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Phase I – Final Technical Report

DEVELOPMENT OF GREAT LAKES ALGORITHMS FOR THE NIMBUS-G COASTAL ZONE COLOR SCANNER

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The Great Lakes Experimental Team (GLET) has conducted a series of experiments in the Great Lakes designed to evaluate the application of Nimbus-G Coastal Zone Color Scanner (CZCS). Absorption and scattering measurement data were reduced to obtain a preliminary optical model for the Great Lakes. Available optical models were used in turn to calculate subsurface reflectances for expected concentrations of chlorophyll-a pigment and suspended minerals.

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20. ABSTRACT (Continued)

Multiple non-linear regression techniques were used to derive CZCS water quality prediction equations from Great Lakes simulation data. An existing atmospheric model was combined with a water model to provide the necessary simulation data for evaluation of preliminary CZCS algorithms.

A CZCS scanner model was developed which accounts for image distorting scanner and satellite motions. This model was used in turn to generate mapping polynomials that define the transformation from the original image to one configured in a polyconic projection.

PREFACE

This final report as issued by the Applications Division of the Environmental Research Institute of Michigan (ERIM) under National Aeronautics and Space Administration (NASA) contract NAS3-22442 for the Lewis Research Center (LeRC) covers the contract period from April 1, 1980 through February 28, 1981. The technical representative for the contract officer was Mr. Thom A. Coney of LeRC. The Principal Investigator was Fred J. Tanis with important contributions to the technical program made by David R. Lyzenga, Glenn Davis, and Robert Dye. This research was conducted by the Applications Division under the direction of Mr. Donald S. Lowe.

This contract involves developing algorithms to map selected constituent concentrations in Great Lakes waters from the Coastal Zone Color Scanner (CZCS). The approach is based upon the inherent optical characteristics of Great Lakes waters.

A number of institutions and universities are involved in the project and are organized as the Great Lakes Experimental Team (GLET). This report covers ERIM's activities in the project during Phase I of an anticipated two phase program.

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INTRODUCTION

The Great Lakes Experimental Team (GLET) is conducting a series of experiments in the Great Lakes region designed to evaluate the application of the Nimbus G Coastal Zone Color Scanner (CZCS). Potential uses foreseen include assessment of trophic status, verification and spatial refinement of whole lake models, and observation of temporal and spatial dynamics of phytoplankton. Currently members of the NOAA Nimbus Experimental Team (NET) are developing chlorophyll and sediment algorithms largely to be applied, to the open ocean [1]. Preliminary examination of these algorithms indicates they have limited applicability to the Great Lakes. Concentrations and compositional differences of suspended materials along with atmospheric aerosol variants are expected to exhibit important differences from the marine environment and result in additional complexities. The focus of the present program is the development and testing of atmospheric and water algorithms appropriate to the Great Lakes as well as evaluation of existing algorithms developed for the marine environment.

1.1 STATEMENT OF THE PROBLEM

The quantification of substances in Great Lakes waters by satellite visible radiometry is dependent on a thorough understanding of the radiative transfer processes in the atmosphere, at the waters surface, and in the water column itself. It has been well established that the content of water, be it particulate or dissolved substances affects the apparent color. By sensing color with a high signal to noise ratio in narrow spectral bands CZCS provides a means of looking at the water content which has been heretofore unavailable from satellite data. Since the air and water effects are coupled to the CZCS radiometric data, removal of atmospheric effects becomes critical to the success of the Great Lakes verification. Once removed the radiance which is scattered upward from beneath the surface can be observed clearly by the satellite. Effectively the radiance reaching the satellite from the lake surface amounts to only five percent of the total radiation and consequently ninety-five percent of the radiation received is from atmospheric backscatter and surface reflectance. Furthermore, the variation in radiance at the satellite due to change in constituent concentration are on the order of one percent while the variation due to atmospheric changes can be considerably higher. The spatially varying atmospheric component is due principally to aerosol scattering. The significance of the atmospheric problem for a water target has been demonstrated by Hovis and Lung [2] and more recently by Quenzel and Kaestner [3] who compared the variability of the atmosphere with the reflected light from phytoplankton suspensions. Thus unless atmospheric effects can be negated resolving quantitative information on water constituents it is considered to be most difficult. Baring elimination of the atmospheric effects the water problem requires understanding how the inherent optical properties relate to the measured quantities of chlorophyll-a pigment, phytoplankton cell count, suspended solids, and dissolved organics. Previous algorithms relied heavily on the availability of extensive surface truth [4,5,6]. For this study algorithms are sought which can be based on optical properties specific to the Great Lakes and which reduce the present requirements for extensive surface truth.

1.2 PROJECT GOALS AND ERIM TASKS

In order to be acceptable to the Great Lakes user community CZCS algorithms must, in our estimation, meet at least two general criteria. First, the algorithms must be able to predict accurately surface concentrations of chlorophyll-a pigments and suspended sediment over widely varying ranges and do so with little or no ancillary measurement data. Second, they must be capable of making predictions over water masses which exhibit spatial variation in atmospheric haze and surface concentration.

The ERIM participation in the Great Lakes experiments involves two phases. The first covers the period from April 1980 through February 1981 and is the subject of this report. This first phase has involved development of computer software to process CZCS tapes received from the NASA Goddard Space Flight Center (GSFC), collection of surface truth measurement data in connection with CZCS overflights of the Great Lakes, and formulation of preliminary algorithms. The second phase will involve development and testing of specific atmospheric and water computer algorithms for CZCS. The water algorithms will be based upon radiative transfer theory and measured optical properties of Great Lakes waters. Existing atmospheric models will be tested, including some recently developed models, using surface truth and low altitude aircraft measurements made during the 1980 GLET experiments. These models in turn will be utilized in the development of operational algorithms for removing atmospheric effects from CZCS data without the direct use of a large number of in situ measurements of atmospheric optical depth. Our approach is to remove spatially variable components using properties of the data itself. It is anticipated that both the algorithm development by Gordon [7] and that by a group at the Scripps Institute of Oceanography [8] will be tested for their suitability to the Great Lakes atmospheric environment.

1.3 PROJECT BACKGROUND

The scientific objective of CZCS is to determine water constituents quantitatively and to carry out such measurements over large areas which are not possible or practical to be obtained with surface ship investigations. Currently the Nimbus experimental team (CZCS-NET) is investigating CZCS capabilities to quantify material suspended or dissolved in the water. These validation studies are concentrating on the ocean environment. The present study is similar in design to the NET investigations but the focus is on a freshwater environment. A number of institutions, research centers, and universities plan to participate various aspects of the program. In addition to LeRC, which has led the current effort, participants in the Great Lakes Experiment include ERIM, Canada Center for Inland Waters, NOAA Great Lakes Environmental Research Laboratory, EPA Grosse Ile, University of Minnesota, University of Wisconsin, and others. These participants have a wide variety of backgrounds and capabilities which can be applied to the project. While it is understood that LeRC will not be able to participate fully in subsequent program phases it is anticipated that they will maintain an active interest in the project and promote the continuity of the GLET.

1.4 SUMMER 1980 GREAT LAKES EXPERIMENTS

During 1980 a number of surface truth measurements were made coincident with CZCS overflights of the Great Lakes. Experiments were conducted at three principal locations in the Great Lakes: western Lake Erie, Duluth area of western Lake Superior, and the Grand Haven area in Lake Michigan. All of these experiments were designed to gather necessary validation data and optical properties specific to the Great Lakes waters. Measurements made included the following:

(1) Aircraft flights were made by NASA LeRC F-106 aircraft fitted with the Ocean Color Scanner at altitudes of 500 and 41,000 feet.

(2) Water samples were gathered by the University of Michigan GLRD and the NOAA GLERL and subsequently analyzed for chlorophyll pigments and suspended solids.

(3) NASA LeRC made various surface ship radiometric measurements.

(4) NASA Langley Research Center deployed a mobile optical laboratory to Cleveland. Optical parameters including absorption, beam attenuation, and scattering were measured on selected water samples.

(5) The Naval Oceans System Center conducted in-situ submersible radiometer measurements of subsurface downwelling and upwelling irradiance at selected sites in Lake Erie.

A total of twenty separate sites were sampled in the Great Lakes, fourteen of which were made in connection with CZCS overflights. Only a very small portion of the above measurements have been analyzed to date but all analyses are expected to be completed in phase II of the program.

2

DEVELOPMENT OF A GEOMETRIC CORRECTION ALGORITHM FOR CZCS

The objective of this task was the modification of existing software and the development of a new scanner model which together will permit transformation to CZCS line and pixel coordinates into earth latitude and longitude. CZCS scanning geometry including variable tilt angle for Great Lakes viewing was combined with ground control points to derive the appropriate transformation matrix. Landsat geometric processing programs were adapted and modified as necessary to process available CZCS taped data for the Great Lakes. The initial accuracy goal was set to one pixel in each direction. In this task our efforts included investigation of geometric correction based on the 77 tie points per line, development of a CZCS scanner model, generation of mapping polynomials, modification of resampling software, and processing of an example image.

The geometric correction of an image results from two operations. First, mapping polynomials are generated that define the transformation from the raw original image to the corrected image. Second, the corrected image is created from the uncorrected image using these mapping polynomials. Two fifth-order, twenty-one term polynomials were used in this process, one for each dimension of the image. These polynomials define the transformation which makes the corrected image conform to a given map projection as well as adjust for viewing distortions such as satellite position, satellite motion, and earth motion. Two approaches were considered in the present study; a geometric regression analysis approach, and an orbit modelling approach. Both of these approaches are based on extensive experience with Landsat image correction. Thus the basic techniques were extended in the present effort to accommodate the Coastal Zone Color Scanner.

2.1 INVESTIGATION OF REGRESSION MODEL TECHNIQUES

Regression analysis was undertaken as the first approach to geometric correction. While this approach is considered to be straightforward it has the disadvantage of requiring extensive ground control points which makes it time consuming. In order to get satisfactory results, fifty or more points should be taken for each scene. The first image considered was taken on November 8, 1978. An image analyst selected forty-six ground control points of which forty-one were found to be suitable. A geometric regression analysis of these points produced mapping polynomials which could predict the location of these points with standard errors of 517 meters in the horizontal dimension and 553 meters in the vertical direction. Since the pixel size of the CZCS is nominally 825 by 825 meters, derived mapping polynomials are estimated to be accurate to within one pixel. These results are comparable to those typically obtained with Landsat processing.

Selecting ground control points is a lengthy process so an alternative method was sought to correct the scene. An attempt was made to use the ephemeris data that accompanies each image tape. Specifically, anchor points are included that describe the geographic position at 77 locations on each scan line. A two hundred point sample distributed throughout the scene was selected for testing. Geometric regression of these points showed errors greater than 13,000 meters in both dimensions. A similar set of points selected from a second scene taken on May 8, 1979 produced errors of the same magnitude. Subsequent to this experiment we learned that later versions of the GSFC processing algorithm had improved the accuracy of the anchor points considerably. Fortunately, we were able to obtain a copy of the May 8 scene with the improved anchor point values. However, this image was the only one available under the new version [9] and thus it was used exclusively for purposes of testing the geometric correction algorithms. A geometric regression was performed on a 429 point sample of anchor points which was in turn used to produce a set of mapping polynomials. Using the mapping polynomials derived from the anchor points the ground control points were predicted with RMS errors of 4068 meters in the horizontal dimension and 4425 meters in the vertical dimension. This five pixel accuracy is within that claimed by GSFC for the anchor point reference system. Geometric regression of a set of sixty-two ground control points taken from the same image showed errors of 557 meters in the horizontal and 893 meters in the vertical.

An attempt was made to obtain additional scenes with which to verify these results. Two scenes were obtained from the Lewis Research Center for this purpose. The first, April 17, 1979 had extensive cloud cover and it was impossible to obtain an adequate number of ground control points. The second, June 20, 1979 was centered in an area east and south of Lake Erie. Most of the image covered the Atlantic Ocean and again ground control points in the Great Lakes area were insufficient.

2.2 COASTAL ZONE COLOR SCANNER MODEL

The scanner model developed for CZCS is based upon our experience with Landsat and in its present form takes each image control point in turn and projects it to the earth's surface. The line number for each point is used to interpolate for the latitude, longitude, and altitude from the values supplied with the tape reference data for each scene. The point number is used to calculate the mirror scan angle, which together with the reported tilt angle determines the scanner line-of-sight vector in spacecraft coordinates.

A series of rotations through the angles of roll, pitch, heading, latitude, and longitude plus a translation provide the transformation to earth centered coordinates. The intersection of the line-of-sight vector with the surface of the eplisoid is then derived and converted to latitude and longitude. These coordinates are compared with the corresponding values obtained from map data, and the discrepancies minimized by successive refinement of the estimated roll, pitch, and heading. The present model permits manual intervention with the operator who can supply needed refinements to the latitude and longitude parameters. It is anticipated that future model versions will eliminate the need for operator interaction and model adjustments.

Once unsatisfactory control points have been eliminated the refined attitude and location data are combined with the model. The cartographic projection is then selected and subjected to polynomial regression analysis which yields in turn the coefficients to a pair of twenty-one term, fifth degree polynomials. These polynomials provide an approximating transformation from cartographic coordinates to the original image coordinates.

The uses to which a scanner model of the imaging system for the CZCS are twofold. First, the image control points and their corresponding map control points may be easily evaluated for consistency with other points and any outliers rejected. Second, the coefficients for global mapping polynomials used in the resampling process can be derived by a fit to the model rather than to the points themselves. This feature permits the use of a much smaller number of points than would be needed for simple regression.

2.3 GENERATION OF MAPPING POLYNOMIALS

An arbitrary set of points were selected from the test image and used together with the scanner model to derive a set of mapping polynomials. A number of scanner variables including satellite attitude and position will influence the model results. Values of latitude and longitude are converted to line and pixel location in the resulting image via the equations that define the desired map projection.

The process used to resample a corrected image works in the reverse direction. For each pixel location in the resulting image the program calculates the corresponding location in the original image. This process implies reversing the projection equations in order to derive the desired latitude and longitude information. However, operation of the scanner model in reverse so as to select original pixel locations which correspond to given location in the corrected image is most difficult and unwieldly. Alternatively, the pair of twenty-one term polynomials is generated to satisfy this mapping requirement. One polynomial describes the east-west position and the other the north-south location. The selected arbitrary image points mentioned above are used to generate coefficients for each term in the polynomial. The complete set of coefficients defines the mapping from the original image to the correct projected image.

Mapping coefficients are generated by step-wise regression in which the correlation matrix is calculated relating each term to its ability to predict the location of the point in the original image. A regression coefficient is calculated for the most influential term. This term is in turn removed from the matrix and the step regression continued until all terms that contribute predictive capability are included in the coefficient matrix. By utilizing points selected throughout the image file derived mapping coefficients are applicable over the entire pixel range in the corrected image. RMS errors are also calculated by the polynomial generation software for predicted locations in the original image. In the resampling process the correct image line and pixel number is translated to a location in the original image. The nearest neighbor pixel is then copied to the corrected image file.

2.4 RESAMPLING OF THE CZCS MAY 8, 1979 IMAGERY

Using the scanner model software fifty-four ground control points of the May 8, 1979 Great Lakes image file were tested for consistency with model parameters. Results indicated north-south RMS errors of 693 meters and east-west errors of 1338 meters respectively. Based upon existing satellite attitude information the scanner model was used to generate latitude and longitude positions from which the appropriate polynomial coefficients could be derived. The polynomial prediction errors were found to be 55 meters in the north-south direction and 583 meters in the east-west direction. Combining these results leads to an expected total error of 748 meters in the north-south and 1921 meters in the east-west or approximately 1.0 and 2.5 pixels, respectively in the original image. Figure 1 shows the original and resampled images for the Great Lakes portion of the CZCS data file. This area includes all of the lakes except Lake Superior and the upper most portions of Lakes Huron and Michigan which are included in the next CZCS data frame.

Unfortunately portions of Lakes Michigan and Huron are obscured by cloud cover. Lakes Erie and Ontario are essential cloud free with the exception of a thin covering over the western basin of Lake Erie. The resampled image was made using a polyconic projection and an arbitrary pixel size of 500 by 500 meters. So as to verify the accuracy of the corrected image twenty additional ground control points were selected and compared to those predicted by the projection polynomials. Table 1 shows the results of this comparison. The maximum difference occurred for the sixth test point which was found to be 3000 meters in the north-south direction and 7500 meters in the east-west direction. Test pixels located near the center of the original image and principal meridian showed, on the other hand, minimal errors. For example the second test pixel had a north-south error of 500 meters and an east-west error of 2500 meters. The mean error was estimated to be 200 meters in the north-south direction and 1875 meters in the east-west direction. A listing of CZCS geometric correction programs developed for the PDP-11/70 computer facility are contained in Appendix A.

Original CZCS Image

Figure 1a. Original and Polyconic Projected CZCS Thermal Band Images of the Great Lakes for May 8, 1979.

Polyconic Projected Image

Figure 1b. Original and Polyconic Projected CZCS Thermal Band Images of the Great Lakes for May 8, 1979.

TABLE 1

GROUND CONTROL LOCATIONS

Location	Predicted Row	Predicted Column	Actual Row	Actual Column	Difference Row	Difference Column
Toledo, Ohio	1028	1274	1029	1278	1	4
Detroit, Michigan	808	1182	806	1191	-2	9
Detroit, Michigan	843	1122	841	1131	-2	9
Flint, Michigan	692	1381	690	1390	-2	9
Flint, Michigan	688	1163	685	1174	-3	9
Tawas City, Michigan	311	1150	305	1165	-6	15
Cleveland, Ohio	1039	1564	1039	1567	0	3
Erie, Pennsylvania	801	1495	801	1500	0	5
Buffalo, New York	731	1806	731	1808	0	2
Buffalo, New York	865	1827	865	1829	0	2
Toronto, Ontario	646	1788	647	1793	1	5
Toronto, Ontario	658	1895	659	1897	1	2
Toronto, Ontario	563	1804	563	1808	0	4
Elmira, New York	785	2204	786	2203	1	-1
Elmira, New York	715	2308	715	2307	0	-1
Rochester, New York	635	2129	636	2129	1	0
Rochester, New York	462	2290	463	2290	1	0
Kingston, Ontario	438	2103	439	2103	1	0
Kingston, Ontario	365	2321	365	2321	0	0
Kingston, Ontario	419	2222	419	2221	0	-1
			Mean Difference		-0.41	3.75
			Standard Deviation		1.79	4.44

3

USE OF OPTICAL MODELS TO DEVELOP CZCS CHLOROPHYLL AND SUSPENDED SEDIMENT ALGORITHMS

A requirement fundamental to the validation of CZCS for the Great Lakes is the development of a working algorithm which can transform the satellite measured radiances into surface concentrations of chlorophyll and suspended sediment. While the ERIM task defined for current study involves development of water algorithms, these algorithms cannot in our estimation be attempted without some examination of and experimentation with atmospheric components. Thus, while we were able to place emphasis on certain water aspects of algorithm development, our approach has considered radiative transfer in the atmosphere. Our efforts to date have involved extensive use of statistical and model simulation techniques. Attempts to test candidate algorithms on real CZCS data have been limited because very few scenes of the Great Lakes were available and no CZCS tapes which correspond to the 1980 summer experiments are expected until mid 1981.

3.1 APPLICABILITY OF EXISTING ALGORITHMS

The removal of atmospheric effects is a necessary prerequisite for all remote sensing applications. Atmospheric effects are especially important in CZCS data for the following reasons.

1. The large swath width of the CZCS implies a large atmospheric variability due to simple considerations of scale as well as scan angle variations.

2. The inherent radiance of the water is low causing path radiance effects to be relatively more important than over land.

3. The CZCS includes wavelengths in the blue region of the spectrum where atmospheric effects predominate.

The study of atmospheric effects in CZCS data can be broken down into two levels. First, one can attempt to develop and/or validate radiative transfer models by making careful measurements of the relevant atmospheric parameters and of the radiance at the surface, and comparing the radiance measured by the satellite with that calculated from the model. Studies of this kind have been carried out for aircraft data at various altitudes [10] and for CZCS data over the Gulf of Mexico [11]. Aircraft studies have resulted in fairly good agreement between model predictions and measurements, although there is a discrepancy at large angles which is thought to be due to surface reflected skylight [10]. Previous studies with CZCS data have encountered some difficulty in obtaining agreement between model predictions and measurements [11]. One possible explanation for this difficulty is the effect of scattering from adjacent land areas which some studies have indicated to be of the same order of magnitude as the directly scattered path radiance [12]. In its studies ERIM will test existing models with aircraft measurements made during last summer's GLET experiments and with data obtained in the Gulf of Mexico Experiment [11].

