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Smoke Plume Definition by Satellite Remote Sensing

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ABSTRACT

Landsat digital data are employed on the CCRS image analysis system to define the maximum extent and lateral distribution of a smoke plume. Two quantitative methods are detailed, in which either a single satellite image or two images of differing dates are used. Detailed instructions are given for the procedures to be followed, and accompanying figures provide an illustrated example.

RESUME

Le C.C.T. utilise des données numériques Landsat dans son système d'analyse des images pour définir l'étendue et la distribution latérale maximales d'une colonne de fumée. Le présent résumé explique deux méthodes quantitatives, l'une utilisant une image simple prise par satellite et l'autre, deux images prises à différentes dates. Les méthodes à suivre sont décrites en détail et les figures présentent un example illustré.

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1. INTRODUCTION

Air pollution is a significant, and rapidly increasing, environmental hazard. The recent classification of acid rain as one of the most serious current environmental problems illustrates the importance of air pollution. To assess its wide ranging and multifaceted effects, a general method of air pollution monitoring must be made available which provides accurate information over large areas.

The purpose of this manual is to describe a technique developed at the Canada Centre for Remote Sensing (CCRS) for monitoring the dispersion of visible smoke plumes through the use of Landsat digital data. The visibility of the plume is essential as this technique is not capable of monitoring non-visible pollution plumes. Although the spectral resolution* of the Landsat Multispectral Scanner (MSS) is not sufficient to permit a constituent analysis of the plume, it does provide synoptic coverage of the area from which ground testing sites can be chosen if desired.

2. BACKGROUND

2.1 THE PROBLEM ADDRESSED

Smoke plume monitoring is important for a variety of reasons. Airborne particulates contained within the smoke plumes are known to adversely affect property, human health, and the microclimate, as well as to have serious environmental effects. Thus, individuals with very diverse interests are concerned with the extent of air pollution. Likewise, knowledge of the extent of pollution plumes can be used for the mapping, monitoring, and control of air pollution in response to the moral and legislative requirements for pollution control.

The principal requirement for an effective smoke plume monitoring technique is the ability to determine the location, extent, composition, height, source, and the diffusion characteristics of smoke plumes of both artificial and natural origins. As well, the method should yield objective and quantitative results. Landsat Multispectral Scanner (MSS) data are capable of providing all of this information. Since data acquisition for smoke plume monitoring is an ongoing activity, the method of acquisition must minimize the costs incurred through repetitive sampling over extended periods. Landsat, due to its comparatively low image acquisition costs and its repetitive orbit pattern, is ideal for this purpose. Furthermore, computer analyses of digital satellite images are able to provide objective evaluations which are repeatable and for which the measurement error can be defined. For these reasons, the technique to be presented in this manual is one which makes use of digital Landsat data and computer-assisted techniques for smoke plume identification.

2.2 BENEFITS ACHIEVED THROUGH THE USE OF REMOTE SENSING

The benefits of using remotely sensed data for smoke plume examination can be grouped into two primary categories. The first of these is concerned primarily with the efficiency and the cost. To achieve a given degree of accuracy, remote sensing techniques are considerably faster and cheaper than other non-remote sensing methods. The second group of benefits is the flexibility of the data collected, both in terms of multiple uses of the same satellite imagery, and the information which could be acquired repeatedly for the same area through the use of multitemporal images.

Additionally, the spatial extent of the detail which can be derived from the Landsat data either alone (such as the lateral and transverse extent of the plume) or in combination with ground sampling (e.g. constituent analysis), is considerably superior to that derived solely from ground surveys.

3. TECHNIQUES

3.1 PRINCIPLES

Remotely sensed data used in this technique are obtained from the Landsat satellites operated by the (U.S.) National Aeronautics and Space Administration (NASA). They orbit the earth in a circular, sun synchronous, near-polar orbit at an altitude of approximately 920 km (570 mi.). This results in the same local time of overpass for repetitive coverage of any one ground point. By orbiting the earth once every 103 minutes, Landsat completes 14 orbits of the earth per day thereby providing complete coverage of the earth every 18 days (General Electric Co., 1976). Ground coverage is provided every nine days when two Landsat satellites are in orbit – covering the same orbital path, nine days behind each other. Landsat receives data using a multispectral scanner which records reflected light in four spectral bands (band 4: 0.5–0.6 micrometres – green; band 5: 0.6–0.7 micrometres – red; band 6: 0.7–0.8 micrometres – infrared; and band 7: 0.8–1.1 micrometres – infrared).

A smoke plume can be identified on a Landsat image because it reflects more radiation at the shorter wavelengths (MSS bands 4 and 5) than do typical land or water features. Also the visual recognition is aided by the typical elongated shape and smooth texture of the smoke plume. Furthermore, it has been noted that longer wavelength radiation (MSS 7) penetrates all but the densest (most opaque) plumes.

*The definitions of all underlined words will be found in the glossary.

The spectral characteristics of the atmosphere are altered by the components of the smoke plume. The solid and gaseous constituents of a smoke plume affect the radiation incident upon the smoke plume by scattering and absorption such that, as the wavelength (λ) of the radiation decreases, approaching the molecular diameter (Dm) of the attenuating medium, the magnitude of the scattering (S) of that radiation increases. The amount of scattering becomes significant when $\lambda < 0.1$ Dm.

The above relationship has been attributed to two principal types of radiation scattering: Rayleigh scattering and Mie scattering. Rayleigh scattering takes place when Dm is much less than the wavelength of the incident radiation and is proportional to λ^{-4}. Mie scattering is more significant in smoke plumes and occurs if the wavelength approximates the particle diameter (Dm $\approx \lambda$) and the amount of scattering is proportional to $\lambda^{-\alpha}$ ($2 < \alpha < 0$). Thus it can be seen that as the wavelength approaches the molecular diameter, the amount of scattering increases rapidly. This explains the typical reflectance characteristics of the smoke plume as observed on the four MSS bands. MSS band 4 radiation (the shortest wavelength) is scattered and reflected the most by the particulate matter in the smoke plume. The longer wavelengths (specifically band 7) can penetrate the plume better due to the smaller amount of scattering. This wavelength-selective reflection/penetration permits multispectral identification of a smoke plume with greater reliability than would single-band image interpretation. Additionally, it has been found that by using multispectral analysis, smoke plumes may be identified at relatively low particulate concentrations.

