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Analysis of Data Systems Requirements for Global Crop Production Forecasting in the 1985 Time Frame

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TABLE OF CONTENTS

	Page
INTRODUCTION	1
OBJECTIVE FROM OUTLOOK FOR SPACE	1
ASSUMED USERS	2
QUANTIFIED STATEMENT OF OBJECTIVE	3
SCOPE OF OBJECTIVE	5
INFORMATION REQUIREMENTS	7
FUNCTIONAL BLOCK DIAGRAM	17
DATA SYSTEMS REQUIREMENTS	18
Global Crop Production Forecasting Trade Study	19
Baseline Trade Study Ground Rules	20
Analysis Approach Used	23
Results Achieved	25
Sampling	29
CONCLUSIONS AND RECOMMENDATIONS	33
Data Collection	37
Information Extraction	37
Additional Studies	38
REFERENCES	39
APPENDIX	41

LIST OF ILLUSTRATIONS

Figure	Title	Page
1.	Crop forecast systems in use throughout the world	4
2.	Temporal progression of reflectance of wheat and principal confusing crops	6
3.	First level subobjectives........................	10
4.	Crop survey subobjective structure.................	11
5.	Crop condition subobjective structure	13
6.	Weather and climate information subobjective structure ..	15
7.	Crop projection subobjective structure	16
8.	Functional diagram, global crop production forecasting...............................	18
9.	Effect of additional crops on loading	26
10.	Effect of editing on data loading	28
11.	TDRSS zone of exclusion	35
12.	Block diagram of conceptual data system	36

LIST OF TABLES

Table	Title	Page
1.	Thematic Mapper Characteristics	21
2.	Area of Regions Used to Bound Cropland in Representative Countries	22
3.	Effects of Additional Crops on Data Loading	27
4.	Number of Samples Required	32
5.	Initial Number of Samples Needed to have Required Samples after 3 Observations (Shown for 1, 2, 3, Satellites)	34

ANALYSIS OF DATA SYSTEMS REQUIREMENTS FOR GLOBAL CROP PRODUCTION FORECASTING IN THE 1985 TIME FRAME

INTRODUCTION

The Outlook for Space [1] defines several objectives for the application of space technology to desirable and practical activities for the 1980 to 2000 time frame. One of the objectives set forth is a Global Crop Production Forecast, objective 011 [1]. Global Crop Production Forecasting was selected as one of the objectives to be analyzed because preliminary analyses indicated that it would be a major driver of the data system in the time frame under consideration.

The objective was analyzed, and potential users were interviewed and surveyed. Then the objective was revised and quantified. Projected information requirements were obtained from the user community; the impact of these requirements on a conceptual data system was analyzed; potential problem areas were identified; recommendations were made to overcome these problems; and future work in specific areas that need more indepth analysis was identified.

OBJECTIVE FROM OUTLOOK FOR SPACE

The objective of global crop production forecasting is to provide a biweekly forecast of the global production of major crops having worldwide food and/or economic significance. There is a need for such a system because the increasing world population will require an increasing production of food.

Approximately 98 percent of the world's food comes from the land and approximately 2 percent comes from the sea. The best conceivable management can do no more than double this amount of food from the sea [2]; therefore, the increase in available food must come from the land. Most of the world's food comes from grain such as wheat, rice, and corn. The reserve of the world food resource has shrunk from 26 percent of the annual consumption in 1959 to 7 percent in 1974. North America is the only major exporting region in the world, and food exports are a major factor in U.S. World trade and balance of payments [1]. Better global crop production forecasting could provide better information concerning impending crop failures and the resulting food shortages and better decisions on the transporting and distribution of the available food. A global crop production forecasting system must be able to accurately predict the production of the important food and fiber crops if it is to be useful to the "food managers" of the world.

An accurate global crop production system offers a variety of potential benefits. Aside from the humanitarian benefits, there are benefits of national policy and economic benefits. Since North America is the only major exporting region of the world, earlier and better information about world crops could help the U.S. and other countries better manage their agricultural production and minimize fluctuation in price and trade volumes. Grain exports could be better planned with less disruption of domestic markets. Decisions on planting, marketing, and transportation requirements could be improved. To provide these benefits, the forecasting system must be timely and accurate.

ASSUMED USERS

There are numerous users of a global crop forecasting system in the public and private sectors. These users vary from large government agencies and private marketing organizations to individual scientists engaged in research. Literature was reviewed, potential users interviewed, and installations were surveyed to determine which users would reap the greatest benefit from a global crop forecasting system. To put realistic bounds on the overall objective, two primary users, the Agency for International Development (AID) of the U.S. State Department and the Foreign Agricultural Service (FAS) of the U.S. Department of Agriculture (USDA), were selected. These are the two agencies of the U.S. Government which are most directly involved in the policy making decisions concerning the exporting of U.S. Agricultural products. The objective was redefined and the conceptual data system was defined to meet the requirements of these two users.

QUANTIFIED STATEMENT OF OBJECTIVE

The objective as stated in Reference 1 was redefined and quantified, based on our concept of the requirements of AID and FAS. The revised objective is as follows:

> To provide a biweekly forecast of the global production of major crops having worldwide nutritional and/or economic significance. The primary goals were to maintain and strengthen the U.S. balance of trade, to support U.S. foreign policy decisions, and also to assist in alleviating the world's famine. The forecast would cover seven principal crops which are important to the U.S. trade and would cover the principal producing countries and regions of the world. A long range (9 month) and a short range (3 months before harvest) forecast would be provided on a biweekly basis within a one week time frame from data gathering to user. The long range forecast would be 95 percent accurate with a 90 percent probability, and the short range forecast would be 98 percent accurate with a 90 percent probability.

At the present time, the data available on crop production throughout the world vary widely. The U.S. has the benefit of a highly sophisticated and usually very accurate crop production forecasting system provided by the Statistical Reporting Service (SRS) of the USDA. Other major food producing countries with sophisticated systems include Canada, Australia, United Kingdom, and USSR; however, the data from these countries may not always be available to the decision makers in AID and FAS. Less sophisticated systems are used in most of the Western European Countries, parts of Central and South America, India, and some parts of Africa. Data in the rest of the world are obtained from very simple systems or are nonexistent. The type and location of the crop production forecast systems throughout the world are shown in Figure 1 [3].

A global crop production forecasting system which would provide information having the accuracy and timeliness stated in the revised objective would provide better information than that now available and would facilitate better decisions relating to the production and exporting of food and fiber.

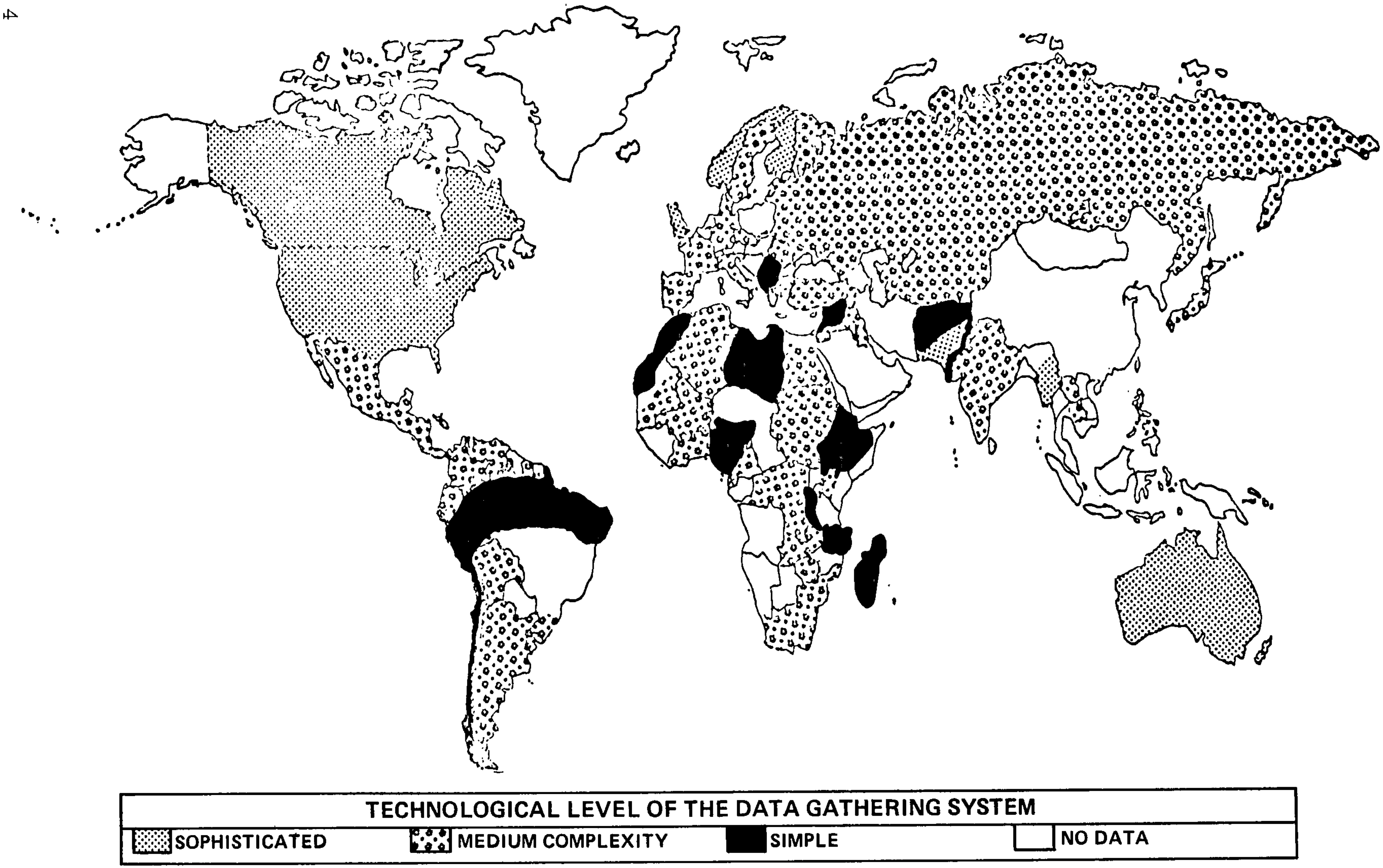

Figure 1. Crop forecast systems in use throughout the world.

SCOPE OF OBJECTIVE

The crop production forecast is influenced by the area in cultivation for a particular crop (usually stated in hectares or acres), and the yield of the crop per unit area (usually in quintals/hectare or bushels/acre). The production is computed by the formula:

$$\text{Area} \times \text{Yield} = \text{Production} \tag{1}$$

The determination of area and yield are very complex with many factors and variables entering into the calculations.

The area in equation (1) will be examined first. Before the area in a certain crop can be measured, it must first be identified. Crop identification presents no problem on the ground, but it is often very difficult to do from orbital altitudes. In the past it had been thought that specific plants would have individual spectral signatures that would permit positive identification. There is evidence from some research that some plants do possess unique differences in their spectral signature in certain narrow bands. However, these subtle differences do not show up in the multispectral data obtained by the MSS from Landsat. Therefore, other methods must be used to identify and classify the different crops. One method to accomplish this is to utilize multitemporal data, or data obtained at several different times during the growing season. The signature from the different crops can be compared several times (usually a minimum of three comparisons) and, with the aid of a crop calendar, the crop can be identified. This is illustrated in Figure 2. It is obvious that the signatures for spring wheat, winter rye, and buckwheat are very similar. In mid-August it would be impossible to distinguish between spring wheat and buckwheat because the reflectance is essentially the same. However, if these two crops were examined in early August, a significant difference would be noticed. At that time, the spring wheat has a high reflectance while the buckwheat has a low reflectance. There is also a significant difference in early September. In that case the buckwheat has a high reflectance while the spring wheat has a low reflectance. This is a very simplified case, but illustrates the principle that can be used to differentiate crops which have similar signatures. The use of this method increases several fold the quantity of data that must be analyzed, and places stringent registration requirements on the data since the same samples must be analyzed each time.

