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A Joint Program for Agriculture and Resources Inventory Surveys Through Aerospace Remote Sensing

Foreign Commodity Production Forecasting

November 1980

WEATHER ANALYSIS AND INTERPRETATION PROCEDURES DEVELOPED FOR THE U.S./CANADA WHEAT AND BARLEY EXPLORATORY EXPERIMENT

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M. H. Trenchard

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16. Abstract

Procedures and techniques for providing analyses of meteorological conditions at segments during the growing season were developed for the U.S./Canada Wheat and Barley Exploratory Experiment. The main product and analysis tool is the segment-level climagraph which depicts temporally meteorological variables for the current year compared with climatological normals. The variable values for the segment are estimates derived through objective analysis of values obtained at first-order stations in the region. The procedures and products documented in this report represent a baseline for future Foreign Commodity Production Forecasting experiments.

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WEATHER ANALYSIS AND INTERPRETATION PROCEDURES DEVELOPED FOR THE U.S./CANADA WHEAT AND BARLEY EXPLORATORY EXPERIMENT

Job Order 74-452

This report describes Weather Interpretation/Crop Condition activities of the Foreign Commodity Production Forecasting project of the AgRISTARS program.

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Under Contract NAS 9-15800

For

Earth Observations Division

Space and Life Sciences Directorate

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
LYNDON B. JOHNSON SPACE CENTER
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LEMSCO-15612

PREFACE

The procedures documented in this report were developed in support of the Agriculture and Resources Inventory Surveys Through Aerospace Remote Sensing program. Under Contract NAS 9-15800, personnel of Lockheed Engineering and Management Services Company, Inc., completed this work for the Earth Observations Division, Space and Life Sciences Directorate, National Aeronautics and Space Administration, at the Lyndon B. Johnson Space Center.

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ABBREVIATIONS

ACC	adjustable crop calendar
AgRISTARS	Agriculture and Resources Inventory Surveys Through Aerospace Remote Sensing
CMI	crop moisture index
CMS	Conversational Monitor System
CRD	crop reporting district
ET	evapotranspiration
FCPF	Foreign Commodity Production Forecasting
LACIE	Large Area Crop Inventory Experiment
LARS	Laboratory for Applications of Remote Sensing
NOAA	National Oceanic and Atmospheric Administration
PE	potential evapotranspiration

1. INTRODUCTION

The Agriculture and Rescurces Inventory Surveys Through Aerospace Remote Sensing (AgRISTARS) program is a major effort to assemble and apply the remote sensing technology to agricultural analyses and Earth resources inventories. AgRISTARS does not rely on remote sensing alone; it also integrates available ground observations and meteorological data to provide an enhanced perspective of crop conditions and increased capability for monitoring temporal and spatial changes. The meteorological conditions and their impact on the environment are vital to the detection of the agricultural conditions. Weather data, therefore, become a major component of the ground-truth information required for the effective use of remote sensing technology.

The Foreign Commodity Production Forecasting (FCPF) project within AgRISTARS is particularly concerned with the application of remote sensing technology to agriculture in foreign areas. The FCPF effort is directed toward inventorying and monitoring the production of crops that are significant to the world's food supply. In few applications does the role of weather have such a tremendous impact as in agriculture. The project, in response to this fact, has required weather analysis and interpretation activity. This activity has specific objectives in support of FCPF experiments and technology.

The primary objective of this task is to provide relevant information about meteorological conditions in all project experiments or similarity regions. This includes an assessment of the impact of weather on crop development, yields, and spectral appearance. Task input relies upon the production of meteorological summaries and displays of various meteorological variables and indices. These products aid in the interpretation and assessment function.

A supporting task objective is to access, develop, and manipulate all available meteorological data. A computer capable of handling large volumes of data is required. The attendant software must be compatible with the mode and format of varied data sources. It also must be flexible in order to respond to different requirements for information.

A third objective is to provide data and interpretive information of quality and detail. This requires procedures to correct inconsistencies in the data and to fill any data hiatus detected. This is accomplished with software based upon operational experience with the characteristics of meteorological observations and knowledge of the vagaries of the spatial distribution of the data.

The final objective is to provide a set of output products which meets user requirements; employs pertinent parameters; and displays all features in a standard, unambiguous manner. These products will be the basic tools of the overall agricultural interpretation and assessment activity.

This report provides a description of the current line of products which was devised and delivered for the U.S./Canada Wheat and Barley Exploratory Experiment. The functions and/or applications of these products are also given. The data requirements to produce these items are exhaustive and are described in detail. Procedures for assembling and processing these data are also presented. The software to accomplish this task, which is still being developed and streamlined, is documented in its current state.

2. PRODUCTS AND FUNCTIONS

The primary purpose of meteorological data is to provide point-specific information, whenever possible. Weather analysis and interpretation procedures developed during the Large Area Crop Inventory Experiment (LACIE) were regional and relied on interpretation of network weather observations. The approach for the AgRISTARS FCPF project is to provide segment-level detail and analysis of weather data in a time series. This method eliminates large volumes of extraneous regional information requiring subjective interpolation and replaces it with segment-specific data obtained objectively. Temporal variations are reduced to a weekly time series.

To display the desired data for a particular site over the growing season, a three-part climagraph is employed. A Fortran program is used to generate this product on a line printer. One climagraph is produced for each segment location in the experiment region.

Part 1 of the climagraph consists of a composite plot of (1) weekly observed and mean temperatures and (2) weekly and normal precipitation totals (see fig. 2-1). The first header line specifies the data acquisition year, the segment number, the state and crop reporting district (CRD) in which the segment is located, and the latitude and longitude of the site. The second header line lists the available Landsat acquisitions. The horizontal time scale is the Julian date for the ending day of the week. The temperature scale is degrees Fahrenheit at 2° intervals, and the precipitation scale is in inches to the nearest two-tenths of an inch. Climatological normals are plotted as asterisks (*); observed values, as pluses (+) for above normal and minuses (-) for below normal values. These four parameters are not observations or records at the segment location but are interpolations of values from the available first-order network for the region. The values at the stations are summarized by week prior to interpolations. For this particular plot, 26 interpolations were needed on 4 variables to provide the segment-level estimates.

PART 1

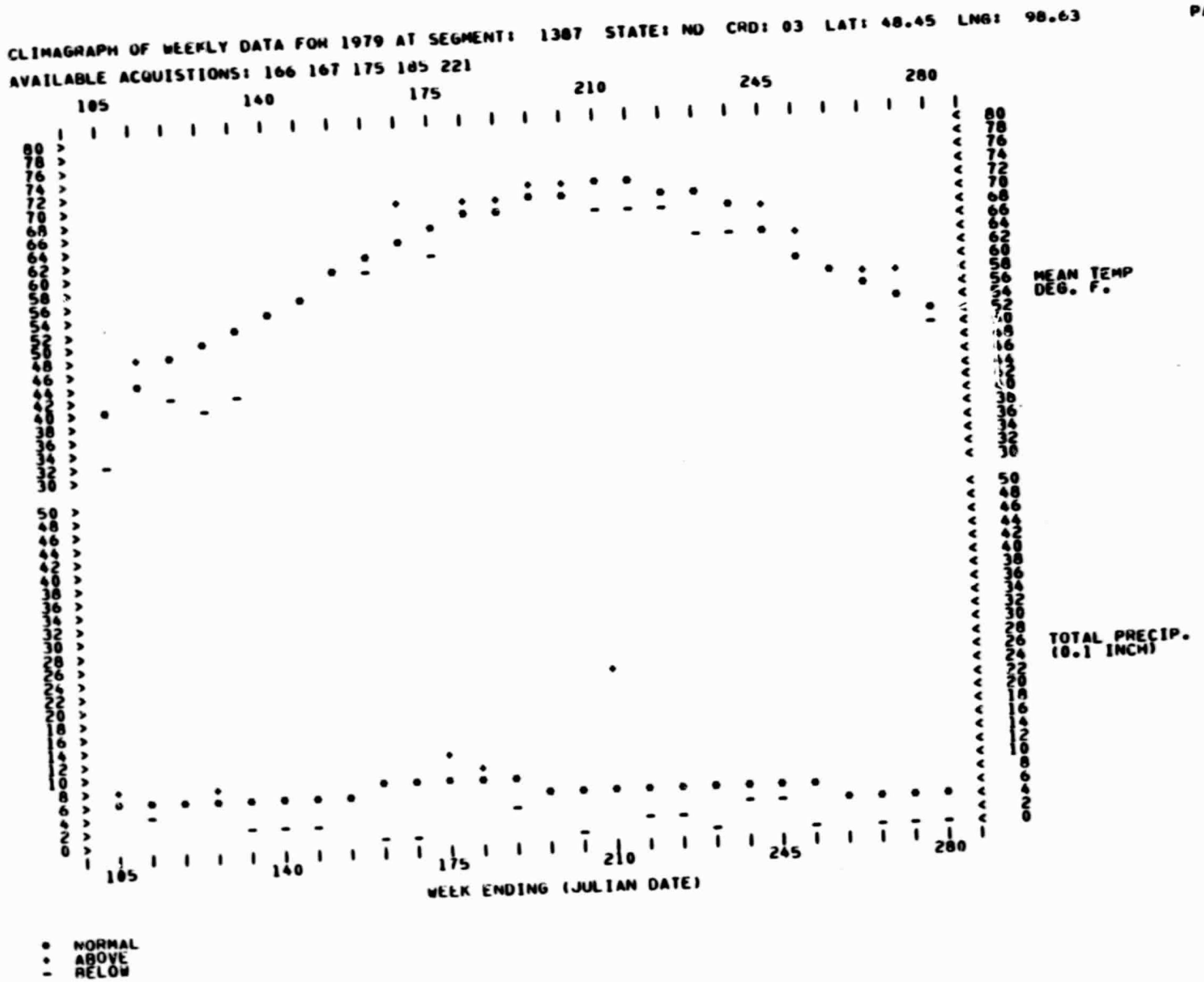

Figure 2-1.- Climagraph product, part 1.

The climagraph display of data permits interpretation of potential interactions of temperature and precipitation with spectral appearance. For example, the week prior to acquisition date 175 was cooler and wetter than normal. This provided some relief from any ongoing stress, as well as conditions for a reduction in the rate of crop development.

The plot also aids in detection of long-term effects and sequences of significant weather features. For example, for 5 weeks prior to day 238, temperatures were consistently below normal. This phenomenon probably delayed ripening of spring wheat. The heavy rainfall during the week ending on day 210, an extreme departure from normal, would probably have been detected as standing water in some fields if an acquisition had been available for that date.

Part 2 of the climagraph depicts the crop moisture index (CMI) and the adjustable crop calendar (ACC) model outputs by week (see fig. 2-2). The header information, available acquisitions, and weekly time scale are the same as in part 1. The scale for the CMI is dimensionless with a normal reference line at zero. The ACC scale, in this case, is for the Robertson biometeorological time scale for spring wheat (ref. 1). The stages in this scale are: planting = 1.0; emergence = 2.0; jointing = 3.0; heading = 4.0; soft dough = 5.0; and ripe = 6.0. This scale is also dimensionless and is used to depict the cumulative development of the crop as estimated in a meteorologically driven model. Again, the 26 values of each variable are interpolated estimates derived from running the models with the available first-order station data.

These two plots characterize the response to the meteorological conditions at the segment level and facilitate the assessment of meteorological impacts on spectral appearance. The CMI integrates the effects of both temperature and precipitation into a budgeted index related to soil moisture and, hence, stress. For interpretation of the index values, consult table 2-1.