Data received by the multispectral scanner are digitized and transmitted to a ground receiving station (in Canada, these are at Prince Albert, Saskatchewan and Shoe Cove, Newfoundland) and recorded on magnetic tape. Landsat data are then processed and transformed into general user formats. The formats available include visual images (paper prints and transparencies) and digital data in the form of computer compatible tapes (CCT's). It is this latter format which is required for smoke plume monitoring. For either format, a single image covers over 34 000 square kilometers.

Analysis of these tapes may be performed on an interactive digital analysis system such as the CCRS Image Analysis System (CIAS). During the analysis, numerous digital analysis techniques must be used in order to evaluate the smoke plume on the image. These techniques (contrast stretching, intensity slicing and spatial filtering) involve digital manipulation of the intensity values in the four spectral bands. Each of the techniques employed will be discussed in Section 3.2.

3.2 METHODOLOGY

A smoke plume monitoring project is carried out in three specific phases: the pre-acquisition; the data acquisition; and the data analysis phase.

3.2.1 Pre-Acquisition Phase

The preparatory phase of the project involves the determination of the geographical boundaries of the area to be studied and the time at which the imagery should be acquired to provide the greatest contrast between the subject of interest and the background – unless specific dates are of interest. Although the season is not the critical factor in the choice of image, summer imagery is preferred in order to maximize contrast between the smoke plume and the ground surface. If such imagery is not available, any season may be used with the exception of winter imagery which would present the combined problems of high spectral reflectance from the snow and a compacted signal range due to the low sun angle. It is worth noting that winter imagery opens the possibility of analyzing the smoke plume shadow on a snow surface. However, this possibility has not been investigated as yet.

When the above factors have been established, the actual Landsat images covering the region under study must be found. This information may be obtained from the User Assistance and Marketing Unit (UAMU)[1] of CCRS. Additionally, the UAMU will be able to provide information concerning the purchase of Landsat photographic images and CCT's.

If it is desirable to use the digital image analysis equipment at CCRS, advance arrangements must be made through the Applications Division of CCRS.

3.2.2 Data Acquisition

To locate the imagery which contains the smoke plume, Landsat microfiche may be examined. These fiche contain MSS band 6 images for all Landsat scenes and are catalogued by numerous agencies across Canada, including CCRS. Available photographs may be found through a computer search by indicating the area of interest (latitude and longitude), the maximum acceptable cloud cover and the quality of image desired by the user. Either the fiche or photographic images may be inspected visually to determine the amount and location of cloud cover, however, the photographs will show smoke plumes better than the lower quality fiche.

1. User Assistance and Marketing Unit, Canada Centre for Remote Sensing, 717 Belfast Road, Ottawa, Ontario.

If multitemporal analysis is desired, images of the same scene at different dates will be required. The images should be of the same season (to eliminate problems of differing reflectances caused by seasonal variations in vegetation), and only one of the images should contain the smoke plume. This latter condition is a function of the analysis method being used as will be discussed in Section 3.2.3.

UAMU can assist the user in ordering the necessary Landsat photos and CCT's. It is recommended that geometrically corrected DICS (Digital Image Correction System) products (Butlin et al, 1978) be ordered, and that radiometric calibration option "R3L" (Ahern and Murphy, 1978) be requested. If contemporary images are to be acquired, the collection of ground data would permit absolute values of plume density to be assigned to the relative rankings obtained by this method. Acquiring accurate and timely ground data for smoke plume concentrations is very difficult, however. Readings must be obtained at the exact time of the satellite overpass at locations which can easily be identified on the satellite image. This is logistically difficult.

3.2.3 Data Analysis

Analysis using digital tapes can be accomplished by means of the CIAS or an equivalent digital analysis system. A sub-scene of 512 pixels by 512 lines is displayed on a colour video screen. Each sub-scene covers approximately 1200 square kilometers. Each pixel (or "picture element") is 57 x 79 metres in size (DICS pixels are 50 x 50 metres). This area represents the Landsat MSS minimum resolution element, a physical limitation which must be accepted by the Landsat user; those desiring better spatial resolution will not find this data or method adequate.

Two types of analysis may be performed in the examination of smoke plume imagery, single image or multitemporal. Although the former may provide sufficiently accurate results, the results of the latter method are better (although more expensive). Hence, multitemporal analysis is recommended if financially feasible.

3.2.3.1 Single Image Analysis

1. Image enhancement of the smoke plume is the first step in single image analysis. The visual delineation of the smoke plume is facilitated through a contrast stretch of the radiometric range. That is, the range of intensity values of a given image, which is frequently quite narrow, is expanded to encompass the entire range of the available brightness levels (256 discrete values in all). To do this, a computer algorithm identifies the smallest and largest intensity values available in a scene and transforms them into the minimum (0) and maximum (255) values, the intermediate values being assigned proportionally. As a result, the brightness contrast between any two similar values in the original image will be increased in the enhanced image. In this manner, features which due to their subtle radiometric differences were not visually distinct, will become visually identifiable on the enhanced image.

2. Secondly, test sites must be established at increasing distances from the plume source. These sites are not restricted in terms of surface cover but must encompass areas both inside and outside the plume (Figure 1).

