SATELLITE ENVIRONMENTAL MONITORING IN SUPPORT OF GLOBAL FOOD SECURITY AND DESERT LOCUST PLAGUE PREVENTION AT FAO : the ARTEMIS SYSTEM

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ABSTRACT

In response to the major food and feed crises which have affected many countries in Africa during the last fifteen years due to widespread drought and successive threats of locust plagues, the Food and Agriculture Organization (FAO) of the United Nations has been developing its Global Information and Early Warning System (GIEWS) on Food and Agriculture. This was established in 1975 as a result of the recommendations of the World Food Conference, held in Rome in 1974.

Since 1978, both GIEWS and the FAO Desert Locust Programme have increasingly been using remote sensing data from environmental satellites for monitoring and forecasting of crop and rangeland productivity and desert locust activity.

This paper summarizes the satellite remote sensing techniques currently used by FAO for precipitation and vegetation conditions monitoring in Africa, as well as vegetation conditions monitoring in the Near East and Southwest Asia based on the use of high frequency Meteosat data and daily NOAA AVHRR data.

Based on the experience, the FAO Remote Sensing Centre has developed a comprehensive operational satellite remote sensing based environmental monitoring system: ARTEMIS (Africa Real Time Environmental Monitoring using Imaging Satellites). The system receives and processes hourly digital Meteosat data and daily NOAA AVHRR Global Area Coverage (GAC) data from which a number of user products are derived.

The ARTEMIS system will generate ten day and monthly estimated rainfall maps as well as monthly rainfall anomaly maps for the land area of Africa and the Near East covered by Meteosat and normalized difference vegetation index (NDVI) maps for defined ten day and monthly periods in a common projection at a spatial resolution of 7.6 km. for Africa and Southwest Asia. Derived thematic products will include ten day crop/rangeland moisture availability maps using the FAO water balance index model and desert locust potential breeding activity factor (PBAF) maps as inputs for Early Warning and Desert Locust Plague Prevention programmes at international, regional and national levels.

The ARTEMIS system was custom designed and built for FAO by the National Aerospace Laboratory (NLR) of the Netherlands in close cooperation with NASA Goddard Space Flight Center (GSFC), the Universities of Reading and Bristol, U.K. and FAO user groups, with financial support from the Government of the Netherlands through an FAO Trust Fund.

The ARTEMIS system will be installed at the FAO Remote Sensing Centre in June 1988.

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1. INTRODUCTION

FAO experience in the use of satellite remote sensing data for monitoring dynamic phenomena in the earth's atmosphere and on the earth's surface, as they relate to the production or protection of food and animal feed, has, so far, been predominantly in the fields of Food Security and Locust Plague Prevention.

Since 1978, the FAO Remote Sensing Centre has been actively engaged in close cooperation with NASA Goddard Space Flight Center (GSFC) and the Universities of Reading and Bristol, U.K., in the development and operational testing of remote sensing techniques for monitoring of precipitation and vegetation development over large areas based on the use of geostationary Meteosat data and data from the polar orbiting NOAA and Landsat satellites.

This paper summarizes the present state of the art in satellite remote sensing based precipitation and vegetation assessment as undertaken by FAO in support of agricultural production monitoring and migratory pest forecasting in Africa, the Near East and Southwest Asia.

Furthermore, the paper describes the operational satellite remote sensing based environmental monitoring system presently being developed by FAO for Agricultural Production and Desert Locust Monitoring and Forecasting in Africa, the Near East and Southwest Asia: the ARTEMIS System: Africa Real Time Environmental Monitoring using Imaging Satellites. The ARTEMIS System was formulated by the FAO Remote Sensing Centre in close cooperation with the FAO Global Information and Early Warning system on food and Agriculture and the FAO Desert Locust Plague Prevention Programme.

