CHAPTER 40

SEQUENTIAL PHOTOGRAPHY OF COASTAL WATER [1]

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ABSTRACT

Sequential photographs from aircraft and satellites provide a source of data for studying dynamic features of coastal waters. Procedures for detecting features in sequential photos follow two approaches; (1) application of sequential signatures, (2) simple comparative analysis. For quantitative analyses images of two or more frames must have proper registration and comparable tones, i.e. tones free of photographic variance from film processing, varying exposure and solar illumination. After a normalization correction for variance is determined through use of density control points, density of successive frames is measured with a microdensitometer, the correction is applied and tonal differences determined. Such differences relate to the time character of a feature and to causal processes. Application of correction values and numerical differencing is best accomplished in a digital or computerized densitometer. However, corrections and differencing can also be accomplished graphically from line traces or plots of an objective densitometer. Application of the procedures is demonstrated by analyses of tonal patterns of suspended sediment concentration in an estuary.

INTRODUCTION

Coastal features are so dynamic, constantly changing in content and position in response to waves, tides and man-made stress, they are difficult to characterize and monitor over large areas. The scientist or coastal engineer is often faced with a number of questions, for example: How stable are the sedimentary materials of tidal inlets and estuaries? How can sediment pollution be detected? What is the circulation pattern and direction of sediment transport? What are the effects of storms and floods? - the environmental impacts of man in his effort to fill land and dredge channels? Many such questions can be answered by remote sensing techniques. Already satellites and repetitive aerial flights are capable of generating volumes of sequential photography but procedures for its analysis are not fully known.

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For example, how can the tonal appearance of coastal water in aerial photographs be used to analyze their movement. This paper aims to show how temporal data can be extracted from sequential photography and reduced to useful information about the dynamic distribution of sediment suspended in coastal waters.

BACKGROUND

As defined by Colwell (1968), the term "sequential photography" pertains to photography taken of any given area at two or more different times. By comparing images in a sequence of photographs, certain time-dependent features may be detected or discriminated, changes evaluated and time-history determined. There are two principal aspects to utilizing the time element: (1) a "sensing" aspect in which the characteristic temporal variations of a feature's reflectance or emittance are used for detection and identification, (2) a change detection aspect in which differences in a feature's shape, position or tone from time to time are utilized to determine water movement or variations in load. Thus, sequential photographs may be used to sense changes in the amount of reflectance from the water as well as to determine varying position and shape of tonal anomalies.

Already a great deal has been accomplished with sequential photographs and related time-coverage. They are widely used for measuring shoreline changes (e.g. Stafford, 1971 and Moffitt, 1969), for visualizing flow in models, and for direct flow measurements by recording successive positions of moving targets (e.g. Waugh, 1963 and Waldichuk, 1966) or by application of a stereo time-lapse Cameron (1962). By utilizing satellite observations they provide information on movement of weather patterns (e.g. Sikdar and Suomi, 1971) and changes of terrestrial features (Sissala, 1972). At the present state of progress satellites and aerial flights are capable of generating volumes of sequential imagery but procedures for its analyses are not well known.

Rationale for sensing

The temporal character of coastal features emerges mainly from the periodic nature of coastal processes that affect a feature's size, shape and position, or its content and composition. Such time-dependent processes include wave action, rise and fall of the tide, ebb and flood currents, heating and cooling, melting and freezing, changes in marine aquatic or plankton populations. They present a wide spectrum of time scales panning minutes, hours, months and years, as illustrated in Figure 1. Variations with short-time scales and large geometric scales are most pronounced, e.g. those due to waves and tides, but any time variation that is characteristic and distinct should have diagnostic value.

