Forecasting Applications of High-Resolution Satellite Cloud Composite Climatologies

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ABSTRACT

In this paper, the authors describe experimental forecasting tools developed from high-resolution satellite cloud composites. The satellite data were extracted from the new 5-km, hourly, global satellite database called Climatological and Historical Analysis of Clouds for Environmental Simulations (CHANCES). Analysis was focused on a region over the former Yugoslavia and Adriatic Sea during summer 1994.

Cloud composite images were constructed using digital infrared data for each hour of the day. The value at each pixel in the cloud composites was the fractional coverage of cloud at that location for the season and represented its systematic variation. Composite images were also constructed for conditional probabilities of cloud 1–12 h past each hour of the day. The values at any particular pixel in the composites represented the conditional probability of cloud given an initial condition of cloudy or clear in that pixel. Data from both types of composite images were combined to produce a climatological forecasting tool. Forecast tables were constructed of values for the pixel centered over Sarajevo. These tables are similar to the conditional climatology statistics familiar to forecasters in any weather station.

A more sophisticated type of conditional probability was tested in which the initial condition was dependent on the average conditions of a region of pixels surrounding the Sarajevo pixel. Results demonstrate powerful operational applications of high-resolution satellite cloud climatologies.

1. Introduction

In the past 15 years, satellite data has greatly advanced our understanding of clouds. In this study we expand on an idea put forward by Reinke et al. (1992). They suggested that high-resolution satellite cloud climatologies could be used to create a forecasting tool through a combination of cloud frequency of occurrence and cloud persistence composites.

This paper describes forecasting tools that use the new 5-km, hourly, global satellite database called Climatological and Historical Analysis of Clouds for Environmental Simulations (CHANCES; Vonder Haar et al. 1995). The results show that satellite-derived climatologies have significant potential for various modeling and operational forecasting applications. The analysis is limited to the summer season for a domain centered over the former Yugoslavia and the Adriatic Sea. Specific forecast applications are demonstrated for satellite data centered over the city of Sarajevo.

2. Background

Kornfield et al. (1967) created the first cloud composites for research by sequentially superimposing satellite images on photographic paper. The early composites were useful for the study of large-scale cloud systems and the general circulation. Eighteen years later Klitch et al. (1985) ushered the compositing technique into the computer age by constructing cloud composites entirely in the digital domain. They used satellite composites to study the relation of convection to terrain in Colorado. More recently, Gibson and Vonder Haar (1990) completed a similar study of convection in the southeastern United States.

On a global scale, there are two primary ongoing satellite cloud climatology projects. The International Satellite Cloud Climatology Project has created a global database of many cloud properties using visible (VIS) and infrared (IR) satellite data with 3-h temporal and 250 km × 250 km spatial resolution. Statistics for some regional data are also available at resolutions as low as 30 km (Rossow et al. 1993). The U.S. Air Force (USAF) produces a cloud composite for operational purposes called the real-time nephanalysis (RTNEPH; Kiess and Cox 1988). RTNEPH is a combination of satellite and surface data and has 47-km horizontal resolution. Cloud climatologies have been created using RTNEPH (Hughes and Henderson-Sellers 1985); however, clouds vary significantly on much finer time and space scales.

A very fine space–time domain is crucial to understanding clouds in relation to mesoscale forcings (Reinke et al. 1992) and, hence, is critical to the creation of cloud climatology composites that can be used as fore-

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cast tools. This is specifically true for Terminal Aerodrome Forecasts (TAFS) and military remote location target forecasts for offensive operations, reconnaissance, and as inputs to electrooptical meteorological decision aids. Vonder Haar et al. (1993) show that the RTNEPH cloud database as well as probability-of-cloud-free-line-of-sight (PCFLOS) models can be significantly improved through the development and use of a high-resolution satellite cloud database.

Today's PCFLOS models are based on surface observations derived on a spatial resolution of approximately 200 km. In addition, 75% of the globe will not have input data (oceans). The results presented by Vonder Haar et al. (1993) show that approximately 90% of all cloud-free intervals are less than 10 km. So climatological forecasts and models based on surface data will not provide a representative measure of the impact of clouds in many geographic locations (Reinke et al. 1993) and provide no reliable data over oceans.

