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# THE ROLE OF METEOROLOGICAL SATELLITES IN AGRICULTURAL REMOTE SENSING

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ABSTRACT

A program is underway at the National Earth Satellite Service to develop products from weather satellite data that are useful for agricultural monitoring. AgRISTARS (Agriculture and Resources Inventory Surveys Through Aerospace Remote Sensing) is a program to develop techniques for monitoring areal extent and condition of major crops worldwide using data collected by earth-orbiting satellites. The Department of Agriculture is the lead agency with NASA providing research and special products from the Landsat research spacecraft, the Department of Interior providing routine Landsat data and the Department of Commerce (NOAA) providing yield models and special products from their operational spacecraft. These special products, being developed by the National Earth Satellite Service (NESS) include daily estimates of precipitation, insolation, maximum/minimum temperature, vegetation index, and, on a weekly basis, snowcover. This paper is an overview of the NOAA program and describes the current status of each product.

## I. INTRODUCTION

The U.S. Department of Agriculture routinely forecasts the production of major crops in all areas of the world having significant output. To do this they must have accurate estimates of the acreage planted for each crop and up-to-date information about the ecnomic factors (use of machinery, fertilizers and insecticide and high-yield seed, for example) and the health and vigor of the crop throughout the growing season. Data to the desired accuracy, coverage and timeliness are simply not available from conventional sources and the forecasters are constantly seeking improved data. Earth-orbiting satellites provide rapid, continuous global coverage and are therefore prime sources of the required information.

NASA and the Department of Agriculture are developing techniques for the identification of crops and the estimation of acreage planted using Landsat data (currently 80m resolution in four spectral bands in the visible and near infrared) and the Department of Commerce, NOAA, is developing mathematical models to predict the yield of each crop (bushels/acre for example) and special meteorological observations to drive these models and at the same time monitor the health and vigor of the crop and provide early warning of damaging environmental situations.

In addition, NOAA/NESS provides a measure of "greenness" which is directly related to the health and vigor of the vegetation. Called a "vegetation index," it is also derived from Landsat data at higher resolution, but only every 18 days under the best of conditions. The daily coverage provided by the NOAA satellites, even though the resolution is 1 km as opposed to the 80 meter Landsat resolution, is important.

This paper presents a review of past progress and the current status of each of these meteorological satellite products.

## II. THE OPERATIONAL ENVIRONMENTAL SATELLITES

The U.S. operational environmental satellite system consists of two spacecraft in geostationary orbit (GOES) and two spacecraft in polar orbits (NOAA). Meteorological information is highly perishable, so the operational satellites make frequent observations and rapidly transmit data over high speed links to central facilities for immediate processing and use. Data are initially received from the satellites at the NOAA Control and Data Acquisition stations located at Gilmore Creek, Alaska and Wallops Island, Virginia, and retransmitted to the NOAA Central Computing Facility in Suitland, Maryland. The data are stored in on-line data bases for immediate processing and distribution.

The GOES system consists of two spin-stabilized spacecraft located above the equator at 75°W and 135°W longitudes. The primary instrument on the GOES is the Visible and Infrared Scanning Radiometer (VISSR) which provides visible and infrared images every 30 minutes for that portion of the earth visible from geostationary orbit (Figure 1). Resolution in the visible band (0.55 to 0.70$\mu$) is about 1 km at the subsatellite point, in the infrared (10.5 to 12.5$\mu$) about 8 km. The visible data are reduced in digital form to 8 km resolution for quantitative products, but are processed into pictures at 1 km resolution. The main function of the GOES system is to provide frequent imagery to aid weather forecasters in tracking meteorological systems. Other operational products generated from GOES data include winds derived from cloud motion, sea surface temperatures, and snow maps.

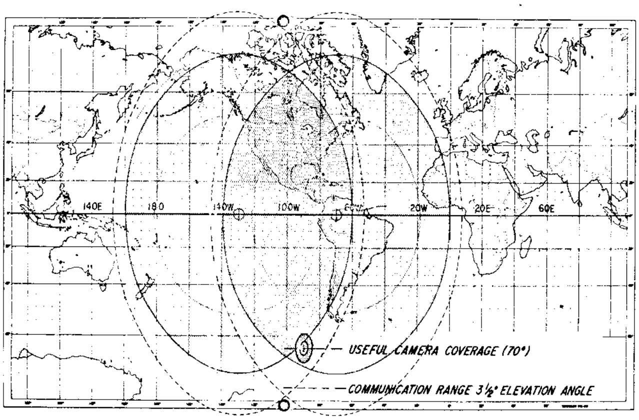


Figure 1. The hatched area indicates the area of useful data from two GOES located on the 75°W and 135°W meridians.

