Satellite Cloud Composite Climatologies: A New High-Resolution Tool in Atmospheric Research and Forecasting

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Abstract

GOES digital imagery has been collected and processed using new techniques over portions of the United States since March 1988. High spatial and temporal resolution satellite cloud composite climatologies (SCCCs) have been produced that represent cloud frequency maps for each season. For each month studied, the cloud composite products represent the cloud occurrence frequency for each GOES pixel location and depict the overall spatial distribution of cloud cover over large portions of the United States.

The satellite composites present a new cloud climatology at a greater spatial and temporal resolution than previously available. Composites with ground resolutions of 2.5 km at hourly time intervals show striking patterns of cloud cover that are not detected in preexisting cloud climatologies.

A comparison between the SCCCs and climatologies produced from conventional surface observations is presented. The comparison is quite good for most stations, yet some significant differences are noted and discussed. Cloud occurrence in the vast areas between surface observing sites can now be analyzed using the new SCCC tool.

1. Introduction

> I've looked at clouds from both sides now,
> From up and down, and still, somehow,
> It's clouds' illusions I recall;
> I really don't know clouds . . . at all.
>
> —*Lyrics from "Both Sides Now" by Joni Mitchell*

Unfortunately, true. We have observed clouds from the earth's surface for hundreds of years and from space for 30 years. Yet we still do not know exactly how many clouds there are, how big they are, how long they last, what their radiative properties are, the interannual variability of these cloud parameters, or requisite quantitative details on how they affect the earth's weather and climate. Fortunately, in the last decade or so, a great deal of effort has been expended to begin answering these questions using satellite data. The purpose of this paper is to describe a new high-resolution space/time satellite cloud composite climatology (SCCC) designed to address the small-scale variation of clouds.

Hughes (1984) presents a good historical background on the production of cloud climatologies. At large scales, two projects stand out. The International Satellite Cloud Climatology Project (ISCCP) (Paltridge and Vonder Haar 1979; Schiffer 1982; Schiffer and Rossow 1983, 1985; Rossow and Schiffer 1991) is determining cloud cover, cloud height, and other cloud properties using visible and infrared satellite data at a resolution of approximately 250 x 250 km. The project, involving a system of five to seven satellites, began in 1983 and is planned to continue through 1995. The Earth Radiation Budget Experiment (ERBE), onboard the *Earth Radiation Budget Satellite* (*ERBS*) and on *NOAA-9* and *-10* satellites, determines mean radiative parameters in cloudy conditions, as well as clear-sky parameters. Since clouds are the single most important difference between mean and clear conditions, the cloud forcing, or the change in net radiation due to clouds, can be determined. For example, Ramanathan et al. (1989) have concluded that, globally averaged, clouds cooled the earth in April 1985. ERBE, together with various cloud climatologies and local area process studies, will eventually reveal much information on large-scale cloud forcing.

At medium spatial scales, the U.S. Air Force has constructed and used a nephanalysis, currently the real-time nephanalysis, or RTNEPH (Kiess and Cox 1988), for operational purposes. Satellite and surface observations are used in forming the database, and its grid resolution is 43 km. Cloud climatologies have been constructed from these data (Hughes and Henderson-Sellers 1985). Satellite data have considerably finer resolution than 43 km, however, and clouds also vary on finer scales. We believe that this very fine scale space/time domain is crucial to understanding clouds, their forcing by terrain, their effect on mesoscale processes, and their relationship to larger scales.

The highest-resolution cloud climatologies presented and described in this paper are constructed by

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compositing hourly GOES images. The spatial resolution of the satellite data, up to 1 km for GOES visible imagery (Clark 1983), determines the resulting resolution of the composite. For the climatologies presented here, image data was remapped into a mercator projection with dimensions of 860 rows by 1000 columns. This size was chosen to enable us to display the images at full image resolution (one pixel per data point) on our display device. We can then view a little more than one-third of the continental United States at a resolution of 2.5 km. For comparison, this is two-orders-of-magnitude-higher linear resolution than the nominal ISCCP resolution of 280 km (four orders higher in areal resolution).

2. Project background

The first cloud composites for research were constructed by sequentially superimposing satellite images on the same piece of photographic paper (Kornfield et al. 1967). These first "multiple-exposure" cloud composites provided considerable information about large-scale cloud systems in the general circulation of the atmosphere. They were not used extensively for studies of small-scale clouds.

Klitch (1982), Kelly (1983), and Weaver and Kelly (1982) improved the photo-averaging techniques by digitizing hardcopy photographs and then producing a digital composite image. Their studies concentrated on mesoscale cloud systems and medium-scale topographic effects.