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2. METEOSAT BASED RAINFALL ESTIMATION METHODOLOGIES

2.1 Rainfall Estimation based on Meteosat Secondary User Station (SDUS) Imagery

The FAO Remote Sensing Centre, in cooperation with the Remote Sensing Unit, Department of Geography, University of Bristol, has developed and implemented an operational methodology for qualitative precipitation monitoring of the African continent using the Meteosat thermal infrared and visible image data, recorded by a Primary Data Users Station (PDUS). (Kalensky et al., 1985). A modified version of this method is based on Meteosat images recorded by the Secondary Data Users' Station (SDUS). It uses a manual image analysis procedure, combined with computerized data processing and end user product generation for obtaining ten day and monthly estimated rainfall images on a 1^{o} grid (approx. 100 x 100 km) as well as monthly rainfall "anomaly" maps obtained from a computerized evaluation of the actual estimated monthly rainfall against the long-term mean monthly rainfall, stored as background fields in the computer system, in terms of percentage departures from normal. The Meteosat SDUS data is transmitted by the satellite as an analog signal and is therefore subject to fluctuations and can, as such, not be used for numerical analysis of the data. Its spatial and radiometric resolutions are limited when compared to the original data acquired by the radiometer on the Meteosat satellites.

The operation of this methodology can be summarized as follows :

- acquisition of VIS/TIR Meteosat SDUS image coverage for the area of interest at an average frequency of three times/day (8 hour cycle);

- application of a 1^{O} grid on the image data and visual determination, on the basis of the VIS/TIR image characteristics, of the presence of precipitable cloud for each grid cell;

- tabulation of observed gridcells with precipitable cloud on daily maps;

- aggregation of daily maps into the ten-day "Number of Rainfall Day Maps";

- entry of observed number of rainfall days for each gridcell into the computer according to prescribed procedure;

- multiplication by computer of the observed number of rainfall days with the mean rainfall/rainday value for each gridcell and date;

- generation of the <u>ten day estimated rainfall map;</u>

- upon completion of three ten-day periods, summation by the computer of th three estimated ten-day totals for each gridcell;

- generation of the <u>monthly estimated rainfall map;</u>

- calculation by computer of the monthly rainfall anomaly map by determining the % departure, either positive or negative, from the long-term mean monthly rainfall for each gridcell;

- generation of the <u>monthly estimated rainfall anomaly map.</u>

This method is presently being used by the FAO Remote Sensing Centre on an operational basis for Africa as an input to the FAO Global Information and Early Warning System on Food and Agriculture and the FAO Desert Locust Plague Prevention Programme. (Hielkema <u>et al.</u>, 1986).

2.2 Rainfall Estimation based on Meteosat Primary Data User Station (PDUS) Data

2.2.1. The TAMSAT Methodology (Milford and Dugdale, 1987)

Data received by Meteosat Primary Data User Stations (PDUS) are transmitted in digital format at full resolution (VIS: 2.5 km; TIR: 5 km) at 256 radiometric levels. This data allows for numerical data processing and development of automated rainfall estimation procedures.

In cooperation with the Tropical Agriculture Meteorology Satellite Project (TAMSAT), Department of Meteorology, University of Reading, the FAO Remote Sensing Centre is presently testing a quantitative, automated rainfall estimation procedure on which the TAMSAT Project has undertaken developmental research in the Sahel under funding from the British Overseas Development Agency (ODA) and FAO.

The TAMSAT methodology of rainfall estimation from Meteosat data is based on a meteorological approach, i.e. assessment of precipitation from all precipitable clouds, using a high frequency of observation in the order of 20 times/day. The method distinguishes between precipitable and non-precipitable clouds on the basis of the principle that the colder the cloudtop, observed in the thermal infrared spectrum by the satellite, the higher the chance of precipitation from the particular cloud. Research has established temperature levels varying generally between -60° at Sahelian latitudes and -40° at tropical latitudes to be the levels below which significant precipitation can be expected. The TAMSAT Meteosat rainfall estimation method determines for each pixel over ten day periods the duration of clouds which had a temperature below the above levels. This yields cold cloud duration (CCD) maps hich for meteorological station locations have been correlated with observed precipitation over ten- day periods. On the basis of the relationships between the CCD values for individual pixels and the observed rainfall for stations located within those pixels, regressions have been established on the basis of which estimated rainfall can be determined for pixels not covering meteorological station locations.

