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SUPPORT FOR THE NAVAL RESEARCH LABORATORY ENVIRONMENTAL  
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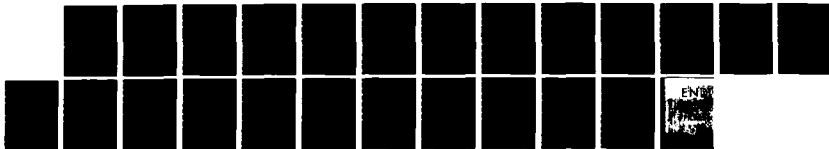
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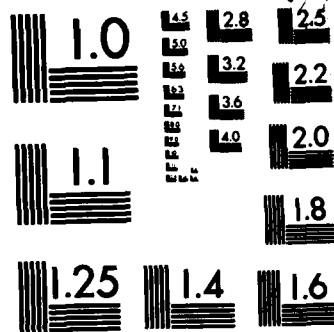
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SUPPORT FOR THE NAVAL RESEARCH LABORATORY  
ENVIRONMENTAL PASSIVE MICROWAVE REMOTE SENSING  
PROGRAM - FINAL CONTRACTOR REPORT

Prepared for

THE NAVAL RESEARCH LABORATORY

By

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Task Assignment 5051

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ABSTRACT

This document summarizes the data acquisition, reduction, and processing support CSC provided Code 7911 of the Naval Research Laboratory (NRL) under contract N00173-80-C-0265. The support for the NRL Environmental Passive Microwave Remote Sensing Program included acquisition, implementation, and evaluation of Scanning Multichannel Microwave Radiometer (SMMR) processing algorithms; Environmental Transfer Function development and verification; aircraft data acquisition; and aircraft data processing.



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## SECTION 1 - INTRODUCTION

The Computer Sciences Corporation (CSC) supported the Environmental Passive Microwave Remote Sensing Program for Code 7911 of the Naval Research Laboratory (NRL) under contract N00173-80-C-0265 from July 25, 1980, to April 30, 1983. This report summarizes the support provided by CSC on this contract.

This report is divided into the following sections: interpretation and evaluation of Scanning Multichannel Microwave Radiometer (SMMR) data (Section 2), Environmental Transfer Function development and verification (Section 3), aircraft data acquisition (Section 4), and aircraft data processing (Section 5).

SECTION 2 - INTERPRETATION AND EVALUATION  
OF SCANNING MULTICHANNEL MICROWAVE  
RADIOMETER (SMMR) DATA

CSC provided support to convert Seasat SMMR sensor data into microwave brightness temperatures. We were instrumental in obtaining an antenna temperature algorithm (ATA) from the Naval Environmental Prediction Research Facility (NEPRF) to compute antenna temperatures from Seasat SMMR sensor data records (SDRs). CSC implemented and updated this ATA on NRL computers. To conserve computer resources, we implemented a simplified Antenna Pattern Correction (APC) algorithm at NRL for computing Seasat SMMR antenna temperatures. The alternative, a full APC algorithm, requires exceedingly long computer runs. The simplified version, which assumes a homogeneous microwave scene, uses very little computer time; this assumption of a homogeneous scene is reasonable when the radiometer is viewing open ocean not too near a coast. This APC algorithm corrects the brightness temperatures for contributions from side lobes, cross-polarization, polarization cross-talk, and cross-track gradients.

In order to verify the ATA, CSC programmed two approaches to correct the Seasat SMMR data for cross-polarization. CSC personnel found that one of the correction methods was relatively unstable. The other correction method was modified in order to estimate the cross-polarization and cross-track errors based on a large set of relatively clean data.

CSC found serious discrepancies between antenna temperatures from the Jet Propulsion Laboratory (JPL) SMMR Sensor Data Record (SDR) tapes and those obtained from the Fleet Numerical Weather Center (FNWC) SDR tapes.



