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ABSTRACT

Methods for detecting and screening cloud contamination from satellite derived visible and infrared data are reviewed in this document. The methods are applicable to past, present, and future polar orbiting satellite radiometers. Such instruments include the Coastal Zone Color Scanner (CZCS), operational from 1978 through 1986; the Advanced Very High Resolution Radiometer (AVHRR); the Sea-viewing Wide Field-of-view Sensor (SeaWiFS), scheduled for launch in August 1993; and the Moderate Resolution Imaging Spectrometer (MODIS). Constant threshold methods are the least demanding computationally, and often provide adequate results. An improvement to these methods is to determine the thresholds dynamically by adjusting them according to the areal and temporal distributions of the surrounding pixels. Spatial coherence methods set thresholds based on the expected spatial variability of the data. Other statistically derived methods and various combinations of basic methods are also reviewed. The complexity of the methods is ultimately limited by the computing resources. Finally, some criteria for evaluating cloud screening methods are discussed.

1. INTRODUCTION

Clouds consist essentially of liquid water aerosols that efficiently absorb and scatter electromagnetic radiation at wavelengths smaller than 0.2 mm. Therefore, cloud detection and screening are important prerequisites to the retrieval of Earth (land or sea) surface data. This paper reviews the methodology for such detection and screening of cloud contamination applied to visible and infrared (IR) radiometers of polar orbiting satellites.

Data obtained from the visible channels of the Coastal Zone Color Scanner (CZCS), flown aboard Nimbus-7 and active from 1978–86, require only daytime cloud detection schemes, as will data from the Sea-viewing Wide Field-of-view Sensor (SeaWiFS), scheduled for launch in August 1993. Both sensors are dedicated to oceanographic applications. The Advanced Very High Resolution Radiometer (AVHRR), flown aboard the National Oceanic and Atmospheric Administration (NOAA) satellite series, is used for land and sea studies and its visible and IR channels require both day and nighttime cloud detection. The Moderate Resolution Imaging Spectrometer (MODIS) is scheduled for launch in the late 1990s as part of the Earth Observing System (EOS) for monitoring global atmospheric, oceanic, and terrestrial changes. By virtue of its wider spectral range, improved ground resolution, and significantly greater spectral resolution, MODIS will not only allow more accurate detection of clouds based on techniques discussed here, but will be capable of deriving a number of important cloud and other atmospheric properties (King et al. 1992).

2. DIRECT THRESHOLDS

Over the visible and reflected IR range, ocean water reflectance through a cloud-free atmosphere is generally on the order of 10% or less, whereas the reflectance of clouds is normally greater than 50%. Therefore, a threshold value may simply be a set that discriminates between the measured radiance of a cloudy and clear pixel over water during daytime. (Ocean reflectance is composed primarily of the reflection of direct and diffuse solar radiation with some contribution from back radiation of the water column.) High reflectance also occurs when snow, ice, or sun glint (specular reflection) is present and a cloud threshold will discriminate against such cases that are just as undesirable for the derivations of sea surface temperatures (SSTs) or chlorophyll pigment concentrations.

Reflectance is a function of the angle of incidence of the observed ray, so satellite and solar zenith and azimuth angles should be taken into account in setting the most effective threshold values for visible and reflected IR channels. Thus, the maximum reflectance expected for a surface of interest and for a given angle consisting of the sun, the earth-located pixel, and the satellite (SPS) will serve best as the threshold value. A large solar zenith angle resulting in low incident light as well as an SPS angle resulting in high probability of glint contamination should be rejected independently and before the application of radiance thresholds in order to improve their effectiveness.

CZCS channel 5 (nominal wavelength, $0.75\,\mu$m) is used to detect land and clouds. A threshold of 21 counts for that channel is usually adequate to screen out the brighter land and cloud pixels from sea surface pixels (McClain et al. 1992). In turn, a threshold of 190 counts in channel 1 ($0.443\,\mu$m) is used to differentiate land from the brighter cloud surfaces. However, in areas of low solar elevations, where clouds tend to be less bright, and in areas of thin clouds, such thresholds may need to be adjusted downward.