In summary, the TAMSAT methodology for Meteosat based rainfall estimation is being operated as follows :

- acquisition of Meteosat digital TIR data on either 1600 or 6250 bpi computer compatible tapes (CCT); reading of required slots from CCT (in ARTEMIS procedure 24 images/day);

- interactive checking of registration of each image as performed by the European Space Operations Center (ESOC) in Darmstadt, F.R. Germany;

- batch processing of selected Meteosat TIR data for each rainfall day (0600 GMT - 0600 GMT) to produce cold cloud duration (CCD) images and daily number of events (NE) images at selected temperature threshold level (e.g. -40°, -50° or 60°) (an event is defined when at the use of the temperature threshold the temperature drops below -60° and ceases when the temperature rises to -20°);

- generation of the <u>cold cloud duration images for ten day periods</u>;

- Calculation by computer of the estimated rainfall for each pixel by application of the appropriate regression relationship;

- generation of estimated rainfall images for ten day periods;

- generation of monthly estimated rainfall images by computer summation of the three ten-day estimated rainfall images.

The TAMSAT methodology is based on the exclusive use of Meteosat thermal infrared (TIR) data. This allows for use of the Meteosat data during 24 hours of the day whereas the Meteosat data acquired in the visible (VIS) spectrum can only be used at the hours of actual and sufficient daylight. For the entire continent of Africa, involving four time zones, the number of full disc images with full daylight are very few.

2.2.2. The Bristol Methodology (Barrett and Power, 1987)

The Remote Sensing Unit of the Geography Department, University of Bristol, has developed two related methodologies for estimating rainfall from Meteosat PDUS digital data:

a. PERMIT: Polar-Orbiter Effective Rainfall Monitoring Integrative Technique

This method uses digital data from either polar-orbiter or geostationary environmental satellites for rainfall monitoring, based on temperature thresholding, climatic information and surface meteorological station reports (as available). In this method, the relationship between estimated rainfall (R) and the various meteorological/climatological parameters is expressed as follows :

$$R = f\,(C_T, C_n, M_c, (S_w)$$

where:
- C_T : cloudtop temperature (-32^o is selected level for rainfall/non-rainfall)
- C_n : number of raincloud days per pixel
- M_c : morphoclimatological weight: mean rainfall/rainday calculated on a month-by-month basis
- S_w : Synoptic weight related to raingauge data, if available.

In this method, first-approximation rainfall fields are obtained as a product of C and M for each pixel. If required, these fields may be weighted by available groundtruth data to provide "meteorologically calibrated" final estimates.

b. ADMIT: Agricultural Drought Monitoring Integrative Technique

This method is an objective, bispectral thresholding technique based on pairs of VIS and TIR data during daylight hours and on TIR data only during nighttime. The analysis of nighttime TIR data only is statisticaly tied to the daytime VIS/TIR relationship of rainclouds to prevent extensive cirrus cloud to be mistaken for raincloud.

The ADMIT technique can be described by the following terms:

$$R = f(C_B, C_T, C_n, M_c, (S_w)$$

where: C_B : cloudbrightness in the visible (VIS) spectrum and the other terms as above

At present, the FAO Remote Sensing Centre is testing and verifying the above quantitative Meteosat based rainfall estimation methodologies, using a Meteost digital VIS/TIR dataset for the month of July 1986. This dataset has been provided to both the Universities of Reading and Bristol for obtaining daily, ten-day and monthly rainfall estimates for West Africa between 7^{o} and 26^{o} North/18^{o} West and 20^{o} East, using the respective methodologies.

3. NOAA AVHRR BASED VEGETATION MONITORING TECHNIQUES

In 1978, the National Oceanic and Atmospheric Administration (NOAA) in the United States launched the first satellite of the third generation polar orbiting environmental satellites, TIROS-N, followed by NOAA-6, NOAA-7, NOAA-8, NOAA-9 and NOAA 10 in the same series between 1979 and 1986. NOAA-11 was launched in April 1988.

