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The Contribution of Satellite Derived Information to Malaria Stratification, Monitoring and Early Warning

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Summary

Malaria is recognised as one of the developing world's most important public health problems. Despite considerable efforts to eradicate or control the disease, it remains the most prevalent and devastating in many regions of the tropics (WHO 1993a). Malaria is the cause of an estimated 1.5 - 2.7 million deaths each year world-wide (WHO 1996). The disease has become more widespread in recent years due in part to the effects of increasing drug and insecticide resistance but also as a consequence of declining health infrastructure. For many countries of Africa south of the Sahara, where 80% of the world's malaria and 90% of all malaria deaths occur, it is certainly one of the most serious problems facing over-stretched health services. New tools are called for to augment those currently used for the control of the disease. An effective vaccine is yet to appear. What is available now? It has long been suggested that malaria control planning would benefit from a more inter-sectoral effort but it has never been clear how such an initiative should develop. This communication presents the possible contribution to malaria control services of remote sensing information, which is being used by resource managers in other sectors. Firstly, the strengths of satellite observations are emphasised. Then, the relevance of satellite data to malaria is presented. This is followed by an outline of its potential for use in improving malaria control strategies. Since many malaria researchers and control workers know little about remote sensing and its techniques, the appendices provide a brief introduction to remote sensing, data interpretation and some of the more appropriate satellites. It is hoped that individuals may then assess the possible uses of this technology for their own areas of work.

Résumé

La malaria est reconnue comme étant un des plus importants problèmes de santé des pays en développement. Malgré des efforts considérables pour supprimer ou contrôler la maladie, celle-ci reste la plus répandue et la plus dévastatrice dans les régions tropicales (WHO 1993a). On estime que la malaria cause la mort de 1,5 à 2,7 millions de personnes dans le monde entier chaque année (WHO, 1996). Le paludisme s'est aggravé ces dernières années en partie suite à l'accroissement de la résistance aux médicaments et insecticides, mais également suite à la faiblesse des infrastructures de santé. 80% des cas de paludisme et 90% des décès déclarés dans le monde sont observés dans de nombreux pays d'Afrique sub-saharienne. Dans ces pays, cette maladie reste l'un des problèmes les plus sérieux auquel sont confrontés les services de santés déjà surchargés. En attendant qu'un vaccin efficace fasse son apparition, qu'y a-t-il de disponible actuellement? On a

longtemps suggéré que la planification de la lutte contre le paludisme bénéficie d'un effort multi-sectoriel, mais la façon dont une telle initiative doit être développée reste obscure. Cette communication présente la contribution attendue de l'information de télédétection aux services du contrôle de la malaria, cette information étant déjà utilisée par les gestionnaires d'autres secteurs. Premièrement, la pertinence des observations satellitaires est mise en évidence. Ensuite, le rapport entre les données satellitaires et la malaria est présenté. Finalement, le potentiel d'une telle information pour l'amélioration des stratégies de lutte contre le paludisme est suggéré. En plus, puisque de nombreux chercheurs et travailleurs dans le domaine de la malaria ont peu de connaissance en télédétection, deux annexes les donnent quelques details à ce sujet, ainsi que des informations concernant les satellites utilisés et l'interprétation de leurs données. Nous espérons ainsi que le lecteur pourra juger le bienfait potentiel de cette technologie dans son propre domaine.

Introduction

The past 40 to 50 years have seen major shifts in the perspectives of malaria as a global health problem (Najera, 1989; Bradley, 1992; Najera *et al.*, 1992). The earlier attempts to eradicate the disease during the 1950s and 1960s showed some remarkable successes. While these successes proved to be most sustainable in continental Europe, North America and parts of the Middle East, they were also successful for a considerable time in South America, North Africa, parts of India and Sri Lanka. Changes in land-use, human population and settlement patterns, budgetary allocations, plus the development and spread of insecticide and drug resistance have since occurred widely and resulted in an increase in malaria in many areas. Eradication was scarcely attempted in much of Africa south of the Sahara where the incidence of the disease is the highest in the world. The present situation with antimalarial drugs is one where the safer and cheaper drugs are rapidly becoming ineffective, while the newer and more effective drugs are more toxic, expensive and, in some cases insufficiently tested. The long awaited vaccine remains operationally unavailable. Reassessment of the global malaria situation, in relation to the growing importance of the disease and the need to make health services in developing countries more widely available, has led to a more pragmatic control strategy based on the Primary Health Care system. This type of control strategy for malaria demands recognition of the underlying variability in the epidemiology of the disease and its potential for continual change, as well as the need to make adequate resources available and to adapt malaria control planning to local conditions.

The Global Malaria Control Strategy, adopted in 1992, calls for the identification of new epidemiological tools to reinforce and redirect the current tools used in malaria control (WHO 1993b). It stresses the need for a *stratification* of epidemiological types of malaria transmission, including the identification of a number of main ecological classes, their further characterisation based on local epidemiological evidence and the identification of specific options for control. The Strategy sets out seven dominant epidemiological settings, each of which has distinct ecological characteristics. Each of these sets of ecological characteristics also have an influence on the way the area is settled and the way the communities, which live in them, organise themselves economically and socially. Prospects for future development in these areas are the concern of resource managers from a number of sectors and the information they gather can have a direct relevance to the needs of malaria control planners. For instance, research which determines the suitability of a region for providing particular crop requirements, such as rainfall, temperature and humidity, may provide valuable information about the potential length of the malaria transmission season, vector species distributions and the potential for malaria control options in that area. Similarly, the exploitation of mineral or forest resources requires detailed information on local natural resources which may be relevant to malaria transmission. New developments often bring in non-immune migrant worker/settler populations who may suffer explosive epidemics of malaria as a result. *Monitoring and evaluation* of malaria control activities too can be guided by information from other sectors: again benefiting from information on seasonal patterns in climatic variables, as well as changes in agricultural practices, deforestation or settlement patterns which are taking place. The Global Strategy for Malaria Control also requires the strengthening of information systems, particularly in all areas prone to epidemics. Once the value of such inputs are established, maps can be drawn up of 'typical' spatial and temporal patterns in environmental variables and their associations with socio-economic activities and malaria transmission in a typical year. Such maps can provide a baseline for the epidemiology of the area. Deviations from this typical pattern can then be monitored with respect to increased malaria risk. For example, in semi-arid or upland areas where malaria transmission is highly seasonal or periodic, deviations from the typical pattern *i.e.* earlier onset or greater extension of the rains could give warning of increased transmission. When an area experiences a period of a few years of lower than average rainfall then the basis exists for mapping epidemic potential in readiness for the period when the more typical rainfall patterns return. The use of environmental information in this way, alongside the collection and analysis of health centre data, improves the possibilities for the development of an epidemic *forecasting* or early warning system.

