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Final Report

on the Project

"Definition and Testing of the Hydrologic Component of the Pilot Land Data System"

submitted by the

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I. INTRODUCTION

This report summarizes the results of the collaborative project between NASA's Goddard Space Flight Center and the Remote Sensing Systems Laboratory at the University of Maryland. The project was part of Goddard's ongoing development efforts towards the design of a Pilot Land Data System (PLDS) to support the land and atmospheric sciences. The PLDS project represents a multidisciplinary system development involving the sharing of design and development tasks between several NASA divisions and several key governmental and university institutions.

The technical objective for the present University of Maryland's collaboration was to provide research and development support to the Land Analysis software design efforts within the PLDS framework. The specific aim of the project was to develop within the PLDS software design environment, an easily implementable and user friendly geometric correction procedure to readily enable the georeferencing of imagery data from the Advanced Very High Resolution Radiometer (AVHRR) onboard the NOAA series spacecraft.

A key aspect in the PLDS development has been the close interaction between a preselected science scenario, the International Scienctific Land Science and Climatology Project (ISLSCP) and the actual systems development team. A benefit of this collaboration has been the avoidance of redundancy in design and the adoption of algorithms that have been found to be well tested by a large science user community. Accordingly, on recommendation by the PLDS Land Analysis Software development Task Team, the geometric correction subsystem was designed using the algorithm originally developed in a different system environment at the Johnson Space Flight Center (JSFC) by Lockheed Corporation. As originally implemented, the system was known as the Image Correction and Registration Utility System (ICARUS) and was only operable in a IBM environment with a minimum virtual memory of six megabytes. The ICARUS approach offers a simple and yet efficient means of mapping image data to earth coordinates.

In order to address the technical goals of the present project, a software subsystem was developed within the guidelines set by the PLDS development environment utilizing NASA GSFC's Image Analysis Facility's (IAF) Land Analysis Software (LAS) coding standards. IAF's current program development environment, the Transportable Applications Executive (TAE) operates under a VAX VMS operating system and was used as the user interface. The developed software, relating to the georeferencing of AVHRR datasets, has been installed, tested and is now operating under LAS as three separate LAS functions - GSC_POINTS, GCS_GEOTAG, GCS_GRID.

Subsequent to testing, the function GCS_GEOTAG has been transported to GSFC's Terrestrial Physics Division's LTP system and is currently in routine use to support the geometric referencing of AVHRR image datasets required by the ongoing First ISLSCP Field Experiment (FIFE) project. FIFE is at present one of the projects currently selected to serve as a vehicle to test the overall system capabilities of the Pilot Land Data System.

Section II of this report provides a brief overview of the ICARUS algorithm that has been implemented in the set of functions developed in this project period. A functional specifications description is provided in Section III and finally, Section IV gives a list of the individual programs and directory names containing the source and executables installed in the IAF system. Appendix A-C provides a USER GUIDE in the LAS system documentation format for the three functions developed.

II. THE ICARUS APPROACH

II.1 The Geometry of the AVHRR Dataset

The AVHRR dataset is obtained directly as a result of digitizing the analog data output from the sensors on board the spacecraft. The instantaneous field of view (IFOV) of each sensor is approximately 1.4 milliradians leading to a resolution at the satellite sub-point of 1.1 kms. for a nominal altitude of 833 kms. in a near "sub-synchronous" orbit. The scanning rate of the AVHRR is 360 scans per minute. At the sampling rate of 39,,936 samples per second per channel, there are 1.362 samples per IFOV. A total of 2048 samples is obtained per channel per earth scan, which spans an angle of ±56 degrees from the nadir (sub-point view).

The processor onboard the satellite also samples the real time AVHRR data to produce reduced resolution Global Area Coverage (GAC) data. Four out of every five samples along the scan line are used to compute one average value, and data from every third scan line is processed. All of the GAC data computed during a complete pass is recorded onboard the satellite for transmission to earth on command.