A careful analysis indicated that CSC implemented the proper ATA algorithm at NRL and that the FNWC Seasat SMMR SDR tapes contain serious errors. Details of this analysis appear in a report included in Appendix A.

A set of correction arrays for all the 10 SMMR frequencies and polarizations was produced based on a large number of scans (240) collected during four of the days when the Gulf of Alaska Seasat Experiment GOASES experiment was in progress. The data were over ocean and near the location of the experiment. These arrays were designed to simplify the process of cross-polarization and cross-track corrections on the GOASEX data set which has been utilized for certain investigations by NRL personnel.

SECTION 3 - ENVIRONMENTAL TRANSFER FUNCTION  
DEVELOPMENT AND VERIFICATION

CSC redesigned and enhanced the NRL Environmental Transfer Function (ETF). The enhanced ETF was implemented on the Texas Instruments Advanced Scientific Computer and on the Control Data Corporation 3800 computer.

CSC conducted a number of sensitivity and trade-off studies with the ETF to verify the program and to further understand the atmosphere-ocean model and the regression estimation scheme involved. Deviations introduced into the mean values from climatology and the resultant error in estimates were examined for sensitivity evaluation. The sea surface temperature and wind speed parameters, which are of particular interest to the Navy, were chosen for the sensitivity studies.

## SECTION 4 - AIRCRAFT DATA ACQUISITION

### 4.1 AIRCRAFT FLIGHTS

CSC personnel participated in several aircraft data acquisition missions for the NRL Environmental Passive Microwave Remote Sensing Program. In order to do this, CSC personnel satisfied all of the Navy's physiological and survival training requirements for flying as a Selected Passenger on the NRL RP-3A. On these flights, the aircraft typically carried a configuration of sensors which includes a millimeter-wave radiometer (90, 140, or 220 GHz) for gathering image and profile data, four microwave radiometers (19, 22, 31, and 37 GHz) for collecting SSM/I simulator and other profile data, an IR radiation temperature sensor, a dew point hygrometer, a strip-film camera, and other environmental sensors. CSC gradually assumed the bulk of the responsibility for operating this equipment. This included running the Motorola 6800 Exorciser microcomputer which controls the radiometer and environmental data acquisition, monitoring and adjusting the radiometers' output amplifiers and filters to obtain the maximum dynamic range of response, scheduling and performing the in-flight calibration of the microwave radiometers, and setting up and operating the strip-film camera and other environmental sensors. Also of significant importance to the missions was the monitoring of the image and profile data for problems, including radio-frequency interference and radiometer instabilities. Three different types or modes of radiometer data were collected on the flights: "image", "profile", and "radiometer". CSC personnel also interacted with the aircrew to set the speed and altitude of the flight lines and to synchronize the data system's operation with the aircraft's flight. Additionally, they often participated in the pre-mission determination of which types of data were to be gathered during each flight.

CSC personnel participated in both local and non-local data acquisition missions. In May 1981, CSC supported a two-week deployment to Barbers Point, Oahu, Hawaii for a special project. CSC personnel operated a laser altimeter and performed other supporting functions. CSC participated in a two-week deployment to Thule, Greenland in October 1981. On this mission, imagery of a seasonal ice pack containing ice of varying age was collected in the Fitzwilliam Strait and Mould Bay area of northern Canada. Also, imagery and profile data of the permanent Arctic ice pack were obtained during a flight to the North Pole. In November 1981, CSC supported another two-week deployment to Andenes, Norway to collect imagery of the Marginal Ice Zone east of Greenland through heavy clouds. In addition, radiometer mode observations of the multi-year ice pack and cold ocean were made using the SSM/I simulator package. Most recently, in November 1982, CSC participated in a one-week mission to Goose Bay, Canada to gather cold ocean data using several microwave radiometers and to collect imagery of icebergs. Local test flights out of the Patuxent River Naval Air Station were performed prior to almost all of these missions. On these, image data of the Dismal Swamp area, the Norfolk Navy Yard, and the Delmarva Peninsula were often collected. Also, radiometer and profile mode data of the Gulf Stream were usually gathered. In June 1982, CSC supported a one-day special project flight out of Patuxent River Naval Air Station.