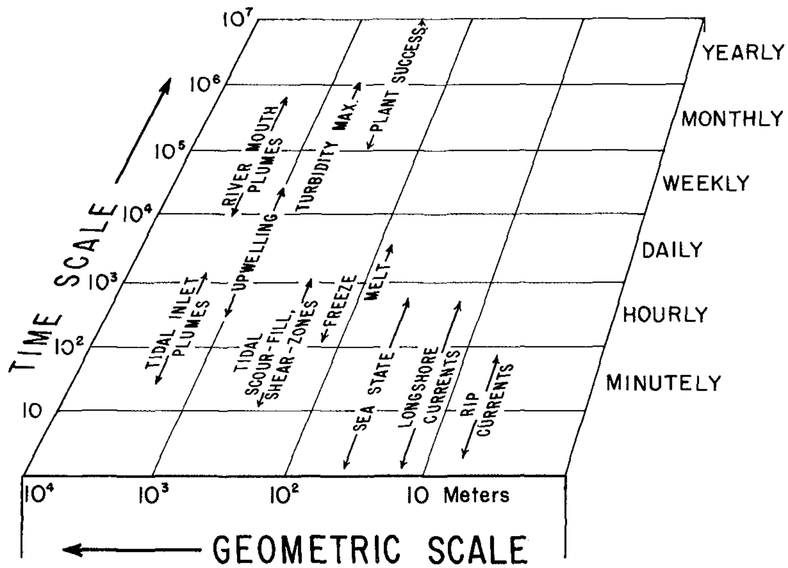


Figure 1. Time scales of some time-dependent coastal features at different geometric scales. Full range of geometric scale for each feature not shown.

Sequential Signatures

Time sensing is based on the fact that a feature reflects or emits electromagnetic energy with a specific and distinctive frequency or period. Just as spectral signatures are characteristic of a feature in multiband images so too "sequential signatures" are diagnostic of time-dependent features in repetitive imagery. At infrared wavelengths, time variations are mainly due to cyclic heating and cooling. Because contrasting coastal materials like mud, sand and water, differ widely in their heat capacities and radiative behavior diurnal changes are especially strong at wavelengths longer than 4μ. At visible wavelengths time variations are mainly due to changing reflectance. Figure 2 shows some examples of prospective sequential signatures developed from surface observations. But continuous measurements of reflectance or emission with time in coastal waters are scarce; successive photographs yield incomplete signatures, and discrimination becomes difficult because signatures are susceptible to contamination by meterological events, by varying water "penetration" or sun glint, and by the dissipation of energy through different party of the temporal spectrum.

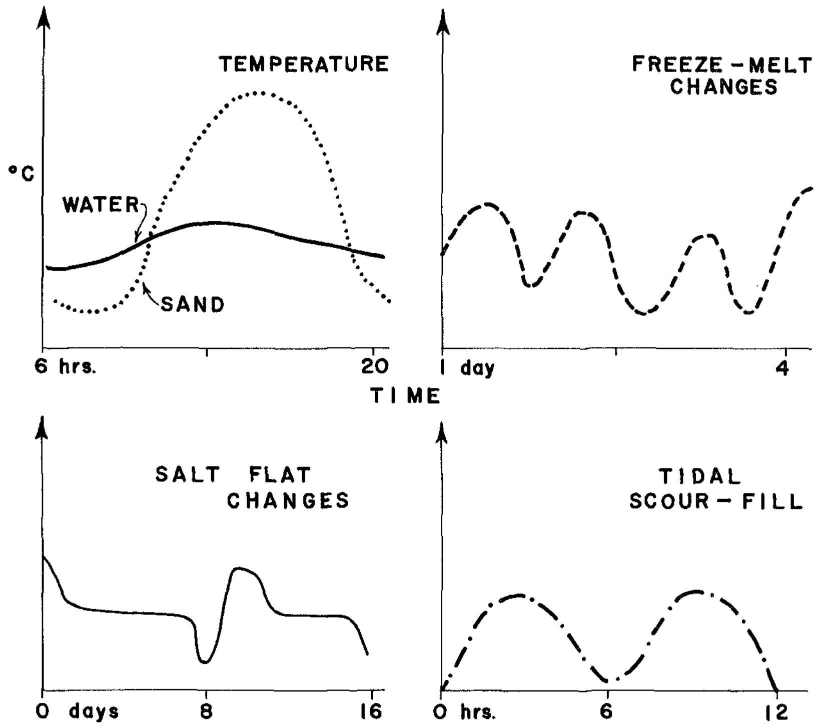


Figure 2. Examples of prospective sequential signatures developed from surface observations. Relative magnitude of reflectance (or emission) is directed along ordinate, time on abscissa.