The original 10 bit precision of the AVHRR data is transmitted from the satellite in real time (High Resolution Picture Transmission or HRPT data), and selectively recorded onboard the satellite for subsequent playback as Local Area Coverage (LAC) data. For the GAC data, the 10 bit data precision is retained but the resolution is degraded to 4.0 kms. along the scan line at the sub-point.

The resultant image geometry is thus a two-dimensional array of digital brightness values in each of the wavelengths. The pixels are uniform samples along the cross-track direction while the orbital motion of the satellite produces the down track scan motion. Since no attempt is made to transform the sampled data to either a spacecraft centered (orbital scanner projection) or earth centered projection (any standard cartographic projection), the distributed GAC, LAC or HRPT datasets are distorted in the spatial sense.

II.2 Description of the ICARUS Algorithm

The approach referred to as the ICARUS approach was originally designed at the Johnson Space Center and is a comprehensive geometric correction software system to process and georeference a number of different satellite imagery including the AVHRR. As originally implemented, the AVHRR geometric correction system requires a minimum available virtual memory of six megabytes. For the present development, the relevant portion of the algorithm for the forward/inverse transformation of AVHRR pixel-line locations to a geodetic coordinate system was obtained from a description of the ICARUS software and has been programmatically implemented.

The ICARUS approach utilizes nominal spacecraft and earth related parameters and the assumptions are listed below:

1. The earth's surface is represented by an oblate spheroid with an assumed equatorial and polar radius;

2. The spacecraft is in circular orbit with a fixed inclination angle and altitude;

3. The sensor has a uniform scan rate with a constant look-angle from nadir and points to the earth's center;

4. The precision rate of the line of nodes is uniform and is one inertial revolution per mean solar year;

5. Atmospheric effects, terrain elevation effects and ground track curvature due to orbit perturbations are ignored;

6. Variations in satellite altitude, orbital velocity, perturbations and non-spherical earth's surface are ignored.

A comprehensive description of the ICARUS software is available separately (Boatwright et al., 1984), and the following is a brief review of the salient steps of the algorithm for mapping between image and geodetic latitude-longitude coordinates.

The ICARUS approach relies on a selected tie-point for which both geodetic (latitude-longitude) and image coordinates (line, pixel) have been predetermined.

A. Assume that the selected tie point lines on the surface of an oblate spheroidal earth.

B. Construct an intersection sphere about the center of the earth and tangential to the spheroid at the tie point.

C. A scanner map projection is then performed on this sphere: a U-axis (equator) is generated from the intersection of the inertial orbit plane of the satellite with this sphere; a V-axis (meridian) is defined by the intersection of the scan plane containing the tie point and the sphere. Thus, the U-V origin is at nadir of the scan containing the tie point. U-V Distances are measured in meters, positive northwards and eastward respectively.

D. Points in the AVHRR scene are then related to U-V coordinates on the 'constructed' sphere by explicit models of the earth's rotation and scan curvature effects.

E. Points on the earth are related to points on the 'constructed' sphere by geocentric projection in which the geocentric latitude is computed from the geodetic latitude.

F. The conversion relations in both forward and inverse directions are analytic.

III. FUNCTIONAL SPECIFICATIONS

The AVHRR data is a cross track scanning system with five spectral channels. The resultant two-dimensional image is invariably associated with distortions due to the influence of the earth's rotation on the scanning geometry, panoramic distortions and earth curvature effects. The implementation of the ICARUS algorithm results in an output array of geodetic latitude-longitude coordinates corresponding to the locations of the pixels at the corners of a conceptual grid superimposed on the original image frame. The size of the grid shall be specified by the user in terms of number of pixels and scan line intervals using the leading top left corner of the image as the origin. The output array of gridded coordinates may also optionally serve as an ancilliary data file for subsequent data retrieval and or image resampling to any user desired cartographic projection.