The CMI plot when compared to the temperature and precipitation plots indicates to some extent the response of the CMI to the other two variables. For example, the week ending on day 168 was warm and dry enough to begin slight

TABLE 2-1.- CMI INTERPRETATION

[As reported in the Weekly Weather and Crop Bulletins prepared by the U.S. Department of Commerce, Department of Agriculture]

Value	Index decreasing	Index increasing
Above 3.0	Some drying but still excessively wet	Excessively wet; some fields flooded
2.0 to 3.0	More dry weather needed; work delayed	Too wet; some standing water
1.0 to 2.0	Favorable, except still too wet in spots	Prospects above normal; some fields too wet
0 to 1.0	Favorable for normal growth and field work	Moisture adequate for present needs
0 to -1.0	Top soil moisture short; germination slow	Prospects improved but rain still needed
-1.0 to -2.0	Abnormally dry; yield prospects deteriorating	Some improvement but still too dry
-2.0 to -3.0	Too dry; yield prospects reduced	Drought eased but still serious
-3.0 to -4.0	Potential yields severely cut by drought	Drought continued; rain urgently needed
Below -4.0	Extremely dry; most crops ruined	Not enough rain; still extremely dry

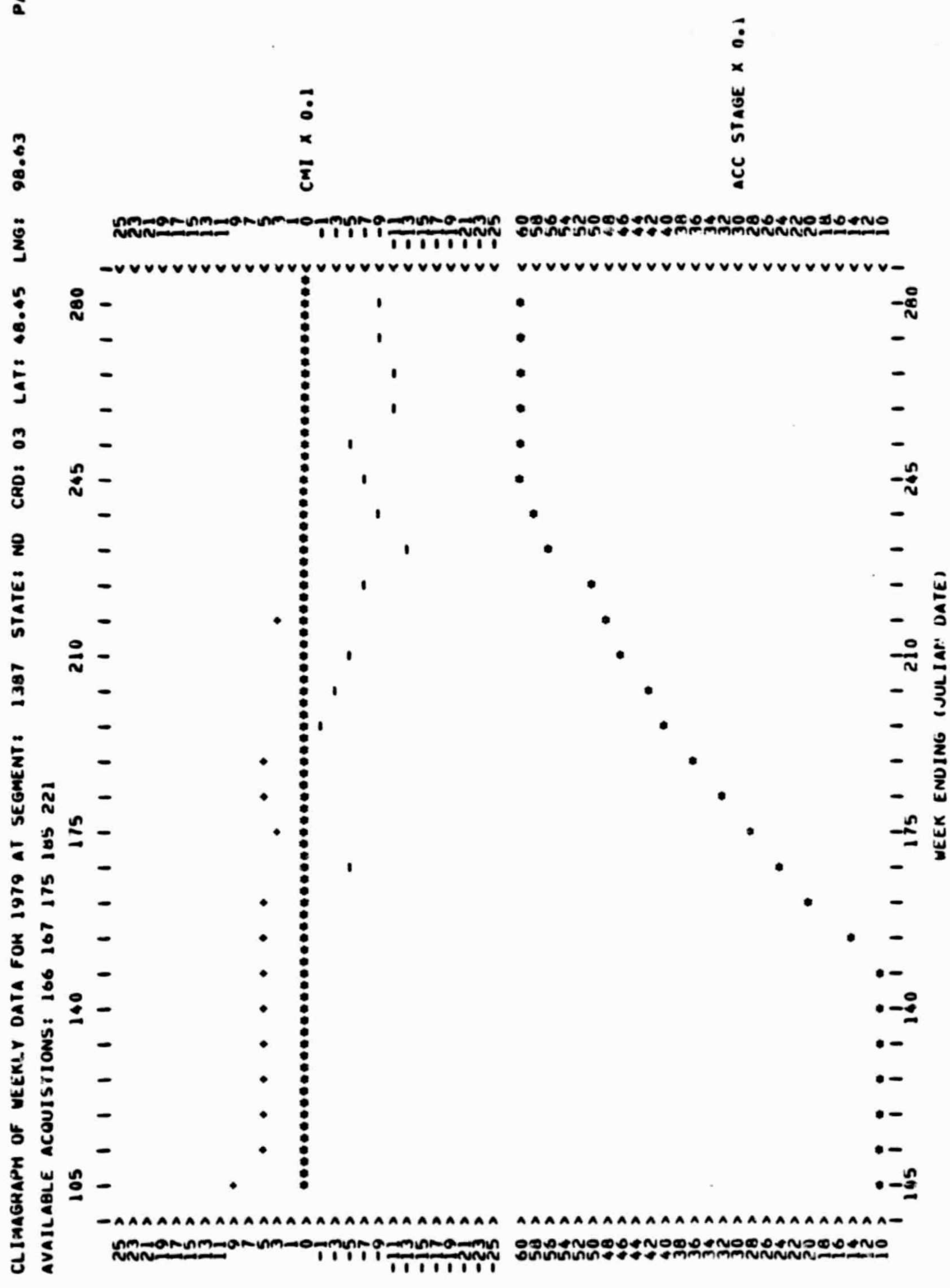

Figure 2-2.- Climagraph product, part 2.

stress, but conditions recovered in the subsequent cool, wet week ending on day 175. In general, the index did not indicate stress, despite below normal precipitation, until the higher temperatures of mid to late summer began to take effect. The sequences in this time series are also harbingers of spectral appearance. Sustained and unrelenting stress conditions are indicated after the week ending on day 224.

The final plot of ACC values by week indicates at what particular stage of crop development favorable or unfavorable meteorological episodes or sequences occurred. It indicates the best current estimate of a crop's stage of development as derived from the current year's weather. The plot, which defines the growing season for the crop, is used to establish the intervals (biowindows) between spectrally significant crop stages. Acquisitions during these intervals are selected for classification procedures.

Part 3 of the climagraph product provides information which cannot be conveniently plotted and a special synopsis of special features of the ACC plot (see fig. 2-3). The header and available acquisition date information is followed by a table entitled "Date and Region of Reported Significant Ecological Events." An effort has been made to collect reports of events or situations, not necessarily weather related, which may effect spectral appearance in the experiment region. This type of information is dated and assigned to the appropriate level of geographic detail. For example, localized hail damage in North Dakota, CRD 3, was reported for the week ending on day 252. Although segment 1387 is located in this CRD, hail may not have affected the segment itself. Likewise, the report from the week ending on day 147 indicates that wild oats was becoming a statewide problem, although not necessarily in segment 1387. Such reports are provided to the analyst as potential clues for explaining anything unusual observed in the segment imagery or spectral sequences.

The next feature of part 3 is entitled "Adjustable Crop Calendar Dates for Spring Wheat by Acquisition Date and Stage." These are data points which may be extracted from the ACC plot but which are displayed here for convenience.

```
CLIMAGRAPH OF WEEKLY DATA FOR 1979 AT SEGMENT:  1387  STATE: ND  CRD: 03  LAT: 48.45  LNG:  98.63         PART  3
AVAILABLE ACQUISTIONS: 166 167 175 185 221

DATE AND REGION OF REPORTED SIGNIFICANT ECOLOGICAL EVENTS

252 ND 03 LOCALIZED HAIL DAMAGE REPORTED
147 ND ST WILD OATS BECOMING A PROBLEM
154 ND ST WILD OATS AND OTHER WEEDS MAJOR PROBLEM
161 ND ST SPRAYING FOR CONTROL OF WILD OATS AND OTHER WEEDS UNDERWAY
161 ND ST INSECT DAMAGE BEGINNING TO APPEAR
168 ND ST HOT DRY WINDS
189 ND ST GRASSHOPPERS CONTINUED TO BE AN INCREASING PROBLEM
203 ND ST SCATTERED GRASSHOPPER PROBLEMS
210 ND ST THUNDERSTORMS COMMON WITH HIGH WINDS, HAIL, HEAVY RAINS AND TORNADOS
231 ND ST FREEZING TEMPERATURES AND WIDESPREAD FROST
238 ND ST RAIN SLOWED HARVEST PROGRESS EXECEPT IN NORTHWEST AND NORTH CENTRAL
245 ND ST LOCALLY SEVERE THUNDERSTORMS PRODUCED SOME LARGE HAIL
252 ND ST SCATTERED LIGHT FROST
259 ND ST SCATTERED FROST
266 ND ST SCATTERED FROST
280 ND ST DRY, WINDY

ADJUSTABLE CROP CALENDAR DATES FOR SPRING WHEAT BY ACQUISTION DATE AND STAGE:

166  2.4
167  2.5
175  2.9
185  3.4
221  5.0

148  PLANTING
160  EMERGING
177  JOINTING
197  HEADING
223  SOFT DOUGH
243  RIPE

WINDOW 1:  143 - 166
WINDOW 2:  187 - 207
```

Figure 2-3.- Climagraph product, part 3.

The model stage estimates for each available acquisition date are given, followed by the estimated dates of the six cardinal stages of the crop model.

The final item on the climagraph is the specification of potential biowindows for acquisition selection. In this case, two are defined in terms of the ACC cardinal stage dates. Window 1 is the 24-day period from 5 days before to 18 days after spring wheat planting. Window 2 is the 21-day period from 10 days before to 10 days after heading. Additional biowindows were defined for barley, the other crop of interest, but ACC models are not yet available.

These windows are determined by comparing the historical average of the biowindow definition date (e.g., barley turning date minus spring wheat heading date) to the available ACC date. For example, if historically for the region, barley turning (key date of the biowindow) occurs 10 days prior to spring wheat heading, the best estimate in the current year for this date is 10 days before the ACC-estimated date of spring wheat heading.

This explains the current version of the climagraph product. Modifications are anticipated in response to user requirements, to analyst evaluation of the usefulness of the displayed variable, and to the introduction of new variables and indicators of spectral appearance. The central theme remains the careful reduction of data to the segment level for a specific time interval.

Two additional products are generated from the weather analysis and interpretation activity. Both contain special interpretations of the CMI, the primary variable for study of crop spectral appearance.

The regional CMI interpretation (fig. 2-4) provides an expanded view of the extent of stress conditions (as indicated by the index) over time and space. The product is a printed narrative for each subregion (CRD) in the experiment region with the segment numbers included.

The second CMI product (table 2-2) provides a subjective assessment of the impact of CMI variations on crop development and spectral appearance. The

TABLE 2-2.- CMI INTERPRETATION FOR CROP DEVELOPMENT AND SPECTRAL APPEARANCE ASSESSMENT

[Spring small-grain areas of stressed growth development, 1979]

CRD	Segment	Planting/tillering		Jointing		Heading		Soft dough		Ripe/harvest	
		Development	Expected colors	Development	Expected colors	Development	Expected colors	Development	Expected colors	Development	Expected colors
North Dakota:											
Northwest	1394 1457 1602	Normal	(a)	Slightly retarded	Light red, orange, purple	Accelerated	Dark red, orange, yellow	Accelerated	Red, orange, yellow	Accelerated	Orange, yellow, white, green
North-central	1392 1461 1611 1612	Normal	(a)	Slightly retarded in early part; may be normal in late part	(a)	Accelerated	Dark red, orange, yellow	Accelerated	Orange, yellow, white	Accelerated	Orange, yellow, white, green
Northeast	1387 1467 1584 1617 1619	Normal	(a)	Retarded	Light red, tan, purple, gray	Normal to accelerated toward full heading	Dark red, orange, yellow	Accelerated	Orange, yellow, tan	Accelerated	Orange, yellow, white, green, tan
Southwest	1650	Retarded	Green, blue, purple, gray, brown	Retarded	Blue, purple, light red	Accelerated in early part; slows in latter part to normal	(a)	Accelerated	Orange, tan, magenta, yellow	Normal	(a)
South-central	1653 1656 1909 1917 1918 1920	Retarded toward full tillering	Purple, light red, gray, brown	Retarded	Purple, light red, orange	Normal	(a)	Normal (except segment 1653, which is accelerated)	Orange, tan, magenta, yellow	Normal (except segment 1653, which is accelerated)	Orange, tan, green, white
Minnesota:											
Northwest	1514 1518 1825 1987	Normal	(a)	Normal	(a)	Normal	(a)	Slightly accelerated	Orange, yellow	Accelerated	Orange, yellow, white, green
Central	1524 1843	Slightly retarded	Green, blue, purple	Normal	(a)	Normal	(a)	Normal	(a)	Normal	(a)
Southwest	1380	Normal	(a)	Normal	(a)	Normal	(a)	Normal to slightly retarded	Orange, light red, dull red	Normal	(a)
South Dakota:											
North-central	1599	Normal	(a)	Slightly retarded in early jointing	Purple, light red	Normal	(a)	Normal	(a)	Normal	(a)
Central	1689 1755	Normal to slightly retarded	(a)	Retarded	Purple, light red	Normal	(a)	Normal	(a)	Normal	(a)
Montana:											
Central	1948	Retarded	Blue, green, purple	Slightly retarded	Blue, purple, light red	Slightly accelerated	Dark red, orange, yellow	Slightly accelerated	Orange, yellow, white	Accelerated	Orange, yellow, white, green