MULTIPLE "LOOK" TECHNIQUE

A more fruitful approach for detecting time-dependent features is to compare successive photographs visually and identify features by simple photo interpretation. For example, the sequence presented in Figure 3 illustrates some dynamic features of a tidal inlet that are best identified through comparative analysis supplemented by surface observations. In the second photograph (0 hour) a large light-toned patch representing a plume of discolored water (p) extends seaward (to the right) off a tidal inlet through barrier islands. Breakers, recorded in very light tones (b), mark an area of shoals. But between the breakers and the plume proper light tones represent either reflectance from submerged shoals or from sediment suspended in the plume overlying the shoals. The two features cannot be differentiated, nor can growth or decay of the plume associated with tidal suspension or settling out be determined from a single photograph. But by comparing the photograph with others taken two hours before and two to four hours after, it should be evident that the plume was mainly dissipating along its seaward edge, except for a lateral extension (downward) at 0-hour (e). Light tone areas in the inlet mouth (m) persist throughout the series indicating relatively stable shoals, in contrast to the more transient tidal plumes. Various small scale patterns are also displayed, e.g. turbid rip plumes and whirlpool patterns, but a much shorter time scale is required for detection. Thus, a single time interval or "net" does not "catch" all features at all time scales. And the minimum time scale depends on the smallest time scale involved plus the diversity of other time-dependent features in the scene or "background".

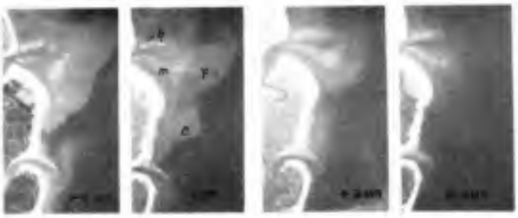


Figure 3. Sequential photographs of Ship Shoal Inlet, Virginia, U. S. East Coast, showing 2-hour variations in a sediment plume. For explanation of symbols see text. Black and white reproductions of 70mm color infrared aerial photos taken from 25000 foot altitude, Oct. 12, 1971. Reproduction of tones necessarily varies from original. Tidal current is flooding at 0, +2 & +4 hours.

The multiple "look" method yields a maximal amount of information from large volumes of aerial photography. It is useful for qualitative evaluations of storm changes, for assessing ecological deterioration or growth and effects of dredging and filling operations. In practice, comparative analysis is facilitated by compiling composites of tonal information on an acetate overlay. Multiple image correlators such as the I^2S Addcol used without color filters, enable viewing four or more sequential frames at a time in register. Features which cannot be identified from study of single photographs often are positively identified through comparative analysis of sequential photography.

TONE ANALYSIS

Image tone consists of variations of gray of "blackening" manifest in the film density. Film density depends mainly on the exposure received and the development time given the film. This relationship is illustrated in Figure 4, which describes the "characteristic curve" of the film for a given development time. Along the straight line portion of the curve (BC), densities increase proportionately to the log exposure whereas densities on the "toe" and "shoulder" do not. Thus, the level and range of density are partly controlled by exposure and developing time.