3. Subsequently, areas with similar surface characteristics must be located, both inside and outside the plume. In this way, the differences recorded over these areas in the band most susceptible to attenuation by the smoke plume (MSS band 4) will provide evidence for the presence of a smoke plume. To establish the nature of the surface cover, band 7 (that MSS band which is the least susceptible to attenuation and hence is the most likely to provide accurate surface reflectance values) is examined on the CIAS and an intensity histogram of band 7 reflectances is displayed. Such a histogram describes the area (or number of pixels) associated with each level of intensity in a given image for band 7. A narrow slice of the histogram, at a fairly high intensity level is isolated and the pixels corresponding to these intensity levels are identified. These pixels represent areas of similar reflectance and hence, similar surface cover, irrespective of the presence of the smoke plume. If there are insufficient pixels inside and/or outside the plume, the histogram slice can be shifted in location slightly, or if necessary, expanded in width.

4. Having located similar surface areas both inside and outside the plume as well as test sites straddling the plume, the two are examined together. Those

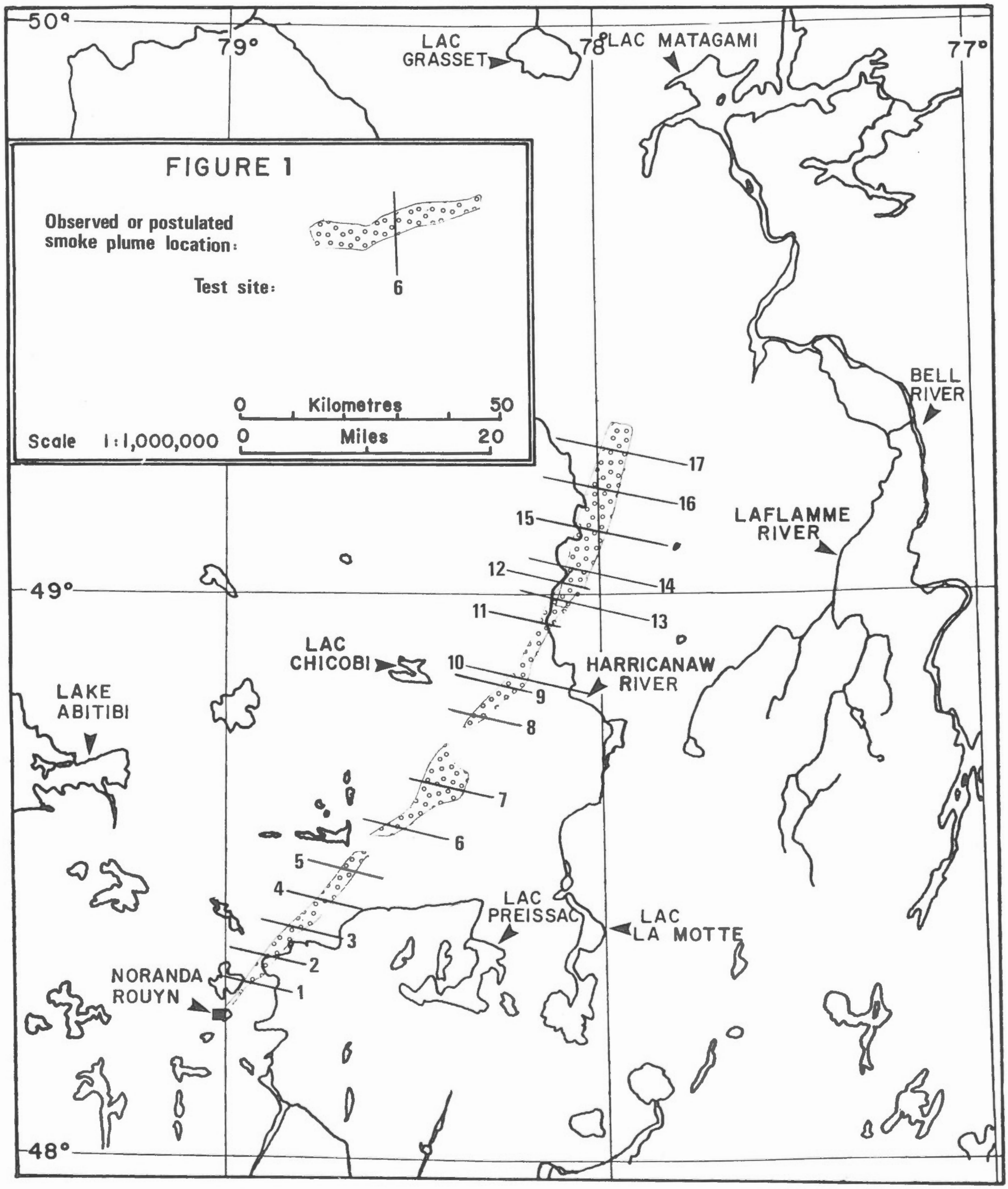
FIGURE 1
Observed or postulated smoke plume location:
Test site:
6
0 Kilometres 50
Scale 1:1,000,000
0 Miles 20
50°
49°
48°
79°
78°
77°
LAC GRASSET
LAC MATAGAMI
BELL RIVER
LAFLAMME RIVER
HARRICANAW RIVER
LAC CHICOBI
LAKE ABITIBI
NORANDA ROUYN
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areas which are defined by the overlap of the test sites with those areas established by the band 7 histogram slice are called "modified test sites" or "sub-sites". It is these sub-sites which will be examined for the remainder of the study.

5. Within these sub-sites differences in band 4 reflectance will be sought so as to verify the existence of a smoke plume. To this end, band 4 reflective intensities are measured separately for the portion of each subsite falling inside and outside the plume. This will result in the mean intensity values derived from the intensity values of several tens of pixels for each sub-site. The mean value for sub-sites outside of the plume is designated N4, and from inside the plume as P4.

6. The ratio of these two numbers N4/P4 (termed the within-image ratio, or WIR) is calculated and plotted for each sub-site (Figure 2). This ratio indicates the likelihood of a smoke plume being present. As the WIR values decrease below 1.0 (which is to say that the reflectivity within the sub-site is higher inside the plume than outside), the probability of the existence of a plume increases. A further indication that the pollution plume is responsible for the change in reflectivity can be found if the graphed values are consistently below the "neutral" or 1.0 line.