[a] No departure from the normal signature sequence is expected.

```
FILE: CMI        SCRIPT   A                    CONVERSATIONAL MONITOR SYSTEM

1.0 CROP MOISTURE INDEX (CMI)

    1.1 GENERAL
        MOST AREAS ENTERED THE DELAYED GROWING SEASON WITH ADEQUATE
        AND FAVORABLE MOISTURE CONDITIONS AS INTERPRETED FROM THE CMI.
        THE EASTERN CRD'S EXPERIENCED LITTLE OR NO STRESS CONDITIONS
        UNTIL LATE JULY AND AUGUST.  HOWEVER SOUTHERN AND WESTERN CRD'S
        EXPERIENCED DRY AND DETERIORATING CONDITIONS IN EARLY JUNE
        WHICH ENDED ABRUPTLY IN THE LATTER PART OF THE MONTH.
    1.2 NORTH DAKOTA
        1.2.1 NORTHWEST (SEGMENTS: 1394,1457,1602)
              AREA MOISTURE WAS ADEQUATE THROUGH THE FIRST WEEK
              OF JUNE.  CONDITIONS GENERALLY DETERIORATED AFTER PLANT-
              ING WITH SPOTTY RELIEF TO DRY CONDTIONS DURING JULY AND
              WORSENING CONDTIONS THROUGH AUGUST.
        1.2.2 NORTH CENTRAL (SEGMENTS: 1392,1461,1611,1612)
              CONDITIONS BECAME MARGINAL AFTER PLANTING IN EARLY JUNE.
              HOWEVER, BY AUGUST VERY DRY CONDTIONS BEGAN AND CONTINUED
              UNABATED.
        1.2.3 NORTHEAST (SEGMENTS: 1387,1467,1584,1617,1619)
              CROP MOISTURE WAS ADEQUATE THROUGH LATE JULY WITH ONLY
              SLIGHT STRESS EXPERIENCED THEREAFTER.
        1.2.4 EAST CENTRAL (SEGMENTS: 1472,1473,1645)
              CROP MOISTURE CONDITIONS REMAINED FAVORABLE UNTIL AUGUST
              THEN DETERIORATED CONSIDERABLY.
        1.2.5 SOUTHWEST (SEGMENTS: 1650)
              CONDITIONS DETERIORATED IN EARLY JUNE WITH SOME IMPROVE-
              MENT DURING JULY AND FAVORABLE CONDITIONS AFTER MID-
              AUGUST.
        1.2.6 SOUTH CENTRAL (SEGMENTS: 1653,1656,1909,1917,1918,1920)
              CONDITIONS BEGAN DETERIORATING RAPIDLY IN EARLY JUNE AND
              WERE QUITE DRY BY EARLY JULY.  THEREAFTER THINGS IMPROVED
              AND CONDITIONS BECAME VERY MOIST BY MID-SEPTEMBER.
        1.2.7 SOUTHEAST (SEGMENTS: 1399,1658,1661,1664,1924,1974)
              THE CMI WAS FAIRLY STABLE WITH CONDITIONS ADEQUATE OR
              FAVORABLE THROUGH MID-SEPTEMBER.
    1.3 MINNESOTA
        1.3.1 NORTHWEST (SEGMENTS: 1514,1518,1825,1987)
              CONDITIONS WERE ADEQUATE OR FAVORABLE OVER THIS REGION
              THROUGH JULY WITH STEADY DETERIORATION IN AUGUST AND
              SEPTEMBER.
        1.3.2 WEST CENTRAL (SEGMENTS: 1835,1842)
              FAVORABLE MOISTURE CONDITIONS PERSISTED THROUGHOUT THE
              GROWING SEASON EXCEPT FOR EXCESSIVE MOISTURE IN MID
              TO LATE JUNE.
        1.3.3 CENTRAL (SEGMENTS: 1524,1843)
              MOISTURE WAS ADEQUATE TO EXCESSIVE THROUGHOUT THE SEASON
              WITH EXTREMELY WET CONDITIONS PRIOR TO THE DELAYED
              PLANTING.
        1.3.4 SOUTHWEST (SEGMENTS: 1380)
              MOISTURE WAS ADEQUATE TO EXCESSIVE THROUGHOUT THE
              SEASON WITH EXTREMELY WET CONDTIONS COMMENCING IN AUGUST
              WITH LITTLE IMPROVEMENT THROUGHOUT THE HARVEST PERIOD AND
              INTO LATE SEPTEMBER.
    1.4 SOUTH DAKOTA
        1.4.1 NORTH CENTRAL (SEGMENT: 1599)
              MOISTURE CONDITIONS WERE ADEQUATE THROUGHOUT THE
              SEASON EXCEPT FOR SOME STRESS DURING THE FIRST HALF
              OF JUNE.
        1.4.2 NORTHEAST (SEGMENT: 1960)
              THE CMI INDICATED FAVORABLE MOISTURE CONDITIONS THROUGHOUT
              THE SEASON BUT MOISTURE WAS EXCESIVE DURING THE LATTER
              HALF OF JUNE.
        1.4.3 CENTRAL (SEGMENTS: 1689,1755)
              CONDITIONS WERE ADEQUATE THROUGH MID-SEPTEMBER EXCEPT
              FOR SOME SLIGHT STRESS IN EARLY JUNE.
        1.4.4 SOUTH CENTRAL (SEGMENT: 1676)
              THE CMI WAS ADEQUATE AND STABLE THROUGH LATE SEPTEMBER.
        1.4.5 SOUTHEAST (SEGMENTS: 1784)
              MOISTURE WAS MORE THAN ADEQUATE THROUGH ALMOST ALL THE
              SEASON WITH EXECSSIVE MOISTURE INDICATED IN MID-MAY.
    1.4 MONTANA - CENTRAL (SEGMENT: 1948)
        MOISTURE WAS ADEQUATE THROUGH MAY BUT DECLINED AND REMAINED
        MARGINAL TO POOR THROUGHOUT THE REMAINDER OF THE SEASON
        REACHING NEARLY DROUGHT CONDITIONS BY LATE AUGUST.
```

Figure 2-4.- Regional CMI interpretation.

assessment is made at the specific CRD level in terms of expected deviations in stage and color at the six normal stage dates. This product represents a detailed interpretation by an experienced analyst of appearance and the reasons for an anticipated spectral sequence of spring wheat in the CRD.

All of these products were prepared and delivered in support of the U.S./Canada Wheat and Barley Exploratory Experiment. They are still under evaluation and subject to modification. For now, these products represent the current state of weather analysis and interpretation techniques in support of FCPF experiments. They can be produced for almost any region for which data are available. These data requirements are not entirely inflexible; however, timely acquisition of meteorological data is the most crucial component and must be supplied without compromise.

3. DATA REQUIREMENTS

Data requirements fall into two categories: (1) ancillary data and (2) meteorological data. The ancillary data are used to define a suitable subset of the meteorological data spatially and temporally and to control the structure of the information displayed in the products. The meteorological data are refined, summarized, used to run models, and displayed for interpretation.

3.1 ANCILLARY DATA

Ancillary data must be obtained for each point (segment) of interest to the user. The types, functions, and sources of these data are listed in table 3-1. These data sets, which are in card image format, do not require a large amount of storage space. Usually, all the data of a particular type can be combined for all segments in a geographic region. For example, items 1 through 5 in table 3-1 can be placed on a single record, and the file of these records can comprise all segments in a given experiment region.

3.2 METEOROLOGICAL DATA

Two classes of meteorological data are required by these procedures: (1) historical records of monthly data and (2) daily records from the weather stations for the year of interest.

The historical records must be a minimum of 10 years in length, preferably 30 years. They must be at the lowest level of representation available (station, whenever possible) and include monthly averages of mean temperature and monthly totals of precipitation. These data are essential for proper implementation of the CMI algorithm. The normals of temperature and precipitation, items 7 and 8 of the ancillary data (table 3-1), may also be determined from these records.

The daily records must include the maximum and minimum temperatures and the total precipitation. The records must be complete for each item for each day of the period of interest and include as many stations as possible within the region bounds.

TABLE 3-1.- ANCILLARY DATA REQUIREMENTS

Type	Function and/or application	Data source
Segment location (latitude and longitude)	Objective analysis estimates, header[a] information	User
Segment identifier (number)	Program control, header information	User
Segment political region (state)	Program control, header information	User and maps
Segment political subdivision (CRD)	Program control, header information	User and maps
Available Landsat acquisition dates	Data selection, header information	User
Estimated planting date for each crop of interest	Initiation of ACC model	Ground truth, starter model, and historical normals
Normal monthly temperature (12 months)	Simulation of weekly normals	Climatological data for division or nearby station
Normal monthly precipitation (12 months)	Simulation of weekly normals	Climatological data for division or nearby station
Estimated soil moisture capacity	CMI operations	Soils surveys and maps
Significant ecological events	Displays	Weekly Weather and Crop Bulletin
Dates for the period of interest	Extraction of appropriate meteorological data	Experiment Plan
Latitude and longitude boundaries of region	Extraction of appropriate meteorological data	Experiment Plan

[a]Header refers to identification information in computer-generated products.

Because of the enormous quantity of historical and daily data, tape and/or disk storage is required. For completeness of the records and the daily observation reports, further processing of raw data is required. Ideally, the historical records will correspond to the daily records station by station.

A summary of the meteorological data requirements for these procedures appears in table 3-2. The international scope of anticipated FCPF experiments requires worldwide coverage for meteorological data. The minimum station density requirements for these procedures have not been determined; however, it does not seem likely that such requirements will ever be exceeded in foreign areas. Therefore, observations from every available station are needed.

TABLE 3-2.- METEOROLOGICAL DATA REQUIREMENTS

Type	Function and/or application	Data source
Mean monthly temperature (120 months)	CMI operations	Historical records and published values
Total monthly precipitation (120 months)	CMI operations	Historical records and published values
Daily maximum temperature	ACC models, computing weekly means, and CMI operations	Daily records from NOAA[a] tapes and published values
Daily minimum temperature	ACC models, computing weekly means, and CMI operations	Daily records from NOAA tapes and published values
Daily precipitation totals	Computing weekly totals and CMI operations	Daily records from NOAA tapes and published values
Latitude and longitude of first-order stations	Objective analysis	Station records

[a]National Oceanic and Atmospheric Administration.

4. PROCEDURES

An idealized configuration for these procedures appears in figure 4-1. A user provides basic inputs about the desired region through an interactive terminal of the Laboratory for Applications of Remote Sensing (LARS) computer at Purdue University. This computer then accesses installed data bases and software to obtain a machine-generated tool of analysis (e.g., climagraph) based on weather conditions for each segment. The computer system provides permanent disk storage, data tape handling facilities, and working temporary storage. The software provides extraction modes for all available data, quality checks of the data, summaries, and algorithm outputs of meteorologically driven models.

4.1 ASSEMBLY OF INPUTS

Prior to the creation of products at the terminal, numerous small data sets and ancillary information relating to the experiment region and its segments must be assembled. The first requirement is a geographic definition of the experiment region. If the region has distinct geopolitical boundaries and does not exceed the size of a square 10° latitude by 10° longitude, the definition becomes the smallest quadrangle, bounded by whole-degree lines of latitude and longitude, which encompasses the region.

This constraint on size has two supporting arguments. First, an area that is much larger would probably not be climatologically homogeneous. The second reason for restricting the geographic size is the result of adaptation of software to objective analysis techniques. The number of grid cells to be analyzed for a particular grid size increases with area. This, in turn, increases computer core requirements and computation time. If the political region exceeds the 10° latitude by 10° longitude size, two or more quadrangles must be specified. Precise information on the climatic regime, topography, and spatial distribution of the segments is required to define the size and positions of these subregions. The distribution of the segments within the region becomes a key feature when geopolitical boundaries are not definitive. The size constraints also apply to the special quadrangle to encompass this distribution.

