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Specializing in METeorological SATellite Systems and Related Computer Technology

ONR

# CLOUD DATA COLLECTION, COMPOSITES AND ANALYSIS FOR WHOLE-SKY IMAGER (WSI) STUDIES

Final Report

Contract Number N00014-86-C-0463

Thomas H. Vonder Haar, Principal Investigator
METSAT, Inc.

July 1991

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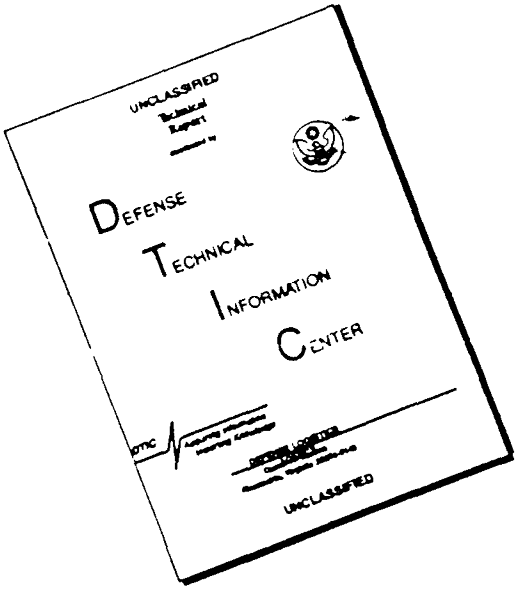

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operation in the successful generation of cloud frequency composites. An innovative "rubber-sheeting" algorithm was developed which not only improved the accuracy of the cloud composite products, but cut the generation time to one-fourth of the time required in the first year of the project.

3. The production of visible background radiance images which represent the cloud-free radiance and are produced from actual image data. To our knowledge, this data set is the most readily accessible archive of multi-year, multi-hour background radiance fields available. There are many applications for this product in space-based viewing in the visible band of the EM spectrum.

4. The production of multi-year seasonal cloud frequency composite images. This is the most extensive set of high-resolution cloud composite images available today. In comparison to the current standard for global cloud climatologies, our composites depict cloud frequency at two orders of magnitude higher resolution (four magnitudes higher areal resolution).

5. Development of automated routines to process and display a topographic data base to match the satellite sector and projection. This includes a set of routines with complex coordinate transformation routines to extract the topographic data for any sector we define in satellite or common projection coordinates.

   In addition, we have developed innovative routines to use the topographic data base for more accurate infrared cloud discrimination. The topographic image is used to identify land/water regimes and to assign a standard lapse rate adjustment for altitude to the infrared brightness temperature.

6. Development of a library of efficient routines to remap both geostationary and polar-orbitter satellite imagery into the whole-sky imager hemispheric projection. These routines are necessary for providing a common coordinate system for comparison of the two data sets. This unique view of the satellite imagery has provided a new area of research into cloud-free arcs, which are essential in the SDI and/or space-ground laser communication operational environment.

A description of these and other research results and innovations are listed in the attached papers. The work done here has already been a springboard to several new areas of research and many of the results and related tools are in use daily at several major universities and government research facilities.

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88-107

# NEW CLOUD COMPOSITE CLIMATOLOGIES USING METEOROLOGICAL SATELLITE IMAGERY

Edward M. Tomlinson
Donald L. Reinke
Chi-Fan Shih
and
Thomas H. Vonder Haar

October, 1988

This paper was presented at CIDOS-88, White Oak, Maryland, October 18-20, 1988. This research was supported by the SDIO via ONR Contract #N00014-86-C-0463.

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This paper was presented at CIDOS-88, White Oak, MD, October 18-20, 1988.

## 1.0 BACKGROUND

Atmospheric variability affects the utility of most existing and planned DOD weapons systems. The goal in assessing the impact of the atmosphere is to establish the frequency and extent of the system performance degradation caused by the environment and identify both design changes and operational employment procedures which will minimize the atmospheric impact and thereby optimize the system performance. With proper understanding of the effect of the atmosphere on system performance, coupled with reliable evaluations of the spatial and temporal occurrences of the constraining environmental phenomena, optimization of system

Historically, cloud climatologies have been produced using observations of sky cover made by weather observers at weather stations around the world. Cloud cover frequency distributions have been computed, generally, by hour of the day and month. These climatologies have been produced for many observation stations around the world, including many over the ocean from ships.

Additional cloud frequency climatologies have been computed using the Air Force 3-D NEPH data base. This cloud climatology provides cloud amount frequency distributions for every three hours during the day and is provided for each month at 46km-spaced grid points over the globe (Hughes, 1979).

When analyses of the probability of cloud-free line-of-sight (PCFLOS) are required, the cloud frequencies from these climatologies have been used (Harms, 1987). Generally, this approach has provided the most reliable assessment of cloud-free scenes presently available.

In the case of high energy beam propagation through the earth's atmosphere, clouds definitely limit system performance. In fact, with current technology, clouds in the line-of-sight are show stoppers. Hence, to maximize the availability of high energy weapons, sites with low frequencies of cloud occurrence need to be identified. The significant issue is the identification of high PCFLOS sites where the correlated PCFLOS can be evaluated. Additionally, specific azimuth directions and elevation angles need to be considered.

The Lund-Shanklin PCFLOS curves can be used in conjunction with the cloud climatologies previously described to provide PCFLOS for specific locations. This approach provides single station (or in the case of 3-D NEPH, grid point) PCFLOS with consideration for elevation look angle. This approach, however, cannot provide correlated PCFLOS evaluation for multiple locations nor can PCFLOS evaluation for locations other than established observation sites or 3-D NEPH grid points be provided. In addition, there is no azimuth dependence in the observation (neither surface observations nor 3-D NEPH) and, hence, this required information cannot be provided using the Lund-Shanklin PCFLOS curves.

Recognizing these shortcomings, SDIO has sponsored an effort to produce new, high time and space resolution cloud composite climatologies using meteorological satellite cloud imagery. METSAT, Inc. has been collecting and archiving satellite data and producing cloud composite climatologies to be used in ground-based laser site selection, simulations and system studies.

## 2.0 NEW CLOUD CLIMATOLOGIES

In order to construct the newly required cloud frequency climatologies with significant areal coverage, a comprehensive and reliable data base of satellite imagery must be available. GOES-West visible and infrared imagery has been collected over the western United States since 1 March 1988. The geographic area extends from 103W to 125W in longitude and 36N to 49N in latitude. The visible imagery is collected every half hour during daylight hours and the infrared imagery is collected every half hour during the 24-hour day. The 6.8 micron water vapor channel imagery has also been collected every half hour. These data are quality-controlled and archived on magnetic tape.

New ground-based whole-sky camera data are also being obtained (Johnson, 1987) for detailed study of site clouds. One rev of DMSP visible and infrared imagery over the western United States is being provided daily by the Air Force Global Weather Center. Data are received in the three nautical mile smoothed format. These images are being archived for co-analyses with the GOES satellite and ground imagery.

The basic idea behind satellite cloud composite climatologies is the production of cloud frequency distribution with a high spatial resolution, i.e., climatologies with spatial resolutions on the order of the satellite imagery (Klitch _et_ _al_., 1985). After cloud covered pixels are identified in each image, the images are composited to produce cloud frequency values for each pixel location. For this effort, composites are constructed for each hour of the day during a month to add extensive time coverage to the spatial results.

Several issues must be addressed in utilizing the satellite images for cloud composite construction. Satellite navigation must be exact to insure the proper location of each pixel in the image. Precise alignment of images is required in order to provide geographically reliable composites. Navigational corrections have been applied to individual images when required and computer techniques developed to exactly align images before compositing.

Another issue is quanititative cloud discrimination. The cloud frequency distributions will certainly be no more reliable than the cloud discrimination techniques used. Dynamic background images have been produced for each hour for each month. The dynamic backgrounds are required due to the large variations in background radiances over the geographic domain. These background images are combined with individual images for that hour to produce individual binary cloud images, i.e., images where each pixel represents cloud or no cloud.

The individual binary images for each hour are then composited, producing a composite image where the brightness value at each pixel indicates the cloud frequency for total cloud at that pixel for that hour. The variation in brightness from pixel to pixel indicates the variation in cloud frequency from location to location. Variations in brightness of a pixel at a given location for various hours yield the temporal variability in cloudiness for that particular site.

Initial composites for the western U.S. are being produced for SDIO for the months of March, July and September, 1988. Satellite data collection is continuing and additional composites will be provided as additional data becomes available. Following a winter season composite from early 1989, additional seasonal samples over the entire study area will be produced to determine interannual variability of the cloud conditions.

# REFERENCES

Harms, Dewey E., 1987: Cloud-free line of sight (CFLOS) simulation, Fifth Tri-Service Clouds Modeling Workshop, Annapolis, MD, 339-352, June, 1987.

Hughes, N. A. and A. Henderson-Sellers, 1985: Global 3D-nephanalysis of total cloud climatology for 1979, J. Climate Appl. Meteor., 24, 669-686.

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Klitch, M. A., J. F. Weaver, F. P. Kelly and T. H. Vonder Haar, 1985: Convective cloud climatologies constructed from satellite imagery, Monthly Weather Review, 113, 326-337.

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88-112

# NEW CLOUD COMPOSITE CLIMATOLOGIES USING METEOROLOGICAL SATELLITE IMAGERY

Edward M. Tomlinson, Donald L. Reinke and Thomas H. Vonder Haar

METSAT, Inc.

December, 1988

Presented at the SPIE Conference, January 15-20, 1989, Los Angeles, CA.

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# ABSTRACT

Atmospheric variability affects the utility of most existing and planned DOD weapons systems. The goal in assessing the impact of the atmosphere is to establish the frequency and extent of the system performance degradation caused by the environment and identify both design changes and operational employment procedures which will minimize the atmospheric impact and thereby optimize the system performance. With proper understanding of the effect of the atmosphere on system performance coupled with reliable evaluations of the spatial and temporal occurrences of the constraining environmental phenomena, optimization of system performance is possible.

In the case of high energy beam propagation through the earth's atmosphere, clouds are a limiting atmospheric phenomena. With current technology, clouds in the line-of-sight are "show stoppers". Hence to maximize the availability of high energy weapons, sites with low frequencies of cloud occurrence should be selected.

For several reasons we have been collecting and archiving meteorological satellite imagery over the western U.S. for use in evaluating cloud conditions at the local scale. Visible light data have been archived during daylight hours and thermal infrared data collected 24 hours each day from the GOES satellite. Using these data, composite cloud climatology images have been constructed which give the frequency of occurrence of cloud cover by hour and month over the western U.S. with a spatial resolution on the order of the satellite pixel resolution.

This paper will describe the techniques used in the construction of these composite cloud climatologies and their use in local area studies. Additional applications of this new satellite-derived cloud climatology will be discussed.

## 1.0 BACKGROUND

Atmospheric variability affects the utility of most existing and planned DOD weapons systems. The goal in assessing the impact of the atmosphere is to establish the frequency and extent of the system performance degradation caused by the environment and identify both design changes and operational employment procedures which will minimize the atmospheric impact and thereby optimize performance. With proper understanding of the effect of the atmosphere on system performance, coupled with reliable evaluations of the spatial and temporal occurrences of the constraining environmental phenomena, optimization of system performance is possible.

Historically, cloud climatologies have been produced using observations of sky cover made by weather observers at weather stations around the world. Cloud cover frequency distributions have been computed, generally, by hour of the day and month. These climatologies have been produced for many observation stations around the world, including many locations over the ocean from ships.

Additional cloud frequency climatologies have been computed using the Air Force 3-D NEPH data base. This cloud climatology provides cloud amount frequency distributions for every three hours during the day and is provided for each month at 46km-spaced grid points over the globe.[1]

When analyses of the probability of cloud-free line-of-sight (PCFLOS) are required, the cloud frequencies from the aforementioned climatologies have been used.[2] Generally, this approach has provided the most reliable assessment of cloud-free scenes presently available.