   One means of testing the homogeneity of the targets within the sub-sites is to calculate the WIR values for band 7. If these values are clustered closely around the 1.0 line, it can be assumed that the targets inside and outside the plume for one sub-site are very similar and that variations within the target do not account for the variations observed in band 4. The basic assumption of a strong correlation between the intensity values in bands 4 and 7 is not always well grounded and consequently the choice of sub-sites using this method is not always ideal.

7. The graphic output produced using this technique includes graphs of the type illustrated in Figure 2 and prints of the contrast stretched image. An image, in which the plume has been manually delineated, along with the WIR values for the test sites, will show how far from its source the plume can be identified with confidence. This method is thus an accurate means of validating and lending support to a visual hypothesis.

3.2.3.2 Multitemporal Analysis

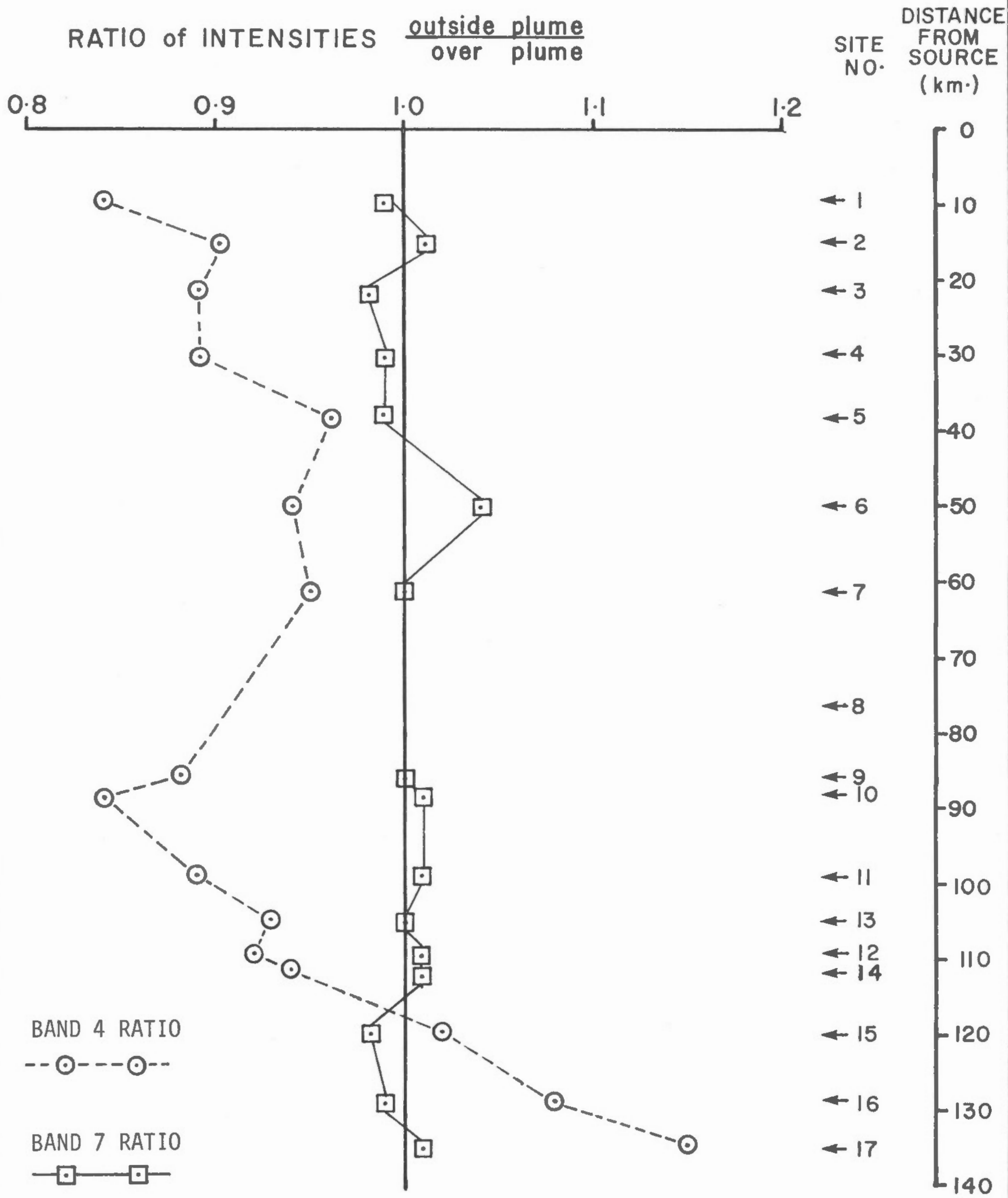
Although somewhat more expensive, this technique is preferable to single image analysis. This type of analysis does not require the troublesome assumption of the previous method concerning the correlation between the intensity values of bands 4 and 7 and therefore tends to be more accurate. Two images of the same area but different dates, one with and one without a smoke plume, are analyzed in a comparative mode to detect differences between them.

1. In order to analyze the images, they must first be made spatially comparable. If DICS tapes are not being used, the images must be geometrically <u>registered</u> on the CIAS so they overlap each other geographically with precision. Additionally, the radiometric range of the reference (non-plume) image should be adjusted so that the intensity histograms of the two images are similar (Figures 3 and 4). This adjustment requires the creation of a band 4 histogram for each image (excluding the area covered by the smoke plume). From these histograms, the minimum and maximum intensity values, the mean and the standard deviation can be determined. Band 4 of the object image is then altered by a look-up-table (radiometric channel correction program) using these parameters as break points, in order to make the histograms (and the associated images) equivalent. This process may be necessary due to differences in atmospheric conditions or sun angles between the two dates, which would alter the reflected intensities.