Thresholds for thermal IR channels (AVHRR channels 3, 4, and 5 at nominal wavelengths of 3.7, 11, and 12 μm, respectively) may be used during the day as well as night when visible channels are not useful. Threshold values may be set to discriminate between cloud-top surfaces, as well

as snow and ice, having brightness temperatures too cold for ocean surfaces. (When available, channel 5 is preferable because of the generally greater optical depth of clouds at this particular wavelength band.) However, in areas of actually low SSTs (down to a minimum of $-2°C$ at high latitudes), the net effect of cloud contamination will be smaller and more difficult to discern on the basis of a simple IR threshold value. Infrared channel thresholds can be very useful for daytime conditions where low clouds are in the shadow of other clouds and would have much lower reflectance.

The use of direct radiance thresholds to identify cloudy pixels suffers when the measurement signature of clouds and the ocean surface approach each other and when only a fraction of the pixel area is obscured by clouds so as not to place the derived quantity beyond the expected range. Partial coverage occurs either when clouds are of sub-pixel size, as is often the case with cumulus or thin, scattered clouds, or when the pixel view area overlaps the edge of a larger cloud. Thus, errors in threshold techniques will depend on the areal size distributions of the observed clouds (Joseph 1985), with best results obtained when most of the cloud cover is accounted for by larger-than-pixel clouds. It is interesting to note that the error resulting from sub-pixel clouds also depends on the resolution of the pixels. Small, widely scattered clouds, for example, are more easily detected in mid-scan pixels than in the elongated, scan-edge pixels.

Nevertheless, the use of direct thresholds requires minimal computational time and may significantly decrease processing time since they eliminate pixels prior to the more computationally intensive derivation of geophysical values. The extent that pixels which should be *excluded* are included (type-1 error) and to which pixels that should be *included* are excluded (type-2 error) is very sensitive to the threshold setting. Moreover, the judicious selection of the exact channel(s) to apply a threshold test will improve its effectiveness. For example, the spectral response of the AVHRR channel 2 can detect cirrus clouds better than channel 1 and would prove a more effective choice in most cases.

For AVHRR local area coverage (LAC) data, which has a nadir resolution of 1.1 km, Olesen and Grassel (1985) combined the use of a direct channel 5 threshold with a threshold based on the difference of the channel 3 and 4 brightness temperatures for ocean images. The difference value exploits the different dependence of these channels' radiances on cloud optical thickness. Using various threshold values in their algorithm, based on assumptions of an average atmospheric profile, they were able to deduce information on the clouds' classification, as well as detecting their presence. The differences between channels 3 and 4 and between channels 4 and 5, have also been used to discern clouds in polar regions (Raschke et al. 1992, Yamanouchi and Kawaguchi 1992).

3. DETERMINING THRESHOLDS

Various methods may be used to define threshold values. An operational method for IR data for SSTs for example, could use the mean of the local pixels (e.g., 1-degree grid centered at the pixel of interest) over the previous few days corrected for the maximum likely atmospheric absorption effects to help determine the expected SST. The forecast from a mesoscale model could be used to define the temperature at the top of the atmosphere in lieu of, or in addition to, the previous days' SST mean. The greater variability of surface temperatures makes such methods less certain over land. (Care would be needed to exclude coastal areas during SST processing.) Eck and Kalb (1991) used a database of average monthly surface temperatures as a function of $500{\times}500$ km areas over Africa to determine optimal channel 5 thresholds for screening cloud contaminated pixels when deriving a vegetation index from AVHRR data. They note that the application of the method in more temperate climates may result in greater errors because of the higher likelihood of anomalously low air temperatures relative to the monthly averages.

Automatic processing may be augmented (or replaced) by having a user display from which one could select from occasional (or all) images of cloud-free land and sea areas likely to be the coldest, e.g., high latitude ocean water and high altitude land areas. The threshold is then set to be just colder so as not to exclude these actual Earth surface values. Thresholds set in this manner are optimal since they represent the actual minimum value for the region to be tested and are for the same time as the data. Such interactive steps may be used to assess the effectiveness of an operational algorithm after it is implemented. Analogous procedures are also applicable for defining albedo thresholds for visible channels (Saunders and Kriebel 1988).

A dynamic method for determining thresholds is to generate the histogram of pixel radiance counts for each area of interest. The size of the area used for this purpose is not critical except that it must be large enough to obtain good statistics for cloud-free land or sea areas. Peaks for the cloud-free areas are then identified and a threshold is established to discriminate such peaks from the contaminated pixels. Cloudy pixels, because of the various degrees to which they can be contaminated, will have a broad range of values to one side of the peaks. For example, cloudy pixels will have generally higher albedo values for visible channels. A major advantage of this method is that it avoids inaccuracies due to calibration variations. This is especially important for data from channels, such as AVHRR channels 1 and 2 (nominal wavelengths, 0.63 and $0.91\,\mu$m), that lack onboard calibration. Moreover, when small areas are used for the histogram and the results are applied to proximate pixels, the dependence of reflectance on SPS angle geometry is not significant.

