment. Benefits may be enormous, as would have been the case if the problem in Central West African nations had been anticipated before mass starvation occurred. Figure 8 shows areas of the world currently thought to be experiencing climatic changes. The absence of rainfall this past year in the central United States may be a symptom of such a change.

Severe weather changes, ranging from floods to drought, have struck many of the world's major agricultural areas so far this year. Climate experts say that even greater variability of weather can be expected in years to come, bringing changes to arable areas that have adjusted to past patterns, thus threatening future output.

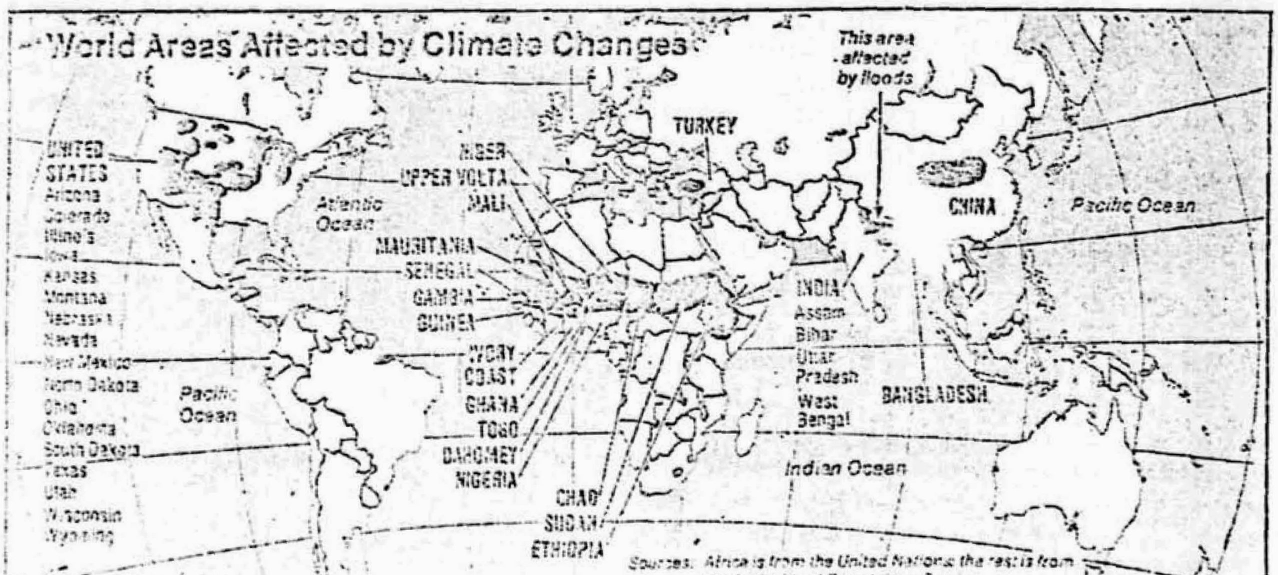

Figure 8 World Areas Affected by Climate Changes

RMF No. 6.7.3

Federal Government Activities and Responsibilities

The Secretary of Commerce is directed in one section of 15 USC 313 to make a record of climatic conditions in the United States. Consequently the National Oceanic and Atmospheric Adminstration (NOAA) is currently participating in the internationally sponsored Global Atmospheric Research Project (GARP) and in an internationally maintained global system of baseline climatological monitoring stations. The newly initiated Geographical Monitoring for Climatic Change program is an effort by NOAA to measure environmental parameters on a long term basis to establish climatic variations.

Functions of Remote Sensing

The synoptic view provided by remote sensing is desirable for monitoring climatological change where it is necessary to recognize and analyze large-scale patterns. Remote sensing techniques are capable of detecting causes of climatic change such as deflection of ocean currents like the Gulf Stream, the climate changes themselves in terms of global temperature, moisture, wind, and precipitation patterns, and the effects of climatic changes such as changes in soil moisture and vegetation.