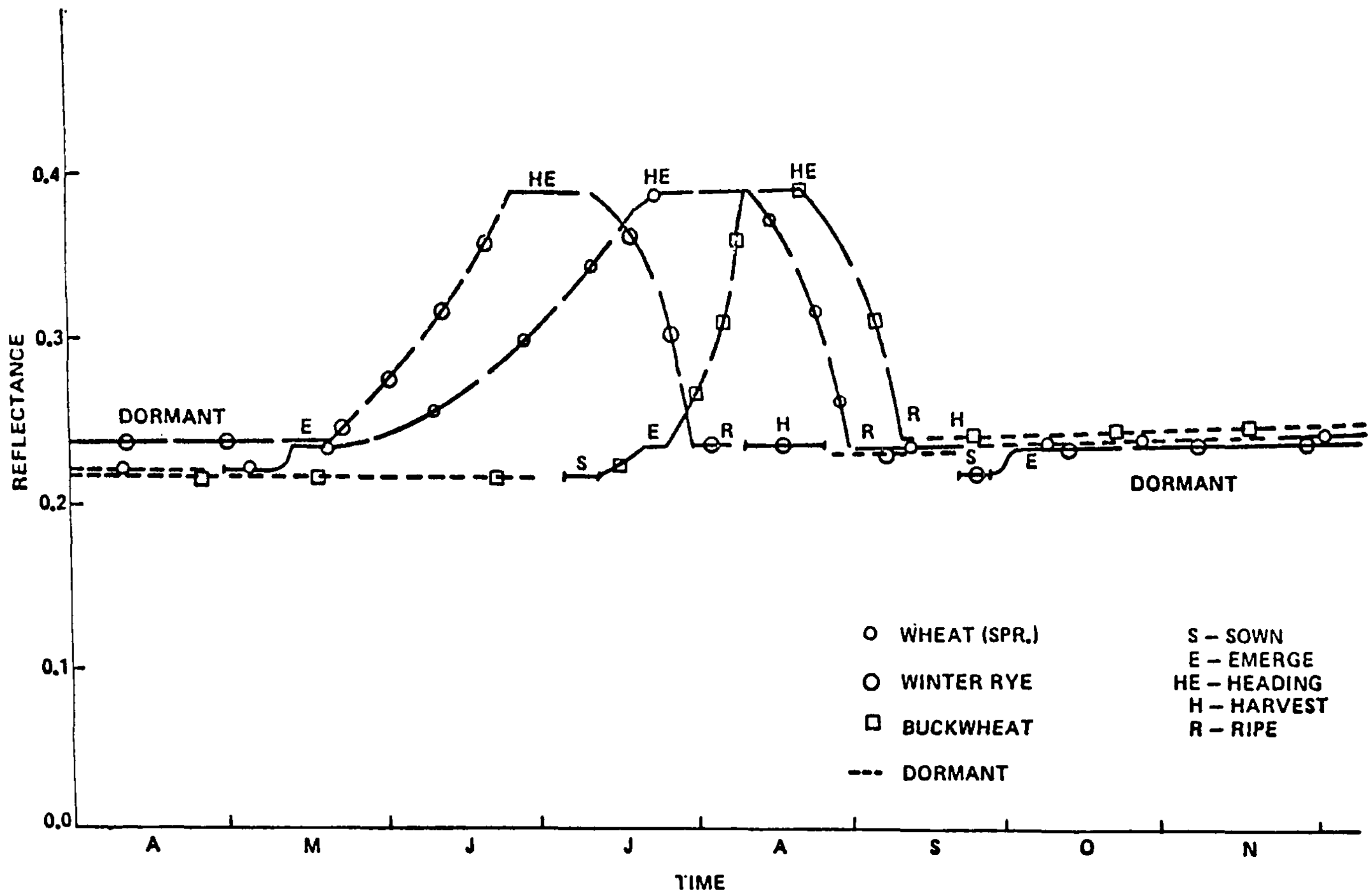

Figure 2. Temporal progression of reflectance of wheat and principal confusing crops.

After a crop is identified, its areal extent must be determined. One method to accomplish this is to measure all the areas in cultivation, or perform a wall to wall inventory. While this would be desirable, it is generally agreed that this would require a prohibitive quantity of data to be processed. Another method would be to use sampling techniques in which sample segments are obtained throughout the agricultural regions. Much less data would be required to be obtained and processed. The sampling method is used by the SRS for crop production forecasting for the U.S. and it is also used in the Large Area Crop Inventory Experiment (LACIE). It is generally agreed that sampling must be used for a global crop production forecasting system, and sampling is utilized in the analysis of this objective.

The second part of equation (1) is yield. Most of the current and projected crop yield models utilize meteorological and historical data together with data on the current crop conditions to predict yield. Remotely sensed data can be used as an input to some of the models to supply information on crop condition and meteorological conditions, but these models rely heavily on ancillary data. When soil moisture information is available from satellites, it can be used as an input to the yield models.

The scope of the objective requires a global crop production forecast. Area and yield must be determined for the crop of interest for each region or country. These are then combined to obtain the production forecast for that particular region or country. All these factors are then summed to obtain a global crop production forecast. It is evident that this will require a large amount of data to be obtained and processed in a short period of time if the objective is to be met.

INFORMATION REQUIREMENTS

The determination of area and yield in a crop forecast requires that many physical parameters be identified and measured. To determine which parameters are required, the literature was reviewed and many personal interviews were conducted with leading scientists in the fields of agriculture, weather and climate, and remote sensing. This was done by MSFC personnel and by New Technology, Inc. on contract NAS8-31423 [4]. A list of the key individuals contacted along with their organization and our assessment of their role in influencing the concept of the data system is given in the Appendix. Much valuable information on user requirements and their influence on the data system was obtained by participating in the Crop Spectra Workshop held in Sterling, Virginia on February 2-3, 1977 [5]. Many key scientists involved in the acquisition and use of remotely sensed data for agricultural purposes were participants in the workshop. The reader is referred to the proceedings of the workshop for the specific details of the workshop and a list of attendees. Special attention and consideration was given to LACIE and the personnel associated with the experiment [6]. As expected, agreement was not unanimous among all these experts as to what parameters should be measured and what influence these parameters would have on the crop forecast and hence on the data system requirements. The parameters selected to be included in the conceptual data system are based on what is considered to be the consensus of the key individuals contacted. Some of these parameters may be wholly or partially obtained by remotely sensed data from space while in-situ measurements, statistical data, and historical data must also be used to obtain others. The parameters to be determined are as follows:

a. Episodic Events

b. Availability of Irrigation Water

c. Potential Productivity

d. Soil Moisture

e. Temperature

f. Photoperiod

g. Precipitation

h. Wind

i. Disease Epidemics

j. Insect Infestations

k. Soil Surface Conditions

l. Plant Density

m. Soil Fertility.

The objective to obtain a global crop projection forecast for seven crops was broken into first and second level subobjectives and contributing elements. The seven crops selected were wheat, rice, corn, sugar, soybeans, cotton, and small grains (other than wheat and rice). These crops were selected because they are important food or economic crops that are traded in the world market, and ones that the U.S. has an appreciable interest or influence in the trade thereof.

The four first level subobjectives influencing the forecast were defined as crop survey, crop condition, weather and climate information, and crop projection. Area is determined by the crop survey, and yield is determined or influenced by the other three first level subobjectives. A block diagram of these subobjectives is shown in Figure 3. Each of these will be broken down into second level subobjectives and contributing elements.

The main output of the crop survey subobjective is quantitative information on the area in cultivation and to be harvested of the seven crops during the growing period. This results in the establishment of two second level subobjectives, surveillance of included crops and statistical data. The surveillance consists of the identification of the crops and the mensuration of the area in cultivation. Scientists in the Agricultural Research Service (ARS) of the USDA indicate that it would be desirable to have resolution in the order of 20 m for remotely sensed data obtained by satellites. Statistical data on crop calendars and cultivation methods will be used as ancillary data in determining the area in cultivation for each crop and the area expected to be harvested. These data will come from the SRS for the U.S. but must be obtained from the FAS or the Food and Agricultural Organization (FAO) of the United Nations for foreign countries. The data base for a sufficient length of time (approximately 10 years) is generally not available for countries other than the U.S. The crop survey subobjectives are illustrated in block diagram form in Figure 4.

The next first level subobjective to be addressed in crop condition. In the literature this is sometimes referred to as crop stress or crop vigor. Crop stress and vigor together with episodic events influence crop condition. The main output of this subobjective is the type of condition, the intensity of the condition, the areal extent of the condition, the duration of the condition, and its concentration and amount. The four primary second level subobjectives supporting the crop condition subobjectives are biological stresses, meteorological stresses, soil stresses, and artificially induced stresses. A uniform input called "crop nominal profile," feeds into each one of these second level subobjectives. Crop nominal profile, or CNP, is a standard set of values for the nominal growth of each crop under consideration on a regional basis.

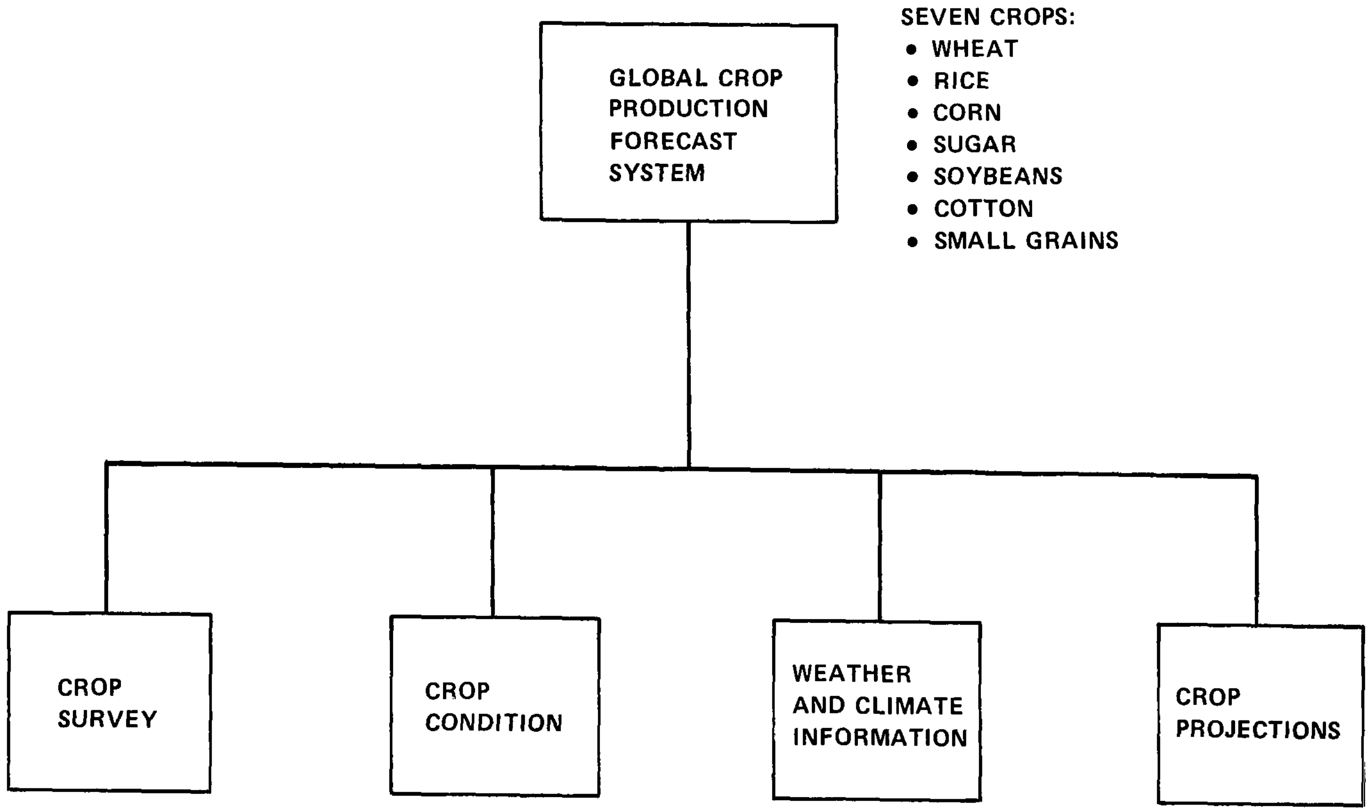

Figure 3. First level subobjectives.