In the case of high energy beam propagation through the earth's atmosphere, clouds definitely limit system performance. In fact, with current technology, clouds in the line-of-sight are "show stoppers". Hence, to maximize the availability of high energy weapons, sites with low frequencies of cloud occurrence need to be identified. The significant issues are (a) the identification of high PCFLOS sites and (b) the evaluation of joint PCFLOS among sites. Additionally, specific azimuth directions and elevation angles need to be considered.

The Lund-Shanklin PCFLOS curves can be used in conjunction with the cloud climatologies previously available to provide PCFLOS for specific locations. This approach provides single station (or in the case of 3-D NEPH, grid point) PCFLOS with consideration for elevation look angle. This approach, however, cannot provide correlated PCFLOS evaluation for adequate numbers of multiple locations since no PCFLOS evaluation is possible for locations other than established observation sites or 3-D NEPH grid points. In addition, there is no azimuth dependence in the observation (neither surface observations nor 3-D NEPH) and, hence, this required information cannot be provided using the Lund-Shanklin PCFLOS curves.

Recognizing these shortcomings, SDIO has sponsored an effort to produce new, high time and space resolution cloud composite climatologies using meteorological satellite cloud imagery. METSAT, Inc. has been collecting and archiving satellite data and producing cloud composite climatologies to be used in various site selection evaluations, simulations and system studies.

## 2.0 NEW CLOUD CLIMATOLOGIES

In order to construct the newly required cloud frequency climatologies with significant areal coverage, a comprehensive and reliable data base of satellite imagery must be available. GOES-West visible and infrared imagery has been collected over the western United States since 1 March 1988. The geographic area extends from 103W to 125W in longitude and 36N to 49N in latitude. The visible imagery is collected every half hour during daylight hours and the infrared imagery is collected every half hour during the 24-hour day. The 6.8 micron water vapor channel imagery has also been collected every half hour. These data are quality-controlled and archived on magnetic tape.

For detailed study of clouds at some sites, new ground-based whole-sky camera data are also being obtained.[3] One orbit of DMSP visible and infrared imagery over the western United States is being provided daily by the Air Force Global Weather Center. Data are received in the three nautical mile smoothed format. These images are being archived for co-analyses using DMSP satellite, GOES satellite and ground imagery.

The basic approach for satellite cloud composite climatologies is the use of certain image processing algorithms for production of cloud frequency distribution with a high spatial resolution (i.e., climatologies with spatial resolutions on the order of the satellite imagery).[4] After cloud covered pixels are identified in each image, the images are composited to produce cloud frequency values for each pixel location. For this effort, composites are constructed for each hour of the day during a month to add extensive time coverage to the spatial coverage results.[5]

Several issues must be addressed in utilizing the satellite images for cloud composite construction. Satellite navigation must be exact to insure the proper location of each pixel in the image. Precise alignment of images is required in order to provide geographically reliable composites. Navigational corrections have been applied to individual images when required and computer techniques developed to exactly align images before compositing.

Another issue is quantitative cloud discrimination. The cloud frequency distributions will certainly be no more reliable than the cloud discrimination techniques used. Dynamic background images have been produced for each hour for each month. The dynamic backgrounds are required due to the large variations in background radiances over the geographic domain. These background images are combined with individual images for that hour to produce individual binary cloud images, i.e., images where each pixel represents cloud or no cloud.

The individual binary images for each hour are then composited, producing a composite image where the digital value at each pixel indicates the cloud frequency for total cloud at that pixel for that hour. When displayed, the variation in brightness from pixel to pixel indicates the variation in cloud frequency from location to location. Variations in brightness of a pixel at a given location for various hours yield the temporal variability in cloudiness for that particular site. A number of additional options for constructing output arrays are available to address specific application (e.g. cloud persistence).

## 3.0 CONSTRUCTION OF COMPOSITES

A significant amount of automated and manual processing is required to produce cloud composites. Storage requirements for the sector collected over the western U.S. is approximately 140 megabytes of memory per day. Because of this large storage requirement, raw full resolution satellite imagery is stored on magnetic tape for further processing. Each image is processed to produce a navigation database. This database is used to locate each picture element, or pixel, in the geocentric coordinate system and eventually to remap the images into a Lambert Conformal or Mercator map projection.

Because the geosynchronous satellite "navigation" can be in error, manual verification and, if necessary, adjustment is performed on each image. If the navigation is in error, image adjustment techniques are used to "fit" the graphic overlay and the navigation table updated to correspond with the new display.

Once the images have been properly aligned they are copied to separate tapes for each hour of the day. This allows us to load all of the images for a specific hour, say 1500 UTC, onto the system and produce a composite of all of the images for that hour. One month of data for a specific hour is approximately 140 megabytes of data so the storage requirement is the same as that for one day of data for all hours.

The process of determining which pixels are cloudy requires an automated technique to discriminate between cloud and background. The technique used in this effort was to construct a background image which represents the radiance that would be detected in a cloud-free scene. This background is then compared to each image to discriminate the occurrence of cloud. In the visible image, a cloud will appear brighter (higher radiance) than the background. The exception would be a very bright background such as white sand or a highly reflective surface such as snow or smooth water. In the infrared region, a cloud should appear cooler (lower radiance) than the underlying surface. The exception here is that very low clouds will be close to the same temperature as the underlying surface, or warmer during inversion conditions. Special effort is being made to perfect techniques to better discriminate over varying surfaces and to minimize the occasional error effects on the overall composite. Because of the areal extent of the sector we are compositing, we are not able to completely account for the anomalies in one portion without impacting the cloud discrimination in another portion. The next phase of the project will include the use of a topographic database and surface observations to better address these problem areas.

Full resolution composites for each hour are produced by an automated process which counts the number of days during the month that each data pixel is cloudy. A new image is then constructed in which the frequency of occurrence of cloud is assigned to each pixel. The image will be composed of pixels with values that range from 0 to 100, representing the frequency of occurrence of cloud at each pixel. The image can be displayed as a grey shade or true color image with ranges of cloud frequency highlighted in preferred colors. For example, see Figure 1.

Initial composites for the western U.S. are being produced for the months of March, July and September, 1988. Satellite data collection is continuing and additional composites will be provided as additional data becomes available. Following a winter season composite from early 1989, additional seasonal samples over the entire study area will be produced to determine interannual variability of the cloud conditions.

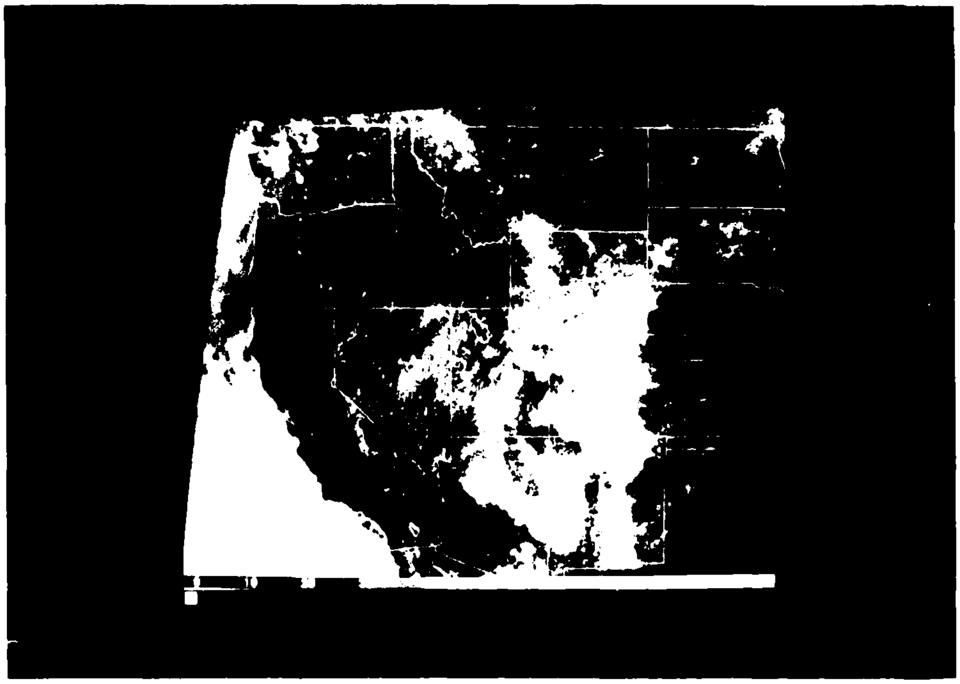

Figure 1. July 1988 2115Z visible composite over western United States.

## 4.0 ACKNOWLEGEMENTS

Our colleagues, Mr. C.F. Shih and Ms. C. Combs, contributed to the cloud analyses. This research was supported by the SDIO via ONR Contract #N00014-86-C-0463.

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2. Harms, Dewey E., 1987: Cloud-free line of sight (CFLOS) simulation, Fifth Tri-Service Clouds Modeling Workshop, Annapolis, MD, 339-352, June, 1987.

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# HIGH RESOLUTION SPACE/TIME CLOUD CLIMATOLOGIES FROM SATELLITE DATA

by

Edward M. Tomlinson,

Donald L. Reinke,

and

Thomas H. Vonder Haar

October, 1989

This paper was presented at the Tenth Annual EOSAEL/TWI Conference held in Las Cruces, New Mexico, November 28-30, 1989.

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# ABSTRACT

Atmospheric variability affects the utility of most existing and planned DoD weapon systems. For many systems which require propagation of signals through the earth's atmosphere, clouds significantly impact the system performance. For some of these systems, clouds in the line-of-sight are "show stoppers." Hence, to maximize the availability of cloud limited systems, reliable analyses need to be available to assess cloud occurrence.

METSAT, Inc. has been collecting and archiving meteorological satellite imagery over the U.S. for use in evaluating cloud conditions at the local scale. Visible data have been archived during daylight hours and thermal infrared data have been collected 24 hours each day from the GOES-West satellite. Using these data, composite cloud climatology images are being constructed which give the frequency of occurrence of cloud cover by hour and month over the U.S. with a spatial resolution of the order of the satellite pixel resolution.

This paper will describe the techniques used in the construction of these composite cloud climatologies and their use in local area studies. Examples of composite cloud climatologies for various seasons over the U.S. will be presented. Additional applications of this new satellite-derived cloud climatology will be discussed including use of this technique for conditional probabilities of cloud cover for individual locations.

## 1.0 INTRODUCTION

Atmospheric cloud variability affects the utility of many existing and planned DoD weapon systems. The goal in assessing the impact of the cloud cover is to establish the frequency and extent of the system performance degradation caused by clouds and identify both design changes and operational employment procedures which will minimize the impact of clouds and thereby optimize performance. With proper understanding of the cloud effects on system performance, coupled with reliable climatologies of spatial and temporal occurrences of cloud cover, optimization of system performance is possible.

Historically, cloud climatologies have been produced using observations of sky cover made by observers at weather stations around the world. Cloud cover frequency distributions have been computed, generally by hour of the day and month. These climatologies have been produced for many observation stations, including locations over the ocean from ships. Additional cloud frequency climatologies have been computed using the Air Force 3-D NEPH database. This cloud climatology provides cloud amount frequency distributions for every three hours during the day and is provided for each month at 46 Km-spaced grid points over the globe. We term these two sources of cloud information "conventional" climatologies.

When analyses of the probability of cloud-free line-of-sight (PCFLOS) are required, the cloud frequencies from the aforementioned conventional climatologies have been used. Generally, this approach has provided the most reliable assessment of the availability of cloud-free lines-of-sight presently available.

In the case of high energy beam propagation through the earth's atmosphere, clouds impose significant limitations to system performance. In fact, with current technology, clouds in the line-of-sight are "show stoppers." Hence, to maximize the availability of high energy weapons, sites with low frequencies of cloud occurrence need to be identified. The significant issues are (a) the identification of high PCFLOS sites and (b) the evaluation of joint PCFLOS among sites. Additionally, specific azimuth directions and elevation angles need to be considered. The highest possible spatial resolution cloud information is desired.