One of the most important functions of remote sensing will be the monitoring of the global heat balance, that is, the amounts of energy absorbed or reflected by the earth, oceans, and atmosphere. As with all aspects of climatic monitoring, observation of the global heat balance will have to be conducted on a global basis over an extended period of time before the magnitude and direction of changes and the extent of man's impact can be determined.

Economic and Technical Models for Estimating Benefits of Remote Sensed Data

Dire predictions and demonstrated climatologic changes are increasing public and private interest in monitoring the climate. As early as 1961 Rachel Carson stated in The Sea Around Us that the warming of the ice caps has already resulted in a recession and disappearance of northern glaciers. Others have observed that the turbidity (dustiness) of the air over Washington, D.C. increased 67% in 60 years,* and that CO_2 in the atmosphere has increased at .2% per year (see Figure 6).

* A discussion of various climatic prophets is presented in George Haber's "The Intemperate Zone", The Sciences (The New Academy of Science) 14, 24 (July/Aug. 1974).

RMF No. 6.7.3

This increasing concern is reflected in the requested increase in the budget of the National Oceanic and Atmospheric Administration's program for global monitoring of climate change. The 1974 budget for observations is $237,000; the requested '975 amount is $713,000. The increase of $476,000 is to operate a new air quality observatory at Pt. Barrow, Alaska in addition to the Mauna Lua and South Pole stations.* These observatories measure such parameters as temperature, humidity, precipitation, pressure, surface winds, sky and solar radiation, atmospheric ozone and carbon dioxide concentrations, turbidity, aerosols, carbon monoxide, and Freon 11.

Economic benefits from observation of climate changes can only accrue from permitting man to adapt in time. It is apparent that some adaptations have not been made soon enough, and projections are that many more millions may perish before man learns to adapt. It is this early lead time that justifies the expense of observation stations.

Satellites are currently being developed with capabilities to measure from orbit the environmental parameters mentioned. The continuous global coverage will not only replace the current observation stations, but will produce continuous distribution maps rather than several isolated points. The very minimum benefit from such a system will be a cost savings of $713,000 from replacement of the NOAA observatories. This, however, is negligible compared to possible benefits from extensive repetitive observations.

Current ERTS Activities

Figure 1-4 in Volume I of this report shows the rather surprising pentagonal region of land in Sahelian Africa.

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* U.S. House of Representatives, Committee on Appropriations Hearings, Departments of State, Justice, and Commerce, The Judiciary and Related Agencies, Appropriations for 1975, part 3.

RMF No. 6.7.3

Nicholas Wade* contends that the Sahelian drought is caused by bad land management practices and is supported, in part, by the analysis of this ERTS-1 picture. The green pentagonal area in the middle of the drought stricken area is an immense field in which cattle grazing is controlled. The fact that grazing is controlled in this area explains why it is still green while all the surrounding area has been reduced to desert. In a single year an estimated 100,000 people died of starvation and seven million people have become dependent on international food relief programs costing hundreds of millions of dollars annually.

Estimate of ERTS Economic Capabilities

Of the various environmental parameters monitored by the NOAA observations, ERTS is only able to measure turbidity, aerosols, and perhaps, from cloud cover, precipitation. The satellite can, however, observe global cloud cover and surface characteristics which the NOAA observations cannot. Other satellites such as Nimbus G will be capable of measuring additional parameters. The ERTS data must be combined with other available data to produce an overview of climatic variations. Benefits attributable to the entire data collection network must be considered immense if we are able to avert or prepare for future crises. Quantitative evaluation, however, is meaningless.

Annual Benefits:

New Capability: Possibly substantial but not quantified.

* Nicholas Wade, "Sahelian Drought, No Victory for Western Aid," Science, July 19, 1974.