Saunders (1986) applied a dynamic visible threshold to AVHRR LAC based on the histograms of the visible

reflected radiances. A constant value above the value of the identified clear-pixel peak served as the threshold. If no dominant peak was identified, all pixels were considered contaminated. Over ocean areas, the channel 2 histogram was used because of that channel's lesser sensitivity to aerosol and molecular scattering, whereas the channel 1 histogram was used over land because of the generally greater contrast between land and clouds in that channel. England and Hunt (1985) used the $11\,\mu m$ IR histograms to fine-tune dynamically visible thresholds for discriminating land, sea, and cloud data from METEOSAT (Meteorological Satellite from the European Space Agency).

Depending on the rate of data to be processed, the speed of the computer, and the accuracy of detection required, different variations of this histogram method may be implemented. For minimum computation, the entire image, or a representative portion of it, could be histogrammed and the derived threshold applied to the entire image. Alternatively, the image may be broken into a grid and each cell treated independently as a sub-image. The most computationally demanding method is to scroll the area to histogram over each pixel, or set of pixels, as they are processed, with the identification of peaks and the setting of thresholds being done automatically using peak-fitting programs. The lack of identifiable peaks may be used to indicate cloud contamination over the entire area. The stringency of the statistical test used to identify (detect) a peak can be set by the user.

4. SPATIAL COHERENCE

The expected variation of the measurement values can itself act as a threshold to detect cloud contamination. This uniformity or spatial coherence test is especially effective for measurements, such as SSTs or some land surfaces at night, having relatively small horizontal gradients. The variation for a pixel and its adjacent pixels is compared with the expected variation determined from a set of nearby (in space and time) cloud-free pixels. Cloud contamination would presumably cause a larger than expected variation. The extent to which pixels are accepted/rejected, and the extent to which type-1 and type-2 errors will occur, can be determined by how small the expected variation threshold is set. However, this method will fail when the cloud variation is smaller than that of the surface of interest. Low-level stratus clouds, for example, have extremely uniform cloud-top temperatures and will fail detection. Optically thin clouds, such as cirrus, will also fail detection by this method.

As mentioned previously, the use of direct radiance thresholds can fail to adequately detect contamination from small, sub-pixel clouds. The effect of sub-pixel clouds on AVHRR global area coverage (GAC) data, which has a nadir resolution of 4 km, was simulated by Kaufman (1987) using an empirical model to represent various cloud types. The results indicated that such small clouds affect the vari-

ability of the radiances and thus are detectable by spatial coherence techniques. A method to correct for the effect of small and thin clouds on thermal data was presented by Gower (1985). The technique relies on the correlation of the error that a small amount of cloud contamination will have on visible or near-IR radiances and on thermal-IR radiances. It was applied to AVHRR images over ocean regions using channels 2 and 4.

A spatial coherence method was used by Coakley and Bretherton (1982) to examine the standard deviation of 2×2 arrays of AVHRR channel 4 GAC data as a function of the arrays' means for an ocean region. Clusters of low variance coupled with low radiating temperatures and low variance coupled with high temperatures identified completely covered and cloud-free pixels, respectively. Partially-covered pixels, on the other hand, exhibited intermediate temperatures with higher and much more variable standard deviations. Crane and Anderson (1984) applied this technique to the discrimination of clouds from snow and ice cover using a near-IR sensor.

Using AVHRR channels 3 and 4 data, Kelly (1985) combined direct and difference thresholds with two spatial variability tests to screen cloud pixels from LAC ocean images. One spatial variability test was based on the magnitude of the difference between pixels. Magnitudes greater than positive and negative thresholds were used as an indication of clouds. The other variability test was based on the mean of 5×5 pixel squares and the presence of pixel values significantly different from that mean in each square. Squares for which such values occurred, and for which most neighboring squares were unequivocally clouds, were assumed to be cloud contaminated on the assumption that clouds occur in clusters.