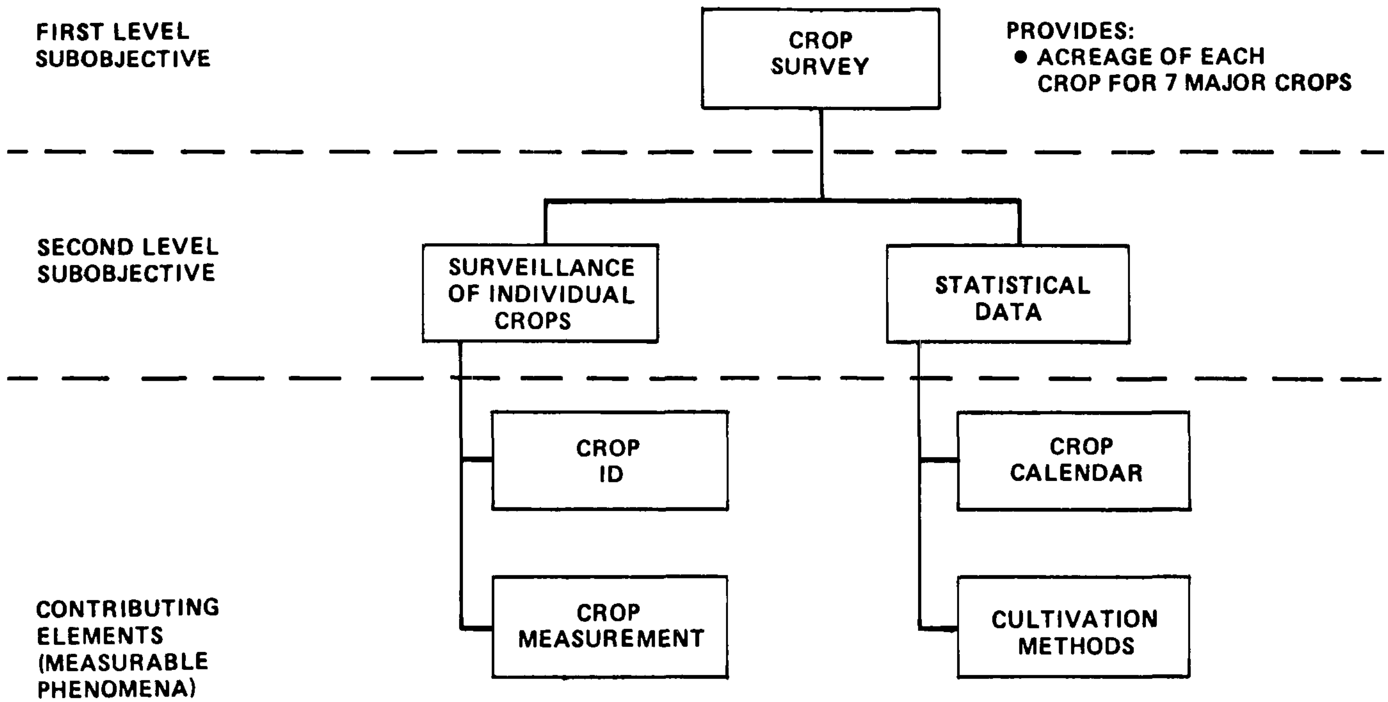

Figure 4. Crop survey subobjective structure.

The major contributing elements or measurable phenomena under biological stresses are disease, insects, weeds, and wildlife. Under meteorological stresses, the measurable phenomena are precipitation, air pollution, humidity, insolation, wind, and drought index. The second level subobjective soil stress is supported by the measurable phenomena soil moisture, soil chemistry, and soil temperature. There seems to be some likelihood that soil moisture measurements could be obtained by 1985 from satellite radar. The condition of irrigated land and monitoring of additional added irrigated land is included as one of the measurable phenomena affecting soil stresses. Artificially induced stresses include over-fertilization and over-irrigation. These subobjectives and contributing elements are shown in block diagram in Figure 5. The data from satellites would be obtained from observation of sample segments. These samples could be either randomly distributed or systematic sampling could be used. Observations at 30 day intervals would be sufficient for determining the crop conditions and episodic events. Repeated observations of the same sample segment would not be required for determining crop condition.

The output of the weather and climate subobjective is moisture/plant/day, maximum and minimum temperature per day, the sunlight/day and the severe storm index. The second level subobjectives supporting weather and climate information are weather monitoring and statistics, soil water availability, long range weather and climate forecast, and short term weather forecast.

The contributing elements or measurable phenomena which support the weather monitoring and statistics subobjective are temperature, wind, sunlight, humidity, precipitation, and statistical data. These statistical data consist of weather profiles from past years and are obtained from the National Climate Center at Ashville, NC.

The contributing elements or measurable phenomena supporting soil water availability are soil temperature, soil type and structure, soil moisture data, useful reserves, and irrigation methods. The Heat Capacity Mapping Mission Satellite (HCMM) may be utilized in making a soil moisture determination of sufficient fidelity to support this contributing element.

The long range weather and climate forecast second level subobjective consists of the following measurable phenomena: temperature (maximum and minimum per day), winds, sunlight or cloud cover, humidity, precipitation, and statistical data.

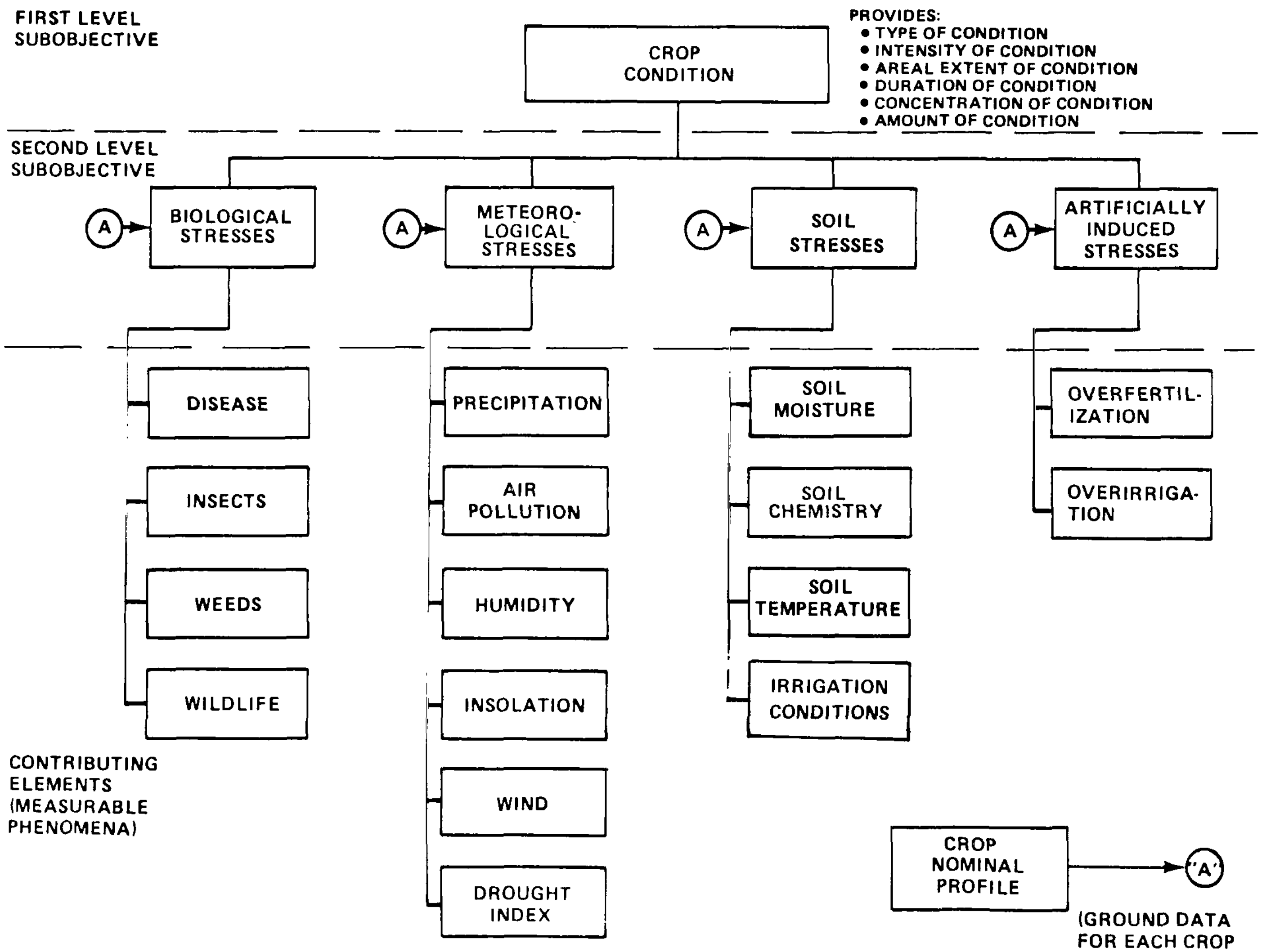

Figure 5. Crop condition subobjective structure.

The short-term weather forecast includes the contributing elements of measurable phenomena of temperature (maximum and minimum per day), winds, sunlight or cloud cover, humidity, precipitation, and severe storm phenomena. Figure 6 presents a block diagram showing the weather and climate subobjective structure.

The last first-level subobjective to be addressed is crop projection. Crop projection provides the projected acreage of the seven major crops and the projected yields for individual crops. This provides the long range forecast in contrast to the short term or short range forecast as determined by the crop survey, crop condition, and weather and climate subobjectives. The crop projections subobjective has as its four primary second level subobjectives crop calendar, cropping practices, agri-chemical applications, and current remotely sensed data.