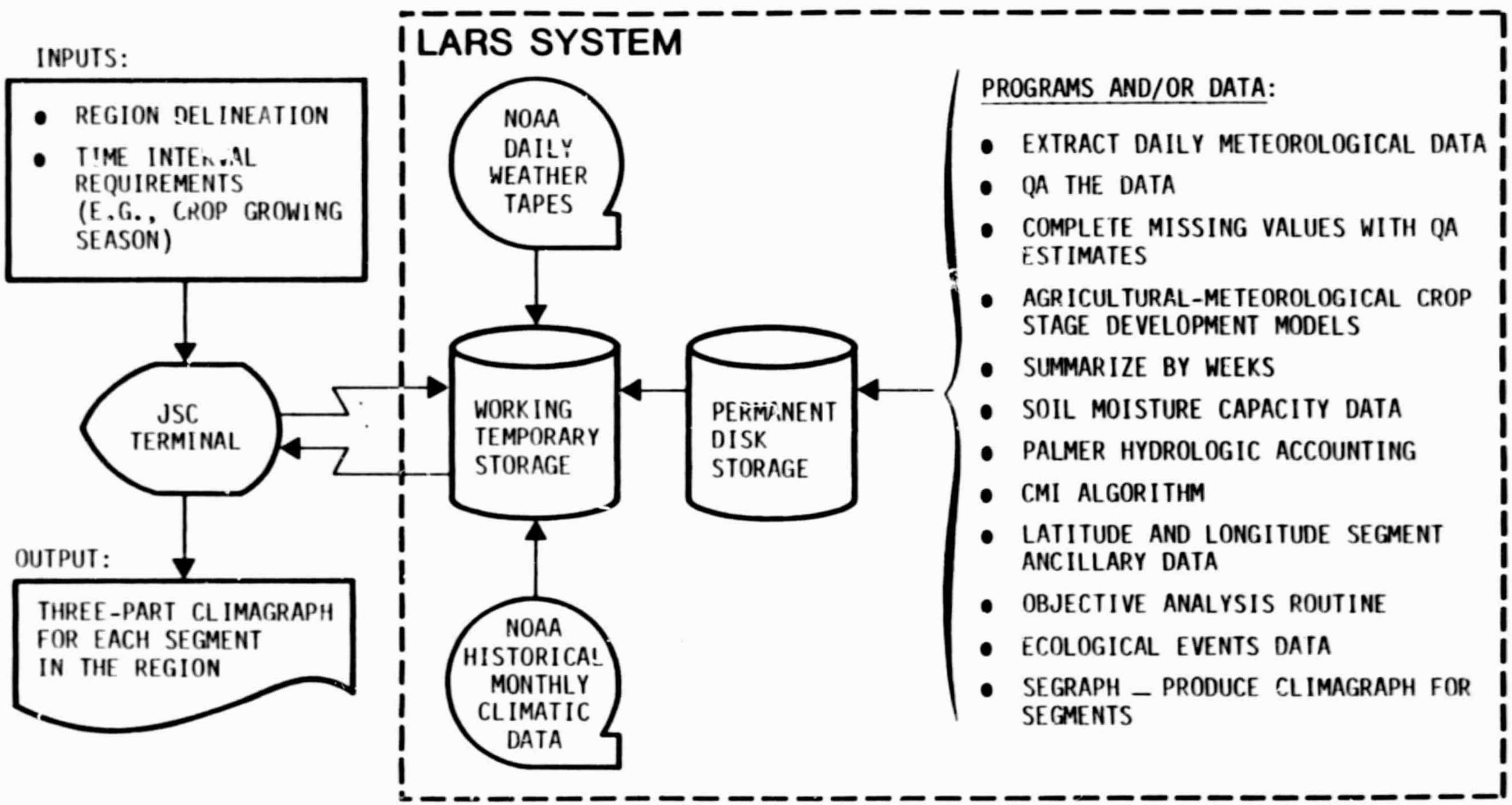

Figure 4-1.- Idealized configuration for weather analysis and interpretation procedures.

The distribution of the segments within a region is best determined from a complete list of the segments, along with their latitudes and longitudes, to be used in the experiment region. Ultimately, the coordinates will be used in an objective analysis to obtain estimates of various meteorological parameters at the segment level.

With the definition of each experiment region quadrangle, the specific regional data must be assembled in disk storage. These data include daily meteorological data for all available stations, monthly climatological data, estimated planting dates for each crop of interest at each regional segment, estimated regional soil moisture capacities, significant ecological events, and open and close dates for data collection.

The period of data collection is largely determined from the historical regional crop calendars. This meteorological data collection period should overlap the imagery collection period during the experiment. The daily meteorological data and the data for significant ecological events are acquired as specified by the open and close dates and may be assembled as they become available.

Daily meteorological data are extracted as specified by the latitudes and longitudes of the quadrangle and the collection period. These raw data require some quality control because of inconsistencies, such as maximum temperature reported as less than or equal to minimum temperature. Such reports are discarded and regarded as missing. All missing values are replaced with estimates, when feasible. If the observation record for a particular station is less than 25 percent complete, it is deleted from the data set because values for too many of its observations would have to be estimated.

The completion of the remaining observation matrix (i stations by j days by 3 variables) is attained through an objective analysis technique. A value for a missing observation of a particular variable on a given day is estimated from the scalar field of that variable. The software can be used to determine objectively a unique solution of the scalar field. This solution, which is obtained from grid specifications and available observations within the grid, can then be used to estimate a value for any given point in the field. This procedure is repeated until a complete data set of maximum and minimum temperatures and total precipitation values is obtained and stored on disk.

The historical records of monthly climatological data acquired within the experiment region quadrangle must be assembled. If the record is for a division rather than an individual station, approximate geographic coordinates of the division must be obtained because the data must be treated like those of a station for computational purposes.

Estimates of soil moisture capacities for each station within the experiment region must be made. This can be accomplished by consulting either the published data for the region or a soils expert capable of utilizing general soils classification maps for the region. The estimates are to the nearest inch and frequently are uniform over entire regions.

A crucial element of data to be assembled is estimates of regional planting dates for each crop of interest. This may be accomplished using any of three resources: (1) historical normals; (2) starter models, such as that developed by Feyerherm for spring wheat; and (3) ground-truth data from the segments. From whichever means is appropriate, dates must be estimated for the first-order stations.

The final data type to be assembled prior to processing is the significant ecological events for the region. These are terse, verbal comments extracted from published reports about crop and weather conditions in the region. Each event must be identified by the approximate Julian date of the reported occurrence. The event must further be identified by region and subregion codes; for example, North Dakota (ND) and northeast CRD (03).

All the preceding data (whether compiled as cards, tapes, or disk files) must be assembled collectively as a set of card images in permanent storage where they are accessible during program execution. The format specification of these files must be consistent with current software.

4.2 DATA PROCESSING

All variables that must be reduced to the segment level through objective analysis must be processed and available at the first-order stations prior to interpolation. This assures that all models and statistical procedures are applied to data with only observational errors. If the raw data for observed temperature and precipitation were reduced and then processed at the segment level, the inherent error of interpolation would be compounded by the error of observation prior to running the models or producing statistics. The impact of this compound error is not known, which complicates any assessment of error statistics of segment-level variables.

The first stage of the processing is to obtain the daily stage of development for each crop of interest by running the ACC model(s) from the estimated planting date and the daily meteorological data for each station. One further step is required prior to interpolation: extract only those values for the week-ending Julian dates for the experiment time period.

The next variables for processing are obtained by contrasting the daily temperatures and precipitation values to the mean temperature and the total precipitation for each week-ending period. These weekly values not only will be interpolated but also will be used to run the CMI algorithm.

Next, the historical records are processed. Two products are obtained: (1) coefficients for the CMI algorithm and (2) normals of temperature and precipitation. Both are outputs of the Palmer hydrological accounting system (ref. 2) operating on the entire record.

The normals of temperature and precipitation are then utilized to obtain simulated weekly values corresponding to those determined for the current year. The simulation is accomplished by harmonic analysis.

The final variable to be obtained at the first-order stations is the weekly CMI values. These values are computed by applying the CMI algorithm to the derived coefficients for the station and the weekly values of temperature and precipitation.

The following weekly variables by station are now ready for objective analysis to obtain the segment-level estimates displayed in the climagraph products: (1) mean temperatures, (2) normal mean temperature, (3) total precipitation, (4) normal total precipitation, (5) final ACC stage estimates, and (6) CMI values. The objective analysis of these six variables for each week utilizes the latitudes and longitudes of both stations and segments and the grid for experiment region quadrilateral.

The final data processing at the segment level applies ancillary data and meteorological data to produce segment-specific climagraph products. These products are printed for delivery in support of FCPF experiments and then are stored on magnetic tape, along with all their contributing data files.

4.3 INTERPRETATION OF THE CMI

Both CMI interpretation products are subjective in nature. The regional narrative is based upon examination of CMI maps and plots to obtain a coarse assessment over time and space. The interpretation for stress and the impact on crop development and signature response are based upon an analyst's experience with the spectral sequence of crops. This is complemented by the analyst tracking the CMI values throughout the season to detect possible deviations from normal development in the region and to anticipate the spectral appearance.

4.4 MODELS AND ALGORITHMS

The important models and algorithms used in these procedures are listed in table 4-1. Fortran implementation of these items has been completed. They exist as flexible subroutines accessible by an evolving line of Conversational Monitor System (CMS) executive processors and other Fortran programs which access, manipulate, and display the meteorological data in the climagraphs. The software of these models and algorithms represents the stable core of current Fortran programs used in these procedures. Documented program listings are given in appendix A of this document. The structure for interactions of this software appears as a flowchart in appendix B.

TABLE 4-1.- MODELS AND ALGORITHMS APPLIED

Name	Function and/or application	Data source
Wagner variational analysis technique	Objective analysis of meteorological variables	Ref. 3
Crop moisture index	Prime stress indicator	Ref. 4
Palmer hydrological accounting	Local coefficients for CMI	Ref. 2
Thornthwaite model for potential evapotranspiration (PE)	PE values for Palmer and CMI algorithms	Ref. 5
Robertson biometeorological time scale model for spring wheat	ACC stage estimates	Ref. 1

The Wagner variational analysis technique (ref. 3) is applied for objective analyses of meteorological scalar fields in regions of sparse data. This method utilizes a low-pass filter to provide a consistent and computationally rapid means of estimating values at grid points in the analyzed field. The errors associated with estimates of the variables used in the climagraphs are being investigated.

The CMI is based upon a relatively simple two-layer soil moisture budget (ref. 4). On a weekly basis, the value of the index is computed using the total precipitation and an "appropriate" value for evapotranspiration (ET). This ET value is an adjusted value of PE computed from mean temperature. Coefficients for PE and the adjustment factor are based upon the Palmer hydrological accounting approach (ref. 2). This technique is applied to the entire monthly climatological record and assumes that an estimated soil moisture capacity for the region can be used in the soil moisture budget. Surpluses and deficits of moisture for the index are therefore linked to normal conditions for the region. The method for computing PE is based upon a model proposed by Thornthwaite in his efforts to simplify climatic classification (ref. 5).

The Robertson biometeorological time scale model for spring wheat (ref. 1) quantifies the progress of the crop toward maturity as functions of daily maximum and minimum temperatures and daylength. The computations result in a daily increment of development during the crop season. These increments are accumulated from an initial value of 1.0 until a value of 6.0 (ripe) is reached. The six stages described earlier require five sets of coefficients (one for each interval). As the accumulated value reaches a new stage, the coefficients applied to the daily variables change, reflecting the changes in the response of the plant to its environment as it matures. The model was tested and used successfully and extensively during LACIE for both weather interpretation and advanced yield modeling.

4.5 SCHEDULING

The procedures described above are applied to two main types of experiments: (1) a crop-year experiment in which the region and time period are specified prior to planting and the data collection and processing progress with the growing season and (2) a historical-year experiment in which the region and time period are specified after harvest and all data have been collected. A generalized schedule for providing support to these two experiment types appears in figure 4-2.