Meteorological data are available to health services in many countries through their national weather centres who measure and record rainfall, temperatures and sometimes humidity from a number of weather stations within their jurisdiction. However, in many areas there are considerable sampling inadequacies in the existing rain gauge network which result in problems of interpolation over large areas and complex terrains. In a number of countries *e.g.* Angola and Sudan, access to meteorological data has become rare or non-existent as a result of conflict and civil unrest.

Data from the weather monitoring satellites are becoming more widely available in an increasing number of developing countries following the development of low-cost satellite receivers and processing systems. These systems have been shown to provide information on a number of environmental variables which have proved useful to planners and resource managers in a number of sectors. This paper presents an outline of the relevance of this type of information to malaria control services and those working in an epidemiological and entomological research capacity in developing countries. Firstly, the overall strengths and characteristics of satellite observations are emphasised. Then, the relevance of satellite data to studies of malaria transmission is presented. This is followed by an outline of their potential for use in improving malaria control strategies. Since many malaria researchers and control workers know little about remote sensing and its techniques the appendices provide a brief introduction to remote sensing, data interpretation and details of some of the more appropriate satellites and their availability. It is hoped that individuals may then be in a better position to assess the value of this technology for their own areas of work.

Remote sensing strengths: a picture is worth a thousand words

Every picture tells a story. A picture taken from a standard camera contains a substantial amount of information. A picture of a landscape may give an overview (at a glance) of a whole area including, for example: an abundant river, a large forest, animals grazing and crops growing. A picture of the same area taken some time later may reveal changes such as less water in the river, a section of the forest has been cleared, more animals and the crops have been harvested. Consequently, pictures allow us to gather a large amount of information in one observation and, additionally, allow us to analyse changes over time in the area. One of the main strengths of meteorological and environmental satellites is that they are able to observe large areas of land, a country or region on a regular basis. In other words, they allow us to systematically and regularly document the state of the land cover on the earth's surface (and therefore its changes) over large and remote areas. Such observation permits the study of spatial and temporal variations at national or regional scale which would otherwise be unrealistic with conventional measurements or survey methods. In this regard, satellite remote sensing offers the only operational system allowing such capabilities of observation within the scope of the limited resources available to many developing countries.

Satellite data can be obtained, archived and analysed long after the satellite transmission. However, for satellite data to be of most use to national services such as sectors responsible for water resources, environment, agriculture, livestock, vegetation, forest and range fire monitoring, it must be directly available at zero or very low cost and be easily combined with local knowledge to generate pertinent information. It is indeed essential that appropriate information is available directly where it can best be used to bring most benefit. This may appear obvious, but there are many examples, in remote sensing, where the information exists but is not available to the end user either because it is protected for various reasons, physically not accessible, or simply too expensive.

The past decade has seen the development and implementation of Local Application of Remote Sensing Techniques (LARST) (Williams and Rosenberg, 1993). One of the principal outputs of this approach has been the development of robust, low-cost satellite data receivers for data from the U.S. National Oceanographic and Atmospheric Administration (NOAA) satellite series and the European Meteosat weather satellites. The second principal output has been the adaptive development of a range of tools specific to real operational needs in the field. These receiving stations are installed in the host country and operated by local, national or regional institutions to provide rapid, direct access to earth observation data within the country; thereby allowing the direct application of observations to improve natural resource monitoring and management. Combined with local information within geographical information systems (GIS), they complement local knowledge to improve resource management. A few examples are: forest fire management in Nicaragua and Indonesia, veterinary applications in Namibia, rangeland vegetation monitoring in countries such as Nicaragua, Namibia, Ethiopia, water temperature monitoring in Indonesia, Malawi and Namibia, locust control in East Africa, and a famine early warning system in Ethiopia. Collected data are available for a wide range of purposes. Once receiving equipment is in place, the data are available from the NOAA and Meteosat[1] satellites at no cost. Costs for the receiving station, data processing and production of outputs may be shared between end-users or may be provided on request as a service to other sectors. NOAA and Meteosat satellite systems are both ideally placed to provide suitable information for national malaria control programmes.

The relevance of satellite data to the ecology of malaria

Malaria is a complex disease and its severity is a function of the interaction between the *Anopheles* mosquito vector - the parasite - the host(s) - and the environment. Vector abundance, the time taken for the parasite to develop in the vector and the survival rate of the vector, when combined with human exposure, determine the risk of malaria infection, the stability of disease transmission, and seasonal patterns of incidence. These biological parameters are directly influenced by meteorological variables such as rainfall, temperature, and humidity/saturation deficit since water is required for *Anopheles* egg laying, a relatively high humidity (>60%) being needed for the survival of adult anophelines. Both vector and parasite development rates are also temperature dependent (Service, 1978). It has been suggested that the monitoring of these meteorological variables may be the most effective procedure for detecting changes in the value of the entomological inoculation rate and thereby predicting changes in malaria transmission dynamics (Onori and Grab, 1980).

Combining information on human factors with environmental information relevant to the biology of the disease may give an overview of the prevailing epidemiological situation. However, measuring environmental variables requires continuous monitoring because it is the combined effect of varying rainfall, temperature, saturation deficit (or relative humidity) as well as vector-host contact over the annual cycle that will determine vector abundance and infection rates.

Satellite data are relevant to studies of malaria since it is possible to use them to map the extent and condition of environmental factors and climatic variables pertinent to malaria transmission dynamics in both space and time (Thomson *et al.*, 1996a). Using low spatial resolution satellite data (such as from NOAA and Meteosat), the scale and extent of observations can cover large remote areas, *e.g.* from African savannah where malaria transmission can range from the highest malaria transmission settings in the world to those of short seasonal or periodic transmission. In addition, high spatial resolution satellite data can be used to provide up-to-date baseline mapping of recent or temporary development activities, such as surface mining, the proliferation of small dams and irrigation schemes, or forest clearance and associated settlements which have changed the environment markedly since conventional paper maps were last drawn up.

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[1] Annual licence fee for Meteosat data may be charged in certain cases, *e.g.* for commercial use.