The CHANCES database used in this study was sponsored by a Small Business Innovative Research Phase II, U.S. Air Force grant. The purpose was to produce a 1-yr, 1-h, 5-km resolution IR, VIS, and global cloud/no-cloud (CNC) database product and to demonstrate the feasibility of producing a longer-term (5-yr) climatological cloud database. CHANCES is ideal for the construction of finescale satellite cloud composites.

3. Data

The CHANCES database is a 1-yr (1 Feb 1994–31 Jan 1995) global satellite imagery database with 1-h temporal and 5-km spatial resolution (Vonder Haar et al. 1995). Each CHANCES image is a ''seamless'' global image created from a combination of geostationary and polar-orbiting satellites. Missing data points are ''filled'' by averaging the data from the previous and subsequent hours when it is available. The database for each hour included IR, VIS, and CNC images. In this study we focused on a sector centered over the former Yugoslavia. The sector spans from approximately 42°–47°N and 23°–33°E. This falls entirely in the domain of the Meteosat geostationary satellite.

To produce CHANCES, STC-METSAT in Fort Collins, Colorado, did a significant amount of preprocessing. This preprocessing included navigation and alignment, correction for various characteristic satellite errors, the creation of radiance background information, and the construction of the binary CNC images. Kidder and Vonder Haar (1995) discuss other possible sources of error that can impact the analysis of meteorological satellite imagery including attenuation, background contrast, contamination, displacement, foreshortening, sensor lag, signal interference, sun–satellite geometry, and viewing angle.

The process to construct binary CNC images capitalizes on the fact that clouds are generally brighter (in the VIS wavelengths) or colder (in the IR wavelengths) than the underlying background. So the first step was to compile VIS and IR background radiance information.

The background radiance represents the cloud-free brightness count detected by the satellite at each pixel. Due to changes in background brightness or temperature with variations in sun angle and surface composition (Minnis and Harrison 1984a,b), a different background was constructed for each observing time and used only for a fraction of a year. For the CHANCES VIS CNC, an initial background for each hour of the day was built by storing the darkest radiance value of each pixel over the first 30 days of data. These background images were then dynamically updated throughout the remaining 11 months of processing. A filter eliminated false background values created by cloud shadows. A different IR background was constructed for each hour based on input from the USAF surface temperature database.

To construct VIS CNC images, each pixel was individually classified as either clear or cloudy by comparing the brightness of each raw VIS image pixel to the background brightness image for the same time. Pixels more than nine counts brighter than the background were classified as cloudy (at least 50% filled with cloud). To construct IR CNC images, a pixel in a raw IR image was classified as cloudy if the pixel was 9–14 K (depending on geographic location) colder than the background.

4. Method

Construction of composites begins with the geographic alignment of each image with a base image. This was done as part of CHANCES preprocessing as described in the previous section. In this study, we used only quality controlled images without noise or data drops.

The aligned images were used to construct seasonal cloud frequency of occurrence composites for each hour of the day for the Yugoslavia–Adriatic sector. Figures 1a–d are cloud frequency of occurrence composites for 1200, 1500, 1800, and 2100 UTC, respectively. For this study, the summer season data spans the 45-day period from 22 June 1994 to 5 August 1994.

In Figs. 1a–d, the frequency at each pixel was computed by simply dividing the number of cloudy days at each hour at that pixel by the number of days with cloud data available at that same pixel. The resultant cloud frequency of occurrence at each pixel was then assigned a specific color and displayed as a composite image. Variation of color from pixel to pixel in an image represents the variation in cloud frequency from location to location. The actual percentage frequency value can be estimated by comparing the color of the target pixel with the scale at the bottom of each image. The scale spans from 0% on the left to 100% on the right.