The polar-orbiting NOAA satellites are in orbits that allow global coverage four times daily. The primary instruments are the TIROS Operational Vertical Sounder (TOVS) which provides atmospheric temperature and moisture profiles, and an Advanced Very High Resolution Radiometer (AVHRR) which provides sea surface temperature and imagery. The TOVS consists of three instruments: a High Resolution Infrared Sounder (HIRS/2) that measures radiation in 20 spectral regions of the infrared spectrum; a Microwave Sounding Unit (MSU) making measurements at four wavelengths in the vicinity of the 5.5mm oxygen band, and a Stratospheric Sounding Unit (SSU) used to retrieve temperatures in the upper atmosphere. The AVHRR has five channels: the visible (0.55-0.75$\mu$), the near infrared (0.7-1.2$\mu$), the mid-infrared (3.7-3.9$\mu$), and the two thermal infrared windows (10.0-11.0$\mu$ and 11.0 to 12.0$\mu$). The AVHRR has a resolution at nadir of 1 km. The tape recorders on the NOAA spacecraft will not accommodate full global data at these resolutions, however, so that global data (called GAC for Global Area Coverage) is reduced on-board to 4 km. The 1 km resolution data (called LAC for Local Area Coverage) can be recorded on-board for limited, special areas of the globe and are also broadcast continuously in real-time to users worldwide who are equipped to receive it. The polar orbiters allow observations at middle and low latitudes at about 0230, 0730, 1530, and 1930 local solar time. The observations from adjacent orbits are contiguous or overlap poleward of 30° latitude.

## III. PRECIPITATION

Mathematical models used to predict the yield of a crop require the best available meteorological information throughout the growing season. Precipitation is one of the most important and its distribution throughout the growing season may be even more influential than the total amount. For AgRISTARS, NESS is developing an estimate of precipitation on a 24-hour basis for important agricultural areas of the world at a spatial resoution of 1/3°.

Both geostationary and polar-orbiter data are used in the technique development. The geostationary spacecraft, which provide continuous coverage of that part of the earth which they view, are the primary source of precipitation data. However, for those areas where geostationary satellite data are not available, techniques using polar-orbiter data alone will be used. Visible and infrared observations are the principal data sources. However, a limited technique development effort will be directed toward microwave data where it is available. Other data sources to be used in estimating precipitation include NMC (National Meteorological Center) analyses and forecasts, conventional atmospheric soundings, radar data (where available), satellite-derived soundings, and rainfall climatologies.

There are two basic types of precipitation-estimation techniques: cloud history and cloud indexing. Cloud history works best where geostationary satellite data are available. The frequent looks from geostationary satellites allow the life cycle of a cloud to be followed and precipitation estimates to be computed for each stage of the cloud's development. In contrast, cloud indexing is the principal method where only polar-orbiter satellite data are available; Only two pictures a day can be obtained from one polar-orbiting satellite. Cloud indexing involves characterizing a cloud by an index number according to its appearance in imagery and then using a look-up table or regression equation to estimate the precipitation from the cloud. Both the cloud history and cloud indexing methods have procedures for modifying the estimates for different climates and environments. Additional information on visible and infrared techniques for flash flood, hydrological, and agricultural applications is presented in a paper by Scofield.[1]

Most of the precipitation research is focusing on the continued development of state-of-the-art visible and infrared techniques. However, the use of microwave and multispectral techniques for estimating precipitation is being examined. Five microwave frequencies (6.6 GHz, 10.7 GHz, 18.0 GHz, 21.0 GHz, and 37.0 GHz) from Nimbus-7 are being tested for their efficacy in detecting and estimating precipitation. In the near future, a microwave radiometer with these same frequencies will be aboard an operational Department of Defense satellite and the microwave data will be available to NESS in real-time. Within the next one to three years, microwave data will be combined with the visible and infrared techniques in an attempt to develop an improved precipitation estimation algorithm from polar-orbiter data.

The following are examples of the use of a cloud history techique and a cloud indexing technique in real-time over the U.S.A. and the U.S.S.R., respectively.