RMF No. 6.8.1

RESEARCH ON EFFECTS OF THERMAL SOURCES ON WEATHER

Rationale for Benefits

As consumption of energy increases in the United States and throughout the world, the final product of that energy will be heated water and air. Federal regulations limit thermal pollution of water, and the effects of water heating are relatively easily monitored. Thus, regulation and enforcement encourage increased usage of air as a coolant. The environmental effects of heating air may be even more destructive than water, although not as localized. These effects will probably be observable as weather changes and they may substantially alter or destroy existing environments. Research on such effects will be extremely important, and ought to be undertaken soon, since increasing energy usage and thermal air pollution is an almost irreversible trend.

Federal Government Activities and Responsibilities

No extensive program of monitoring of thermal sources exists at the moment. However, the National Advisory Committee on Oceans and Atmosphere, recognizing the prospects of inadvertent weather modification in its oversight hearings before Congress on November 1972, called for a major research program in this area.

Functions of Remote Sensing

The effects of thermal sources on weather may not occur until the thermal plume has reached high altitude, many miles from the source as was true of the particulate caused weather modification discussed in RMF 6.6.1 and shown in Figure 1-2 of Volume 1. Thermally initiated weather effects also depend on the wind direction and local climatic conditions. Satellite observation of such phenomena produces the synoptic scale coverage necessary to correlate sources with effects. A thermal infrared capability combined with visible wavelength sensing will produce a combination thermal source and cloud picture that may readily be analyzed for any identifiable weather modification.

Economic and Technical Models for Estimating Benefits of Remote Sensed Data

Puffy little cumulus clouds over plowed fields are a familiar sight to glider pilots since they are caused by the strong updraft from the sun heated dark colored dirt.

Similiar thermals and downdrafts over surface features frequently cause turbulence felt by aircraft and affect weather. Even ERTS pictures, such as Figure 1 in Volume IX of the New York area show clouds forming over the land and not over the water, apparently due to thermal and surface land features.

There can be no doubt that weather is affected, especially by large heat producers such as cities and power plants. The extent to which this is happening is probably small since man's energy output compared to the energy received from the sun is negligible. The problem, however, is that what changes there are no doubt affect society since they will occur predominantly in populated areas. The economic benefit of such research is indefinite, however it certainly needs to be done.

Estimate of ERTS Economic Capabilities

Without the thermal infrared detector, ERTS is limited to pictures of cloud cover from which statistics may be derived. With the thermal IR, these may be correlated to sources and the temperature and extent of the source may be measured. Such data are not economically quantifiable, but results from research may lead to new pollution controls or at least a better perspective from which to make decisions.

Annual Benefit:

New Capability: Possibly substantial but not quantified.

RMF No. 6.8.2

RESEARCH ON AIR-SEA INTERACTIONS

Rationale for Benefits

Research in this area is directed toward improving our capability to predict the marine environment and the earth's weather. The sea-air interface is of critical importance since the atmosphere derives much of its energy from the sun-warmed sea,* while the wind imparts momentum to the waves of the ocean and affects evaporation. Knowledge of these complex interactive mechanisms and of the exchanges of vapor and energy across the interface is essential to a global prediction sytem.**

Federal Government Activities and Responsibilities

The National Oceanic and Atmospheric Administration's NOAA Atlantic Oceanographic and Meteorological Laboratory is currently engaged in an active research program in this area. Systems for examining surface temperature, sea state and the like is expected to be flown on the SEASAT Satellites.

Economic and Technical Models for Estimating Benefits Of Remote Sensed Data.

There is no model available for determining the value of research in this area. The only available benefits which might be realized are cost reductions in data collection.

Current ERTS Activity

None. The only sensor which is applicable to this area (the thermal IR band sensor which could measure sea surface temperature in cloud-free area) was not flown on ERTS-1.

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* The oceans act as enormous thermal reservoirs and are increasingly recognized as having a critical effect on the world's weather.

** R.W. Knecht, Remote Sensing of the Troposphere, NOAA, August 15, 1972, p. 1-8

RMF No. 6.8.2

Estimate of ERTS Economic Capabilities

There is no information in this area that ERTS (even with a thermal IR capability) can provide that cannot be more efficiently obtained by other systems (particularly SEASAT).