#### 4.2 DATA ACQUISITION SOFTWARE AND HARDWARE

CSC participated in troubleshooting of the passive millimeter-wave and microwave data acquisition system. This included the Motorola 6800 Exorciser computer, the peripheral interface cards on the Exorciser bus, the real-time data acquisition software, and the analog-to-digital (A/D) converter. In response to data acquisition problems, CSC assisted in measuring

input signal levels, tracing software control of peripheral devices, and checking the consistency of data as it moved through the system. On one occasion, CSC discovered a change in the A/D converter calibration which was leading to falsely high calibration values.

CSC performed minor modifications to the real-time data acquisition software for the Motorola Exorciser, which is written in 6800 assembly language. These included changes to accommodate a new real-time clock circuit and insertion of new tape format codes and image color bars. CSC burned new EPROMs containing the updated software in each case, and installed these EPROMs in the computer system.

CSC additionally provided some support for maintaining and enhancing the data acquisition hardware. CSC personnel participated in adding a new real-time clock circuit to a peripheral board for the Exorciser microcomputer. CSC also built a copy of the Inertial Navigation System data interface and real-time clock peripheral board when the old one failed.

#### 4.3 RADIOMETER CALIBRATION

As part of the NRL passive microwave data acquisition task, CSC personnel participated in laboratory calibrations of the millimeter-wave and microwave radiometers. Calibrations involved measuring the radiometers' output in response to viewing liquid nitrogen, absorbent foam, and internal reference and calibration loads. With this procedure, radiometer response at hot and cold temperature extremes was measured, and the temperature of the internal calibration noise sources was determined. Imaging radiometers, which are the total-power type, were calibrated in a dynamic setup using the rotating-mirror scanner and its attached reference loads; while, the profiling microwave radiometers, which are the Dicke-switched type, were calibrated in a static configuration where

the external loads fill the antenna beam. From these static calibrations, the parameters for deriving antenna temperatures from radiometer output voltages were obtained. The dynamic calibrations provide information on the side lobes of the imaging radiometers which determines part of the relationship between antenna and brightness temperatures. These calibration results were used in the reduction of the image and profile data.

## SECTION 5 - AIRCRAFT DATA PROCESSING

### 5.1 IMAGE PROCESSING PROGRAMS

CSC designed and implemented several data reduction programs for the aircraft millimeter-wave image data. The programs were written in FORTRAN for the DECsystem-10 computer. These programs reduce the laboratory and in-flight radiometer calibration data, apply these results to obtain antenna or brightness temperatures from the raw radiometer data, perform a first-order geocorrection of the imagery, and decode and incrementally average the environmental and navigation data collected. To counteract the effects of undersampling and noise on the in-flight calibration load measurements, statistical methods for editing, smoothing, and fitting this data were developed which provide more accurate calibration and prevent striping of the images. The geocorrection algorithms are tailored to the aircraft platform used for the millimeter-wave radiometers. An aircraft roll correction is applied to each scan line, and the images are resampled from equiangular pixel separation to a uniform ground spacing using a cubic-convolution algorithm. Also, scan lines are averaged or inserted according to the ratio of along-track to cross-track sampling, which in turn depends on the flight altitude. The reduction programs handle the three existing image data formats and two radiometer calibration methods, and because of their modularity could easily be adapted to any new data formats used by NRL. The sequence of programs used to process the image mode aircraft data is shown in Figure 5-1.

The CALDAT program reduces the laboratory calibration data for the imaging radiometers, providing the information needed to calculate the antenna-to-brightness temperature conversion coefficients. The program produces histograms of the raw A/D





converter counts for the radiometer output, as well as averages and standard deviations for the thermistor measurements of the scanner loads.