On August 9-12, a cloud history technique using geostationary satellite data was applied in real-time to Hurricane Allen as it moved westward from the Gulf of Mexico through southern Texas and into northern Mexico. Estimated isohyets were produced and transmitted to National Weather Service Forecast Offices in Texas. The period of heaviest rainfall occurred along a convective cloud band shown in Figure 2 between A and A'. Twenty-four hour observed and estimated rainfall amounts ending at 1200 GMT, August 11, are displayed in Figures 3 and 4, respectively. The estimated rainfall pattern and amounts over southern Texas were quite good especially along the heavy rainfall band between A and A'.

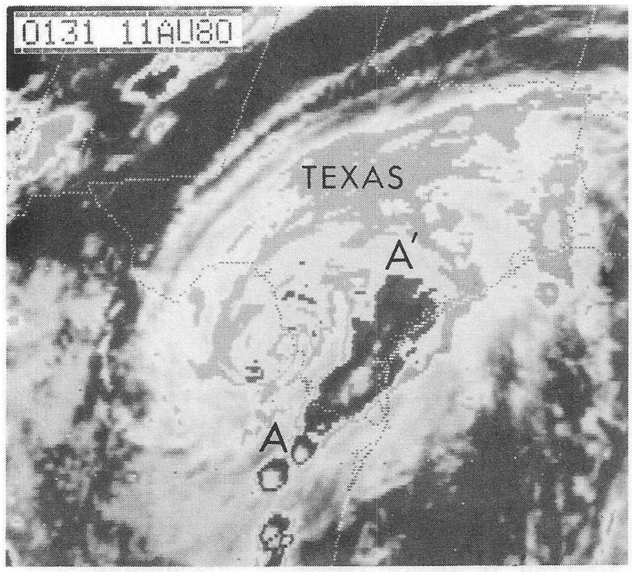


Figure 2. Enhanced infrared GOES imagery, 0130 GMT, August 11, 1980.

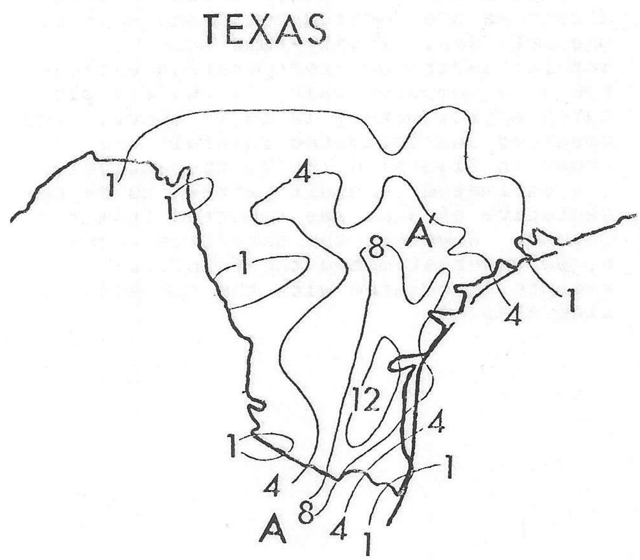


Figure 3. Twenty-four hour observed rainfall in inches ending at 1200 GMT, August 11, 1980.

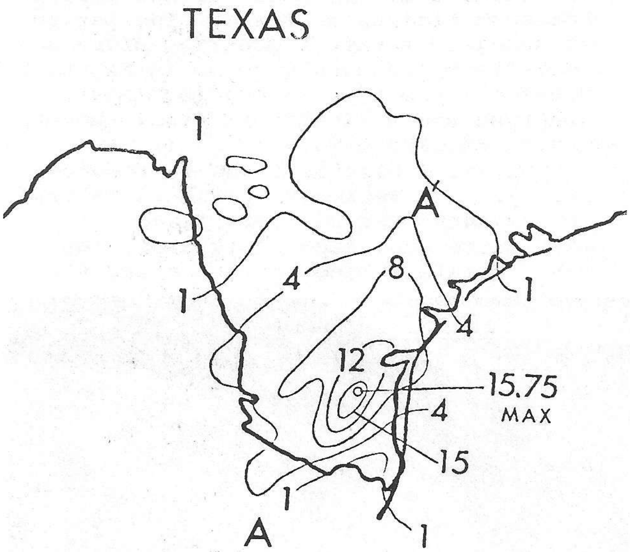


Figure 4. Twenty-four hour satellite-derived rainfall estimates in inches ending at 1200 GMT, August 11, 1980.