A second kind of atmospheric study involves the development of operational algorithms for removing atmospheric effects from CZCS data without the use of an unreasonable number of in situ atmospheric measurements. The primary goal of these studies is to remove the variable component of the atmospheric effect using some property of the data itself to obtain the necessary correction parameters. One such algorithm was developed by Gordon [7] and applied to CZCS data over the Gulf of Mexico [10]. However, the formulation of Gordon's algorithm involves the assumption of zero intrinsic radiance in the 679 mm band which is not met in some parts of the Great Lakes and other coastal areas. Modifications to this algorithm have been made by a group at Scripps Institution of Oceanography for conditions occurring in Pacific coastal waters, but there is some doubt that their assumptions would hold in the Great Lakes. In addition to testing these algorithms, new directions have been pursued in the development of more suitable approaches.

3.2 OPTICAL MODELS AND RADIATIVE TRANSFER THEORY

Most existing algorithms are based upon empirical relationships between constituent concentrations and remotely sensed radiances, and are generally valid for the limited range of environmental conditions under which these relationships were derived. In order to systematically approach the evaluation of existing algorithms or the development of new algorithms, it is necessary to understand the relationships among the observed quantities on a more fundamental level. The study of these relationships is conveniently divided into two phases. The first phase deals with the inherent optical properties of the water aand atmospheric constituents, and the second phase deals with the large-scale radiative transfer processes which relate these inherent optical properties to the radiances measured by the satellite.

3.2.1 OPTICAL MODELS

A full description of the optical properties of a passive (non-emitting) medium include the absorption coefficient and the volume scattering function. For most remote sensing purposes, however, it is not necessary to specify the complete volume scattering function. Commonly two parameters describing the scattering properties are considered: the total scattering coefficient (which is the integral of the volume scattering function over all angles), and the back-scattering coefficient (which is the integral of the volume scattering function over the angular range of 90° to 180° from the incident direction).

It is generally assumed that the inherent optical properties are linear functions of the concentrations of the various constituents of the medium. Thus, for natural bodies of water we can write

$$a = a_w + \sum_{i=1}^{N} \hat{a}_i C_i$$

$$Bb = Bb_w + \sum_{i=1}^{N} \hat{Bb}_i C_i \qquad (1)$$

$$b = b_w + \sum_{i=1}^{N} \hat{b}_i C_i$$

where a_w, Bb_w, and b_w are the absorption, backscattering, and total scattering coefficients of pure water; $\hat{a}_i$, $\hat{Bb}_i$, and $\hat{b}_i$ are the absorption, backscattering, and total scattering cross sections (i.e., the coefficients for unit concentration) of constituent i, and C_i is the concentration of constituent i. These are clearly approximations, since the actual optical properties may depend upon factors other than the concentrations. The scattering properties of suspended particulates, for example, depends upon the size distribution as well as the mass per unit volume. Some preliminary studies of the effect of size distribution are described in section 3.3.

Accepting the linear model for the optical properties described above, there are several possible approaches to the determination of the absorption and scattering cross sections for each constituent. One approach would be to attempt to isolate each constituent and measure the optical properties for different concentrations of that constituent. Isolation can obviously be accomplished more easily with some types of constituents than with others. The danger of this approach is that by artificially changing the sample, the measured conditions might not be representative of naturally occurring waters.

A second approach for determining the optical cross sections is to measure the optical properties and the constituent concentrations of a large number of diverse natural samples, and performing a statistical analysis (i.e., a multiple linear regression) of the results. This approach avoids the possibility of encountering unrealistic conditions, but is subject to biases introduced by natural correlations between various constituents, for example between phytoplankton and sediments associated with phytoplankton nutrients. Examples of this approach include the work of Bukata et al [13] and the preliminary analysis presented in section 3.3 of this report.

It should be pointed out that some of the optical properties, i.e., the scattering cross sections, can be calculated from electromagnetic theory if the size distribution, shapes, and indices of refraction of the particles are known. Although it is instructive to make such calculations in order to determine the sensitivity of the cross sections to the size distribution, for example, there is no particular advantage to the exclusive use of this method since it requires measurements which are at least as difficult as the direct measurement of the optical properties.

3.2.2 RADIATIVE TRANSFER THEORY

The radiance at any point in the ocean/atmospheric system is provided, in principle, by the solution of the radiative transfer equation with the proper boundary conditions and the proper optical properties specified at each point. Unfortunately, an exact solution of this equation is not obtainable in closed form for even the simplest geometry. Two general types of approach are, therefore, possible. The first approach is to develop approximate solutions which give reasonably accurate results over the range of conditions encountered. The advantage of this approach is that results can be obtained at a relatively low cost, and that considerable insight can be gained by merely examining the functional form of the solutions.

The alternative approach is to develop exact numerical solutions of the radiative transfer equation. Several types of numerical solutions exist, perhaps the most prominent for this application being the Matrix Operator and Monte Carlo methods. The Monte Carlo method is especially powerful because of its ability to incorporate complex boundary conditions (e.g., at the water surface) and spatially variable optical properties. The advantage of the numerical approach is, of course, the accuracy of the results. The disadvantages are the cost of obtaining these results and the fact that insight can be gained into the nature of the solutions only by examining a large number of cases with different input parameters.

The preliminary modeling work done on this project has involved a combination of the approaches described above. For the purpose of formulating candidate algorithms it has been useful to consider a simplified model in which the water radiance is calculated using Gordon's Power Series Approximation, and the atmospheric effects are described by a model which assumes constant transmittance and a path radiance which is a linear function of the aerosol optical depth. According to this model, the radiance at the satellite is given by

$$L = L_p(\tau_a) + TE\rho_w(x) \qquad (2)$$

where

$L_p(\tau_a)$ = path radiance (assumed to be a linear function of the aerosol optical depth τ_a)

T = atmospheric transmittance (assumed constant)

E = irradiance at water surface (assumed constant)

$$\rho_w(x) = \frac{T_{w1} T_{w2} x}{2\pi n^2 (\mu + \mu_o)}$$

$$x = \frac{Bb}{a + Bb}$$ (c.f. previous definitions of a and b in text)

T_{w1}, T_{w2} = water surface transmittance for incoming and outgoing light

μ_o, μ = cosine of solar zenith angle and observation angle, respectively

n = index of refraction of water

The algorithms developed using this model are described in sections 3.4 of this report. For the purpose of evaluating these and other algorithms, a more comprehensive simulation model was also developed. This model incorporates the Monte Carlo calculations of the subsurface water reflectance using the following power series expansion [14]

$$\rho_w(x) = \frac{T_{w1}\, T_{w2}}{\pi\, n^2}\,[.0001 + .3244x + .1425x^2 + .1308x^3]$$

where x is defined as previously. Atmospheric effects are calculated using the QSS model for the path radiance, and the double-delta model [11] for the irradiance and sky radiance. The surface-reflected sky radiance is included, assuming a nominal surface reflectance of 2.0 percent. The atmospheric state is described in terms of the horizontal visibility using the relationships developed by Elterman [15] to calculate the optical depth. The results of this simulation model are presented in section 3.5 of this report.

3.3 PRELIMINARY ANALYSIS OF OPTICAL PROPERTIES FOR THE GREAT LAKES

During late July 1980 twenty-one individual samples gathered by LeRC were analyzed by the NASA/Langley research Center (LaRC) portable laboratory stationed at the LeRC flight facility. Samples were flown in on the same day as collection and usually received by the LaRC staff within four hours for analysis. Underwater optical properties were measured in vitro with identical spectral range (400-800 nm) and intervals (50 nm). These properties included absorption, beam attenuation, and volume scattering. Three separate instruments were used to measure these parameters, (1) a combination beam attenuation and small angle scattering meter (SASM, θ = 0.379, 0.751, 1.49°) developed by LaRC and patterned after the Scripps Institution of Oceanography ALSCAT instrument; (2) a Brice Phoenix (BP) scattering meter modified to accommodate large angle measurements (25° $\leq \theta \leq$ 155°); and (3) the LaRC spectral absorption coefficient instrument (SPACI) [16]. Standard errors for these instruments are reported to be as follows: (1) for the SASM less than 5% α, and less than 12% $\beta(\theta)$; and (3) for the SPACI less than 10% a.

The optical measurements made by LaRC during the 1980 summer experiments were for lake samples. In this case the measured optical properties pertain to the particular mix of constituents in the lake sample. If sufficient number of measurements are made in this manner and if the principal constituents present are known then multiple regression techniques can be used to derive the optical cross sections for a common constituent. While the present data are considered limited for this purpose a preliminary set of optical properties were derived for the Great Lakes.

Of the twenty-one optical data sets taken, three Lake Erie samples contained sufficient quantities of sediment to saturate the optical measurement instruments. Samples collected from Green Bay in Lake Michigan and from Western Lake Superior were found to have distinctive local optical properties. Four of the six samples collected from the Grand Haven area were essentially sediment-free and the presence of very low concentrations of phytoplankton made absorption measurements difficult. Attempts to include these samples in the regression analysis have so far not been productive.

The best regression results were obtained when nine samples from Lake Erie were combined with two samples from Lake Michigan. Several regression models were formulated and tested against the above selected optical measurement sets. These models were based upon the available surface truth sampling data which included Secchi depth, surface temperature, chlorophyll-a pigment, phaeophytins, and residue (total, ashed, and volatile) [17]. Of these parameters chlorophyll-a, chlorophyll-a plus phaeophytins, total residue and ashed residue were selected for regression. Each of the candidate models contained two components and a constant which includes absorption or scattering for pure water. Models involving ashed residue produced generally better statistics than those with total residue. Each regression model consists of four equations pertaining to the backscatter cross section. In each case the four equations correspond to four CZCS wavelengths (443, 520, 550, 670 nm). The optical model considered for these analyses describes the surface water mass to be a combination of pure water (w), unique organics as represented by chlorophyll-a (chl) and phaeophytin (pp) concentration and unique inorganics as represented by the measurement of suspended minerals (sm). The two component model equations are written as

$$a(\lambda) = a_w(\lambda) + xa_{chl}(\lambda) + ya_{sm}(\lambda) + \text{constant } a(\lambda)$$

$$Bb(\lambda) = Bb_w(\lambda) + xBb_{CHL}(\lambda) + yBb_{sm}(\lambda) + \text{constant } Bb(\lambda)$$

where x and y are the concentrations of chlorophyll a and suspended minerals (ashed weight) respectively, and a and Bb are the absorption and backscatter cross sections.

Optical cross sections as derived from these regression analyses are given in Table 2. These optical cross sections are the only such data available, to our knowledge for the Great Lakes. Note that the a_w or Bb_w are included in the constant term given for each analysis. As shown in Table 2, two preliminary optical models were derived based upon chlorophyll-a and chlorophyll + phaeophytin concentrations, respectively. Also shown for comparison are values of four and five component Lake Ontario models [18] which were derived indirectly from apparent rather than inherent optical measurements. The four component model included chlorophyll, suspended sediment, pure water, and dissolved organics. The five component model has an additional term for non living organics which includes detritus. The dissolved organics term accounts for the presence of yellow substance which was found in the Ontario study to be about 2 mg/ℓ and fairly constant throughout the

TABLE 2

OPTICAL CROSS SECTIONS FOR GREAT LAKES WATER QUALITY MODELS

(1) Great Lakes 1980 Preliminary Models

Model 1a	Wavelength (nm)	$a_{CHL}(m^2/mg)$	$a_{sm}(m^2/g)$	Constants	Multiple Regression Coefficient
	443	.01620	.0764	.3088	.961
	520	.00836	.0636	.2484	.952
	550	.00529	.0577	.3034	.945
	670	.00450	.0556	.3897	.942
		$Bb_{CHL}(m^2/mg)$	$Bb_{sm}(m^2/g)$		
	443	.000152	.0312	.0424	.900
	520	.000372	.0284	.0370	.911
	550	.000469	.0287	.0232	.911
	670	.000428	.0250	.0197	.913
Model 1b		$a_{CHL+pp}(m^2/mg)$	$a_{sm}(m^2/g)$		
	443	.01142	.07290	.3794	.970
	520	.00599	.06178	.2813	.963
	550	.00384	.05658	.3220	.954
	670	.00323	.05468	.4072	.947
		$Bb_{CHL+pp}(m^2/mg)$	$a_{sm}(m^2/g)$		
	443	.000043	.03117	.04590	.890
	520	.000213	.02832	.0408	.910
	550	.000273	.02856	.0277	.910
	670	.000254	.02490	.0237	.912

(2) Lake Ontario Five Component Model

	$a_{CHL}(m^2/mg)$	$a_{sm}(m^2/g)$	Constant
443	.0354	.0557	.020
520	.0240	.0281	.028
550	.0173	.0185	.037
670	.0100	.0225	.370

	Bb_{CHL} (m^2/mg)	Bb_{sm} (m^2/g)	Constant
443	.00199	.0328	0
520	.00182	.0474	0
550	.00241	.0525	0
670	.00175	.0333	0

(3) Lake Ontario Four Component Model

	a_{CHL} (m^2/mg)	a_{sm} (m^2/g)	Constant
443	.0343	.0557	.185
520	.0232	.0281	.119
550	.0173	.0185	.122
670	.0105	.0225	.388

	Bb_{CHL} (m^2/mg)	Bb_{sm} (m^2/g)	Constant
443	.00163	.0328	.0010
520	.00153	.0474	-.0058
550	.00202	.0525	-.0099
670	.00156	.0333	-.0080

lake. Since for the present study no effort was made to analyze the samples for a non-living organics or dissolved organics term they were not included in our preliminary model except as part of the constant term.

The absorption cross sections as derived from the 1980 optical measurement sets are for chlorophyll, about half of those derived for the Lake Ontario models. Derived chlorophyll backscatter coefficients were found to be only one tenth of those obtained by the Lake Ontario study. Chlorophyll absorption and scattering cross sections as obtained by regression are considerably less than those reported elsewhere in the literature [17]. On the other hand, derived optical cross sections for the suspended sediment are comparable to the Lake Ontario values.

All of the above models have utilized phaeophytin free chlorophyll determinations. Since chlorophyll and phaeophytins have similar absorption properties they cannot be readily distinguished by CZCS. Therefore, it seemed appropriate to combine these determinations in the above regression analyses and determine cross sections for chlorophyll plus phaeophytin. The resulting cross sections as given in Table 2 model 1b are smaller for the chlorophyll term and larger for the constant term than in the phaeophytin free analysis of model 1a. Since the direction of these changes are opposite to our expectations, additional investigation into the optical properties of phaeophytins is warranted.

In addition to the statistical analyses of the collected samples described above a brief investigation was made of an indirect technique for measuring scattering and absorption properties of suspended sediment in Lake Erie. The approach involved making a series of physical and optical measurements on a single turbid water sample at various time intervals. A portion of the suspended sediment was allowed to settle out between each measurement. Optical parameters measured by the LaRC portable laboratory included the beam attenuation coefficient and the volume scattering function at 90°. Both of these measurements were made at a single wavelength of 550 nm. Physical measurements included the particle size distribution (using a Coultor counter) and the total suspended solids concentration. There were two objectives to these measurements. First the change in suspended solids concentration could be related to the corresponding change in the optical properties from which optical cross sections could be obtained. Second, Mie particle scattering theory could be used to calculate the same optical properties based upon the change in particle size distribution. Unfortunately, the total suspended solids measurements were found to be unreliable, either because of sampling or measurement errors, and were not included in the analysis. The optical measurements are summarized in Table 3, and the particle size measurements are shown in Figure 2 (panel a). It should be noted that Coulter counter measurements are difficult and subject to considerable error in the particle size range necessary for studies of this kind.

Because of the unreliability of the total suspended solids measurements, it was not possible to derive the optical cross sections directly from this set of measurements. Instead, the data set was used to test the feasibility of the approach of calculating the optical properties with Mie scattering theory. Of course, these calculations also requires a knowledge of the index of refraction of the particles. Since no measurements of the index of refraction were made, an average value of 1.1 was assumed. The extinction efficiency was calculated from the Mie theory using J.V. Dave's algorithm [19] for particle diameters between 1.0 and 25.4 μm. The portion of the total extinction coefficient arising from this particle size range was then obtained for each sample by multiplying by the size distribution function and integrating (summing) over this range. For particle diameters less than 1 micron, the extinction efficiency was calculated using Van de Hulst's approximation [20].

$$Q_{ext} = 2 - \frac{4}{\rho} \sin \rho + \frac{4}{\rho^2} (1 - \cos \rho) \tag{6}$$

TABLE 3

OPTICAL MEASUREMENTS MADE DURING SETTLING EXPERIMENT

Sample	Settling Time (hrs)	α(550 nm)	β(90°, 550 nm)
1	0	23.7 m^{-1}	0.1380 m^{-1} sr^{-1}
2	1.5	19.3 m^{-1}	---
3	19.0	8.7 m^{-1}	0.0685 m^{-1} sr^{-1}
4	23.5	7.0 m^{-1}	0.0617 m^{-1} sr^{-1}
5	40.0	4.5 m^{-1}	0.0319 m^{-1} sr^{-1}

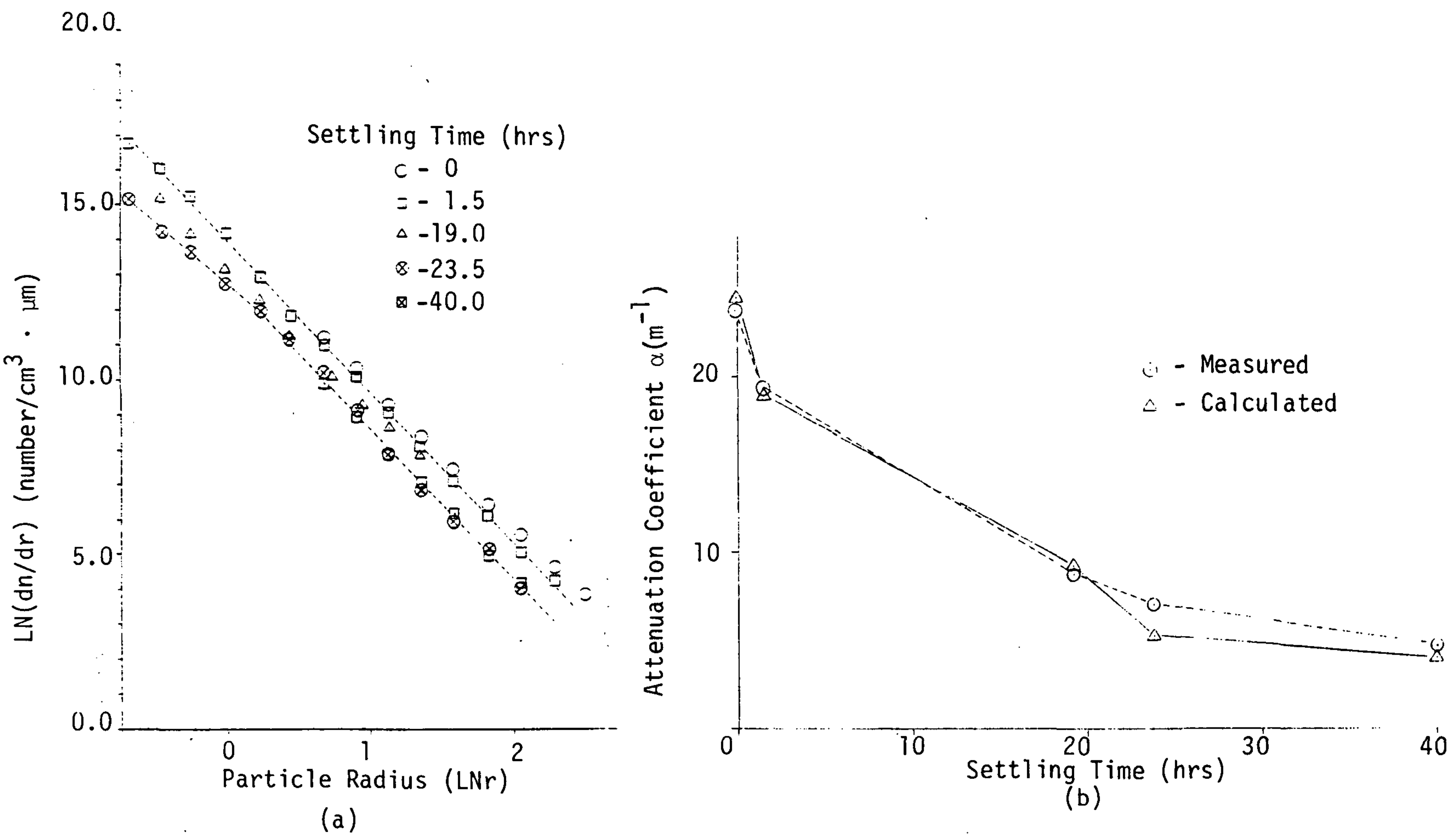

FIGURE 2. RESULTS FROM THE LAKE ERIE SETTLING EXPERIMENT. Panel (a) shows the particle size distribution measured at selected time intervals. Panel (b) compares measured attenuation coefficient with that calculated from the particle size distribution based upon Mie scattering theory.

where

$$\rho = \frac{4\pi(n-1)r}{\lambda}$$

(n is the index of refraction and λ is the wavelength). The contribution to the total extinction coefficient from particles less than 1 micron in diameter is than given by

$$\sigma'_{ext} = \int \pi r^2 \, Q_{ext}\left(\frac{dn}{dr}\right) dr \qquad (7)$$

For this particle size range, the size distribution was assumed to have the form

$$\frac{dn}{dr} = cr^{-4} \qquad (8)$$

where c is chosen to fit the measurement of r = 0.5 μm. The extinction coefficients calculated from this procedure are shown in Table 4, and are compared with the measured extinction coefficients in Figure 2 (panel b). In view of all the uncertainties and assumption required to make these calculations the agreement shown is surprisingly good. While these results are obviously insufficient to validate the approach they do suggest that further controlled studies of this type would be beneficial. If a technique could be derived for universal Coulter Counter measurements instead of the present elaborate and not readily available optical measurements the overall benefits of the present program would be substantial.