The crop-year experiment schedule runs for about 12 months, approximately 9 of which are devoted to data collection during the growing season. Final processing begins after 11 months when the final meteorological data become available. At this point, coordinates for the segments in the region are essential to the objective analysis of meteorological variables and the production of the final climagraph product.

The schedule for a historical-year experiment runs about 4 months after the selection of the region and crop year. Approximately 6 weeks is anticipated to procure the meteorological data required for the experiment. An additional 9 weeks is required to extract the station data, run the models, receive the segment coordinates, perform the objective analysis, and produce the products. This schedule would probably have to be extended to 6 months if multiple years for a particular region are included in the experiment design.

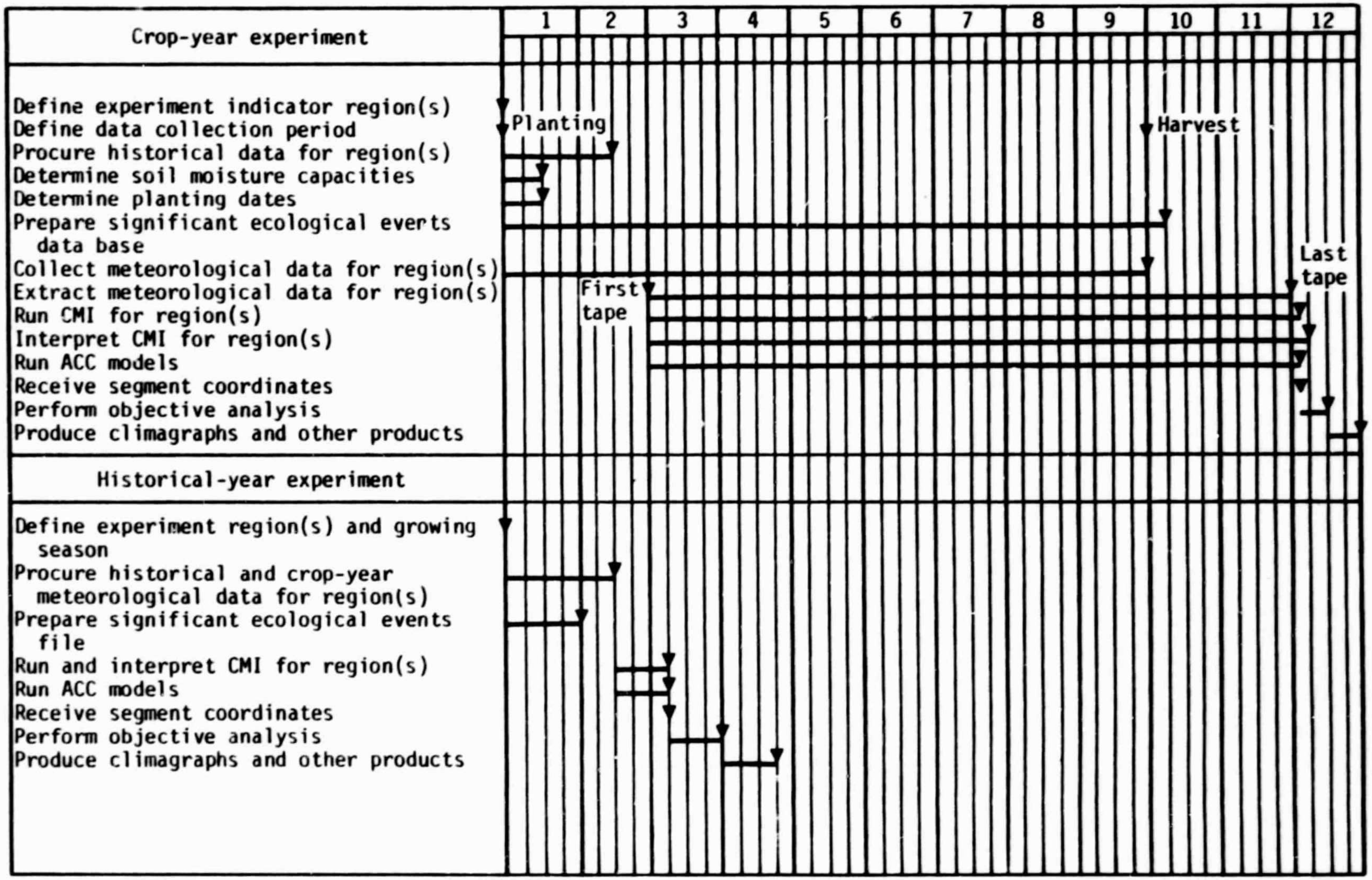

Figure 4-2.- Generalized weather analysis and interpretation procedure schedule.

5. CONCLUDING REMARKS

The procedures and products developed for the weather analysis and interpretation activity supporting the U.S./Canada Wheat and Barley Exploratory Experiment are described in this report. Innovative approaches have been applied in order to meet the task objectives, and an improved line of products has been created. These products are tools in this effort and are subject to evaluation and revision as user requirements are better defined and understood.

The major emphasis is to develop segment-specific information about weather conditions and an objective, machine-oriented representation of this information.

The data requirements of these procedures have not increased significantly since LACIE; however, the requirements of accessibility and geographic coverage have changed. Data tape libraries and disk data bases are needed to assure timely processing and to support the massive data reduction described.

The procedures will continue to change as new requirements and techniques evolve and as new products are designed. As data bases become comprehensive and stabilize in format and reliability, the software for their manipulation and reduction will become more uniform and streamlined. The basic software for models and algorithms will expand as new ones are developed by supporting research. Future changes probably will require revision of these procedures. This document represents the current state of development for weather analysis and interpretation techniques for the FCPF project of the AgRISTARS program.

6. REFERENCES

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4. Sadowski, A.: Crop Moisture Index. Technical Procedures Bull. 13, U.S. Dept. Commerce, 1975.

5. Thornthwaite, C. W.: An Approach Toward Rational Classification of Climate. Geographical Review, vol. 38, 1948, pp. 55-59.

APPENDIX A

PROGRAM LISTINGS OF MODEL AND ALGORITHM SOFTWARE

APPENDIX A

PROGRAM LISTINGS OF MODEL AND ALGORITHM SOFTWARE

Listings for the WAGNER, CMISUBS, and ROBBMTS computer programs are given in this appendix.