On July 27-28, a cloud indexing technique using polar-orbiter data was applied in real-time to a convective situation over the U.S.S.R. The infrared picture over the U.S.S.R. in Figure 5 shows a convective cloud line between A and A'. Other areas of thunderstorms are located north and east of the Aral Sea. Twenty-four hour satellite-derived precipitation estimates were computed using IR and VIS pictures approximately 12 hours apart. The observed and estimated rainfall are shown in Figures 6 and 7, respectively. The estimated rainfall pattern is representative of what was reported from the ground. However, the satellite technique underestimated the rainfall amounts associated with the convective line A to A'.

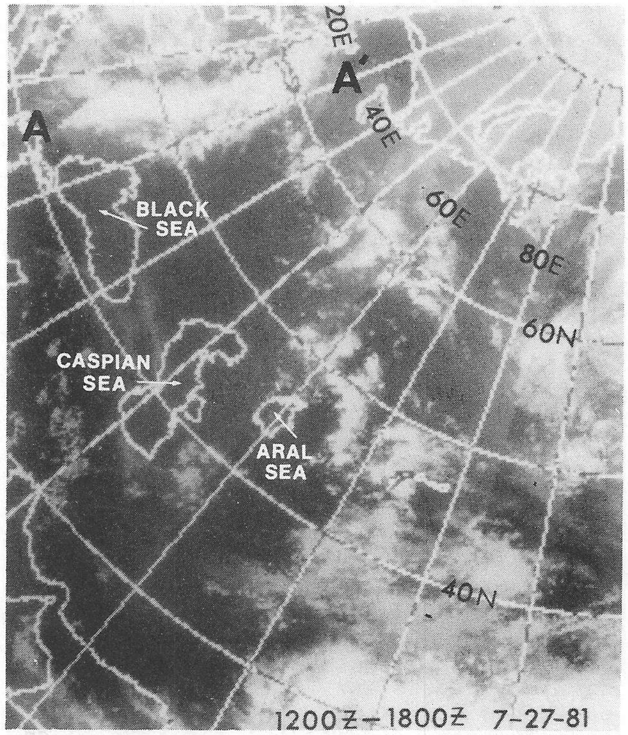


Figure 5. Infrared imagery, 1200-1800 GMT, July 27, 1981.

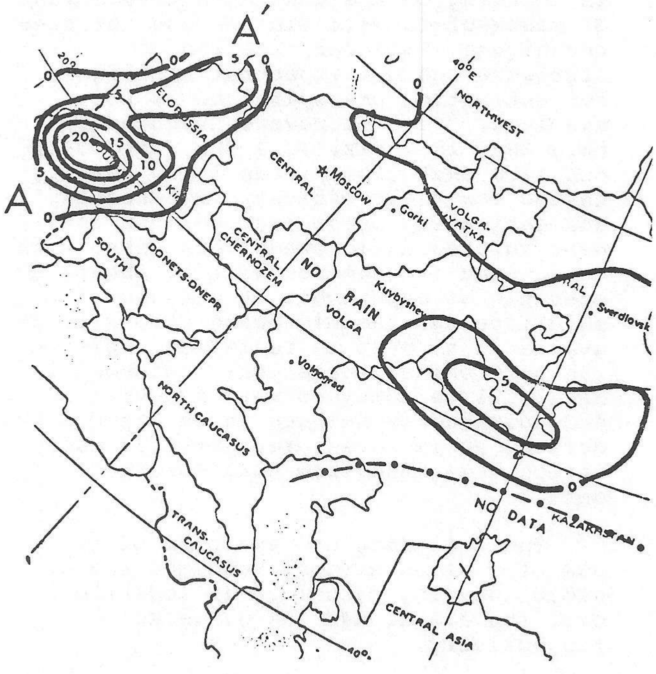


Figure 6. Twenty-four hour observed rainfall (mm) ending at 1200 GMT, July 28, 1981.

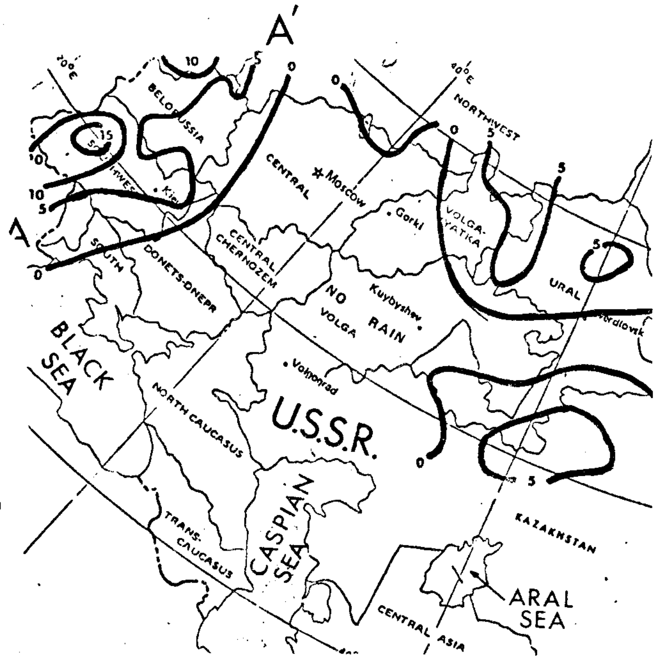


Figure 7. Twenty-four hour satellite-derived rainfall (mm) ending at 1200 GMT, July 28, 1981.