3.4 DISCUSSION OF ATMOSPHERIC EFFECTS AND CORRECTIONS

A necessary preliminary step before attempting to extract any information about the water itself is to remove the effects of atmospheric variations from the measured radiances. Atmospheric effects are

TABLE 4

EXTINCTION COEFFICIENTS CALCULATED FROM MIE SCATTERING THEORY

Sample	Contribution From $r < 0.5\ \mu m$	Contribution From $r > 0.5\ \mu m$	Total $_{ext}(m^{-1})$
1	7.2	18.3	25.5
2	4.8	14.1	18.9
3	2.5	6.7	9.2
4	1.0	4.3	5.3
5	0.7	3.2	3.9

particularly important in CZCS data because of the large swath width and the band placement. The development of radiative transfer models for the atmosphere is an important step in understanding this problem, but ultimately the goal must be to remove the atmospheric effects on a point-by-point basis with the aid of only a very limited number of external measurements.

The first attempt to formulate such an atmospheric correction algorithm for CZCS data was made by Gordon [7]. This algorithm is based upon the assumption that the total radiance in a suitable wavelength band may be interpreted as an index of the atmospheric state (i.e., the aerosol optical depth) and thus used to correct the atmospheric effects in the other bands. In this formulation it is assumed that the water radiance in the 670 nm band is zero or negligible compared to the path radiance, an assumption which is valid in clear ocean waters but is frequently violated in more turbid coastal waters, including the Great Lakes. In fact, our modeling study has shown the 670 nm band displays the greatest sensitivity to sediment concentration. Therefore, although the algorithm gives apparently good results in ocean areas [1] it cannot be applied directly to the Great Lakes.

The assumptions about the atmosphere in Gordon's algorithm seem to be valid for a reasonably wide range of atmospheric variations. These assumptions are essentially the same as those listed for the simplified model described in section 3.2, namely: (1) the path radiances in the various wavelength bands are linearly related to each other, and (2) the atmospheric transmittance changes relatively slowly and may be assumed constant. Under these assumptions one can define a large class of linear combinations.

$$X_i = \sum_{j=1}^{N} A_{ij} L_j \qquad (9)$$

which are independent of atmospheric variations. Gordon's algorithm is one member of this class, but is not necessarily the optimum one. The condition for the X_i's to be independent of atmospheric variations can be written as

$$\sum_{j=1}^{N} A_{ij} \frac{\partial L_{pj}}{\partial \tau_a} = \sum_{j=1}^{N} A_{ij} A_j' = 0 \qquad (10)$$

where i=1...N-1, L_{pj} is the path radiance in band j and τ_a is the aerosol optical depth. The coefficients A_{ij} may be interpreted as components of the vector $\vec{A}_i$, and the above condition viewed as the requirement that these vectors be perpendicular to the vector

$$A_N = (A_1', A_2', \ldots, A_N') \qquad (11)$$

If we require in addition that the vectors $\vec{A}_1 \ldots \vec{A}_{N-1}$ be orthonormal, i.e.,

$$\vec{A}_i \cdot \vec{A}_j = \begin{matrix} 0, & i \neq j \\ 1, & i = j \end{matrix} \qquad (12)$$

then the transformation (9) has the properties of a projection onto a hyperplane perpendicular to $\vec{A}_N$, and the projected variables are linearly independent of each other. Although this would seem to be a desirable condition, the actual benefits of this procedure, as opposed to Gordon's procedure for example (which does not satisfy equation (12), have not yet been demonstrated. Work has begun on the evaluation of this procedure using the simulation model described in section 3.2, but a full comparison with Gordon's algorithm has not yet been completed.

It should be noted that the direction of the vector A_N can be determined empirically from the CZCS data itself, if an area of variable haze over a uniform water background can be located in the image. The direction cosines are obtained readily by a principal components analysis of the radiances observed over such an area.

As discussed previously in section 3.2 the signal variants due to spatial changes in the aerosol content (haze) are linear. As discussed by Gordon in his correction method the aerosol contribution at one wavelength is approximately proportional to the other wavelengths. In CZCS four channel signal space,atmospheric variation is visualized as a vector oriented by these proportions and offset from the origin by the presence of water constituents and atmospheric transmittance effects. By comparison the water variants represent separate orientations for each constituent and generally much smaller than the atmospheric haze vector. Thus for open clear waters of the Great Lakes the observed variations are due essentially to atmospheric haze and system noise.

In order to explore the haze phenomenon several segments from two available CZCS images were examined. Each segment (200-1000 pixels) was first scaled to radiance and then analyzed for principal components. Two available CZCS scenes were selected for analysis: Great Lakes May 8, 1979 and Gulf of Mexico, November 9, 1978. Results of these analyses are shown in Table 5. Also shown is the principal component for atmospheric variation as derived from simulations using the preliminary atmospheric model discussed in section 3.2. Atmospheric vectors derived by this analysis show strong similarity in orientation. Differences in orientation are likely due to cloud effects and variations in water constituents. Radiometric changes due to scan angle effect may also account for some of the observed differences. Excellent agreement (1.1°) was found between the combination of Lake Huron data sets and the theoretical orientation of the haze vector. In general, the orientation of the haze vector for the Gulf of Mexico data sets were similar to those for Lake Huron but with less consistency and lower accounting of the percent of total variance. Clouds and variation of chlorophyll and suspended materials could possibly account for the observed variability in principal components.

TABLE 5

FIRST PRINCIPAL COMPONENTS DERIVED FROM
CZCS SATELLITE MEASURED RADIANCES

Sample Location	First Principal Component	Percent of Total Variance
Georgian Bay, Lake Huron (1)	(.563, .539, .543, .313)	94.8%
Georgian Bay, Lake Huron (2)	(.440, .499, .565, .488)	94.2
Southern Lake Huron	(.435, .577, .594, .355)	95.4
Combination Set, Lake Huron	(.426, .5520, .547, .500)	95.5
Gulf of Mexico (2)	(.596, .580, .467, .298)	98.3
Gulf of Mexico (3)	(.487, .548, .538, .416)	94.8
Gulf of Mexico (4)	(.559, .597, .465, .339)	91.7
Gulf of Mexico (5)	(.604, .679, .330, .256)	85.1
Combination Set, Gulf of Mexico	(.521, .579, .518, .353)	87.4
Atmospheric Model	(.426, .510, .524, .533)	100.0

CZCS Imagery

Lake Huron: May 8, 1979 Orbit 2715

Gulf of Mexico: November 9, 1978 Orbit 227

An analysis was made to observe if the haze vector was present and significant in apparent low haze area. Several samples were selected in the May 8 image from a test area south of Nova Scotia in the open ocean and at least 160 kilometers from the US mainland. The image appeared to be free of haze. Nevertheless the haze vector appeared as the principal component in each sample and subsample and with as few as fifteen pixels. These analyses further demonstrate the need to account for the atmospheric variants even under the clearest of conditions.

3.5 PRELIMINARY CZCS WATER ALGORITHMS

The atmospheric, interface, and subsurface water reflectance models discussed in section 3.2 were used to calculate expected satellite radiances for a variety of water masses at each of the CZCS wavelengths. The primary input for these calculations were the optical cross section data as described per the three optical models in section 3.3. Different water masses were simulated by varying the concentrations of chlorophyll and suspended mineral concentrations. In the case of the Lake Ontario five component model the level of non-living detrital material was taken as 2.0 mg/ℓ and dissolved organics at 2.5 mg/ℓ. These levels are similar to those measured in the Lake Ontario study [13]. Presently we have no measurement data to support the representativeness of these values to Lakes Erie or Michigan.

Having made these assumptions the subsurface irradiance reflectance can be readily calculated for each CZCS band (443, 520, 550, 670 nm) as a function of the concentration of chlorophyll and suspended minerals. The spectral characteristics of the irradiance reflectance function can be depicted with iso-concentration curves for each pair of wavelengths. Figures 3, 4, and 5 show calculated subsurface reflectance for each of the two Lake Ontario models and the preliminary 1980 optical model, respectively. Each of the four panels of each figure has nine curves of increasing suspended mineral concentration and constant value of chlorophyll pigment concentration (0.0, 1.0, 2.0, 5.0 10.0, 20.0, 50.0,

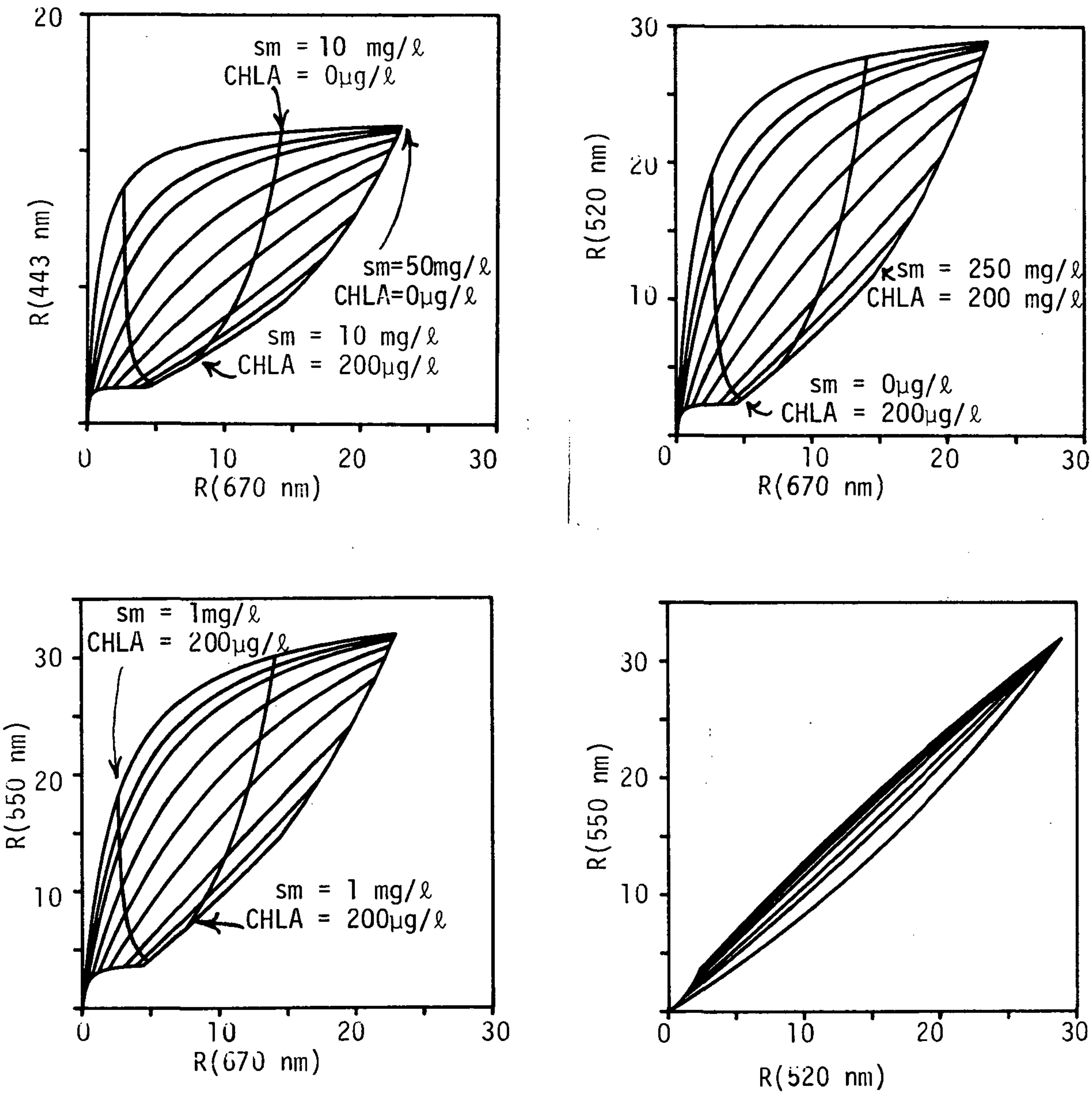

Figure 3. Subsurface reflectance (percent) at CZCS wavelengths (443 nm, 520 nm, 550 nm, 670 nm) as predicted by the Lake Ontario 5-component model [18]. Each figure has nine parametric curves of increasing suspended mineral concentration (0.0-50.0 mg/ℓ) with constant values of chlorophyll pigment concentration (0.0, 1.0, 2.0, 5.0, 10.0, 20.0, 50.0, 100, 200 μg/ℓ). Each figure also contains four parametric curves of increasing chlorophyll a (0.0-200.0μg/ℓ) at constant values of suspended mineral concentration (0.0, 1.0, 10.0, 50.0 mg/ℓ).

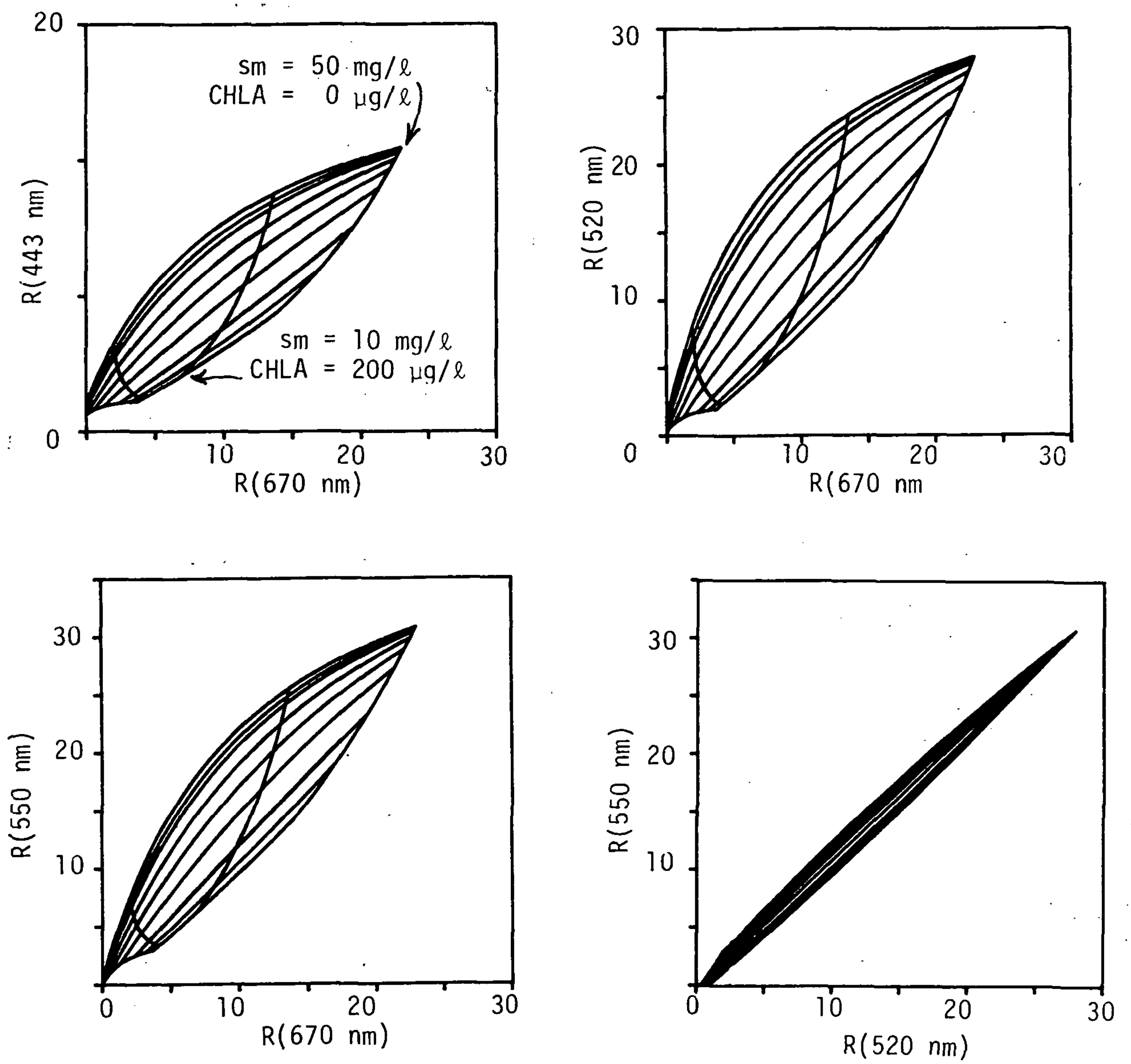

Figure 4. Subsurface reflectance (percent) at CZCS wavelengths (443 nm, 520 nm, 550 nm, 670 nm) as predicted by the Lake Ontario 4-component model [18]. Each figure has nine parametric curves of increasing suspended mineral concentration (0.0-50.0 mg/ℓ) with constant values of chlorophyll pigment concentration (0.0, 1.0, 2.0, 5.0, 10.0, 20,0, 50.0, 100, 200 μg/ℓ). Each figure also contains four parametric curves of increasing chlorophyll a (0.0-200.0 μg/ℓ) at constant values of suspended mineral concentration (0.0, 1.0, 10.0, 50.0 mg/ℓ).

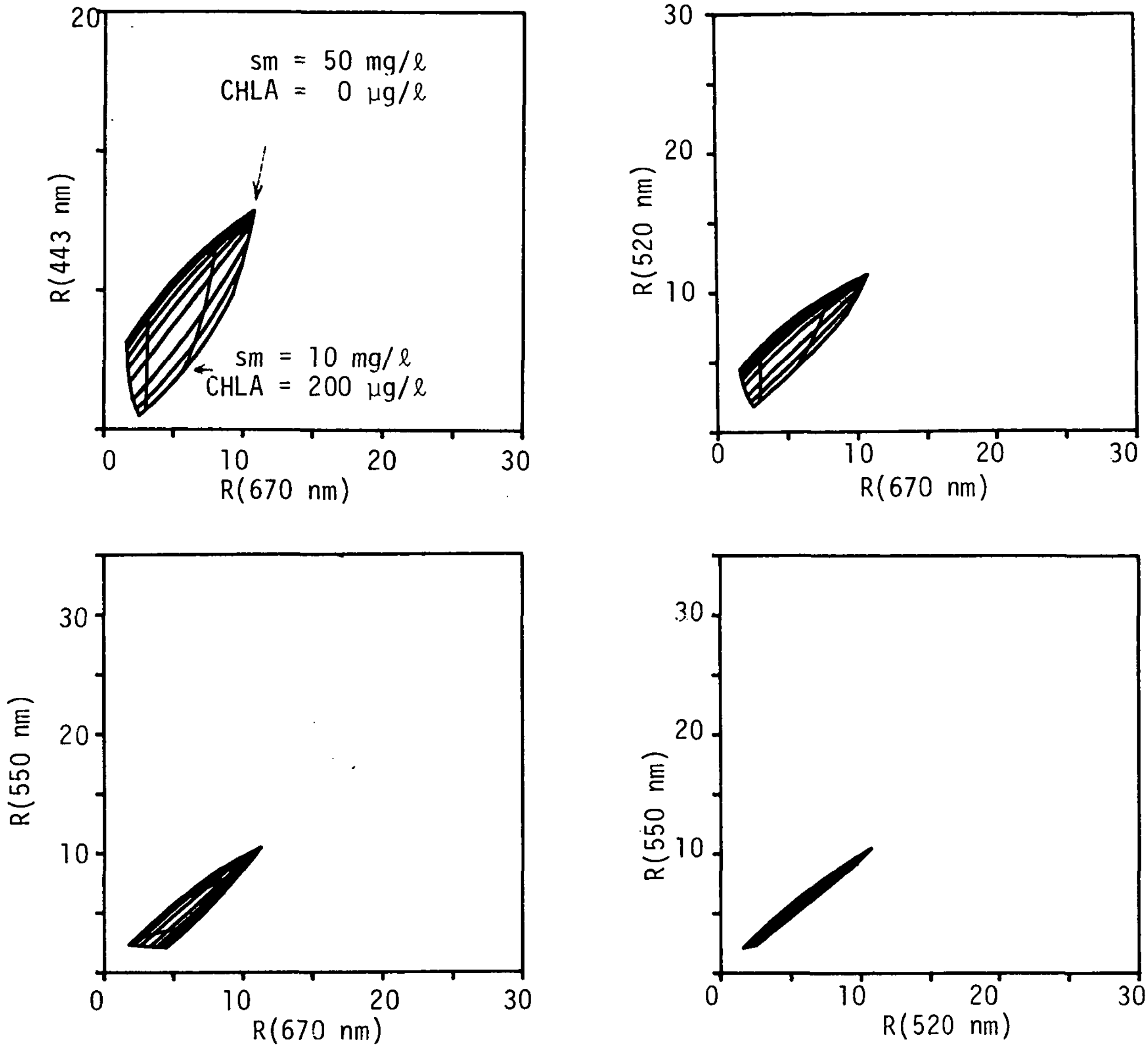

Figure 5. Subsurface reflectance (percent) at CZCS wavelengths (443 nm, 520 nm, 550 nm, 670 nm) as predicted by the Preliminary 1980 Optical Model. Each figure has nine parametric curves of increasing suspended mineral concentration (0.0-50.0 mg/ℓ) with constant values of chlorophyll pigment concentration (0.0, 1.0, 2.0, 5.0, 10.0, 20.0, 50.0, 100, 200 μg/ℓ). Each figure also contains four parametric curves of increasing chlorophyll a (0.0-200.0 μg/ℓ) at constant values of suspended mineral concentration (0.0, 1.0, 10.0, 50.0 mg/ℓ).

