Integration of Supplementary Information with NOAA AVHRR Data for State-Wide Vegetation Studies: A Method for Biomass Assessment

E-034

Final Report Submitted To:

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July, 1984

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Summary

"Drought" is a term which carries a variety of meanings. Both agricultural and meteorological droughts exist. A meteorological drought might be defined as deviations of precipitation below some mean value, while an agricultural drought is primarily determined by the moisture content of the soil. AVHRR data characterize the emissive and reflective properties of the landscape. Most of Oklahoma is covered by vegetation, therefore, the AVHRR signal is largely dependent on vegetation patterns. As a result, an agricultural definition of drought is of the most use in the present application.

Formulation of drought indicators is not straightforward due to the nature of agricultural drought. First, agricultural drought is a function of the interplay between rainfall, temperature, evaporation, and soil moisture storage. The indicators used must deal implicitly or explicitly with these dimensions. Second, the spatial resolution of the AVHRR is much better than available meteorologic data. Hourly reporting sites providing complete data are scarce in Oklahoma. A denser network (by a factor of 10) is found in the Oklahoma Cooperative Observation Network. Unfortunately, these 180+ stations are limited to daily readings of minimum temperature, maximum temperature, and, at less than 20 sites, pan evaporation and wind movement. Consequently, drought indicators have been limited to those which can be primarily constructed with daily temperature and precipitation data. These indicators have been linearly interpolated from the observation stations to the individual grid cells corresponding to the AVHRR data. Although the occurrence of air mass thunderstorms could locally impair the validity of this interpolation,

examination of the growing season conditions for 1980 indicates this problem will not be of major concern.

Supplementary environmental data acquired, assembled, manipulated, and stored can be integrated with satellite data and analyzed. All meteorologic variables for all 32 weeks of the study period can be statistically manipulated in an attempt to determine the timing and location of drought conditions in Oklahoma during the year 1980. It is important to precisely determine the spatial and temporal function of the "drought zone" throughout the study site and period. In this way, control data can be firmly established against which the AVHRR data can be compared and evaluated. Satellite-derived vegetation indices that summarize plant conditions such as biomass for relatively large geographic cells require support data at a similar resolution to aid in the analysis procedure. Suppression of detail is an advantage when synoptic monitoring is the objective. Integration of related environmental variables with AVHRR data should be considered, in order to increase the utility and the explanation of your findings.

Problem

The Advanced Very High Resolution Radiometer (AVHRR) on-board the National Oceanic and Atmospheric Administration's satellites, NOAA-6 and -7, are showing good potential for use in the monitoring and analysis of vegetation over extensive regions. A vital characteristic of data secured from such satellites is its high temporal resolution. The daily radiometric coverage of the earth afforded by NOAA-6 and NOAA-7 provides a capability to assess the dynamic characteristics of vegetation. The relative low resolution of the satellites (1.1 Km), however, precludes the detailed spatial analyses of vegetation, but is well suited to inventories requiring less detail, especially over extensive regions. Research by Norwine and Greegor (1983) and Brown and

Bernier (1982) indicate that the result of vegetation analyses achieved through the use of the first two channels of AVHRR data are very similar to the result secured from the Landsat Multispectral Scanner (MSS) channels 2 and 4 (Bands 5 and 7) (Table 1). The spectral reflectance of chlorophyll pigment in the visible and near infrared portions of the electromagnetic spectrum provides a good measure of density and vigor of green vegetation.

Currently, little research has been devoted to the evaluation of the sensitivity of NOAA AVHRR data for vegetation analysis. Rather, studies have been initiated to map landcover over continents and sub-continents. Research regarding AVHRR data also has not investigated the use of supplementary data assembled for extensive regions and integrated with AVHRR information to assist in determining the impact of these disparate data on the spectral reflectance recorded by the AVHRR sensors. Research by this author looks at the state of Oklahoma; investigates the study area at a 1.1 Km resolution; evaluates the spatial and temporal persistence of drought conditions revealed in the AVHRR-derived vegetation indices by comparison to meteorologic variables and various climatological indices; integrates soils, landcover, terrain, and climatic data at a 1.1 Km cell for the state of Oklahoma in order to portray drought location, progression, and severity; and, in general, seeks to evaluate AVHRR data for global habitability research by understanding ground conditions over extensive areas and evaluating the response of AVHRR data to such conditions.

This project evaluates the value of AVHRR data for the monitoring of vegetation conditions. Further, it describes the development of a state-wide data base of climatic and meteorologic variables essential in the evaluation and explanation of drought as reflected in multi-temporal vegetation conditions sensed by NOAA-6 and -7 satellites.