## IV. MAXIMUM/MINIMUM TEMPERATURE

Daily maximum and minimum temperature is a quantity that is important in crop yield models, soil moisture models, and crop stress detection. Crop canopy temperature is the quantity most closely correlated with crop development, but since it is not routinely available, shelter temperature (air temperature near the ground) is used in current crop models. Shelter temperature has a high spatial variability which contributes to crop forecasting errors where observations are sparse and not representative of the whole region. Quantities derived from satellite data are by their nature area averages. For large crop districts a single satellite estimate may be more representative than one or two conventional observations within the area.

Estimation of daily maximum and minimum temperatures is a two-step process. The first step is estimation of shelter temperature; the second is blending of satellite and conventional temperatures and estimation of daily extremes. Considerable progress has been made toward shelter temperature estimation; research and development has just begun on the second step.

The TOVS system on the NOAA polar-orbiting satellites is the data source for shelter temperatures. Two of the four daily observations of the NOAA satellites are at good times for daily temperature extremes. One pass is in the early morning (0230 local time) near the expected time of minimum, and the other is in the afternoon (1430 local time) near expected maximum. Surface temperatures observed from satellites are subject to significant errors introduced by the water vapor, haze and cloud in the intervening atmosphere. Accuracy is determined by how well their effects can be measured and removed to produce a "clear radiance." Much effort has been expended on fully automated algorithms for obtaining clear radiances as part of the NESS operational sounding system and those methods are adopted in the AgRISTARS maximim/minimum temperature processing[2].

A regression technique is used to estimate shelter temperatures from TOVS soundings[3]. Figure 8 shows results obtained from NOAA 6 for cloudy and partly cloudy scenes. The standard deviation between satellite estimates and surface observations is usually less than 2.0°K for both clear and partly cloudy areas. When the scene is completely obscured by clouds, the retrieval is made from microwave data and the standard error rises to around 3.0°K.

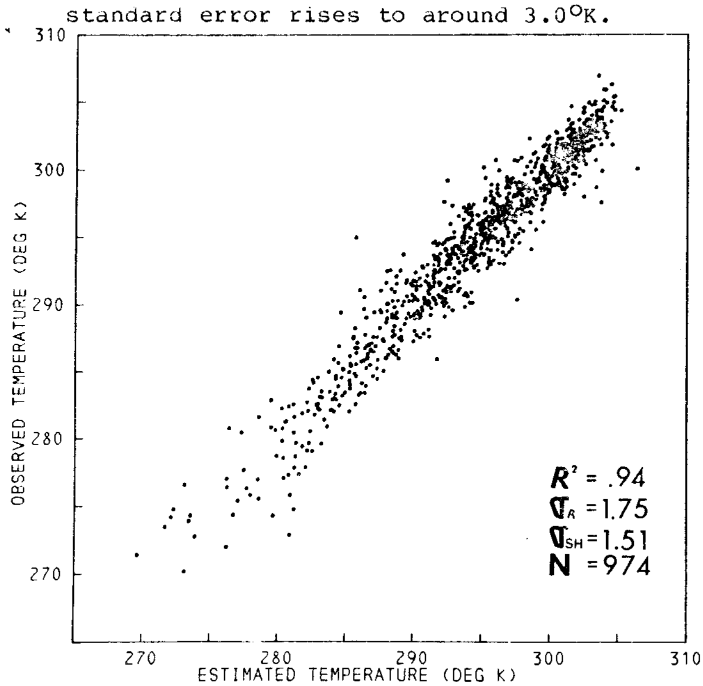


Figure 8. Shelter temperature plotted against satellite estimates for clear and partly cloudy retrievals for April through July, 1981.

From TOVS the ground resolution of the shelter temperatures is rather low, 250 to 500 km. Research is underway to increase the resolution to 60 to 100 km.