The greatest advance in cloud compositing in the last 10 years was introduced by Klitch et al. (1985). They constructed cloud composites entirely in the digital domain. Digital GOES images collected at the Colorado State University Satellite Earthstation were processed to remove registration (navigation) problems and digitally composited by selecting a threshold brightness to discriminate cloudy from cloud-free areas.

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3. Cloud compositing procedure

Producing a cloud composite climatology is conceptually simple but operationally time consuming. Each pixel in each image to be composited is classified as either clear or cloudy; then, the frequency of occurrence of cloud at that pixel location is calculated as the fraction of the pixels that were classified as cloudy during the composite period. Figures 1–4 illustrate this process.

Figure 1 shows a typical GOES visible image of the western United States. This image was taken by *GOES-7* from geostationary altitude (35 790 km) over the equator at 98°W longitude. We used visible radiance data to achieve the highest possible resolution.

Using such high-resolution data poses some problems, which can be overlooked at global scales (>200 km). Because the navigation parameters for each GOES image can be in error, each image must be checked by comparison with landmarks to see whether it was properly navigated. We have found that errors of only a few kilometers will produce over- or underestimates of cloud cover by as much as 80% over areas with a sharp contrast gradient such as land/water boundaries. Those images that are found to be misnavigated are adjusted until the landmarks match as closely as possible. (We are currently evaluating an automated alignment routine, which will eliminate much of the time consumed in this step.) The images are mapped into a standard map projection prior to being aligned (Mercator in the present study).

A "background" image is constructed for each time period being composited. The background image represents the cloud-free brightness count detected by the satellite, i.e., the cloud-free scene of the earth's surface. Because variations in sun angle and surface composition produce changes in background brightness (Minnis and Harrison 1984), a different background image must be constructed for each observing time and is used only for a fraction of a year. We constructed a background image for each hour of the day and for a one-month period. Figure 2 is a background image for 2100 UTC, September 1989, representing the cloud-free scene for that specific hour and month. A minimum-value analysis was used to construct the background image, based on the assumption that the darkest (warmest) pixel during the month will represent the cloud-free radiance at that location.

Next, each pixel must be classified as either clear or cloudy. This is done by comparing the pixel brightness of each raw image with the background brightness image for that same time. Those pixels that are more than a specified number of counts brighter than the background are classified as cloudy. Figure 3 shows the resultant cloudy/clear image produced from Fig. 1. We selected nine GOES visible brightness counts as the optimum threshold based on work done by Rossow et al. (1985). That is, pixels that are nine counts higher than the background are classified as cloudy. The cloud discrimination technique has difficulty with thin clouds and with clouds over very bright backgrounds, as do virtually all cloud discrimination algorithms.

Finally, the monthly satellite cloud composite climatology (SCCC) is constructed from the daily cloud/clear images. This process involves a simple computation of the number of days during the month that each pixel was classified as cloudy. Figure 4 shows a completed cloud frequency composite. The colors represent the frequency of occurrence of cloud (0%–100%) at that time (2100 UTC) during the month of September 1989. To date, cloud composite climatologies have been produced over the United States west of the Mississippi for the months of March (1988–1990), July (1988–1990), September (1988–1990), and December (1989). In addition, a full United States composite was produced during April 1989. Figures 8–11 show a sequence of composites from July 1988 at 1500 UTC, 1800 UTC, 2100 UTC, and 0000 UTC. Note the diurnal "explosion" of cloudiness over the mountains in the west.

4. Intercomparison with surface-based observations

The new satellite cloud composite climatologies were compared with ground-based cloud observations. To our knowledge, this is the first time a comparison between satellite and surface cloud observations has been made in this manner. Data from over 250 surface stations were obtained from the National Center for Atmospheric Research (NCAR) and were composited for the months of July 1988, September 1988, and March 1989. Images shown in Figs. 5–7 were used in the comparison for July 1988 for the hour of 1500 UTC. The figures contain: (in Fig. 5) the satellite cloud composite climatology, (in Fig. 6) the frequency of occurrence from surface observations (the circles are 50 km in diameter, plotted on the satellite image projection), and (in Fig. 7) the absolute difference between the satellite-derived frequency and the surface observation–derived frequency.

The frequency of occurrence of cloud from surface observations was determined by assigning a cloud/no cloud value for a specific hour of each day. If a station reported 5/8 or more of opaque cloud, it was considered cloudy. The satellite frequency was computed by averaging all of the composite pixels (from Fig. 5) within a 50-km–diameter circle about the geographic location of the surface observation site. This distance was selected to approximate the surface observer's "sky dome," which is the imaginary hemisphere that the observer reports to be obscured by cloud.