Vegetation Monitoring With Remote Sensing

The visible and near-infrared radiation bands have been extensively used in vegetation studies (Richardson and Wiegand, 1977). Remotely sensed measurements can provide an estimate of the surface soil moisture conditions, which can be extrapolated via a model or used to update a model simulation for biomass production, evapotranspiration rates, and drought assessment.

Visible and near-infrared reflectances from plant canopies can provide information about the condition of the vegetation. Healthy plant leaves exhibit low reflectance of near-infrared energy. Wavelengths of red light are strongly absorbed by chlorophylls and, therefore, the reflectance of red light is related to the amount of green vegetation present. As the amount of vegetation increases more near-infrared energy is reflected away from the plant canopy, but at an exponentially decreasing rate as the leaf-area index increases (Brakke et al., 1981). Kanemasu (1974) found that the longer the wavelength, the higher the reflectance. The highest reflectance was in the near-infrared. Tucker (1979) found the reflectance of red light exhibited a non-linear inverse relationship between integrated spectral reflectance and green biomass, while the near-infrared wavelengths indicated a non-linear direct relationship. Holben et al. (1980) evaluated red and near-infrared radiation and found the most significant correlations occurred between the spectral radiance and the green leaf area index and/or the green leaf biomass.

Frequently, information from the visible and near-infrared spectral regions are combined and manipulated in order to construct vegetation indices for determining estimates of vegetation conditions, such as, density, vigor, biomass, greenness, and moisture stress. Curren (1980) indicated that indices are sensitive to the rate of plant growth, as well as the amount of growth, and, therefore, is sensitive to the response seen in vegetation affected by moisture stress.

Landsat MSS data secured in the visible and near-infrared wavelengths have been used by Kanemasu (1978) to estimate the Leaf Area Index (LAI) of wheat. The Perpendicular Vegetation Index (PVI), Green Vegetation Index (GVI), and the Transformed Vegetation Index (TVI) were favorably compared by Kanemasu to sets of ground based measurements of LAI. Kauth and Thomas (1976) developed a multi-dimensional model of seasonal crop development using the four MSS channels as axes. They identified four vectors related to four environmental plant characteristics from which they defined four MSS band transformations. One of these transformations, called "Green Stuff" by the authors has subsequently been developed into an index of chlorophyll presence. Thompson and Wehmanen (1979) used the Green Index Number (GIN) developed by Kauth and Thomas to detect moisture stress in the Great Plains.

Literature pertaining to the use of AVHRR data for evaluating vegetation conditions through vegetation indices is scarce in comparison to Landsat MSS. Gray and McCrary (1981) have shown, however, that NOAA-6 AVHRR and Landsat MSS vegetation indices were in close agreement when compared over a primary crop growing region along the Brazil-Argentina border. Since early 1982, the Vegetation Index (VI) and the Normalized Vegetation Index (NVI) have been routinely calculated by the U.S. National Climatic Data Center. The NVI is recommended for global vegetation monitoring because it partially compensates for changing illumination conditions, surface slope, and viewing angle (U.S. National Climatic Data Center, 1983). Norwine and Greegor (1983) used the NVI to sample vegetation types along an east-west transect in Texas. They equated this index with surface greenness and indicated the value of AVHRR data to detect changes in the greenness of vegetation associated with changes in vegetation type. Barnett and Thompson (1983) related both MSS and AVHRR to wheat yields over the Great Plains. Their results showed a relationship between yield and both types of satellite data, and, therefore, they recommended that AVHRR data be used for large area monitoring of agricultural crops. Townshend and Tucker (1984) have shown that for three contrasting regions that the AVHRR data represents approximately 70 percent of the variation in Landsat MSS bands 5 and 7 and over 50 percent of the variation in the normalized difference vegetation index, which is the AVHRR NVI versus the MSS NVI. The results are obtained despite tremendous differences in the MSS and AVHRR spatial resolution.

During the growing season, satellite sensors are capable of discerning changes in physiognomic characteristics seen on the landscape, many of which can be evaluated through satellite-derived vegetation indices (Hall, 1982). Use of AVHRR data to assess these vegetation conditions particularly over extensive regions is useful because of the satellite sensor's temporal, spatial, spectral, and radiometric resolution. For repetitive vegetation analyses throughout a growing season, it is important to integrate related environmental variables with the AVHRR indices of vegetation condition because of their pronounced impact on the indices and their importance in the explanation of the behavior of the vegetation revealed in the indices.