The MMDATA program performs the bulk of the actual data reduction. For a user-specified set of image data records, MMDATA converts the radiometer data from A/D counts to brightness temperatures, using both the in-flight measurements of the scanner loads and the calibration coefficients determined using CALDAT. The program also decodes the environmental sensor measurements and the Inertial Navigation System data collected. Averages of these values (where appropriate) are computed for both the entire image and for 120-record subgroups. MMDATA also determines and applies the correction for aircraft roll to each scan line of an image. Several output products are produced by the program. These are listings of the scanner load measurements and ancillary data for each record; histograms of pixel brightness temperature for each image subgroup; and a computer tape containing the pixel brightness temperatures, environmental and INS data averages, and image identification information.

The RESAMP program accomplishes the final geocorrection of the millimeter-wave images. Using a cubic-convolution resampling algorithm, the program resamples the pixels in each scan line to convert them from equal observation-angle separation to equal ground spacing. The spacing used is calculated by the MMDATA program, and it is related to aircraft altitude and ground speed and to radiometer sampling rate. To create square pixels, either new scan lines are synthesized using an averaging technique, or adjacent scan lines are averaged together. The resulting image is written out to computer tape.

The MAPTAP program was written to generate any or all of the following products from image tapes produced by the RESAMP program: line-printer character maps, 3-D brightness temperature plots, brightness temperature histograms, and computer

tapes for input to image display systems. The display tapes are readable on the Motorola Exorciser, PDP-11/34A, and Data General MV/8000 computer systems. These output products can cover an entire image or any number of user-specified subsets.

A number of small utility programs were also written for manipulating the millimeter-wave image data. These include FMTUPD, which updates the format code on raw image data tapes; ENDFIL, which writes an end-of-file mark after a user-specified file and record count on raw data tapes missing an end-of-file due to equipment problems; and ANCILL, which decodes the environmental and INS data from a raw image data tape and writes it out to an 8-bit ASCII, 32-bit word format tape which is readable on almost all computer systems.

## 5.2 IMAGE PROCESSING

CSC reduced much of the millimeter-wave image data acquired during the past three years. This task included selecting the images to be processed in accordance with the analysis goals and data quality, running the calibration data reduction programs, and running the programs to apply the calibration coefficients to the raw radiometer data and to geocorrect the images. The sequence of programs used to process the image mode aircraft data is shown in Figure 5-1. As the data was reduced, it was checked for excessive noise or systematic trends. Also, consistency checks were made between the observed temperatures and those calculated for various features using the NRL environmental model.

The following image data was reduced under the NRL contract:

- o 90 GHz images of agricultural land northeast of the Chowa River, the Great Dismal Swamp, the industrial district of Portsmouth, the Norfolk Navy Yard, and ship wakes in the Chesapeake Bay from the April 1980 flights over eastern Virginia

- o 90 GHz images of agricultural land northeast of the Chowan River, the Great Dismal Swamp, downtown Portsmouth, the Norfolk Navy Yard, and cargo ships at anchor in the Chesapeake Bay from the January 1981 flights over eastern Virginia
- o 22, 31, 90, and 140 GHz images from a special project mission in Hawaii during May 1981
- o 90 and 140 GHz images of a variety of ice types in Fitzwilliam Strait, Mould Bay, and Hardinge Bay from the Thule-based Arctic sea ice mission of October 1981
- o 90, 140, and 220 GHz images of the Marginal Ice Zone and multi-year pack ice from the Norway-based Arctic sea ice mission of November 1981
- o 90 GHz images from a Gulf Stream special project flight in June 1982

Display tapes of all the images reduced were made using the MAPTAP program. After the stepwise-linear mapping of the brightness temperature ranges provided by MAPTAP, pseudo-color mappings were developed which best distinguished features of interest. The Motorola Exorciser microcomputer and the Ramtek 9100 video display generator were used for viewing the images. Photographs of the final pseudo-color displays of the images were taken using a 35mm SLR. Brightness temperature histograms of the reduced images were also made, and these were used in developing the pseudo-color mappings and for studies of the images by NRL personnel. Line-printer character maps were produced for the Mould Bay ice images. These were used by NRL personnel to determine the brightness temperature ranges of the different types of sea ice present. Three-dimensional plots were made of the image data from the Hawaii mission, as these were uniquely suited to the presen-

tation and study of the features of interest. These output products have been incorporated in several NRL and Department of Defense presentations and reports, and they have also been used by NRL personnel at various scientific conferences.