FILE: WAGNER   FORTRAN A   PURDUE / LARS 3031

```
      INTEGER IDATA(100,6)
      DIMENSION XLAT(500),XLONG(500),X(100,8),YLAT(500),YLONG(500)
      DIMENSION P(50,50),U(50,50),IX6(512),LAB(5)
      REAL MAXLAT,MINLAT,MAXLNG,MINLNG
5     READ(5,101,END=513)MAXLAT,MINLAT,MAXLNG,MINLNG,ISIZE,JSIZE,LAB
  101 FORMAT(F2.0,F3.0,2F4.0,2I3,1X,5A4)
      IF(MAXLAT.LT.-90.0) STOP
      GO TO 514
 513  STOP
514   CONTINUE
      WRITE(6,901) MAXLAT,MINLAT,MAXLNG,MINLNG,ISIZE,JSIZE
901   FORMAT(1H1,4X,22HMAXIMUM LATITUDE        ,F6.2/5X,
     122HMINIMUM LATITUDE        ,F6.2,/5X,22HMAXIMUM LONGITUDE       ,
     2F6.2/5X,22HMINIMUM LONGITUDE       ,F6.2/5X,
     322HNUMBER N-S GRID POINTS,I6/5X,22HNUMBER E-W GRID POINTS,I6///,
     4' ',15A4/////)
C MAXLAT = MAXIMUM LATITUDE ON MAP
C MINLAT= MINIMUM LATITUDE ON MAP
C MAXLNG= MAXIMUM LONGITUDE ON MAP
C MINLNG=MINIMUM LONGITUDE ON MAP
C ISIZE=NUMBER OF GRID IN N-S DIRECTION
C JSIZE = NUMBER OF GRID IN E-W DIRECTION
C ISIZE,MAXLAT,MINLAT MUST BE ADJUSTED SO ISCALE IS AN INTEGER
C JSIZE,MAXLNG,MINLNG MUST BE ADJUSTED SO JSCALE IS AN INTEGER
      AAAAA = 100.0
      BBB = 1.0
      CCC = 1.0
      ISCALE=(FLOAT(ISIZE-1))/(MAXLAT-MINLAT)
      JSCALE=(FLOAT(JSIZE-1))/(MAXLNG-MINLNG)
51    L=0
      WRITE(6,6666)LAB
 6666 FORMAT('1',5A4,//)
    1 L=L+1
5112  READ(5,100) XXID,XLAT(L),XLONG(L),JYEAR,(X(L,J),J=1,4)
100   FORMAT(A3,F5.2,F6.2,I4,F3.0,F4.0,F4.0,F5.0)
      IF(XLONG(L).LT.-90.0.AND.L.EQ.1) STOP
      IF(XLONG(L).LT.-90.0) GO TO 40
      WRITE(6,6100) XXID,XLAT(L),XLONG(L),JYEAR,(X(L,J),J=1,4)
 6100 FORMAT(' ',A3,2F7.2,I4,4F7.1)
801   FORMAT(5X,A3,2F7.2,I5,8F8.4)
      IF (XLAT(L).GT.MAXLAT.OR.XLAT(L).LT.MINLAT.OR.XLONG(L).GT.MAXLNG
     1.OR.XLONG(L).LT.MINLNG) L=L-1
      IYEAR = JYEAR
      GO TO 1
   40 CONTINUE
      L=L-1
      WRITE (6,106) L
  105 FORMAT (1X,//,1X,' NUMBER OF STATIONS READ IN = ',I10,//)
      LL = L
      DO 3241 MLZ = 1,4
      DO 104 I=1,ISIZE
      DO 104 J=1,JSIZE
  104 P(I,J)=0.0
      DO 102 M=1,LL
      XI=(MAXLAT-XLAT(M))*ISCALE+1
      XJ=(MAXLNG-XLONG(M))*JSCALE+1
      I=XI
      IF (XI-FLOAT(I).GE.0.5) I=I+1
      J=XJ
      IF (XJ-FLOAT(J).GE.0.5) J=J+1
102   P(I,J) = X(M,MLZ) + 100.0
      CALL ANAL(ISIZE,JSIZE,AAAAA,BBB,CCC,25,.01,P,U)
      DO 1021 I=1,ISIZE
      DO 1021 J = 1,JSIZE
1021  U(I,J) = U(I,J) - 100.0
      IPRINT = 0
      IF(IPRINT.EQ.1)
     1CALL BONTUR (U,ISIZE,JSIZE,00,2,1.0,LAB)
C ***********************************************************
C BEGINNING OF INTEGRATION OVER A POLYGON ON THE MAP
      REWIND 2
      READ(2,108) IPOLY
53    CONTINUE
C IPOLY= THE NUMBER OF POLYGONS TO BE PLACED OVER THE FUNCTION U FOR INT
      DO 268 INUM=1,IPOLY
  108 FORMAT (2I2)
56    READ(2,700) ID,YLAT(M),YLONG(M)
700   FORMAT(A4,F5.2,F6.2)
      XI=(MAXLAT-YLAT(M))*ISCALE+1
```

```
      XJ=(MAXLNG-YLONG(M))*JSCALE+1
      I=XI
      J=XJ
      IF (XI-FLOAT(I).GE.0.5) I=I+1
      IF (XJ-FLOAT(J).GE.0.5) J=J+1
      K2=J
      IF(K2.GT.JSIZE) WRITE (6,286)
  286 FORMAT (' POINT IS OUTSIDE OBJECTIVE FIELD IN LONGITUDE ')
      IF (K2.GT.JSIZE) CALL EXIT
  107 SUM=U(I,J)
      IF(I.GT.ISIZE) WRITE (6,296)
  296 FORMAT (' POINT IS OUTSIDE OBJECTIVE FIELD IN LATITUDE ')
      IF (I.GT.ISIZE) CALL EXIT
      IF(SUM.GT.0.)ISUM=SUM+0.5
      IF(SUM.LT.0.)ISUM=SUM-0.5
      IDATA(INUM,1)=ID
      IDATA(INUM,2)=IYEAR
      IDATA(INUM,ML7+2)=ISUM
      WRITE (6,267)ID,SUM
  267 FORMAT ( ' VALUE AT POINT ',5X,A4,2X,'EQUALS',2X,F15.5
     1)
  269 CONTINUE
 3241  CONTINUE
      DO 4444 I=1,IPOLY
      PUNCH 7000,(IDATA(I,J),J=1,6)
 7000 FORMAT(A4,I4,I3,I4,I4,I5)
 4444 CONTINUE
      GO TO 51
      END
      SUBROUTINE BONTUR(Z,NI,NJJ,MIN,INT,SCALE,LAB)
C     ...PRINTS STANDARD NI X NJ GRID WITH CONTOURING BETWEEN LINES
C     ...MIN IS THE MINIMUM VALUE. INT IS THE CONTOURING INTERVAL
C     ...ZERO INT MEANS NO CONTOURS
C     ...SCALE IS THE SCALING FACTOR FOR PRINTING.
C     IF NJJ.GT.26, TWO GRIDS ARE PRINTED 1 TO 26 AND 26 TO NJJ
      DIMENSION IZ(100,100),Z(100,100),LAB(5)
      DIMENSION KALP(16),LINE(126),LIN(26)
      DATA KALP/1H ,1HA,1H ,1HB,1H ,1HC,1H ,1HD,1H ,1HE,1H ,1HF,1H ,
     1  1HG,1H ,1HH/
      LTOT=INT*16
      NJ=NJJ
      J1=1
      IF(NJJ.GT.26) NJ=26
      DO 10 I=1,NI
      DO 10 J=1,NJJ
   10 IZ(I,J)=Z(I,J)*SCALE
      IF (INT) 51,50,51
   51 NIM=NI-1
   60 NJM=NJ-J1
801   PRINT 910,LAB
  910 FORMAT('1',5A4,//)
      NUM=5*NJM+1
802   PRINT 900,(IZ(1,J),J=J1,NJ)
  900 FORMAT(2X,26I5)
      DO 1 IR=2,NI
      DO 2 JD=1,2
      IF(J1.NE.1) GO TO 20
      DO 3 L=1,NJ
    3 LIN(L)=((IZ(IR,L)-IZ(IR-1,L))*JD)/3+IZ(IR-1,L)
      GO TO 30
   20 DO 40 L=26,NJJ
   40 LIN(L-25)=((IZ(IR,L)-IZ(IR-1,L))*JD)/3+IZ(IR-1,L)
   30 K=1
      DO 4 J=1,NJM
      LINJ=LIN(J)
      LINE(K)=LINJ
      NDZ=LIN(J+1)-LINJ
      DO 5 L=1,4
      K=K+1
    5 LINE(K)=(NDZ*L)/5+LINJ
      K=K+1
    4 CONTINUE
      LINE(K)=LIN(NJM+1)
      DO 6 L=1,NUM
      JDF=LINE(L)-MIN
      IF(JDF)8,9,9
    8 JDF=JDF-LTOT*((JDF+1)/LTOT-1)
    9 J=JDF/INT
      IF(J-16)6,26,26
```

```
   26 J=J-(J/16)*16
    6 LINE(L)=KALP(J+1)
803     PRINT 901,(LINE(L),L=1,NUM)
  901 FORMAT(7X,126A1)
    2 CONTINUE
804     PRINT 900,(IZ(IR,J),J=J1,NJ)
    1 CONTINUE
      IF(NJ.EQ.NJJ) RETURN
      NJ=NJJ
      J1=26
      GO TO 50
805     PRINT 910,LAB
50      CONTINUE
      DO 52 I=1,NI
806     PRINT 902,(IZ(I,J),J=1,NJ)
  902 FORMAT(    /3X,26I5)
807     PRINT 903
52      CONTINUE
  903 FORMAT(1H )
      IF (NJ.EQ.NJJ) RETURN
      NJ=NJJ
      J1=26
      GO TO 50
      END
      SUBROUTINE ANAL(NI,NJ,AA,ALF2,ALF4,MAXPAS,ERR,UO,U)
C     VARIATIONAL ANALYSIS BY KIT WAGNER  2ND DERIVATIVE FILTERING
C     UO IS DATA  U IS ANALYSIS   TREATS ZERO IN UO AS NO DATA
C     ROUTINE WILL ANALYZE FOR AREAS OF NO DATA
C AA,ALF2,ALF4 ARE FILTER WEIGHTS REFERENCE K.WAGNER FOR APPROPRIATE
C     VALUES   MAXPAS  IS MAXIMUM NO. OF ITERATIONS  ERR IS APPROX
C     CRITERIA. DIMENSIONS OF ARRAYS ARE U(NI,NJ),UO(NI,NJ),WA(NI,NJ)
C     YA(NI+2,NJ+2)  WHERE NI AND NJ ARE THE INPUT ARRAY SIZE
C THIS ROUTINE MINIMIZES THE INTEGRAL (THE SQUARES OF THE DIFFERENCES *
C + THE SAUARES OF THE GRADIENT*ALF2
C + THE SQUARES OF THE LAPLACIAN*ALF4)
C WHERE AA,ALF2,AND ALF4 ARE WEIGHTS FOR THE ANALYSIS.
C FOR MESOSCALE ANALYSIS OF MAGNITUDE 10,TYPICAL PARMAETERS ARE AA=100.0
C ALF2=1.0,ALF4=1.0   ,MAXPAS=99,ERR=.01
C NI,ANDNJ ARE SIZE OF ARRAY OF UO AND U
C INCREASING ALF2 AND OR ALF4 REDUCES HIGHER FREQUENCIES
C TYPICAL MAX VALUES ARE ALF2=10.0,AND ALF4=10.0
C FOR AA=100.0
C THE VALUES OF ALFA2 AND ALFA4 USUALLY ARE .1,1.,OR 10.0
      DIMENSION U(100,100),UO(100,100),YA(104,104),WA(100,100)
      EQUIVALENCE (YA(1,1),WA(1,1))
      IO=6
      NJP2=NJ+2
      NIP2=NI+2
      NIM1=NI-1
      NIM2=NI-2
      NJM1=NJ-1
      NJM2=NJ-2
      NJP1=NJ+1
      NIP1=NI+1
      BETA=2.0
C     INITIALIZE GUESS FIELD BY AVERAGING
      DO 16 J=1,NJ
      DO 16 I=1,NI
   16 U(I,J)=UO(I,J)
      DO 10 J=1,NJP2
      DO 10 I=1,NIP2
   10 YA(I,J)=0.0
      KNT=1
  201 CONTINUE
C     CHECK FOR NUMBER OF NO GUESS
      IF (KNT) 15,200,15
   15 KNT=0
      DO 12 J=2,NJP1
      DO 12 I=2,NIP1
   12 YA(I,J)=U(I-1,J-1)
      DO 99 J=2,NJP1
      DO 99 I=2,NIP1
      IF(YA(I,J).GT.0.00001) GO TO 86
   98 SUM=0.0
      CNT=0.0
C      AVG NINE POINTS
   24 DO 97 JK=1,3
      DO 97 IK=1,3
      II=I-2+IK
```

```
      JJ=J-2+JK
      IF(YA(II,JJ).LE.0.00001) GO TO 97
   96 SUM=SUM+YA(II,JJ)
      CNT=CNT+1.
   97 CONTINUE
      IF(CNT.LE.2.5) GO TO 92
      IF(SUM.LE.0.00001) GO TO 94
      GO TO 95
C     USE .0001 INSTEAD OF ZERO AVG
   94 U(I-1,J-1)=.0001
      GO TO 99
   95 U(I-1,J-1)=SUM/CNT
      GO TO 99
   92 KNT=KNT+1
      GO TO 99
   86 U(I-1,J-1)=YA(I,J)
   99 CONTINUE
  200 CONTINUE
C     WRITE(IO,100) KNT
  100 FORMAT(1H0,I5,29H POINTS UNSPECIFIED THIS PASS)
      IF (KNT) 201,79,201
   79 CONTINUE
C     SMOOTH FIELD OF AVERAGES
      DO 31 J=2,NJM1
      DO 31 I=2,NIM1
   31 WA(I,J)=(4.*U(I,J)+U(I-1,J-1)+U(I+1,J-1)+U(I+1,J+1)+U(I-1,J+1)
     1+2.*(U(I,J-1)+U(I+1,J)+U(I,J+1)+U(I-1,J)))/16.
      DO 32 J=2,NJM1
      WA(1,J)=(6.*U(1,J)+2.*(U(2,J)+U(1,J-1)+U(1,J+1))+U(2,J-1)+U(2,J+
     1))/16.
   32 WA(NI,J)=(8.*U(NI,J)+2.*(U(NIM1,J)+U(NI,J-1)+U(NI,J+1))+U(NIM1,J-1
     1)+U(NIM1,J+1))/16.
      DO 33 I=2,NIM1
      WA(I,1)=(8.*U(I,1)+2.*(U(I,2)+U(I-1,1)+U(I+1,1))+U(I-1,2)+U(I+1,2
     1))/16.
   33 WA(I,NJ)=(8.*U(I,NJ)+2.*(U(I,NJM1)+U(I-1,NJ)+U(I+1,NJ))+U(I-1,NJM1
     1)+U(I+1,NJM1))/16.
      WA(1,NJ)=(3.*U(1,NJ)+2.*(U(2,NJ)+U(1,NJM1))+U(2,NJM1))/8.
      WA(NI,NJ)=(3.*U(NI,NJ)+2.*(U(NIM1,NJ)+U(NI,NJM1))+U(NIM1,NJM1))/8.
      WA(NI,1)=(3.*U(NI,1)+2.*(U(NIM1,1)+U(NI,2))+U(NIM1,2))/8.
      WA(1,1)=(3.*U(1,1)+2.*(U(2,1)+U(1,2))+U(2,2))/8.
      DO 36 J=1,NJ
      DO 36 I=1,NI
   36 U(I,J)=WA(I,J)
C  39 WRITE(IO,301)
39    CONTINUE
  301 FORMAT(1H0,23H SMOOTH HAS BEEN CALLED)
C   2 DIMENSIONAL ANALYSIS
C     INTERIOR POINTS AND WEIGHTS
      GPD=(NI-4)*(NJ-4)
      ALF4B=ALF4*BETA
      UIJ0=4.*ALF2+20.*ALF4
      UI1J1=-ALF2-8.*ALF4
C     WRITE(IO,500) AA,ALF2,ALF4,UIJ0,UI1J1
C    ITERATIVE SCHEME
      DO 41 IT=1,MAXPAS
      IA=1
      SUM=0.0
      DO 42 J=3,NJM2
      DO 42 I=3,NIM2
      UIJ=UIJ0
C     CHECK FOR OBSERVATION
      IF(UO(I,J).GT.0.00001) GO TO 43
   44 AL=0.0
      GO TO 45
   43 AL=AA
      UIJ=UIJ+AL
C      EQUATION FOR RESIDUAL
   45 RES=-AL*UO(I,J)+UIJ*U(I,J)+UI1J1*(U(I+1,J)+U(I-1,J)+U(I,J+1)+U(I,J
     1-1))+ALF4B*(U(I-1,J-1)+U(I-1,J+1)+U(I+1,J-1)+U(I+1,J+1))
      RES=RES+ALF4*(U(I,J+2)+U(I,J-2)+U(I+2,J)+U(I-2,J))
      RLAXP=1./UIJ
C     CORRECT GUESS OF U
      U(I,J)=U(I,J)-RLAXP*RES
C      CHECK FOR APPROXIMATION SATISFIED AT ALL POINTS
      IF (ABS(RES)-ERR) 46,46,47
   47 IA=2
   46 SUM=SUM+RES*RES
   42 CONTINUE
```