Environmental Data Base Development

The state of Oklahoma is a particularly good place to study drought and its expression observed within AVHRR satellite vegetation indices. The state covers over 180,000 square kilometers in area, is astride the forest/grassland ecotone, and is prone to substantial climatic inter-seasonal and intra-seasonal variations. Precipitation varies from a mean of 130 cm annually in the southeast to less than 40 cm in the northwest portion. Precipitation in Oklahoma is strongly tied to the advection of moisture from the Gulf of Mexico. Without the southerly flow of maritime Tropical air over the state, drought conditions will occur.

Meteorologic Data Input

The primary data source for the meteorologic analysis were 273 NOAA Cooperative Weather Stations: 176 stations are located in Oklahoma and 97 stations were selected from adjacent states bordering Oklahoma. The additional 97 stations were utilized in order to insure a more accurate interpolation of data along the state boundaries. These Cooperative weather stations represent the densest surface observation network in Oklahoma, but are limited in the number of variables they collected.

Variables computed from the Cooperative weather stations include: (1) maximum temperature, (2) minimum temperature, (3) average temperature, (4) total precipitation, and (5) total pan evaporation (used as a check against selected data output). In addition, 19 U.S. National Weather Service first order weather stations (eight within Oklahoma and 11 in surrounding states) were utilized to obtain the following variables: (1) average wind speed, (2) total hours of actual sunshine, (3) percent of possible sunshine, and (4) average relative humidity. Since these First Order variables have been shown to be more spatially homogenous, the fewer number of stations adequately provided information over the state.

Data Manipulation

Weekly averages for all nine variables were computed by station and by week for the period of February 24 through October 4, 1980. Each week is defined as a Sunday to Saturday period in order to match other acquired data sets, particularly, the Crop Moisture Index (CMI). Figures 1-6 are maps of six selected meteorologic variables for one of the 32 study weeks, June 22-28, 1980. The six variables have been manipulated into an appropriate form for use in selected climatic indices and for comparison to satellite-derived vegetation measures. As can be seen from figures 1 through 6, even the