As indicated in Appendix 1, satellites only measure radiation (reflected light or emitted energy). While information about the state and evolution of the surface may be preferable (*e.g.* vegetation type and amount, productivity and health, air humidity, air temperature, soil moisture), the amount and characteristics of a particular radiation depends on the earth's surface status. Consequently, the analysis and the interpretation of these radiation measurements can help infer information on the state of the earth's surface.

The basic products that are commonly extracted from satellite observations are Vegetation Index, Surface Temperature, and Cloud Temperature. These products are widely used to determine the ecological conditions on the ground.

The significance of these products and their potential use are summarised here (more details can be found in Appendix 1):

- *Vegetation.* Vegetation Indices (VI) are easy and simple formulae. Due to the spectral combination of measurements used in their formulae, VI are sensitive to chlorophyll absorption (chlorophyll activity in green vegetation) and to the structure and condition of leaf (vegetation health). The more "greenness" on the ground and the healthier the vegetation, the higher will be the value of a VI. VI gives an estimation of the presence and amount of vegetation at the surface. In addition, especially when time acquisitions are compared, VI can contribute to inferences on any factor that is going to influence the vegetation amount and status; *e.g.* a decrease in VI value may indicate a decrease in green vegetation density, and therefore in water availability. Conversely low VI values may indicate areas where vegetation is suppressed due to flooding. Thus, VI can contribute not only to knowledge on vegetation status, but also factors such as on land dryness, land use changes and surface moisture. There are several types of VI, but the most widely used is the Normalised Difference Vegetation Index (NDVI).

- *Surface Temperature.* Land Surface Temperature (LST) is computed from a combination of spectral thermal channels. For each single measurement covering an area, LST corresponds to an integration of the temperature at the surface of that area, *e.g.* soil and top of canopy temperatures. Although LST does not directly correspond to ground or air temperature measurements, LST from remote sensing can provide a unique spatial integration that no thermometer can give. Where wet soils or moist vegetation use the solar energy to evaporate or transpire soil water the LST is low, and conversely, when little water is present at the surface or in the air and the solar energy is available for heating the surface, the LST will be high. Consequently, LST can contribute to knowledge of surface temperature, but also other factors such as moisture content and vegetation status. Thus, LST can infer local climate conditions. Similar to the LST, the Sea Surface Temperature (SST) infers surface temperatures of water bodies.

- *Cloud Temperature (rainfall).* The cloud temperature relates in some ways to the rainfall. Cold Cloud Duration (CCD) values made from cloud temperature, represent the length of time during which a cloud top is below a particular, cold threshold temperature. This product has been shown to be very good in providing rainfall estimates. In tropical Africa, rain is largely produced from deep convective storms and the clouds with the coldest top surface produce the heaviest rainfall. By measuring the length of time a cloud is below a critical threshold temperature, it is possible to estimate the actual amount of rainfall using simple regression techniques (Milford and Dugdale, 1990). CCD is frequently accumulated over a 10 day period and is now used routinely by Meteorological Services in Africa to give dekadal rainfall estimates over large areas of land (Tadesse *et al.*, 1995).

While each product is useful in its own right, it may be that a combination of them will contribute most accurately to an estimation of environmental variables. NDVI, LST and CCD have been used together to infer information conditions at the Earth's surface, *e.g.* vegetation status, forest boundaries, vegetation stratification, climate and humidity. These basic products and their interpretation constitute a *contribution* to existing knowledge in the field, allowing them to be used most effectively. Remote sensing data have been analysed extensively and used by a large research community to study the Earth's surface, and have now been used in relation to many sectors such as environment, agriculture, forestry, fisheries, veterinary and health. The following are a few examples with most relevance to malaria control:

- *Pest Control.* NDVI and rainfall information have been used in monitoring desert locust breeding sites (*e.g.* Cherlet and Di Gregorio, 1993; Tappen *et al.*, 1991). Rainfall from cold cloud measurement has been used for grasshopper control (Burt *et al.*, 1995).

- *Veterinary and Medical.* The accumulation of surface temperature from Meteosat into degree-day units has been used in Namibia to determine the time and the areas in which the development of *Oestrus ovis* pupae in the soil reach maturity, and therefore, to warn small stock farmers of the potential infection by this nasal fly (Flasse *et al.*, 1995). Linthicum *et al.*, (1990) have shown that high NDVI values (approximately 0.43 or greater) in Kenya corresponded with the short term flooding of the breeding sites of both *Aedes* spp. and *Culex* spp, vectors of Rift Valley Fever virus. Extensive studies relating AVHRR NDVI to tsetse distribution have been undertaken in order to predict land-use constraints due to cattle trypanosomiasis in Africa (Rogers and Williams, 1994, Rogers *et al.*, 1996). In the latter study, channel 4 surface temperature data from the AVHRR sensor were found to be the most important predictors of tsetse fly distribution in West Africa, when compared with CCD and NDVI. Diurnal temperature difference maps, derived from day and night thermal imagery obtained from the AVHRR sensor, have been used to define the hydrological conditions suitable for schistosomiasis transmission in Egypt (Malone *et al.*, 1997).

- *Vegetation documentation and stratification.* The stratification of vegetation by type, status, and seasonal changes is increasingly being established by remote sensing, and used as a framework to assess variation from the norm (*e.g.* Lambin and Ehrlich, 1995; Sannier *et al.*, 1996). It is being used for Famine Early Warning Systems (FAO, 1990) and for assessments of crop yield/rangeland production, desertification, and human pressure on forests.

- *Evapotranspiration/moisture*. Evapotranspiration and moisture content of biomass are variables that can be observed from remote sensing. Several approaches exist and have been used in various fields, such as fuel moisture in fire risk assessment (Vidal *et al.*, 1994), soil/vegetation moisture in irrigation (Moran *et al.*, 1994), and biomass and crop monitoring (Rosema, 1993; Seguin *et al.*, 1994).

These examples illustrate the use of satellite data to assess information on ecological variables relevant to planning of malaria control. They mainly make use of NOAA and Meteosat data because they are the most available. It is clear, however, that other satellite sources could also be useful to malaria studies. For example:

- While Meteosat covers mainly Africa, other similar satellites, covering the Americas, Russia, Eurasia, Asia, and Australasia, can potentially provide the same type of information (for more details see Appendix 2).

- High resolution data, even if expensive or with restricted access, can be used at time intervals of several years to create precise land use maps that can serve as basis for the interpretation of both low resolution satellite and other socio-economic data (for more details see Appendix 1).