### 5.3 PROFILE DATA PROCESSING PROGRAMS

CSC has designed, coded, and tested several programs on the DECsystem-10 computer for reducing the profiling microwave radiometer data acquired in "radiometer mode". These handle any set of radiometers flown, including the Special Sensor Microwave/Image (SSM/I) simulator package and its tiltable pallet. The programs reduce the laboratory and in-flight radiometer calibration data, apply these results to convert the radiometer measurements from A/D counts to antenna or brightness temperatures, reduce the environmental sensor and INS data recorded, and produce various output products including computer tapes readable on both the DECsystem-10 and Texas Instruments (TI) Advanced Scientific Computer (ASC) systems used by the Space Sensing Applications Branch. The sequence of programs used to process radiometer mode aircraft data is shown in Figure 5-2.

The PROCAL program reduces the laboratory and the in-flight calibration data for the profiling radiometers, which are of the Dicke-switched type. For the laboratory calibration data, the average A/D counts for the various loads observed are computed by the program to determine the calibration noise tube temperatures. For the in-flight calibrations, the averages and standard deviations of the reference load and calibration tube observations are computed, along with the thermistor reading of the reference load temperature, to enable determination of the relation between A/D counts and antenna temperature for each data leg. Both A/D count histograms

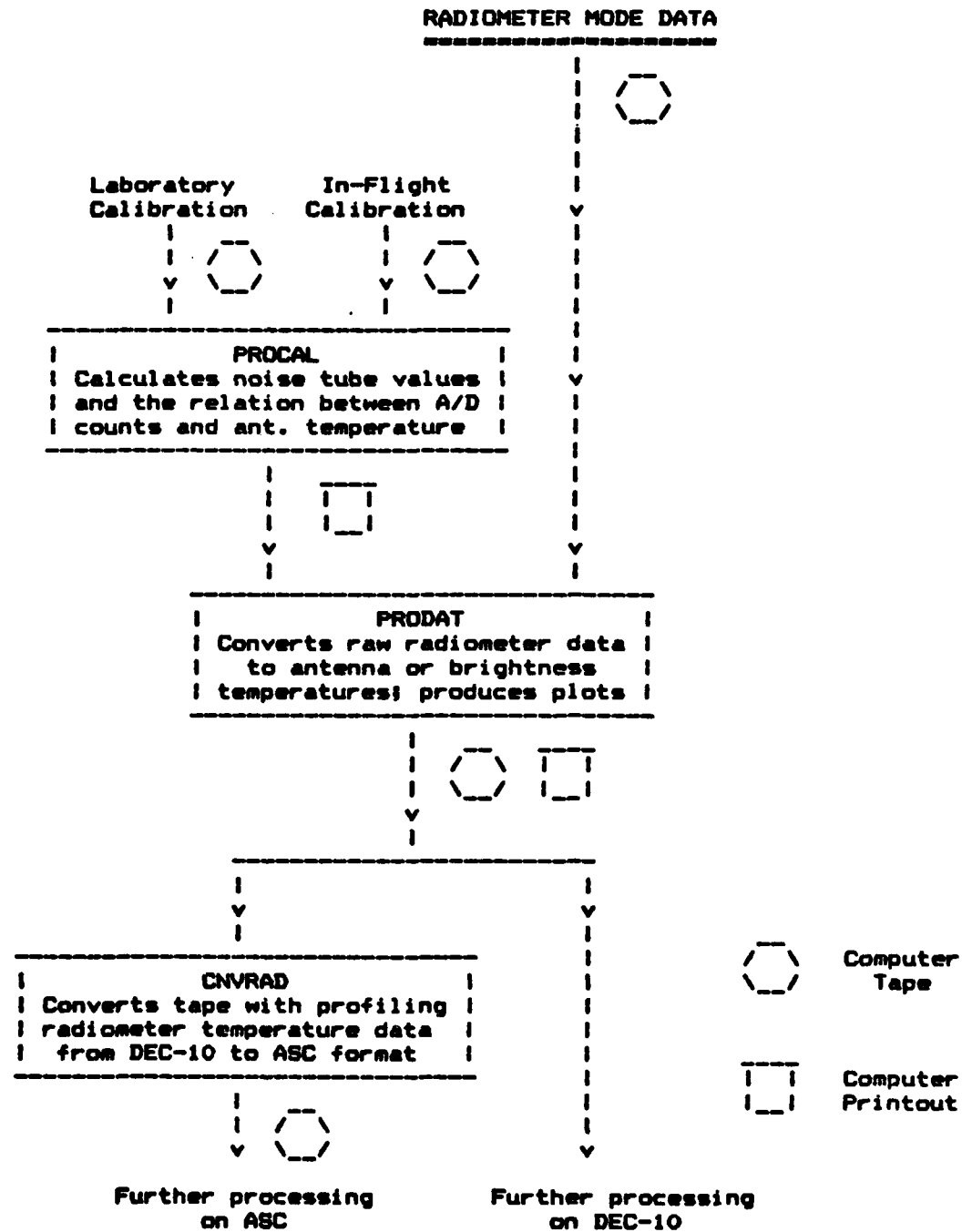


Figure 5-2 Steps for Computer Processing of Radiometer Mode Data

for each observation type and plots of A/D count versus record number are produced by the program. Additionally, listings of each sample for each radiometer are printed to enable checking of the radiometers' output for slow calibration tube rise time and other problems.