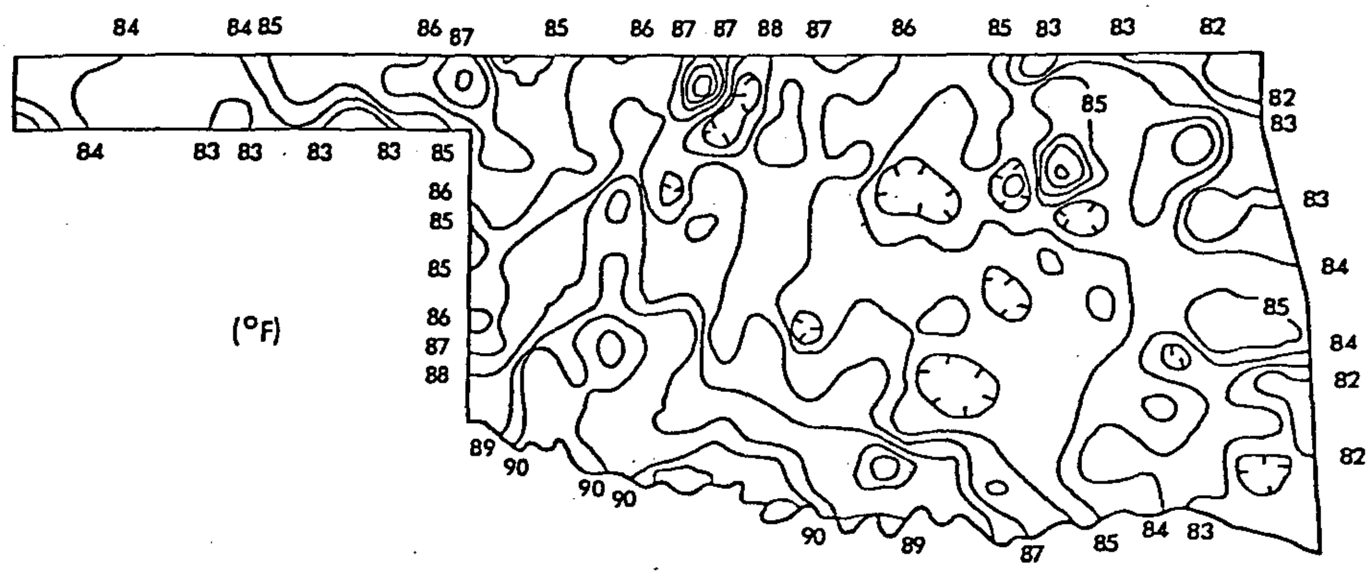

Figure 1. Weekly Average Temperature - June 22-28, 1980

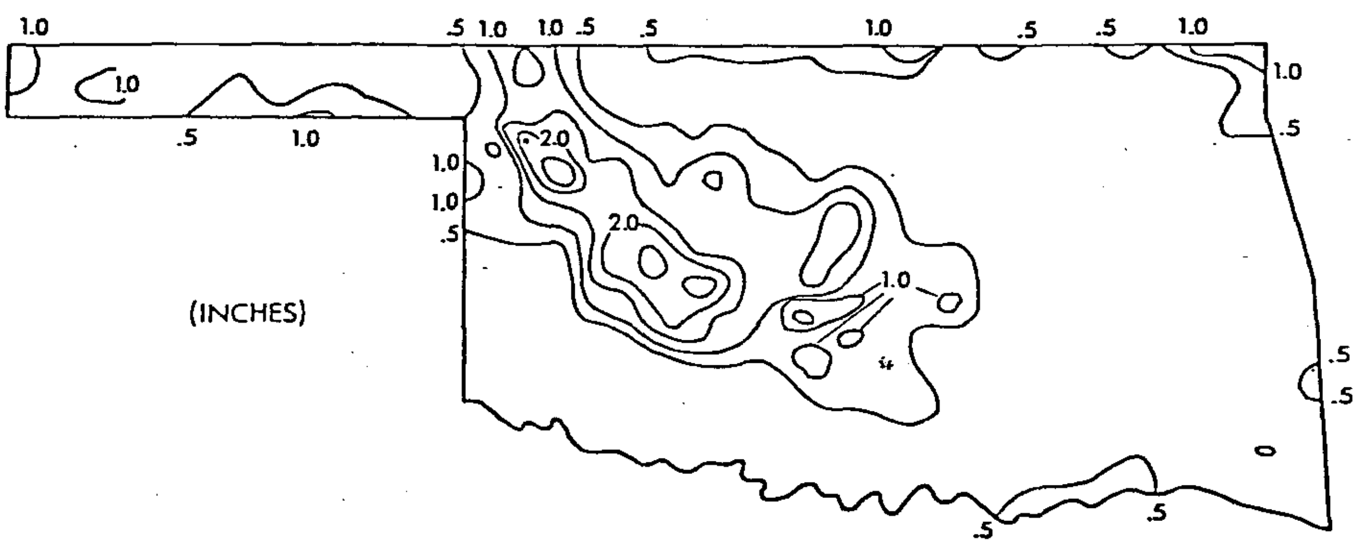

Figure 2. Weekly Total Precipitation - June 22-28, 1980

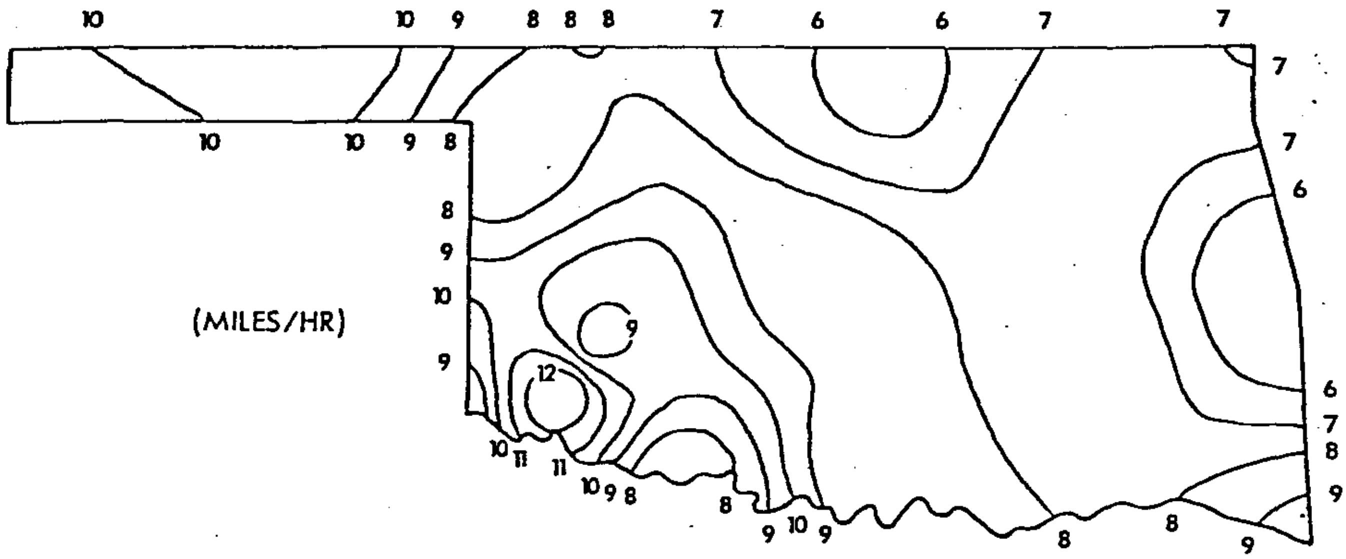

Figure 3. Weekly Average Wind Speed - June 22-28, 1980

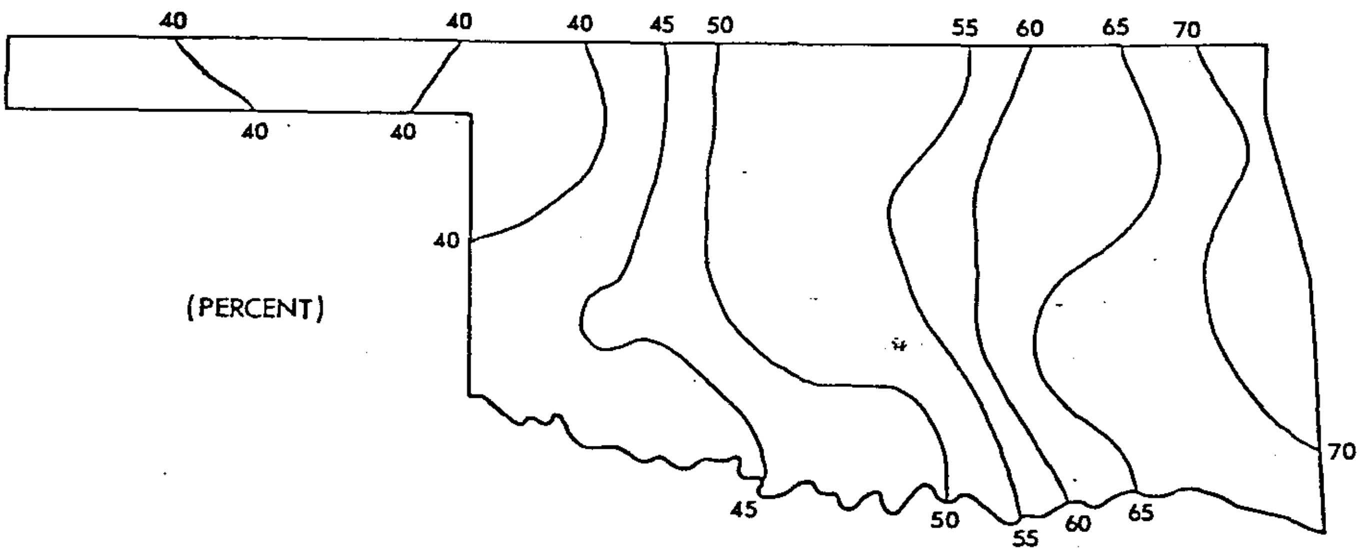

Figure 4. Weekly Average Relative Humidity - June 22-28, 1980