## V. INSOLATION

Insolation is of interest to agriculture because solar radiation is the primary energy source for growing plants. It is used in numerical models for estimating crop yield, potential evapotranspiration and soil moisture. The reason for obtaining insolation from satellite data is coverage. Many more estimates over large geographic areas can be produced from satellites than are practical or affordable with conventional ground-based methods.

The radiant energy incident at the top of the atmosphere, $Q_O$, is divided after interaction with the earth-atmosphere system according to:

$$Q_O = Q_R + Q_A + Q_G \qquad (1)$$

where $Q_R$, $Q_A$, and $Q_G$ are the components of the incident energy reflected to space from the earth-atmosphere system, absorbed in the atmosphere, and absorbed at the ground, respectively.

The incident radiation, $Q_O$, can be predicted with acceptable accuracy for any location and time, while the reflected and absorbed components are determined by the state of the atmosphere. The reflected radiation term, $Q_R$, explains up to 80% of the variability in the portion of incident radiation that reaches the ground, and cloud cover determines the size of $Q_R$. Radiance in the visible spectrum measured by satellites is directly related to $Q_R$. All satellite insolation techniques amount to obtaining solutions to equation (1) either by physical or statistical models.

GOES is the preferred data source for satellite estimates of insolation because its repeat observations throughout a day allow tracking of changing cloud conditions and more accurate specification of $Q_R$. For areas of the globe where geostationary satellite data are not routinely available, it is necessary to use the polar orbiters for insolation estimates.

Two GOES insolation techniques have been developed--a regression technique and a physical model--both of which provide estimates with approximately the same accuracy, but which have different requirements on data calibration, ground truth and computer time.[4,5,6] The regression technique has been run at NESS since the summer of 1980 for the eastern two-thirds of the U.S. The program provides daily estimates of insolation in Langleys (1 Ly = 1 cal/cm$^2$) on a 1$^\circ$ latitude-longitude grid. A contoured example of the product is shown in Figure 9. Similar products have been developed for the western United States, Mexico, and the agriculturally important parts of Brazil and Argentina. Comparisons and ground truth pyranometer data for the eastern U.S. estimates have shown errors in the daily total insolation of 10 to 15% of the mean daily total when a sufficient number of pictures (at least 4) are used in the daily estimate. An example comparison with a pyranometer at Auburn, Alabama, is shown in Figure 10.

GOES INSOLATION PRODUCT

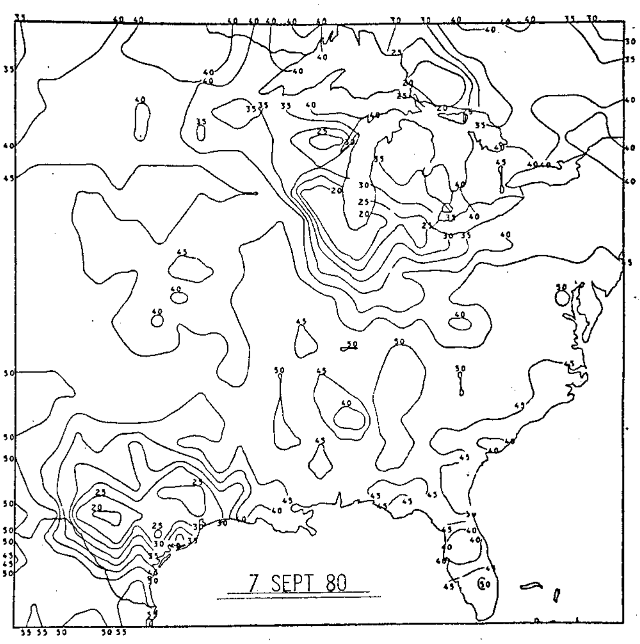


Figure 9. Analysis of satellite-derived daily insolation for September 7, 1980. Contour interval is 50 Ly.

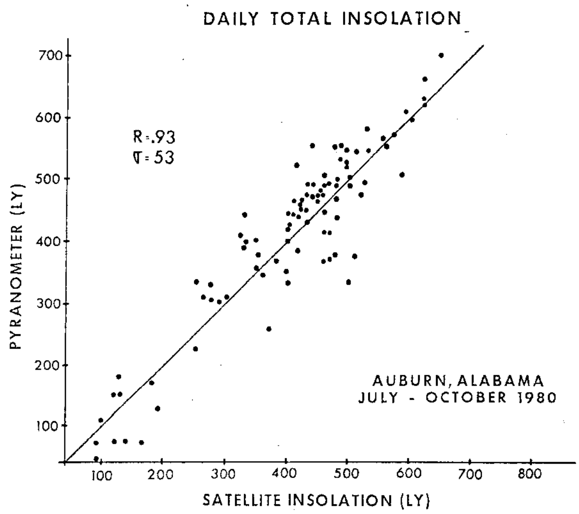


Figure 10. Pyranometer estimates of daily insolation vs. satellite estimates from five GOES pictures/day.