The measurable phenomena supporting crop calendar are growth stage, percent ground cover, plant height, and stand quality rating.

The cropping practices second level subobjective consists of the following measurable phenomena or contributing elements: crop rotation practices, tillage practices, and irrigation practices.

Under the second level subobjective agri-chemical applications, the following contributing elements are found: growth enhancers, physiological stress inhibitors, and biological stress inhibitors.

These three second level subobjectives (crop calendar, cropping practices, and agri-chemical applications) consist essentially of statistical data.

The fourth second level subobjective under crop projections is remotely sensed data (current). Contributing elements supporting remotely sensed data are identification, mensuration, condition, and weather and climate parameters. The crop projections first level subobjective structure is shown in block diagram form in Figure 7.

Throughout the examination of these subobjectives, the role of ancillary data was noted. It should be emphasized that ancillary data are essential in addition to remotely sensed data in the design and implementation of a data management system.

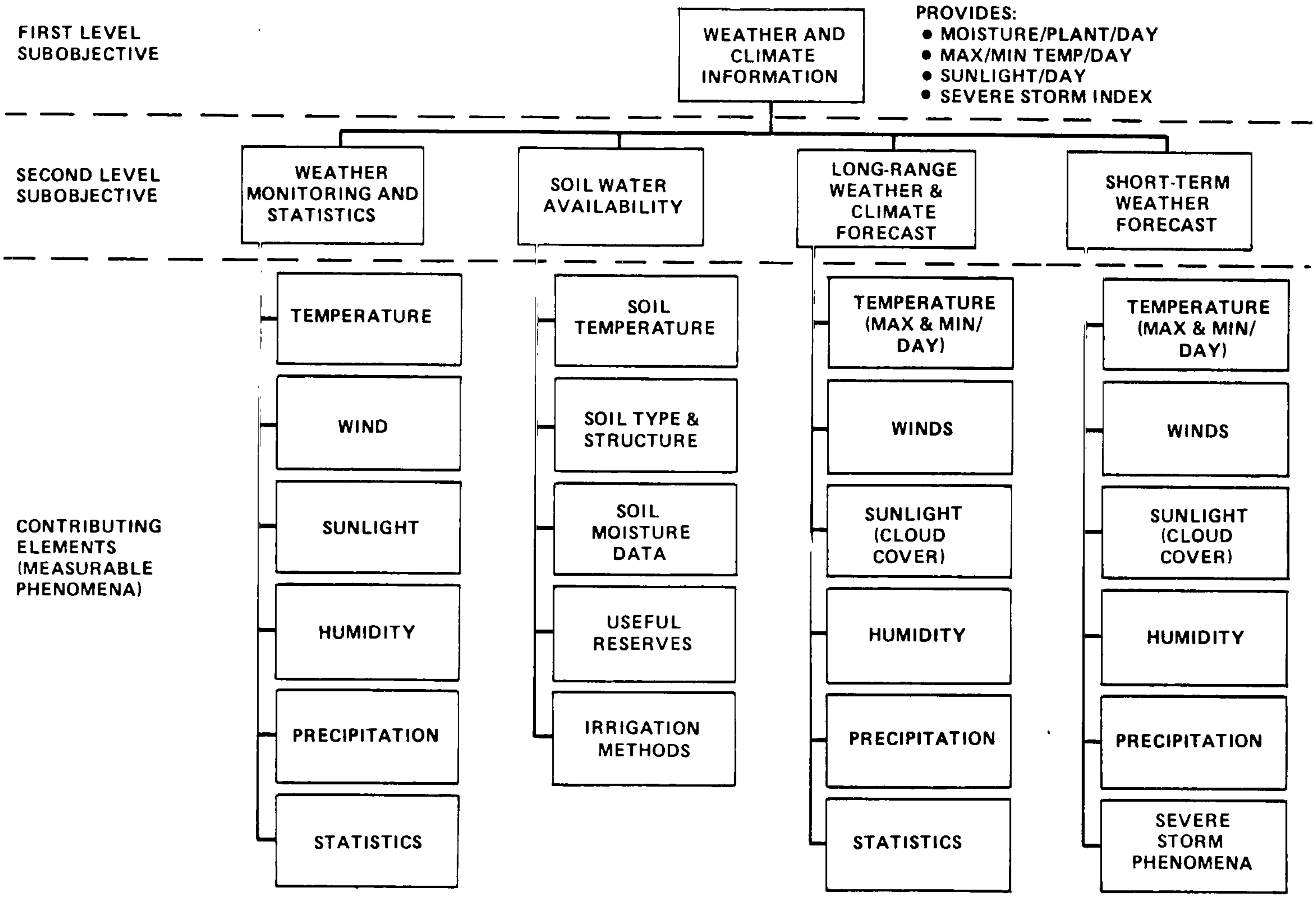

Figure 6. Weather and climate information subobjective structure.

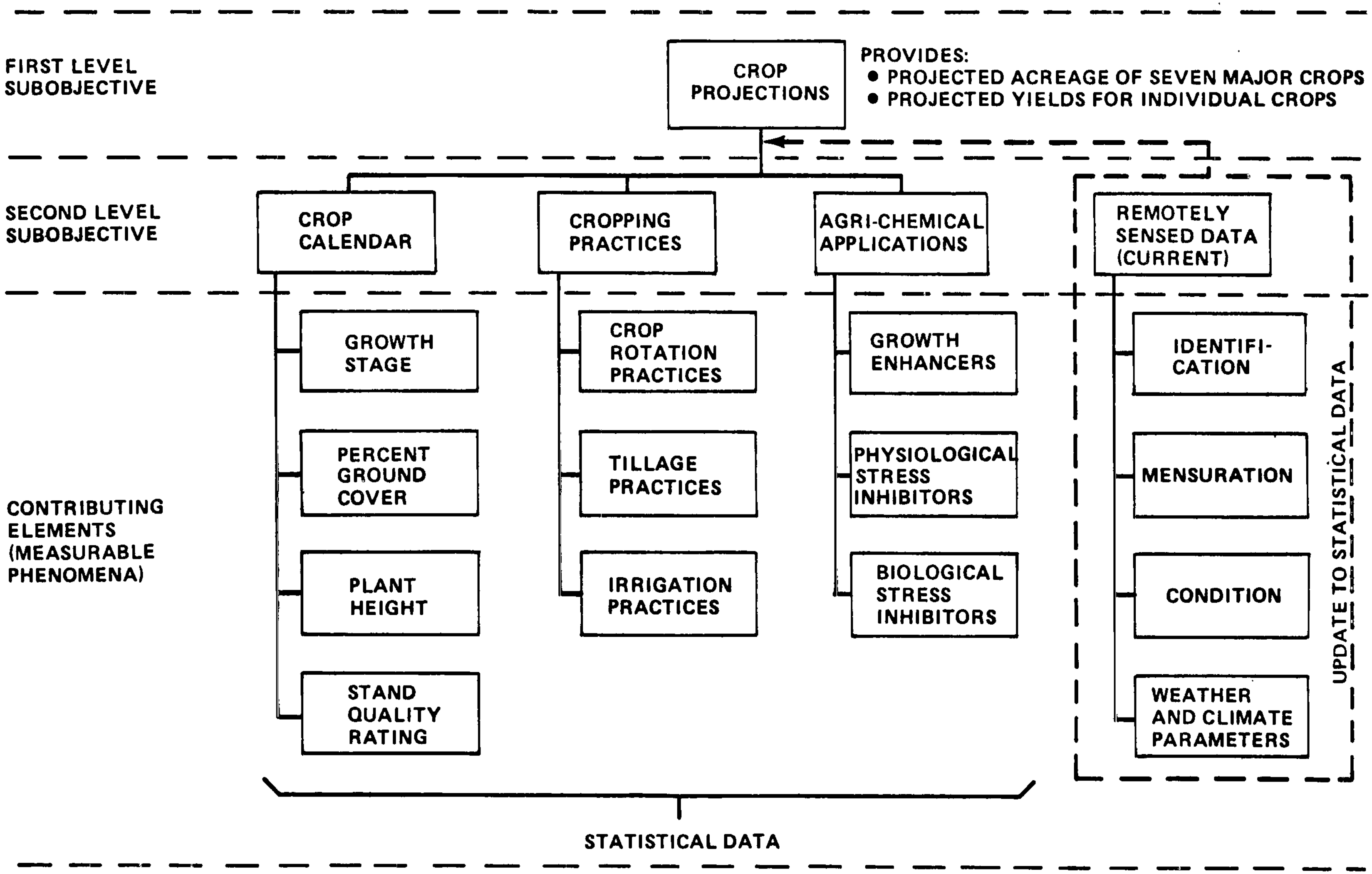

Figure 7. Crop projection subobjective structure.

FUNCTIONAL BLOCK DIAGRAM

A concept of a functional diagram for a global crop production forecasting system is shown in Figure 8. The multispectral data obtained from a thematic mapper (TM) and/or multispectral scanner (MSS) located on a satellite are utilized in crop identification and mensuration. These data are selected for the desired cloud cover, are geometrically and radiometrically corrected, and have been corrected for atmospheric effects in f_1. In f_2 the crops are identified by using multispectral and multitemporal data together with the ancillary data such as crop calendar and historic data. Three observations during the growing season, at specified times determined by the phenologic differences between the principal and main confuser crops, will be needed. Observations of these sample segments must be repeated three times during the growing season. To have the required number of samples at the end of the growing season, a much larger number of observations of the samples must be obtained at the beginning of the growing season to compensate for those samples lost due to cloud cover. Mensuration will be performed in f_3 using a sampling system of the type used by SAS. The mensuration and identification data will be combined in f_4 to give the area. Satellite multispectral data and ancillary data on crop condition, eposodic events, and soil moisture will input to the plant condition model at f_5 to determine the crop condition. Satellite meteorological data, in-situ meteorological data, and historical meteorological data input to the meteorological model at f_6. Hydrologic data from spacecraft, in-situ measurements, and historical data input to the hydrologic model at f_7. From the hydrologic model, water availability will be calculated in f_8. The agromet model, f_9, combines the outputs from the meteorological model, water availability and plant condition models, and ancillary data such as soil nutrients, soil temperature, and fertilizer applications. The output of this model results in yield at f_{10}. The flow previously described must be repeated for each different crop, region or country, and different growing condition. All these repetitions are summed in f_{11} to obtain the production forecast. The resulting forecast report is generated at f_{12} and distributed to the users.