Several observations may be made from the comparison between SCCCs and surface observation–based cloud frequencies:

a) The satellite data are vastly superior to the surface data in revealing spatial details. The relative minimum cloudiness in the Snake River Valley of Idaho and the relative maximum over the central and southern Rocky Mountains are only suggested by the surface data (Fig. 5); they are dramatically portrayed in the satellite composite (Fig. 6). The general pattern of cloudiness is certainly evident in the composite made from surface reports, but not to the detail shown in the satellite composites (note the "empty spaces" in the surface composite shown in Fig. 6).

The increased resolution allows us to depict the striking effects of topography on the diurnal cycle of cloudiness, and the sharp gradients in frequency of occurrence of cloud that are associated with topographic boundaries such as mountains and coastlines. Figures 8–11 show a sequence of SCCCs from July 1988 at 1500, 1800, 2100, and 0000 UTC. Note the diurnal explosion of cloudiness over the southern Rocky Mountains in contrast with a general decrease in cloudiness over the Pacific Northwest. The stratus/stratocumulus clouds over western Washington and Oregon are dissipated by the same heating that generates cloud cover over the Rocky Mountains. The 1500 UTC image (Fig. 8) shows how the atmosphere has stabilized during the nighttime hours, with frequencies generally less than 30% over the central and southern Rockies. Contrast that with the dramatic increase in cloud cover at 1800 and 2100 UTC (Figs. 9 and 10), and the large expanse of cloudiness (most likely due to the tops of cumulonimbus spreading over large geographic areas) by 0000 UTC (Fig. 11). Note

TABLE 1. Comparison between satellite and surface-observation cloud frequencies. Shown are the mean frequency of occurance of cloud, the mean absolute difference between the satellite- and surface-derived frequencies, and the correlation coefficient. Note the low correlation for March at 1500 UTC, due to darkness on the western third of the region.

Month/Year/Time	Mean Freq Obs./Sat.	Mean Abs. Difference	Correlation Coefficient
July 1988, 1500 UTC	30.0/24.1	7.5%	0.905
July 1988, 1800 UTC	23.8/20.2	7.2%	0.829
July 1988, 2100 UTC	23.8/22.6	6.5%	0.867
July 1988, 0000 UTC	27.5/23.2	7.0%	0.894
Sept 1988, 1500 UTC	32.9/27.3	7.4%	0.905
Sept 1988, 1800 UTC	28.5/23.6	6.7%	0.915
Sept 1988, 2100 UTC	21.4/18.4	4.9%	0.917
Sept 1988, 0000 UTC	21.2/14.2	8.2%	0.876
Mar 1988, 1500 UTC	54.0/7.3	46.7%	0.582
Mar 1988, 1800 UTC	45.8/37.3	9.8%	0.930
Mar 1988, 2100 UTC	51.5/44.3	11.1%	0.887
Mar 1988, 0000 UTC	63.5/47.1	16.8%	0.891

also the sharp gradient in frequency that exists along the California coast and between the mountains and southwestern deserts in Arizona.

b) Some of the largest differences between the satellite- and surface observation–derived frequencies occur in areas of high cloud-cover gradient, such as the coastal area of southern California. Figure 12 shows a blowup of two 50-km circles taken from the July 1988, 1500 UTC satellite cloud composite climatologies (extracted from the image in Fig. 5). Note the strong gradient across both circles, with values ranging from a frequency of <10% (blue) to >90% (red). The left circle represents the SCCC centered on San Diego, California, and the right circle is centered on Oceanside, California. The surface observations from San Diego produce a frequency of occurrence of cloud of 96%, while the SCCC frequency was 71%. This is most likely due to the fact that low stratiform overcast conditions are common over the observation site, and the view of clear skies several miles inland was obscured by cloud cover. These blowups highlight the increased spatial resolution that can be obtained from the satellite cloud observations. The mean cloud frequency from surface observations will not identify the sharp boundaries between cloudy or clear conditions occurring within the station circle. Elimination of these areas of sharp gradient from our sample set produces even better agreement between the satellite- and surface observation–derived composites.

c) The satellite cloud frequencies generally compare well with surface observations on a site basis. Figure 13 is a scatter plot of the satellite versus surface frequencies. Note that the surface observations consistently show a somewhat higher frequency of occurrence of cloud than do satellite observations. This same feature, discussed by Henderson-Sellers and McGuffie (1990), is due, in part, to the tendency for overestimation of cloud amounts by ground-based observers when looking at the sky dome at increasingly large angles from local zenith.

Table 1 shows comparison statistics between the surface-observed and satellite-observed frequency of occurrence of cloud. The mean absolute difference between surface- and satellite-derived frequencies was consistently less than 20% (except for March 1989), and during the months of July and September was less than 10%. The mean frequency, shown in Table 1, is the mean of all reporting sites. The mean difference is based on absolute differences, and the correlation coefficient is based on the first-order regression line shown in Fig. 13 (solid line). The statistics shown in Table 1 are based on the comparison of only those synoptic stations for which reports were available to match each satellite image used in the composite.