Annual Benefit: 0

RMF No. 6.8.3

RESEARCH IN DISPERSION OF POLLUTION IN THE ATMOSPHERE

Rationale for Benefits

The life cycle of pollutants in the atmosphere has obvious impact on pollution control. Time required for dispersion and assimilation of different species of pollutants will affect the establishment of standards, the location of pollution sources, and the location of health, recreation and living facilities. Current pollution standards have been set using a rather arbitrary procedure simply because of the lack of such data plus data on physiological effects of pollutants. We may find that strongly polluting sources may be safely located in some regions, or that sources allegedly non-polluting ought not to be operated. Only through such research can an equitable, safe environmental control be maintained.

Federal Government Activities and Responsibilities

Research is currently funded by the Environmental Protection Agency under the $30,441,800 allocated in 1974 for research on air pollution processes and effects.

Functions of Remote Sensing

Smoke plumes and other pollutants are almost impossible to measure directly in the atmosphere. Numerous researchers supported by EPA and NOAA are developing remote sensing techniques to measure pollutant distributions and concentrations. Most of these employ active systems such as laser radar (LIDAR), Raman backscatter, and spectroscopic techniques. All are limited to a single path or series of single path measurements. Satellites, however, will be able to measure the entire pollutant distribution at a single time.

Current ERTS Activities

Of the numerous researchers listed in RMF 6.1.2, Copeland et al have been particularly successful in observing and interpreting smoke plumes. They have correlated their data with ground and aerial observations with notable success.

The synoptic view afforded by a satellite allows the entire dispersion from source to ambient background to be observed in a single photograph. Densitometer scans across the smoke plume yield particulate densities [as is shown for the three plumes across which the densitometer was scanned in

Figures 9 and 10. Air pollution diffusion models may be verified and refined using such data.

Estimate of ERTS Economic Capabilities

The success of ERTS in observing diffusion of pollution into the atmosphere is important for the understanding and establishment of pollution controls. As Copeland points out, his observed plumes follow well established models, however unique weather or geologic conditions may alter the plume dispersion and cause different pollution control mechanisms to be required. An infrared capability would, of course, produce similar scans of thermal plumes which are generally not visible from the ground. Benefits in this area fall into a better research category and cannot be quantified at more than a hundred thousand dollars or so. Indirect benefits of this research will reduce damage due to pollution and therefore fall into the benefits discussed in RMF 6.2.2.

Annual Benefit:

Increased Capability: ($0.1 million)

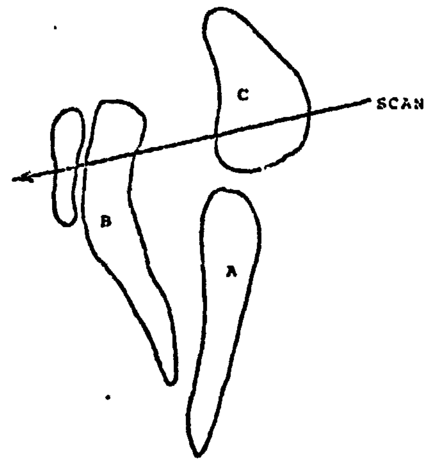

Figure 9 | MSS 5 23 Sept 1972 Image I.D. 1062 15193 5
Several smoke plumes near Chester, Virginia (from Copeland et al.)