DATA SYSTEMS REQUIREMENTS

The global crop production forecast will require a large amount of data to be acquired and processed. The amount of data will be much greater than is now required for the LACIE. The LACIE is limited to wheat, and the regions where most of the wheat is grown are more favorable for obtaining remotely

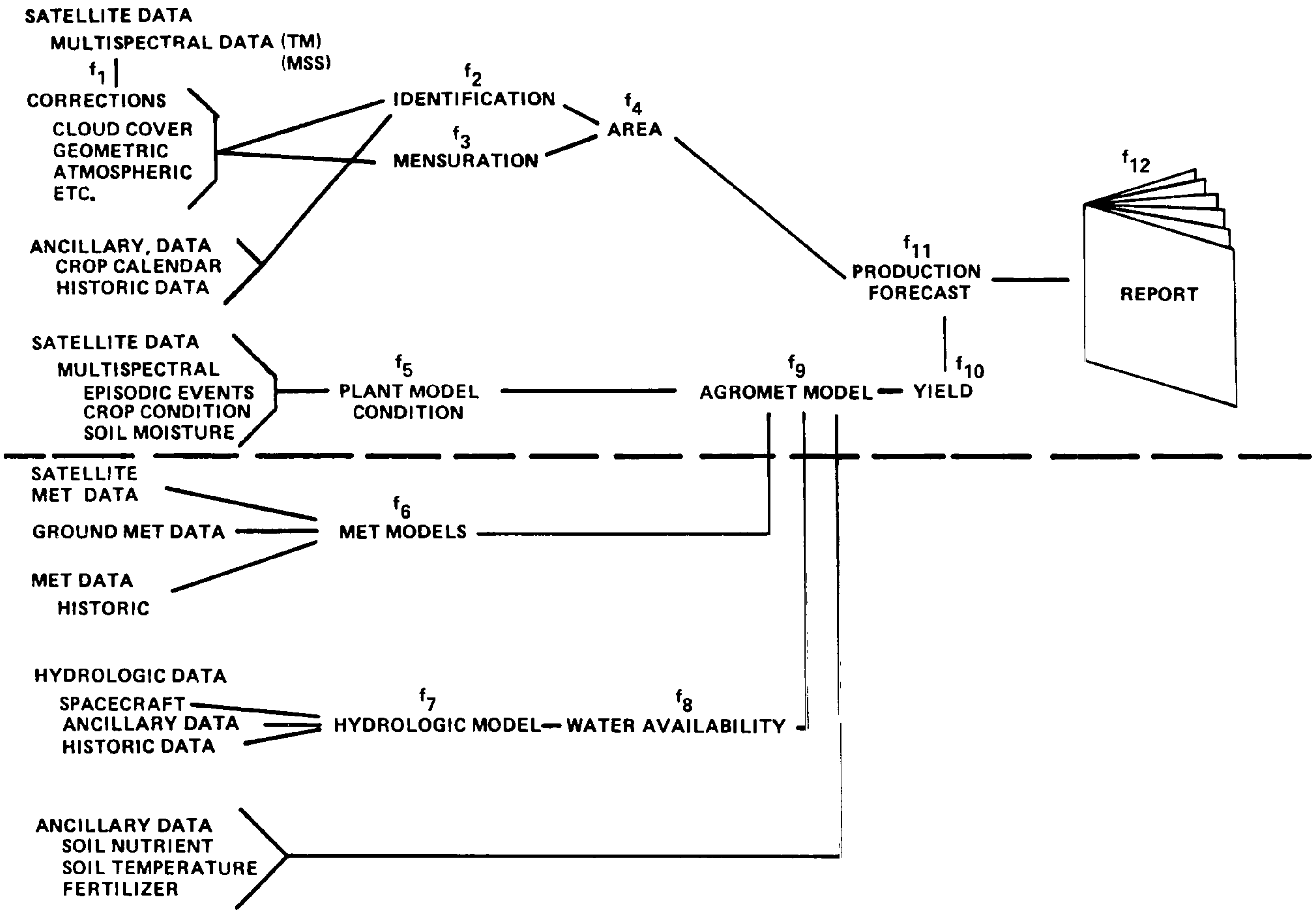

Figure 8. Functional diagram, global crop production forecasting.

sensed data than those of most other crops. Wheat has a long growing season and is generally grown in areas with less than 50.8 cm of rainfall annually and hence having less cloud cover. At the other extreme, rice has a short growing season of approximately 30 days and is generally grown in areas of high rainfall and high humidity which decreases the probability of obtaining good remotely sensed data. A trade study was performed to determine the effects of the many variables on the quantity of data that would be acquired and processed.

Global Crop Production Forecasting Trade Study

To place the goals of the Global Crop Production Forecasting Trade Study in determining data system requirements in proper perspective, it may be helpful at this time to briefly review what has been discussed so far. This report began with the rather general objective to provide a biweekly forecast of the global production of major crops having world wide nutritional and/or economic significance. To make such a broad objective amenable to detailed analysis, it was scoped and quantified in terms of relevant crops, producing regions, primary users of the forecasting information (AID and FAS), achievable forecasting accuracies, and reporting frequencies. Some of the many variables associated with computing crop areas and yields were discussed together with the diverse information sources needed to make these computations. A functional block diagram for a global crop production forecasting system was described, showing the sequence of steps leading to a forecast report. Lying at the heart of all of this, and crucial to the production of any forecast report, is an end-to-end processing system with the capability to gather and manipulate the enormous quantities of remotely sensed image data entailed by the global nature of this objective. As a first step toward defining concrete data systems requirements, the Global Crop Production Forecasting Trade Study had set for itself two principal goals: (1) determine the data processing load for an operational global crop production forecasting system as a function of data frequency, crop types, their biophases, cloud coverage, and number of satellites; and (2) in case the data load exceeded projected processing capabilities, investigate and propose alternate strategies, e.g., editing, sampling, to reduce the load while still achieving the forecast accuracy given in the revised objective. Considering the complexities and unknowns involved in attaining these goals, certain basic and, in some instances, simplifying assumptions had to be made to establish reasonable bounds within which the analysis could proceed. This being the case, it naturally follows that for any interpretation of the trade study results to be valid, reference must be made to this basic framework of underlying assumptions.

Baseline Trade Study Ground Rules

In establishing a realistic mission baseline, two constraints were placed on the study. First it was assumed that the system would be operational in the 1985 time frame, far enough into the future to place it beyond currently planned programs, but close enough to be able to predict with some certainty related technological development. The study was placed within the context of what is likely in 1985 given normal progress, not what is possible, so that the study goals could be pursued without the necessity of assuming significant technological breakthroughs. This meant that any data system components needed for a projected 1985 operational system were already available, or at least under laboratory development. Furthermore, this involved a pragmatic approach in harmony with currently known and planned capabilities. A conceptional data system to perform global crop production forecasting could have been defined which was divorced from programmatic and cost considerations, but it would have had little success of being implemented, no matter what its technological sophistication.

Second, only the "front end," the [illegible]a acquistion and ground preprocessing for radiometric, geometric, and format adjustments, of the total end-to-end data system was studied in detail. A system capable of processing 70 full scenes per day, similar to the currently planned GSFC Landsat-D ground preprocessing system (50 full and 50 partial Thematic Mapper scenes per day), was assumed as a base line with which to compare the operational data load for a global system. Accuracy of classification and yield prediction capability were presumed to be adequate. Ancillary data and data from nonspace platforms or satellites beyond the Thematic Mapper were not included but are planned to be incorporated in future studies. However, in the present study no exhaustive attempt was made to define data system requirements in the extractive and subsequent processing steps.

Within the two basic constraints previously discussed, certain additional specific assumptions were made in an effort to accurately size the data load. The space platform orbit was taken as a Landsat-D Sun-synchronous one with a repeat cycle of 16 to 18 days and a 185 km swath width. Sun synchronization was chosen to avoid possible problems in classification due to a varying Sun angle. The sensor would be a passive whisk broom Thematic Mapper type with a 30 m instantaneous field of view, in all probability the spatial resolution limit in 1985 for use in crop estimation. Target areas of interest would include all land areas containing crops of significance, with the frequency of coverage dependent on such factors as crop types, biophases, cloud cover, etc. Engineering specifications for the orbital and sensor characteristics are found in Table 1.

TABLE 1. THEMATIC MAPPER CHARACTERISTICS

Orbital Characteristics	
Altitude at Equator	705.3 km
Altitude at Pole	723.2 km
Velocity	7.5027 km/sec
Ground Trace Velocity	6.87 km/sec
Period	5932.82 sec
Inclination	98.2°
Repeat Cycle	16 days
Orbits per Repeat Cycle	233
Overlap at Equator	7.125%
Overlap versus Latitude (ϕ)	(100-92.875 cos ϕ)%
Sensor Characteristics	
Swath Width	185 km
Bands	5-30 m Bands 1-120 m Band
Bits/Band	8
Pixels	6167 × 6167 — Hi Resolution
Pixels	1542 × 1542 — Low Resolution
Data Bits/Scene	1540 MBITS
Data Rate	61.6 MB/sec
Data Rate (Including Calibration and Ancillary Data)	84 MB/sec

The next major set of assumptions concerned the selection of the crops that would be the source of the remotely sensed data burdening a global crop production forecasting system. The criteria employed in the selection of representative crops required that they be limited to those significantly affecting the data load; that they be economically important; and that they be crops for which adequate statistical data were available to make a determination of yearly production, areas cultivated, and regions in which grown. It was found that wide variations existed in these statistical data, and that no single source could be consulted for all the desired information. Yearly production fluctuations, different reporting practices, and lack of data on different crops for the same time period made the task of selecting candidate crops extremely difficult. Seven crops were finally selected: wheat (winter and spring), corn, rice, potatoes, sugar (beet and cane), small grain (barley, oats, rye, millet), and soybeans. Wheat leads the list in economic importance, has large cultivated areas, and is the one crop for which the use of remotely sensed data for production forecasting has been demonstrated with some success. The next to be judged as satisfying the selection criteria was corn. The third crop, rice, offers some unique problems. It is usually planted in small fields, growing seasons often overlap resulting in a given region having fields with different biophases present simultaneously, and it is commonly planted in areas experiencing greater cloud cover than those for other crops. All these factors impose rather stringent data gathering requirements. In the course of the trade study, these three crops (wheat, corn, rice) were found to contribute 80 percent of the data system load and, therefore, were given the most thorough examination. The corresponding cultivated areas and producing countries used to bound the data load are presented in Table 2 [7].

TABLE 2. AREA OF REGIONS USED TO BOUND CROPLAND IN REPRESENTATIVE COUNTRIES

Country	Wheat (km^2)	Corn (km^2)	Rice (km^2)
U.S.	2 075 168	2 908 159	309 124
U.S.S.R	6 841 899	1 299 892	336 745
China	2 872 896	4 111 510	3 854 329
India	1 538 475	1 178 227	2 674 000
Australia	971 593	67 648	62 225
Poland	330 138	0	0
Venezuela	0	0	153 400
Canada	936 767	50 875	0

Analysis Approach Used

Much of this trade study was performed using the Data Systems Dynamic Simulator (DSDS) developed by MSFC. Because of the complicated nature and the many interacting real-time variables comprising such a study, the DSDS was ideally suited and readily available for producing meaningful and timely results. The DSDS is a reconfigurable software simulation system consisting of 6 basic core models and 136 precoded data system element models which may be connected in whatever way required to simulate a particular data system of interest. They range from high level components of which satellites, ground stations, and operation control centers are examples, to more detailed data system elements such as sensors, transmitters, receivers, and timing units. Once a specific data system or subsystem is configured and exercised, the DSDS generates information reports on the system's performance, allowing the system to be restructured if it does not function within specifications. For this study, four models were used in constructing the data system: the Mission Model and Throughput Model were core models already part of the DSDS system; and the Crop Model and Cloud Model were added to the simulation system. To properly understand their functions, relationships to each other, and use in this study, individual descriptions are in order.

For determining crop viewing times, the Mission Ephemeris Generator of the DSDS Mission Model was used to simulate a Landsat-D type helisynchronous skip orbit. It has a 9:30 a.m. local Sun time equatorial crossing, a 705.3 km altitude at the equator, an inclination of 98.2 degrees, a 5932.82 second period, and a 16-day repeat cycle. The space craft velocity was 7.5 km/sec. Within the Mission Model, the ephemeris was updated 360 times/orbit, with the platform nadir checked at each update for crop cell crossings. The crop cell identification, target acquisition, and target loss times were then provided to the other models so that they might determine the crops in view, their biophases, the cloud conditions, and the data rates at this point in time.