- Other type of data (*e.g.* radar) may provide useful information for malaria studies, but their interpretation is still essentially at a research level. In addition, new satellite platforms may also be relevant in the future.

How can satellite data contribute to malaria control strategies

Whilst a number of ecological studies on larval breeding sites have been undertaken using high resolution satellite imagery (Washino and Wood 1994), few studies of malaria transmission have involved, to date, the use of meteorological satellite data. Nevertheless, the evidence gathered by these limited studies suggests that the techniques are eminently suitable to studies of both vector distribution and abundance and may provide valuable information on the timing and length of the malaria transmission season (Thomson *et al.*, 1996, 1997). Some of the ways that meteorological satellite data may contribute to malaria control are indicated below.

As mentioned earlier, it is important to emphasise that satellite data *contributes* to existing and local knowledge on the malaria situation. Both types of information should be used in a complementary way. On one hand, remote sensing information provides a unique spatial and temporal framework on which local knowledge can be built; whilst, on the other hand, remote sensing information can best be interpreted when placed in its local context. Integration of both sources of information are increasingly achieved within geographical information systems (GIS-a computer software tool) where they are placed, along with other information, in relational databases. GIS, therefore, allows the user to *analyse* and *establish* the interrelationships between the variables within their spatial and temporal context, the results of which can be used in prediction models. A GIS can eventually become a 'unique' tool for data analysis, information management and decision making. Whilst GIS technologies have been in existence for a number of years, they have only recently been exploited by workers in health research and operations (Glass *et al.*, 1993; de Savigny and Wijeyaratne, 1995; Connor *et al.*, 1995; Bertrand and Mock, 1995). They allow health centre records from an existing database to be entered and correlated, for instance, with proximity of villages to river flood margins, forest fringe, and other environmental characteristics. GIS can also be used for planning the optimal siting of health services following the analysis of existing use of centres and their catchment areas. The analysis of environmental data from satellites can be used in a GIS to plan where entomological surveys should be focused such as larval surveys of dry season breeding sites, or vector refugia. Only in this framework can satellite data be used efficiently.

Malaria Stratification. Information on environmental characteristics is required to stratify malaria transmission at the national and local level. Characteristics which may be important include the normal timing and length of the transmission season. To obtain an idea of what might be considered normal, archived data covering a number of years can be used. Archived satellite data from the NOAA-AVHRR sensor now goes back 15 years and can be processed to produce information on the mean, amplitude, and variation of a product such as a VI for a particular period *i.e.* month, season or year. As discussed above, three factors are of paramount importance to determining the timing and length of the transmission season *e.g.* the availability of breeding sites, an environment suitable to adult survival (*i.e.* low saturation deficit) and an ambient temperature which determines the rate of both parasite and vector development. In many areas the onset of the transmission season is determined by the arrival of the rains or the passing of 'winter', *i.e.* higher ambient temperatures. Peak vector abundance may directly follow the period of peak rainfall, such as with *An. gambiae* s.l. when breeding in small pools, and therefore the timing of peak vector abundance may be associated with the status of vegetation following peak rainfall. Vector survival is associated with saturation deficit, the drying power of the air. Saturation deficit is shown to be well correlated with VI's in areas of The Gambia away from the coastal influence, and there is evidence to suggest that this relationship is more general. It is not possible to obtain ambient temperature from current remote sensing products but other temperature-based information may be found to be relevant. Topography will undoubtedly be an important co-variable in any analysis used to develop an environmental stratification but this can now be achieved relatively simply by incorporating a digital elevation model (DEM) into a GIS. At its most basic, an environmental stratification could be developed using the seasonal patterns of NDVI overlaid on a DEM.

In combination with a broad environmental stratification, the key to a strong basis for comparison and forecasting is to build, as a reference base, a historical knowledge of malaria related elements, *i.e.* the building of an institutional memory. This should include, for example:

- where and when the rains usually fall;
- which soil types usually provide persistent breeding sites;
- what is known about the epidemiology of malaria in a particular area;
- where there have been epidemics in previous years;
- with what environmental, social and economic factors were they associated.

Such knowledge can then be analysed and specific relations established for certain times of the year or climatic situations, as well as for specific locations. A large scale initiative is currently underway which uses GIS to map the risk of malaria across the whole of Africa (Le Sueur *et al.*, 1997). This initiative - the MARA/ARMA Project - will incorporate epidemiological and entomological data from all available sources to determine the differing malaria epidemiological situations that exist, and their respective malaria risk. Environmental satellite data will be used in this project to help determine the implications of seasonal weather patterns and environmental variables acting on malaria transmission intensity. The products of the MARA/ARMA collaboration will form an important intervention planning framework which will help decision makers assess the suitability of particular control methods to particular environmental/epidemiological strata.

Monitoring change. It is essential to constantly monitor the situation in terms of disease transmission to be able to assess whether a situation is evolving in one direction or the other. Consequently, the ability to know the actual situation and to compare it with the 'norm' or with historical records naturally leads into *forecasting* of an event, and eventually to *early warning* of possible malaria outbreaks. Continuous acquisition of data on the malaria related elements is desirable. However, it is difficult to gather this type of information regularly and reliably over large regions. Low resolution remote sensing data offer the frequency, consistency and reliability of data acquisition over large areas which is essential to the monitoring of change. Since environmental factors play a key role in malaria transmission, it is inferred that satellite observation could improve malaria monitoring and forecasting. Changes in the immune status of the human population as a result of increases or decreases in malaria transmission will have a 'knock on' effect in subsequent years. Thus several years of drought may result in a population with low levels of malaria immunity. The return of the more normal rainfall patterns may then result in serious epidemics, as happened in many parts of Southern Africa after the period of prolonged drought during the mid 1980s. The extent of flooding in Sudan in 1988, which resulted in an epidemic of malaria cases, was clearly detected using Meteosat thermal imagery. Meteorologists were also able to predict the rise and fall of the floods using satellite imagery depicting water movement down the Nile. However, much remains to be done if these new technologies are to be fully exploited for malaria control as results may vary from place to place depending, for example, on vector species, local ecology and human behaviour (Thomson *et al.*, 1997).

The Famine Early Warning (FEWS) programme of the Food and Agriculture Organization use NOAA-AVHRR data which are collected daily for the region of interest and processed to produce dekadal (10 daily composite) VI images. The VI images are then compared with similar data collected from the same time period in previous years. Deficits in vegetation activity, which may indicate drought, are detected easily and this information is then combined with socio-economic information specific to the region to establish if a real food security problem exists, and if it does, where and to what extent it exists. The methodologies required for malaria monitoring and epidemic forecasting could develop following a similar line to that of FEWS, albeit using a different range of criteria.