Gutman et al. (1987) combined constant visible and thermal-IR thresholds with a standard deviation threshold that was a function of space and time for screening cloud-contaminated pixels from AVHRR GAC data over the Great Plains of the United States. The direct thresholds should be applied first in order to diminish the influence of uniform cloudy areas on the standard deviation. After this first screening, it was assumed that the lowest standard deviation for an approximately $40\times 40\,km$ area over a four week period represented the cloud-free, or background, variability of the area and that changes in this background variability with time were small relative to such changes caused by clouds. Empirically, they used a constant factor of 1.4 times the background variability to determine the threshold but note that an improvement would be to use a factor that is a function of time and space. Good results were obtained by using albedo as well as thermal background variabilities for the spatial coherence test. However, visible data generally provide a better contrast between clouds and land, especially for low warm clouds, and the background visible variability is more stable, while thermal data allows better detection of high thin cirrus clouds. A spatial coherence test based on the com-

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bined use of visible and thermal data should therefore provide even better results.

Saunders and Kriebel (1988) refined methodology suggested by Saunders (1986) that combined direct, dynamic, difference, and ratio thresholds and a spatial coherence test for AVHRR LAC data. A combination of five criteria were used with variations for open ocean, land, or coastal areas, for day or nighttime, and for 4- or 5-channel instruments. In all cases, a direct threshold based on the interactively identified coldest IR radiances from each image of channel 5, or channel 4 if 5 was not available, was used. This IR threshold was applied first, resulting in the elimination of a significant percent of cloudy pixels and thus a significant computational savings. The spatial coherence test was based on 3×3 pixel arrays of channel 4 brightness temperatures. Because of greater surface variability, the spatial coherence test was not used for land and coastal areas during the day and not for coastal areas at night. For the 5-channel AVHRR, a threshold based on the brightness temperature difference between channels 4 and 5 was used for day and night to help detect all but low clouds.

For daytime images, a dynamic visible threshold (see above) was also applied, followed by a threshold based on the ratio of the channel 2 to channel 1 reflectances. At sea, this ratio is well defined around 0.5 for cloud-free pixels because of the greater visible molecular and aerosol scattering, whereas a wide range of values greater than 1.0 occur for land due to the increased near-IR reflectance of vegetation. On the other hand, clouds, as well as snow and ice, concentrate around values of 1.0 due to their similar reflectances in both channels. For nighttime images, a threshold based on the brightness temperature difference of channels 3 and 4 was used primarily as a test for low clouds and fog, and one based on the differences for channel 3 and 5 (or 4 when 5 was not available) was used for sub-pixel and semi-transparent clouds as well as most medium and high-level clouds. Because they defined cloud-free pixels as those that passed all five tests for day or night images, the Saunders and Kriebel (1988) results likely included a significant percent of type-2 pixels. By the same token, the stringency of the combined tests ensured that very few cloud-contaminated pixels would be used for their sea or land-surface analysis (type-1 errors). The procedures of Saunders and Kriebel (1988) have been applied with good success by Saunders (1989) and Weare (1992).

A similar screening scheme for AVHRR GAC data, based on a combination of tests that utilize all five channels, has been used by Stowe et al. (1991). Different sets of tests are applied to day and nighttime scenes, and different test criteria are established for ocean and land regions. The tests include direct, difference, and ratio thresholds, and thresholds based on variability. A global set of constant thresholds are obtained from an associated database. Future development includes the dynamic setting of thresholds based on the analysis of clear pixels from the previous coverage of the area during operational processing.

Thiermann and Ruprecht (1992) used a variant of the usual spatial coherence test in which the pixel being investigated was given greater weight than the neighboring pixels. This was done by basing the variance metric on the difference between the central pixel only and its neighbors. This resulted in an increased sensitivity to cloud contamination. They followed this test with an IR threshold test to detect cases of homogeneous cloud cover that defy coherence tests. However, they determined the threshold from a histogram of pixels remaining after the application of their coherence test in order to minimize the number of falsely rejected pixels (type-2 errors).

5. MORE COMPLEX METHODS

A number of more involved procedures have been devised to improve upon the use of simple radiance thresholds described above, although all are necessarily based on differences in the spectral responses between Earth surfaces and clouds. For example, Bernstein (1982) applied a set of tests to extract cloud-free pixels from daytime AVHRR LAC data for use in determining SSTs. First, 30×30 pixel squares meeting a prescribed sun to satellite geometry and having a viewing angle that ensures the absence of specular reflection were identified for areas visually determined to be relatively cloud free (low channel 2 albedo). Then, the pixel or pixels having the minimum albedo within each area was used if that albedo was less than 2% and fell within an acceptable range of expected radiance according to a simple, linear Rayleigh scattering model. To ensure that these minima were not due to cloud shadows, pixels whose adjacent pixels' albedo were greater than 2% were rejected.