An item of interest is the mean frequency of occurrence of cloud. The values shown in Table 1 are taken from synoptic observation sites only, and represent the mean frequency of occurrence that would be determined from historical surface observations of cloud. Table 1 values indicate that the mean frequency of occurrence of cloud in July 1988 decreased between 1500 and 0000 UTC (from 30.0 to 27.5 for surface-based frequencies and from 24.1 to 23.2 for satellite). One would conclude from these numbers (taken from samples at synoptic reporting sites only) that there is a net decrease in cloud occurrence from 1500 to 0000 UTC. The satellite image shows clearly that there is in fact a dramatic overall increase (see Figs. 8 and 11). When we produce the mean fre-

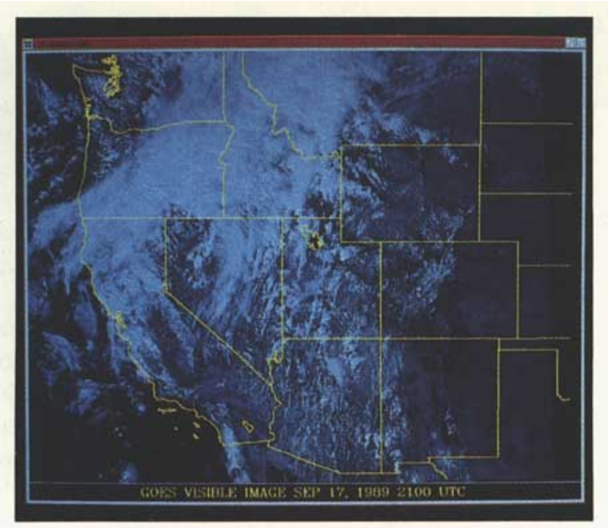

Fig. 1. GOES-East visible image for 2100 UTC, 15 September 198

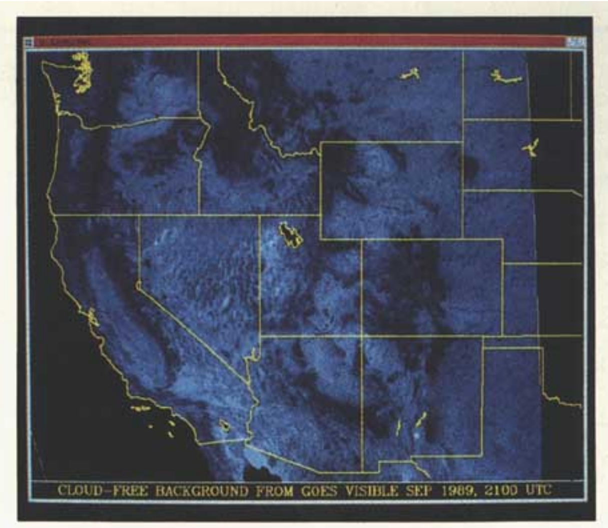

Fig. 2. Background image for 2100 UTC, September 1989.

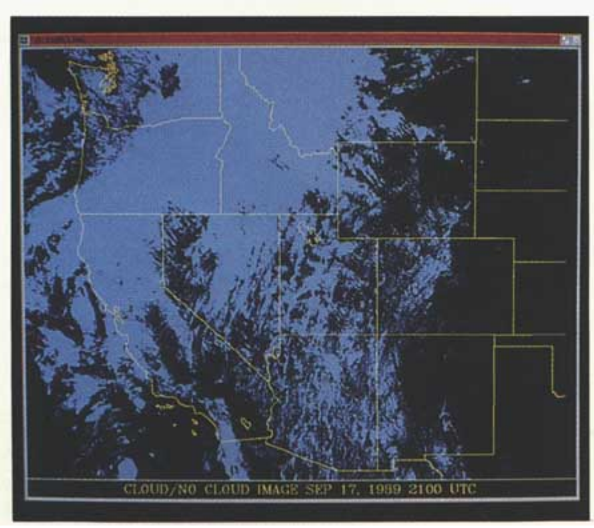

Fig. 3. Cloud/no cloud image for 2100 UTC, 15 September 1989.