Conclusions

The contribution that low cost remote sensing and its satellite derived environmental proxies can make to local environmental monitoring and natural resource management is evident. The combination, within a GIS, of this information along with local epidemiological, entomological and socio-economic data could undoubtedly improve our understanding of the dynamics of malaria transmission and, therefore, our options for control. These technologies could contribute to malaria control planning in the following manner:

- the establishment and regular update of localised environmental stratification which will help identify areas of differing transmission patterns;
- provide a system which allows real-time monitoring and surveillance of the environmental factors influencing transmission;
- provide a component of an early warning system to indicate epidemic potential.

The use of satellite data within a GIS provides an opportunity to integrate up-to-date environmental information, local knowledge and recent historical trends in a way which draws attention to areas of change and its potential problems. The argument for including these powerful tools in an analysis of malaria transmission patterns is a logical extension of their role in the study of other environmental phenomena. However, despite their proven capabilities, their effective application requires more than a mere demonstration of their potential usefulness. Local access to data is increasing as a result of a number of initiatives in which low cost receivers are sited in many malaria endemic countries. This is of critical importance. The development of local expertise in GIS and remote sensing is also essential, as is a clear commitment from institutions to encourage and support their application in a wider range of local sectorial concerns. The *real* value of these techniques for malaria control can only be tested as more local users apply the products to a full range of epidemiological settings in the context of their operational control needs.

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APPENDIX 1: REMOTE SENSING: THE BASICS

Introduction

This section is intended to provide a basic introduction to remote sensing. It attempts to reduce and explain the jargon and put forward the key concepts necessary for gaining a basic understanding of the technology.

What is remote sensing?

Remote sensing is about observing the world around you; 'remote sensing' simply means to 'sense' something from a distance. When you look at a fire or feel the heat coming from it you are remotely sensing. The eyes, for example, are highly specialised sensors that relay data about a scene to our brains. When you take a picture with a camera you use a lens and special paper to reveal the picture, with the bonus that the data is recorded for later reference. Satellite remote sensing uses other instruments to sense light, heat and other types of radiation. The readings made during the observation are recorded as a series of numerical values which represent the picture. This digital picture is usually called an *image*. These images can then be analysed, processed and interpreted.

What can you get from remotely sensed images?

How much detail can be seen in an image?

If you enlarge a section of an image you can see that it is made up from little square blocks called picture elements, or *pixels* for short. Each pixel holds a recorded numerical value corresponding to the amount of radiation received (observed) by the sensor for the ground area covered by the pixel. When an image is displayed, each pixel is given a colour or shade corresponding to its numerical value. The pixels are arranged in rows and columns to build up the image.

The area on the ground covered by one pixel gives the *ground* or *spatial resolution*. The single numerical value of each pixel is the combined reading for the whole area that the pixel covers on the ground. This reading is not representative of a single point within the pixel area but is influenced by all points within the area. Hence objects smaller than one pixel, and those falling on the pixel boundaries, will have an influence on the information that each pixel records, but the size and shape of the object is completely lost within the pixel. Therefore the pixel size sets the limit of the detail that can be seen in an image. This pixel measurement is unlike point data, such as those collected at ground meteorological stations or in most field work, because it truly represents the whole continuous area. The spatially complete nature of the coverage information gathered is a unique aspect of satellite observations and offers opportunities for spatial analysis of data that no local observations can provide.

The spatial resolution of a particular satellite sensor and its images is often quoted so that users can decide whether the data are appropriate. For example, it would be appropriate to choose a sensor such as LANDSAT Thematic Mapper, with a high spatial resolution of 30 m (pixel size of 30 m by 30 m), if you want to map in detail the land use of an area. However, if you want to examine the state of vegetation across an entire country or continental region, it would be more appropriate to choose a sensor such as NOAA-AVHRR (Advanced Very High Resolution Radiometer) with a lower spatial resolution of 1.1 km.

How often can you get images?

Although one image can provide good information, it is often more useful to have a series of images acquired over time. A time series of imagery enables the user to monitor conditions as they change.

Satellites are particularly useful for monitoring the environment as they *catch* (take) images regularly. The frequency with which a satellite is able to catch an image of a particular area of ground is important. The shortest reliable time interval between images is known as the *temporal resolution* of the sensor. This currently varies between 15 minutes and 30 days depending on the characteristics of the satellite's orbit and sensor.

Usually the more detailed the spatial resolution becomes, the longer it will take to cover the whole globe and hence the longer the interval between images. So the choice of appropriate data for a task must depend partially on whether you wish to observe a lot of detail on the ground or whether you wish to observe less detail more frequently. For example, observation of the motion and persistence of rapidly changing clouds requires frequent data such as that from Meteosat PDUS which is available every 30 minutes. The spatial resolution of 5 km is adequate for this task. However, it would be more appropriate to use averaged weekly images, at a spatial resolution of about 1 km, such as available from NOAA-AVHRR data, to observe changes in vegetation status over a country. The mapping of detailed land use in a small region will, however, require high spatial resolution images (*e.g.* 10 meters), but one cover every few years should suffice due to the slower rate of change of land use. In this situation, a sensor such as SPOT HRV or IRS LISS would be appropriate. Such a land use map can serve as a basis for better interpretation of the more frequent lower spatial resolution data.

Different ways of observing

When we look at the world around us our eyes see visible light. This is emitted (radiated) from the Sun and artificial light sources, and then reflected back off other objects. Visible light is a form of electromagnetic radiation. There are many other forms of this radiation, most of which we cannot see. The range of all electromagnetic radiation is called the spectrum. The electromagnetic spectrum is usually divided into spectral bands according to the wavelength of the radiation. These bands of radiation are called gamma rays, X-rays, ultraviolet, visible, near infrared, thermal infrared, microwaves and radio waves. Sensors have been developed to be sensitive to these different bands of radiation.

Observation of an object using different spectral bands is very useful because various perspectives can be obtained. For example, although a doctor can examine a patient using visible light, an X-ray image can provide different, complementary information about the state of the patient's bones. As each object responds differently in different wavelengths, the combination of these responses can also help to describe it. For example, suppose you took a picture with your camera during a night flight over a town. The picture will show many bright points. If you had a thermal infrared band filter for your camera, you would also be able to get a picture of all the heat sources in the town, *i.e.* those which are emitting thermal infrared radiation. Combining the two pictures, you could probably identify those points that are fires or flares, *i.e.* both bright and hot.