If multiple pixels passed these tests for each area, the maximum channel 4 and, if needed, channel 3 temperatures were used to select the pixel most likely to be cloud free. Importantly, the purpose of this screening was to select pixels for SST calculations whose results were to be compared with *in situ* values. Since relatively few pixels were required for this purpose, the restrictiveness of the criteria, and its consequent exclusion of many cloud-free pixels (type-2 errors), was not problematic. Such a data loss, however, would be unacceptable if the generation of an SST field, for example, was the goal.

Another study for deriving daytime SST values determined the empirical albedo as a function of solar zenith angle and used a nonlinear statistical model to determine cloud-free albedo as a function of Rayleigh scattering cross section (Simpson and Humphrey 1990). A pixel was rejected for SST calculation if the AVHRR channel 2 albedo was greater than the empirical value for its zenith angle or was outside a standard deviation of the model value. They called this procedure the local dynamic threshold nonlinear Rayleigh (LDTNLR) test. A direct threshold test, based on the channel 4 radiances, was then applied to detect clouds having low reflected-IR radiances due to

shadows from higher clouds and which could thus pass the LDTNLR test. Eckstein and Simpson (1991) also applied the LDTNLR procedure to CZCS data using that sensor's near-IR channel 5.

The averaging of pixels will improve the accuracy of radiance measurements since sensor noise errors are reduced. This is an effective procedure when a lower resolution is acceptable and when horizontal gradients are relatively small. However, the presence of cloud contamination will negate such improvement. An accurate method for detecting cloud contamination when averaging is used, is to compare the histogram of each set of averaged pixels with that of a set of cloud-free pixels. For the cloud-free pixels, the shape of the histogram will approximate a Gaussian spike that is centered at the average value. If the averaged pixels are contaminated, their histogram will contain a tail to one side. (For example, a cool tail will occur for IR channel data.) By fitting the spike of the cloud-free pixels, the center of the histogram, and therefore the desired average value of the contaminated pixels, may be determined (Smith et al. 1970). Although computational requirements are smaller when the comparison is done for low-level data (radiance counts), the atmospheric transmission conditions for the cloud-free pixels and the averaged pixels must then be similar.

More elaborate cloud detection methods for SST determinations are especially useful at night and exploit the differences in the IR channels' sensitivity to clouds. For example, the presence of clouds has the effect of causing SSTs calculated by split-, dual-, and triple-window algorithms to diverge (McClain 1989). A difference greater than a specified amount may be used to indicate cloud-contamination. Similarly, dual-window algorithms using channels 3 and 4 and channels 4 and 5 calculate the differences in brightness temperatures, $T3-T4$ and $T4-T5$, respectively (McClain et al. 1985). The ratio $(T3 - T4)/(T4 - T5)$ is not sensitive to atmospheric conditions other than cloudiness. For opaque clouds covering a pixel area, the emissivity of such clouds is less at channel 3 than at channels 4 and 5 and the ratio will be smaller. For partially cloudy pixels, the measured radiance is composed of the radiances from the warmer sea surface and the colder cloud tops. Since the radiance for channel 3 is more sensitive to temperature than the other channels, the ratio will be greater for such conditions. These methods are obviously more intensive computationally since they require multiple, quasi-independent calculations of SST for each pixel, even those subsequently rejected as cloudy.

A purely statistical approach using a principle component transformation with a split-merge classification has been developed recently for AVHRR nighttime IR data but should also be applicable to day IR and visible data (Gallaudet and Simpson 1991). The procedure first calculates the difference images for the channel 3, 4, and 5 combinations to improve the dynamic range of the data. (Only two difference images are required.) A principle component analysis is performed on the difference images, removing interband correlations and reducing the dimensionality of the data to a small number of clusters that adequately account for the variance. The clusters are then identified as cloud, land, or ocean data by a labelling algorithm using objective, *a priori* criteria. Note that the method can potentially identify types of clouds or ocean regimes should they result in separate clusters.