2. With two comparable images, the changes in reflectivity over time (and hence the changes caused by the pollution plume) can be determined by creating a <u>ratioed image</u>. This is done by dividing the intensity value for each pixel in one band 4 image (which contains the plume) by the value for the corresponding pixel in the other band 4 image (without a plume). The result of this is an image wherein mid-gray shades represent locations of unchanged reflectivity, while dark and bright areas indicate temporal changes in reflectance (Figure 5). The increased reflectance in band 4 caused by the smoke plume (the smoke plume

FIGURE 2

SMOKE PLUME DEFINITION



being analogous to the right tail of the histogram in Figure 5) is thus illustrated on a ratioed image as being brighter than mid-gray. This explains why the two images cannot both contain the plume: if two plumes were to be geographically coincident they would represent an area of unchanged reflectivity and hence would be useless for this analysis.

3. In order to increase the visibility of the smoke plume, the ratioed image can be digitally filtered to reduce high spatial frequencies and emphasize low spatial frequencies. This is known as low-pass filtering. Areas with a low spatial frequency (e.g. a smoke plume) are those areas with a small number of brightness changes across the image and hence are areas of fairly uniform brightness. Likewise, areas with a high spatial frequency are those areas with frequent changes in gray levels (e.g. forests, towns, etc.). The spatial filtering is, in effect, removing the interference by those surface features with sharp edges (as well as residual image misregistration "speckle") by slightly defocussing the image (Figure 6). Also included in the spatial filtering program is the capacity to adjust the contrast and the brightness of the image. This is known as gain and offset application. Figure 6 has been treated in this manner.

4. The extent of a smoke plume may be delineated despite its lack of a finite boundary. This is done by choosing a threshold on the histogram of the ratioed image at a level which is one standard deviation greater than the mean value of the ratioed scene (Figure 6). The smoke plume corresponds to those intensities which are above that value. However, this value is a function of the relative areal coverage of the smoke plume as well as the type of ground cover in the sub-scene. For scenes with significantly different plume or ground cover conditions, the investigator should try to place the threshold at the lowest level of the histogram (of the ratioed image), above which the corresponding area is only the body of the plume, but not any portion of the ground cover pattern.

5. An optional step at this point is the application of the contrast stretching procedure to the ratioed image. Although this step is not essential for image interpretation, it does permit greater visual distinction between the plume and non-plume intensities (Figure 7).

6. Further processing on the CIAS may be employed to visually enhance the diffusion characteristics of the plume. Of primary interest is the capacity of the CIAS to display the different radiometric intensities in a variety of ways. The range of intensities within the plume itself may be displayed either as a continuum, or "sliced" into different levels (Figure 8). In the latter case, up to eight colour coded slices may be displayed, their limits either being defined by the analyst or chosen automatically by the computer. In this manner, the severity of the pollution problem and areas of maximum pollution concentration can be illustrated and specific values can be applied to it for calibration purposes if available.

7. A final modification which might prove to be useful is the removal of features which are ambiguous and hinder the analysis process. If for no other reason, these features should be removed to improve the visual image appearance. Such features as roads and lakes whose reflectivity has changed between the two imaging dates and which can easily be identified visually as being non-plume are removed from the image (Figure 8).

8. When all manipulation of the data has been completed, the final results can be printed out in hard copy format, either in colour or black and white, in paper or photographic form, with optional annotation and map grids overlaid.

The success of this technique was described in an experimental study (Alföldi, 1977). Using this method a smoke plume could be traced 30 km further than was possible through simple visual interpretation. It should be noted, however, that individual visual analysis is highly subjective. Many factors influence the degree of accuracy of the plume mapping, including: the quality of the image, the surface brightness, the sun angle (a function of the season), the nature of the surface, the opacity of the plume (a function of its constituent materials and density), and the geometry of the plume.

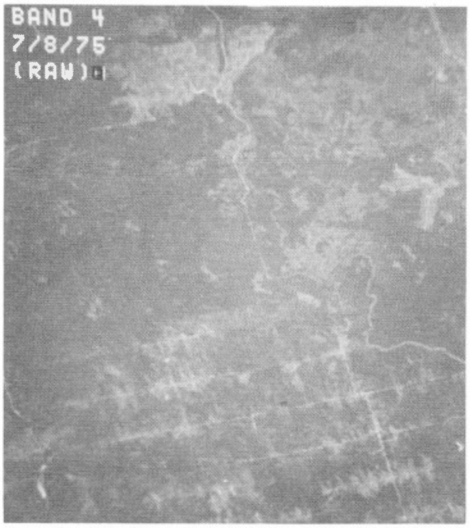


Figure 3

Band 4 (7/8/75) raw data.

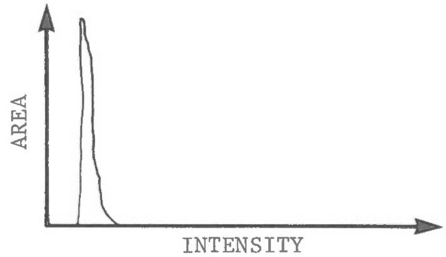
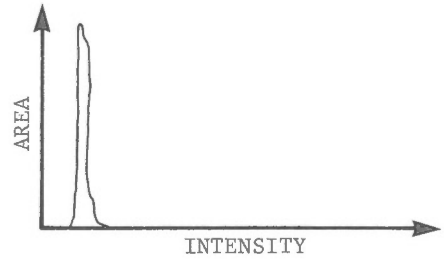


Figure 4

Band 4 (18/8/76) raw data.