Many satellites carry sensors that can sense radiation in more than one band, as well as in different parts of each band. For example, the NOAA-AVHRR has five bands; these are in the visible, near infrared, mid infrared and two thermal infrared bands. This combination is particularly useful for monitoring vegetation and temperature changes.

Image interpretation

Although interpretation of satellite imagery can appear intuitive, their quantitative use is, unfortunately, not simple. Data recorded by a satellite rarely correspond directly to the desired information, because the satellite measures only radiation. This measurement has to be interpreted in terms of what has actually caused the radiation. For example, humid dense forest does not reflect and emit radiation in the same way as dry savannah. Consequently, the required useful information must be *extracted* or *derived* from the satellite measurements based on an understanding of the radiation observations.

Initially, the *raw data* from the satellite is transformed using known information about the sensor characteristics and the radiation band of the data. The application of these standard transformations is usually called *pre-processing*. This takes the digital numbers received and produces data that corresponds more closely to what the satellite actually observed, *i.e.* as geo-referenced calibrated radiation measurements.

These calibrated radiation measurements can then be used to derive more meaningful physical quantities. For example, the majority of the radiation received in the visible and near infrared bands at the sensor has been emitted from the sun and then reflected from the Earth's surfaces and atmosphere. Hence, the amount of received radiation can be compared to the amount of incoming solar radiation at the time the image was taken. This calculation produces the physical quantity, *reflectance,* which is given as a percentage.

In the thermal infrared bands, most of the radiation detected has been emitted by the Earth and the atmosphere. In this case the measured radiation is converted to the physical quantity *brightness temperature*. The brightness temperature depends on both the temperature and the *emissivity* of the emitting object.

Subsequent processing to extract specific information can then be based upon the characteristic responses of Earth surface (and atmosphere) cover types. The basic reflectance and emissivity characteristics of common Earth surface cover types are generally well known and can be measured on the ground. Using these known characteristics, methods can be designed to detect and identify various cover types and extract information about them.

Various standard processing methods are available; techniques range from empirically-based to physical model-based techniques. Each of these techniques has advantages and disadvantages, but such a discussion is beyond the scope of this paper.

The following are the commonly used products derived from satellite data to indicate the ecological conditions on the ground:

- *Vegetation indices (VI)*

  The use of Vegetation Indices is the simplest and most convenient way to monitor vegetation cover. Vegetation indices allow rapid estimations of vegetation cover properties from remotely sensed data. They do this by making use of the characteristic combination of responses of vegetation in the visible and near infrared parts of the electromagnetic spectrum as compared to other cover types.

  The choice of these two bands to observe vegetation is based on knowledge of the biochemical processes taking place in vegetation. Green vegetation grows by assimilating carbon dioxide from the atmosphere into its leaves, a biochemical process known as photosynthesis. This process uses pigments in the leaves, particularly chlorophyll, to absorb solar radiation. This radiative energy is then used to synthesis organic molecules which form the basis of all plant and animal life. However, not all solar radiation is useful for this process. Electromagnetic waves with wavelengths longer than about 0.7 μm do not carry enough energy to drive these biochemical processes. Plant leaves are structured to harness the useful energy; chlorophyll molecules absorb very well in the visible wavelengths, especially in the red and blue wavelengths. However, most of the radiation beyond this threshold of 0.7 μm is not useful to the plant and so it is simply scattered away by the cell walls. Thus, the reflectance of visible light away from plants is low due to chlorophyll absorption but the reflectance of near infrared radiation, *i.e.* that just beyond 0.7 μm, is high due to scattering. This produces a rapid change with a strong spectral gradient around the 0.7 μm threshold which is uniquely characteristic of living green plants. The characteristic shape of this response, *i.e.* the *spectral signature* of vegetation, can be exploited since just two spectral measurements are required, in the visible and the near infrared bands on either side of this threshold, to detect the presence of vegetation.

Simple combinations (vegetation indices) of observations in the visible and near infrared spectral bands have been developed to try to enhance the contrast between living material and other natural targets. The NDVI (Normalised Difference Vegetation Index) is the most widely used vegetation index (Rouse *et al.*, 1974). Its formula is simple and is given by

$$NDVI = (near\ infrared - red)/(near\ infrared + red)$$

where *red* and *near infrared* are the bi-directional reflectance factors in red and near infrared channels respectively.

The NDVI equation produces values in the range -1.0 to 1.0. Typically an NDVI value of 0.0 to 0.2 corresponds to bare soils; higher index values such as 0.2 to 0.6 indicate the presence of green vegetation, while negative values indicate water. NDVI is a poor discriminator of clouds and data should, therefore, be used with an appropriate cloud mask.

Vegetation indices must be interpreted with care. They are empirical formulae and sensitive to variations in reflectance measurements that are not only due to vegetation changes at the surface. For example, the atmosphere, whose effects are always present in space observations, can influence reflectance measurements in complex ways. The reflectance measurements are also dependent on the soil background and on the particular geometry of the illumination and observation points at the time of the image. Time series of NDVI data are often composited to reduce the influence of these effects. This is usually done over periods of approximately ten days (with three *dekads* per month) as this is the normal reporting period for meteorological and agricultural services. Recently, a number of other vegetation indices have been proposed in the literature. These manipulate the mathematical expression in such a way that the resulting index remains sensitive to the presence of vegetation but is less affected by undesirable perturbing factors. Consequently, a vegetation index should be chosen according to the requirements of a particular task.

NOAA-AVHRR is the spaceborne sensor most often used to repetitively monitor vegetation over large regions. Its two first channels observe reflectance in the red and near infrared bands on either side of the 0.7 μm threshold mentioned above. NDVI is calculated as a standard product from AVHRR data. A 15-year archive of NOAA-AVHRR derived NDVI data is now available. These allow the compilation of long time series of vegetation status over large regions. These are particularly important as changes in the vegetation status, through the year, and from year to year, can be examined. These time series form a good basis for building predictive models.

Further information on vegetation indices can be found in Leprieur *et al.*,(1996); Verstraete and Flasse, (1996); Baret and Guyot, (1991); and Lambin and Ehrlich (1995).