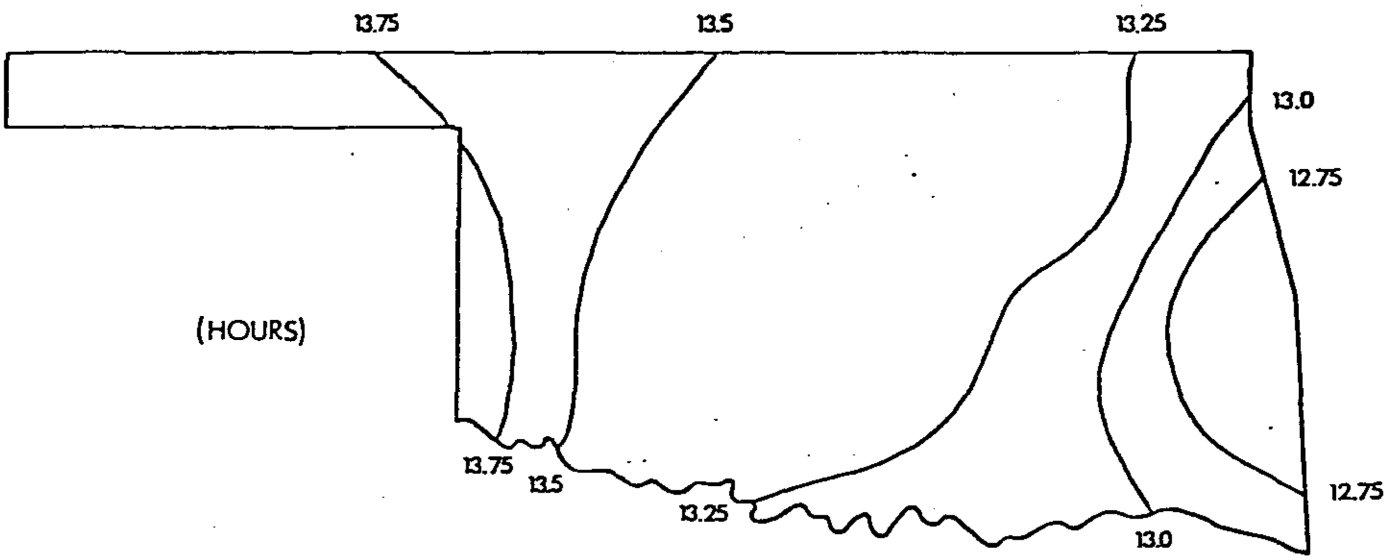

Figure 5. Daily Average Sunshine - June 22-28, 1980

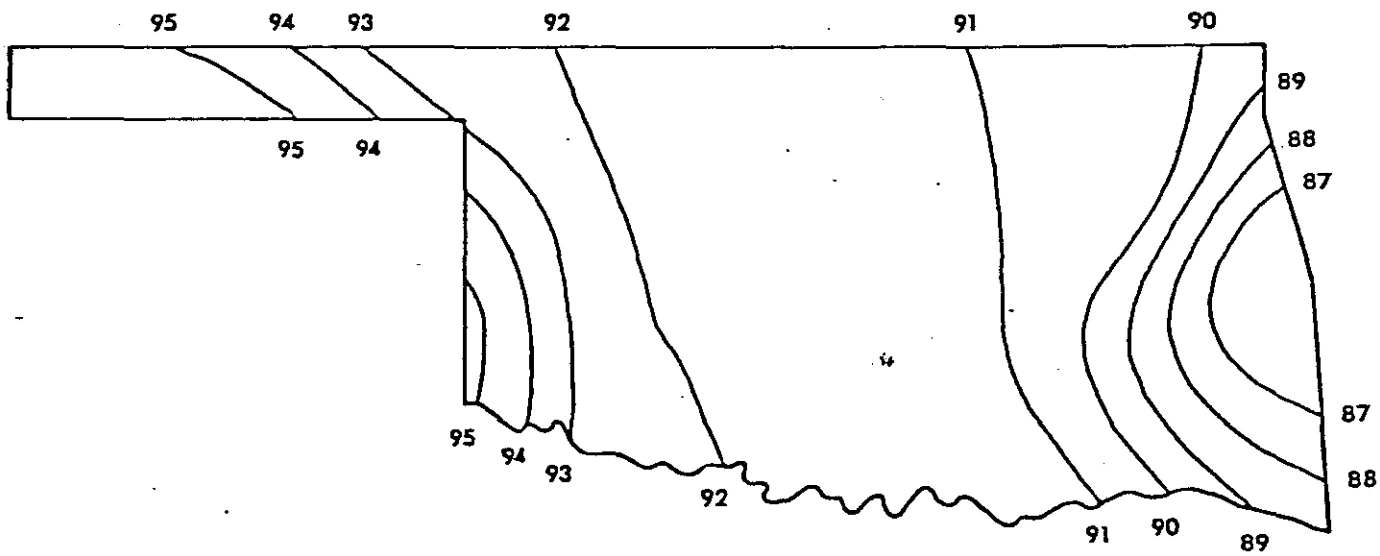

Figure 6. Weekly Average Percent Sunshine - June 22-28, 1980

necessarily coarse scale of our weekly meteorologic inputs exhibits considerable spatial variation. These patterns changed markedly through the study period, therefore, a geographic information system approach is useful in managing these temporal variations.

Most of the data for the construction of the maps were retrieved from magnetic tape archive by the National Climatic Data Center, although some First Order data were recorded from microfiche and then entered into the Oklahoma State University IBM computer system in a format consistent with the data already stored on magnetic computer tape.