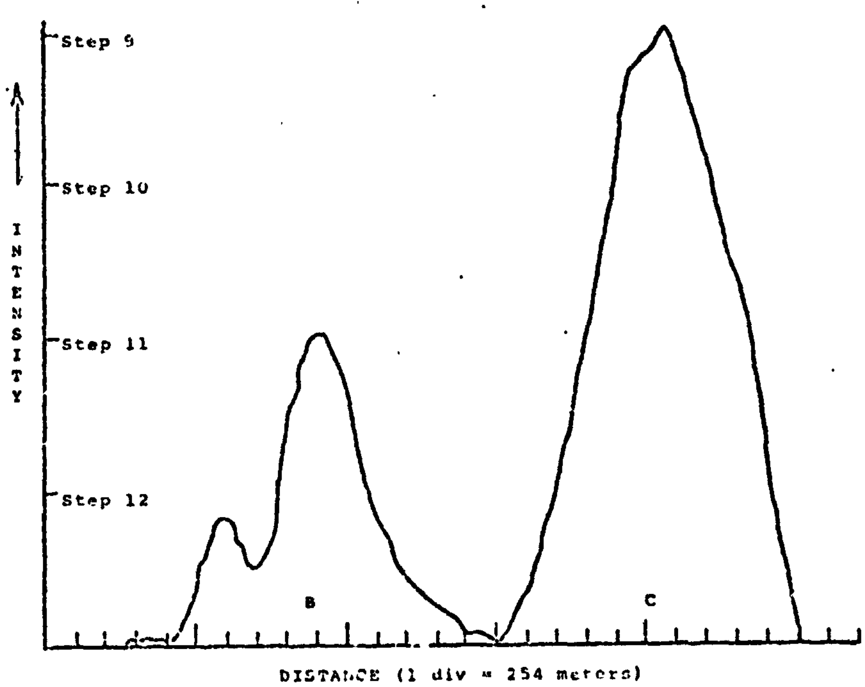

Figure 10 : Densitometer Scan Perpendicular to Symmetry Axis. (from Copeland et al.)

RMF No. 6.8.4

RESEARCH ON WEATHER PHENOMENA

Rationale for Benefits

Weather affects everyone, and benefits from even marginal improvements in forecasting are immense. Correlation of weather changes with green wave and brown wave passage will have major agricultural benefits. Long range predictions derived from the temperature of the ocean, the location of the jet stream, solar activity, and atmospheric haze content may aid farmers with crop planning as well as planting, harvesting, and other obviously weather dependent activities. Long term predictions will also impact the Commodities Market and national food reserves.

Federal Government Activities and Responsibilities

The Secretary of Commerce is directed by 15 USC 313 not "to study fully and thoroughly the internal structure of thunderstorms, hurricanes, cyclones, and other severe atmospheric disturbances"; he is also directed by 49 USC 1463 to "promote and develop meteorological science and foster and support research projects in meteorology through the utilization of private and governmental research facilities . . ."

Functions of Remote Sensing

(See RMF No.'s 6.1.1 and 6.2.3 for a discussion of the applicability of remote sensing to the observation of weather phenomena.)

Economic and Technical Models for Estimating Benefits of Remote Sensed Data

Research on weather phenomena is valuable for increasing the timeliness and accuracy of weather forecasts. The extent to which these more accurate forecasts provide benefits must be examined within the individual industries and governmental agencies affected.

Estimate of ERTS Economic Capability

ERTS will be able to provide baseline meteorological data of high resolution for much of the earth at a specific time of day (its 9:00 a.m. local passing time). These data, combined with other observations, are useful for studying local and regional weather patterns. The high resolution of

RMF No. 6.8.4

ERTS imagery will also be helpful in providing synoptic images in studying the origin, development, and movement of various meteorological phenomena.

Benefits of ERS data will arise as regional and local weather pattern statistics are generated. Air stagnation probability, pollution dispersion, inadvertent weather modification, and local geographically induced weather patterns will ultimately be understood and correlated with location of polluting industries health facilities, and other air flows or weather dependent activities. Specific numerical quantification of the benefit of such data is not possible.

Annual Benefit:

New Capability: Possibly substantial but not quantified

RMF No. 6.9.1

CONTROL OF PARTICULATE POLLUTION

Rationale for Benefits

The Environmental Protection Agency is charged with controlling particulate emissions and ambient air quality. The enforcement of standards requires extensive monitoring facilities for both on-site and ambient measurements. Particulates have been found to constitute both a health and nuisance hazard and the control of sources will have strong aesthetic, economic, and health benefits.