The crop model contained all the information needed to simulate the crop types growing, their locations, areal extent, and biophases on the Earth's surface as a function of latitude. This information on crop producing areas and crop calendars was primarily obtained from the Oxford Economic Atlas of the World [8] and the World Atlas of Agriculture [7] supplemented with 1976 data from the USDA. When insufficient crop calendar data existed for a particular crop, calendar data for a similar crop were used. Also, because of the uncertainty of making long range cropland usage predictions, no attempt was made to project usage to 1985. The growing pattern for each grain crop was modeled using four biophases: the period from planting to emerging, from emerging to heading, from heading to ripening, and from ripening to harvest. In actual practice such clear cut distinctions cannot always be made for all crops, at all times, in all locations, but for the purposes of this simulation such was assumed. To make the information contained in the Crop Model compatible with the Mission Model, a cell structure which divided the Earth's surface into 10 368 2 1/2 × 2 1/2 degree cells was used. Since the areas of these cells varied with latitude, while the image data in an operational system would be acquired in a continuous 185 km wide swath, it was necessary to use a conversion factor between the varying cell sizes and the constant Landsat scenes. As the mission Model acquired a crop cell, it relayed the acquisition and loss times to the Crop Model. Based on these times and the cell's location on the Earth's surface, the Crop Model determined the crops growing in this cell, their biophases, and called the Cloud Model for the extent of cloud cover for the current time, date, and cloud region in which the cell was located. Due to the lack of precise crop data and to increase simulation efficiency, certain approximations were necessary. For example, all cells for the same crop and latitude used the same crop calendar.

The data used in the Cloud Model were prepared from statistics compiled by Allied Research Associates [9]. Cloud cover statistics in this report were gathered from approximately 100 worldwide observation stations over a 10 to 15 year period. Five cloud cover categories were defined for 30 climatological regions covering 80 geographic world areas. These categories were 0 to 10 percent, 0 to 30 percent, 0 to 50 percent, 0 to 90 percent, and 0 to 100 percent cloud cover. Because the statistical data in the ARA report were based on the cloud coverage as seen by a ground observer with a 30 n. mi. field-of-view versus satellite observation with a different field-of-view, the data had to be scaled to the satellite scene size before incorporation into the Cloud Model. Also, since the satellite was assumed to have a 9:30 a.m. equatorial crossing, only the statistics for this time frame were used. In an attempt to validate the scaled statistics employed in the Cloud Model, a comparison was made between them and cloud cover statistics contained in the Marshall Earth Resources Information Transfer System data base. Scaled Cloud Model statistics from May through September for the eastern half of the United States over a span of several years were compared to actual cloud cover percentages contained in previously acquired Landsat scenes for the same area and time. For 50 percent or less cloud cover, the difference between cloud cover in Landsat scenes and the scaled cloud cover statistics used in the simulation was approximately 2 percent.

The final model to be considered is the Throughput Model. It controlled the sensor data rates, i.e., the amount of data generated for each crop target based on the engineering specifications of the sensor, in this case a Thematic Mapper producing a full 185 by 185 km scene every 24 sec. In addition, using information supplied by the Mission, Crop, and Cloud Models, it monitored data transit times, throughput rates, and processing delays, thus providing the capability of generating simulation performance reports. The stage was now set for pursuing the two principal goals of this trade study: (1) determining data loading, and (2) investigating means of reducing the data loading through editing and sampling strategies.

Results Achieved

Using the DSDS to correlate the interrelated influences of orbital parameters, crop calendars, and cloud conditions, comprehensive sets of global data loading profiles were generated. The effects on the data load of various crops and their biophases were investigated together with the effects of cloud cover and the number of satellites in orbit. Schemes for reducing the data load through cloud rejection editing and sampling strategies were also studied. All these analyses produced results far too extensive to be covered in their entirety in this report alone, and the reader is referred to General Electric Report 77HV091 [10] for detailed discussions.

The first phase of the study centered on the generation of day-to-day data loading profiles for all the major crops. The upper left hand chart in Figure 9 shows the global viewing time in minutes per day from January to December for wheat. This data loading profile is for the possible viewing time of one satellite regardless of cloud cover, i.e., for how many minutes per day would one satellite sweep out a continuous 185 km swath on the Earth's arable surface containing only wheat in any of four biophases. As can be seen from Figure 9, the peak viewing time extends from early May to early November, the growing season for spring wheat in the Northern Hemisphere. Daily viewing times during this peak period range from a minimum of 17 min (42 scenes per day) to a maximum of 34 min (or 85 scenes per day). The daily vertical fluctuations in the graph are due to the areal distributions of the Earth's croplands as viewed from the satellite.

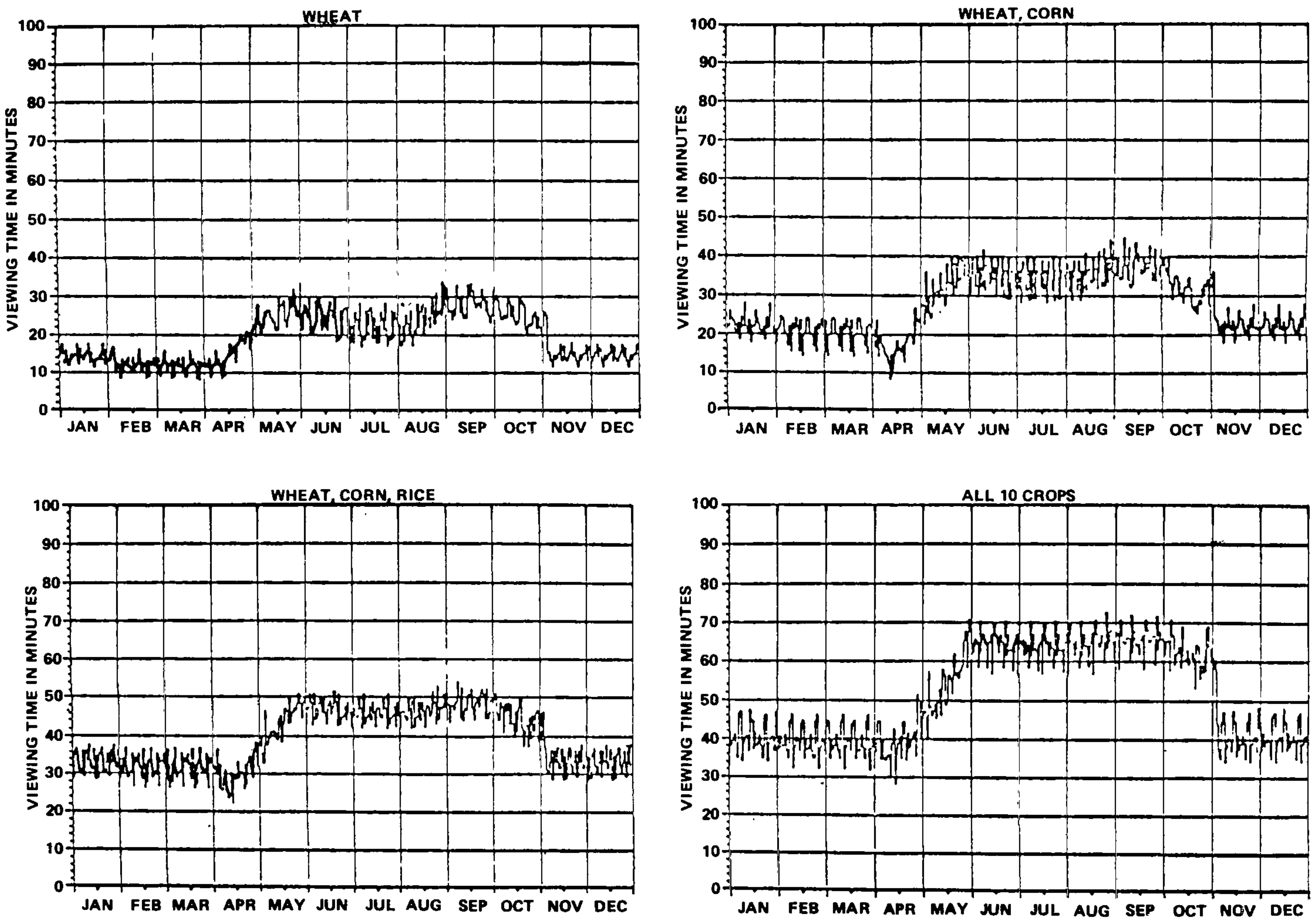

Figure 9. Effect of additional crops on loading (daily viewing time for cloud categories 1 through 5).

With the addition of corn, the average daily viewing time increases from approximately 25 to 36 min per day, while for all crops the average daily viewing time is 64 min or 160 scenes, with a peak of 73 min or 183 scenes per day. A tabulation of Figure 9 is given in Table 3.

TABLE 3. EFFECTS OF ADDITIONAL CROPS ON DATA LOADING

Crops	Average Daily Viewing Time in Minutes for June Through September	Scenes per Day ($185\ km^2$ per Scene)
Wheat	25	62
Wheat, Corn	36	90
Wheat, Corn, Rice	47	117
All Crops	64	160

Simulations to determine viewing times for multiple satellites were also conducted in an effort to see what effect this would have on the data load. For all crops and cloud conditions, two satellites with an 8 day separation gave a daily peak viewing time of 134 min, and an average of 131 min. Three satellites with a 5 day separation resulted in 205 min of peak viewing time and 196 min of average viewing time per day. It is evident from these results that processing full scenes from just one satellite for all crops far exceeds planned processing capacity (70 scenes per day or 28 min of viewing time), without considering multiple satellite cases. The necessity for some type of editing is obvious.