In addition to the meteorological data recorded for each station and summarized by week, the latitude and longitude coordinates for the location of each of the 273 Cooperative weather stations and the 19 First Order stations were recorded. These geographic coordinates permitted the mapping and display of any variable for any time period for any or all parts of the state of Oklahoma.

In order to enter the data into a geographic information system, each of the nine meteorologic variables were interpolated to produce matrices of data. The interpolations resulted in matrices where each newly generated value represented a cell whose center was 1.6 km from its surrounding neighbors. The newly created matrices were composed of 56 columns for each degree of latitude and 69 rows for each degree of longitude.

The interpolated matrix for each meteorologic variable for each week was produced utilizing SURFACE II, a software package written by the state of Kansas Geological Survey. The software is flexible in that it allows generation of interpolated data at any desired scale. The grid nodes of the newly generated matrices were calculated utilizing a scaled inverse distance squared weighting function with a nearest neighbor search. The eight nearest neighbor original data points were used for the generation of each new data value. All interpolated points within the state boundaries had an adequate number of sample points over minimum distances to assure accurate interpolation. Due to the large number of available sample points, missing values for any station for any week were deleted before the interpolation process was performed.

The development of the matrices resulted in the formation of area data covering the state of Oklahoma at a scale where each cell value represents an area of 2.56 square km (1 sq. mile). The aligned matrices include values for each of the nine meteorologic variables for any of the 32 weeks of the analysis period. These matrices can be overlaid and spatially registered to other cellular data sets, such as, satellite data.

Development of Drought Measures

Beyond simple temperature and precipitation values, much more sophisticated measures of drought are possible using the available nine variables. Potential evapotranspiration has been a concept well-used in describing aridity. Christiansen (Bordne and McGuinness, 1973) has formulated a measure of potential evapotranspiration which contains data types commonly available. From the values within the various planes of a geographic information system, it is possible to calculate the Christiansen equation of potential evapotranspiration. These data can then be used to derive other drought measures such as the UNESCO aridity index and the moisture availability index (Figure 7).

Benefits

This research has focused on the detection and monitoring of drought in Oklahoma through the use of vegetation indices derived from satellite data. The project benefits all those involved in regional, state, and multi-state