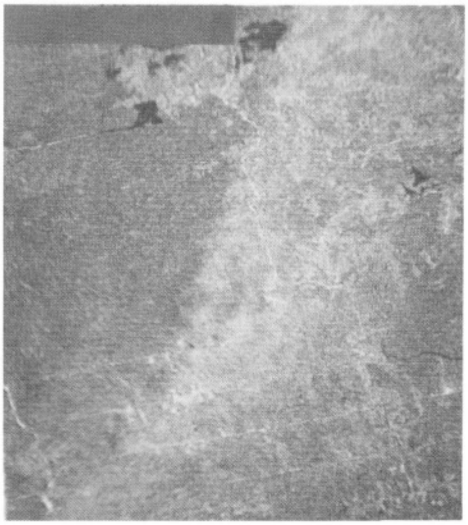
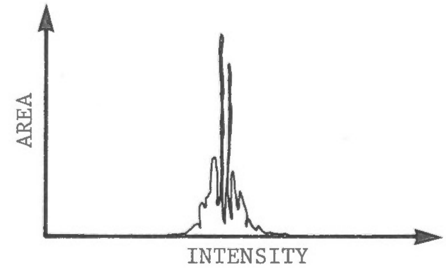


Figure 5

Band 4 ratio: (7/8/75) (18/8/76).



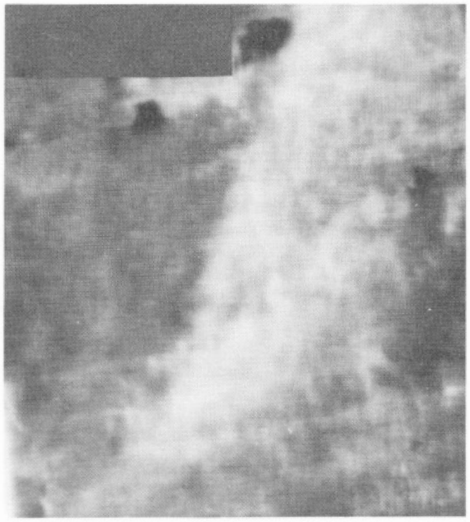
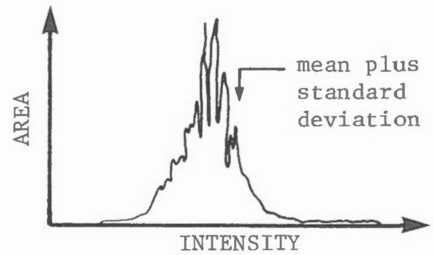


Figure 6
Low pass filter applied.



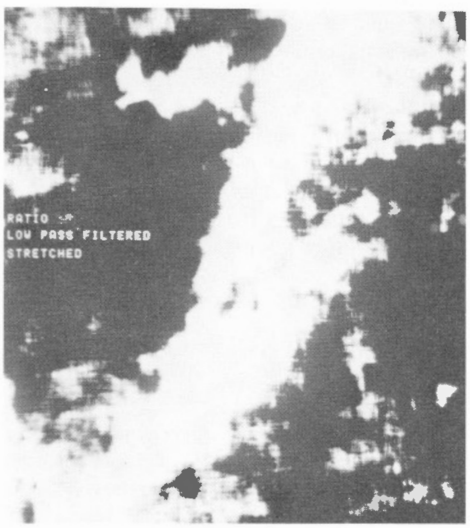
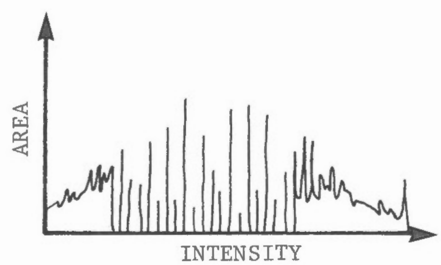


Figure 7
Selective stretch applied.



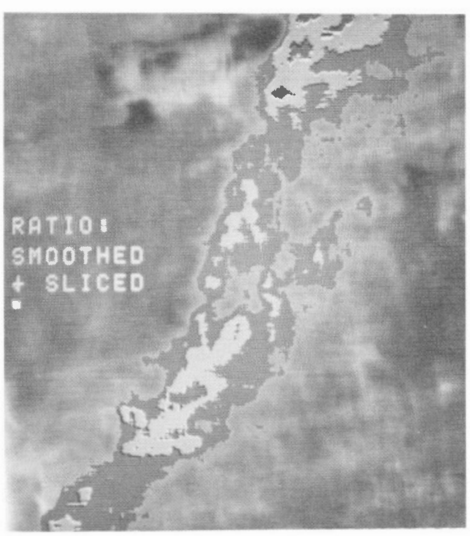
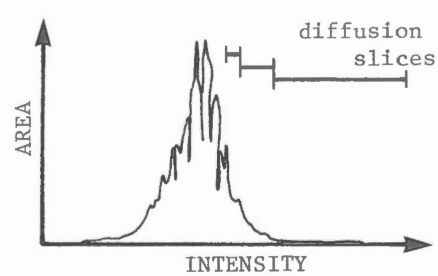


Figure 8
Plume diffusion slices.



3.3 COSTING

The technique described in this manual was developed in 1977 as a response to a problem encountered by a particular agency. It is from this specific work that the illustrations herein were drawn. Based on that example, Table 1 lists an approximation of the costs likely to be encountered in the use of this method.

Table 1

DICS CCTs (4) @ $110.		$440.00
Photographic Hard Copies of results		$100.00
Computer Analysis Time	5 hours	$150.00
(current CCRS rates are $30.00 per hour)		

4. LIMITATIONS

4.1 CRITICAL FACTORS

The primary limitation of this technique is that it cannot be used for non-visible pollution plumes. Therefore, prior to undertaking a project using this technique, the investigator must ascertain the nature of the plume and ensure its visibility.

Given the applicability of this technique to a particular project, other factors which could affect its usefulness or accuracy must be considered.