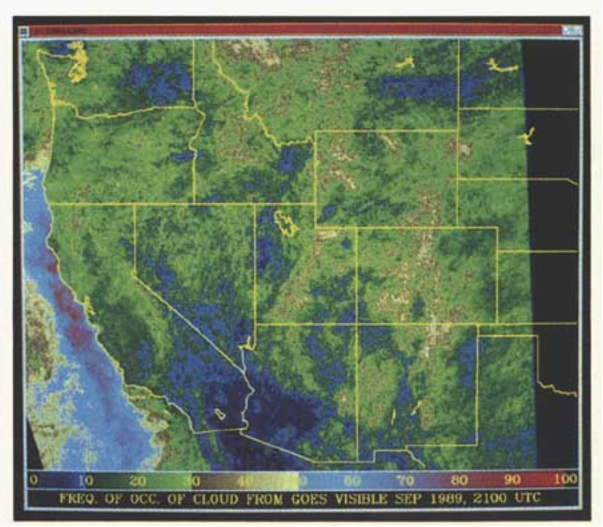

Fig. 4. Cloud frequency composite for 2100 UTC, September 1989

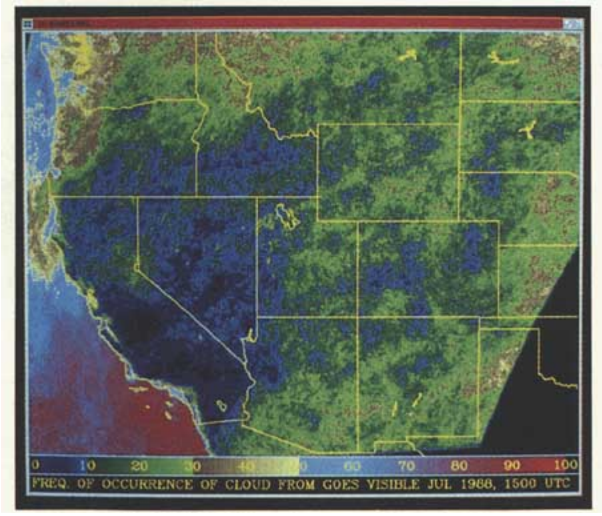

Fig. 5. Cloud frequency composite from the GOES satellite for July 1988, 1500 UTC. Image resolution is approximately 2.5 km per pixel.

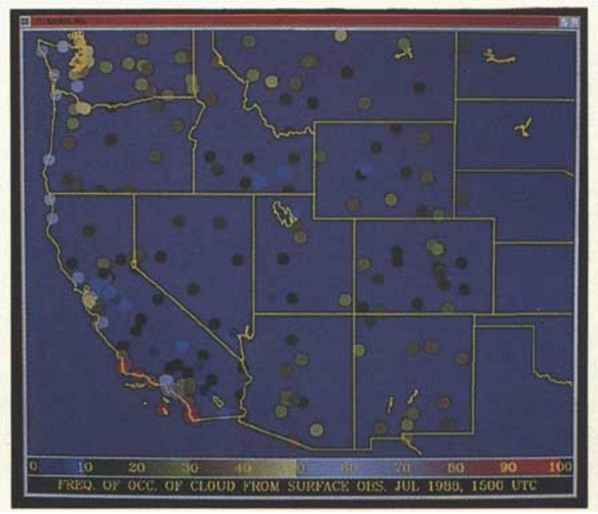

Fig. 6. Cloud frequency composite from surface observations for July 1988, 1500 UTC. Circles represent a 50-km diameter centered on the reporting station.

FIG. 7. Difference image. Colors represent the absolute difference (in percent cloud cover) between the satellite-derived cloud frequency and the frequency computed from surface observations (July 1988, 1500 UTC).

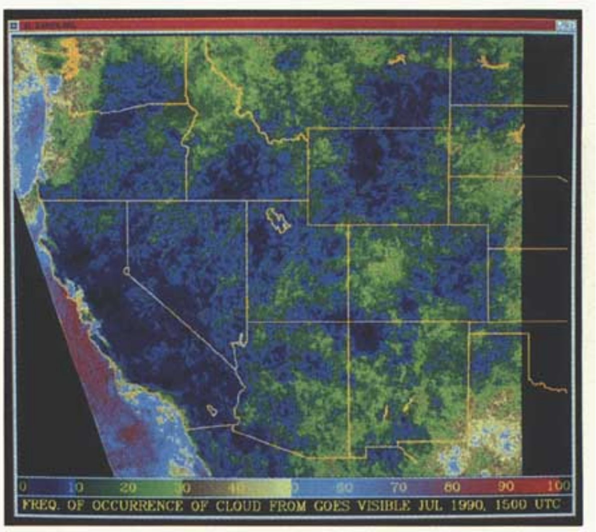

FIG. 8. Cloud frequency composite from the GOES satellite for July 1990, 1500 UTC. Image resolution is approximately 2.5 km per pixel.