The Lund-Shanklin PCFLOS curves can be used in conjunction with the conventional cloud climatologies previously noted to provide PCFLOS estimates for specific locations. This approach provides single station (or in the case of 3-D NEPH, grid point) PCFLOS estimates with consideration for elevation look angle. This approach, however, cannot provide correlated PCFLOS evaluation for multiple locations and lacks analysis capabilities for azimuth dependence.

Recognizing these shortcomings, SDIO has sponsored an effort to produce new, high temporal and spatial resolution cloud frequency composite climatologies using meteorological satellite cloud imagery (Tomlinson et al., 1988; Reinke et al., 1989). METSAT, Inc. has been collecting and archiving satellite data and producing cloud frequency composite climatologies for use in various site selection evaluations, simulations and system studies.

In order to produce these cloud frequency climatologies, a comprehensive and reliable database of satellite imagery is needed. GOES visible and infrared imagery has been collected over the western United States beginning March 1, 1988, and was expanded to include the entire continental

U.S. in April, 1989. The visible imagery is collected during daylight hours and the infrared imagery is collected during the 24-hour day. The 6.8 micron water vapor channel imagery has also been collected. Data are quality-controlled and archived on magnetic tape.

The basic approach for satellite cloud composite climatologies is the use of image processing algorithms for production of cloud frequency distribution with a high spatial resolution (i.e., climatologies with spatial resolutions on the order of the satellite imagery). After cloud covered pixels are identified in each image, the images are composited to produce cloud frequency values for each pixel location. For this effort, composites are constructed for each hour of the day during a month to add extensive time coverage to the spatial coverage results.

Several key issues have been addressed in utilizing the satellite images for cloud frequency composite construction. Satellite navigation must be exact to insure the proper location of each pixel in the image. Equally important is precise alignment of images in order to provide geographically reliable composites. Navigational corrections have been applied to individual images as required and computer techniques developed to exactly align images before compositing.

Quantitative cloud discrimination has been studied and refined for many years. The cloud frequency distributions will certainly be no more reliable than the cloud discrimination techniques used. Dynamic background images have been produced for each hour for each month. The dynamic backgrounds are required due to the large variations in background radiances over the geographic domain. These background images are combined with individual images for that hour to produce individual binary cloud images; i.e., images where each pixel represents cloud or no-cloud.

The individual binary images for each hour are then composited, producing a composite image where the digital value at each pixel indicates the cloud frequency for total cloud at that pixel for that hour. When displayed, the variation in brightness from pixel to pixel indicates the variation in cloud frequency from location to location. Variations in brightness of a pixel at a given location for various hours yield the temporal variability in cloudiness for that particular site. A number of additional options for constructing output arrays are available to address specific application (e.g., cloud persistence, spatial correlations).

## 2.0 CONSTRUCTION OF WSI CLOUD COMPOSITES

A significant amount of both automated and man-interactive computer processing is required to produce cloud composites. Storage requirements for the sector collected over the western U.S. is approximately 140 megabytes of memory per day. Because of this large storage requirement, raw full-resolution satellite imagery is stored on magnetic tape for further processing. Each image is processed to produce a navigation database which is used to locate each picture element, or pixel, in the geocentric coordinate system and eventually to remap the images into a Lambert Conformal or Mercator map projection. Figure 1 shows a flow diagram of the composite process.

Because the geosynchronous satellite "navigation" can be in error, manual verification and adjustment, if necessary, is performed on each image. If the navigation is in error, image adjustment techniques are used to align the graphic overlay and the navigation elements table updated to correspond with the new display. These adjustments were originally performed by man-interactive computer processing but recent alignment software development now allows for more automated and objective alignment man-interactive option.

Once the images have been properly aligned they are copied to separate tapes for each hour of the day. This makes it convenient to load numerous images for a specific hour, say 1500 UTC, onto the system and composite all the images for that hour. One month of data for a specific hour is approximately 140 megabytes of data so the storage requirement is about the same as that for one day of data for all hours.

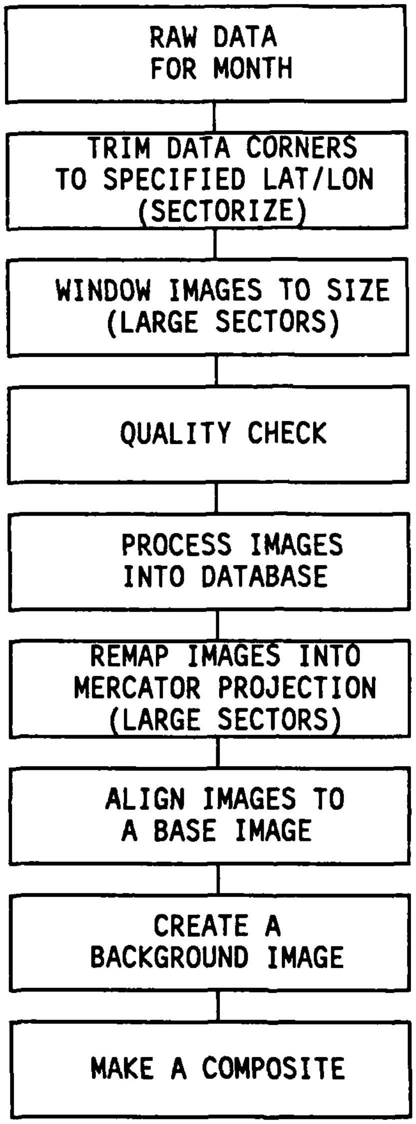

FIGURE 1: Procedures for constructing composites.

The process of determining which pixels are cloudy requires an automated technique to discriminate between cloud and background. The technique used in this effort requires the construction of a dynamic background image which represents the radiance that would be detected in a cloud-free scene. This background is then compared to each image to discriminate the occurrence of cloud. In the visible image, a cloud will appear brighter (higher radiance) than the background. The exception would be a very bright or a highly reflective surface such as sand, snow or specular reflectance from water. In the infrared region, a cloud should appear cooler (lower radiance) than the underlying surface. The exception here is that very low clouds will be close to the same temperature (i.e., same radiance) as the underlying surface, or even warmer (i.e., high radiance) during temperature inversion conditions. Special effort is being made to develop reliable techniques to better discriminate over varying background surfaces and to minimize the occasional threshold error effects on the overall composite. Because of the large geographic extent of the sectors composited, unless special techniques are used, we are not able to completely account for the anomalies in one portion of the image sector without impacting the cloud discrimination in another portion. Current efforts to improve reliability include the use of a topographic database, surface observations and a hierarchy of methods to better address these problem areas.

Full-resolution composites for each hour are produced by an automated process which counts the number of days during the month that each data pixel location is cloudy. A new image is then constructed in which the frequency of occurrence of cloud is assigned to each pixel. The image will be composed of pixels with values that range from 0 to 100 representing the percent frequency of occurrence of cloud at each pixel. The image can be displayed as a grey shade or true color image with ranges of cloud frequency highlighted in preferred colors. For example, see figs. 2-6 where black equals 0% and white equals 100%.

Initial composites for the western U.S. are being produced for the months of March, July (figs. 2-5) and September, 1988, and March, 1989, along with April, 1989 for the entire continental U.S. (see fig. 5).

Satellite data collection is continuing and additional composites will be provided as additional data become available. Following a winter season composite from early 1989, additional seasonal samples over the entire study area will be produced to determine interannual variability of the cloud conditions.

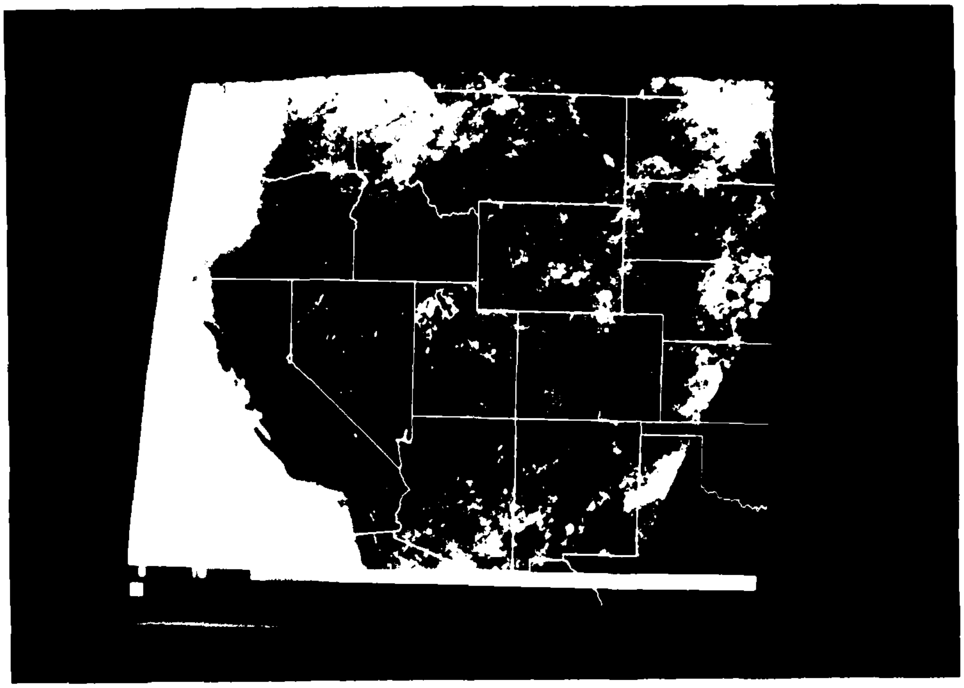

FIGURE 2: Cloud frequency composite from GOES visible imagery for July, 1988 at 1500 GMT.

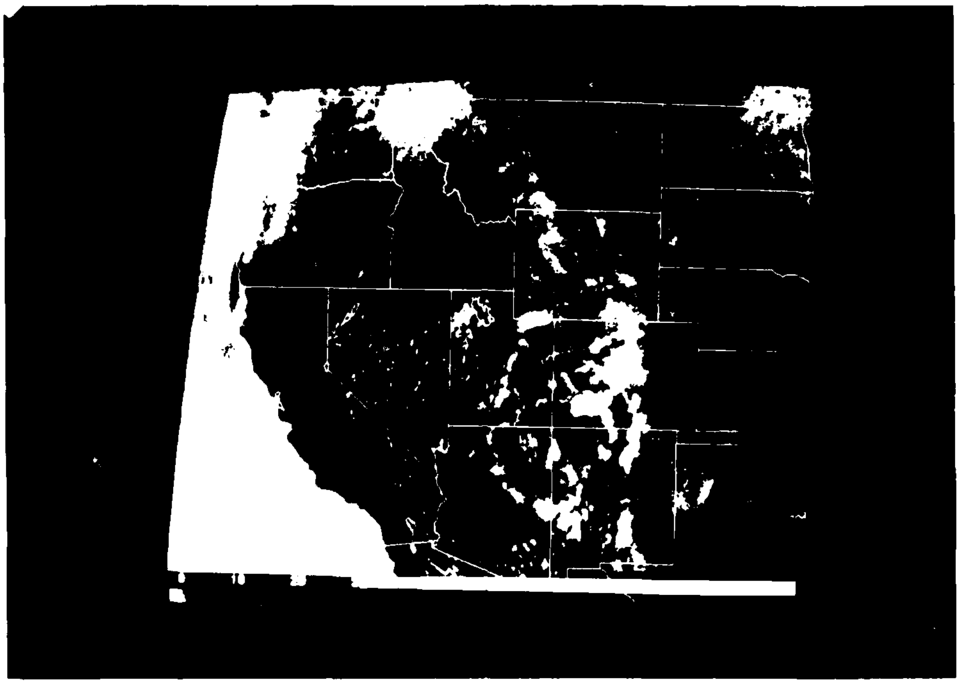

FIGURE 3: Cloud frequency composite from GOES visible imagery for July, 1988 at 1800 GMT.