The Landsat satellites follow fixed orbits around the earth, covering a swath 185 km wide with each southward pass. Without exception, if the smoke plume is not contained within one swath (i.e. it extends to the east or to the west), it will be impossible to perform this analysis on the entire plume. This is because the two adjacent swaths are acquired on different days: the previous day (east) and the following day (west). Hence the plume characteristics will most likely be different in two adjacent images. If the plume extends to the north or south beyond the limits of an individual frame, the complete plume may be analyzed by examining two frames in the same swath (thus requiring 2 CCT's) or, if the plume is small enough by ordering a specially prepared CCT (not a DICS CCT) which is centered so as to include the entire plume. A final constraint imposed by the technical limitations of Landsat concerns the size of the smoke plume. As noted above the spatial resolution of the multispectral scanner is 57 x 79 m. In order for a block of pixels to be identifiable as a smoke plume, it must cover several adjacent pixels. Hence this analysis cannot be performed on very small plumes. Similarly, the data recorded by the MSS is not sufficient to permit a constituent analysis of the plume.

The presence of atmospheric haze should also be considered. If significant, haze may blur the edges of the smoke plume or obscure it entirely. Hence it is recommended that where possible, images of minimal atmospheric haze should be chosen for analysis.

Some problem areas which have not been directly addressed during the development of this technique could, conceivably, create difficulties in data analysis. Two such potential problem areas are, the presence of a major body of water directly under the smoke plume for part or all of its extent, and a major change in surface cover in the area beneath the smoke plume. In the first case, it is believed that the presence of a large body of water would create no major problems, particularly if the single image analysis technique is used. Indeed, the homogeneity of the water surface would probably simplify the task of outlining the smoke plume. In the case of the multitemporal analysis technique, the possible variations in the surface condition of the water body or changes in the concentration of various water constituents might produce some confusion. Hence it is suggested that if large water bodies are present in the vicinity of the plume, single-image analysis might be preferable. However, it should be noted that this has not been tested.

If there is a significant transition in the scene from one cover type to another (say forest to agriculture) along the plume path, then single image analysis may have to be performed separately over each cover type region. There should be no problem, however, in using multitemporal techniques, except perhaps slightly, over agricultural areas where crop rotation is practised.

4.2 POSSIBLE ALTERNATIVE REMOTE SENSING TECHNIQUES

Although alternative approaches to the problem of smoke plume monitoring exist, none of them is as economical or as efficient as Landsat MSS data and digital analysis.

One potentially viable alternative method is airborne multispectral scanning. The primary disadvantage of this technique is the lack of synoptic coverage for large areas. Since a longer period of time is required to acquire the necessary imagery, an additional (temporal) variable is added into the measurements. This increases the potential for error since the wind and weather conditions might change during the course of the flight thereby altering the shape and degree of dispersion of the smoke plume. Additionally, the cost of the data acquisition is considerably higher, given the typically large areas which must be covered to ensure total coverage of the smoke plume. Thus, airborne multispectral scanning is a considerably inferior alternative.

5. SUMMARY

This manual describes a technique for smoke plume monitoring. It has been concluded that the use of digitally analyzed Landsat MSS imagery is a very practical method currently available for accomplishing the task quickly, cheaply and accurately. It is anticipated that, as development continues, the capabilities of remote sensing will be extended, particularly in terms of the quantity and precision of the detail obtainable. At the present time however, this technique certainly provides an efficient and cost-effective method of smoke plume monitoring.

6. ACKNOWLEDGEMENTS

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8. GLOSSARY

TAKEN IN PART FROM:

- The Manual of Remote Sensing. Vol. 11. R.A. Reeves, A. Anson and D. Landen. American Society of Photogrammetry, Falls Church, Va., 1975. pp. 2061-2110.
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- Computer Eye - Handbook of Image Processing. (1st Edition). Spatial Data Systems, Inc. Goleta, Calif., 1975
- Remote Sensing: Principles and Interpretation. Floyd F. Sabins, Jr. W.H. Freeman and Company, San Francisco, 1978.

Algorithm (Computing Terminology): A statement of the steps to be followed in the solution of a problem. An algorithm may be in the form of a word description, an explanatory note, or a labeled diagram or flowchart.

CIAS (CCRS Image Analysis System): An interactive, computer driven, digital analysis system, operated by the Canada Centre for Remote Sensing.

Computer Compatible Tapes (CCTs): Landsat digital data are available in the form of CCT's. Tapes are high speed, quality .5" polyester-base magnetic tapes, typically 9-track and 1600 bpi (bytes per inch) recording density. One Canadian CCT contains 1 Landsat scene of 13,000 square miles.

Contrast: The magnitude of brightness range found in an image.

Contrast Stretch: A computer algorithm which expands the gray scale from a relatively narrow range on the original to a greater contrast, image - enhancing the contrast and thereby rendering the image more easily interpretable.

DICS (Digital Image Correction System): A system developed by CCRS which produces precision processed subscenes of Landsat MSS imagery compatible with the NTS (National Topographic System) maps. The products of this system are recorded on CCT's after being corrected, resampled, rotated and framed to be compatible with the NTS map sheets. All products of a particular location are based on the same reference image and are automatically registered. Each CCT covers approximately 4200 sq. km (varies with latitude) which corresponds to 1/4 of a 1:250,000 scale map.

Diffusion: The scattering of EMR upon reflection from a rough (at the λ of the EMR) surface, or upon transmission through a translucent medium.

Electromagnetic Radiation (EMR): Energy propagated through space or through material media in the form of an advancing interaction between electric and magnetic fields. The term radiation, alone, is used commonly for this type of energy although it actually has a broader meaning.

EM Spectrum: The array of all EMR which moves with the velocity of light characterized by wavelength or frequency. The optical wavelengths (0.3 to 1.5 μm) are the ones most used in remote sensing. Energy at these wavelengths can be reflected and refracted with solid materials like mirrors and lenses.

Enhancement: Data filtering and other processes which improve the visual quality of the pictorially presented data or which visually accentuate a characteristic of that data, e.g. edge enhancement, noise reduction.