100, and 200 μg/ℓ). These curves tend to converge to a point beyond the calculated range. One could refer to this ideal point as the "point of all sediment". Each figure also contains four curves of increasing chlorophyll with constant values of sediment (0.0, 1.0, 10.0, and 50.0 mg/ℓ). These latter iso-concentration curves tend to converge in several of the panels to a point on the 670 nm axis. This ideal could be referred to as the "point of all chlorophyll". Each panel of these figures is a projection and together suggest the reflectance space is a three dimensional hyperplane and nearly perpendicular to the R(550)/R(520) plane.

For the five component Lake Ontario model the constant optical cross sections are very small relative to those for chlorophyll and sediment. As a result the sensitivity of reflectance to changes in concentration is large. By comparison the Lake Ontario four component model has slightly smaller cross sections and a larger constant term. Consequently the panel figures are slightly smaller. The effect of the relatively small optical cross sections of the preliminary 1980 optical model with a large constant term is shown by the small magnitudes of change in each panel of Figure 5. The difficulties of using this latter optical model to predict concentrations is apparent. The above figures also show generally that reflectance is more sensitive to changes in sediment (as mg/ℓ) than chlorophyll (as μg/ℓ) which is consistent with their relative optical cross sections.

As discussed in the previous section, the spectral changes observed in CZCS data due to chlorophyll and sediment will be influenced by the presence of atmospheric variants. A principal component analysis of pure chlorophyll and sediment data indicated spectral orientation with angular separations from the pure atmospheric vector of 26.1° and 18.7°, respectively. Thus it seems apparent that the atmospheric variants are indeed coupled to those we wish to determine in the water. Unless there is some way to separate the atmospheric and water components by spatial filtering it seems appropriate to remove this influence by projecting these reflectance data along the atmospheric vector. This projection reduces the four dimensional reflectance space to one of three dimensions which is free of any atmospheric influence. Figure 6 shows the projected space for each of the three optical models under consideration. The panel figures on the right are nearly a planer view of the depicted leaf like projected structure. Thus corresponding projected axis hold promise for decifering the water components. Since there are an infinite set of transformations which will project the four dimensional reflectance space into three dimensions the panel figures shown can be rotated to any orientation. This feature may provide a means to later optimize candidate algorithms.

Thus far our efforts to obtain chlorophyll and sediment algorithms have utilized the above projection technique. Using non-linear regression techniques algorithm prediction equations were derived as third order, second degree polynomials with nine terms. These equations have the following form:

$$f(conc) = C_1(R_1')^2 + C_2(R_2')^2 + C_3(R_3')^2 + C_4(R_1',R_2') + C_5(R_1',R_3') + C_6(R_2',R_3') + C_7 R_1' + C_8 R_2' + C_9 R_3' + C_{10} \quad (13)$$

where the R's refer to the three axis of projection and the C's are the multiple regression coefficients.

Using the model described in section 3.2 and the optical properties of Table 2 data sets of simulated CZCS radiances were generated for water quality conditions similar to those that exist in the Great Lakes. Several simulation data sets were generated for each model. These included each of the following types:

(1) Variable chlorophyll, fixed sediment, fixed haze, zero system noise;

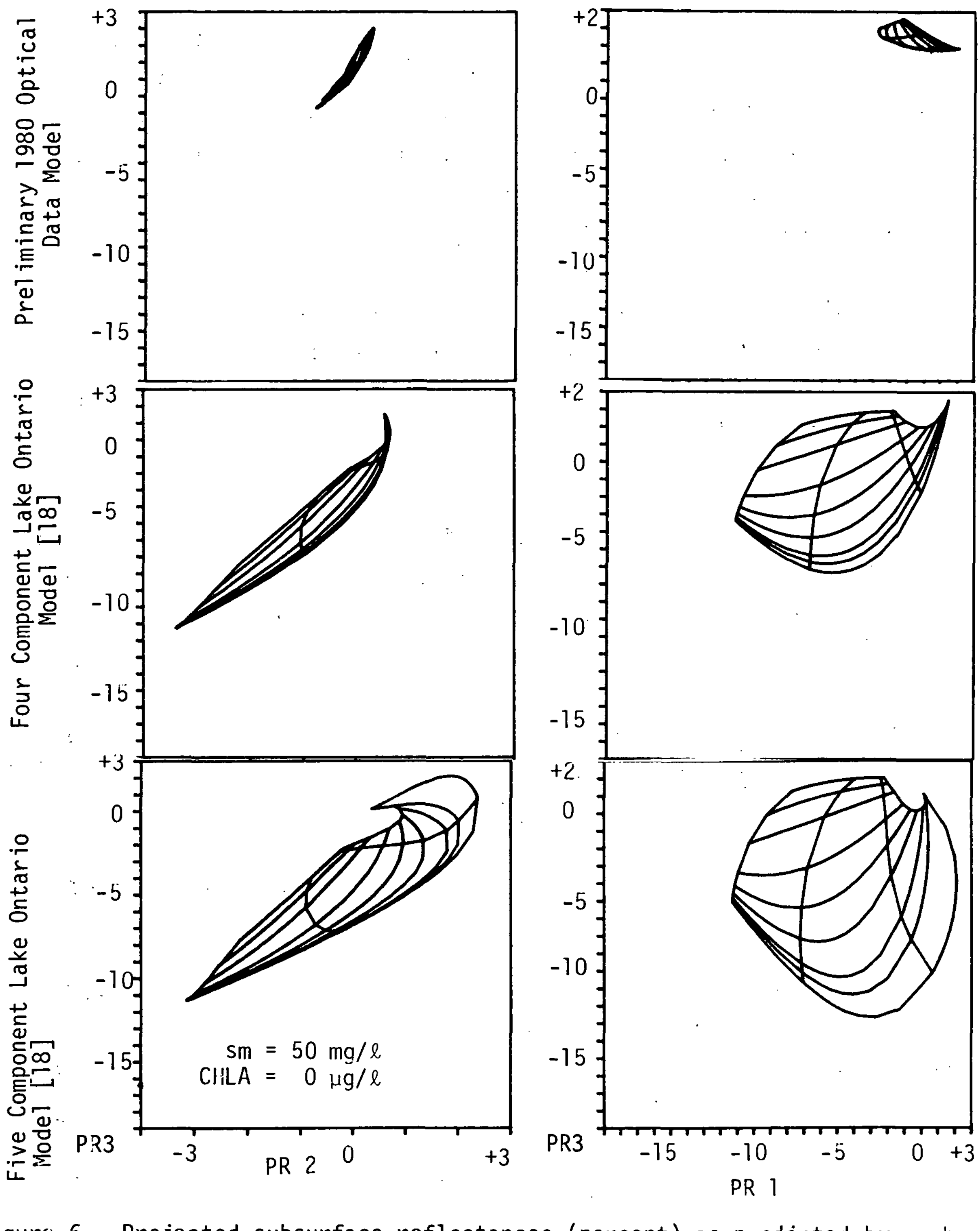

Figure 6. Projected subsurface reflectances (percent) as predicted by each of the above reflectance models. Projected variables are linear combinations of the corresponding predicted CZCS reflectances as shown in Figures 3, 4, and 5.

(2) Fixed chlorophyll, variable sediment, fixed haze, zero system noise;

(3) Variable chlorophyll, variable sediment, variable haze condition, standard system noise level.

The simulations included the effects of system noise by adding a normally distributed random variable with standard deviation equal to the mean radiance divided by the signal-to-noise ratio. The signal-to-noise ratio used were those reported by Gordon for CZCS [1]. The preliminary algorithms derived from these simulation data sets use as a first step the atmospheric projection procedure described in section 3.4. The orientation of the atmospheric vector was that given in Table 5. Data set (1) as described above was then used to derive a prediction function of the form given in equation (13). Similarly data set (2) was used to derive a corresponding equation for sediment. The third type of data sets (3) were used subsequently to test performance of the derived prediction equations.

Results of these analyses are summarized as follows:

1. Sediment equations for the Lake Ontario models were able to predict sediment concentrations under conditions of variable haze and system noise to within approximately 50% over wide ranges of concentrations (1 to 20 mg/ℓ) and to within 30% over narrow ranges (1 to 5 mg/ℓ).

2. The sediment equation for the preliminary 1980 optical model were able to predict sediment concentration to less than 50% only after the signal-to-noise ratio was doubled.

3. None of the regression equations for chlorophyll were capable of predicting chlorophyll to within 50% under standard system noise conditions. When the noise was reduced by four times the

Lake Ontario optical model predictions fell within the 50% error range. The presence of sediment, as might be expected, was found to have a deteriorating effect on the prediction algorithms for chlorophyll.

4. Satisfactory results were obtained with the preliminary 1980 optical model only when the presence of sediment was reduced to very small quantities (<< 1 mg/ℓ) and the system noise was virtually eliminated.

While we are encouraged by these simulation results additional investigations of this type will be needed under Phase II in order to produce satisfactory algorithms. The simulation techniques developed in the present study will become a powerful analytical tool for investigating and evaluating the applicability of Phase II CZCS algorithms to the Great Lakes.

Attempts to apply derived chlorophyll and sediment algorithms to Great Lakes CZCS data sets were not viable because of the lack of surface truth. However, some preliminary analysis was performed on the May 8, 1979 scene. The derived atmospheric vector compared well with that obtained from the atmospheric model as discussed in the previous section.

The processing portions of the final algorithm is anticipated to be able to classify the image and separate it into a land and water file. The water file, which will contain the surface area of the Great Lakes, will be then radiometrically calibrated in the first four bands. In turn, the water file will be transformed to one suitable for constituent determinations by projecting the data along the atmospheric vector. Applying the sediment and chlorophyll prediction equations to the projected file will produce the desired pixel by pixel concentrations maps. These concentration data files would then be recombined in the computer with the land mass file to produce a final map product.

A first attempt at performing some of these manipulations was made for the May 8, 1979 scene. While complete processing was beyond the scope of the present program phase we were able to separate the image into land and water files, color slice the water file, and recombine the separated image as shown in Figure 7.

FIGURE 7. GREAT LAKES CZCS IMAGE FOR MAY 8, 1979 RECONSTRUCTED FROM WATER AND LAND FILES. In this image the water is represented by a CZCS band 4 (670 nm) level slice depicting sediment concentration. The land area is shown as continuous grey tone image of band 5 (750 nm). It should be noted that the original image was color coded and, therefore, the dark areas of the lakes as seen above do not accurately represent the quantity of sediment present.

4

SUMMARY AND CONCLUSIONS

Much of the work accomplished to date is preliminary to the validation of CZCS in the Great Lakes. During the first phase of an anticipated two phase program, efforts were initiated and directed toward development of the necessary algorithms and supporting processing software which will allow the transformation of CZCS images of the Great Lakes into maps depicting concentrations of chlorophyll-a and sediment. The second phase will involve analyses of the CZCS imagery and surface truth measurements collected during the 1980 summer experiments.

Preliminary examination of existing CZCS atmospheric correction algorithms developed by NOAA for the open ocean indicates that the assumptions required are not valid for much of the Great Lakes area. Work has begun on the development of new atmospheric correction algorithms which are appropriate to the Great Lakes. While these algorithms appear to be promising, they have not as yet been thoroughly tested with actual CZCS data.

A preliminary optical model was derived from the LaRC optical measurements made for Great Lakes waters. Derived chlorophyll-a cross sections were found to be less than those reported with the Lake Ontario models [18] and elsewhere in the literature.

Efforts to derive chlorophyll and suspended sediment algorithms were based upon simulations of the preliminary optical model and the Lake Ontario models. Simulations included system noise and atmospheric variants as calculated using existing models. Multiple non-linear regression techniques were used to derive water quality prediction equations from Great Lakes CZCS simulation data. While results produced are encouraging they are thus far incomplete because of the lack of sufficient optical data and appropriate CZCS images. Suspended sediment algorithms were found to be able to predict sediment concentrations with single pixel accuracy to within 50% of the true value over the range (1-20 mg/ℓ) for all optical models under consideration. Chlorophyll on the other hand was found to be more difficult to predict because of its smaller optical cross section. A 50% prediction accuracy could only be obtained after substantial reduction was made to the system signal to noise ratios. Furthermore this improvement was only realized with the Lake Ontario optical models. Satisfactory chlorophyll predictions could not be obtained using the preliminary optical model for the Great Lakes. This result was anticipated in part since the derived chlorophyll optical cross sections were much smaller than expected.

A second activity of the current work involved development of a geometric correction algorithm for CZCS. A scanner model specific to CZCS was developed which accounts for image distorting scanner and satellite motions. This model was used in turn to generate mapping polynomials that define the transformation from the original image to one configured in a polyconic projection.

Actually two approaches were investigated in the present study to obtain these mapping polynomials; geometric regression and orbit modeling. Based on a single available CZCS scene for the Great Lakes a geometric regression of anchor points produced mapping polynomials which predicted the location of ground control points with RMS errors of approximately five pixels in both the horizontal and vertical directions. By comparison the scanner model produced RMS errors of less than one pixel in the horizontal and 1.5 pixels in the vertical directions. Thus the scanner model approach is presently considered to be superior to exclusive use of image anchor points.

While some minor modifications to the scanner model are anticipated as additional imagery is acquired the software package to provide CZCS geometric correction is essentially complete.

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APPENDIX A

CZCS GEOMETRIC CORRECTION SOFTWARE

This appendix contains FORTRAN IV listings of four programs as developed for the PDP-11/70 computer system under the present contract. These programs form the basis of ERIM's present capability to transform NASA/GSFC CZCS image files into an image with desired metric qualities. The four programs include: (1) the CZCS Scanner Model, (2) CZCS Image Ground Control Program, (3) the Mapping Projection Polynomial Generation Program, and (4) an adapted Nearest Neighbor Resampling Program. These programs do not constitute a stand alone capability but instead require selected supporting software from ERIM's Earth Resources Data Center (ERDC) operating system. Available documentation and operating instruction can be obtained by request from ERDC.

COASTAL ZONE COLOR SCANNER MODEL

```
SEQ    CZCSMRG.FTN          26-FEB-81    12:44:07     PAGE      1
       !.........!.........!.........!.........!.........!.........!.........!....
             PROGRAM CZCSMR
       C     COASTAL ZONE COLOR SCANNER MERGE   'CZCSMRG'
       C
       C
       C
       C     MODIFIED FROM EDIPSMRG ON AUGUST 27, 1980 BY GLENN DAVIS
       C     THIS PROGRAM WILL READ A COASTAL ZONE COLOR SCANNER DATA TAPE
       C     AS DESCRIBED IN "NIMBUS G, NIMBUS OBSERVATION PROCESSING SYSTEM
       C     (NOPS) TAPE SPECIFICATION T744041 CZCS CRT TAPE, 4/19/79".
       C     THE HEADER INFORMATION IS EXTRACTED AND COPIED TO THE HEADER FILE.
       C     THE DATA CHANNELS ARE INTERLEAVED AND COPIED TO THE IMAGE FILE.
       C
       C     OPTIONALLY THE ANCHOR POINTS ARE COPIED TO A FILE
       C
             PARAMETER EOF=1,BEGIMG=861,BEGANC=237,ANCLEN=616,ENDANC=852
             PARAMETER ANCREC=154,BEGILT = 1549, OFFDAY = 7, OFFSEC = 9
             PARAMETER GRPSZ = 405, SUBATT=21,PREATT=69,BEGATT= 1705
             PARAMETER NLONSZ=33,NLATSZ=36,NALTSZ=39,POSSZ = 45
             PARAMETER GMTSZ = 18,SECGRP=16,GMTINC=1702
             PARAMETER PITOFF = 0, YAWOFF = 3, ROLOFF = 6
       C
             INTEGER START,DEGREE,FRAC1,FRAC2,FRAC3,END,WHCANC
             INTEGER OFFSET, GMTD12, WHCGRP, WHCSEC
             INTEGER*4 NADALT(4), NADTIM(4)
             INTEGER * 4 RESULT,SECNDS,IMGSZ,GMTSEC,LOMIN,HIMIN,WHCMIN
             INTEGER*4 WORK,FRAC,TWO16,TWO8,NADCNT,SPAN,IMGEDG,MINMRK,IMGBEG
             INTEGER UNIT,DEN,RECNBR,YEAR,DAY,LATLON(2)
             INTEGER OBUF2(5904),TILTID,TILT,TILTSV,ANS
       C
       C
             REAL LT,LN,GDAY12,GSEC
             REAL GEO,TWO22,POINTS(154),OPMR,GTBASE,RTIME
             REAL  NADLAT(4), NADLON(4)
       C     REAL SUMROL, SUMPIT, SUMYAW, PITRAT, ROLRAT, YAWRAT
             REAL*8 RWORK
       C
       C
             LOGICAL*1 LBF(12780),HFN(18),ST(10),OBUF(11808)
             LOGICAL*1 SID(12),HT(30),COORDS(4),SWAP,LOAD
             BYTE ANCHOR,SEC(4)
             EQUIVALENCE ( YEAR,LBF(17)),(SECNDS,LBF(21)),( DAY,LBF(19))
             EQUIVALENCE (TILT,LBF(17)),(TILTID,LBF(19))
             EQUIVALENCE ( OBUF,OBUF2 ),(IMGSZ,LBF(251)),(GMTSEC,SEC(1))
             EQUIVALENCE (LBF(1),RECNBR)
             EQUIVALENCE ( LATLON,COORDS),( RESULT,COORDS)
       C
       C
       C
       C     OPEN FILES, SET CONSTANTS
       C
             ASSIGN 99402 TO I99400
             GO TO 99400
       99402 CONTINUE
       C
       C     GET FIRST NADIR VALUES
       C
```