The present version of the AVHRR geometric correction capability has been implemented on the IAF computer facility and is available under TAE as part of LAS. The programs have been written in DEC/VAX Fortran 77 under the VMS operating system. No VMS specific utilities have been implemented except those called under TAE controlled user interfacing. The disk resident input data to the geometric correction subsystem may be either HRPT (LAC) or GAC data. The format of input image data is expected to be in LAS image file format after the original GAC/LAC/HRPT dataset has been ingested through the PLDS data ingestion facility.

The functional implementation of the ICARUS algorithm has resulted in three LAS/TAE functions: GCS_POINTS, GCS_GEOTAG and GCS_GRID. The capabilities of the three functions are given below:

- GCS_POINTS — Given a user desired pixel location and scanline address, determine its corresponding latitude and longitude; alternatively, given a user input lat-long, the corresponding pixel-line location; the input is interactive, while the output is on screen and optionally to a disk resident session log file.

- GCS_GEOTAG — Generate a user desired grid of latitude-longitudes at user specified grid intervals of pixels and scan lines currently in a FIFE recommended format (this format will later be changed to a PLDS format). The present output is in two disk resident files, one for latitudes and the other for longitudes.

- GCS_GRID — Generate a mapping grid of coordinates in user specified output coordinate space (either AVHRR image space or geodetic coordinate space, i.e., latitude-longitude).

A prerequisite to using any of the three functions is that the user is required to determine one preselected tie point coordinate in both image and geodetic coordinate space. Usually this is accomplished using an image processing facility at either the user's or the IAF's system.

The user scenario for the use of the three functions are typically as follows:

1. Point to a pixel on the AVHRR from an image display of the same, and determine its corresponding latitude-longitude - use GCS_POINTS.

2. Fix a geodetic latitude-longitude on a map and determine its corresponding pixel-line address on the original image frame - use GCS_POINTS.

3. Input (rectangular) corner coordinates in pixel-line locations of a window in a AVHRR image, input pixel and line interval for a desired grid, and georeference (output latitude-longittude for) every corresponding grid intersection on the image - use GCS-GEOTAG.

4. Transform a selected image frame or rectangular image subset from original image space into a geodetic (lat-long) projection - Step I. use GCS_GRID
Step II. use GEOM

GCS_GRID creates the ancilliary mapping grid data required by LAS function GEOM as input. The output of GCS_GRID is, as described earlier, a mapping grid of coordinates, or a file of grid coordinates that reflect the mapping of AVHRR to geodetic coordinates. The mapping transformation applied by GEOM uses this data to perform the resampling. Thus GCS_GRID is required to be implemented only for geometric transformation of AVHRR imagery to latitude-longitude space. The grid may be generated over a user desired window in the original image frame and for a maximum grid size of 64x64 .

In the event that GCS_GRID is being implemented for the purpose of invoking GEOM, it is essential to rememeber that the original image frame be checked for the direction of the pass. Since the origin of the image frame coordinate system is the bottom right corner of the frame for an ascending pass, the image must be flipped 180 degrees before using as input to tie-point selection or to GEOM. While the image coordinates as applied to the designed functions are always referred to in full frame coordinates, it is possible to selectively input a part of the frame for actual geometric transformation using GEOM, and in this case, one may use screen coordinates (upper right corner - 1,1 : bottom right corner 512,512) to define the window.

IV. SOFTWARE DIRECTORY

The programs that have been supplied under the present contract are disk resident in the IAF system. The program modules are fortran coded subroutines and are linked together through a driver module for each of the three functions.

The modules are as follows:

User-interface	Calls routine to handle the TAE interface and parameter handling
Initialize	Initializes parameters for geocentric (OSC) to AVHRR scene coordinate conversions
AVOSC	Performs conversion from AVHRR to OSC coordinates
OSCAV	Performs conversion from OSC to AVHRR scene pixel, line coordinates
OSCLL	Computes conversion from geocentric (OSC) coordinates to geodetic latitude-longitude
LLOSC	Computes latitude-longitude of pixel location within GAC, LAC or HRPT dataset

These modules have been linked as appropriate within each of the three functions. Examples of the program logic are given below:

Function GCS_POINTS

```
Program POINTS//

        Call user-interface
        Call initialize
        DO for every user input pixel location

                Case:   Geodetic to AVHRR
                        Call LLOSC
                        Call OSCAV

                Endcase:

                Case:   AVHRR to Geodetic
                        Call AVOSC
                        Call OSCLL

                Endcase:

                        Enter output coordinate in session log file and on screen

        Enddo.

End Program //
```

Function GCS_GEOTAG

```
Program GEOTAG //

        Call user-interface
        Call initialize
        DO for every pixel location
                within user input window //  window defined by pixel, line position

                Case:   Geodetic to AVHRR
                        Call LLOSC
                        Call OSCAV
                Endcase:

                Case:   AVHRR to Geodetic

                        Call AVOSC
                        Call OSCLL
                Endcase:
                        Enter output coordinates in output files;
        Enddo.

End Program //
```

Function GCS_GRID

Program GRID //

Call user-interface
Call initialize
DO for every user defined grid intersection

Case: Geodetic to AVHRR
Call LLOSC
Call OSCAV

Endcase:

Case: AVHRR to Geodetic
Call AVOSC
Call OSCLL

Endcase:

Enter output coordinate in session log file and on screen:

Enddo.

End Program //

Directory Contents:

The source codes and executables are resident under the following subdirectories and filenames -

CL$DUA3:[JOY.AVHRR_GCS.POINTS] TAE Usage- tutor POINTS

BLD_POINTS.COM, COMPILE.COM, LINK.COM .. Command file to compile and link GCS_POINTS

GCS_COMMONS.INC, GCS_DATA.INC, GCS_DEF.INC, GCS_FUNC.INC

GCS_TABLES.INC, GCS_VARIABLES.INC, IO.INC, MATH_CONSTANTS.INC ,

MSG.INC, OUT.INC, PARAMS.INC, TAE.INC, POINTS.HLP, POINTS.PDF

DRIVER.FOR, USER_INTERFACE.FOR, GET_PARMS.FOR, INITIALIZE.FOR

LLAVHRR.FOR, AVHRRLL.FOR, AVOSC.FOR, OSCAV.FOR, OSCLL.FOR,

LLOSC.FOR, MSG_POINTS.MSG, POINTS.CMT, POINTS.EXE

CL$DUA3:[JOY.AVHRR_GCS.GEOTAG] TAE Usage- tutor GEOTAG

BLD_GEOTAG.COM , COMPILE.COM, LINK.COM .. Command file to compile and link GEOTAG.

GCS_COMMONS.INC, GCS_DATA.INC, GCS_DEF.INC, GCS_FUNC.INC

GCS_TABLES.INC, GCS_VARIABLES.INC, IO.INC, MATH_CONSTANTS.INC ,

MSG.INC, OUT.INC, PARAMS.INC, TAE.INC, GEOTAG.HLP, GEOTAG.PDF

GEOTAG.FOR, INTERFACE.FOR, INITIALIZE.FOR, AVHRRLL.FOR,

AVOSC.FOR , LATLON.FOR, GET_PARMS.FOR,

OSCLL.FOR, GEOTAG.EXE, MSG_GEOTAG.MSG,

POINtTS.CMT

CL$DUA3:[JOY.AVHRR_GCS.GRID] ; TAE USAGE - tutor GRID

BLD_GRID.COM , COMPILE.COM, LINK.COM .. Command file to compile and link GCS_GRID