Conditional probability images were prepared by comparing each image from an initial time with an image from a forecast time. If a cloud (or no cloud) exists at a

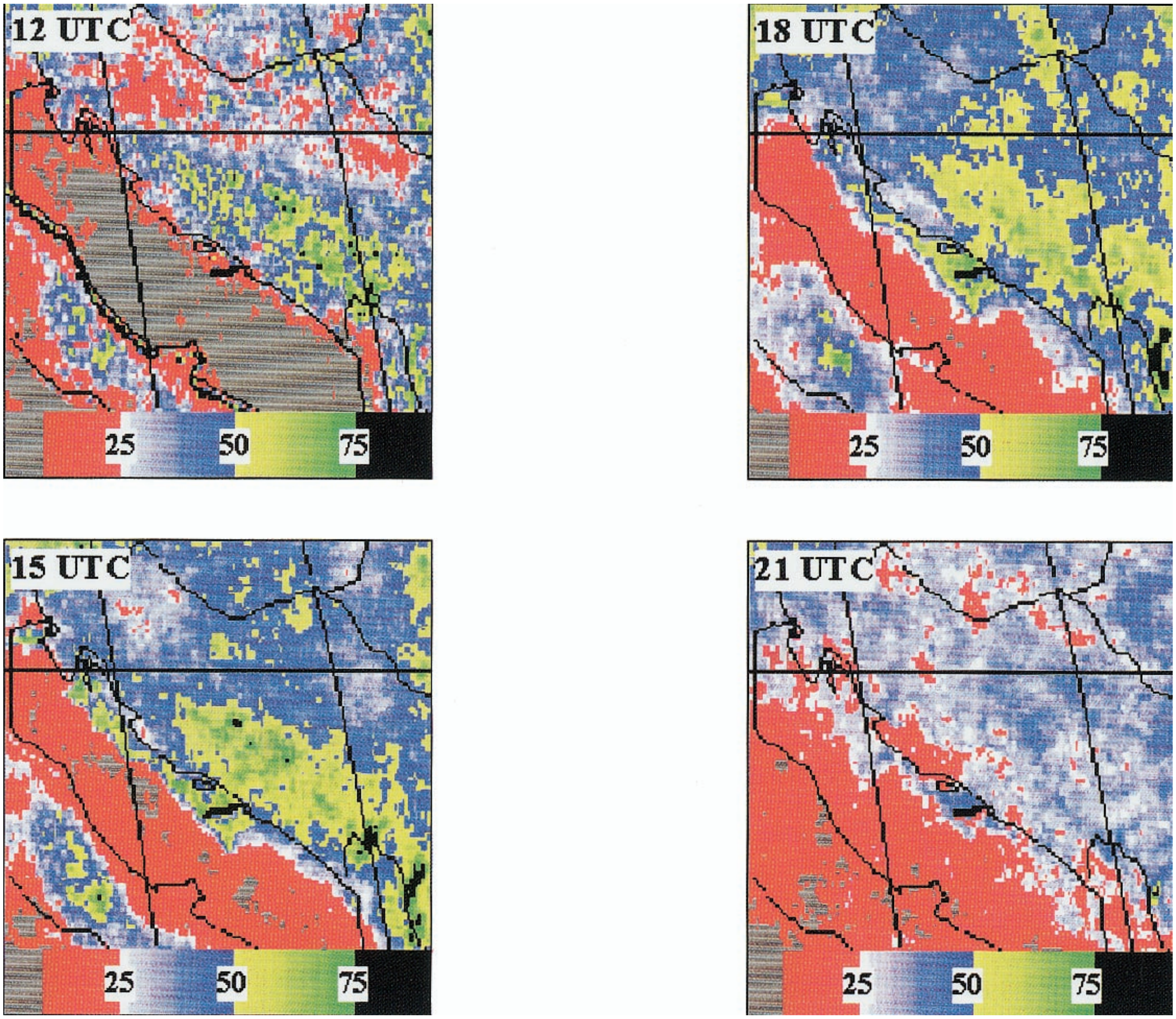

FIG. 1. Cloud frequency composite from Meteosat satellite for 22 June 1994–5 August 1994: (a) 1200, (b) 1500, (c) 1800, and (d) 2100 UTC.

pixel on the initial image and a cloud exists at the same pixel location of the target (forecast) image, it is summed for that pixel. An algorithm repeated this process for every pixel of every image for each of the 45 days of summer (1994) to compile data for 1–12 h beyond each hour of the day. Six hours represents the most important forecast interval for TAFs since active TAFs are updated every 6 h. Some operational applications require accurate cloud forecasts with a 6–12-h lead time or greater.