- *Land Surface Temperature (LST)*

All surfaces (objects) emit radiation as a function of their temperature, hence it is possible to estimate land surface temperature remotely. Some satellite sensors include channels that are sensitive to such thermally emitted radiation and their data can therefore be used to measure the amount of radiation emitted by a surface. A sensor is sensitive to a different temperature range according to the wavelength of the channel used. There are various algorithms available to compute the temperature of the sea, land surface and cloud. This section will discuss land surface temperature derivation.

There are two main problems involved in converting the measurements of radiance emissions from the ground into surface temperatures. The first is the atmosphere, which absorbs and emits radiation of its own. The second is that land surfaces are not perfect emitters of radiation *i.e.* they are not theoretical blackbodies. The radiation emitted by a real surface is less than the radiance emitted by a blackbody at the same temperature. The proportion of radiation emitted by a particular surface, compared to the radiation emitted by a blackbody at the same temperature, is defined as the *emissivity* of the surface. The emissivity can range between 0 and 1. Some examples are: water, at 0.99; vegetation, which varies around 0.98-0.99; and soil, which can be as low as 0.95. When no account is taken of the emissivity of the surface and the influence of the atmosphere, radiation measurements in thermal infrared bands are transformed into *brightness temperatures*. Another source of errors in the derivation of LST can occur if the sensor observes the ground across a large range of viewing angles.

Several methods to measure land surface temperatures have been developed in an attempt to minimise the sources of error given above. These include single channel, multi-angle (*i.e.* observations with different path lengths through the atmosphere), and split-window methods. The split-window methods are based on knowledge of different atmospheric transmittance characteristics in two adjacent thermal infrared bands *i.e.* at around 11-12 μm wavelengths. Split-window methods are numerous and by far the most widely used because sensors, such as the NOAA-AVHRR, have been designed with appropriate bands for temperature derivation.

The final absolute accuracy depends mainly on the type of surface cover. For vegetation with a closed canopy, the error can be less than 2° K, while for bare soil it may be substantially larger. The level of acceptable error depends on the aim of the study. For example, highly accurate temperature estimates will be critical for the estimation of the surface energy balance or regional evapotranspiration rates. For other applications, such as the analysis of the temporal pattern of temperature, relative accuracy between observations is the main criterion. Spatially consistent LST measurements, such as those derived from NOAA-AVHRR data, are difficult to obtain in other ways and their accuracy compares favourably to LST interpolated from local point measurements, when available.

Further information on surface temperature can be found, for example, in Vogt (1995) and Prata (1994).

- *Cloud temperature - Cold Cloud Duration (CCD)*

Cold Cloud Duration images can be used to give a good first impression of the relative distribution of rainfall. Rainfall estimates can then be produced where calibration data are available. The methodology works by detecting cold cloud in thermal infrared data over a series of sequential images. These detections are then converted into a rainfall estimate using a simple linear regression equation. Cloud is a rapidly changing phenomenon so this methodology requires thermal infrared images to be available as frequently as hourly or half-hourly. Hence imagery from geostationary satellites is appropriate for producing CCDs (see Appendix 2).

The cold cloud technique is valid for monitoring a particular type of rain, that from convective clouds. Convective clouds are formed when small warm bodies of air, called thermals, rise up to produce clouds. These clouds begin small and round and, as they grow, become colder. They cool down as they rise and thicken into storm clouds. It is possible to estimate the amount of rainfall produced by these clouds because more rain will fall as the cloud becomes colder and thicker. This simple linear relationship between the cloud temperature and the amount of rain produced is used to estimate the quantity of rainfall.

The cold cloud method does not work so well for estimating rainfall from other types of cloud, such as layer (stratiform) clouds which are formed either when air rises consistently or by night time cooling, and cloud associated with weather fronts. In these cases, more complex conditions exist and the linear relationship of cold cloud duration to rainfall breaks down.

Hence the CCD method of rainfall estimation works well in the tropics where most of the cloud is convective, but less well in mid and high latitudes where other types of cloud are dominant.

Cold cloud is detected by passing a temperature threshold over each thermal infrared image. For each pixel colder than the threshold, the incidence of cold cloud is recorded and a Cold Cloud Duration (CCD) image is obtained. As each new thermal infrared image comes in, each new set of cold cloud detections is added to the CCD image. This image shows, for each pixel, the total number of images where cold cloud is detected. This is later converted into hours and shows the relative persistence of cold cloud for each area.

CCD images are usually accumulated over a dekadal period but daily CCD images have been used to produce catchment statistics for hydrological applications.

CCD images can be converted into rainfall estimates where calibration data are available. Rain gauge data for the area of interest should be compared to the cold cloud durations at a range of different temperatures. As a result, the best temperature threshold for detecting cold cloud and the coefficients of the linear equation to convert cold cloud to rainfall estimates can be determined for each part of the region of interest. These calibration parameters can then be used to produce rainfall estimations.

Further information on CCD can found in Bonifacio (1991).

APPENDIX 2 SOME OF THE SATELLITES

1. The Geostationary Meteorological Satellite Network

Geostationary satellites are so-called because they appear to be stationary in the sky from any point on the ground. Hence, they can only observe the part of the Earth they face. However, they can usually scan the whole of the Earth disk below them frequently, *e.g.* about every 15-30 minutes. The geostationary satellites in the meteorological network around the Earth are similar in their sensor characteristics, imaging the ground in visible, near infrared and thermal infrared bands. Data from these satellites are usually collected directly from the satellite. Subsampled and overview images are often available on the Internet.

The properties of the geostationary satellites make them very suitable for meteorological applications. The rapid repeat and broad spatial scale, with thermal data available, make them ideal for monitoring weather systems on a country to continental scale.