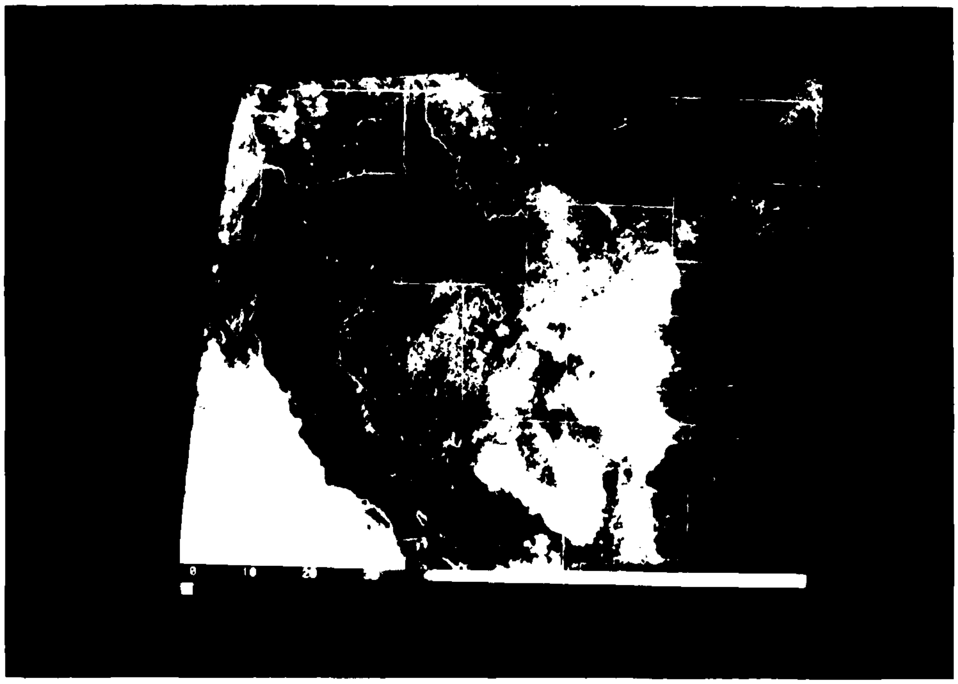

FIGURE 4: Cloud frequency composite from GOES visible imagery for July, 1988 at 2100 GMT.

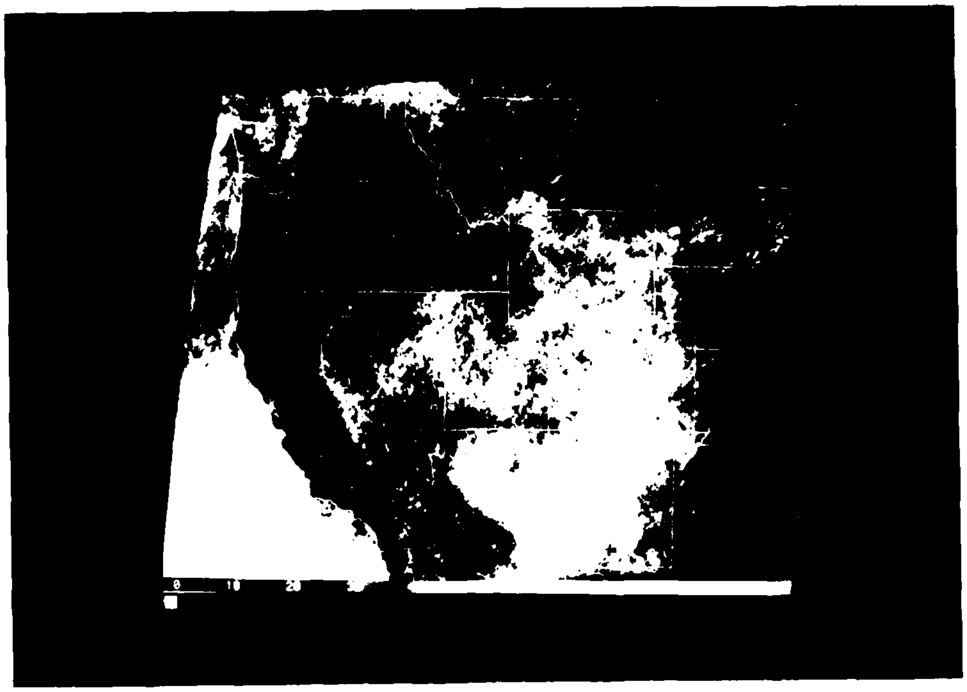

FIGURE 5: Cloud frequency composite from GOES visible imagery for July, 1988 at 0000 GMT.

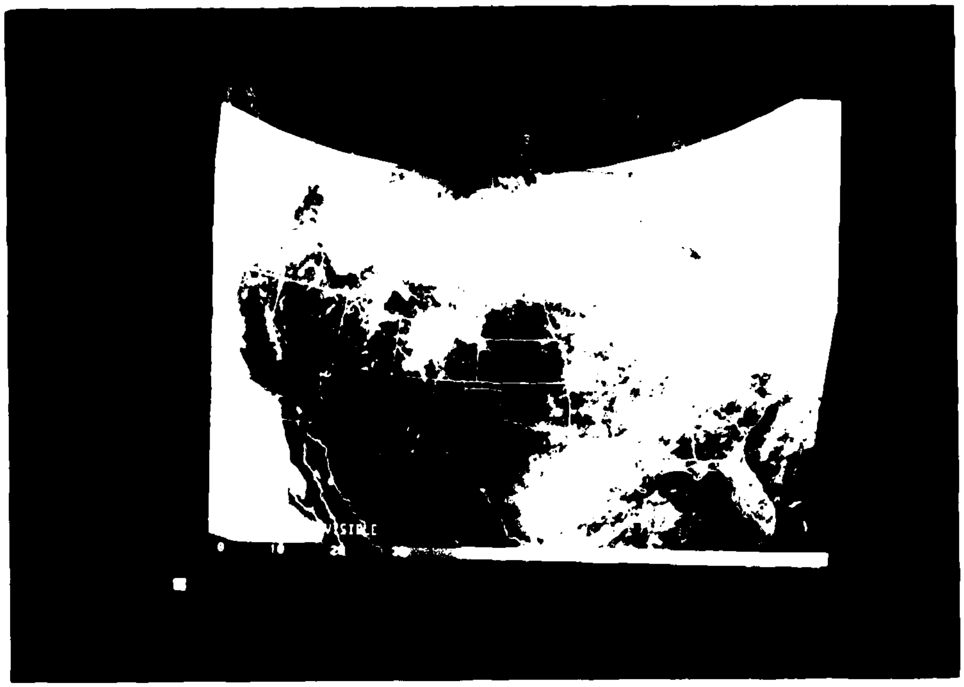

FIGURE 6: Cloud frequency composite from GOES visible imagery over U.S., April, 1989 at 1800 GMT.

## 3.0 APPLICATIONS OF COMPOSITES AND CLIMATOLOGIES

There are a number of applications of the new high space/time resolution satellite cloud climatologies that are anelogous to the standard synoptic climatologies or cloud analyses. Among these are conditional climatology (probability) forecasts, empirical input to climatological or dynamical models, real-time verification of forecasts and determination of cloud-free or cloudy sites.

The composite climatologies and individual cloud/no-cloud images can also be used to produce a probability cloud forecast (Kelly, 1988). The forecast can be based solely on the frequency of occurrence of cloud cover, or on the probability that a given location will be cloudy based on the current condition of either clear or cloudy. The latter would be based on tables generated from individual cloud/no-cloud images and the frequency of occurrence composites.

Cloud/no-cloud or cloud frequency composites can also serve as input to test cloud models, dynamic models which carry cloud liquid water or models which use cloud cover to compute radiative heating/cooling rates. The high resolution composites or cloud/no-cloud images can also serve as a verification tool for the real-time assessment of model performance.

Cloud composites offer higher resolution, both spatially and temporal, than conventional climatologies. The problem of site selection for cloud-free or cloudy locations often requires a resolution below that of the conventional synoptic network. The nominal 2.5 Km resolution of composite climatologies offer the best resolution available for this purpose. In addition, probability of cloud-free arcs can be computed for any point on the composite image.

## 4.0 FUTURE EFFORTS

Our intent is to continue to build up our composite base while improving the composite generation techniques. The initial composites consist of selected months which are representative of seasonal regimes and time intervals of three hours. Future products will include multi-year composites for the select months, 30-minute interval composites over smaller areas, reduced resolution composites over the continental U.S. and 24-hour infrared composites.

An infrared cloud discrimination model is being tuned to allow for continuous day/night cloud composites. The current phase of the project includes the use of topographic data, multi-channel infrared discrimination techniques and a hierarchy of discrimination techniques such as discrimination of clouds against snow/ice to distinguish stratus from fog and detecting clouds over bright backgrounds such as white sand.

In addition, we will produce composites of other channels such as the water vapor (6.7 µ) channel to examine their signatures. These composites may aid in improvements of cloud frequency composite climatologies.

We will also perform additional statistical analyses on the climatologies to determine if there is a consistent structure or trend in certain geographic regions that has not been detected by conventional climatologies. These tests will also provide some measure of comparison between the synoptic cloud climatologies and the satellite derived frequency composites.

## 5.0 SUMMARY

Cloud climatologies have been an important part of our social and meteoro-logical databases since man first discovered that some locations on earth are "cloudier" than others. We have found many applications for existing cloud climatologies and many applications are waiting for more reliable climatologies or a higher temporal and spatial resolution. We present in this discussion our attempt to produce what we believe to be the best cloud climatology database available to meet those requirements, taking into account today's environmental data collection platforms.

These satellite cloud composite climatologies and cloud/no-cloud images produced from geostationary satellite imagery provide a high-resolution cloud climatology for a large area of the globe, including much of the ocean areas that have sparse, if any, synoptic observations.

This effort is making efficient use of digital satellite imagery that has been available for decades but has not, for lack of resources or technique development, been used extensively to assess climatological cloud frequencies. New computer processing techniques and simple cloud discrimination models are being used to produce these satellite cloud climatologies that will provide a valuable addition to our meteorological database.

## 6.0 ACKNOWLEDGMENTS

This research has been sponsored by SDIO and ONR via contract N00014-86-C-0463.

## 7.0 REFERENCES

Kelly, F., 1988: Spatial and Temporal Short Range Total Cloud Cover Estimation by Metric Analysis of Composite Imagery, 152pp, Ph.D. Dissertation, Department of Atmospheric Science, Colorado State University, Fort Collins, Colorado 80523.

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Tomlinson, E., D. Reinke and T. Vonder Haar, 1988: New Cloud Composite Climatologies Using Meteorological Satellite Imagery, Presented at SPIE Conference, January 15-20, 1989, Los Angeles, CA.

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90-102

# INTERANNUAL VARIABILITY IN CLOUD FREQUENCY AS DETERMINED FROM GOES SATELLITE

by

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and

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January, 1990

This paper was presented at the CIDOS 89/90 Conference in Monterey, California, January 9-11, 1990.

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# ABSTRACT

METSAT, Inc. has collected special high-spatial and time resolution GOES digital imagery over portions of the United States since March, 1988. High-spatial resolution cloud composite climatologies have been produced for four months of each year, representing the frequency of cloud occurrence for each season. As the project completes its second year, initial interannual comparisons of the cloud composites can be made. For each month, the cloud composites provide the cloud frequency for each pixel location and the overall spatial distribution of cloud cover over the entire geographic domain.

To represent interannual variability, monthly composite images are differenced and a third image produced. The color or grey shade of each pixel in the new image represents the quantitative difference in cloudiness between the two years. Difference images have been produced for selected hourly time periods in March and September. Each shows definite interannual variation for various locations, especially over California. Additional comparisons with conventional data from these months will be presented.