Federal Government Activities and Responsibilities

The Environmental Protection Agency was allocated $7,351,600 for enforcement of air pollution regulations for stationary sources and $1,246,800 for mobile sources.* Most of these funds, however, were used for hearings, paper work, and review of state compliance schedules, although some 3,000 "inquiries, inspections, and investigations of sources" were conducted. Primary action for enforcement is the responsibility of the state, although if the state fails to act within 30 days, the EPA can require compliance according to the Clean Air Act.

Non-Federal Activities

Most of the enforcement responsibility falls to the state and local agencies which have filed a State Implementation Plan with EPA. Only in the absence of such a plan or delinquence on the part of the state does EPA step in.

Functions of Remote Sensing

Observation of particulate emissions from stationary sources requires on site inspection and some method of quantifying smoke plume particulate density. Emissions from such sources vary from hour to hour, day to day and may not coincide with the observation time. Each separate source must be monitored individually using current techniques. Remote sensing of particulate emissions would permit many sources to be observed simultaneously. The costs associated with such synoptic observations are much less than the cost of separate on-site investigations. A satellite view also yields information about previously unidentified pollution sources.

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* U.S. House of Representatives Committee on Appropriations, 93rd Congress, 2nd Session, Agriculture - Environmental and Consumer Protection Appropriations for 1975, part 5.

RMF 6.9.1

Current ERTS Activities

Investigators currently involved in atmospheric aeorsol and particulate studies are listed in RMF 6.1.2. Of these, several have found ERTS photos useful for air pollution monitoring. Copeland, et al, have found that quantitative monitoring of smoke stack plumes over large regions is possible from their studies in East Virginia. They were able to identify three plumes each over 10 kilometers long in one photograph (see Figure 10). Figure 1.3 of Volume I of this report, the picture of pollution-caused weather modification over Lake Michigan, shows that pollution plumes over a uniform background such as a lake are easily observable.

Estimate of ERTS Economic Capabilities

Possibilities of using ERS data for enforcement are limited. The infrequent coverage and relatively low resolution limit an ERTS-like ERS to a supplementary role at best. Copeland's data indicates at least some usefulness. EPA intends to increase field surveillance programs from 3,000 investigations in 1974 to 6,000 in 1975. ERS may be able to reduce the expense of these investigations. Additional expenditures of $1,000,000 dollars in FY 1975 are expected to cover the activities in enforcement of stationary pollution sources. Assuming that 50% of that increase will cover the additional 3,000 inspections, that makes an impactable budget of $1,000,000 for 6,000 inspections. Approximately 1-5% increase in efficiency might be expected from ERTS imagery. Thus, benefits on the order of $10,000 to $50,000 can be identified. Additional benefits to state and local agencies may also be realized.

Annual Benefit:

Equal Capability: $10,000 - 50,000

RMF No. 6.9.2

CONTROL OF NOXIOUS GAS SOURCES

Rationale for Benefits

Noxious gas sources constitute a substantial health hazard plus damage materials, property, and vegetation. Oxidents and sulfur oxides lead the list of pollutants destructive to vegetation and materials. Noxious gases constitute better than half of the estimated national cost of pollution.* Enforcement of noxious gas pollution standards falls within the purview of the Environmental Protection Agency. Monitoring these gases is difficult since many are transparent, and very low concentrations cause substantial damage.

Federal Government Activities and Responsibilities

The government enforcement of the air quality and emission standards established under authority of the Clean Air Act mostly involves cooperative programs with the states and enforcement of each state's implementation plan. The Environmental Protection Agency, however, conducts some investigations on its own to determine compliance.

Possibly, activities associated with compliance with the still pending Hazardous Waste Management (S. 1086, H.R. 4873) or Toxic Substances Control Act (S. 888, H.R. 5087) may be aided by satellite observation of noxious gases.

Non-Federal Acitivites

Responsibility for enforcement falls to state and local agencies with the aid of the Environmental Protection Agency.