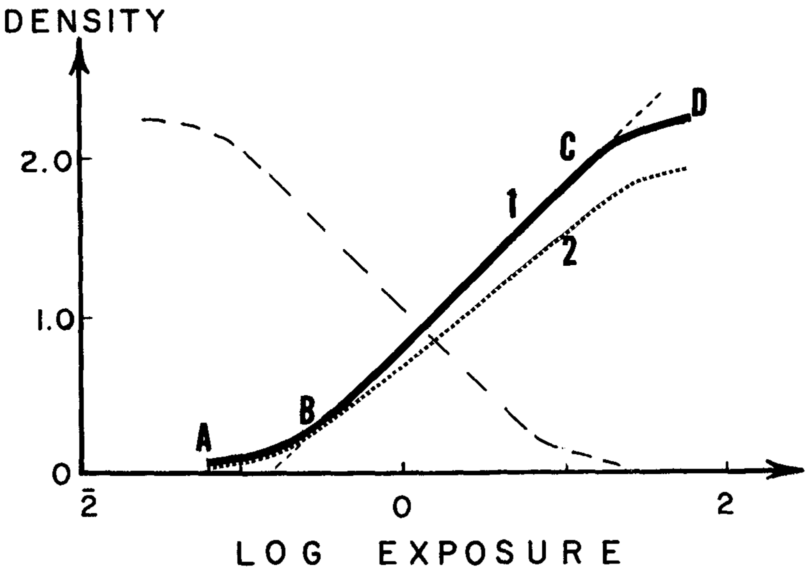


Figure 4. Characteristic curves of a photographic film; A-B is "toe", C-D "shoulder". Dotted curve (2) shows typical variance from ideal curve (1) due to developing time. Dashed line is typical curve of negative in contrast to positive solid line.

The tone or brightness of a feature in a photograph mainly represents the amount of reflectance recorded on the film. Such changes however, are influenced by many factors other than changes in reflectance of water itself with its variable load of particle backscatters. A part of the reflectance is due to changes of solar intensity and direction of incidence. Another part may be due to changes in atmospheric scattering or absorption, or to changes in surface roughness which affect reflection at the surface. Additionally, spectral reflectance of the water may change temporally with changes in depth or light penetration. In clear or shallow water, reflectance often varies with the amount of light backscattered from the bottom. Therefore, when a time-sequence of photographs is obtained, the reflectance recorded on the film is affected by variations in energy from the water surface, the water column as well as the bottom. Additionally, variations associated with optics and film characteristics or photographic processing must be taken into account. While all these factors appear to limit analysis, in practice they may be controlled or corrected within limits.

Analyses of sequential photography requires (1) proper image registration and (2) comparable image tones in successive frames. The chief procedural problem is to remove unwanted photographic and environmental variance and bring tones to a common datum.

Normalizing

To bring the density of two or more scenes to a common reference or datum for comparing transient tonal anomalies, it is necessary to normalize the density distributions. For accurate measurements a calibrated step wedge is exposed with each scene at the time of photography and processed to a 1:1 density-log exposure relation. However, wedge-film exposures are not commonly obtained in aircraft photography. As an alternate, panels of known reflectance are installed on the ground, or where not available, the reflectance of objects such as runways, or road surfaces is measured and their density values are used to construct a characteristic curve. Subsequently, densities in successive frames are adjusted by ratioing to what they would have been had each frame been processed to a 1:1 density-log exposure relation.

As an expedient a series of relatively stable objects are selected to serve as density control points. The densities of these points, which consist of common geographic points or identical objects in successive frames, are read in a microdensitometer and the average density difference of three or more points is applied, added or subtracted, to the densities of transient features in frames that require normalization. In practice, selection of suitable control points is critical to normalization. The following criteria are suggested:

1. Locate control points close to the transient feature that requires normalization. Avoid tonal fall-off in corners and

outer edges; locate points in central two-thirds of frame. In scenes with many prospective locations, a grid of points can be established and normalizing values applied throughout a series of reference quadrants.

2. Density of the points should cover a range that lies within the density range of the feature to be normalized.

3. Density of both the points and the feature to be normalized must fall within the straight-line portion of the characteristic curve.

4. Points must have "stable" reflectance characteristics, e.g. objects free of shadows, wind stirring, and relief. Paved runways, parking lots, or roadways are good; ponds and grass lawns are often stable.

5. Density within large "points" must be uniform.

Success of selecting control points can be checked by examining the range of differences between sets of points in successive frames. If optical characteristics of the normalized features are known from surface observations, differences from time to time should be proportional to corresponding density differences.

Positive-Negative Composites

A simple means of detecting tonal changes is to prepare a composite of oppositely matched positive and negative transparencies; i.e. a positive taken at time "1" and a negative taken at time "2". When tones are "matched", like images cancel out by contrasting bright-dark film density whereas unlike tones are displayed. Thus, differences are simply and effectively highlighted; and conventional enhancing techniques (Colwell, 1969; Ross, 1969) can be used to reveal subtle differences. Registration is accomplished by superposition on a light table but scale variations and geometric distortions often require correction. Matching tones of frames processed under different conditions is difficult and requires a great deal of patience in the dark room. However, frames exposed and processed under the same conditions, i.e. one roll at one time, can be matched by processing duplicate positive-negative frames to a 1:1 density-log exposure relation. This is accomplished by using a film, developer and developing time of known specifications that yields a 1:1 density-log exposure.