## 1.0 INTRODUCTION

Historically, cloud climatologies have been produced using observations of sky cover made by observers at weather stations around the world. Cloud cover frequency distributions have been computed generally by hour of the day and month. These climatologies have been produced for many observation stations, including locations over the ocean from ships. Additional cloud frequency climatologies have been computed using the Air Force 3-D NEPH (now RTNEPH) database. This cloud climatology provides cloud amount frequency distributions for every three hours during the day and is provided for each month at 46 km-spaced grid points over the globe. These two sources of cloud information are termed "conventional" climatologies.

When analyses of the probability of cloud-free line-of-sight (PCFLOS) are required, the cloud frequencies from the aforementioned conventional climatologies have been used. Generally, this approach has provided the most reliable assessment of the availability of cloud-free lines-of-sight presently available.

The Lund-Shanklin PCFLOS curves can be used in conjunction with the conventional cloud climatologies previously noted to provide PCFLOS estimates for specific locations. This approach provides single station (or in the case of 3-D NEPH, grid point) PCFLOS estimates with consideration for elevation look angle. This approach, however, cannot provide correlated PCFLOS evaluation for multiple locations and lacks analysis capabilities for azimuth dependence.

Recognizing these shortcomings, SDIO has sponsored an effort to produce new, high-temporal and spatial resolution cloud frequency composite climatologies using meteorological satellite cloud imagery (Tomlinson _et al_., 1988; Reinke _et al_., 1989). METSAT, Inc. has been collecting and archiving satellite data and producing cloud frequency composite climatologies for use in various site selection evaluations, simulations and system studies.

In order to produce these cloud frequency climatologies, a comprehensive and reliable database of satellite imagery is needed. GOES visible and infrared imagery has been collected over the western United States beginning March 1, 1988, and was expanded to include the entire continental U.S. in April, 1989. The visible imagery is collected during daylight hours and the infrared imagery is collected during the 24-hour day. The 6.8 micron water vapor channel imagery has also been collected. Data are quality-controlled and archived on magnetic tape.

The basic approach for satellite cloud composite climatologies is the use of image processing algorithms for production of cloud frequency distribution with a high-spatial resolution (i.e., climatologies with spatial resolutions on the order of the satellite imagery). After cloud covered pixels are identified in each image, the images are composited to produce cloud frequency values for each pixel location. For this effort, composites are constructed for each hour of the day during a month to add extensive time coverage to the spatial coverage results.

Several key issues have been addressed in utilizing the satellite images for cloud frequency composite construction. Satellite navigation must be exact to insure the proper location of each pixel in the image. Equally important is precise alignment of images in order to provide geographically reliable composites. Navigational corrections have been applied to individual images as required and computer techniques developed to exactly align images before compositing.

Quantitative cloud discrimination has been studied and refined for many years. The cloud frequency distributions will certainly be no more reliable than the cloud discrimination techniques used. Dynamic background images have been produced for each hour for each month. The dynamic backgrounds are required due to the large variations in background radiances over the geographic domain. These background images are combined with individual images for that hour to produce individual binary cloud images (i.e., images where each pixel represents cloud or no-cloud).

The individual binary images for each hour are then composited, producing a composite image where the digital value at each pixel indicates the cloud frequency for total cloud at that pixel for that hour. When displayed, the variation in brightness from pixel to pixel indicates the variation in cloud frequency from location to location. Variations in brightness of a pixel at a given location for various hours yield the temporal variability in cloudiness for that particular site. A number of additional options for constructing output arrays are available to address specific application (e.g., cloud persistence, spatial correlations).

## 2.0 CONSTRUCTION OF WSI CLOUD COMPOSITES

A significant amount of both automated and man-interactive computer processing is required to produce cloud composites. Storage requirements for the sector collected over the western U.S. is approximately 140 megabytes of memory per day. Because of this large storage requirement, raw full-resolution satellite imagery is stored on magnetic tape for further processing. Each image is processed to produce a navigation database which is used to locate each picture element, or pixel, in the geocentric coordinate system and eventually to remap the images into a Lambert Conformal or Mercator map projection.

Because the geosynchronous satellite "navigation" can be in error, manual verification and adjustment, if necessary, are performed on each image. If the navigation is in error, image adjustment techniques are used to align the graphic overlay and the navigation elements table updated to correspond with the new display. These adjustments were originally performed by man-interactive computer processing but recent alignment software development now allows for more automated and objective alignment man-interactive option.

The process of determining which pixels are cloudy requires an automated technique to discriminate between cloud and background. The technique used in this effort requires the construction of a dynamic background image which represents the radiance that would be detected in a cloud-free scene. This background is then compared to each image to discriminate the occurrence of cloud. In the visible image, a cloud will appear brighter (higher radiance) than the background. The exception would be a very bright or a highly reflective surface such as sand, snow or specular reflectance from water. In the infrared region, a cloud should appear cooler (lower radiance) than the underlying surface. The exception here is that very low clouds will be close to the same temperature (i.e., same radiance) as the underlying surface, or even warmer (i.e., high radiance) during temperature inversion conditions. Special effort is being made to develop reliable techniques to better discriminate over varying background surfaces and to minimize the occasional threshold error effects on the overall composite. Because of the large geographic extent of the sectors composited, unless special techniques are used, we are not able to completely account for the anomalies in one portion of the image sector without impacting the cloud discrimination in another portion. Current efforts to improve reliability include the use of a topographic database, surface observations and a hierarchy of methods to better address these problem areas.

Full-resolution composites for each hour are produced by an automated process which counts the number of days during the month that each data pixel location is cloudy. A new image is then constructed in which the frequency of occurrence of cloud is assigned to each pixel. The image will be composed of pixels with values that range from 0 to 100 representing the percent frequency of occurrence of cloud at each pixel. The image can be displayed as a grey shade or true color image with ranges of cloud frequency highlighted in preferred colors.

Initial composites for the western U.S. are being produced for the months of March, July and September, 1988, and March, 1989, along with April, 1989 for the entire continental U.S. Satellite data collection is continuing and additional composites will be provided as additional data become available. Following a winter season composite from early 1989, additional seasonal samples over the entire study area have been produced to determine interannual variability of the cloud conditions.

## 3.0 INTERANNUAL COMPARISONS

With the production of composites from March of 1989 we were first able to compare composites on an interannual basis. There was some concern, as the 1988 composites were produced from GOES-6 and the 1989 from GOES-7, however, the remapping difficulties were overcome and except for some areas on the periphery we were able to overlap the two data sets. Figure 1 shows a cloud frequency composite at 2100Z for March of 1988. The grey shades represent the percentage of the month that a given location was cloudy, ranging from near zero in the dark areas to 100% in the white. Note that the region over California was predominately cloud-free along with the anticipated cloud-free regions in the desert southwest. The importance of a representative period of record became obvious when the March 1989 composites were built (Figure 2). The region over California was much cloudier in 1989 in the clear areas that were evident in the 1988 composite. A similar set of images is shown in Figures 3 and 4 where the 2100Z composites from September of 1988 and 1989 can be compared. Again, the anomalous cloud-free conditions over the west coast do not appear in the fall of 1989. The variability is even more evident when the images are compared directly as shown in figures.

Several pieces of information have begun to surface during the analysis of these images. By comparing the two composite images directly a "difference" image is made (Figure 5). This image will highlight regions that exhibit a high degree of variability from year to year, as well as delineating locations that maintain a relatively constant cloud frequency of occurrence. We are very much interested in the areas that are consistently clear, or consistently cloudy. Another analysis which can be performed is to look at the persistence probability of cloud cover during each year to isolate the locations which have a high probability of remaining cloudy or cloud-free, or becoming cloudy or cloud-free.

The early examination of these images indicate that there appear to be some locations which can be characterized as predominately cloudy or cloud-free. By analyzing the images together with a corresponding topographic image we can find a meteorologically sound explanation for most. Some cloud-free locations, however, appear to be quite anomalous and are being identified for further study. Some of the questions may become clearer as we move into the third year of the effort and add the March, 1990 composite to the analysis base.

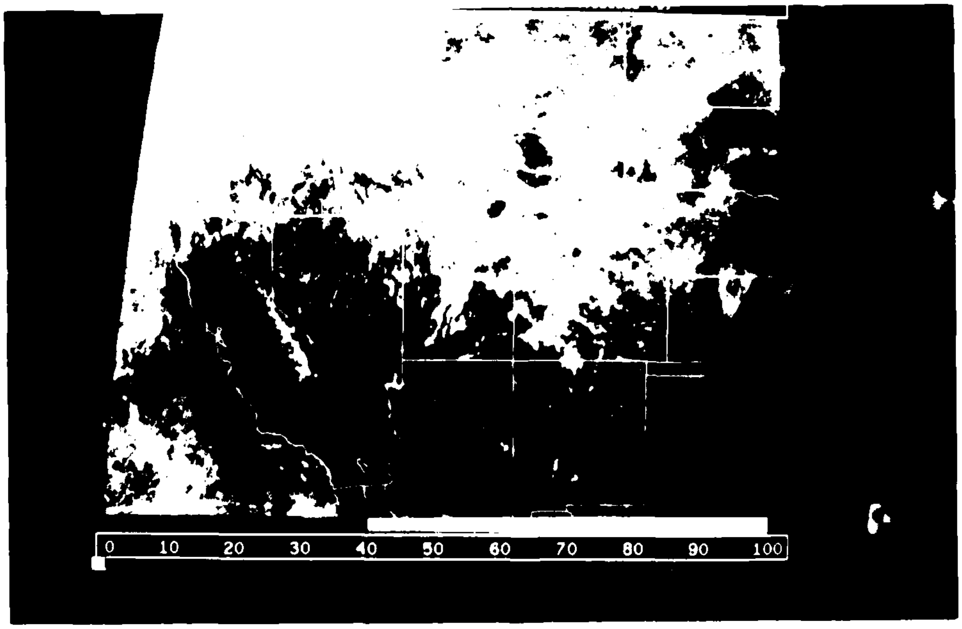

Figure 1. Cloud frequency composite from GOES-West visible imagery for March 1988, 2100Z. Grey shades indicate the frequency of occurrence of cloud at each pixel for the month. Values range from near zero in the dark areas to almost 100% in the white areas.

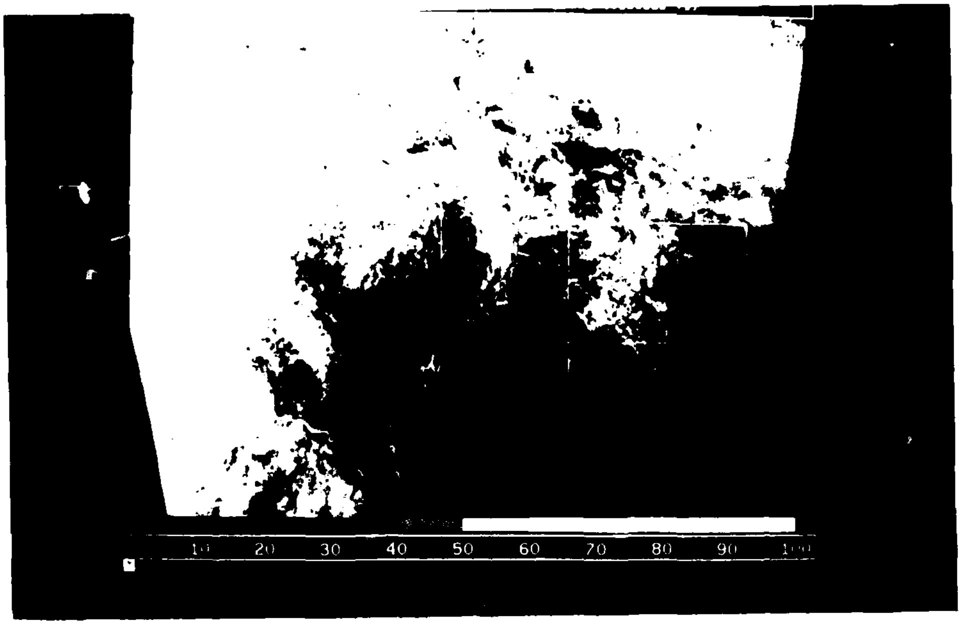

Figure 2. Cloud frequency composite from GOES-West visible imagery for March, 1989, 2100Z.