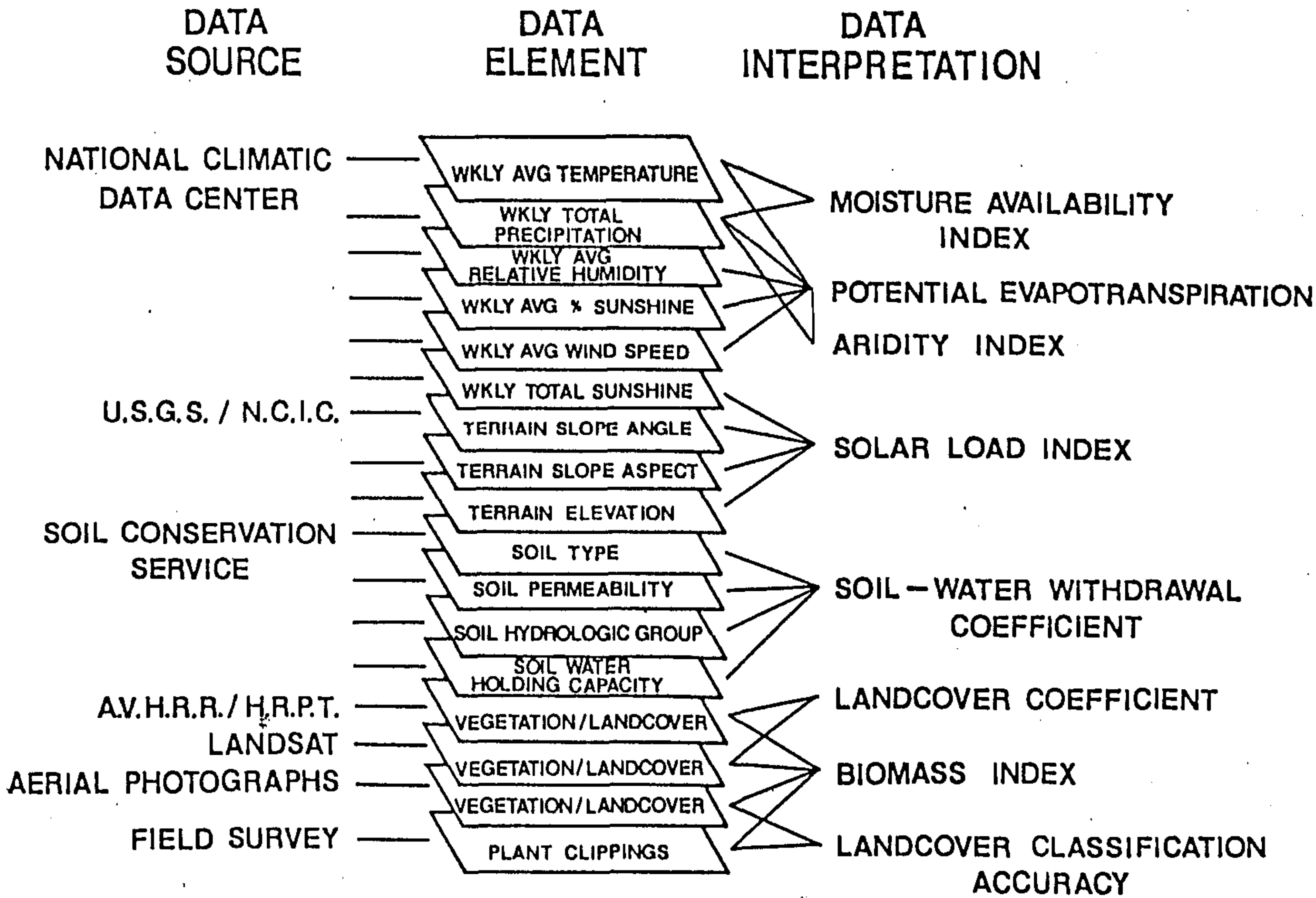

FIGURE 7. INTEGRATION OF SATELLITE DATA WITH COMPLIMENTARY DATA TO DERIVE ESTIMATES OF MOISTURE STRESS AND DROUGHT.

water resource planning, since the method of data collection provides a distinct vantage point of earth reconnaissance and, yet, provides sufficient detail regarding the landscape of Oklahoma for assessing the dynamic character of the state's vegetation. The methodology utilized in this project benefits Oklahoma since it attempts to assess a statewide issue, detection of drought and its impact on vegetation, and looks at a leading industry of Oklahoma--agriculture and its development throughout a growing season.

Contributions to Knowledge

The AVHRR sensor on-board NOAA-6 records in four spectral bands. The sensor on NOAA-7 senses spectral data in five bands. The AVHRR spectral bands are spectrally wider than most satellite sensors commonly used for vegetation analysis. The first two AVHRR spectral bands, however, have been found adequate for the same vegetation mapping purposes as narrower bands and are similar to Landsat MSS band 5 and 7 (Tucker et al, 1984). While the AVHRR spectral bands may not be as optimum for remotely sensed monitoring of vegetation as compared to Landsat, the advantages of temporal frequency, large area data acquisition, and fewer data points for analysis of large areas promote AVHRR data as a potential data source for analyses requiring vegetation information over extensive areas.

This research describes vegetation indices used to evaluate the dynamic character of Oklahoma's vegetation. Satellite data require, however, the integration of related environmental variables to fully exploit the resource evaluation effectiveness afforded by their spatial, spectral, radiometric, and temporal resolution for resource assessment. Through this project a data base of soils, landcover, terrain, climate, and meteorologic variables have been assembled. Currently, NASA Climate Program has chosen a field test in Oklahoma because of the availability of the data base. Our involvement in that program will be facilitated due to the work conducted in conjunction with this project.

Publications, Meetings, and Presentations

Various aspects of the project were presented. They include:

J.D. Vitek, S.J. Walsh, M.S. Gregory, "Accuracy in Geographic Information Systems: An Assessment of Inherent and Operational Erros," PECORA IX Symposium, Presentation and proceedings publication, October, 1984.

S.J. Walsh, "Geographic Information System Approach: A Strategy for Resource Management," Journal of Soil and Water Conservation, July, 1984, pending review.

S.J. Walsh and M.S. Gregory, "Integration of Supplementary Information with NOAA AVHRR Data for State-Wide Vegetation Indices," Remote Sensing of Environment, July, 1984, pending review.

S.J. Walsh, S.J. Stadler, M.S. Gregory, "Modeling of Regional Evapotranspiration through a Geographic Information System Approach," International Conference on Spatial Data Handling, Zurich, Switzerland, August, 1984.

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Thompson, D. R. and O.A. Wehmanen. 1979. "Using Landsat Digital Data to Detect Moisture Stress," Photogrammetric Engineering and Remote Sensing, Vol. 45, p. 201-207.

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