Comparative Densitometry

A microdensitometer is employed for quantitative analyses of tonal changes. Density control points are established, scenes singly read or scanned and the pre-determined normalizing correction applied. After the output is registered, differences are determined graphically or by computation, areas of change delineated and further related to causal processes as dictated by the problem. Figure 5

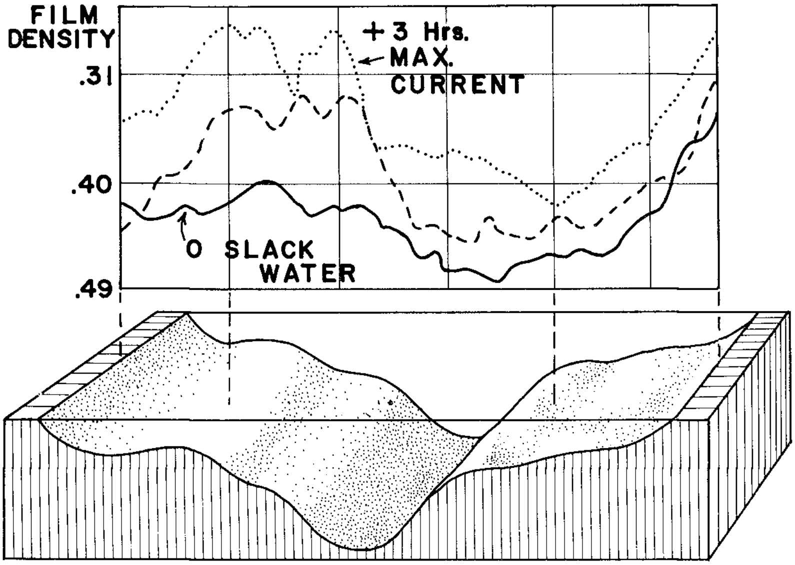


Figure 5. Graph of film density in a transect across the James Estuary, Virginia. Derived from Joyce Loebl microdensitometer tracing across frames 1, 2 and 3 reproduced in Figure 6A.

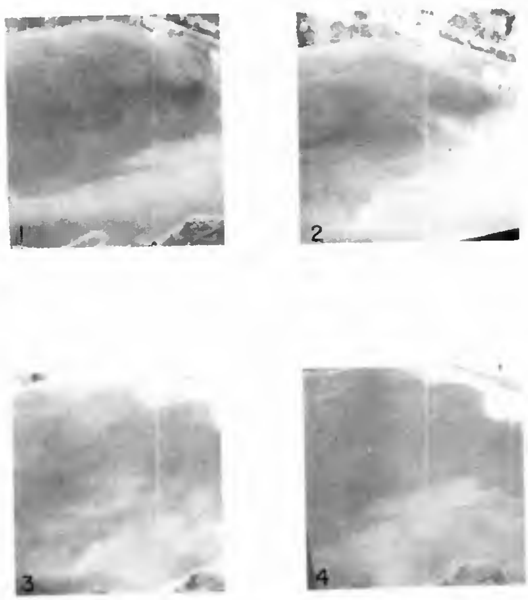
shows the distribution of film density at approximately 2-hour intervals across an estuary reach as illustrated in Figure 6A. It is in the form of normalized line traces derived from a Joyce Loebl microdensitometer. Differences between solid and dotted lines indicate the magnitude of density change, in this case a change due to differences in suspended load that varies with current strength. Outputs in the form of X-Y plots are treated similarly. Changes are revealed by comparing changes in the magnitude of density, by recording varying locii of maximum and minimum densities, or by examining the changing position of isodensity lines, their symmetry, character or axial position. Figure 6B shows the distribution of density change in surface water of the same reach shown in Figure 5. Changes from slack water to maximum current are greatest over the shoals.

Once a sequence of normalized density plots have been prepared many different sorts of analyses can be performed. Figure 7 gives the concept of a film density "stack" from which densities may be averaged or integrated over a given time span. A time "thread" through the stack at one point (small arrow) yields a time-distribution of film density representative of a sequential signature for suspended sediment concentrations that varies with tidal current velocity.