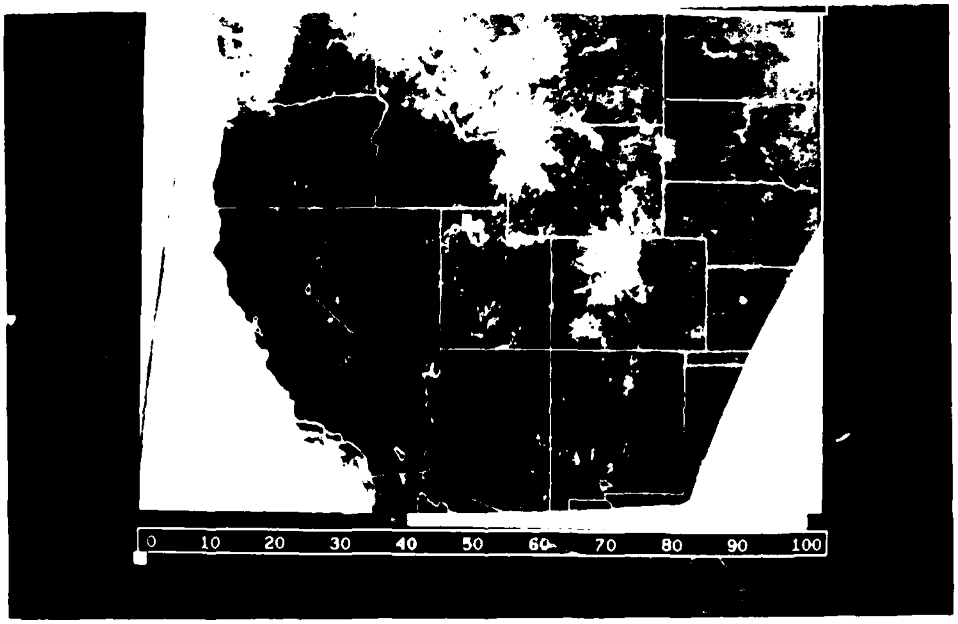

Figure 3. Cloud frequency composite from GOES-West visible imagery for September, 1988, 2100Z.

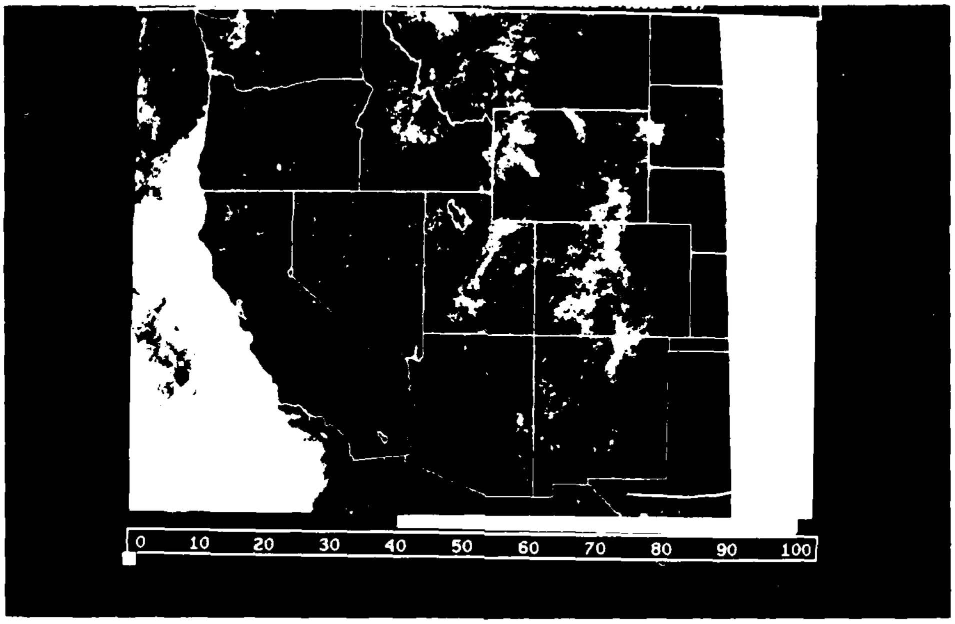

Figure 4. Cloud frequency composite from GOES-West visible imagery for September 1989, 2100Z.

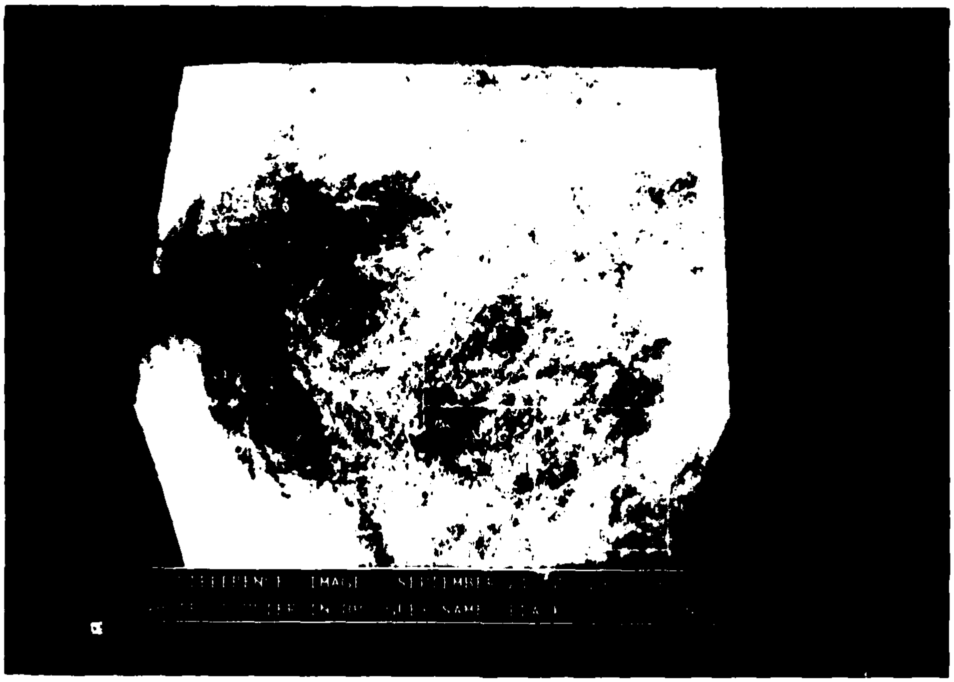

Figure 5. Image showing the difference of September 2100Z composites for 1988 and 1989. The dark areas indicate cloudier conditions in 1989 and the light areas show where it was cloudier in 1988 with grey indicating little or no change (less than 10%).

## 4.0 APPLICATIONS OF COMPOSITES AND CLIMATOLOGIES

There are a number of applications of the new high space/time resolution satellite cloud climatologies that are analogous to the standard synoptic climatologies or cloud analyses. Among these are conditional climatology (probability) forecasts, empirical input to climatological or dynamical models, real-time verification of forecasts and determination of cloud-free or cloudy sites.

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# PERSISTENCE FORECASTS FROM HIGH-RESOLUTION CLOUD COMPOSITE CLIMATOLOGIES

by

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and
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January, 1990

This paper was presented as a poster session at the CIDOS 89/90 Conference in Monterey, California, January 9-11, 1990.

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# ABSTRACT

High-resolution cloud composite climatologies are now being constructed which provide cloud information at a temporal and spatial resolution that has not been available in the past. These cloud frequency composites are used to produce cloud persistence and cloud formation/dissipation statistics. These statistics are based on the observed systematic trends and on the temporal variability derived from full-resolution (1-2 km) GOES imagery obtained every 30 minutes.

Individual GOES visible cloud scenes have been navigated and aligned geographically to produce cloud frequency composites. Cloud persistence and frequency of occurrence statistics are derived for each pixel at the full-resolution of the satellite sensor. The statistic is then applied to a baseline image to produce a probability of occurrence of cloud at each pixel for each time interval. In addition, a probability threshold may be used to create a cloud/no cloud image for each image time step (an estimated satellite image.)

Statistical cloud forecasts are then generated, at each pixel, for a 1-6 hour window at one-hour intervals. The hourly interval was chosen to provide a better response in the cloud field over the length of the forecast period, however, the statistical forecast could also be generated for 30-minute time steps (or shorter in the case of abundant rapid-scan imagery available in our data set).

## 1.0 METHODOLOGY

The cloud forecast technique proposed here is designed to take advantage of the high resolution cloud composites and persistence probabilities generated from the images used to construct the composites.

Composite images are first built for the forecast area of interest. These composites are generated from the highest resolution satellite imagery available and at the highest temporal resolution which gives a reasonable sample size (rapid-scan imagery is normally not available in sufficient quantity to produce composites or persistence images). Composites were prepared for this presentation from hourly GOES-East images over Florida during the month of April, 1989. They were constructed for the hours 1500Z to 2200Z inclusive, at one-hour intervals. Figures 1 and 2 are sample composites from 1500Z and 2100Z respectively. Construction of composites begins with the alignment of each image with a base image. This time consuming task is necessary to minimize the error inherent in the navigation and geo-location of image pixels. Only quality-controlled images without noise or data drops were used to construct composites. In this case, 28 images were available for each hour. The aligned images are then processed to produce a "background" cloud-free image. The background is produced by sampling each image for the "warmest" pixel. Over the course of the month, the warmest pixel should represent the cloud-free background radiance (exceptions are bright sandy or snow covered ground). Then finally each image is compared to the background to produce a cloud/no cloud image. A pixel is considered cloudy if it is "cooler" (brighter) than the background by more than nine brightness counts. This threshold is used to minimize the detection of noise as cloud. The cloud frequency at each pixel is then computed by simply dividing the number of cloudy days by the number of days available. The resultant cloud frequencies are displayed as a composite image.

Persistence images are prepared from the aligned images by comparing each image from the initial time with the image from the forecast time. If a cloud exists at a pixel on the initial image and a cloud exists at the same pixel location on the target image it is summed for that pixel. After repeating the process for each pixel of the image, and for each day of the month, we are able to compute the probability of: (a) being cloudy at the forecast time if cloudy at the initial time (Figure 3) and (b) being cloudy at the forecast time if clear at the initial time (Figure 4). (By simply subtracting the probability of being cloudy from 100%, we can conversely compute the probability of being clear.) The resultant probabilities are again displayed as an image. Note that in many locations there is a higher probability of being cloudy at 2100Z if the location is initially clear at 1500Z.

These two probability images, the frequency of occurrence of cloud and the probability of being cloudy based on an initial condition (referred to as the "conditional probability"), can then be used to produce a probability forecast for cloud at each full-resolution pixel. One technique is to compute a cloud occurrence probability by adding the cloud persistence probability to the frequency or simply using both probabilities in a forecast matrix in which the final probability is based on the cloud frequency and/or conditional probability exceeding a pre-determined threshold.