We compiled persistence data for two simple types of conditional probability forecasts: 1) cloudy at forecast time when cloudy at initial time (type 1) and 2) cloudy at forecast time when clear at initial time (type 2). Two other scenarios (clear at forecast time when clear at initial time and clear at forecast time when cloudy at initial time) can be constructed from 1) and 2), respectively, by subtracting the probability of being cloudy at forecast time from 100%. As with the cloud frequency data, the conditional probability (persistence) data can also be displayed as an image. Figures 2a and 2b are type-2 conditional probability images for 6 and 9 h after 0600 UTC (0800 LST). Figure 2a represents the probability of cloud at 1200 UTC (1400 LST) at each pixel when the pixel is clear at 0600 UTC. Similarly, Fig. 2b depicts the probability of cloud at 1500 UTC (1700 LST). Following images through chronologically from the initial time (including the intermediate times not shown), one finds that the quality of a persistence forecast of clear for this sector goes down with time (e.g., the probability of cloud goes up). This is a signal of the convective diurnal cycle of cloud cover over this region in summer.

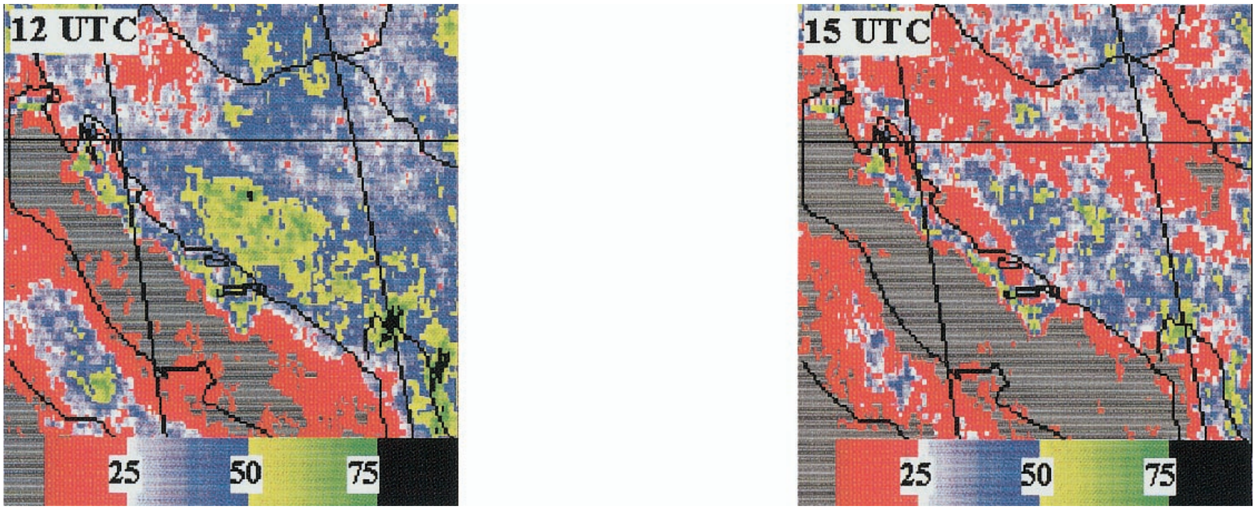

FIG. 2. Probability of cloudy or clear persisting at (a) 1200 and (b) 1500 UTC from initial value at 0600 UTC 22 June 1994 to 5 August 1994.

With cloud frequency and cloud persistence data, you have all the necessary tools to produce simple probability forecasts for cloud at each pixel. Reinke et al. (1990) suggest various techniques. They note that a cloud frequency composite itself can be used as a forecast tool. The frequency of occurrence of cloud over each pixel at any given time is a reasonable first guess for a cloud/no-cloud forecast at that location. Individual composites can be compared to note the change in frequency of occurrence of cloud at a location. This would represent the systematic variation of cloud cover over that pixel. To account for random variation in cloud cover, one needs to consider information in the persistence images. Reinke et al. (1990) suggest two ways to include the persistence data. First, one could compute cloud occurrence probability by adding the cloud persistence probability to the frequency. Second, one could use both probabilities in a forecast matrix in which the final probability is based on the cloud frequency and/or conditional probability exceeding a predetermined threshold. Taking an even more sophisticated approach, the initial image could be stratified by wind direction, air mass, or other climatologically significant variables as has been done by the Air Force Combat Climatology Center (AFCCC, formerly the Environmental Technical Applications Center) for many years with conditional climatology ceiling and visibility tables.