SEQ CZCSMRG.FTN 26-FEB-81 12:44:07 PAGE 2

```
            ASSIGN 99802 TO I99800
            GO TO 99800
      99802 CONTINUE
      C
      C
      C
      C     GET FIRST GROUP OF ATTITUDE VALUES
      C
      C     ASSIGN 99302 TO I99300
      C     GO TO 99300
      C99302 CONTINUE
      C
            IMGBEG = IMGEDG
      C
      C
        900 CALL READ(UNIT,LBF,12780,NAR,IC)
            IF (NAR.NE.12780) GO TO 950
      C
            IF (.NOT.(LOAD.OR.ANCHOR)) GO TO 900
      C
            SWAP = LBF(1)
            LBF(1) = LBF(2)
            LBF(2) = SWAP
      C
      D     TYPE 910,RECNBR,RECNBR
      D910  FORMAT(I5,O6)
      C
            RECNBR = 971 - ( RECNBR/16 ) + 1
                                      ! ADD ONE TO MAKE VALUE ONE RELATIVE
                                      ! SUBTRACT FROM 971 TO INVERT IMAGE
                                      ! DIVIDE BY 16 TO SHIFT RIGHT 4 BITS
      C
      C     TYPE 910,RECNBR,RECNBR
            TILTID = MOD(TILTID,256)
            IF (TILTID.NE.2) GO TO 680
            SWAP = LBF(17)
            LBF(17) = LBF(18)
            LBF(18) = SWAP
      C
            IF (TILT.EQ.TILTSV) GO TO 680
            TILTSV = TILT
      C     DIVIDE BY 256 TO USE LEFT HALF OF WORD WHICH IS THE WHOLE PART
      C       OF THE NUMBER
            RWORK = FLOAT( TILT / 256 )
            TLTVAL = RWORK * -.367 + 29.87
      D     WRITE(5,682) RWORK,TLTVAL,RECNBR
      D682  FORMAT(' TILT = ',F5.0,' TILT (DEG) = ',F8.4,' AT RECORD ',I5)
        680 CONTINUE
      C
      C
            IF (.NOT.ANCHOR) GO TO 684
      C
      C     GET LINE OF ANCHOR POINTS
      C     ASSIGN 99902 TO I99900
      C     GO TO 99900
      C99902 CONTINUE
```

```
SEQ   C7CSMRG.FTN          26-FEB-81    12:44:07     PAGE      3
      !.........!.........!.........!.........!.........!.........!..
      C
      C
      C
        684   IF (.NOT.LOAD) GO TO 900
              DO 690 BAND = 1 , NOVL
              START = BEGIMG + (BAND - 1) * NE
        690   CALL MOVE(LBF(START),1,OBUF(BAND),NOVL,NE,0)
      C
      D       WRITE(KB,920)  (LBF(I),I=BEGIMG,866),(OBUF(J),J=1,30)
      D920    FORMAT( 6 (1X,O3),2( /, 3( 6 (1X,O3),3X)))
      C
      C
              CALL IMWRIT(1,RECNBR,OBUF2)
      C
              GO TO 900
      C
        950   CONTINUE
      C
              IF (LOAD) CALL CLOSE (1)
      C       IF (ANCHOR) CLOSE(UNIT = 3)
      C
      C       GET SECOND SET OF NADIR VALUES
              ASSIGN 99803 TO I99800
              GO TO 99800
      99803   CONTINUE
      C
      C
      C
      C       GET SECOND GROUP OF ATTITUDE VALUES
      C
      C       ASSIGN 99202 TO I99200
      C       GO TO 99200
      C99202  CONTINUE
      C
      C
      C       COPY NADIRS POINTS TO NADIR FILE
      C
              ASSIGN 99002 TO I99000
              GO TO 99000
      99002   CONTINUE
      C
      C
              IF (.NOT.LOAD) GO TO 310
      C
      C
      C
      C       LOAD HEADER FILE
      C
              ASSIGN 99602 TO I99600
              GO TO 99600
      99602   CONTINUE
      C

              CLOSE ( UNIT = 4 )
      C
      310     CALL REWIND (UNIT)
```

```
SEQ     C7CSMRG.FTN          26-FEB-81    12:44:07     PAGE      4
        !.........!.........!.........!.........!.........!.........!.........!.........!....
        C
              STOP
        C
        C99901 GO TO I99900,(99902)
        C
        99801 GO TO I99800,(99802,99803)
        C
        C99701 GO TO I99700,(99702,99706,99707,99708,99709)
        99701 GO TO I99700,(99706,99707,99708)
        C
        99601 GO TO I99600,(99602)
        C
        C99501 GO TO I99500,(99502,99503,99504,99505)
        C
        99401 GO TO I99400,(99402)
        C
        C99301 GO TO I99300,(99302)
        C
        C99201 GO TO I99200,(99202)
        C
        C99101 GO TO I99100,(99102,99103,99104)
        C
        99001 GO TO I99000,(99002)
        C
        C**********************************************************
        C
        C     GET ANCHOR POINTS
        C
        C99900 CONTINUE
        C
        C     LONGITUDES MUST BE CONVERTED FROM 0 TO 360 SYSTEM TO +- 180 DEG.
        C
        C
        C     EACH GEOGRAPHIC COORDINATE OCCUPIES FOUR BYTES.
        C     BIT 31 REPRESENTS THE SIGN
        C     BITS 30-22 REPRESENT THE WHOLE DEGREES PORTION OF THE NUMBER.
        C     BITS 21-0 REPRESENT THE SEVEN-DIGIT DECIMAL FRACTION OF DEGREES.
        C
        C     SINE = LBF ( WHCANC ) .AND. "200             ! SIGN IS ALWAYS POSITIVE
        C     SINE = ISIGN(1, SINE )
        C
        C
        C     WHCPNT = 0
        C
        C     DO 982 WHCANC = BEGANC,ENDANC,4
        C
        C
        C     DEGREE = LBF ( WHCANC ) .AND. "177
        C     DEGREE = ISHFT(DEGREE,2)
        C     WORK = LBF ( WHCANC + 1 ) .AND. "300
        C     WORK = WORK / 64          ;           ! SHIFT  6 BITS TO RIGHT
        C
        C     DEGREE = DEGREE + WORK
        C
        C     FRAC1 =LBF ( WHCANC + 1) .AND. "077
        C
```

```
SEQ    CZCSMRG.FTN          26-FEB-81    12:44:07     PAGE     5
       C      FRAC2 =LBF ( WHCANC + 2) .AND. "377
       C
       C      FRAC3 =LBF ( WHCANC + 3) .AND. "377
       C
       C      END = WHCANC + 3
       C
       D      TYPE 931,WHCANC,(LBF(I),I=WHCANC,END),(LBF(I),I=WHCANC,END)
       D931   FORMAT( ' POINT ',I5,2X,' DEC: ', 4(I6,1X)
       D      + ,/,14X,' OCT: ',4(O6,1X) )
       C
       C      FRAC = FRAC1 * TWO16 + FRAC2 * TWO8 + FRAC3
       C
       C      RWORK = FLOAT ( FRAC ) / ( TWO22 )
       C
       C      GEO =  FLOAT(DEGREE ) + RWORK
       C
       C      IF (GEO.GT.180) GEO = - (360. - GEO )
       C
       D      TYPE 930,DEGREE,FRAC1,FRAC2,FRAC3,FRAC,RWORK,TWO22
       C930   FORMAT( 4(I6,1X),I10,F15.12,F10.2)
       C
       D      TYPE 932, GEO
       C932   FORMAT( 1X, F12.8)
       C
       C      WHCPNT = WHCPNT + 1
       C      POINTS(WHCPNT) = GEO
       C
       C982   CONTINUE
       C
       C
       C      WRITE(3'RECNBR) ( POINTS(K),K=1,WHCPNT)
       C685    FORMAT( < WHCPNT > F9.4 )
       C
       C
       C
       C      GO TO 99901
       C**********************************************************************
       C
       C      PROCEDURE TO EXTRACT NADIR INFORMATION
       C
       C
       99800 CONTINUE
       C
       C
       C        GET GMT IMAGE EDGE (IMGEDG) AND LENGTH OF IMAGE (SPAN )
       C
       C        SWITCH BYTES AND WORDS TO MATCH DEC CONVENTIONS
       C
              DO 90 WORK = 21,25,4
       C
                  SWAP = LBF(WORK)
                  LBF( WORK ) = LBF (WORK + 3 )
                  LBF( WORK + 3 ) = SWAP
       C
                  SWAP = LBF(WORK + 1 )
                  LBF( WORK + 1 ) = LBF ( WORK + 2 )
```

```
SEQ   CZCSMRG.FTN          26-FEB-81    12:44:07    PAGE      6
      I.........I.........I.........I.........I.........I.........I.........I........
                      LBF( WORK + 2 ) = SWAP
            90   CONTINUE
      C
      C
                 IMGEDG = SECNDS
                 SPAN = IMGSZ
      C          IMGEDG = IMGEDG + SPAN
      D          TYPE *,'IMGEDG ',IMGEDG, '     SPAN ',SPAN
      C
      C          VALUE GIVEN ON TAPE FOR SPAN DOESN'T APPEAR TO BE RELIABLE
      C          SO A DEFAULT SIZE OF 128 SECONDS IS USED.
      C
                 SPAN = 128000
      C
      C..........................................
      C
      C          EXTRACT TIME OF GMT MINUTE MARK ( MINMRK )
      C          UNSCRAMBLE GMT 1/12 DAY
                 OFFSET = BEGILT + OFFDAY
                 GMTSEC = 0
                 SEC(2) = LBF( OFFSET )
                 SEC(1) = LBF ( OFFSET + 1 )
                 GMTD12 = GMTSEC
      C          EXCLUDE DAYS BEFORE CURRENT DAY
                 WORK = MOD (GMTD12,12)
      C          CONVERT TO MILLISECONDS
                 WORK = WORK * 2 * 3600000
      C
      C
      C          UNSCRAMBLE GMT MILLISECONDS OF 1/12 DAY
                 OFFSET = BEGILT + OFFSEC
                 GMTSEC = 0
                 SEC ( 3 ) = LBF( OFFSET)
                 SEC ( 2 ) = LBF ( OFFSET + 1 )
                 SEC ( 1 ) = LBF ( OFFSET + 2 )
      C
      C          ADD MILLISECONDS OF THIS TWO HOUR SEGMENT
                 MINMRK = GMTSEC + WORK
      D          TYPE *, ' WORK ',WORK,'  GMTSEC  ',GMTSEC,'  MINMRK  ',MINMRK
      C
      C..........................................
      C
      C          CHOOSE MINUTE MARK INDEXES
      C
                 RTIME = FLOAT( MINMRK / 60000 ) - 1.
                 GTBASE = MIN( GTBASE, RTIME )
      D          TYPE *, ' GTBASE ',GTBASE
      C
      C
      C
      C..........................................
      C
      C
      C          GET NADIR VALUES
                 DO 200 WHCMIN = 1,2
      C
```

```
SEQ     CZCSMNG.FTN          26-FEB-81    12:44:07    PAGE     7
        !.........!.........!.........!.........!.........!.........!.........!........
                NADCNT = NADCNT + 1
                    START = BEGILT + GMTSZ + (WHCMIN - 1) * POSSZ
                    OFFSET = NLONSZ  + START
        C
        C           GET LON VALUE
                    ASSIGN 99706 TO I99700
                    GO TO 99700
        99706       CONTINUE
        C
                    NADLON(NADCNT)  = FLOAT( RESULT) * DPMR
        C
                    OFFSET = NLATSZ  + START
        C           GET LAT VALUE
                    ASSIGN 99707 TO I99700
                    GO TO 99700
        99707       CONTINUE
        C
                    NADLAT(NADCNT)  = FLOAT( RESULT ) * DPMR
        C
                    OFFSET = NALTSZ  + START
        C           GET ALT VALUE
                    ASSIGN 99708 TO I99700
                    GO TO 99700
        99708       CONTINUE

                    NADALT(NADCNT) =  RESULT
        C
                    NADTIM(NADCNT) = ( MINMRK + ( (WHCMIN - 1) * 60000 ))
             +                               / 60000
        C
        D           TYPE *, ' NADIR LAT,LON,TIM,ALT ',NADLAT(NADCNT),
        D    +                   NADLON(NADCNT),NADTIM(NADCNT),NADALT(NADCNT)
        C
          200   CONTINUE
        C
        C
        C
                GO TO 99801
        C*********************************************************************
        C
        C
        C           OPEN FILES, SET CONSTANTS
        C
        C
        99400 CONTINUE
                PI = 3.1415927
                DPMR = 1.E-6 * 180 / PI     !   DEGREES PER MILLIRADIAN
                TWO22 = 2. ** 22
                TWO16 = 2 ** 16
                TWO8  = 2 ** 8
                NBRATT = 0
                NADCNT = 0
                GTBASE = 999999.
        C
        C
                KB=5
```

ORIGINAL PAGE IS
OF POOR QUALITY


```
SEQ    CZCSMRG.FTN           26-FEB-81    12:44:07     PAGE      8
       I.........I.........I.........I.........I.........I.........I.
              IDR=1                                    ! DRIVE 1
       C
              WRITE (KB,20)
       20     FORMAT (' CZCS DATA TAPE MERGE VER 1.0',/)
       C
              WRITE (KB,30)
       30     FORMAT ('$INPUT UNIT AND DENSITY?  ')
       C
       C      THIS STATEMENT READS A DIAGNOSTIC CONTROL VARIABLE
       C      AND = 0 LOADS BOTH IMAGE AND ANCHOR POINT FILES
       C      ANS = 1 LOADS ONLY IMAGE FILE
       C      ANS = 2 LOADS ONLY ANCHOR POINT FILE
              READ (KB,40) UNIT,DEN,ANS
       40     FORMAT (2I10)
       C
              CALL INIT (UNIT,DEN,2)
              CALL REWIND (UNIT)
       C
              IF ( ANS.NE.0.AND.ANS.NE.1 ) GO TO 72
              LOAD = .TRUE.
              WRITE (KB,50)
       50     FORMAT ('$SCENE TITLE ?    ')
              READ (KB,60) ST
       60     FORMAT (120A1)
       C
              WRITE (KB,65)
       65     FORMAT ('$DRIVE NUMBER?   ')
              READ (KB,40) IDR
       C
              WRITE (KB,70)
       70     FORMAT ('$HEADER TITLE?   ')
              READ (KB,60) HT
       C
         72   CONTINUE
       C
       C      ANCHOR = .FALSE.
       C      IF (ANS.NE.0.AND.NE.2) GO TO 74
       C      ANCHOR = .TRUE.
       C      OPEN ( UNIT = 3, NAME = 'ANCHOR.DAT',TYPE='NEW'
       C     +    ,ACCESS='DIRECT',FORM='UNFORMATTED',RECORDSIZE=ANCREC
       CC    +    ,INITIALSIZE=1940
       C     +    ,MAXREC = 970,ASSOCIATEVARIABLE = INDX )
       C
       C
       C          SKIP TO SECOND FILE
       C
       C 74     CONTINUE
              CALL SKIP (UNIT,2,IC)
       C
                  CALL SKIP (UNIT,1,IC)
              IF (IC.NE.EOF) STOP 'EXPECTED END OF FILE '
       C
       C
                  CALL READ (UNIT,LBF,5328,NAR,IC)
       C
                  IF (NAR.NE.5328) STOP 'UNKNOWN FORMAT'
```

```
SEQ     CZCSMRG.FTN          26-FEB-81    12:44:07     PAGE      9
        !.........!.........!.........!.........!.........!.........!.........!.........
        C
        C          CONSTANTS FOR HEADER FILE
        C
                   NE=1968                 ! NUMBER OF OUTPUT ELEMENTS
                   NL=970                  ! NUMBER OF OUTPUT LINES
                   NBP=6                   ! NUMBER OF BYTES/PIXEL
                   IPN=5                   ! PROJECTION NUMBER
                   NPP=0                   ! NUMBER OF PROJECTION PARAMETERS
                   IEO=0                   ! ELEMENT OFFSET
                   ILO=0                   ! LINE OFFSET
                   NOVL=6                  ! NUMBER OF OVERLAYS
                   DX=825.                 ! SAMPLING INTERVAL (METERS) ACROSS TRACK
                   DY=825.                 ! SAMPLING INTERVAL (METERS) ALONG TRACK
        C
                   NB=NE*NBP
        C
                   IF (LOAD) CALL IMOPEN(1,ST,,IDR,NB,NL,'M')
                   OPEN ( UNIT = 4, NAME = 'CSP.DAT',TYPE='NEW')
        C
                   GO TO 99401
        C
        C*****************************************************************
        C
        C
        C          LOAD HEADER FILE
        C
        99600      CONTINUE
        C
                   CALL GHFN (ST,HFN)
                   CALL ASSIGN (1,HFN)
        C
        C
                   CALL MOVE(LBF(33),1,COORDS(1),1,4,0)
        C
        C
                   SWAP = COORDS(2)
                   COORDS(2) = COORDS(1)
                   COORDS(1) = SWAP
        C
                   SWAP = COORDS(4)
                   COORDS(4) = COORDS(3)
                   COORDS(3) = SWAP
        C
        C
                   LATLON(1) = LATLON(1) - 9000
                   IF (LATLON(2).GT.18000) LATLON(2) = - ( 36000 - LATLON(2) )
                   LT = FLOAT(LATLON(1)) /100
                   LN = FLOAT(LATLON(2)) / 100
        C
        C
                   WRITE(1,150) YEAR,DAY,HT
          150      FORMAT(1X,I4,':',I3,2X,30A1,7X)
        C
        C
                   WRITE (1,160) NE,NL,NBP,IPN,NPP,IEO,ILO,NOVL
        160        FORMAT (8I5,40X)
```

```
SEQ     CZCSMRG.FTN          26-FEB-81    12:44:07     PAGE     10
        !.........!.........!.........!.........!.........!.........!.........!....
        C
        C
                WRITE (1,170) DX,DY,LT,LN
        170     FORMAT (4F12.6,32X)
        C
        C
                WRITE (1,170) TH,Z,Z,Z
        C
        C
                WRITE (1,180) (1,I,I=1,NOVL)
        180     FORMAT (16I5)
        C
                CALL CLOSE (1)
        C
                GO TO 99601
        C
        C*********************************************************************
        C
        C
        C       LOAD NADIR FILE
        C
        99000 CONTINUE
        C
        C
                SWAP = LBF(17)
                LBF(17) = LBF(18)
                LBF(18) = SWAP
        C
                SWAP = LBF(19)
                LBF(19) = LBF(20)
                LBF(20) = SWAP
        C
                WRITE(4,150) YEAR,DAY,HT
                RTIME = FLOAT( IMGBEG ) / 60000. - GTBASE      ! UNITS = MINUTES
                RWORK = RTIME + ( FLOAT( SPAN ) / 60000. )     ! END OF IMAGE
                WRITE(4,925) RTIME, RWORK       ! TIME IMAGE STARTS, ENDS
                DO 920 WHCGRP = 1, 4
        C       CALCULATE TIME OF MINUTE MARK RELATIVE TO GTBASE, UNITS  = MINUTES
                RTIME = FLOAT ( NADTIM( WHCGRP )) - GTBASE
          920      WRITE(4,925) NADLAT(WHCGRP),NADLON(WHCGRP),NADALT(WHCGRP)
             +                      ,RTIME
          925   FORMAT( 2F 12.6  , I12 , F12.6 )
                WRITE(4,927) TLTVAL
          927   FORMAT(F12.6)
        C
        C
                GO TO 99001
        C
        C*********************************************************************
        C
        C
        C         EXTRACT THREE BYTES AND FLIP TO CONFORM TO DEC CONVENTIONS
        C
        99700 CONTINUE
        C
                   COORDS(4) = "000
```

```
SEQ     CZCSMRG,FTN          26-FEB-81    12:44:07      PAGE     11
        !.........!.........!.........!.........!.........!.........!.......
                       COORDS(3) = LBF( OFFSET )
                       COORDS(2) = LBF( OFFSET + 1 )
                       COORDS(1) = LBF( OFFSET + 2 )
        C              TEST FOR NEGATIVE SIGN
                       WORK = LBF( OFFSET) .AND. "200
                       IF (WORK.NE.0 ) COORDS(4) = "377
        C
                 GO TO 99701
        C
        C
        C
        C**************************************************
        C        INCLUDE 'CZCSMRG.INC'
        C**************************************************
        C
        C
                 END
```