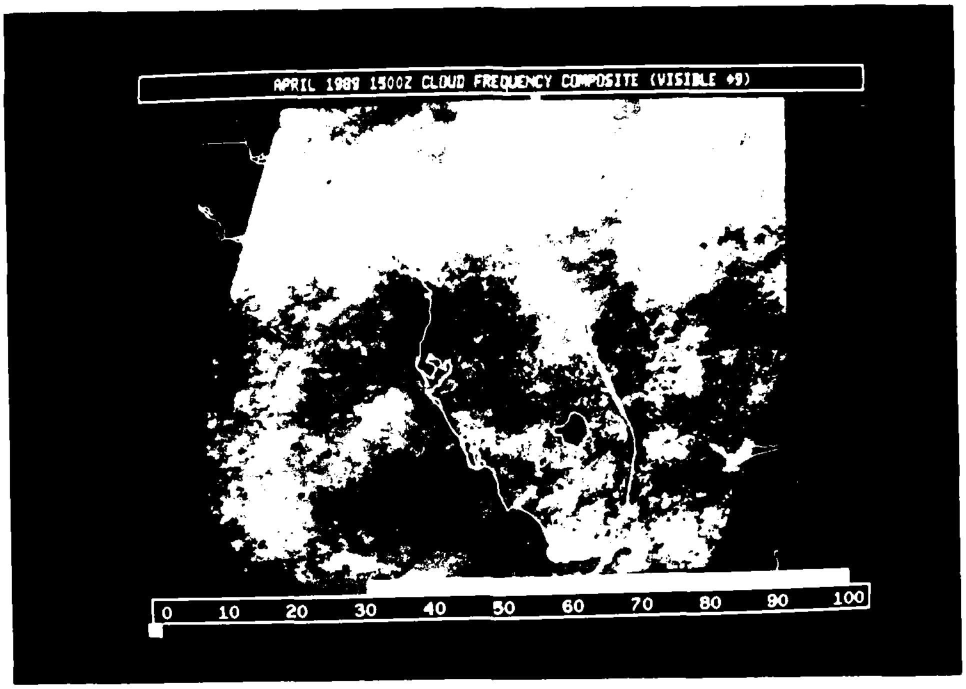

Figure 1. Cloud frequency composite from GOES-East visible imagery for April, 1989, 1500Z. Grey shades represent the frequency of occurrence of cloud at each pixel.

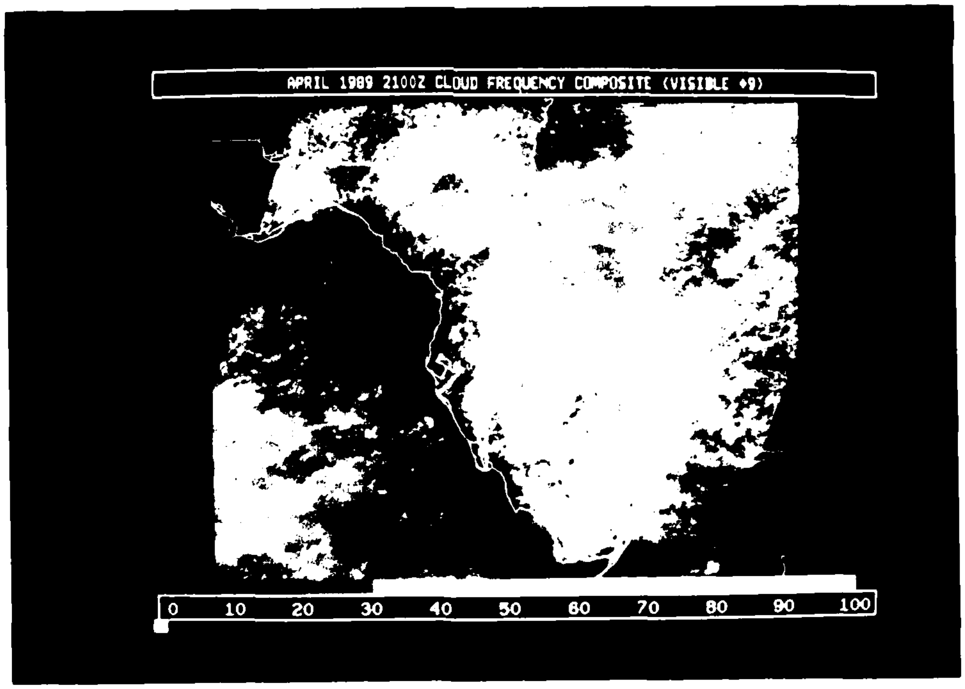

Figure 2. Cloud frequency composite from GOES-East visible imagery for April, 1989, 2100Z.

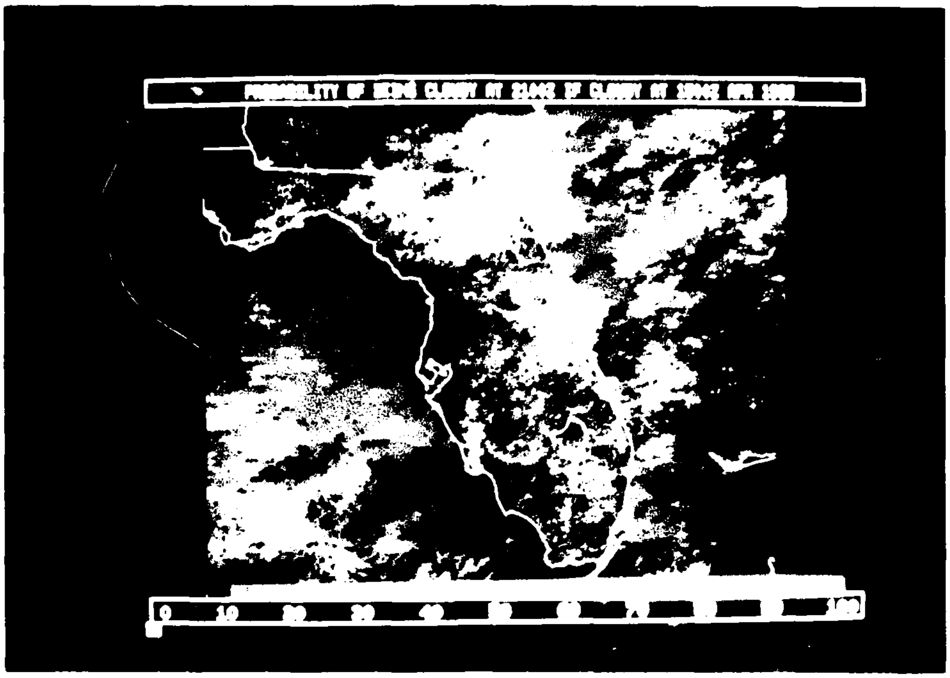

Figure 3. Cloud conditional frequency composite from GOES-East visible imagery for April, 1989, 2100Z. This image gives the frequency of occurrence of cloud at 2100Z if a location is initially cloudy at 1500Z.

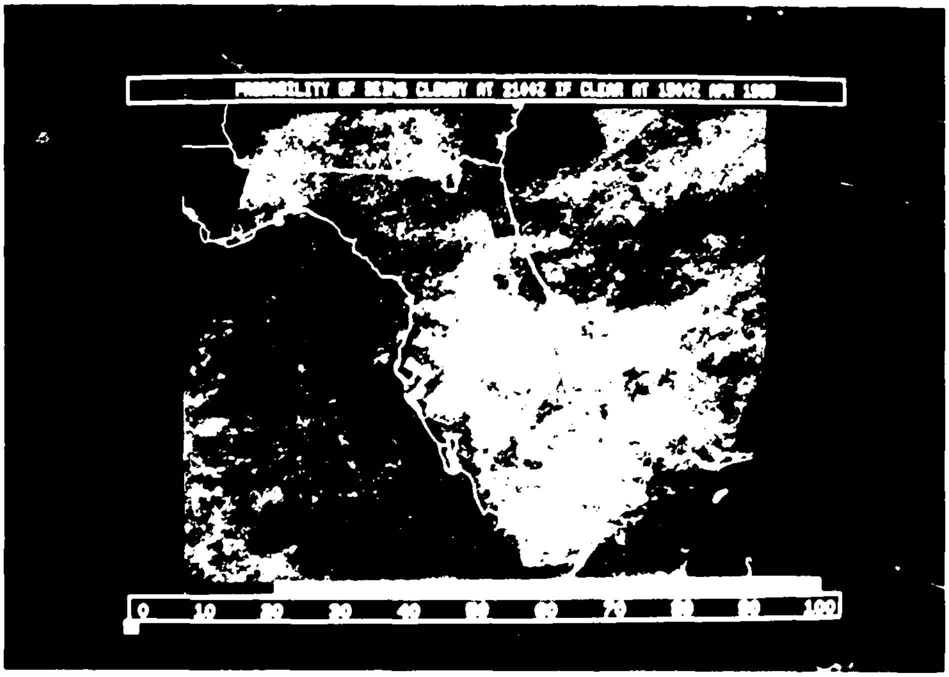

Figure 4. Cloud conditional frequency composite from GOES-East visible imagery for April, 1989, 2100Z. This image gives the frequency of occurrence of cloud at 2100Z if a location is initially clear at 1500Z.

## 2.0 CONCLUSIONS

Cloud frequency composites themselves can serve as a forecast tool. The composite for 2100Z will give the frequency of occurrence of cloud over each pixel which is a reasonable first guess for a forecast of being cloudy at that location. In addition, individual composites can be compared to note the change in frequency of occurrence of cloud. This would be representative of the "Systematic variation" in the cloud cover over that sector. The composite, however, does not include the information available from a persistence image which represents the "Random variation" in cloud cover. To add this component, cloud persistence images can be constructed to indicate the probability of being cloudy when a known initial condition exists. In this instance, the cloud persistence image constructed over Florida gives a lower frequency of occurrence of cloud when the initial image is cloudy and a higher frequency of being cloudy when initially clear over many locations on the image.

Additional probabilities can be constructed by stratifying the initial image by wind direction, air mass or other climatologically significant categories. This technique has been used successfully for standard synoptic variables such as ceiling and visibility, and should be easily adapted to digital satellite imagery. Future studies will include the examination of stratified probabilities.

# ACKNOWLEDGMENTS

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# TECHNIQUE FOR CLOUD DISCRIMINATION ON GOES INFRARED IMAGERY

by

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and

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January, 1990

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# ABSTRACT

Cloud discrimination is the process of determining whether an element of a digital satellite image is covered entirely or partially by cloud. Accurate cloud discrimination is a critical step in the use of satellite imagery for determination of cloud-free line-of-sight as well as a necessary step in the preparation of high-resolution cloud composite climatologies. Many techniques have been used to minimize the inherent errors involved in determining the presence of a cloud within an image picture element (pixel). We present a technique which involves geographic data to separate the water from land and topographic elevation data to determine a more accurate separation between the surface and cloud-top temperatures (the difference that forms the basis for most discrimination techniques). Suggestions are also made for future refinements to the technique which take more complete advantage of the information present in the geo-topo database.

Results from two test cases are presented which use GOES digital infrared data sets over Florida and over the southern coastal region of California. In addition, a short review of cloud discrimination techniques is presented as background for the present technique.

## 1.0 METHODOLOGY

The cloud discrimination technique used here is an automated technique for determining a cloud/no cloud threshold from visible and/or infrared satellite imagery. It is a combination of several methods which have been used with varying degrees of success. The technique uses a brightness count threshold which is determined dynamically from the data values within the image. The use of a threshold for cloud discrimination is common. What is shown here is an improved method for determining that threshold.

The technique is based on a *multi-modal distribution* in the histogram of pixel values within the image or a portion of the image. The theory is that there should be a mode at the count value which corresponds to water, land and cloud pixels. In the visible, the water pixels should "clump" around the lower (darker) values, the land should show up lighter and the clouds will naturally appear in the higher (brighter) count range. The distribution of water, land and/or cloud pixels should be such that a point between the modes as a cloud/no cloud (or land/water) threshold can be selected. In practice, this technique does not always work because there are often land pixels that appear brighter than cloudy pixels. In addition, the distribution may be highly skewed toward land or cloud. In an effort to improve the technique, another cloud discrimination method is included which uses the homogeneity of water/land/cloud features to further isolate the candidate pixels when building the image histogram.

The assumption here is that clouds and land will be homogeneous in nature. By running a filter over the data points and only selecting those whose value is very close to their neighbors, most of the boundary (i.e., partly cloudy) points can be eliminated. The remaining points should then be either water, land or cloud (or sand/snow/ice - another item to be dealt with). These points can then be used to generate a much "cleaner" multimodal distribution for determining a threshold.