Functions of Remote Sensing

Noxious gas emissions are generally transparent to the eye and extremely hazardous. They are not easily monitored since emission from stationary sources usually occurs through smoke stacks and emission from mobile sources is widely distributed. Currently, research on emission control using laser backscatter and spectroscopic techniques of remote observation**

* T.E. Waddel, The Economic Damages of Air Pollution, (May 1974) EPA document number EPA 600/5-74-012.

** B. Harneg, D. McCrea, A. Forney, "The Application of Remote Sensing to Air Pollution Detection and Monitoring," U.S. Bureau of Mines Information Circular 8577 (1973).

is underway with the expectation that ground based devices for local monitoring will soon be operational. Satellite based sensors using passive absorption spectroscopy will be able to determine pollution concentrations from loss of signal from the ground due to the very strong and selective infrared absorption bands associated with all noxious gas pollutants. Such a synoptic view may be the only way of continuously monitoring noxious gas sources since spot checks by mobile ground based units will necessarily be infrequent.

Estimate of ERTS Economic Capability

Currently ERTS has no infrared sensors in the region necessary for observation of noxious gases.

Annual Benefit: 0

RMF No. 6.9.3

PROVIDE A DATA BASE FOR ESTABLISHING APPROPRIATE AIR QUALITY REGULATIONS

Rationale for Benefits

There is currently heated discussion concerning the proper standards that should be maintained for air pollution. With the pressure of the energy crisis and the automotive industries to relax standards of particulate and nitrogen oxide pollution* on the one side and the Sierra Club claiming extensive damage from low level pollutants on the other,** the Environmental Protection Agency is being forced to establish a "best guess" standard. Certianly as the cost of energy increases, the cost of pollution control is higher and the minimum-cost points of the graphs presented in RMF 6.2.2 move to the right, i.e., a higher pollution level becomes acceptable. If, however, costs of pollution are substantially greater than estimated, then severe social disbenefits may occur. A data base establishing the cost and the regional variations of air pollutants is necessary for judicious decisions in the midst of severe political and economic pressures.

Federal Government Activities and Responsibilities

The Environmental Protection Agency is required by the Clean Air Act to promulgate primary and secondary ambient air quality standards. "The maximum concentrations of pollutants permitted by the national air quality standards are based on scientific evidence of their effects on public health and welfare."*** The states must then set and enforce emission standards to meet these ambient air standards. If a state fails to set or meet standards, the EPA has authority to set and enforce standards for the state. The EPA also sets emission standards for new stationary sources.

Non-Federal Activities

As mentioned above, it is the responsibility of each state to establish an implementation plan establishing emission standards and enforcing them to meet the national air quality

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* The New York Times, August 17, 1974, p.1.

** L.I. Moss (Pres. Sierra Club) "How to Prevent Significant Deteoriation of Air Quality in Any Portion of Any State," Statement before the EPA, hearings on Significant Deteoriation, Washington, D.C. August 27, 1973.

*** Action for Environmental Quality, USEPA (March 1973) standards in each of its Air Quality Control Regions.

Functions of Remote Sensing

Remote observation of pollution sources and distribution, plus observation of the effects that pollutants might have on the weather and environment will lead to a better understanding of the behavior and hazard of each pollutant. Effects of pollutants will vary depending on the geologic and climatologic conditions of each region. Statistics from these observations will be useful in setting standards, particularly if different standards are to be set for different regions in accordance with the argument that clean air should be kept clean as suggested by the Sierra Club. In such a case, statistics on different zones would have to be generated.

Estimate of ERTS Economic Capabilities

Current budgeting allocations in the Environmental Protection Agency for Research on processes and effects of air pollutants is 30.4 million dollars. The major activity is the determination of primary standards affecting human health. ERS images will yield only limited information in this area since human health is not observable from satellites. There may be some useful correlations of pollutant distributions measured by an ERS system with health problems. ERS will more directly impact the secondary standards, those intended to protect public welfare. Such data will not greatly affect the budget since no manpower changes are expected, only the procurement of otherwise difficult to obtain information. Benefits in the order of 1 to 2 hundred thousand dollars attributable to the cost of contracts otherwise required for similar data seem reasonable. The more substantial benefit associated with "setting and enforcing environmental standards so as to maximize net gains . . (by) . . ensuring efficient allocation of scarce air resources"* is discussed in RMF 6.2.2.