GCS_COMMONS.INC, GCS_DATA.INC, GCS_DEF.INC, GCS_FUNC.INC

GCS_TABLES.INC, GCS_VARIABLES.INC, IO.INC, MATH_CONSTANTS.INC ,

MSG.INC, OUT.INC, PARAMS.INC, TAE.INC, GRID.HLP, GRID.PDF

GRID_DRIVER.FOR, USER_INTERFACE.FOR, GET_PARMS.FOR,

INITIALIZE.FOR, AVOSC.FOR, OSCAV.FOR, OSCLL.FOR, LLOSC.FOR,

MSG_POINTS.MSG, POINTS.CMT, GRID.EXE

V. CONCLUSION

The project has resulted in the successful implementation of a practical technique to obtain in a timely manner, the geographic referencing of pixels contained in a full AVHRR scene frame. The programs have been implemented in fortran without implementing VAX specific code. Accordingly, the set of geometric correction routines may be transportable to smaller workstations easily. While most of the available methods result in a mapping from AVHRR scene to latitude-longitude only, the implemented algorithm in the present package allows the reverse mapping, lat-long to pixel, line - also. In consequence, the package has proved to be highly useful in supporting the day to day requirements of the FIFE project. The success of the program in the science scenario tests makes it attractive for adoption in the overall PLDS system capabilities.

REFERENCES

Boatwright, J.A. et al, "Image Correction and Registration Utility System Design Document", Interdepartmental Communication to G. Clouette, JSFC, NASA, 1984.

APPENDIX - 'A'

USER'S GUIDE

Name: POINTS

Function: GCS_POINTS generates the mapping from AVHRR image to geodetic latitude-longitude and vice versa. The output is placed on the screen and written to disk resident session log file.

The purpose of this function is to allow the user the ability to transform a AVHRR image frame from its image frame coordinate system (LINE-PIXEL) to a geodetic projection.

PARAMETERS :

OUT Name of outout report file, or User desired file name for outputting the mapping grid (No default value; e.g., OUT = GRID.MAN)

ID NOAA spacecraft identifier ; for

NOAA-7, ID = 3
NOAA-8, ID = 4, etc.

The present version of GCS_ POINTS contains spacecraft nominal orbit parameters for upto NOAA- 10.

ISPACE Input coordinate space; ISPACE = 2 for input image or image to be projected into lat-long space
ISPACE = 1 for input in lat-lon

OSPACE Output coordinate space; OSPACE = 1 specifies the direction of mapping or contents of the mapping grid to be in longitude coordinate. OSPACE=2 implies desired output in AVHRR image frame coordinates.

TIELAT Latitude of tie point in deg. min. sec. Enter negative number for degrees for locations south of equator.

TIELON Longitude of tie point in deg. min. sec. Enter negative degrees for images west of greenwich.

TIEPIX Pixel location of tiepoint in full scene AVHRR line-pixel coordinates

TIELIN Line number of of tie point in full scene AVHRR frame coordinates.

*

GCS_ POINTS **requires** that the user determine an appropriate tiepoint through an examination of the original AVHRR scene. It is not necessary that the selected tiepoint be within the image subset to be used for mapping.

EXAMPLES:

```
TAE > GCS_POINTS= LOG.DAT ID=3 ISPACE=2 OSPACE=1
                 TIELAT=14.0 17.0 20.0004
                 TIELON= -16.0 55.0 59.988
               TIEPIX = 1026  TIELIN= 1150
```

APPENDIX - ' B'

USER'S GUIDE

Name: GEOTAG

Function: GCS_GEOTAG generates the mapping from AVHRR image to geodetic latitude-longitude and vice versa for a user selected window in either image frmae coordinates or latitude-longitude coordinates.The output is written to disk as two files- a file containing lattitude and a file containing longitude for respective pixels as specified in the window.

The purpose of this function is to allow the user the ability to quickly georeference a AVHRR image frame from its image frame coordinate system (LINE-PIXEL) to a geodetic projection. (LAT-LON) for all pixels contained within a user specified image window in either an ascending or descending pass.

PARAMETERS :

OUTLAT Name of output report file of latitudes.

OUTLON Name of output file of longitudes.

CRAFTID NOAA spacecraft identifier ;
for
NOAA-7, ID = 3
NOAA-8, ID = 4, etc.

The present version of GCS_ GEOTAG contains spacecraft nominal orbit parameters for upto NOAA- 10.