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OF POOR QUALITY

```
      STD=SQRT(SUM/GRD)                                                 WAG03170
C     WRITE(IO,510) IT,STD                                              WAG03180
      GO TO (9,41),IA                                                   WAG03190
   41 CONTINUE                                                          WAG03200
C   9 WRITE(IO,511) IT                                                  WAG03210
9     CONTINUE                                                          WAG03220
  510 FORMAT(1X,I3,F12.5)                                               WAG03230
  511 FORMAT(1X,17HNO. OF ITERATIONS,I5)                                WAG03240
  500 FORMAT(1X,8H WEIGHTS/5E15.2/28H  STD DEVIATION OF RESIDUAL )      WAG03250
      RETURN                                                            WAG03260
      END                                                               WAG03270
```

```
C          THIS SUBROUTINE COMPUTES THORNTHWAITE COEFFICIENTS
      SUBROUTINE THORN(T,I,A,LAT,ADJ,PET)
      REAL T(12),I,LAT,ADJ(12),PET(12)
      IF(T(7).GT.40.0)CALL TCON(T)
      WRITE(6,6001)
      WRITE(6,6002) LAT
 6001 FORMAT('1','THORNTHWAITE COEFFICIENTS AS ESTIMATED FROM THE 12 VAL
     1UES')
 6002 FORMAT(' ','OF MEAN MONTHLY TEMPERATURE FOR A STATION AT ',F5.2,'N
     1 LATITUDE,',//)
      I=0.
      DO 5 J=1,12
      TT=T(J)
      IF(TT.LE.0.)GO TO 5
      I=I+(TT/5.)**1.514
    5 CONTINUE
      A1=0.675
      A2=-77.1
      A3=17920.
      A4=492390.
      A=(A1*I**3+A2*I**2+A3*I+A4)/10**6
      WRITE(6,6000) A,I
 6000 FORMAT(' ','A = ',F10.5,'    I = ',F10.5,//)
      WRITE(6,6004)
 6004 FORMAT(' ',' MON        DL        ADJ       T        PET',/)
      DO 10 J=1,12
      IF(T(J).LE.0.)PET(J)=0.
      IF(T(J).LE.0.)GO TO 6
      PET(J)=16.0*(10.0*T(J)/I*1.0)**A
    6 ADJ(J)=DLBAR(LAT,J)/12.
      PET(J)=PET(J)*ADJ(J)
      IF(T(J).LT.0.)PET(J)=0.
      DL=DLBAR(LAT,J)
      T(J)=T(J)*1.8+32.0
      PET(J)=PET(J)/25.4
      WRITE(6,6005) J,DL,ADJ(J),T(J),PET(J)
 6005 FORMAT(' ',I3,2X,4F8.2)
   10 CONTINUE
      RETURN
      END
      FUNCTION DLBAR(LAT,MONTH)
C          COMPUTES AVERAGE DAYLENGTH BY MONTHS FOR GIVEN LATITUDE
      REAL LAT
      INTEGER JD(13)
      JD(1)=0
      JD(2)=31
      JD(3)=59
      JD(4)=90
      JD(5)=120
      JD(6)=151
      JD(7)=181
      JD(8)=212
      JD(9)=243
      JD(10)=273
      JD(11)=304
      JD(12)=334
      JD(13)=365
      JD1=JD(MONTH)+1
      JD2=JD(MONTH+1)
      DLBAR=0.
      DO 5 I=JD1,JD2
      IF(LAT.GT.40.) DLBAR=DLBAR+DAY41(LAT,I)
      IF(LAT.LE.40.)DLBAR=DLBAR+DAY40(LAT,I)
    5 CONTINUE
      DLBAR=DLBAR/(JD2-JD1)
      RETURN
      END
      FUNCTION DAY41(W,J)
C               ------------------------------------------------------
C               THIS FUNCTION SUBROUTINE COMPUTES DAYLENGTHS FOR
C               LATITUDES NORTH OF 40 DEGREES.
      DAY41=12.25+(1.6164+1.7643*(TAN(3.1416*W/180.))**2)*COS(0.0172*J-2
     1.94)
      RETURN
      END
      FUNCTION DAY40(W,J)
C               ------------------------------------------------------
C               THIS FUNCTION SUBROUTINE COMPUTES DAYLENGTHS FOR
C               LATITUDES AT OR SOUTH OF 40 DEGREES.
```

```
C     ------------------------------------------------------------------
      DAY40=12.14+(3.37*TAN(3.1416*W/180.))*COS(0.0172*J-2.94)
      RETURN
      END
      FUNCTION PET(T,TI,TA,TC)
C      COMPUTES THORNTHWAITE'S ESTIMATE OF POTENTIAL EVAPOTRANSPIRATION
      IF(T.LE.0.)PET=0.
      IF(T.LE.0.)RETURN
      PET=16.0*TC*((10.0*T)/TI)**TA
      RETURN
      END
      SUBROUTINE TCON(T)
      REAL T(12)
      DO 5 I=1,12
    5 T(I)=(T(I)-32.0)/1.8
      RETURN
      END
      SUBROUTINE HYDRA(T,P,SPS,SPU,SP,W,PR,PE,PL,ET,R,L,HI,TA,TC)
C A.  RUNS PALMER'S HYDROLOGIC ACCOUNTING FOR ONE MONTH.
C B.  T:  THE MEAN MONTHLY TEMPERATURE IN DEGREES F.
C C.  P:  THE TOTAL MONTHLY PRECIPITATION IN INCHES.
C D.  SPS:  INITIAL AMOUNT OF AVAILABLE MOISTURE IN THE SURFACE LAYER OF
C           THE SOIL IN INCHES.
C F.  SPU:  INITIAL AMOUNT OF AVAILABLE MOISTURE IN THE UNDERLYING LAYER
C           OF THE SOIL IN INCHES.
C F.  SP:  INITIAL AMOUNT OF AVAILABLE MOISTURE IN BOTH LAYERS OF THE
C          SOIL IN INCHES OR (SPS+SPU).
C G.  W:  THE AVAILABLE MOISTURE CAPACITY IN INCHES MINUS 1.0 INCH.
C H.  PR:  POTENTIAL RECHARGE IN INCHES.
C I.  PE:  POTENTIAL EVAPOTRANSPIRATION IN INCHES.
C J.  PL:  POTENTIAL LOSS OF SOIL MOISTURE IN INCHES.
C K.  ET:  COMPUTED EVAPOTRANSPIRATION IN INCHES.
C L.  R:  RECHARGE: NET GAIN IN SOIL MOISTURE IN INCHES.
C M.  L:  NET LOSS OF SOIL MOISTURE IN INCHES.
C N.  HI:  THORNTHWAITE'S HEAT INDEX.
C O.  TA:  THORNTHWAITE'S COEFFICIENT COMPUTED FROM HI.
C P.  TC:  THORNTHWAITE'S MONTHLY ADJUSTMENT FOR DAYLENGTH.
      REAL T,P,SP,PR,PE
      REAL PL,ET,R,L,LS,LU
      SP=SPS+SPU
      PR=W+1.0-SP
      TT=(T-32.0)/1.8
      PE=PET(TT,HI,TA,TC)/25.4
      A=SPS-PE
      IF(A)5,10,10
    5 PLS=SPS
      PLU=(PE-PLS)*SPU/(W+1.0)
      IF(SPU.LT.PLU)PLU=SPU
      GO TO 15
   10 PLS=PE
      PLU=0.
   15 PL=PLS+PLU
      B=P-PE
      IF(B)20,40,40
   20 AB=ABS(B)
      IF(SPS-AB)25,30,30
   25 LS=SPS
      RS=0.
      SS=0.
      LU=(AB-LS)*SPU/(W+1.0)
      RU=0.
      SU=SPU-LU
      GO TO 35
   30 LS=AB
      RS=0.
      SS=SPS-LS
      LU=0.
      RU=0.
      SU=SPU
   35 RO=0.
      ET=P+LS+LU
      GO TO 75
   40 C=1.0-SPS
      IF(C-B)45,65,65
   45 RS=C
      LS=0.
      SS=1.0
      D=B-RS
      E=W-SPU
```

```
      IF(E-D)50,55,55
   50 RU=E
      RO=D-RU
      GO TO 60
   55 RU=D
      RO=0.
   60 LU=0.
      SU=SPU+RU
      GO TO 70
   65 RS=R
      LS=0.
      SS=SPS+RS
      RU=0.
      LU=0.
      SU=SPU
      RO=0.
   70 ET=PE
   75 R=RS+RU
      L=LS+LU
      SPS=SS
      SPU=SU
      SP=SPS+SPU
      RETURN
      END
      SUBROUTINE HARM(Y,YBAR,AMP,PHASE)
      INTEGER T,L/12/
      REAL Y(12),AMP(6),PHASE(6),R(6)
      DO 20 K=1,6
      SUMA=0.
      SUMB=0.
      SUMY=0.
      SUMYSQ=0.
      PI=3.1416
      DO 5 T=1,L
      SUMA=SUMA+Y(T)*COS(K*2*PI*T/L)
      SUMB=SUMB+Y(T)*SIN(K*2*PI*T/L)
      SUMY=SUMY+Y(T)
      SUMYSQ=SUMYSQ+Y(T)**2
    5 CONTINUE
      A=2*SUMA/L
      B=2*SUMB/L
      YBAR=SUMY/L
      YVAR=(SUMYSQ-L*YBAR**2)/(L-1)
      AMP(K)=SQRT(A**2+B**2)
      ALPHA=ATAN(ABS(A/B))
      PHASE(K)=ALPHA
      IF(A.GE.0.AND.B.LT.0)PHASE(K)=PI-ALPHA
      IF(A.LT.0.AND.B.LT.0)PHASE(K)=PI+ALPHA
      IF(A.LT.0.AND.B.GE.0)PHASE(K)=2*PI-ALPHA
      R(K)=(AMP(K)**2)/(2.0*YVAR)
      APHASE=PHASE(K)*180./PI
      IF(APHASE.GE.180.)APHASE=APHASE-360.
      ANGLE=360./L
      SDY=SQRT(YVAR)
      WRITE(6,6000) K
 6000 FORMAT(' ','STATISTICS OF HARMONIC NUMBER: ',I2,//)
      WRITE(6,6005)
 6005 FORMAT(' ','MEAN OF Y   AMP(K)   ANGLE   PHASE    R**2   SD OF Y',
     1/)
      WRITE(6,6010) YBAR,AMP(K),ANGLE,APHASE,R(K),SDY
 6010 FORMAT(' ',2F9.4,F8.2,F9.2,F7.4,F10.4,/////)
   20 CONTINUE
      RETURN
      END
      SUBROUTINE CMI(LAT,W,HI,TA,ABAR,AAMP,APHASE)
C A.  COMPUTES WEEKLY VALUES OF CMI.
C B.  LAT:  LATITUDE IN DEGREES (HUNDRETHS).
C C.  W:  AVAILABLE WATER CAPCITY IN INCHES MINUS 1.0 INCH.
C D.  HI:  THORNTHWAITE'S HEAT INDEX.
C E.  TA:  THORNTHWAITEE'S COEFFICIENT COMPUTED FROM HI.
C F.  ABAR:  THE MEAN VALUE OF ALPHA FOR ALL MONTHS.
C G.  AAMP:  THE AMPLITUDE OF THE K TH HARMONIC OF ALPHA.
C H.  APHASE:  THE PHASE ANGLE OF THE K TH HARMONIC OF ALPHA.
      DATA PI/3.14159/
      REAL LAT,AAMP(6),APHASE(6),M
      INTEGER LOC(5)
      AWC=W+1.0
      READ(4,4000,END=95)LOC
 4000 FORMAT(5A4)
```

```
      READ(4,4001,END=95)SPS,SPU,YP,GP
C A.  SPS:  INITIAL SURFACE SOIL MOISTURE CONDITIONS IN INCHES
C B.  SPU:  INITIAL SUBSURFACE SOIL MOISTURE CONDITIONS IN INCHES
C C.  YP:  INITIAL VALUE OF INDEX OF EVAPOTRANSPIRATION DEFICIT.
C D.  GP:  INITIAL VALUE OF INDEX OF EXCESSIVE MOISTURE.
 4001 FORMAT(F4.2,3F5.2)
      WRITE(6,6000)LOC,LAT
 6000 FORMAT('1','WEEKLY CMI VALUES FOR:  ',5A4,' LATITUDE:  ',F5.2,//)
      WRITE(6,6001)AWC,SPS,SPU,YP,GP
 6001 FORMAT(' ','INITIAL CONDITIONS:',//,' ','AWC:  ',F5.2,/,' ','SPS:
     1 ',F5.2,/,' ','SPU:  ',F5.2,/,' ','YP:    ',F5.2,/,' ','GP:    ',F5.
     12,//)
      WRITE(6,6005)
 6005 FORMAT(' ',' WE   T    P     DE    PE    ET   ALPHA CET    YP    M    SP
     1   GP    CMI',/)
    5 READ(4,4005,END=95)JD,T,P
 4005 FORMAT(I3,F3.0,4X,F4.1)
      IF(LAT.GT.40)TC=7.0*DAY41(LAT,JD)/365.25
      IF(LAT.LE.40)TC=7.0*DAY40(LAT,JD)/365.25
      CALL HYDRA(T,P,SPS,SPU,SP,W,PR,PE,PL,ET,R,L,HI,TA,TC)
      A=12.0*(JD+15.0)/365.25
      DO 10 I=1,6
   10 ALPHA=ALPHA+AAMP(I)*SIN(2*PI*A/12.0+APHASE(I))
      IF(ALPHA.GT.1.0)ALPHA=1.0
      IF(ALPHA.LT.0.0)ALPHA=0.0
      CET=ALPHA*PE
      DE=(ET-CET)/SQRT(ALPHA)
      YP=0.67*YP+1.8*DE
      M=(SP+SPS+SPU)/(2*(SP+PR))
      IF(YP.LT.0.)Y=YP
      IF(YP.GE.0.)Y=M*YP
      IF(GP.EQ.0.)H=0.
      IF(GP.GT.0.)H=GP
      IF(GP.GT.0.5)H=0.5
      IF(GP.GT.1.0)H=0.5*GP
      G=GP-H+M*R+RO
      C=Y+G
      GP=G
      IT=T
      WRITE(6,6010)JD,IT,P,DE,PE,ET,ALPHA,CET,YP,M,SP,GP,C
 6010 FORMAT(' ',2I3,F5.1,F6.2,F5.2,F5.2,F6.3,F5.2,F6.2,3F5.2,F5.1)
      GO TO 5
   95 WRITE(6,6015)
 6015 FORMAT(' ',///,' ','WE:      JULIAN DATE OF WEEK ENDING.',/,' ','T:
     1        MEAN TEMPERATURE FOR THE WEEK (DEG. F.)',/,' ','P:        TOTA
     1L PRECIPITATION FOR THE WEEK IN INCHES.',/,' ','DE:      RELATIVE T
     1RANSPIRATION ANOMALY FOR THE WEEK',/,' ','PE:      POTENTIAL EVAPOT
     1RANSPIRATION FOR THE WEEK.',/,' ','ET:      COMPUTED EVAPOTRANSPIRA
     1TION FOR THE WEEK.',/,' ','ALPHA:  ESTIMATED COEFFICIENT OF EVAPOT
     1RANSPIRATION FOR THE WEEK.',/,' ','CET:     ALPHA X PE')
      WRITE(6,6020)
 6020 FORMAT(' ','YP:      INDEX OF EVAPOTRANSPIRATION DEFICIT.',/,' ','M
     1:       AVERAGE PERCENT OF FIELD CAPACITY DURING THE WEEK.',/,' ','
     1SP:      INCHES OF WATER IN THE SOIL.',/,' ','GP:      INDEX OF EXCE
     1SSIVE SOIL MOISTURE.',/,' ','CMI:     CROP MOISTURE INDEX VALUE FOR
     1 THE WEEK.')
      RETURN
      END
```

```
      FUNCTION DAYLG(W,J)
C           COMPUTES DAYLENGTH FOR A GIVEN JULIAN DATE AND LATITUDE
      DAYLG=12.25+(1.6164+1.7643*(TAN(3.1416*W/180.))**2)*COS(0.0172*J-2
     1.94)
      IF(W.GT.40.0)RETURN
      DAYLG=12.14+(3.37*TAN(3.1416*W/180.))*COS(0.0172*J-2.94)
      RETURN
      END
      SUBROUTINE SWBMTS(PD,LAT,WX)
C        COMPUTES DAILY SSPRING WHEAT STAGE DATES FROM DAILY TEMPERATURES
      REAL WX(6,366)
C           ARRAY WX CONTAINS ONE YEAR OF DAILY WEATHER VARIABLES
C           WX(1,N)=DAILY MAXIMUM TEMPERATURE IN DEG. F.
C           WX(2,N)=DAILY MINIMUM TEMPERATURE IN DEG. F.
C           WX(4,N)=COMPUTED SPRING WHEAT STAGE
      INTEGER PD
      REAL LAT,RA0(5),RA1(5),RA2(5),RB0(5),RB1(5),RB2(5),RC1(5),RC2(5)
      REAL CRITA(5),CRITB(5),CRITC(5)
      DO 10 I=1,5
      CRITA(I)=99999.9
      CRITB(I)=99999.9
      CRITC(I)=99999.9
      READ(22,22000)RA0(I),RA1(I),RA2(I),RB0(I),RB1(I),RB2(I),RC1(I),RC2
     1(I)
22000 FORMAT(8E10.4)
      IF(RA2(I).NE.0.)CRITA(I)=-(RA1(I)-2*RA2(I)*RA0(I))/(2*RA2(I))
      IF(RB2(I).NE.0.)CRITB(I)=-(RB1(I)-2*RB2(I)*RB0(I))/(2*RB2(I))
      IF(RC2(I).NE.0.)CRITC(I)=-(RC1(I)-2*RC2(I)*RB0(I))/(2*RC2(I))
C           READS THE FIVE SETS OF ROBERTSON COEFFICIENTS FOR EACH STAGE
C           AND COMPUTES CRITICAL VALUES OF EACH QUADRATIC
   10 CONTINUE
      K=1
      CUM=0.0
      DID=0.0
      DO 25 I=1,365
      DL=DAYLG(LAT,I)
      IF(I.EQ.PD)CUM=1.0
      IF(I.LT.(PD+1))GO TO 25
      IF(CUM.GE.6.0)DID=0.0
      IF(CUM.GE.6.0)GO TO 25
      V1=QUAD(DL,RA0(K),RA1(K),RA2(K),CRITA(K))
      IF(RA0(K).EQ.999.)V1=1.0
      V2=QUAD(WX(1,I),RB0(K),RB1(K),RB2(K),CRITB(K))
      V3=QUAD(WX(2,I),RB0(K),RC1(K),RC2(K),CRITC(K))
      DID=V1*(V2+V3)
      ACUM=CUM+DID
      IF(ACUM.GT.6.0)GO TO 15
      IF(ACUM.LT.(K+1))GO TO 15
      IF(DID.LE.0.0)GO TO 25
      DIF=(K+1)*1.0-CUM
      PCT=DIF/DID
      RPCT=1.0-PCT
      V1=QUAD(DL,RA0(K+1),RA1(K+1),RA2(K+1),CRITA(K+1))
      IF(RA0(K+1).EQ.999.)V1=1.0
      V2=QUAD(WX(1,I),RB0(K+1),RB1(K+1),RB2(K+1),CRITB(K+1))
      V3=QUAD(WX(2,I),RB0(K+1),RC1(K+1),RC2(K+1),CRITC(K+1))
      DIDN=V1*(V2+V3)
      DID=PCT*DID+RPCT*DIDN
   15 CUM=CUM+DID
      IF(CUM.GE.(K+1))K=K+1
      IF(CUM.GE.6.0)CUM=6.0
   25 WX(4,I)=CUM
      RETURN
      END
      FUNCTION QUAD(X,A0,A1,A2,C)
C        COMPUTES VALUE OF ROBERTSON'S QUADRATIC TERMS.
      QUAD=A1*(X-A0)+A2*(X-A0)**2
      IF(A2.GT.0.AND.X.LT.C)QUAD=0.
      IF(QUAD.LT.0.)QUAD=0.
      RETURN
      END
```