Annual Benefit:

Increased Capability: ($.1 to .2 million)

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* T.E. Waddel, The Economic Damages of Air Pollution, EPA report number EPA-600/5-74-012, page 7.

APPENDIX B:

SUMMARY OF APPLICABLE FEDERAL BUDGETS

Table 6 summarizes the budgets of the National Oceanic and Atmospheric Administration, the Environmental Protection Agency, the Department of Agriculture and the Department of Transportation that are impacted by remote sensing from satellites.

Table 6 Summary of Applicable Federal Budgets FY 1975	
Federal Agency	Budget, $ thousands(1973)
National Oceanic and Atmospheric Administration (Dept. of Commerce)	
Basic Environmental Services	
Basic Observations	
Upper Air	14,687
Radar	8,699
Remote Sensing Research	1,470
Basic Weather Analysis and Prediction	
Analysis	4,879
Predictions	6,351
Forecast Technique Development	677
Environmental Modeling	8,717
Public Forecast and Warning Services	
Public Weather Services	
Forecast Preparation	10,190
Public Weather Research	1,194
Marine Prediction Services	
Marine Weather and Ocean Services	1,653
Marine Prediction Research	485
Hurricane and Tornado Warning Service	
Tornado and Severe Storm Warning Preparation	679
Hurricane Research	778
Tornado Research	2,434
Specialized Environmental Services	
Air Pollution and Fire Weather Services	
Air Pollution Weather Services	1,365
Fire Weather Services	1,638
Agricultural Weather Services	2,249
Aviation Weather Services	
Observations	564
Aviation Weather Research	174

Table 6 Summary of Applicable Federal Budgets FY 1975 (Cont'd)	
Federal Agency	Budget, $ thousands(1973)
National Oceanic and Atmospheric Administration (Dept. of Commerce)	
Upper Atmosphere and Space Services	
Observations	598
Upper Atmosphere and Space Research	2,829
Environmental Data and Information Services	
Environmental Data Services	
Climatic Data Services	5,070
Environmental Data Research	636
Global Monitoring of Climatic Change	
Air Quality Observations and Analysis	831
International Projects	
GARP Atlantic Tropical Experiment	6,181
International Field Year for the Great Lakes	2,222
Total	87,250
Environmental Protection Agency	
Research and Development: Air	
Processes and Effects	30,441.8
Control and Technology	7,655.3
Abatement and Control: Air	
Mobile Sources	9,839.4
Stationary Source Standards and Guidelines	7,126.6
Ambient Trend Monitoring	1,694.5
Control Agency Support	51,518.0
Enforcement: Air	
Stationary Source Enforcement	7,351.5
Mobile Source Enforcement	1,246.8
Total	116,874

Table 6 Summary of Applicable Federal Budgets FY 1975 (Cont'd)	
Federal Agency	Budget, $ thousands (1973)
Department of Agriculture	
Agricultural Research Services	
Research on Pollution	12,083,166
Department of Transportation	
Federal Aviation Administration	
Aviation Weather (Research)	1,999,000
Aircraft Safety/Environment	9,390,000
Total	11,389,000

APPENDIX C:

SUMMARY OF APPLICABLE LAWS AND STATUTES

Table 7 summarizes the Federal laws and statutes applicable to this resource management area.

Table 7 Summary of Applicable Laws and Statutes

Reference		Title of Statute
42	USC 1857	Clean Air Act
15	USC 313	(delegates weather forecasting responsibility to the Secretary of Commerce)
S 888,	HR 5087 (pending)	Toxic Substances Act
49	USC 1463	National Weather Services
42	USC 4371-4374	The Enviornmental Quality Improvement Act of 1970
42	USC 4321-4347	The National Environmental Policy Act of 1919