Figure 10 shows the combined effects of crop and cloud cover editing on the data load from one satellite. In the upper left hand chart, average throughput (scenes per day) for a 16 day period in June is plotted against cloud cover acceptance criteria for various combinations of crops. The horizontal dotted line represents the planned processing capacity of 70 full scenes per day. Taking the plot for wheat, corn, and rice, if all scenes with 30 percent or less cloud cover (cloud category two) are accepted, 60 scenes per day will need to be processed. If scenes with 50 percent or less cloud cover (cloud category three) are accepted, 75 scenes per day on the average remain to be processed, already exceeding the planned capability. The lower left hand chart shows the peak

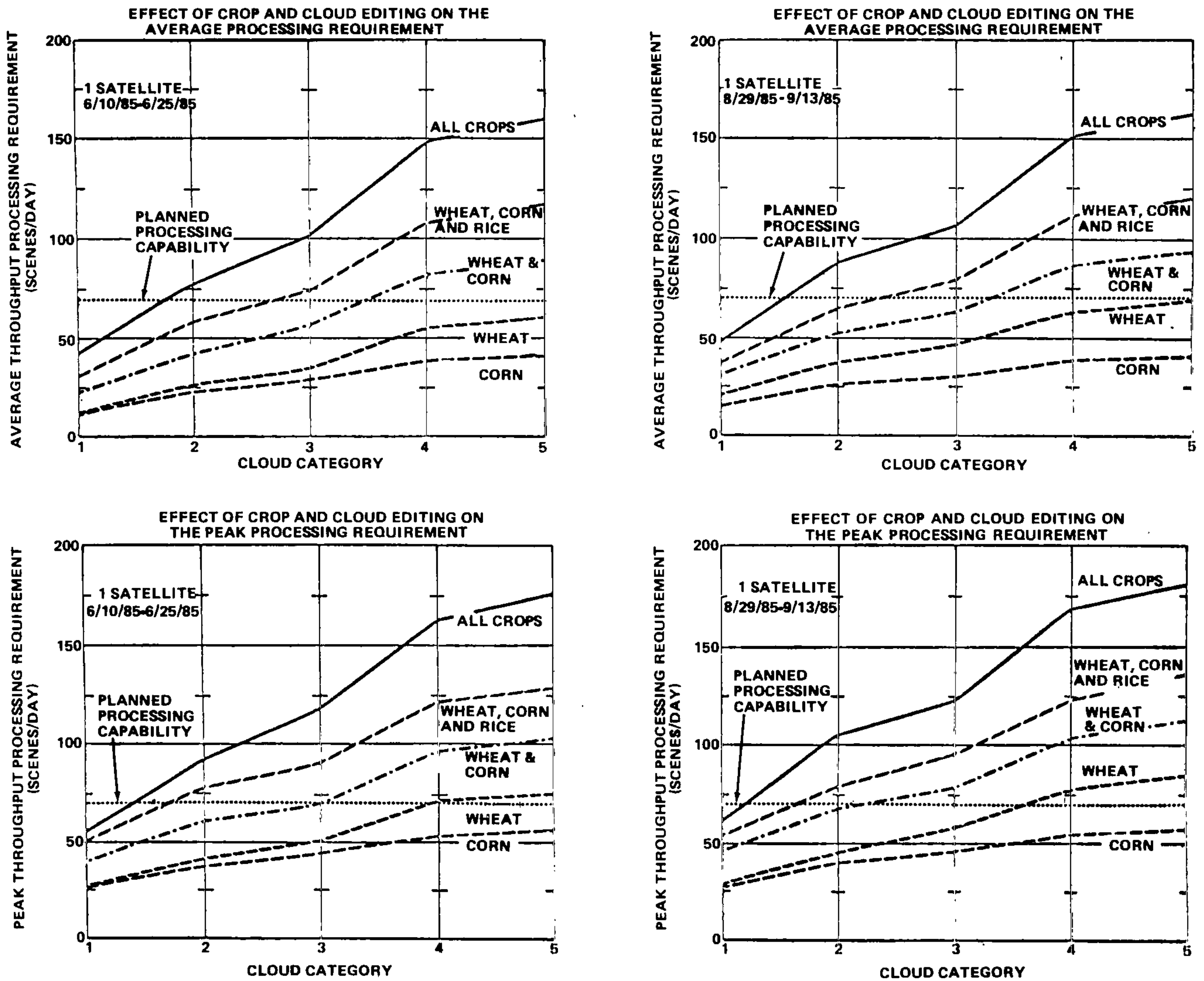

Figure 10. Effect of editing on data loading.

processing requirement for the same time period. Here, if scenes containing wheat, corn, and rice with 30 percent or less cloud cover are accepted, 77 scenes still remain to be processed for the worst daily case. All four charts indicate that severe crop and cloud cover editing would have to be employed to reduce the daily data load, but at the cost of losing scenes with usable information content. A much more sophisticated approach is needed.

Sampling

A sampling technique similar to that being used in the LACIE Program was considered as the next most feasible approach for reducing the data volume while retaining scene information content.

It has been stated previously that it is necessary to have three observations of a particular sample segment during the growing season to accurately identify the crops. Since some of the samples will be under cloud cover during the subsequent passes, it is necessary to obtain data on many more samples on the first pass to have the required number at the end of the three growth phases. Calculations were made to determine the number of samples required for three crops in three countries to obtain some indication of the magnitude of the data required. These calculations were for corn in the U.S., wheat in Canada, and rice in India. A brief description of the methods used follows.

The proportion of each region being sampled is determined by the ratio, or proportion, of the area of the crop being inventoried to the total agricultural area in the country. The figures for areas are based on historical data, and it is realized that the current crops may not be of exactly the same proportion, which is the reason the inventory is being done. However, the use of historical data to determine the number of samples required is acceptable sampling theory.

Bernoullian distribution is assumed to determine the number of samples required. The region to be sampled is divided into a number of segments. If the segment contains more of the crop being inventoried than the proportion for the entire region in the crop, it is assigned a value of 1. If it contains less than the proportion for the entire region, it is assigned a value of 0. The proportion, p, can then be calculated for the number of segments having values of 1 and the total number of segments.

In Bernoullian distribution, the standard deviation, σ, is

$$\sigma = np(1 - p) \quad (2)$$

and the mean, μ, is

$$\mu = np \quad (3)$$

where p is the proportion of the crop in the area being sampled and n is the number of samples [11].

The relative sampling error, e, is

$$e = \frac{\sigma}{\mu} = \frac{np(1 - p)}{np} = \frac{1 - p}{np} \quad (4)$$

Since the Bernoullian distribution is only an approximation, the sampling error determined by equation (4) will be an approximation. If the distribution is normal, or Gaussian, the approximation will be quite good. The question is, how close do the samples from the Bernoullian distribution approach Gaussian distribution. It is a well known statistical condition that if a large number of samples are drawn from a non-Gaussian distribution, the distribution of the sample will approach Gaussian distribution. Generally, this will be the case if the number of samples is greater than 30. It is thus assumed that for the number of samples used, the distribution will be Gaussian.

The sample error determined by equation (4) is then based on a Gaussian distribution and will be correct for a confidence level of 1 σ (68.27 percent). If the confidence level is to be greater than 1 σ, it is intuitively recognized that the error in equation (4) must be modified by a confidence multiplier, k. Equation (4) is rewritten as

$$e = k\sqrt{\frac{1 - p}{np}} \quad (5)$$

For confidence of 68.27 percent, the multiplier is $k = 1$. For 90 percent confidence, $k = 1.645$. The value of k for any confidence level can be determined from a normal distribution curve or table [12].

To compute the number of samples required for a given allowable error and confidence level, equation (5) can be rewritten as

$$n = \frac{10^4 k^2 (1 - p)}{e^2 p} \quad , \qquad (6)$$

where e is in percentage.

The number of samples required for the three crops and countries previously mentioned were calculated using allowable accuracies of 90, 95, and 98 percent with a confidence level of 90 percent. The areas in each country and crop were obtained from Reference 7. The number of samples required are presented in Table 4.

To have required number of samples at the end of the three observations, it is necessary to obtain more sample observations on the first two observation periods. The number of samples required is influenced by the number of observations possible and the effects of cloud cover, and can be determined by dividing the number of samples required by the product of the probabilities that an observation can be obtained or

$$\text{initial number of samples} = \frac{\text{required number of samples}}{(\text{probability})^x} \quad , \qquad (7)$$

where x is the number of observations required of each sample segment. The probability numbers are a function of the cloud cover and the amount of overlap for each scene. The calculation of the probability numbers is complex, and the method and probability numbers used are available in Reference 10.

TABLE 4. NUMBER OF SAMPLES REQUIRED

Crop Country	Agricultural Area (1000 Ha.)	Specific Crop Area (1000 Ha.)	Proportion in Crop	Accuracy Required at 90% Confidence	Number of Samples Required[a]
Corn U.S.	178 736	34 225	0.19	90	1 200
				95	4 700
				98	30 000
Wheat Canada	41 845	11 340	0.27	90	750
				95	3 000
				98	19 000
Rice India	147 823	35 815	0.24	90	870
				95	3 500
				98	22 000

a. Rounded to two significant figures.

The number of samples required on the initial observation to obtain the required number were calculated for the three crops previously used. It was assumed that scenes having 50 percent or less cloud cover would be usable. The samples required for one, two, or three satellites are given in Table 5 for the allowable accuracies and confidence levels previously assumed.

The previous calculations show a requirement for three Landsat-D type satellites each with a 16 day repeat cycle. The data would be relayed to the ground by the use of TDRSS. There is a problem with the use of TDRSS since the zone of exclusion includes most of India, and parts of Pakistan, U.S.S.R., and Peoples Republic of China. The zone of exclusion is shown in Figure 11. Eliminating this much of the world's agriculture would have a serious adverse effect on the global crop forecast. Also to obtain all the data required from the satellite would require a dedicated TDRSS channel.

To relay the data from the TDRSS ground receiving station to the ground processing facility will require a dedicated DOMSAT channel and will result in a significant cost of data transmission.

A study was performed by General Electric [13-17] for GSFC which indicated a need for processing 480 scenes a day for an agricultural mission. This requirement far exceeds the planned capability. The results of the GE study are not repeated here.

The conceptional data system, with data rates, is shown in Figure 12.

CONCLUSIONS AND RECOMMENDATIONS

Based on the results of this investigation, it can be concluded that it is not possible to meet the revised objective (as previously stated) with the projected data systems available in the 1985 time frame. Some of the reasons are as follows:

TABLE 5. INITIAL NUMBER OF SAMPLES NEEDED TO HAVE REQUIRED SAMPLES AFTER 3 OBSERVATIONS (SHOWN FOR 1, 2, 3, SATELLITES)

Crop Country	Accuracy at 90% Confidence	Samples Required	Oversampling Required for Satellites		
			1	2	3
Corn U.S.	90	1 200	2 374	1 396	1 245
	95	4,700	9 297	5 468	4 877
	98	30 000	59 346	34 903	31 129
Wheat Canada	90	750	1 029	785	756
	95	3 000	4 115	3 140	3 026
	98	19 000	26 059	19 884	19 163
Rice India	90	870	2 022	1 056	911
	95	3 500	8 136	4 247	3 666
	98	22 000	51 142	26 694	23 041