Filter: Any mechanism which modifies optical, electrical or digital signals in accordance with specified criteria. Often a filter is a means of extracting a particular subset of data from a larger set containing irrelevant data. An optical filter passes only desired optical wavelengths of energy. A digital filter is an arithmetic procedure that operates on a digitized data stream in much the same way as an electrical filter operates on a continuous electrical signal; its purpose is generally to eliminate irrelevant data or noise.

Gain: A digital or electronic adjustment of contrast on the CIAS. A feature particularly useful for emphasizing certain intensity ranges thereby highlighting certain earth features.

Ground Data: Supporting data collected on the ground, and information derived therefrom, as an aid to the interpretation of remotely recorded surveys, such as airborne imagery, etc. Generally, this should be performed concurrently with the airborne or satellite surveys. Data as to weather, soils and vegetation types and conditions are typical.

Histogram: The graphical display of a set of data which shows the frequency of occurrence (along the vertical axis) of individual measurements or values (along the horizontal axis); a frequency distribution.

Infrared Radiation: EMR in the wavelength interval from about .75 μm to 1 mm. Also called long wave radiation. At its lower limit, the infrared radiation spectrum is bounded by visible radiation, and on its upper limit by microwave radiation.

Intensity (or Level) Slicing: A general class of electronic or digital techniques used to assign image points or data vectors to particular classes based on the intensity or level of the response in a single image or channel; classification by thresholds.

Landsat: An unmanned, earth-orbiting NASA satellite that transmits multispectral images in the 0.4 to 1.1 μm region to earth receiving stations (formerly called ERTS).

Micrometer (abbr. μm): A unit of length equal to one-millionth (10^{-6}) of a meter or one-thousand (10^{-3}) of a millimeter.

Mie Scattering: Any scattering produced by spherical particles without special regard to comparative size of EMR wavelength and particle diameter.

Multispectral Scanner (MSS): A line-scanning sensor which uses an oscillating or rotating mirror, a wavelength selective dispersive mechanism, and an array of detectors to measure simultaneously the energy available in several wavelength bands, often in several spectral regions. The movement of the platform usually provides for along-track progression of the scanner. In the case of Landsat, 6 lines are scanned simultaneously in each of the 4 spectral bands for each mirror sweep. This information is recorded on 24 optical units. This results in continuous strip imagery which is then transformed into framed images of 185 km (115 mi.)/side.

Offset: A digital adjustment performed on the CIAS whereby the saturation level of each colour is altered individually. May be used to emphasize certain intensity levels and highlight specific surface features.

Pass: In digital filters this refers to the spatial frequency of data transmitted by the filter. High-pass filters transmit high-frequency data; low-pass filters transmit low-frequency data.

Pixel (An acronym for "picture element"): The minimum resolution element, having both spatial and spectral responses, for which data are recorded by a multispectral scanner. The spatial variable defines the apparent size of the resolution cell (i.e. the area on the ground represented by the data values), and the spectral variable defines the intensity of the spectral response for that cell in a particular channel. In the case of Landsat 1, 2 and 3, the unique area of a pixel is approximately 60 x 80 m or 1.1 acres.

Radiometric Range: The range of intensity (radiance) values in a particular spectral band.

Ratioed Image: A computer operation whereby the digital intensity values of each pixel in one image are divided by the intensity values of corresponding pixels of another image of the same location taken at a different time. Used in multitemporal studies, this procedure indicates the amount of change which has occurred in each pixel in the given time frame. Alternatively, the two images being ratioed may be of the same date but of different spectral bands.

Rayleigh Scattering: Selective scattering of light by particles in the atmosphere that are small relative to the wavelength of light. The scattering is inversely proportional to the fourth power of the wavelength.

Real Time: Time in which the reporting or recording of an event is simultaneous with the event. For example the real time of a satellite is that time in which it simultaneously reports its environment as it encounters it, the real time of a computer is that time during which it is accepting data and performing operations on it.

Reflection (EMR Theory): EMR which is neither absorbed nor transmitted is reflected. Reflection may be diffuse, when the incident radiation is scattered upon being reflected from the surface, or specular, when all or most angles of reflection equal the angle of incidence.

Register: The process of geometrically aligning two or more sets of image data such that the resolution cells for a single ground area can be digitally or visually super-imposed. Data being registered may be from different kinds of sensors, or collected at different times.

Resolution: A measure of the ability of an optical system to distinguish between signals that are spatially near or spectrally or radiometrically similar. Spatial resolution is a measure of the smallest angular or linear separation between two objects (usually expressed in radians or meters) with a smaller resolution parameter denoting greater resolving power. The spatial resolution of a remote sensing system is a function of the contrast between objects in the scene and their background, of the shape and size of the objects, and of the signal-to-noise ratio of the system. Spectral resolution refers to how well two targets may be distinguished, based on their differing spectral characteristics. Radiometric resolution refers to the ability of a sensor to detect small brightness differences in a specific spectral band.

Scattering: The reflection and refraction of electromagnetic energy by particles in the atmosphere; frequently wavelength dependent.

Spatial Filtering: A computer operation which allows an image to be separated into high-frequency and low-frequency components. Low-pass filtering eliminates high-frequency interfering lines or textures in an image. High-pass filtering can be used to enhance image details by removing low-frequency changes caused by vignetting or uneven illumination.

Spatial Frequency: The number of changes per unit of distance in gray scale across an image. A low spatial frequency indicates an area of relatively uniform brightness while a high spatial frequency indicates a higher degree of contrast and detail in small areas.

Spectral Signature: Quantitative measurement of the properties of an object at one or several wavelength intervals.

Sun Synchronous: An earth satellite orbit in which the orbit plane is near polar and the altitude such that the satellite passes over all places on earth having the same latitude, at the same local sun time.

Synoptic Coverage: The ability to see or otherwise measure widely dispersed areas at the same time and under the same conditions e.g. the overall view of a large portion of the earth's surface which can be obtained from satellite altitudes.

Visible Radiation: EMR of the wavelength interval to which the human eye is sensitive; the spectral interval from approximately 0.4 to 0.7 micrometers.