The current NOAA satellites carry seven different sensor systems for observing the earth and its atmosphere and two data collection/ transmission systems. Of the sensor systems, the Advanced Very High Resolution Radiometer (AVHRR) has a multispectral capability similar to that of the Landsat and SPOT satellites. The AVHRR collects reflected and emitted radiation in five different spectral bands, i.e. the visible, near infrared, middle infrared and thermal infrared (2), (Kidwell, 1984). Table 1 summarizes the characteristics of the AVHRR, MSS, TM and SPOT sensors, all having similar capabilities for remote sensing of greenleaf vegetation biomass. (Tucker et al., 1985).

Table 1
Main characteristics of satellite sensors suitable for detection/monitoring of green-leaf-vegetation biomass

Characteristic	LANDSAT MSS	LANDSAT TM	NOAA/ AVHRR	SPOT
Spatial resolution	80m(0.5ha)	30m(0.1ha)	1100m(120ha)	20/10m(0.04; 0.01 ha)
Spectral resolution	4 bands	7 bands	5 bands	3 bands/1 band
Useful bands for vegetation monitoring	2	4 (optimized for veget. monitoring)	3	3/1
Radiometric resol. (quantizing levels)	64	256	1024	256
Temporal resolution	16 days	16 days	2-3 days ev. 9 days	9 days
Swath width	185 km.	185 km.	2700 km.	92 km.
Single-frame cov.	34 000 $km.^2$	34 000 $km.^2$	2000 000 $km.^2$	3 600 $km.^2$

In close cooperation with the Global Inventory, Modelling and Monitoring Systems (GIMMS) Group at NASA Goddard Space Flight Center (GSFC), the FAO Remote sensing Centre continues to develop the use of NOAA AVHRR red/near infrared data for large-scale crop development condition assessment and rangeland productivity monitoring.

The combination of Meteosat based rainfall assessments and NOAA AVHRR based vegetation index imagery for the detection and monitoring of active desert locust habitats in the vast recession area in the deserts between the West African coast and Northwest India. The NOAA vegetation index imagery is proving to be effective for pinpointing areas where significant rainfall has produced active potential breeding habitats and, as such, provides the basis for a more rational and efficient field survey and preventive control operations. (Hielkema, 1980, 1986).

For this purpose, NOAA AVHRR data is processed in a vegetation index format, using the following band combination:

$$\text{Normalized Difference Vegetation Index (NDVI)} = \frac{\text{Channel 2} - \text{Channel 1}}{\text{Channel 2} + \text{Channel 1}}$$

The NOAA satellites provide effective worldwide data coverage every 2-3 days in the form of Global Area Coverage (GAC) data which is produced through an on-board resampling of the primary AVHRR data acquired by the satellite at full (1.1 km.) resolution to a 4 km. resolution. The full resolution data can be received directly by regional receiving stations in the form of high resolution picture transmission (HRPT) data. There is a limited capability for on-board recording of full resolution data and subsequent transmission to a ground receiving station in the United States in the form of Local Area Coverage (LAC) data.

The relatively high temporal repeat frequency of the NOAA AVHRR data as compared to those generated by the Landsat and SPOT satellites, allows for detection and monitoring of green vegetation dynamics even in seasonally frequently cloudcovered areas. The NASA GIMMS Group has developed and successfully tested techniques for obtaining virtually cloudfree NOAA AVHRR NDVI imagery on a ten-day basis on a continental and even global scale. (Tucker, 1985). This technique uses the daily available NOAA AVHRR data in the red, near infrared and thermal infrared channels. The thermal infrared data is used to identify cloudcovered areas. Data for a ten-day period is mapped to a selected geographic projection and cloudfree composite images are obtained for these periods by computer mapping of the cloudfree parts by selection of the pixels with the highest NDVI, thus minimizing the effects of atmospheric influences as dust and haze. (Holben, 1986).