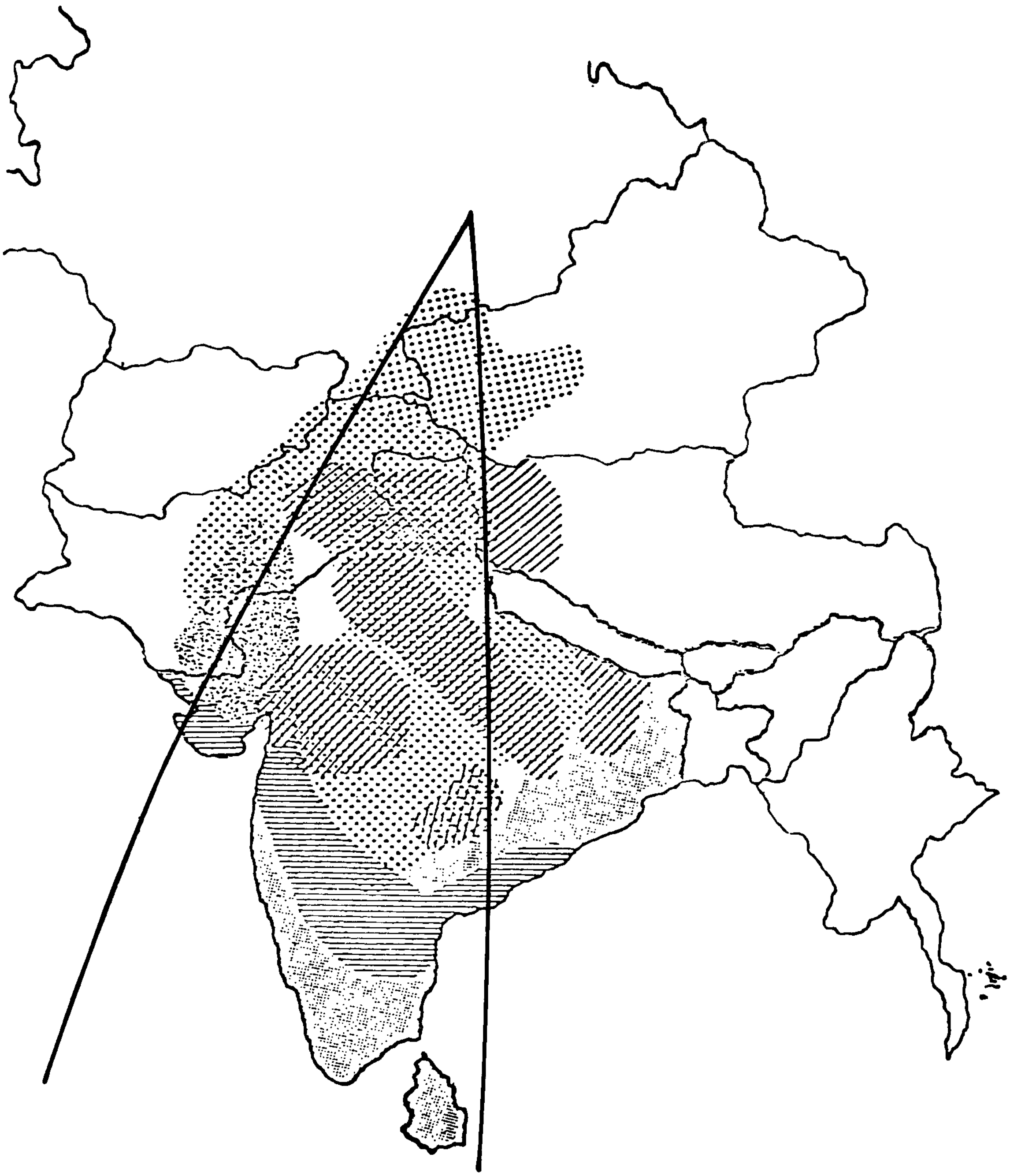

Figure 11. TDRSS zone of exclusion.

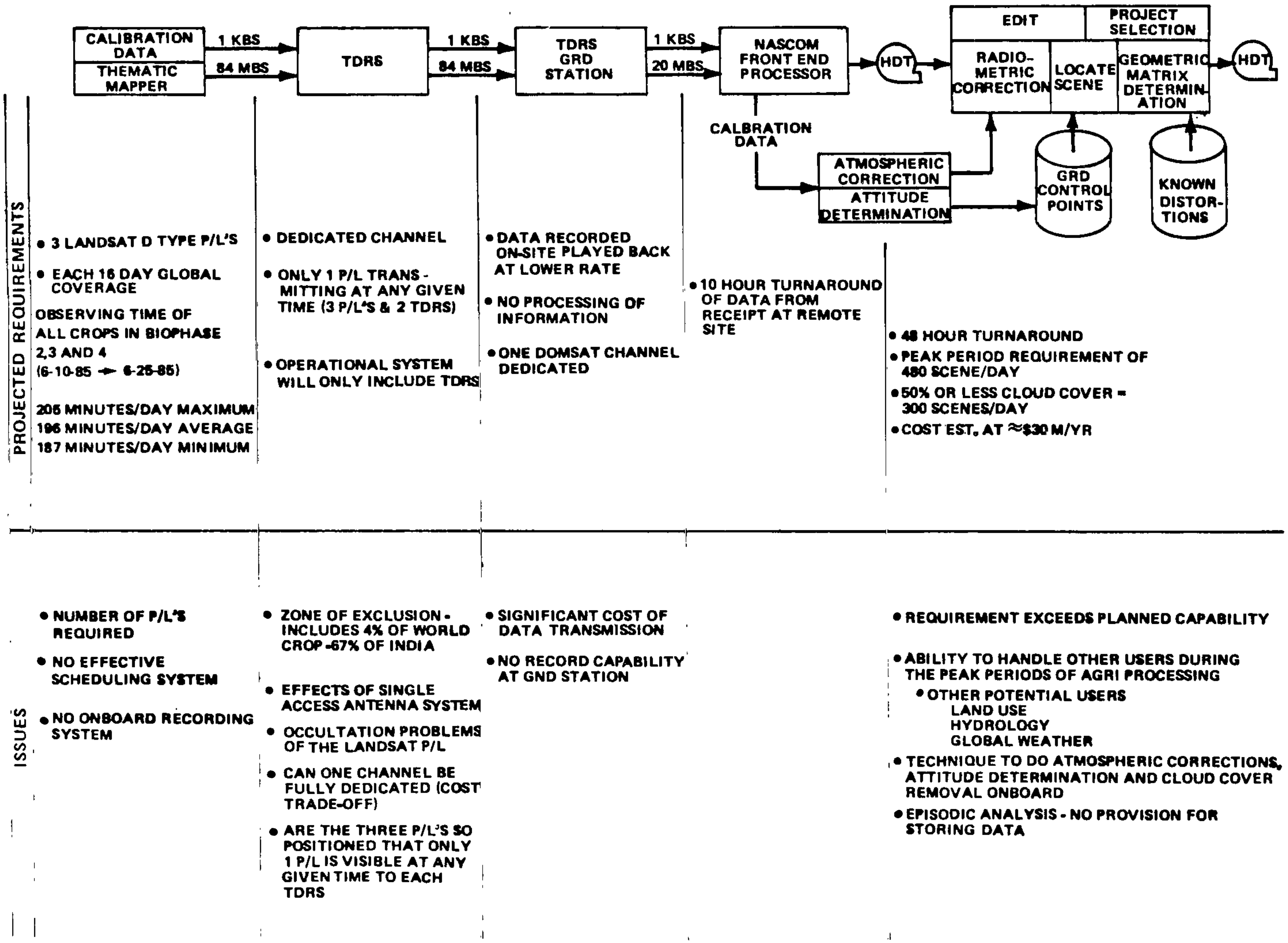

Figure 12. Block diagram of conceptual data system.

Data Collection

Three satellites are required and these are not projected to be available.

The peak scene processing requirement of 480 scenes per day is far beyond the planned capability. In fact, processing full scenes from only one satellite for all crops is beyond the capability of any planned system.

Onboard processing would reduce the quantities of data being transmitted to the ground. For example, simple crop and cloud editing can significantly reduce the data load, but at the possible expense of losing valuable information content which would reduce the accuracy of the forecast. Scenes with 50 percent or less cloud cover appear to be usable. However, for all crops, only scenes with 30 percent or less cloud cover could be processed daily by the assumed system.

A sampling approach was shown to reduce the data load to an acceptable level (under certain assumed conditions the equivalent of 3.14 scenes versus 84.9 scenes for corn in the U.S.) while preserving information content. However, oversampling must be used to reduce statistical error caused by cloud conditions and viewing opportunities for different crops.

The TDRSS must be upgraded to include a dedicated channel to handle the additional data requirements (three satellites and two TDRS's with only one satellite transmitting at any given time). Also the zone of exclusion must be eliminated.

DOMSAT must be utilized for ground to ground communication if the 10 hr turnaround time is to be maintained. Location of the preprocessor close to the TDRSS ground station should result in a time and cost savings.

Information Extraction

A breakthrough is needed in crop identification if the processing requirements are to be reduced, but this is not likely to occur. The use of multitemporal data is a method to overcome the identification problem, but its use greatly increases the processing, and no other method of accurate identification is available or expected to be available by 1985.

There is a lack of a historic data base for crop calendars and agricultural practices outside the U.S. This data base should be for a minimum of 10 years.

A reduction of accuracy in the forecast would result in much less data processing. If the accuracy requirements were reduced from 98 percent to 95 percent or 90 percent, the number of samples would be greatly reduced. This effect is shown in Table 4. With the samples reduced, the processing load would be greatly reduced. In fact, 95 percent accuracy on a worldwide basis appears acceptable.

Additional Studies

Figure 12 identifies a number of issues not yet resolved, indicating the need for additional trade studies to be performed. Some of these studies are:

1. Determine the data systems costs associated with each satellite configuration (1, 2, or 3) taking into account varying altitudes, swath width, spatial resolutions, orbital (skip or retrograde) periods, and sensor pointings.

2. Using precise definitions of windows, length of times, number of samples by country or region, and make-up of samples (multipurpose or single purpose), study various editing techniques to determine processing requirements more accurately than was done in this present analysis.

3. Develop cost estimates for an agricultural ground processing system.

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APPENDIX

LIST OF KEY INDIVIDUALS AND THEIR ROLE IN INFLUENCING THE CONCEPT OF THE DATA SYSTEM

No.	Organization	Key Individual	"Data Systems" Role
1	USDA/ARS/Weslaco, TX	Dr. Craig Wiegand	Influences requirements
2	USDA/ARS/Weslaco, TX	Dr. Jerry Richardson	Influences requirements/uses data-research mode
3	USDA/ARS/Weslaco, TX	Mr. Paul Nixon	Influences requirements/uses data-research mode
4	USDA/ARS/Weslaco, TX	Mr. Ross Leamer	Influences requirements
5	USDA/ARS/Weslaco, TX	Mr. Joe Cuellar	Influences requirements-ground truth
6	USDA/ARS/Akron, CO	Dr. Darryl Smika	Influences requirements/uses data-yield models
7	NASA/JSC/Houston, TX	Mr. Norm Foster	USDA requirements for various crops, and system definitions for other USDA requirements
8	NASA/JSC/LACIE/Houston, TX	Mr. Wayne Eaton	LACIE project management
9	USDA/JSC/LACIE/Houston, TX	Mr. James Murphy	Deputy program manager for LACIE
10	NASA/ARC/Moffett Field, CA	Mr. Roger Arno	USDA remote sensing survey requirements aircraft segment
11	USDA/SRS/Washington, D.C.	Dr. Galen Hart	Influences requirements and uses data/chief R&D branch

No.	Organization	Key Individual	"Data Systems" Role
12	Clemson University, SC	Dr. J. R. Haun	Yield model development
13	NASA/ JSC/ Houston, TX	Mr. Gary Graybeal	Influences requirements/ member of agriculture subpanel of Earth resources applications panel

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15. SUPPLEMENTARY NOTES

Prepared by Data Systems Laboratory, Science and Engineering Directorate

16. ABSTRACT

Starting with the description for the Global Crop Production Forecasting objective as given in "Outlook for Space," Marshall Space Flight Center undertook the task to define the data systems concepts that would be needed to implement this objective in an orderly transition from experimental to operational status in the 1985 time frame. The objective was carefully examined with consideration of the data system implications. Cognizant personnel were interviewed; data processing facilities were surveyed; the impact of future technology development was assessed; pertinent documentation was studied; and previous and current activities in this objective area were evaluated. This investigation served as the foundation for quantifying the objective by obtaining from the most important users their projected information needs. These information needs were then converted into data system requirements, and the influence of these requirements on the formulation of a conceptual data system was analyzed. Any potential problem areas in meeting these data requirements were then identified in an iterative process whereby the scoped objective was further refined as the analysis continued and recommended solutions and alternatives were developed.

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