COASTAL ZONE COLOR SCANNER GROUND CONTROL PROGRAM

```
SEQ   C.FTN               26-FEB-81    12:47:11     PAGE     1
      I.........I.........I.........I.........I.........I.........I.........I.........I....
C
C      COASTAL ZONE COLOR SCANNER GROUND CONTROL - CZGC
C
C      ADAPTED ON OCTOBER 8, 1980 BY GLENN DAVIS FROM LGC;
C         REV 2.0 R DYE 30 OCT 80 TO INCORPORATE CONICAL SCAN
C         REV 2.1 R DYE 11 DEC 80 TO USE LAGRANGE INTERPOLATION
C
C
C
C
C
C
C      **** WARNING: CHANGES IN MODEL SHOULD ALSO BE MADE IN CZMP.FTN
C
       REAL*4 LT,LN,LTLP,LNLP,LTD,LND,LTSH,LNSH,SID(4)
       DIMENSION IX(100), IY(100), PLT(100), PLN(100), EN(100), EE(100)
       DIMENSION TALF(4), PALF(4,100), IDL(390), PALT(100)
       DIMENSION A(10), X(4), XB(4), SDY(4), R(4)
       DIMENSION B(15), Y(5), YB(5), SDY(5), P(5)
         DIMENSION TT(4),TLT(4),TLN(4),TALT(4)
       INTEGER*2 IPT(100),IW(100),IGN(100)
       INTEGER*2 AN,AE,AY,RPF,ONE
       LOGICAL*1 TM(8),DA(9)
       DATA RE,RP,DPR/6378200.,6356800.,57.2957795/
       DATA AN,AE,AY/'N','E','Y'/
       DATA SF/1000000./
       DATA REV/2.1/
       LF(IP,NIP,I,J)=J-I+NIP+1-((IP-I+1)*(IP-I+2))/2
       ONE = 10
C
       WRITE (5,20) REV
 20    FORMAT ('0COASTAL ZONE COLOR SCANNER GROUND CONTROL   REV '
      + ,F5.1,//)
 30    FORMAT (2F10.0)
       RES=RE*RE
       EC=RE/RP
       ECS=EC*EC
       CALL ASSIGN (6,'DB1:CZCG.LST')
       LP=5
C
       IALL = 1968
       LLD = IALL / 2
C
       CALL ASSIGN(4,'CSP.DAT')
       READ (4,40) SID
 40      FORMAT(4A4)
         WRITE(5,40)SID
         READ (4,50)T0
 50      FORMAT(2F12.6,F12.0,F12.6)
         DO 60 I=1,4
         READ(4,50)TLT(I),TLN(I),TALT(I),TT(I)
 60      WRITE(5,50)TLT(I),TLN(I),TALT(I),TT(I)
         READ(4,50)TILT
       CALL CLOSE (4)
         TS=NINT(TILT)/(2.*DPR)
         FF=45./DPR
```

```
SEQ     C.FTN                26-FEB-81    12:47:11    PAGE    2
        C
        C
                CALL ASSIGN (2,'DB:DSL.001')
                DEFINE FILE 2(100,18,U,INDX)
                CALL ASSIGN (3,'DB:MCP.DAT')
                IG=1
                M=1
                LR=1
        C
        C
                N=0
        160     CONTINUE
                I=N+1
                READ (3,170,END=200) M,PLT(I),PLN(I),ALT,(PALF(J,I),J=1,4)
        170     FORMAT (I3,1X,2F12.6,F12.1,1X,4A4)
                IF (M.EQ.0) GO TO 160
                I=N+1
                READ (2'M) IG,ND,IX(I),IY(I)
                IF (IG.EQ.0) GO TO 160
                N=N+1
                IPT(N)=M
                IW(N)=1
                IGN(N)=IG-1
        C
        C
                GO TO 160
        C
        200     CALL CLOSE (3)
                WRITE (5,210)
        210     FORMAT ('$PITCH AND ROLL DEGREE ? ')
                READ (5,220) IDG
        220     FORMAT (I5,2F10.0)
                IF (IDG.LT.1.OR.IDG.GT.3) IDG=1
        C
        C
        230       CONTINUE
                  WRITE(5,251)
        251       FORMAT('$LNSH,LTSH,VM,TILT ? ')
                  READ (5,252)LNSH,LTSH,VM,TS
        252       FORMAT(4F10.0)
                  TS=TS/DPR
                DO 440 JI=1,10
                K=1
                DO 240 I=1,4
                XB(I)=0.
                IF (JI.EQ.1) R(I)=0.
                DO 240 J=I,4
                A(K)=0.
        240     K=K+1
                K=1
                DO 250 I=1,5
                YB(I)=0.
                IF (JI.EQ.1) P(I)=0.
                DO 250 J=I,5
                B(K)=0.
        250     K=K+1
```

ORIGINAL PAGE IS
OF POOR QUALITY


```
SEQ    C.FTN                    26-FEB-81    12147111    PAGE    3
       I.........I.........I.........I.........I.........I.........I.........I.........I......
              SSN=0.
              SSE=0.
              SW=0.
                 CTEW=0.
                 CTEW2=0.
                 CTNS=0.
       C
              DO 280 ICP=1,N
              ST = FLOAT ( IY(ICP) ) - 485.         !    NORMALIZE  ALONG TRACK DIMENSION
              ST = ST /485.                         !    NORMALIZE  ALONG TRACK DIMENSION
       C
                 T=(970.-IY(ICP))*128./(970.*60.)+T0
                 CALL LGR(TT,TLT,T,LTD)
                 CALL LGR(TT,TLN,T,LND)
                 CALL LGR(TT,TALT,T,ALT)
       C         WRITE(5,50)LTD,LND,ALT,FLOAT(IY(ICP))
       C
              LT = LTD / DPR
              LN = LND / DPR
                 LN=LN+LNSH
                 LT=LT+LTSH
              SLT=SIN(LT)
              CLT=COS(LT)
              SH=.15839/CLT
              CH=-SQRT(1.-SH*SH)
              HD=ATAN2(SH,CH)
              HD=HD+YW
              HDD=HD*DPR
       C
              AL=ATAN(SLT/(EC*CLT))
              RAL=RE*COS(AL)+ALT*CLT
              X0=RAL*COS(LN)
              Y0=RAL*SIN(LN)
              Z0=RP*SIN(AL)+ALT*SLT
              C=RAL*RAL+Z0*Z0*ECS-RES
              GCLT=ATAN(Z0/RAL)
       C
       C
                 RL= .00
              RL=RL+(((R(4)*ST+R(3))*ST+R(2))*ST+R(1))/ALT
                 PT= .0
              PT=PT+(((P(5)*ST+P(4))*ST+P(3))*ST+P(1))/ALT
              HD=HD-P(2)
       C
              PN=IY(ICP)-LLD
                 TH=PN*VM/1000000.
              X1=0.
              Y1=0.
                 Z1=ALT
                 CALL SAR(X1,Z1,TS,X2,Z2)
                 Y2=Y1
                 CALL SAR(Y2,X2,-TH,Y3,X3)
                 Z3=Z2
                 CALL SAR(X3,Z3,FF,X4,Z4)
                 Y4=Y3
                 Y4=-X4             !MIRROR REFLECTION
```

```
SEQ     C.FTN                 26-FEB-81    12:47:11     PAGE     4
              CALL SAR(X4,Z4,-FF,X5,Z5)
              Y5=Y4
              CALL SAR(Y5,X5,TH,Y6,X6)
              Z6=Z5
              CALL SAR(X6,Z6,-TS,X7,Z7)
              Y7=Y6
              CALL SAR(X7,Y7,-RL,X2,Y2)
              Z2=Z7
           CALL SAR (Z2,X2,PT,Z3,X3)
           CALL SAR (Y2,Z3,HD,Y4,Z4)
           CALL SAR (Z4,X3,GCLT,Z5,X5)
           CALL SAR (Y4,X5,LN,Y6,X6)
      C
           AQ=X6*X6+Y6*Y6+Z5*Z5*ECS
           BQ=2.*(X6*X0+Y6*Y0+Z5*Z0*ECS)/AQ
           T=.5*(-BQ-SQRT(BQ*BQ-4.*C/AQ))
           XE=X6*T+X0
           YE=Y6*T+Y0
           ZE=Z5*T+Z0
           LTLP=ATAN(ZE*ECS/SQRT(XE*XE+YE*YE))
           LNLP=DPR*ATAN2(YE,XE)
           LTLP=DPR*LTLP
           ELT=LTLP-PLT(ICP)
           ELN=LNLP-PLN(ICP)
           WT=IW(ICP)
           ENI=ELT*RE/DPR
           EEI=ELN*RE*CLT/DPR
           CALL SAR (ENI,EEI,HD,PTE,RLE)
              RLE=RLE*COS(TH)
           X(1)=RLE
           X(2)=ST
           X(3)=ST*ST
           X(4)=ST*ST*ST
           K=1
           DO 260 I=1,4
           XB(I)=XB(I)+X(I)*WT
           DO 260 J=1,4
           A(K)=A(K)+X(I)*X(J)*WT
      260  K=K+1
      C
           Y(1)=PTE
           Y(3)=ST
           Y(4)=ST*ST
           Y(5)=ST*ST*ST
           Y(2)=TH*ALT
      C
           K=1
           DO 270 I=1,5
           YB(I)=YB(I)+Y(I)*WT
           DO 270 J=1,5
           B(K)=B(K)+Y(I)*Y(J)*WT
      270  K=K+1
           SW=SW+WT
           SSN=SSN+ENI*ENI*WT
           SSE=SSE+EEI*EEI*WT
           EN(ICP)=ENI
```

```
           EE(ICP)=EEI
             CTEW=CTEW+TH*RLE
             CTEW2=CTEW2+TH*TH*RLE
             CTNS=CTNS+TH*TH*PTE
  280      CONTINUE
C
C
             CTEW=CTEW/SW
             CTEW2=CTEW2/SW
             CTNS=CTNS/SW
           K=1
           DO 290 I=1,4
           DO 290 J=I,4
           A(K)=A(K)-XB(I)*XB(J)/SW
  290      K=K+1
           K=1
           DO 300 I=1,4
           XB(I)=XB(I)/SW
           DO 300 J=I,4
           A(K)=A(K)/(SW-1.)
  300      K=K+1
           DO 310 I=1,4
  310      SDX(I)=SQRT(A(LF(4,10,I,I)))
           K=1
           DO 320 I=1,4
           DO 320 J=I,4
           A(K)=A(K)/(SDX(I)*SDX(J))
  320      K=K+1
           DO 330 I=2,1+IDG
           IF (A(LF(4,10,I,I)).LT.1.E-5) GO TO 740
  330      CALL STEP (A,10,4,I)
C
           Y(1)=XB(1)
           DO 340 I=2,1+IDG
           Y(I)=SDX(1)*A(LF(4,10,1,I))/SDX(I)
  340      Y(1)=Y(1)-Y(I)*XB(I)
           DO 350 I=1,1+IDG
  350      R(I)=R(I)+Y(I)
C
           K=1
           DO 360 I=1,5
           DO 360 J=I,5
           B(K)=B(K)-YB(I)*YB(J)/SW
  360      K=K+1
           K=1
           DO 370 I=1,5
           YB(I)=YB(I)/SW
           DO 370 J=I,5
           B(K)=B(K)/(SW-1.)
  370      K=K+1
           DO 380 I=1,5
  380      SDY(I)=SQRT(B(LF(5,15,I,I)))
           K=1
           DO 390 I=1,5
           DO 390 J=I,5
           B(K)=B(K)/(SDY(I)*SDY(J))
```

```
SEQ     C.FTN                     26-FEB-81     12:47:11     PAGE      6
        390     K=K+1
                DO 400 I=2,2+IDG
                IF (B(LF(5,15,I,I)).LT.1.E-5) GO TO 740
        400     CALL STEP (B,15,5,I)
        C
                Y(1)=YB(1)
                DO 410 I=2,2+IDG
                Y(I)=SDY(1)*B(LF(5,15,1,I))/SDY(I)
        410     Y(1)=Y(1)-Y(I)*YB(I)
                DO 420 I=1,2+IDG
        420     P(I)=P(I)+Y(I)
                SSN=SSN/SW
                SSE=SSE/SW
                SDN=SQRT(SSN)
                SDE=SQRT(SSE)
                   WRITE(5,430)SDN,SDE
        430        FORMAT(4F15.1)
        440     CONTINUE
        C
                   WRITE(5,441)CTEW,CTEW2,CTNS
        441        FORMAT(3E15.5)
        C
        445     CALL DATE (DA)
                CALL TIME (TM)
                WRITE (LP,450) REV,DA,TM
        450     FORMAT ('1 COASTAL ZONE GROUND CONTROL POINTS REV ',F3.1,5X,9A1,2X
               1,8A1,//)
                WRITE (LP,460) SID
        460     FORMAT (' SCENE ID    ',4A4,/)
                   WRITE(LP,465)LNSH,VM,TS*DPR
        465        FORMAT(3F12.5)
                WRITE (LP,470) SDE,SDN
        470     FORMAT (' RMS ERRORS   EAST ',F7.1,'  NORTH  ',F7.1,'  (METERS)')
                WRITE (LP,480) P(1),P(3),P(4),P(5)
        480     FORMAT ('0PITCH:',4F10.1)
                WRITE (LP,490) R
        490     FORMAT (' ROLL :',4F10.1)
                WRITE (LP,500) P(2)*1.E6
        500     FORMAT (' YAW  :'F10.1)
                WRITE (LP,510)
        510     FORMAT (//' POINT FILE  WEIGHT       EAST              NORTH',/)
                DO 530 I=1,N
                NSDE=NINT(EE(I)/SDE)
                NSDN=NINT(EN(I)/SDN)
                WRITE (LP,520) IPT(I),IGN(I),IW(I),EE(I),NSDE,EN(I),NSDN,(PALF(J,I
               1),J=1,4)
        520     FORMAT (I4,I5,I6,F14.1,I4,F12.1,I4,4X,4A4)
        530     CONTINUE
                   IF(LP.EQ.6)GO TO 610
                IPWF=0
                WRITE (5,540)
        540     FORMAT ('$ALTER POINT WEIGHT ?  ')
        550     READ (5,560) IP,ITW,FFF
        560     FORMAT (2I10,F10.0)
                IF (IP.EQ.0) GO TO 590
                ITW=IABS(ITW)
```

```
SEQ     C.FTN                       26-FEB-81    12:47:11     PAGE     7
        !.........!.........!.........!.........!.........!.........!.........!.........!......
              IF (ITW.GT.10) ITW=10
              DO 570 I=1,N
              IF (IP.EQ.IPT(I)) IW(I)=ITW
        570   CONTINUE
              IPWF=1
              WRITE (5,580)
        580   FORMAT ('$ANOTHER ?     ')
              GO TO 550
        590   IF (IPWF.NE.0) GO TO 230
              WRITE (5,600)
        600   FORMAT ('$ OUTPUT ON LINE PRINTER ?   ')
              READ (5,605) LPA
        605   FORMAT(A1)
              IF (LPA.NE.AY) GO TO 610
              LP=6
              GO TO 445
        610   WRITE (5,620)
        620   FORMAT ('$PRINTER PLOTS ? ')
              READ (5,605) LPA
              IF (LPA.NE.AY) GO TO 720
        C
              WRITE (5,630)
        630   FORMAT ('$METERS PER DIVISION ? ')
              READ (5,30) PPS
              IF (PPS.EQ.0.) PPS=200.
              PPSF=PPS/10.
              WRITE (6,640) PPS
        640   FORMAT ('1PIXEL V.S. ERRORS',T28,'EAST',T88,'NORTH',F10.0,'METERS/
             1DIV'/)
              DO 670 I=1,60
              LL=(I-1)*33
              LU=I*33
              DO 660 J=1,N
              IF (IW(J).EQ.0) GO TO 660
              IF (IX(J).LE.LL) GO TO 660
              IF (IX(J).GT.LU) GO TO 660
              IEE=EE(J)/PPSF+30.
              IEN=EN(J)/PPSF+90.
              IF (IEE.LT.2) IEE=2
              IF (IEE.GT.60) IEE=60
              IF (IEN.LT.61) IEN=61
              IF (IEN.GT.120) IEN=120
              WRITE (6,650) IPT(J),IPT(J)
        650   FORMAT ('+',T<IEE>,I2,T<IEN>,I2)
        660   CONTINUE
        670   WRITE (6,680)
        680   FORMAT (5(9X,'I'),10X,5(9X,'I'))
              WRITE (6,690)
        690   FORMAT ('1LINE V.S. ERRORS',T28,'EAST',T88,'NORTH'/)
              DO 710 I=1,60
              LL=(I-1)*17
              LU=LL+17
              DO 700 J=1,N
              IF (IW(J).EQ.0) GO TO 700
              IF (IY(J).LE.LL) GO TO 700
              IF (IY(J).GT.LU) GO TO 700
```

```
SEQ   C,FTN                    26-FEB-81    12:47:11    PAGE    8
      1.........1.........1.........1.........1.........1.........1.........1.......
              IEE=EE(J)/PPSF+30
              IEN=EN(J)/PPSF+90.
              IF (IEE.LT.2) IEE=2
              IF (IEE.GT.60) IEE=60
              IF (IEN.LT.61) IEN=61
              IF (IEN.GT.120) IEN=120
              WRITE (6,650) IPT(J),IPT(J)
      700     CONTINUE
      710     WRITE (6,680)
      720     WRITE (4,730) P(1),P(3),P(4),P(5)
              WRITE (4,730) R
              WRITE (4,730) P(2)*1,E6
      730     FORMAT (6F10.3)
                CLOSE(UNIT=6,DISPOSE='PRINT')
              STOP
      740     WRITE (5,750)
      750     FORMAT (' GCP DATA NOT SUITABLE FOR DEGREE SELECTED')
              STOP
              END
              SUBROUTINE LGR( V , FV , XI , XRESLT)
      C
      C-----------------------------------------------------------------
      C
      C         FNVAL1    -
      C                   I                                 FNVAL3 -
      C                   I         XRESLT -                  I    FNVAL4 -
      C                   I           I      FNVAL2 -         I      I
      C                   I           I          I            I      I
      C  I+++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
      C                   -           -          -            -      -
      C              VAL1 -    XINTRP  -      VAL2 -    VAL3 -   VAL4  -
      C
      C        GIVEN FOUR VALUES ( VAL1 -> 4 OR ARRAY V ) AND
      C       GIVEN FOUR CORRESPONDING VALUES ( FNVAL1 -> 4 OR ARRAY FV ) THAT
      C       ARE A FUNCTION OF THE FORMER VALUES,
      C       AND  GIVEN A VALUE XINTRP ( XI ) THAT IS ADJACENT TO  VAL1 -> 4
      C       THEN THIS ROUTINE RETURNS A VALUE, XRESLT,  THAT IS THE LAGRANGE
      C       INTERPOLATION OF XINTRP ABOUT FNVAL1 -> 4.
      C
      C
      C
              REAL V(4) , FV(4) , XRESLT , XI, PART(4)
              REAL A,B,C,D
      C
              A = XI - V(1)
              B = XI - V(2)
              C = XI - V(3)
              D = XI - V(4)
      D
      D       TYPE 500,A,B,C,D
      D 500   FORMAT(4F12.6
      D       TYPE 500,V
      D       TYPE 500,FV
      D       TYPE 500,XI
      C
              PART(1) = ( B * C * D  )
```

```
         +         / (( V(1) - V(2)) * ( V(1) - V(3)) * ( V(1) - V(4)) )
         +         * FV (1)
C
          PART(2) = ( A * C * D  )
         +         / (( V(2) - V(1)) * ( V(2) - V(3)) * ( V(2) - V(4)) )
         +         * FV (2)
C
          PART(3) = ( A * B * D  )
         +         / (( V(3) - V(1)) * ( V(3) - V(2)) * ( V(3) - V(4)) )
         +         * FV (3)
C
          PART(4) = ( A * B * C  )
         +         / (( V(4) - V(1)) * ( V(4) - V(2)) * ( V(4) - V(3)) )
         +         * FV (4)
          XRESLT = PART(1) + PART(2) + PART(3) + PART(4)
C
D         TYPE 500,PART
D         TYPE 500,XRESLT
C
C
          RETURN
          END
          SUBROUTINE STEP (A,NIP,IP,KAY)
          DIMENSION A(15)
          LF(IX,JX)=JX-IX+NIP+1-((IP-IX+1)*(IP-IX+2))/2
          LKK=LF(KAY,KAY)
          M=0
          DO 70 I=1,IP
          DO 70 J=I,IP
          M=M+1
          IF (I-KAY) 10,70,20
   10     LIK=LF(I,KAY)
          GO TO 30
   20     LIK=LF(KAY,I)
   30     IF (J-KAY) 40,70,50
   40     LKJ=LF(J,KAY)
          GO TO 60
   50     LKJ=LF(KAY,J)
   60     A(M)=A(M)-A(LIK)*A(LKJ)/A(LKK)
   70     CONTINUE
          DO 110 I=1,IP
          IF (I-KAY) 80,110,90
   80     LIK=LF(I,KAY)
          GO TO 100
   90     LIK=LF(KAY,I)
  100     A(LIK)=A(LIK)/A(LKK)
  110     CONTINUE
          A(LKK)=-1./A(LKK)
          RETURN
          END
```