Each pixel in the image is assigned an operator that represents the homogeneity of the pixel. The one used in the example is an "absolute difference", which is computed by taking the mean difference between the value at the pixel and neighbors. Each pixel can then be "binned" by its operator value. For example, all of the pixels with an operator of zero will represent those pixels that are the same as their neighbor. All of the pixels with an operator value of 20 will vary from their neighbor by an average of 20 pixel counts and will most likely represent pixels that are clouds next to land. By isolating these pixels into bins, only the homogeneous pixels can be used to construct our histogram (Figure 1) and the best threshold can be selected. Conversely, the pixels with a high operator value to isolate the "boundary" values can be used. These boundary values should produce a mode at the actual threshold between land and cloud.

An additional refinement of the technique shown here is to use it on selected portions of an image based on the topographic characteristics of the area. The DMA topographic database is used to isolate land and water points on the satellite image. The cloud discriminator then runs separately on land and water. Finally, the topographic database is used to identify the elevations where it is very difficult to distinguish cloud from snow, again treating these pixels separately.

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        BIVARIATE FREQ DISTRIBUTION    ORDINATE = ( RAW INFRARED )

          0     1     2     3     4     5     6     7     8     9    10
 65    101.  133.   50.   20.    7.    3.    0.    3.    1.    0.    0.
 66    126.   99.   38.   25.    5.    4.    1.    2.    2.    0.    1.
 67    106.  128.   62.   21.   13.    6.    0.    1.    3.    0.    0.
 68     57.   82.   46.   31.   13.    3.    1.    3.    0.    0.    1.
 69     76.   82.   64.   22.   10.   10.    6.    2.    1.    0.    1.
 70     43.   72.   36.   19.    8.    6.    3.    2.    1.    0.    0.
 71     42.   60.   43.   24.   14.    4.    3.    1.    0.    1.    0.
 72     69.   94.   42.   33.   19.    8.    2.    5.    2.    3.    0.
 73     86.   91.   47.   19.   10.   12.    9.    5.    4.    1.    2.
 74     91.  115.   55.   26.   23.    9.    1.    8.    2.    2.    3.
 75    122.  149.   76.   34.   12.    8.    9.    2.    1.    1.    2.
 76    106.  135.   92.   29.   18.   10.   10.    3.    2.    1.    2.
 77    110.  170.   83.   30.   17.    6.    7.    0.    7.    2.    0.
 78    227.  195.  144.   45.   28.   18.    9.    5.    2.    3.    0.
 79    206.  189.  107.   47.   27.   15.    7.    5.    4.    1.    0.
 80    221.  282.   97.   55.   26.   15.    7.    6.    3.    4.    3.
 81    322.  292.  130.   67.   36.   13.   10.   10.    2.    1.    5.
 82    110.  178.   76.   56.   26.    9.   11.   10.    6.    0.    3.
 83    103.  119.   90.   64.   22.   11.    6.    7.    5.    2.    3.
 84    104.  115.   61.   56.   29.   17.    9.    8.    9.    3.    1.
 85    133.  115.   79.   58.   48.   19.   14.   12.    6.   10.    5.
 86     77.   84.   51.   39.   24.   21.    7.    4.    6.    2.    3.
 87     66.   78.   54.   32.   21.   20.   10.    8.    5.    5.    5.
 88    135.  108.   74.   44.   28.   16.   15.    8.    7.    4.    1.
 89    188.  134.   64.   47.   27.   11.    9.   17.    5.    4.    1.
 90    211.  172.   60.   27.   14.   17.    5.    6.    8.    8.    4.
 91    301.  193.   76.   16.   21.   18.    9.    8.    2.    2.    2.
 92    378.  204.   71.   37.   50.   29.   13.   13.   13.   10.    1.
 93    179.  167.   49.   36.   28.   15.   16.   12.   12.    2.    3.
 94    136.  153.   66.   30.   16.    9.    6.    9.    5.    6.    3.
 95    131.  127.   69.   41.   27.   14.    8.    6.    7.    7.    3.
 96    127.  132.   52.   44.   25.   22.    8.    8.   12.    7.    2.
 97    121.   90.   49.   48.   29.   20.   10.    3.   10.    4.    1.
 98     72.   64.   45.   37.   22.   11.   16.   10.    3.    6.    4.
 99     67.   61.   59.   28.   26.    4.   14.    5.    2.    4.    1.
100     53.   47.   37.   38.   26.   15.   12.    9.    4.    7.    4.
101     42.   39.   35.   36.   31.   19.   18.   13.    6.    8.    5.
102     34.   39.   34.   19.   24.   14.   13.    8.    5.    4.    4.
103     27.   35.   37.   31.   17.   19.    7.   12.    4.    6.    1.
104     38.   45.   31.   16.   23.   11.    9.    5.    4.    4.    3.
105     36.   32.   18.   22.   20.   18.   13.   19.   12.   16.    2.
106     24.   18.   26.   29.   11.   22.   12.    6.    5.    4.    3.
107     13.   24.    9.   13.   13.   13.    5.    3.    4.    6.    2.
108     36.   17.   27.   32.   16.   14.    8.    2.    5.    3.    3.
109     15.   24.   16.   16.    9.   17.    7.    9.    7.    7.    3.
110     21.   20.   21.   15.   10.   14.   10.    6.    8.    6.    5.
111     29.   45.   19.   16.   21.   26.   14.    8.    9.    5.    3.
112     61.   26.   25.   22.   19.   10.   11.    3.    5.    0.    3.
113     20.   23.    6.   10.    7.    7.    5.    5.    6.    2.    0.
114     29.   21.   18.   26.   14.   15.   13.    3.    2.    5.    2.
115     30.   35.   14.   17.   10.    6.    7.   12.    3.    2.    1.
116     47.   32.   23.   24.   31.   10.   12.    4.    5.    5.    3.
117     35.   26.   33.   17.   10.   15.    1.    3.    5.    2.    5.
118     22.   25.   25.    9.    8.    7.    8.    4.    4.    1.    4.
119     30.   29.   20.   29.   17.    9.    4.    5.    1.    1.    0.
120     44.   33.   19.   25.   13.    8.    3.    2.    6.    1.    1.
```

Figure 1. Histogram of raw infrared brightness count values (ordinate) vs. absolute difference operator (abscissa) for the whole infrared image. Modes appear at brightness counts of 81 and 91, with the optimum threshold selected at 88.

## 2.0 CONCLUSIONS

The following series of photographs demonstrates the use of thresholds calculated by the given method for an April 16Z infrared image (Figure 2). The visible image from the same time (Figure 3) is also provided for comparison.

In this example, the need for separate thresholds over land and water is clearly seen. Our method found an ocean threshold 12 counts higher than the one for land. If the ocean threshold is used over the entire image, there would be an under-estimation of clouds over land areas. Yet the use of the land threshold over ocean would result in the entire area to be classified as cloud (Figure 4) which the visible image shows is not the case. Each threshold does a good job of distinguishing clouds in its given regime (Figures 5 and 6). In fact, the high cirrus in a few places are shown more clearly on the infrared than on the visible image.

One problem with most cloud discrimination techniques is the case of snow versus cloud. By using the topographic database, the high elevations that are snow covered, which are more likely to be mistaken for cloud, can be separated out (Figure 7).

In the future, it is hoped further improvements on the techniques presented here can be made. Other potential uses for the topographic database include better cloud classification over areas of rugged terrain during the diurnal cycle.

Figure 2. A GOES-East infrared image from April 23, 1989 at 1601Z over a section of California.

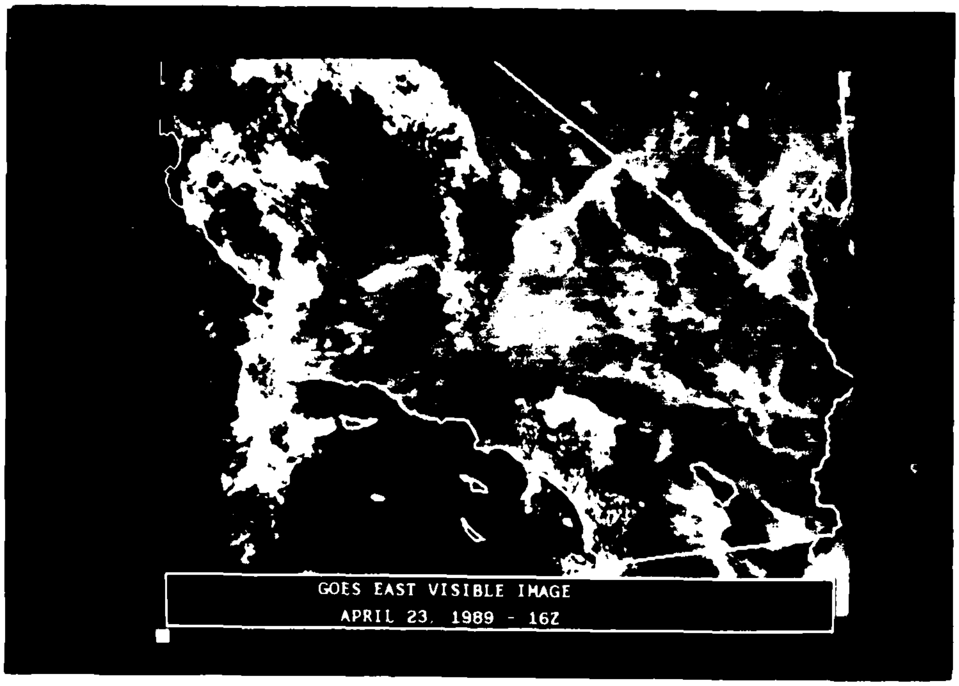

Figure 3. A GOES-East visible image for the same time and area as Figure 2.

Figure 4. The infrared image using the cloud threshold chosen for the entire image.

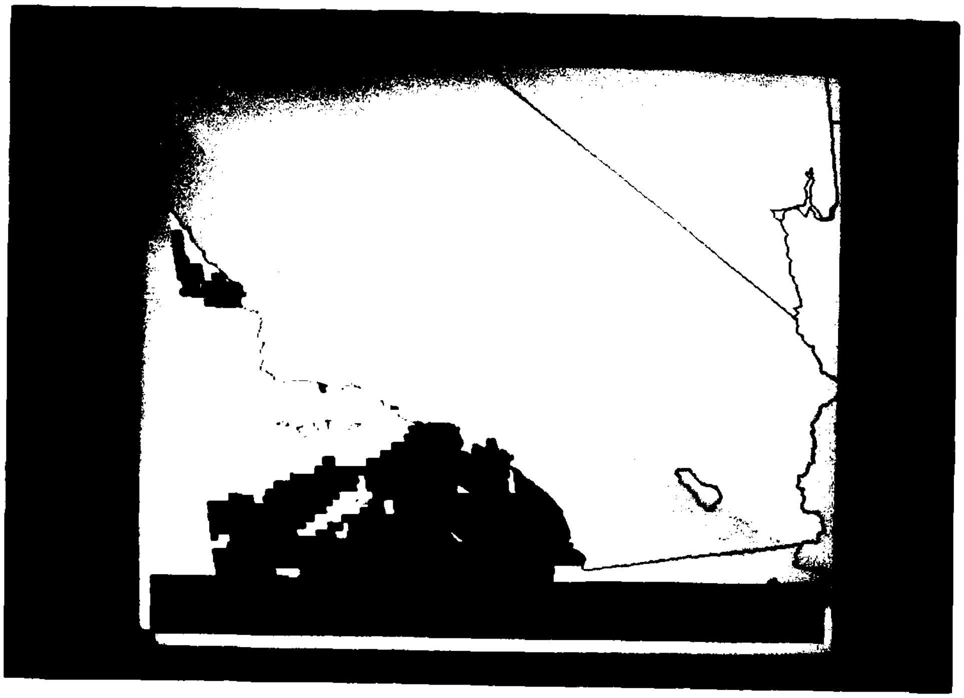

Figure 5. Ocean areas only using the ocean cloud threshold.

Figure 6. Land areas only using the land cloud threshold.

Figure 7. Land areas with the highest elevations subtracted out.

## 3.0 ACKNOWLEDGEMENTS

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