For this study, we developed a forecast tool for Sarajevo that combined cloud frequency and persistence data (Tables 1 and 2). These tables were created by extracting cloud frequency and persistence information from many composite images for the pixel centered directed over Sarajevo. As a forecaster, this type of data would be a valuable asset for a TAF or target forecast. From personal experience, we believe that the greatest inhibitor to an accurate target forecast is not having firsthand knowledge of the weather in the target area. For remote sites, satellite-derived conditional probabilities (Tables 1–4) could be a viable surrogate to firsthand experience and substitute for the conditional ceiling and visibility tables familiar to forecasters in any weather station. A forecaster could combine these statistics with knowledge of the current and forecast synoptic and mesoscale weather conditions to optimize the forecast. In the results section below, we discuss an empirical climatological forecast index developed in this study.

In Tables 3 and 4, we present a more sophisticated type of conditional probability computed for Sarajevo. For these statistics the initial condition was stratified by the percentage of cloudy or clear pixels in a 15 km × 15 km region surrounding the target location. The initial conditions were divided into three categories: 1) less than 33% of pixels cloudy (clear) at initial time (Table 3), 2) 33%–66% of pixels cloudy (clear) at initial time (not shown), and 3) 66%–100% of pixels cloudy at initial time (not shown). Table 3 depicts the conditional probability of cloud over Sarajevo at forecast times of 1–12 h given the 33% or less of the pixels within 15 km of the target are overcast at the initial time. This adds a level of spatial dependence to the conditional probabilities that cannot be well duplicated with surface observation data, especially as the radius from the target increases. For instance, one could expand out to 25 km from the target pixel. In the next section we compare these spatially conditional probabilities to the single-pixel conditional probabilities presented in Table 1.

5. Results and discussion

Figure 3 is a histogram of the average cloudy infrared pixel counts at each hour of the day for the Yugoslavia sector shown in Figs. 1 and 2. This represents the sys-

TABLE 1. Conditional probabilities of cloud at all times given cloud at initial time for Sarajevo, 22 June 1994–5 August 1994.

Time (UTC)	Cloud % freq.	Forecast hours 1	2	3	4	5	6	7	8	9	10	11	12
0000	24	71	75	50	63	43	38	43	50	57	63	75	75
0100	21	75	63	50	43	50	50	57	71	63	75	75	88
0200	19	75	63	43	50	43	38	50	50	63	63	88	71
0300	14	83	60	67	50	50	75	67	83	83	100	83	83
0400	17	83	71	57	57	80	71	100	100	100	100	100	100
0500	18	67	67	60	57	67	71	71	100	86	88	71	86
0600	14	67	67	80	67	100	100	100	100	100	100	100	100
0700	46	71	83	86	100	100	83	83	100	100	86	100	71
0800	26	71	86	100	100	67	67	100	100	86	100	71	71
0900	40	67	80	80	80	70	89	90	70	90	67	40	78
1000	46	92	92	77	69	92	93	79	86	77	57	67	50
1100	65	94	94	89	100	100	89	94	67	44	50	33	29
1200	68	87	83	86	87	83	91	64	43	45	32	30	24
1300	71	88	84	81	77	79	56	35	46	28	28	30	27
1400	58	92	88	79	82	55	38	36	22	26	22	19	13
1500	72	97	83	81	59	43	44	28	30	26	24	21	14
1600	76	81	80	55	39	41	29	28	26	23	21	14	17
1700	64	92	67	46	48	35	31	30	26	25	17	17	16
1800	68	67	50	52	36	31	29	26	25	17	21	20	20
1900	46	65	78	53	47	43	43	40	27	27	29	19	15
2000	33	77	46	46	36	33	33	17	25	29	15	20	9
2100	37	64	57	50	50	50	33	33	36	23	18	27	36
2200	22	78	63	75	75	50	38	38	38	29	43	44	43
2300	20	57	83	67	50	50	43	43	33	60	57	50	80

tematic change in cloud cover for the summer season. The minimum occurred just after sunrise at 0700 LST (0500 UTC) while the maximum occurred at 1800 LST (1600 UTC). This suggests that a majority of the summer season cloud cover is convective in nature. Figure 4 is a histogram of IR pixel counts at each hour of the day with a brightness temperature less than 232 K to isolate deep convection. The maximum occurs at 1700 LST (1500 UTC). The second column of Table 1 contains the cloud percentage frequency of occurrence at