APPENDIX B

INTERACTIONS OF SUPPORTING SOFTWARE

APPENDIX B

INTERACTIONS OF SUPPORTING SOFTWARE

The structure for interactions of the supporting software for the models and algorithms used in these procedures is depicted in figure B-1.

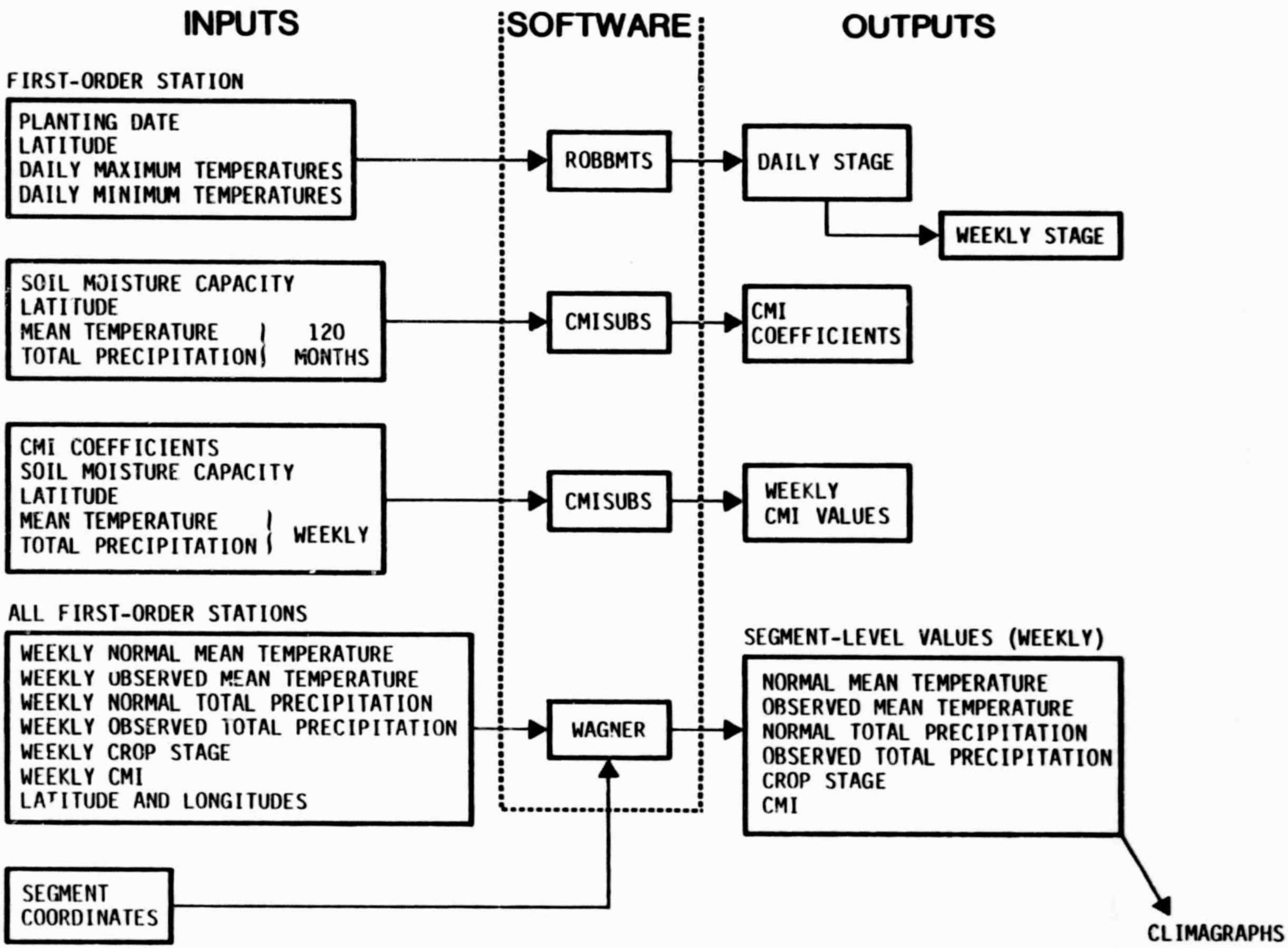

Figure B-1.- Functional flowchart for the supporting software.