4. ARTEMIS System Characterics

4.1. Hardware

The FAO ARTEMIS System consists of a number of integrated hardware components which can be summarized as follows:
(Van Ingen Schenau et al., 1986)

A. A Meteosat Primary Data User Station (PDUS) for direct reception of high frequency, full resolution digital Meteosat data in the visible, thermal infrared and water vapour spectral bands through a three meter dish antenna, down converter and receiver which will replace the SDUS antenna at FAO RSC. Data acquisition status and data quality assessment is performed through a display and colour monitor. Received data is stored before processing on two 132 Mb discs.

B. A computer unit consisting of a Hewlett-Packard A900 computer supported by a high-speed tapedrive, two discs (132 and 571 Mb.), a clock, a modem (direct connection with NASA/GSFC), a system console and a line printer.

C. An Interactive Image Workstation consisting of a Ramtek interface to the HP-A900 with a 1280 x 1024 resolution, a high resolution colour monitor, a graphics terminal with touch screen capability, trackball and a printer.

D. An output subsystem consisting of a colour hardcopy camera, a six-pen colour plotter and an HP VECTRA microcomputer for IBM PC compatible digital output on floppy disc.

The ARTEMIS hardware system configuration is shown in Figure 1.

4.2. Software

The ARTEMIS system software can be divided into the following groups according to function :

A. Meteosat PDUS operating system software for controlling data reception, quality control, temporary storage and transfer of data to the HP hostcomputer for processing.

B. HP A900 operating system software for operating the computer subsystem and related peripheral equipment.

C. Applications software for basic and thematic processing and mapping of Meteosat and NOAA AVHRR data into a common database and the generation of user products in specific formats (developed by NASA/GSFC/GIMMS, the University of Reading/TAMSAT project and NLR).