TABLE 2. Cloud forecast matrix based on cloud frequency and conditional probability data in Table 1. If conditional probability $> 70\%$, value is 1. If conditional probability is $<70\%$ and $>50\%$, then value is 1 if average of conditional probability and cloud frequency for forecast time is $>60\%$. Here, 1 is a forecast for cloud, and 0 for clear.

Time (UTC)	Forecast hours 1	2	3	4	5	6	7	8	9	10	11	12
0000	1	1	0	0	0	0	0	0	0	0	1	1
0100	1	0	0	0	0	0	0	1	0	1	1	1
0200	1	0	0	0	0	0	0	0	1	1	1	1
0300	1	0	0	0	0	1	1	1	1	1	1	1
0400	1	1	0	0	1	1	1	1	1	1	1	1
0500	0	0	0	0	0	1	1	1	1	1	1	1
0600	0	0	1	1	1	1	1	1	1	1	1	1
0700	1	1	1	1	1	1	1	1	1	1	1	1
0800	1	1	1	1	1	1	1	1	1	1	1	1
0900	0	1	1	1	1	1	1	1	1	0	0	1
1000	1	1	1	1	1	1	1	1	1	0	0	0
1100	1	1	1	1	1	1	1	0	0	0	0	0
1200	1	1	1	1	1	1	1	0	0	0	0	0
1300	1	1	1	1	1	0	0	0	0	0	0	0
1400	1	1	1	1	0	0	0	0	0	0	0	0
1500	1	1	1	0	0	0	0	0	0	0	0	0
1600	1	1	0	1	0	0	0	0	0	0	0	0
1700	1	0	0	0	0	0	0	0	0	0	0	0
1800	1	0	0	0	0	0	0	0	0	0	0	0
1900	0	0	0	0	0	0	0	0	0	0	0	0
2000	1	0	0	0	0	0	0	0	0	0	0	0
2100	1	0	0	0	0	0	0	0	0	0	0	0
2200	1	0	1	1	0	0	0	0	0	0	0	0
2300	0	1	0	0	0	0	0	0	0	0	0	1

TABLE 3. Conditional probability of cloud given 1%–33% of pixels within 15 km of Sarajevo covered with cloud at initial time 22 June 1994–5 August 1994.

Time	Cloud %	Forecast hours											
(UTC)	freq.	1	2	3	4	5	6	7	8	9	10	11	12
0000	24	33	0	0	0	0	0	0	33	33	33	67	67
0100	21	0	0	0	0	0	0	0	0	0	0	0	0
0200	19	0	0	0	0	33	33	33	100	67	100	33	33
0300	14	40	40	20	60	40	60	60	80	80	60	60	80
0400	17	50	50	50	0	0	0	0	0	50	50	50	50
0500	18	33	33	0	0	33	33	33	67	100	100	67	100
0600	14	25	25	25	25	50	50	75	75	75	75	75	75
0700	46	0	0	25	25	25	75	75	75	75	50	50	25
0800	26	50	75	75	75	100	100	100	75	100	100	50	50
0900	40	33	67	67	83	83	83	67	83	83	50	33	17
1000	46	83	83	83	83	83	83	83	83	67	33	33	17
1100	65	38	50	25	38	38	25	25	13	13	13	0	0
1200	68	64	55	55	45	27	27	9	0	18	9	9	18
1300	71	40	80	60	60	40	20	20	20	20	20	0	0
1400	58	50	50	33	50	50	33	50	33	17	17	17	17
1500	72	0	0	0	0	0	0	0	0	0	0	0	0
1600	76	14	43	43	14	29	14	0	14	14	14	14	14
1700	64	50	33	17	17	0	0	0	0	0	0	17	17
1800	68	0	0	20	0	0	20	20	20	20	20	20	0
1900	46	13	13	0	0	13	13	13	13	13	0	0	0
2000	33	20	0	0	0	0	0	0	0	0	0	0	0
2100	37	0	0	0	0	0	0	0	0	0	0	0	0
2200	22	0	33	0	0	0	33	33	0	0	0	0	67
2300	20	50	25	50	25	0	0	0	0	0	25	25	25