ORBITDIR Direction of satellite orbit :
A = ascending; D = descending pass;

ISPACE	Input coordinate space; ISPACE = 2 for input image or image to be projected into lat-long space ISPACE = 1 for input in lat-lon
OSPACE	Output coordinate space; OSPACE = 1 specifies the direction of mapping or contents of the mapping grid to be in geodetic latitude-longitude coordinate. OSPACE=2 implies desired output in AVHRR image frame coordinates.
TIELAT	Latitude of tie point in deg. min. sec. Enter negative number for degrees for locations south of equator.
TIELON	Longitude of tie point in deg. min. sec. Enter negative degrees for images west of greenwich.
TIEPIX	Pixel location of tiepoint in full scene AVHRR line-pixel coordinates
TIELIN	Line number of of tie point in full scene AVHRR frame coordinates.

*

GCS_GEOTAG **requires** that the user determine an appropriate tiepoint through an examination of the original AVHRR scene. It is not necessary that the selected tiepoint be within the image subset to be used for mapping.

EXAMPLES:

TAE > GCS_GEOTAG= LAT.DAT LON.DAT CRAFTID=3 ORBITDIR=A
ISPACE=2 OSPACE=1
TIELAT=14.0 17.0 20.0004

TIELON= -16.0 55.0 59.988
TIEPIX = 1026 TIELIN= 1150

f

USER'S GUIDE

Name: GRID

Function: GCS_GRID generates a file of grid coordinates that contains the mapping from AVHRR image to geodetic latitude-longitude. The output file from this function is used as an input to the LAS Geometric correction program GEOM. The output data file is also referred to as the user supplied mapping grid file in the GEOM user's guide.

The purpose of this function is to allow the user the ability to transform a AVHRR image frame from its image frame coordinate system (LINE-PIXEL) to a geodetic projection. A mapping transformation is required to be applied to the original image through the use of the GEOM function. However, GEOM requires the availability of an appropriate mapping grid. GCS_GRID offers the user the means to generate this mapping grid using a single user supplied tie point. The mapping grid file, output from this function is used as an input to GEOM's input parameter GRIN (mapping grid file name) and MAPMODE (man: manually generated grid file).

PARAMETERS :

OUT Name of outout report file, or
User desired file name for outputting the mapping grid (No default value; e.g., OUT = GRID.MAN)

ID NOAA spacecraft identifier ;
for
NOAA-7, ID = 3

NOAA-8, ID = 4, etc.

The present version of GCS_GRID contains spacecraft nominal orbit parameters for upto NOAA- 10.

ISPACE — Input coordinate space; ISPACE = 2 for implementing GCS_GRID;
ISPACE = 2 for input image or image to be projected into lat-long space specified in AVHRR original image space/line-pixel frame referencing.

OSPACE — Output coordinate space; OSPACE = 1 for this implementation of GCS_GRID; OSPACE = 1 specifies the direction of mapping or contents of the mapping grid to be in geodetic latitude-longitude coordinate.

TIELAT — Latitude of tie point in deg. min. sec.
Enter negative number for degrees for locations south of equator.

TIELON — Longitude of tie point in deg. min. sec.
Enter negative degrees for images west of greenwich.

TIEPIX — Pixel location of tiepoint in full scene AVHRR line-pixel coordinates

TIELIN — Line number of of tie point in full scene AVHRR frame coordinates.

*

GCS_GRID **requires** that the user determine an appropriate tiepoint through an examination of the AVHRR scene to be reprojected to lat-lon domain prior to implementing GCS_GRID. It is not necessary that the selected tiepoint be within the image subset to be tranformed through GEOM. In addition, if the user desires to transform using the output of GCS_GRID as input to GEOM, it is advisable that the input AVHRR image be rotated 180 degrees using LAS function FLIP in those instances where the AVHRR dataset is from an ascending pass.

EXAMPLES:

```
TAE > GCS_GRID  OUT=GRID.MAN ID=3 ISPACE=2 OSPACE=1
                  TIELAT=14.0 17.0 20.0004
                  TIELON= -16.0 55.0 59.988
                TIEPIX = 1026   TIELIN= 1150
```

f