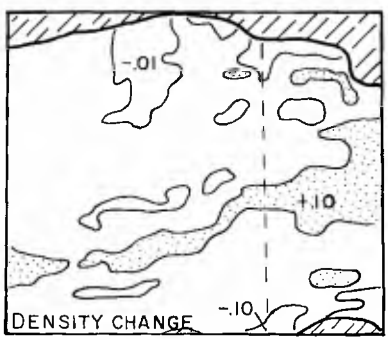
Figure 6A. Sequential photographs of a portion of the James River estuary taken at approximately 2-hour intervals, Oct. 12 1971. Reproduced from black and white red band photographs. Tones necessarily differ from originals due to reproduction and printing.

6B Distribution of density change between frames 1 and 3 above derived by computing density differences after normalization.

A



B



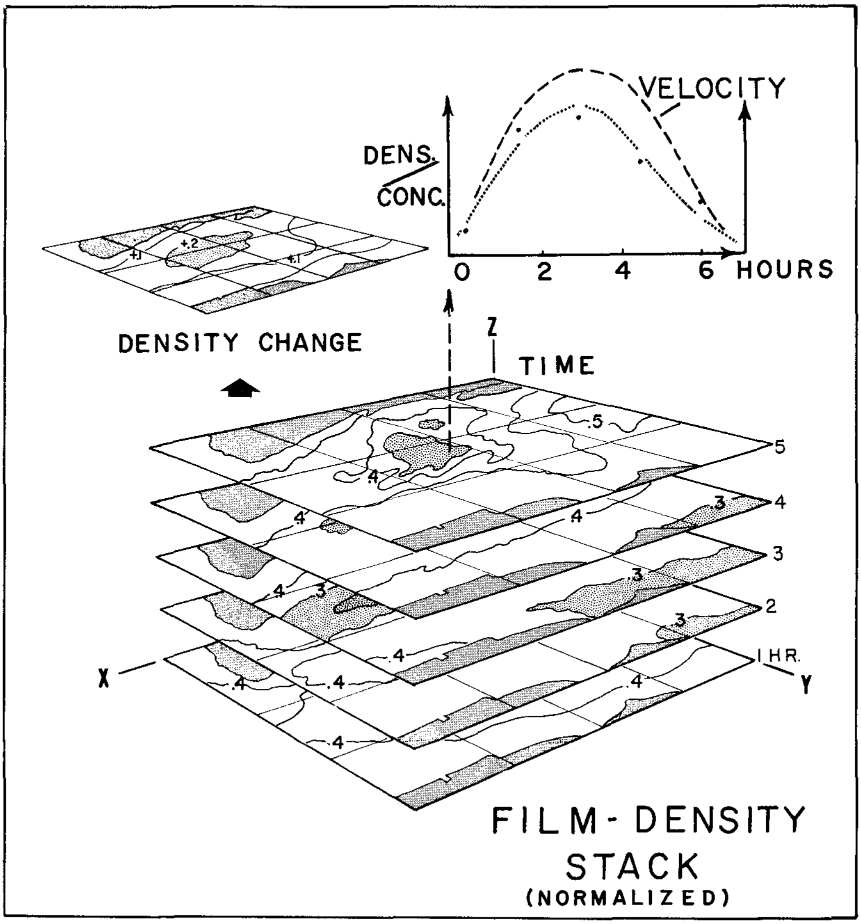


Figure 7. Concept of the film density "stack"; schematic. For explanation see text.

A great deal of comparative densitometry can be rapidly accomplished by employing an image scanning vidicon camera system such as the Spatial Deta Systems, "Data Color", or I^2S "Digicol". The equipment is most useful when extensive normalization or high resolution are not required. Two or more frames can be examined on a display screen at one time. The systems allow great flexibility in selection of density range and distributions that relate to surface observations.

Digital Densitometry

Normalizing film densities and computing differences, averages etc. of sequential photographs is best accomplished with a computerized system or a densitometer having a digital output. Densities, including both those of control points and transient features, are scanned, digitized and identified in a geographic matrix system prior to storage on magnetic tape in register. The computer is programmed to make density corrections and "change" computations as well as to electronically process photo-like displays of "change" distributions.