MAPPING PROJECTION POLYNOMIAL GENERATION PROGRAM

```
SEQ     CZSMP.FTN           26-FEB-81    12:44:28     PAGE    1
      C      COASTAL ZONE SCANNER MAPPING POLYNOMIALS
      C      ADAPTED FROM HMP BY GLENN DAVIS ON JANUARY 13, 1981
      C
             LOGICAL ADVFL
             DOUBLE PRECISION X,XN,A
             DOUBLE PRECISION XMEAN,STDEV,POSD
             DIMENSION Y(40), A(840), C(40), F(40), FE(40)
             DIMENSION XMEAN(40), STDEV(40), B(40), D(40), TOLEV(40), R(40), NI
            1EN(40), INEN(40)
             DIMENSION TT(4),TLT(4),TLN(4),TALT(4)
             INTEGER SID(5),AY,RPF
             LOGICAL*1 IT(10),HFN(18),TM(8),DA(9)
             REAL LT,LN,LTLP,LNLP,LTSC,LNSC,PT,RL,LTSH,LNSH,SF
             REAL LTD,LND
             DIMENSION PS(2),PITCH(5),ROLL(4),DELTA(2)
             COMMON X,XN,A,C,F,FE,L,NTGC,IP,NIP,FINC,FOUT,KAY,FLAG,KOEP,OF,TOL
             DATA RE,RP,DPR,SF/6378200.,6356800.,57.2957795, 1000000./
             DATA RMVE/4HRMVE/,ENTR/4HENTR/
             DATA AY/'Y'/
             LF(IX,JX)=JX-IX+NIP+1-((IP-IX+1)*(IP-IX+2))/2
             ADVFL=.TRUE.
             KB=5
             LP=3
             CALL ASSIGN(3,'CZSMP.LST')
             WRITE (KB,20)
      20     FORMAT ('0COASTAL ZONE SCANNER MAPPING POLYNOMIALS  REV 1.0'/
            1'$PROJECTION NUMBER ?  ')
             READ (KB,30) IPN,LR
      30     FORMAT (2I10)
             RES=RE*RE
             EC=RE/RP
             ECS=EC*EC
      C
             IALL = 1968
             LLD = IALL / 2
      C
             WRITE (KB,37)
      37     FORMAT ('$IMAGE TITLE ?   ')
             READ (KB,31) IT
      31     FORMAT (10A1)
             CALL GHFN (IT,HFN)
             CALL ASSIGN (2,HFN)
             READ (2,32) SID
      32     FORMAT (1X,5A2)
             READ (2,33) NIE,NIL,NBP,IIP,NIPP,IEO,ILO
      33     FORMAT (7I5)
             READ (2,34) DELTA(1),DELTA(2),LTSC,LNSC
      34     FORMAT (4F12.6)
             CALL CLOSE (2)
             CALL GT(LTSC,LNSC,IPN,U0,V0)
      C
             CALL ASSIGN(4,'CSP.DAT')
             READ (4,40) SID
      40      FORMAT(5A2)
             WRITE(5,40)SID
             READ (4,50)T0
```

ORIGINAL PAGE IS
OF POOR QUALITY


```
SEQ     CZSMP.FTN          26-FEB-81     12:44:28     PAGE      2
        !.........!.........!.........!.........!.........!.........!.........!......
        50     FORMAT(2F12.6,F12.0,F12.6)
               DO 60 I=1,4
               READ(4,50)TLT(I),TLN(I),TALT(I),TT(I)
        60     WRITE(5,50)TLT(I),TLN(I),TALT(I),TT(I)
               READ(4,50)TILT
               READ (4,730) PITCH(1),PITCH(3),PITCH(4),PITCH(5)
               READ (4,730) ROLL
               READ (4,730) PITCH(2)
         730   FORMAT(6F10.3)
               CALL CLOSE (4)
               TS=NINT(TILT)/(2.*DPR)
               FF=45./DPR
        C
        C
               IP=21
               NIP=(IP*(IP+1))/2
               CALL ALTPRI(,45)
        C
               CALL ASSIGN (1,'COEF.GEO')
               WRITE (1,100) SID,IPN
        100    FORMAT (5A2,I10)
        C
               CALL DATE (DA)
               CALL TIME (TM)
               WRITE (1,110) DA,TM
        110    FORMAT (1X,9A1,2X,8A1)
               WRITE (LP,120) DA,TM
        C
        120    FORMAT ('1COASTAL ZONE SCANNER MAPPING POLYNOMIALS  '9A1,2X,8A1//)
               WRITE (LP,130) SID,IPN
        130    FORMAT (' SCENE ID   ',5A2,'      PROJECTION NUMBER',I4)
        C
               WRITE(KB,251)
         251   FORMAT('SLNSH,LTSH,VM,TILT  ?  ')
               READ(KB,252) LNSH,LTSH,VM,TS
         252   FORMAT(4F10.0)
               TS = TS / DPR
        C
        C
        C      INITIALIZE ACCUMULATORS AND MATRIX A
        C
               DO 660 ITT=1,2
               M=0
               DO 140 I=1,IP
               XMEAN(I)=0.
               DO 140 J=1,IP
               M=M+1
        140    A(M)=0.
        C
               N=0
        C
               DO 180 INS = 1 , 27
               TY = (INS-14)  * 35 + 485
               ST = FLOAT ( TY ) - 485.    !     NORMALIZE  ALONG TRACK DIMENSION
               ST = ST /485.                     !   NORMALIZE  ALONG TRACK DIMENSION
        C
```

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OF POOR QUALITY


```
SEQ     C2SMP.FTN            26-FEB-81     12:44:28     PAGE     3
        I.........I.........I.........I.........I.........I.........I.........I......
                  T=(970.-IY)*128./(970.*60.)+T0
                  CALL LGR(TT,TLT,T,LTD)
                  CALL LGR(TT,TLN,T,LND)
                  CALL LGR(TT,TALT,T,ALT)
                  IF (LR.LT.3) GOTO 142
                   WRITE(5,50)LTD,LND,ALT,FLOAT(IY)
           142    CONTINUE
        C
                  LT = LTD / DPR
                  LN = LND / DPR
                  LN=LN+LNSH
                  LT=LT+LTSH
                  SLT=SIN(LT)
                  CLT=COS(LT)
                  SH=.15839/CLT
                  CH=-SQRT(1.-SH*SH)
                  HD=ATAN2(SH,CH)
                  HD=HD+YW
                  HDD=HD*DPR
        C
                  AL=ATAN(SLT/(EC*CLT))
                  RAL=RE*COS(AL)+ALT*CLT
                  X0=RAL*COS(LN)
                  Y0=RAL*SIN(LN)
                  Z0=RP*SIN(AL)+ALT*SLT
                  C0=RAL*RAL+Z0*Z0*ECS-RES
                  GCLT=ATAN(Z0/RAL)
        C
        C
                  RL= .00
                  RL=RL+(((ROLL(4)*ST+ROLL(3))*ST+ROLL(2))*ST+ROLL(1))/ALT
                  PT= .0
                  PT=PT+(((PITCH(5)*ST+PITCH(4))*ST+PITCH(3))*ST+PITCH(1))/ALT
                  HD=HD-PITCH(2) / SF
        C
                  DO 180 IFW = 1 , 27
                  IX = (IFW-14) * 70 + 984
                  PN = IX - LLD
                  TH=PN*VM/SF
                  X1=0.
                  Y1=0.
                  Z1=ALT
                  CALL SAR(X1,Z1,TS,X2,Z2)
                  Y2=Y1
                  CALL SAR(Y2,X2,-TH,Y3,X3)
                  Z3=Z2
                  CALL SAR(X3,Z3,FF,X4,Z4)
                  Y4=Y3
                  X4=-X4           !MIRROR REFLECTION
                  CALL SAR(X4,Z4,-FF,X5,Z5)
                  Y5=Y4
                  CALL SAR(Y5,X5,TH,Y6,X6)
                  Z6=Z5
                  CALL SAR(X6,Z6,-TS,X7,Z7)
                  Y7=Y6
                  CALL SAR(X7,Y7,-RL,X2,Y2)
```

```
SEQ   CZSMP,FTN          26-FEB-81    12:44:28     PAGE     4
      1.........1.........1.........1.........1.........1.........1.....
            Z2=Z7
            CALL SAR (Z2,X2,PT,Z3,X3)
            CALL SAR (Y2,Z3,HD,Y4,Z4)
            CALL SAR (Z4,X3,GCLT,Z5,X5)
            CALL SAR (Y4,X5,LN,Y6,X6)
      C
            AQ=X6*X6+Y6*Y6+Z5*Z5*ECS
            BQ=2.*(X6*X0+Y6*Y0+Z5*Z0*ECS)/AQ
            T=.5*(-BQ-SQRT(BQ*BQ-4.*C0/AQ))
            XE=X6*T+X0
            YE=Y6*T+Y0
            ZE=Z5*T+Z0
            LTLP=ATAN(ZE*ECS/SQRT(XE*XE+YE*YE))
            LNLP=DPR*ATAN2(YE,XE)
            LTLP=DPR*LTLP
            CALL GT (LTLP,LNLP,IPN,U,V)
            U=(U-U0)/SF
            V=(V-V0)/SF
      C
            IF (LR.GT.2) WRITE(KB,168) LTLP,LNLP,U,V
        168 FORMAT( 2F12.3,2F12.6)
      C
            K=1
            UI=1.
            DO 175 I=1,6
            VJ=1.
            DO 170 J=I,6
            X(K)= UI*VJ
            VJ=VJ*V
        170 K=K+1
        175 UI=UI*U
      C
            IF (ITT.EQ.1) X(1)=IX
            IF (ITT.EQ.2) X(1)=IY
            N=N+1
            M=0
            DO 180 I=1,IP
            XMEAN(I)=XMEAN(I)+X(I)
            DO 180 J=I,IP
            M=M+1
            A(M)=A(M)+X(I)*X(J)
        180 CONTINUE
            XN=N
            XNT=N
            RESDF=XN
            M=0
            RESDF=XN-1.0
            DO 190 I=1,IP
            DO 190 J=I,IP
            M=M+1
        190 A(M)=A(M)-XMEAN(I)*XMEAN(J)/XN
      C
      C     REPLACE XMEAN WITH MEAN VECTOR, A WITH COVARIANCE MATRIX,AND
      C     COMPUTE STANDARD DEVIATIONS
      C
            M=0
```

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SEQ   CZSMP.FTN          26-FEB-81    12:44:28     PAGE      5
            DO 200 I=1,IP
            XMEAN(I)=XMEAN(I)/XN
            DO 200 J=I,IP
            M=M+1
            A(M)=A(M)/RESDF
      200   CONTINUE
            DO 210 I=1,IP
            LII=LF(I,I)
            STDEV(I)=DSQRT(A(LII))
      210   CONTINUE
      C
      C
      C     REPLACE UPPER DIAGONAL SECTION OF MATRIX WITH CORRELATION MATRIX
      C
            M=0
            DO 250 I=1,IP
            DO 250 J=I,IP
            M=M+1
            IF (I-J) 220,240,220
      220   POSD=STDEV(I)*STDEV(J)
            IF (POSD.EQ.0.0) GO TO 230
            A(M)=A(M)/POSD
            GO TO 250
      230   A(M)=0.
            GO TO 250
      240   A(M)=1.
      250   CONTINUE
      C
            XN=XN-1.0
      C
      C
            KDEP=1
            FINC=.5
            FOUT=.1
            TOL=1.E-10
            MAXSTP=IP*2
            DO 260 I=1,IP
            C(I)=2.0
      260   CONTINUE
            LDD=LF(KDEP,KDEP)
            C(KDEP)=1.0
            NVO=0
            DO 300 I=1,IP
            IF (I-KDEP) 270,300,280
      270   LID=LF(I,KDEP)
            NVO=NVO+1
            GO TO 290
      280   LID=LF(KDEP,I)
            NVO=NVO+1
      290   FE(NVO)=A(LID)**2*XN/(1.-A(LID)**2)
      300   CONTINUE
            DF=0.0
            L=0
      310   L=L+1
      C     CALL SUBROUTINE TO ENTER VARIABLE, CALCULATE VALUES TO BE PRINTED
            CALL STEPRG (ADVFL)
```

```
      IF (FLAG) 320,620,330
320   ENTER=RMVE
      GO TO 340
330   ENTER=ENTR
340   LDD=LF(KDEP,KDEP)
      RESDF=XN-DF
      RESSS=XN*(STDEV(KDEP)**2)*A(LDD)
      RESMS=RESSS/RESDF
      RSSD=SQRT(RESSS/XNT)
      REGDF=DF
      REGSS=XN*(STDEV(KDEP)**2)-RESSS
      REGMS=REGSS/REGDF
      FRATIO=REGMS/RESMS
      STERR=SQRT(RESMS)
      XMULTR=DSQRT(1.-A(LDD))
      IDF=DF
      IRDF=RESDF
      IF (LR.LT.2) GO TO 370
      WRITE (LP,350) L,ENTER,KAY,XMULTR,STERR,RSSD
350   FORMAT ('1   STEP NUMBER',T35,I3/T5,'VARIABLE ',A4,'D',T35,I3/'0
     1 MULTIPLE R',T35,F8.4/T5,'STD. ERROR OF EST.',T31,F12.4/T5,'RESIDU
     2AL SAMPLE RMS DEV.',T31,F12.4)
      WRITE (LP,360) IDF,REGSS,REGMS,FRATIO,IRDF,RESSS,RESMS
360   FORMAT ('0   ANALYSIS OF VARIANCE '/T28,'DF      SUM OF SQUARES
     1        MEAN SQUARE            F-RATIO'/T13,'REGRESSION',3X,I4,3X,
     2F16.3,3X,F14.3,3X,F14.3/T13,'RESIDUAL',5X,I4,3X,F16.3,3X,F14.3)
C
C     A VARIABLE IS IN THE EQUATION IF C(I) IS LESS THAN OR EQUAL TO 0.0
C
370   NVI=0
      NVO=0
      ALPHA=XMEAN(KDEP)
      DO 460 I=1,IP
      LII=LF(I,I)
      IF (I-KDEP) 380,460,390
380   LID=LF(I,KDEP)
      GO TO 400
390   LID=LF(KDEP,I)
400   IF (C(I).GT.0.) GO TO 410
C
C     COMPUTE MULTIPLE REGRESSION EQUATION COEFFICIENTS,STD.ERROR,
C     AND F TO REMOVE, FOR VARIABLES IN THE REGRESSION
C
      NVI=NVI+1
      B(NVI)=STDEV(KDEP)*A(LID)/STDEV(I)
      D(NVI)=(STERR/STDEV(I))*DSQRT(-A(LII)/XN)
      F(NVI)=(B(NVI)/D(NVI))**2
      ALPHA=ALPHA-B(NVI)*XMEAN(I)
      INEN(NVI)=I
      GO TO 420
C
C     A VARIABLE IS OUT OF THE REGRESSION IF C(I) IS GREATER THAN OR
C     EQUAL TO 1
C
C
C     COMPUTE PARTIAL CORRELATION COEFFICIENTS, TOLERANCE, AND
```

```
SEQ   CZSMP.FTN            26-FEB-81    12:44:28    PAGE     7
      C       F TO ENTER FOR VARIABLES OUT OF THE REGRESSION
      C
      410     NVO=NVO+1
              NIEN(NVO)=I
              TOLEV(NVO)=A(LII)
              R(NVO)=A(LID)/DSQRT(A(LII)*A(LDD))
              FE(NVO)=(A(LID)**2*(RESDF-1.))/(A(LII)*A(LDD)-A(LID)**2)
      420     IF (I-KAY) 460,430,460
      430     IF (C(I)) 440,440,450
      440     FKAY=F(NVI)
              GO TO 460
      450     FKAY=FE(NVO)
      460     CONTINUE
      C
              IF (LR.LT.2) GO TO 310
      C       WRITE HEADING FOR COEFFICIENTS
      C
              WRITE (LP,470)
      470     FORMAT (/57X,1H./21X,21HVARIABLES IN EQUATION,15X,1H.,19X,25HVARIA
             1BLES NOT IN EQUATION/57X,1H./6X,8HVARIABLE,6X,11HCOEFFICIENT,2X,10
             2HSTD. ERROR,2X,13HF TO REMOVE .,5X,8HVARIABLE,4X,13HPARTIAL CORR.,
             35X,9HTOLERANCE,4X,10HF TO ENTER/57X,1H.)
      C
      C       PRINT THE REGRESSION ANALYSIS TABLE
      C
              WRITE (LP,480) ALPHA
      480     FORMAT (57X,1H./10X,9H(CONSTANT,1X,F11.5,2H ),24X,1H.)
              NGO=0
      490     IF (NVO) 530,530,500
      500     IF (NVI.LE.0) GO TO 560
              LNV=MIN0(NVI,NVO)
      C
      C       NVO AND NVI BOTH POSITIVE,PRINT BOTH SIDES OF TABLE
      C
              DO 520 I=1,LNV
              WRITE (LP,510) INEN(I),B(I),D(I),F(I),NIEN(I),R(I),TOLEV(I),FE(I)
      510     FORMAT (8X,I3,1X,F19.5,1X,F11.5,1X,F11.1,3H  .,7X,I3,1X,F19.5,1X,F
             113.8,1X,F12.4)
      520     CONTINUE
              NVI=NVI-LNV
              NVO=NVO-LNV
              NGO=LNV
              GO TO 490
      C
      C       NVO ZERO, PRINT LEFT SIDE ONLY
      C
      530     IF (NVI.LE.0) GO TO 590
              DO 550 I=1,NVI
              II=I+NGO
              WRITE (LP,540) INEN(II),B(II),D(II),F(II)
      540     FORMAT (8X,I3,1X,F19.5,1X,F11.5,1X,F11.1,3H  .)
      550     CONTINUE
              NVI = NVI + LNV ! RESTORE TO NUMBER OF VARS IN REGRESSION
              GO TO 590
      C
      C       NVI ZERO,PRINT RIGHT SIDE ONLY
```

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SEQ    CZSMP.FTN          26-FEB-81    12:44:28     PAGE      8
       !.........!.........!.........!.........!.........!.........!.........!
       C
       560       DO 580 I=1,NVO
                 II=I+NGO
                 WRITE (LP,570) NIEN(II),R(II),TOLEV(II),FE(II)
       570       FORMAT (57X,1H.,7X,I3,1X,F19.5,1X,F13.8,1X,F12.4)
       580       CONTINUE
       590       IF (L-MAXSTP) 310,600,600
       600       WRITE (LP,610)
       610       FORMAT (23H SPECIFIED STEP REACHED)
       620       RMS=RSSD*DELTA(ITT)
                 IF (ITT.EQ.1) WRITE (LP,630) RMS
       630       FORMAT ('0EAST-WEST FIT',F7.1,'  METERS RMS')
                 IF (ITT.EQ.2) WRITE (LP,640) RMS
       640       FORMAT ('0NORTH-SOUTH FIT',F7.1,'  METERS RMS')
                 WRITE (LP,650) NVI,ALPHA,(INEN(I),B(I),I=1,NVI)
                 WRITE (1,650) NVI,ALPHA,(INEN(I),B(I),I=1,NVI)
       650       FORMAT (I5,F10.3)
       660       CONTINUE
                 CLOSE ( UNIT=3, DISP='PRINT')
                 STOP 'RESULTS IN CZSMP.LST'
                 END
                 SUBROUTINE STEPRG (ADVFL)
                 LOGICAL ADVFL
                 DOUBLE PRECISION X,XN,A
                 DIMENSION X(40), A(840), C(40), F(40), FE(40)
                 COMMON X,XN,A,C,F,FE,L,NTGC,IP,NIP,FINC,FOUT,KAY,FLAG,KDEP,DF,TOL
                 LF(IX,JX)=JX-IX+NIP+1-((IP-IX+1)*(IP-IX+2))/2
                 VMIN=1.E20
                 VMAX=-1.
                 KVI=0
                 KVO=0
                 DO 30 K=1,IP
                 IF (K.EQ.KDEP) GO TO 30
                 IF (C(K).GT.0.) GO TO 10
                 KVI=KVI+1
                 V=F(KVI)+(C(K)+7.)**4
                 IF (V.GT.VMIN) GO TO 30
                 VMIN=V
                 KMIN=K
                 GO TO 30
        10       KVO=KVO+1
                 IF (C(K).EQ.1.) GO TO 30
                 V=FE(KVO)+(C(K)-2.)**4
                 IF (V.LE.VMAX) GO TO 30
                 LKK=LF(K,K)
                 IF (A(LKK)-TOL) 30,20,20
        20       VMAX=V
                 KMAX=K
        30       CONTINUE
                 IF (.NOT.ADVFL) GO TO 100
                 IF (VMIN-FOUT) 40,40,60
        40       IF (L-1) 60,60,50
        50       C(KMIN)=C(KMIN)+9.
                 KAY=KMIN
                 FLAG=-1.
                 GO TO 60
```

```
SEQ   CZSMP.FTN          26-FEB-81    12:44:28     PAGE      9
      I.........I.........I.........I.........I.........I.........I.........I.
60      IF (VMAX-FINC) 90,70,70
70      C(KMAX)=C(KMAX)-9.
        KAY=KMAX
        FLAG=1.
80      CALL STEP
        DF=DF+FLAG
        RETURN
90      FLAG=0.
        RETURN
100     CONTINUE
        IF (DF.GT.1.) GO TO 50
        GO TO 90
        END
        SUBROUTINE LGR( V , FV , XI , XRESLT)
C
C-----------------------------------------------------------------
C
C         FNVAL1  -
C                  I                                       FNVAL3 -
C                  I     XRESLT -                         I     FNVAL4 -
C                  I              I      FNVAL2 -          I          I
C                  I              I        I               I          I
C  I-----------------------------------------------------------------------
C                  -              -        -               -          -
C             VAL1  -    XINTRP   -        VAL2 -      VAL3  -     VAL4  -
C
C         GIVEN FOUR VALUES ( VAL1 => 4 OR ARRAY V ) AND
C       GIVEN FOUR CORRESPONDING VALUES ( FNVAL1 => 4 OR ARRAY FV ) THAT
C       ARE A FUNCTION OF THE FORMER VALUES,
C       AND  GIVEN A VALUE XINTRP ( XI ) THAT IS ADJACENT TO  VAL1 => 4
C       THEN THIS ROUTINE RETURNS A VALUE, XRESLT,  THAT IS THE LAGRANGE
C       INTERPOLATION OF XINTRP ABOUT FNVAL1 => 4.
C
C
C
        REAL V(4) , FV(4) , XRESLT , XI, PART(4)
        REAL A,B,C,D
C
        A = XI - V(1)
        B = XI - V(2)
        C = XI - V(3)
        D = XI - V(4)
D
D       TYPE 500,A,B,C,D
D 500   FORMAT(4F12.6
D       TYPE 500,V
D       TYPE 500,FV
D       TYPE 500,XI
C
        PART(1) = ( B * C * D  )
     +          / (( V(1) - V(2)) * ( V(1) - V(3)) * ( V(1) - V(4)) )
     +          * FV (1)
C
        PART(2) = ( A * C * D  )
     +          / (( V(2) - V(1)) * ( V(2) - V(3)) * ( V(2) - V(4)) )
     +          * FV (2)
```