In addition to the detection of clouds, bispectral and multispectral cluster analyses can derive other cloud parameters (Reynolds and Vonder Haar 1977, Phulpin et al. 1983, Arking and Childs 1985, Key et al. 1989). Many other methods have been used for the derivation of cloud and other atmospheric information (Rossow et al. 1988, Stowe et al. 1988, Key and Barry 1989, Rossow et al. 1989, Detwiler 1990, Stone et al. 1990, Rossow and Schiffer 1991). Methods based on patterns of radiances have also been described (Parikh 1977, Wu et al. 1985, Chin et al. 1987, Ebert 1992). Garand (1986) discussed a method for the automated recognition of cloud patterns in satellite images for the purpose of cloud classification. Although cloud detection is performed in all these methods, their purpose is to study clouds or other atmospheric phenomena, not merely to screen them out. They are generally not appropriate for the operational detection of clouds by SeaWiFS or AVHRR because of their processing demands (including user interaction) or requirements for special, coincident ancillary data. Nevertheless, they can be used in special studies and to help validate the effectiveness of a cloud detection procedure.

6. EVALUATING METHODS

A number of criteria must be taken into account when evaluating the adequacy of any cloud-detection scheme. The extent to which a scheme eliminates cloud contaminated pixels (avoids type-1 errors) is perhaps the most important criterion since it will determine the ultimate accuracy of the derived Earth surface data. For cases where the sparseness of the data is of concern, a scheme's ability to not reject uncontaminated pixels (type-2 errors) becomes important. The robustness of a scheme is a measure of how applicable it is over diurnal and seasonal time ranges, regional or global scales, and the variety of cloud types and densities that can exist. For localized studies, schemes that are applicable over a narrow range of conditions may be acceptable; for global and long-term data sets, such as AVHRR SSTs and SeaWiFS pigment concentrations, clouds must be detected for a wide variety of conditions. Finally, the computational requirements of any scheme must be considered, especially in the case of real time or near-real time satellite data processing.

Thus, the selection of a cloud-detection scheme must obviously take into account the type of data processing (historical vs. near real-time), the areal coverage and time length of the data, the computing resources, and the strin-

gency of the accuracy requirements for the derived data. Schemes such as those outlined above and their variants may be used in any number of combinations to provide an optimum procedure for the task at hand. The setting of threshold values must also be fine-tuned for the specific requirements to ensure that, although cloud contamination by very small clouds may not be completely eliminated, any resulting errors will be contained within acceptable bounds. For operational usage, the effectiveness of the cloud detection algorithm must be evaluated frequently—an effort that is an essential element of overall data validation.

Glossary

AVHRR	Advanced Very High Resolution Radiometer
CZCS	Coastal Zone Color Scanner
EOS	Earth Observing Satellite
GAC	Global Area Coverage
IR	Infrared
LAC	Local Area Coverage
LDTNLR	Local Dynamic Threshold Nonlinear Raleigh (a test)
METEOSAT	Meteorological Satellite (European Space Agency)
MODIS	Moderate Resolution Imaging Spectrometer
NOAA	National Oceanic and Atmospheric Administration
SeaWiFS	Sea-viewing Wide Field-of-view Sensor
SPS	Sun, pixel, and satellite angle
SST	Sea Surface Temperature

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13. ABSTRACT *(Maximum 200 words)*

Methods for detecting and screening cloud contamination from satellite derived visible and infrared data are reviewed in this document. The methods are applicable to past, present, and future polar orbiting satellite radiometers. Such instruments include the Coastal Zone Color Scanner (CZCS), operational from 1978 through 1986; the Advanced Very High Resolution Radiometer (AVHRR); the Sea-viewing Wide Field-of-view Sensor (SeaWiFS), scheduled for launch in August 1993; and the Moderate Resolution Imaging Spectrometer (MODIS). Constant threshold methods are the least demanding computationally, and often provide adequate results. An improvement to these methods is to determine the thresholds dynamically by adjusting them according to the areal and temporal distributions of the surrounding pixels. Spatial coherence methods set thresholds based on the expected spatial variability of the data. Other statistically derived methods and various combinations of basic methods are also reviewed. The complexity of the methods is ultimately limited by the computing resources. Finally, some criteria for evaluating cloud screening methods are discussed.

14. SUBJECT TERMS

SeaWiFS, Cloud Detection, Cloud Screening, Satellite Remote Sensing, Visible Radiometers, Infrared Radiometers, AVHRR, Coastal Zone Color Scanner (CZCS), MODIS

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