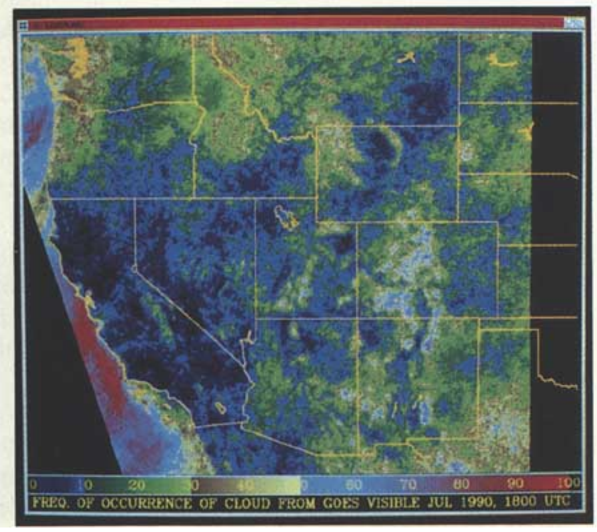

FIG. 9. Cloud frequency composite from the GOES satellite for July 1990, 1800 UTC.

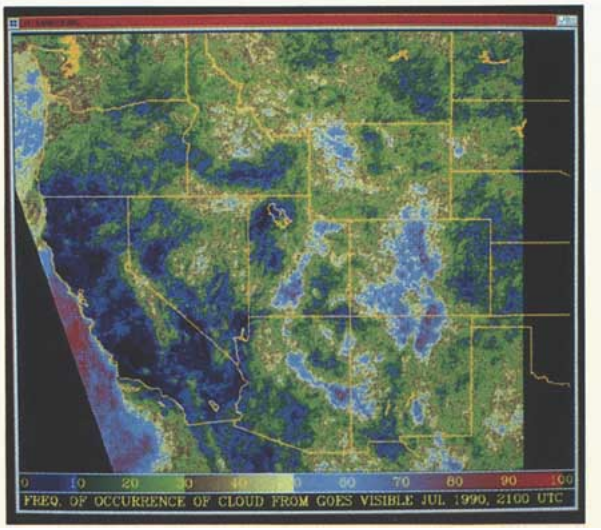

FIG. 10. Cloud frequency composite from the GOES satellite for July 1990, 2100 UTC.

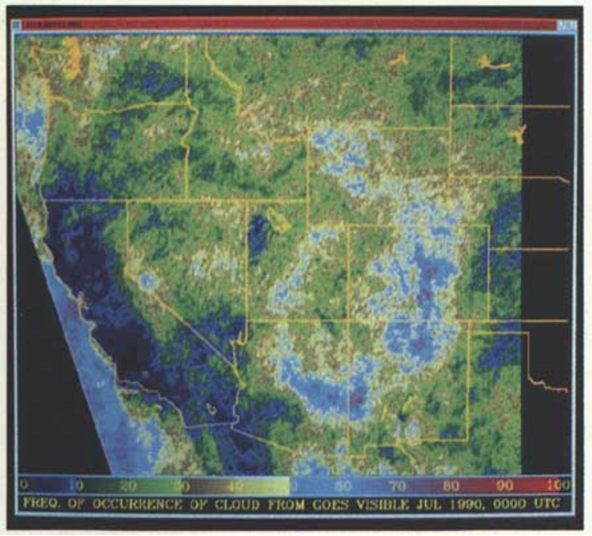

FIG. 11. Cloud frequency composite from the GOES satellite for July 1990, 0000 UTC.

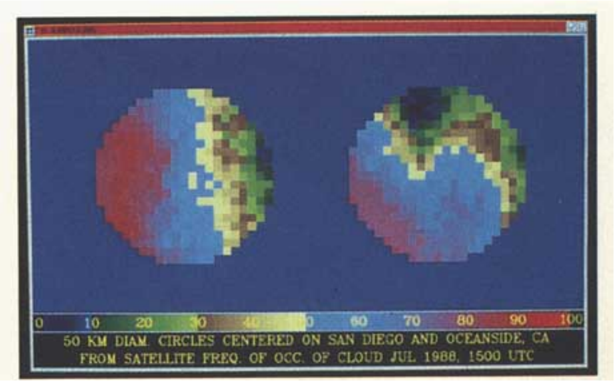

FIG. 12. Blowup of several 50-km–diameter circles from the satellite cloud frequency composite for July 1988, 1500 UTC. Circles represent satellite-derived cloud frequencies that varied from surface observation–derived frequencies by more than 25%.