Experience in running the GOES insolation product for 18 months revealed two problems. The first is that the product is more labor intensive than anticipated. It requires a knowledgeable analyst to monitor the product and manually correct errors that can appear in parameters used in the regression. The second is lack of reliability in the GOES data base in the NOAA computers. As presently configured the program attempts to use 5 pictures per day, but on too many occasions only 3 or fewer are available. The software is being modified to access 7 pictures per day to increase the probability of getting at least 4 per day.

For areas where geostationary satellite data is not available, a technique was developed to estimate daily total insolation using data from the operational polar orbiting satellites.[7] The overpasses of the polar orbiters are not timed well for insolation, with only the 1430 observation in full daylight. To make use of the observations in the early morning and late afternoon, a model was developed that uses cloud amount and cloud type, quantities that can be estimated from infrared as well as visible data. The technique was designed to be implemented interactively along with the precipitation estimation algorithms. Cloud type and amount determinations are made by an analyst looking at satellite imagery on a TV screen, and atmospheric precipitable water is obtained from either satellite soundings or from NMC fields. A satellite observation at any time within a 24-hour period is sufficient to make an estimate of daily insolation. If two or more satellite observations are available, a weighted average daily total is computed. The weighting factors are functions of the local solar time of the satellite observations, with increased weight given to estimates at times of low solar zenith angle.

Test results with this algorithm show an error in the daily insolation estimates of 15-20% when imagery at the times of the 0730, 1430, and 1930 overpasses is used.

## VI. SNOWCOVER

At present only the area of snow coverage can be measured reliably from space. However, this is useful for agricultural monitoring, because snow is necessary in northern wheat growing regions to protect winter wheat from damage from low temperatures.

Figure 11 illustrates a northern hemisphere snow and ice map for the period March 1-8, 1982, produced at NESS. This product is produced in digital form as the center 544x704 grid points of a sixteenth submesh grid of the standard NMC 65x65 polar stereographic projection. The input data is mapped 7-day minimum brightness composites of NOAA-7 Global Area Coverage (GAC) data. Snow and ice boundaries are drawn by analysts on a CRT using a moveable cursor and the mapped visible and infrared composites. Beginning November 1, 1982, this product will be prepared once a week and shipped to USDA in Houston.

This product defines an area of relatively long-lived snowcover. Snowfalls lasting only a day or two are overwritten in the 7-day compositing process.

## VII. VEGETATION INDEX

One of the most significant developments from the Landsat Multispectral Scanner (MSS) was the use of the visible and reflective infrared, channels 5 and 7 respectively, for monitoring the health and vigor of crops. The visible and near infrared channels on AVHRR have spectral response curves similar to channels 5 and 7 on the MSS. This spectral combination allows monitoring of ice, snowcover, water quality, vegetation, and terrain classification.[8] Vegetation index (VI)