each time of day for the pixel centered over Sarajevo. Just as with the seasonal average for the entire sector (Fig. 3), there is a maximum in cloud cover at 1800 LST (1600 UTC). The data from Table 1 represents the systematic variation of cloud over Sarajevo and would make a good climatological forecast in the absence of other data. However, the forecast could be greatly improved by combining the frequency statistics with cloud persistence data. Table 2 is a yes/no climatological cloud forecast decision matrix constructed by combining the

TABLE 4. Forecast matrix as in Table 2 except with initial condition of 1%–33% of pixels within 15 km of Sarajevo classified as cloudy.

Time	Forecast hours											
(UTC)	1	2	3	4	5	6	7	8	9	10	11	12
0000	0	0	0	0	0	0	0	0	0	0	1	1
0100	0	0	0	0	0	0	0	0	0	0	0	0
0200	0	0	0	0	0	0	0	1	1	1	0	0
0300	0	0	0	0	0	1	0	1	1	1	1	1
0400	0	0	0	0	0	0	0	0	1	0	1	1
0500	0	0	0	0	0	0	0	1	1	1	1	1
0600	0	0	0	0	0	0	1	1	1	1	1	1
0700	0	0	0	0	0	1	1	1	1	0	0	0
0800	0	1	1	1	1	1	1	1	1	1	0	0
0900	0	1	1	1	1	1	1	1	1	0	0	0
1000	1	1	1	1	1	1	1	1	0	0	0	0
1100	0	0	0	0	0	0	0	0	0	0	0	0
1200	1	0	0	0	0	0	0	0	0	0	0	0
1300	0	1	1	1	0	0	0	0	0	0	0	0
1400	1	1	0	0	0	0	0	0	0	0	0	0
1500	0	0	0	0	0	0	0	0	0	0	0	0
1600	0	0	0	0	0	0	0	0	0	0	0	0
1700	0	0	0	0	0	0	0	0	0	0	0	0
1800	0	0	0	0	0	0	0	0	0	0	0	0
1900	0	0	0	0	0	0	0	0	0	0	0	0
2000	0	0	0	0	0	0	0	0	0	0	0	0
2100	0	0	0	0	0	0	0	0	0	0	0	0
2200	0	0	0	0	0	0	0	0	0	0	0	0
2300	0	0	0	0	0	0	0	0	0	0	0	0

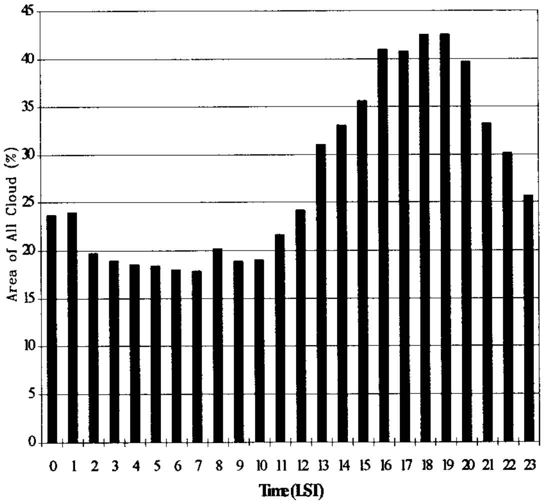

FIG. 3. Histogram of average daily percentage of area covered by cloud 22 June 1994–5 August 1994 at each time of day.