D. General applications software for data manipulation for development purposes.

E. Database management software for manipulation and integration of the various ARTEMIS databases with current data.

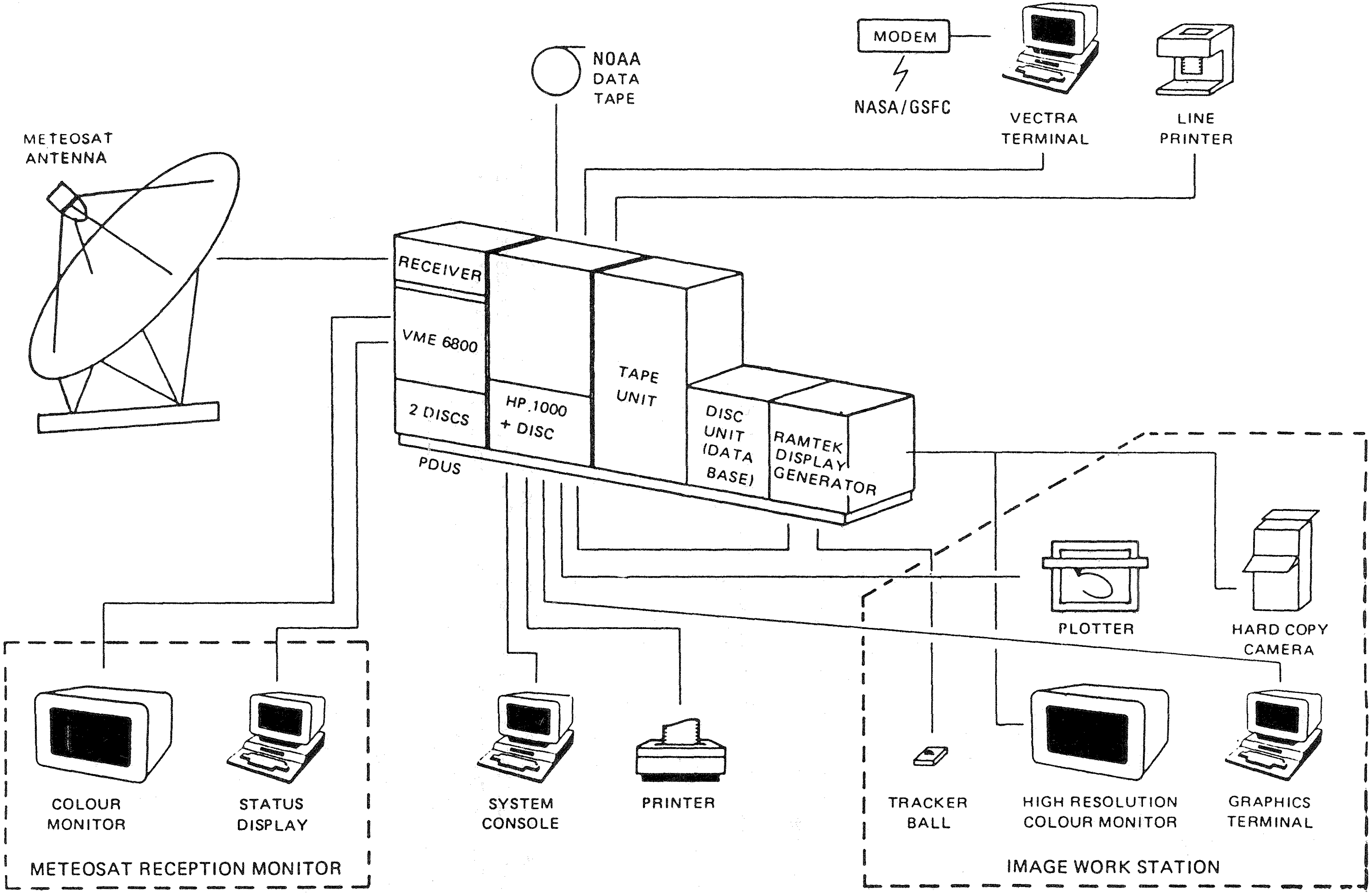

Fig. 1 ARTEMIS system configuration (Van Ingen Schenau et al., 1986)

4.3 ARTEMIS Databases

The ARTEMIS System will contain a number of databases which will be stored in the system in a geographic information system mode to support the automated generation of the thematic user products.

The following databases are being developed for incorporation into the system:

A. Geographic Database:
- coastlines
- country boundaries
- region/district/province boundaries
- major rivers
- capital cities
- geographic coordinates

coverage: global

B. Agroclimatological Database:
- mean monthly/annual precipitation
- potential evapotranspiration (PET) (ten-day/monthly)
- length/type of growing season(s)
- time of growing season(s)

coverage: Africa

C. NOAA AVHRR Vegetation Index (NDVI) database:
- ten-day/monthly NDVI for the period 1980-1988

coverage: global

D. Desert Locust Habitat Database:
- five class ranking of potential habitats

coverage: Desert Locust recession area in Africa, the Near East and Southwest Asia.

The spatial resolution of the agroclimatological, NDVI and desert locust habitat databases will be 7.6 km. The databases will be primarily georeferenced in an equal area (Hammer-Aitoff) projection, but will also be able to accommodate several other projections (e.g. Transverse Mercator).

4.4. ARTEMIS Output Products

The operational ARTEMIS system output products in 1988, are the following:

A. Main Products:
- raw Meteosat data (three spectral bands and ancillary data)
- raw NOAA AVHRR Global Area Coverage (GAC) data (five spectral bands)
- ten-day composite NDVI Map
- monthly composite NDVI Map
- ten-day estimated rainfall Map
- monthly estimated rainfall Map
- number of estimated raindays per ten days
- number of estimated raindays per month

B. Thematic Products:
- monthly estimated rainfall anomaly map in mm and % departure from normal, where the normal will be for a period of $\pm$ 30 years
- a ten-day potential locust breeding activity factor (PBAF) map
- a crop moisture availability map
- extracted areas from maps in common geographic format
- map point data lists.

The common geographic format of all mapped output products will conform to the Hammer Aitoff equal area projection of the databases at a spatial resolution of 7.6 km.

The ARTEMIS System will have two regional image formats:

1. covering the entire continent of Africa (18°W-52°E/40°N-40°S);

2. covering the Near East and Southwest Asia (50°E-95°E/40°N-0°).

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