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SEQ   CZSMP.FTN          26-FEB-81    12:44:28    PAGE    10

C
      PART(3) = ( A * B * D )
     +          / (( V(3) - V(1)) * ( V(3) - V(2)) * ( V(3) - V(4)) )
     +          * FV (3)
C
      PART(4) = ( A * B * C )
     +          / (( V(4) - V(1)) * ( V(4) - V(2)) * ( V(4) - V(3)) )
     +          * FV (4)
      XRESLT = PART(1) + PART(2) + PART(3) + PART(4)
C
D     TYPE 500,PART
D     TYPE 500,XRESLT
C
C
      RETURN
      END
      SUBROUTINE STEP
      DOUBLE PRECISION X,XN,A
      DIMENSION X(40), A(840), C(40), F(40), FE(40)
      COMMON X,XN,A,C,F,FE,L,NTGC,IP,NIP,FINC,FOUT,KAY,FLAG,KDEP,DF,TOL
      LF(IX,JX)=JX-IX+NIP+1-((IP-IX+1)*(IP-IX+2))/2
      LKK=LF(KAY,KAY)
      M=0
      DO 70 I=1,IP
      DO 70 J=1,IP
      M=M+1
      IF (I-KAY) 10,70,20
10    LIK=LF(I,KAY)
      GO TO 30
20    LIK=LF(KAY,I)
30    IF (J-KAY) 40,70,50
40    LKJ=LF(J,KAY)
      GO TO 60
50    LKJ=LF(KAY,J)
60    A(M)=A(M)-A(LIK)*A(LKJ)/A(LKK)
70    CONTINUE
      DO 110 I=1,IP
      IF (I-KAY) 80,110,90
80    LIK=LF(I,KAY)
      GO TO 100
90    LIK=LF(KAY,I)
100   A(LIK)=A(LIK)*FLAG/A(LKK)
110   CONTINUE
      A(LKK)=-1.D0/A(LKK)
      RETURN
      END
```

CZCS NEAREST NEIGHBOR RESAMPLING PROGRAM

```
SEQ     CZSNR,FTN/3        26-FEB-81    12:46:08    PAGE    1
        !.........!.........!.........!.........!.........!.........!.........!.....
        C       CZCS NEAREST RESAMPLER

        C
        C       ADAPTED BY GLENN DAVIS ON SEPTEMBER 21,1980 FROM LNR
        C
        C
        C
        C
                PARAMETER NSL=34,NBL=620,MAXOLY=16,BYTBYT=0,WRDWRD=2
                INTEGER*2 WC,WR
                INTEGER*2 IOFF(NSL),ID(5), CVAL, START,FIRST
                LOGICAL*1 LBF(2048),JBUF(NBL,NSL),ST(10),STO(10),HFN(18)
                LOGICAL*1 PRNTJH, PRNTHD
                LOGICAL*1 DA(10),TM(10)
                INTEGER*2 OHN,IV(MAXOLY),NBRMVS,MVTYPE,INSKIP,OUTSKP
        C        NBLTS IS NUMBER OF BLOCKS TO SKIP ON SHORT READ
                DIMENSION DRVAL(6),DCVAL(6), DR(6), DC(6)
                REAL LTSC,LNSC
        C
        D       CALL ASSIGN( 4,'CZCS.LST')
        C
                CALL DATE(DA)
                CALL TIME(TM)
        C
                WRITE (5,20) DA,TM
        D       WRITE (4,20) DA,TM
        20      FORMAT ('0CZCS NEAREST RESAMPLER V 1.0',4X,10A1,4X,10A1/)
                NSLM=NSL-1
                NWL=NBL/2
                NBTR=NBL+512
        C
        C
                IALL=ALL
                WRITE (5,30)
        30      FORMAT ('$INPUT IMAGE TITLE ?   ')
                READ (5,40) ST
        40      FORMAT (10A1)
                CALL GHFN (ST,HFN)
                CALL ASSIGN (2,HFN)
                READ (2,50) ID
        50      FORMAT (1X,5A2)
                READ (2,60) NIE,NIL,NBP,IIP,NIPP,IEO,ILO
        60      FORMAT (7I5)
                READ (2,70) DELP,DELL,LTSC,LNSC
        70      FORMAT (4F12.6)
                CLOSE ( UNIT = 2)
                CALL P1 (ID,IPN)
                NBI=NIE*NBP
                NEL= NBL/NBP
                IF(IIP.NE.2)GO TO 77
        77      WRITE (5,80)
        80      FORMAT ('$WHICH DRIVE  ?  ')
                READ (5,90) IIDR
        90      FORMAT (7I5)
        C
                WRITE (5,100)
```

```
SEQ     CZSNR.FTN;3          26-FEB-81    12:46:08     PAGE      2
        !.........!.........!.........!.........!.........!.........!.........!...
        100   FORMAT ('$OUTPUT IMAGE TITLE ?  ')
              READ (5,40) STO
              CALL GHFN (STO,HFN)
              CALL ASSIGN (2,HFN)
              READ (2,40) ID
              READ (2,60) NE,NL,NBP,IP,NPP
              READ (2,70) DX,DY,FLT,FLN
              NLA=NSL/2
              CLOSE ( UNIT = 2)
        C
              IF (MOD(NBP,2).EQ.0) GO TO 110
                 INSKIP = 1
                 OUTSKP = 1
                 NBRMVS = NBP
                 MVTYPE = BYTBYT
                 GO TO 120
        C
         110  INSKIP = 2
              OUTSKP = 2
              NBRMVS = NBP/2
              MVTYPE = WRDWRD
        C
         120  CONTINUE
        C
              WRITE(5,80)
              READ (5,90) IODR
              NBO=NE*NBP
              NBTM= 1024
        C
              HDN=DY/2.
              CALL GT (FLT,FLN,IP,XFO,YFO)
              CALL GT (LTSC,LNSC,IP,XSC,YSC)
        C
              WRITE (5,170)
        170   FORMAT ('$BEGINNING ROW AND COLUMN ? ')
              READ (5,180) IBR,IBC
        180   FORMAT (2I10)
              IF (IBR.NE.0) GO TO 200
              IBR=1
              IBC=1
              IER=NL
              IECC=NE
              WRITE (5,190) IBR,IBC,IER,IECC
        D     WRITE (4,190) IBR,IBC,IER,IECC
        190   FORMAT ('0DEFAULT VALUES:   ',4I5/)
              GO TO 220
        200   WRITE (5,210)
        210   FORMAT ('$ENDING ROW AND COLUMN ? ')
              READ (5,180) IER,IECC
              IF (IER.GT.NL) IER=NL
              IF (IECC.GT.NE) IECC=NE
              WRITE (5,60)
        D     WRITE (4,60)
        220   NOF=100
              IRMN= ILO+1
              IRMX= ILO+NIL
```

```
SEQ   CZSNR,FTN13          26-FEB-81    12:46:08    PAGE     3
      !.........!.........!.........!.........!.........!.........!.........!.........!....
                ICMN= IEO+1
                ICMX= IEO+NIE
                CALL ALTPRT(,40)
      C
      C
                CALL IMOPEN (1,ST,,IIDR,NBI,NIL,'R')
                CALL IMOPEN (2,STO,,IODR,NBO,NL,'M')
      D         CALL ASSIGN ( 3, 'CZCS3.LST')
      C
      C
      C         WRITE (4,144) XFO,YFO,XSC,YSC
      C144      FORMAT( '      XFO                YFO               XSC               YSC '
      C     +        ,/,4F15.4 )
      C         WRITE(4,148) INSKIP,OUTSKP,NBRMVS,MVTYPE
      C148      FORMAT( '  INSKIP  OUTSKP  NBRMVS  MVTYPE ',/,4I8 )
      C
      C
      230       IEC=IBC+NOE-1
                IF (IEC.LE.IECC) GO TO 240
                IEC=IECC
                NOE=IEC-IBC+1
      240       NOL=IER-IBR+1
                IECP=IEC+1
                KO=(IBC-1)*NBP
                NO=KO/512
                IF(NO.LT.0) NO=0
                KO=KO-NO*512
      C
      C         THESE VALUES ARE SWATH LIMITS
      C
                DLX = XFO-XSC
                DLY = YFO-YSC
                XMIN=DLX+(IBC-.5)*DX
                XMAX=XMIN+(NOE-1)*DX
                YMAX=DLY-(IBR-.5)*DY
                YMIN=YMAX-(NOL-1)*DY
      C
      C          THE 21 TERM POLYNOMIALS DEFINE BOTH U AND V ADJUSTMENTS.
      C          SINCE THIS SCHEME WORKS ALONG A SINGLE OUTPUT LINE, THE
      C          VERTICAL COMPONENT NEEDS TO BE CHANGED ONLY WHEN A NEW
      C          OUTPUT LINE IS CHOSEN.  P2 EXTRACTS FROM THE POLYNOMIAL
      C          COEFFICIENTS THE HORIZONTAL ADJUSTMENTS, OR SO THE STORY
      C          GOES.
      C
                CALL P2 (XMIN,XMAX,YMAX,Y,DX,DY,DY1)
      C
      C         WRITE (4,140) XMAX,XMIN,YMAX,YMIN
      C140      FORMAT( '      XMAX               XMIN              YMAX              YMIN '
      C     +        ,/,4F15.4 )
      C         WRITE (4,142) DX,DY,DLX,DLY
      C142      FORMAT( '       DX                 DY                DLX               DLY '
      C     +        ,/,4F15.4 )
      C         WRITE (4,146) TH,Y,DY1
      C146      FORMAT( '       TH                 Y                 DY1               '
      C     +        ,/,4F15.4 )
      C
```

```
SEQ     CZSNR.FTN;3          26-FEB-81    12:46:08     PAGE      4
        !.........!.........!.........!.........!.........!.........!.........!.........!.
              ORN=IBR
        D     WRITE (4,60)IEC
        C
        C
        C
        D     KBAND = 6
        D     KMIN = 9999
        D     KTIMER = 0
              DO 500 J=1,NOL
        C
        C     P3 CALCULATES THE 0TH THROUGH 5TH DERIVATIVES OF BOTH THE
        C     ROW AND THE COLUMN TERMS WHICH GIVE THE CHANGE FROM ONE
        C     EVALUATION OF THE POLYNOMIAL TO THE NEXT. BY ADDING THE
        C     CHANGE TO THE PREVIOUS VALUE OF THE FUNCTION, A LOT OF
        C     CALCULATIONS ARE AVOIDED.  THE 0TH DERIVATIVE IS THE
        C     FUNCTION ITSELF.  THE DERIVATIVES ARE WITH RESPECT TO THE
        C     EASTING OR ALONG ROW DIMENSION STARTING FROM THE RIGHT SIDE
        C     OF THE SWATH.
        C
              CALL P3 (Y,RL,CL,DR,DC)
              DC(1)= DC(1)-1
              WC= DC(1)
              WR= DR(1)
              ICL= CL
              IRL= RL
              IF (J.EQ.1) ILN=IRL
              NPN=WC-ICL+1
              NLN=WR-IRL+1
              IF (NPN.GT.NEL) STOP 'INSUFFICIENT ELEMENT STORAGE'
              IF (NLN.GT.NSL) STOP 'INSUFFICIENT LINE STORAGE'
        C
        C
        C     INVOKE FILL JBUF
        C     ASSIGN 99903 TO I99900
        C     GO TO 99900
        C99903 CONTINUE
        C***********************************************************
        C         PROCEDURE TO FILL JBUF
        C***********************************************************
        C
        C99900 CONTINUE
        250   IF (IRL+NSLM.LE.ILN) GO TO 280
        C
              YVAL = Y + ( ILN - IRL  ) * DY1
              CALL P3( YVAL, RLVAL, CLVAL, DRVAL, DCVAL )
              CVAL = DCVAL(1) + 10
        C     ICLVAL = CLVAL
        C
        C     ICLVAL IS PIXEL CONTAINING LEFT EDGE OF INPUT WINDOW.
        C     SUBTRACT ONE TO SKIP OVER ONLY THOSE THAT ARE TO THE
        C     LEFT OF THE EDGE, SUBTRACT ANOTHER AS A MARGIN OF SAFETY.
        C
        C     ICLVAL = ICLVAL - 2
        C
              LC=MOD(ILN-1,NSL)+1
        C
```

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SEQ      CZSNR.FTN;3          26-FEB-81     12:46:08      PAGE      5
         1.........1.........1.........1.........1.........1.........1.........1.....
         255        IF(LC.GT.0) GO TO 256
                 LC= LC+NSL
                 GO TO 255
          256        CONTINUE
         C
                 START = MAX( 0, CVAL - IEO - ( NBL/NBP ))
                 NBLTS= START *NBP/512
                 IF(NBLTS.LT.0) NBLTS=0
                 IRN=ILN-ILO
                 IF (IRN.GE.1.AND.IRN.LE.NIL) GO TO 260
                 CALL MOVE (0,0,LBF,2,1024,2)
                 GO TO 270
            260  CONTINUE
                 CALL IMSHRT (1,NBLTS,NBTR)
                 CALL IMREAD (1,IRN,LBF)
          270    NBYTS= NBLTS*512
                 K= START *NBP-NBYTS+1
          275    CALL MOVE (LBF(K),1,JBUF(1,LC),1,NBL,0)
         C
         C       THE INPUT SPACE IS SKEWED IN RELATION TO THE OUTPUT SPACE.
         C       THE OFFSETS CALCULATED HERE ALLOW THE INPUT SPACE TO BE STORED
         C       AS A RECTANGULAR AREA.  WHEN IT IS INDEXED INTO, THE OFFSETS
         C       ARE USED TO SELECT THE PROPER AREA.
         C
                 IOFF(LC)= START*NBP
                 ILN=ILN+1
         C       IF (J.EQ.1) KMIN = MIN( START, KMIN )
                 GO TO 250
         C
            280  CONTINUE
         C
         C       GO TO 99901
         C
         C99901 GO TO I99900,(99903)
         C************************************************************
         C************************************************************
         C
                    IF(NO*512+NBTM.GT.NBO)NBTM=NBO-NO*512
         C
         C
                 CALL IMSHRT (2,NO,NBTM)
                 CALL IMREAD (2,ORN,LBF)
         C
         D       IF ( MOD( J-1,50).LE.0) WRITE(4,4098)
         D4098 FORMAT('1',' LINE      WC      ICL      NPN      WR      IRL',
         D       +        '     NLN    STARTS # LINE'
         D       +,T80,    '    I       K       WC       LC   IOFF(LC)  WR')
         D       WRITE(4,4099) J,WC,WR,ICL,IRL,NPN,NLN,START,LC
         D4099 FORMAT(9I8 )
                 KOUT= KO+(NOE-1)*NBP+1
         D       IF (MOD(KTIMER,NSL).LT.1) PRNTJB = .TRUE.
         D       KTIMER = KTIMER + 1
         C
                 DO 400 I=1,NOE
                 R= DR(I)
                 WR= R
```

```
SEQ   CZSNR.FTN;3        26-FEB-81    12:46:08     PAGE     6
            CALL MOVE(0,0,IV,2,NBP,1)
            IF(WR.GT.IRMX.OR.WR.LT.IRMN) GO TO 399
D           IF(WR.GE.IRMN.AND.WR.LE.IRMX)GO TO 382
D           WRITE(4,380) I,WR,IRMN,IRMX
D380        FORMAT( ' ROW VALUE OUT OF BOUNDS : I,WR,IRMN,IRMX ',4I6 )
D           GO TO 399
C
 382        LC=MOD(WR-1,NSL)+1
C
            C= DC(1)
            WC= C
C
C
            IF(WC.LT.ICMN.OR.WC.GT.ICMX)GO TO 399
D           IF(WC.GE.ICMN.AND.WC.LE.ICMX)GO TO 384
D           WRITE(4,383) I,WR,ICMN,ICMX
D383        FORMAT( ' COLUMN VALUE OUT OF BOUNDS : I,WC,ICMN,ICMX ',4I6 )
D           GO TO 399
C
 384        K= WC*NBP-IOFF(LC)+1
C
D375        KDELT = KPREV - K
C           WRITE(4,4095) I,K,WC,LC,IOFF(LC),WR,KDELT
C4095       FORMAT(T80,7I7 )
D385        KPREV = K
C
D           IF (K.LE.NBL.AND.K.GE.1 ) GO TO 388
C           KERRCT = KERRCT + 1
C           IF ( MOD( KERRCT,100).GT.10) GO TO 399
D           WRITE(4,386) J,I,K,WR,WC,IOFF(LC),LC
D386        FORMAT(' K OUT OF BOUNDS: OUTROW  OUTCOL        '
D          +,'K       WR       WC IOFF(LC)      LC'
D          + / 18X,7(I6,2X))
D           GO TO 399
C
            IF(K.GT.NBL)GO TO 399
            IF(K.LT.1)GO TO 399
 388        CALL MOVE(JBUF(K,LC),INSKIP,IV,OUTSKP,NBRMVS,MVTYPE)
            K=K+NBP
C
 399        CALL MOVE(IV,INSKIP,LBF(KOUT),OUTSKP,NBRMVS,MVTYPE)
            KOUT= KOUT-NBP
C
            DO 402 JD=1,5
            JP= JD+1
            DC(JD)= DC(JD)+DC(JP)
 402           DR(JD)= DR(JD)+DR(JP)
C
D           IF (.NOT.PRNTJB) GO TO 400
D           PRNTJB = .FALSE.
D           PRNTHD = .TRUE.
D           KMIN = ( IOFF(LC) / NBP ) - 5
D           JPLUS = LC + NSL -1 - NLN
C
D           DO 4083 KINDX = LC - NLN + 1 , JPLUS
D           KWHC = MOD(KINDX - 1,NSL) + 1
```

```
D        KEND = ( IOFF(KWHC) /NBP - KMIN  ) * 4 + 1
D        KEND = MAX(KEND,1)
D        KEND = MIN( KEND,25)
D        IF (.NOT.PRNTHD) GO TO 4083
D        PRNTHD = .FALSE.
D        INDX = IOFF(KWHC)/NBP
C        INDX = IOFF(KWHC)/NBP + 1
D        FIRST = K /NBP + KBAND - 1
D        WRITE(3,4081) IRL,INDX, FIRST
D4081    FORMAT('1INPUT SPACE STARTS AT ROW ',I4,'  COLUMN ',I4,
D    +         /'                    DISPLAYED FROM COLUMN ',I4)
D        WRITE (3,20) DA,TM
C        IF (KEND.GT.80.OR.KEND.LT.0) TYPE *, '  KEND = ',KEND
C    +   ,' IOFF(LC) ',IOFF(LC),'  LC ',LC,' KMIN ',KMIN
D4083    WRITE(3,4085) (JBUF(INDX,KWHC),INDX= FIRST,156 + FIRST,NBP)
D4085    FORMAT( T <KEND >,3004 )
D        WRITE(3,4084) IBC
D4084    FORMAT('1',' OUTPUT SPACE'/ ' LINE PIXEL' / 5X,I4)
C
   400   CONTINUE
C
D        KEND = NOE * NBP + NBP
D        KEND = MIN( 180, KEND )
D        KEND = ( KOUT + KBAND -1 + KEND ) - NBP
D        WRITE(3,4080) ORN, (LBF(INDX),INDX=KOUT + 5 + NBP,KEND,NBP)
D4080    FORMAT( ' ',I4, 3004 )
C
         CALL IMWRIT (2,ORN,LBF)
         WRITE (5,490) ORN,IBC,IEC,DR(1),DC(1)
   490   FORMAT ('+',3I5,2F10.1)
         ORN=ORN+1
   500   Y=Y+DY1
C
         IF (IEC.EQ.IECC) GO TO 510
         IBC=IEC+1
         GO TO 230
C
   510   CONTINUE
D        CLOSE ( UNIT=4, DISP = 'PRINT' )
D        CLOSE ( UNIT=3, DISP = 'PRINT' )
         STOP
C
C
         END
```