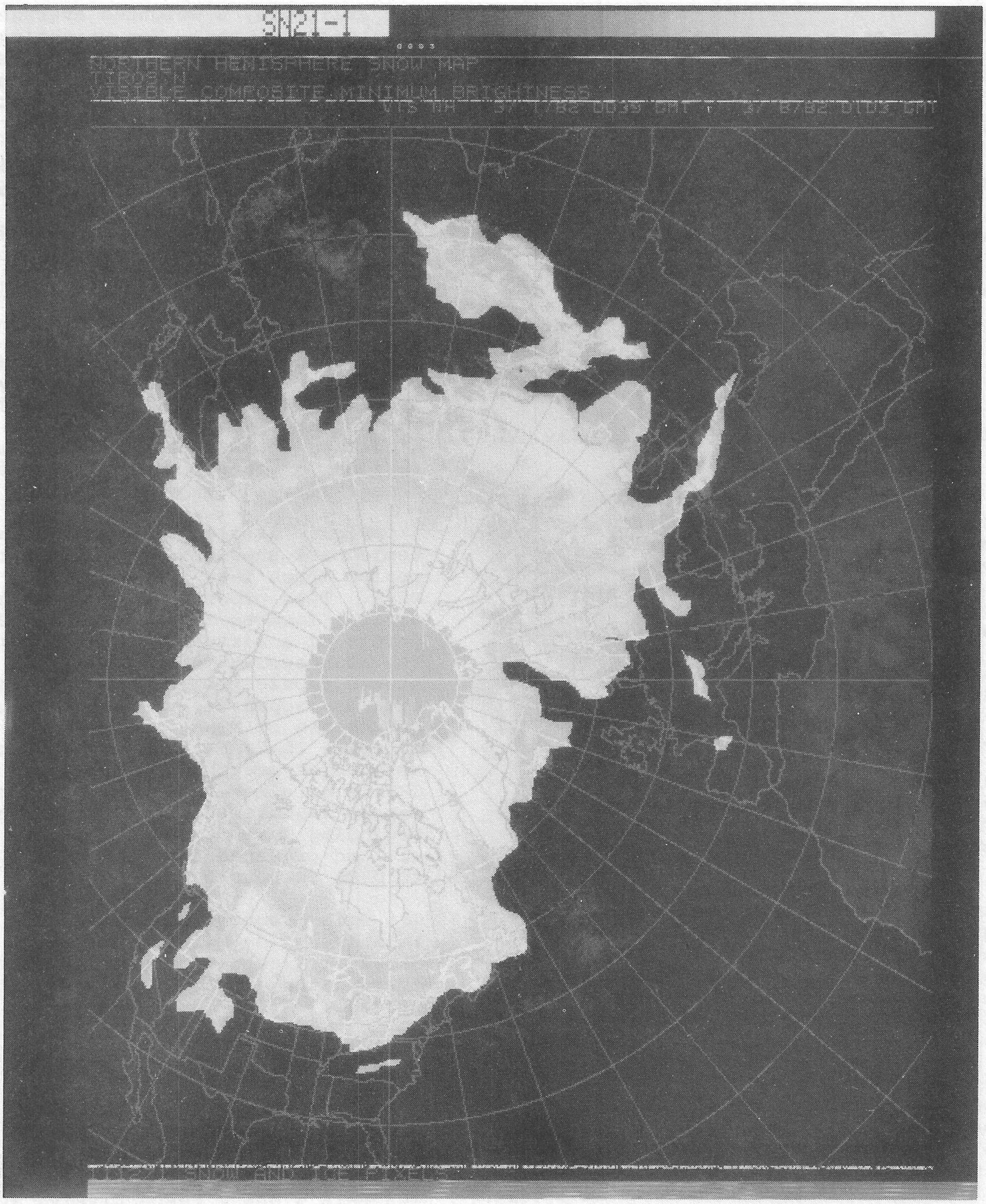


Figure 11. Northern hemisphere snow and ice map for March 1-8, 1982. Map is made from 7-day AVHRR minimum brightness composite.

derived from the AVHRR data is of particular interest for agricultural remote sensing and a paper being presented at this meeting reviews the current research.[9]

The advantage of the NOAA satellites for monitoring green vegetation is that they provide daily observations while Landsat has a repeat time of 18 days. If the area of interest is cloudy, large gaps occur in the Landsat coverage. The improved temporal coverage from NOAA is an important adjunct to the Landsat data.

An experimental vegetation index product for global monitoring is being produced from the AVHRR GAC data. The product is a mapped mosaic computed from the equation

$$VI = \frac{Ch_2 - Ch_1}{Ch_2 + Ch_1} \qquad (2)$$

where $Ch_1$ and $Ch_2$ are the count values from channels 1 and 2 respectively. The VI is generated daily from daytime NOAA-7 data for both the northern and southern hemispheres. The value of VI when calculated from equation (2) ranges from 0.1 to 0.5 for vegetated areas with the value increasing with the greenness of the vegetation, while atmospheric attenuation, backscatering, and cloud effects all act to decrease VI. A 7-day composite is produced which consists of the maximum VI found in the daily maps. Compositing reduces or eliminates transient atmospheric effects. An example of the composite for North America is shown in Figure 12.

The maps are a sixteenth submesh grid of the standard 65x65 polar stereographic projection used by the National Meteorological Center and the Air Force Global Weather Center. Resolution ranges from 15 km at the equator to 30 km at the poles.

The first uses of this product will be qualitative. Analysts will look at images of VI to assess general conditions of vegetation and crops in different locations around the world. Neither high resolution nor precise calibration will be required. However, an archive of quantitative values will be produced and we expect that further study will prove the numerical vegetation index more useful than imagery.

Figure 12. Seven-day composite vegetation index. Darker values indicate green vegetation.

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