The PRODAT program reduces the data from the surface feature observations. For a user-specified set of data records, the program applies the calibration coefficients to the radiometer data, decodes the environmental sensor and INS data acquired, and organizes the radiometer samples into groups of several seconds duration and averages the ancillary data associated with them. PRODAT produces partial listings of the environmental and INS data; histograms of each radiometer's antenna or brightness temperatures; plots of sample temperature versus record number; and a computer tape containing leg identification information, the radiometer temperature data, and the ancillary data. The PRODAT program is modularly designed and has a flexible output tape format which will enable it to be adapted to the reduction of "profile mode" data and profiling radiometer data collected during image data acquisition.

The CNVRAD program converts the DEC-10 format tapes produced by the PRODAT program to a format readable on the TI ASC computer. CNVRAD converts the header and ancillary data information from 7-bit ASCII to 8-bit EBCDIC character coding, and converts the radiometer temperature data from DEC-10 to ASC internal floating-point representation. The program also converts the PRODAT tape from 36-bit to 32-bit word format. CNVRAD makes it possible for NRL personnel who use the ASC computer to immediately access and analyze the microwave profile data.

#### 5.4 PROFILE DATA REDUCTION

CSC has reduced the "radiometer mode" profile data acquired with the SSM/I simulator at the SSM/I's 53° incidence angle during the November 1981 Arctic sea ice mission. High-altitude ocean transit, Marginal Ice Zone, and multi-year ice pack flight legs were reduced using the PROCAL and PRODAT programs. All of the reduced data were placed on ASC-readable computer tapes using CNVRAD, and these tapes along with the listings and plots generated by PRODAT were delivered to NRL personnel for studies of the profile data.

APPENDIX A - EVALUATION OF SEASAT/  
SCANNING MULTICHANNEL MICROWAVE  
RADIOMETER (SMR) SENSOR DATA  
RECORD TAPES (SDR)



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