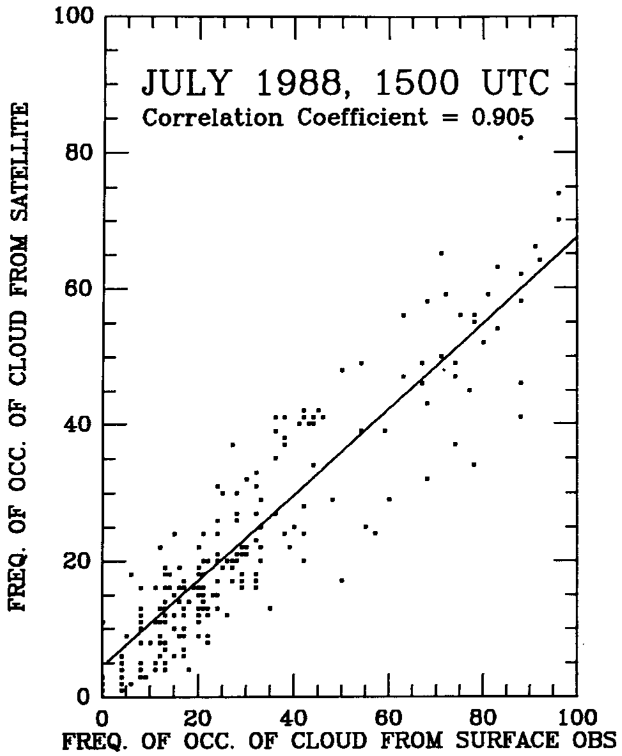

FIG. 13. Scatter plot of satellite-derived cloud frequencies vs frequencies from surface observations for data from July 1988 at 1500 UTC. The dashed line represents the first-order regression line. Only stations that reported every day of the month are plotted.

quency of occurrence of cloud from the satellite composites, by averaging each 2.5-km–resolution data point, we obtain a mean of 23.3 at 1500 UTC and a mean of 28.9 at 0000 UTC. We believe this to be more representative of the diurnal change in cloudiness than the historical surface reports would indicate.

We believe that these high-resolution cloud composite climatologies are more representative of the diurnal change in cloudiness than the historical surface reports would indicate.

To test our comparison, we included a composite image that was known to be unreliable. Because of the low sun angle, the 1500 UTC satellite images from March are dark over the western third of the image. We constructed a composite for March 1989 of 1500 UTC and compared it with the surface observation–derived frequencies. As can be seen from Table 1, the comparison was very poor, and additionally, the "difference" image (not shown here) identified the regions of unreliable data.

5. Applications of high-resolution composites

We envision a number of applications of the digital cloud composites. One is the relationship between cloud occurrence and the terrain (see also Gibson and Vonder Haar 1990). The primary areas of interest are land/water boundaries and mountainous terrain. A second question involves the joint correlation between two or more station locations or geographic regions. For example, four stations may have a frequency of occurrence of cloud of 50%. What is the probability that at a given time all stations will be cloudy or, conversely, clear?

Another application is in "conditional" cloud climatologies (Reinke et al. 1990a). For example, suppose that it is cloudy at 1500 UTC. What is the probability that it will be cloudy at that location at 1800 or 2100 UTC? What is the probability that it will be cloudy if it is initially clear? These questions can be answered with high-resolution cloud composite data.

Still another area of interest is to examine how the cloud frequencies vary in time. This comparison can be done on a daily basis (derived variation as shown in Figs. 8–11) to study cloud or cloud system "life cycles" or by looking at the interannual or seasonal variation of cloudiness (Reinke et al. 1990b).

Finally, we suggest that regional and local cloud climatologies will complement global-scale satellite-derived cloud frequencies such as ISSCP. Both cloud datasets are needed for application to initialization/validation of numerical models. Climate diagnostic and cloud/radiation process studies definitely present questions that demand the highest resolution climatologies.

6. Conclusions

Satellite cloud composite climatologies (SCCC) provide information on high space and time variation of clouds that is not presently available by other means. Satellite composites can be used in applications that have previously relied on cloud information derived from surface observations. The new satellite composites provide a higher spatial resolution and adequate temporal coverage, and are more representative of the distribution of cloud cover.

High-resolution satellite cloud composite climatologies will greatly improve our overall knowledge of clouds and their effect on the earth's climate.

This is a primary objective of the U.S. Global Change Research Program. Research lines of inquiry that couple this new information on high-frequency cloud occurrence with our new knowledge of small-scale dynamics and thermodynamic processes will allow better overall understanding of the complex linkage between persistently cloudy (and cloud-free) regions and local weather features.

Acknowledgments. We would like to acknowledge Dr. Frank Kelly and Mr. C.F. Shih for their invaluable assistance in the development of the algorithms required to process the images used in construction of the composites, and Dr. Ed Tomlinson and Dr. Jim Purdom for their technical assistance and encouragement during the initial phases of the high-resolution cloud climatology project. Also thanks to Ms. Julie Smith for her expert preparation of this manuscript. Data collection and processing for the initial phase of this project were sponsored by the Office of Naval Research (contract N00014-86-C-0463), with the most recent work being sponsored by the Air Force Geophysics Laboratory (contract F19628-89-C-0083).

References

Clark, J.D., 1983: *The GOES User's Guide.* U.S. Department of Commerce, 90 pp.