PROCEDURAL SUMMARY

Steps for analyzing sequential photos are summarized schematically in Figure 8.They are as follows:

1. Obtain photographs repetitively on the same flight line or track with the photos centered on the same image points to facilitate registration. Constant flying altitude and minimal aircraft and camera tilt are required, in addition to uniform time intervals and constant exposure-shutter speeds.
2. Process film in a single "batch" under controlled conditions and close to a 1:1 density-log exposure relation. A step wedge exposed on the head and tail of each roll provides a record to compare processing results from roll to roll.
3. Scrutinize film to determine if quality allows registration, density normalization and differencing. Geometric distortions may require rectification. If density level and range appear to preclude further analyses, some improvements may be accomplished by reprocessing duplicate transparencies.
4. Select density control points using criteria previously presented. Read film density in a microdensitometer and compute average correction values. Program corrections as necessary for normalizing subsequent outputs.
5. Scan film in a microdensitometer utilizing reference marks for subsequent registration of the output. Use the same instrument settings throughout each sequence taking into account the full density range of the sequence.

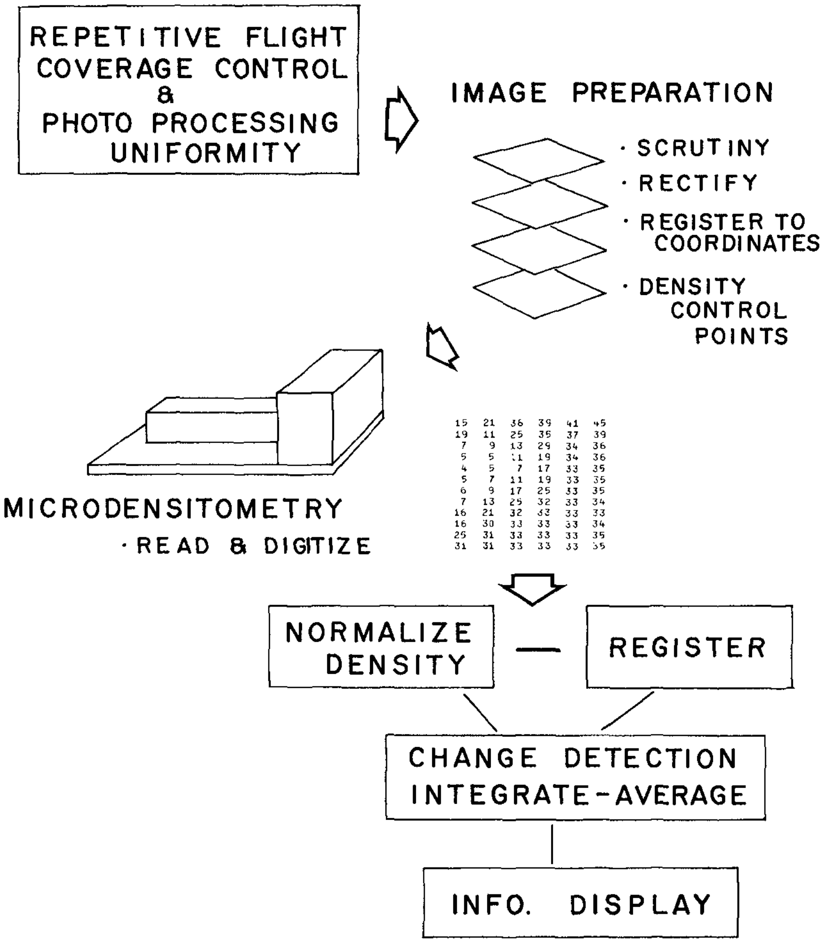


Figure 8. Schematic summary of procedural steps for densitometric analyses of sequential photographs. For details see text.

6. Apply normalization value to density distributions under examination.
7. Register frames to be compared utilizing predetermined reference marks.
8. Compute changes or averages as required.
9. Contour change distributions and relate to environmental processes or impacts as problem dictates.

ACKNOWLEDGEMENTS

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