The satellites in this network are:

Meteosat

Coverage:	Europe, Africa, the Atlantic Ocean
Maintained by:	Europe/EUMETSAT [some data are encrypted, licences to decrypt are available, the type and cost depends on the usage of the data and may be free for non-commercial users]
Main Sensor:	High Resolution Radiometer via PDUS (Primary Data Users System)
• Spatial resolution	5 km (at optimum)
• Temporal resolution	30 minutes (with full decryption rights)
• Bands available	3 channels: visible, thermal infrared, water vapour

GOES (Geostationary Operational Environmental Satellite)

Coverage:	the Americas (with 2 satellites)
Maintained by:	USA/NOAA (National Oceanic and Atmospheric Administration)
Main Sensor:	Imaging Radiometer
• Spatial resolution	1 km (visible channel), 4 km (infrared channels)
• Temporal resolution	30 minutes
• Bands available	5 channels: 1 visible, 4 infrared

GMS (Geostationary Meteorological Satellite)

Coverage:	Japan, Australasia, the Pacific Ocean
Maintained by:	Japan/NASDA (National Space Development Agency)
Main Sensor:	VISSR (Visible and Infrared Spin Scan Radiometer)
• Spatial resolution	1.25 km (visible channel), 5 km (infrared channel)
• Temporal resolution	30 minutes
• Bands available	2 channels: 1 visible, 1 thermal infrared

INSAT

Coverage:	India, Asia, the Indian Ocean
Maintained by:	India
Main sensor:	VHRR (Very High Resolution Radiometer)
• Spatial resolution	2 km (visible channel), 8 km (thermal infrared channel)
• Temporal resolution	30 minutes
• Bands available	2 channels: 1 visible, 1 thermal infrared

GOMS (Geostationary Operational Meteorological Satellite)

Coverage:	Russia, Central Asia, the Indian Ocean
Maintained by:	NPO Planeta (Russian Space Research Institute)
Main sensor:	STR (Scanning TV Radiometer)
• Spatial resolution	1.5 km (visible channel), 6.5-8 km (infrared channel)
• Temporal resolution	30 minutes
• Bands available	2 channels: 1 visible, 1 thermal infrared

2. The Polar Orbiting Satellites

Polar orbiting satellites fly around the Earth on orbital tracks similar to lines of longitude, their orbital tracks on each subsequent orbit cross over the poles. They are able to image the whole of the surface of the Earth as it turns beneath their orbits. They are much closer to the ground than geostationary satellites so can have higher spatial resolutions. However, they can only observe the part of the Earth immediately below their position and so can not obtain repeat images so frequently. The sensor characteristics of these satellites vary considerably.

Only visible and infrared band sensors are considered here, radar data are now available but standard applications are currently less well developed (other band sensors are mostly not applicable to Earth observation).

Some of the commonly used satellites for Earth observation are described below.

Low Resolution Imagery

NOAA (National Oceanic and Atmospheric Administration) series

Main Sensor:	**AVHRR** (Advanced Very High Resolution Radiometer)
• Spatial resolution	1.1 km (optimum, *i.e.* at the sub-satellite point)
• Temporal resolution	12 hours (6 hours with 2 complementary satellites in orbit)
• Bands available	5 channels: visible, near infrared, mid infrared and two thermal infrared
Main Usage:	Mainly used for meteorology and wide scale environmental monitoring. A useful attribute of the AVHRR is that images can be collected at twelve hourly intervals *e.g.* in the early afternoon and at night. This is particularly useful for monitoring change as daily imagery can be collected in

which the diurnal conditions can be assumed to be relatively constant.

Data availability:	The raw data are available in various forms. The full 1.1 km data can be collected freely and directly by anyone who has or builds a receiver sited beneath the satellite pass. Alternatively, it can be recorded on board by special request. Sub sampled data are also recorded (Global Area Coverage [GAC]; spatial resolution 4 km). GAC data are downloaded at the main NOAA reception station in the US and is then available to users at nominal cost (Kidwell, 1991; Belward *et al.*, 1992). A 15 year archive of GAC data is available.

High Resolution

Data can usually be bought from the maintainers of the satellite and often can be ordered from other image suppliers. Image catalogues, many including browse imagery, are sometimes available on the Internet. Many suppliers of imagery have special discount rates for older data and bulk orders. A direct reception capability is being developed for some of these satellites.

LANDSAT

Maintained by:	NOAA (National Oceanic and Atmospheric Administration, USA)
Main Sensor:	**TM** (Thematic Mapper)
• Spatial resolution	30 m, except thermal infrared band - 120m
• Temporal resolution	16 days
• Bands available	7 bands: 3 visible, 1 near infrared, 2 mid infrared, 1 thermal infrared
Main Usage:	Mainly used for land use classification and monitoring

SPOT (Satellite Pour L'Observation de la Terre)

Maintained by:	CNES (Centre National D'Etudes Spatiales, France)
Main Sensor:	**HRV** (High Resolution Visible)
• Panchromatic mode:	
* Spatial resolution	10 m
* Bands available	1 channel across the visible and near infrared bands
• Multispectral mode:	
* Spatial resolution	20 m
* Bands available	3 channels in green, red and near infrared bands
• Temporal resolution	26 days (possible revisit on special request 3.7 days)
Main Usage:	Mainly used for mapping and geological, agricultural surveys

IRS (Indian Remote Sensing Satellite)

Maintained by:	ISRO (Indian Space Research Organisation)
Main Sensor:	**LISS-III** (Linear Imaging Self-Scanning Sensor)
• Spatial resolution	23.5 m
• Temporal resolution	24 days
• Bands available	4 channels: 3 visible, 1 near infrared
Main Usage:	Mainly used for land and water resources management

ADEOS (Advanced Earth Observing Satellite)

Maintained by:	NASDA (National Space Development Agency, Japan)
Main Sensor:	**AVNIR** (Advanced Visible and Near-Infrared Radiometer
• Spatial resolution	16 m (8 m for panchromatic channel)
• Temporal resolution	variable (sensor can be tilted on user request)
• Bands available	5 channels: 3 visible and 1 near infrared, 1 panchromatic
Main Usage:	land and coastal observations, reflectance measurements (on board calibration)

JERS (Japanese Earth Resources Satellite)

Maintained by:	NASDA (National Space Development Agency, Japan)
Main Sensor:	**OPS** (Optical Sensor)
• Spatial resolution	18.3 x 24.2 m
• Temporal resolution	44 days
• Bands available	8 channels: 4 visible and near infrared (including one stereoscopic), 4 short wave infrared
Main Usage:	Mainly used for land usage, environment, geology, etc.

RESURS

Maintained by:	NPO Planeta (Russian Space Research Institute)
Sensor:	**MSU-E** (High-Resolution Multispectral Scanner with Electronic Scanning)
• Spatial resolution	27 m
• Temporal resolution	18 days
• Bands available	3 channels: 2 visible, 1 near infrared
Sensor:	**MSU-SK** (Multispectral Scanner of moderate resolution with conical Scanning)
• Spatial resolution	170 m (visible), 600 m (infrared)
• Temporal resolution	3-5 days
• Bands available	5 channels: 2 visible, 2 near infrared, 1 thermal infrared
Main Usage:	Mainly used for crop state, hydrological, fire and pollution monitoring.

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