Gibson, H.M., and T.H. Vonder Haar, 1990: Cloud and convection frequency over the southeast United States as related to small-scale geographic features. *Mon. Wea. Rev.,* **118,** 2215–2227.

Henderson-Sellers, A., and K. McGuffie, 1990: Are cloud amounts estimated from satellite sensor and conventional surface-based observations related? Remote sensing letters. *Int. J. of Remote Sensing,* **11,** 543–550.

Hughes, N.A., 1984: Global cloud climatologies: A historical review. *J. Climate Appl. Meteor.,* **23,** 724–751.

——, and A. Henderson-Sellers, 1985: Global 3D-nephanalysis of total cloud amount: Climatology for 1979. *J. Climate Appl. Meteor.,* **24,** 669–686.

Kelly, F.P., 1983: An extreme event forecast guidance method using satellite cumulus cloud climatologies. M.S. thesis, Colorado State University, Department of Atmospheric Science, 104 pp.

——, T.H. Vonder Haar, and P.W. Mielke, Jr., 1989: Imagery randomized block analysis (IRBA) applied to the verification of cloud edge detectors, *J. Atmos. Oceanic Technol.,* **6,** 671–679.

Kiess, R.B., and W.M. Cox, 1988: The AFGWC automated real-time analysis model. AFGWC/TN-88/001, AFGWC, Air Weather Service (MAC), Offutt AFB, Nebraska, 82 pp.

Klitch, M.A., 1982: Compositing digital satellite data to detect regions of orographically induced convection on the northern High Plains. Colorado State University, M.S. thesis, Department of Atmospheric Science, paper no. 351, 87 pp.

——, J.F. Weaver, F.P. Kelly, and T.H. Vonder Haar, 1985: Convective cloud climatologies constructed from satellite imagery. *Mon. Wea. Rev.,* **113,** 326–337.

Kornfield, J., A. Hasler, K. Hanson, and V. Suomi, 1967: Photographic cloud climatology from ESSA III and V computer produced mosaics. *Bull. Amer. Meteor. Soc.,* **48,** 878–883.

Minnis, P., and E.F. Harrison, 1984: Diurnal variability of regional cloud and surface radiative parameters derived from GOES data. Part I: Analysis method, Part II: Cloud results. *J. Climate Appl. Meteor.,* **23,** 993–1031.

Paltridge, G., and T.H. Vonder Haar, 1979: Plan for implementation of a real-time satellite observed cloud climatology project. Report for the Joint Organizing Committee for Climate Dynamics Sub-programme of GARP, ICSU/WMO, Geneva.

Ramanathan, V., B.R. Barkstrom, and E.F. Harrison, 1989: Climate and the earth's radiation budget. *Phys. Today,* **42(5),** 22–32.

Reinke, D.L., C.L. Combs, E.M. Tomlinson, and T.H. Vonder Haar, 1990a: Persistence forecasts from high-resolution cloud composite climatologies. Poster presentation at the *Cloud Impacts on DoD Systems Conf.,* Monterey, CA.

——, ——, ——, and ——, 1990b: Interannual variability in cloud frequency as determined from GOES satellite. Presented at the *Cloud Impacts on DoD Systems Conf.,* Monterey, CA.

Rossow, W.B., F. Mosher, E. Kinsella, A. Arking, M. Desbois, E. Harrison, P. Minnis, E. Ruprecht, G. Seze, C. Simmer, and E. Smith, 1985: ISSCP cloud algorithm intercomparison. *J. Climate Appl. Meteor.,* **24,** 877–903.

——, and R.A. Schiffer, 1991: ISCCP cloud data products. *Bull. Amer. Meteor. Soc.,* **72,** 2–20.

Schiffer, R.A., 1982: The International Satellite Cloud Climatology Project (ISCCP), preliminary implementation plan. WCP-35, WMO, Geneva, 77 pp.

——, and W.B. Rossow, 1983: The International Satellite Cloud Climatology Project (ISCCP), the first project of the World Climate Research Program. *Bull. Amer. Meteor. Soc.,* **64,** 779–784.

——, and ——, 1985: ISCCP global radiance data set: A new resource for climate research. *Bull. Amer. Meteor. Soc.,* **66,** 1498–1505.

Weaver, J.F., and F.P. Kelly, 1982: A mesoscale, climatologically-based forecast technique for Colorado. Preprints, *Ninth Conf. Weather Forecasting and Analysis,* Seattle, Amer. Meteor. Soc., 277–280.

——, ——, M. Klitch, and T.H. Vonder Haar, 1987: Cloud climatologies constructed from satellite imagery. Preprints, *Third Intl. Conf. Interactive Info. and Proc. for Meteorology, Oceanography and Hydrology,* New Orleans, Amer. Meteor. Soc., 169–172.