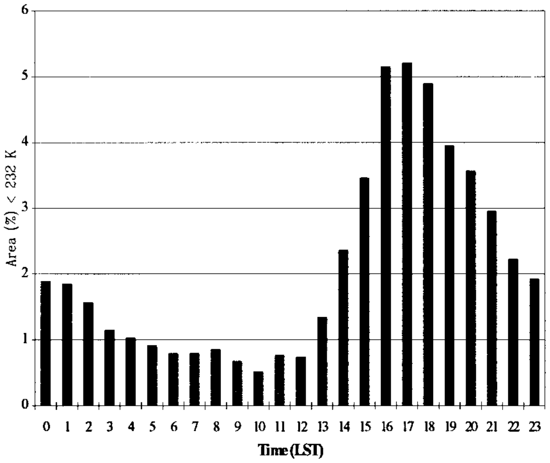

FIG. 4. Histogram of average daily percentage of area covered by cloud colder than 232 K for period from 22 June 1994 to 5 August 1994 at each time of day.

frequency and persistence data (Table 1) into a single binary index. Here, 1 (yes) is a forecast for cloud and 0 (no) is a forecast for clear.

Although definitive yes/no cloud criteria are certainly a topic for further research, we use the following criteria for this study. Of the two types of data in Table 1 (frequency occurrence and conditional probability), the conditional probability is a more reliable forecast tool since it includes an initial condition. Therefore, we weight the yes/no cloud decision more heavily to the persistence probability. If the conditional probability at any hour is greater than 70%, then the forecast for cloud is yes. If the persistence probability is less than 70% but greater than 50%, then we compute the average of the frequency of occurrence and the persistence probability for the forecast time. If the average is greater than 60%, then the forecast is yes (1); otherwise it is no (0). These particular thresholds were chosen so that the mean amount of cloud predicted in the yes/no matrix of Table 2 was comparable to the average frequency of occurrence of cloud for all hours from column two of Table 1. The average of the frequency of occurrence for all the hours is 41%. Assigning 1 for yes and 0 for no, the average frequency of occurrence of cloud as predicted by the corresponding forecast matrix (Table 2) is 44%.

The importance of this weighting scheme is illustrated in Table 1. At 0400 UTC (0600 LST) the systematic frequency of occurrence of cloud is 17%. However, when cloud occurs at 0300 UTC, the probability of cloud at 0400 UTC is 83%. Similarly, the conditional probability of cloud at 0600 UTC given cloud at 0300 UTC is 67% compared to a systematic occurrence of 14%. This makes sense meteorologically for Sarajevo. Climatological data for Sarajevo shows that nocturnal low-level stratus cloud and fog occurs on about 10% of summer season mornings. Other cloud occurring in the early morning was likely associated with synoptic-scale disturbances and hence was forced by larger-scale dynamics. Other data in Table 1 further illustrate the importance of heavily weighting the conditional probability in the forecast index. Note that given cloud over Sarajevo at 0600 UTC, the 12-h forecast for cloud at 1800 UTC is 100%. The systematic variation of cloud for summer 1994 was for overcast 68% of the time at 1800 UTC. In fact, given an initial condition of cloud at any hour after 0500 UTC, the conditional probability of being overcast at 1800 UTC is higher than 68%.

As mentioned in the previous section of this paper, a more sophisticated approach is to stratify the probability in terms of a percentage of pixels in a region surrounding the target that are cloudy (clear) at the initial time. Table 4 is a forecast matrix derived from the persistence probabilities and cloud frequencies in Table 3. By considering pixels in a 15-km region surrounding the target in the conditional probability, as opposed to a single pixel, the forecast can change significantly. Table 4 is a CNC forecast matrix analogous to Table 2 with an initial condition of less than 33% of pixels within 15 km of the Sarajevo pixels classified as overcast. Comparing Table 4 to Table 2, one can qualitatively see that the amount of yes (1) cloud forecasts is greatly reduced. The mean cloud forecast for all times in Table 4 is 21%. In contrast, the mean cloud amount from Table 2 is 44%. The mean amount of cloud predicted with an initial condition of 66% of pixels within 15 km cloudy is 44%. Evidently, considering only a single pixel at the initial time is equivalent to assuming overcast conditions over a larger region. This same bias would likely occur with conditional probabilities computed using cloud cover statistics from the conventional surface observations of a single station.

6. Conclusions

In this paper we described forecasting applications of high-resolution satellite cloud climatologies and developed a climatological forecasting tool that is well suited to the operational environment. The feasibility of creating a global database of IR data at full resolution was demonstrated by the CHANCES project (Vonder Haar et al. 1995). To make the tool complete, the database should be expanded to at least five years and tables created for every pixel for each month of the year for the entire globe. The climatological forecast tool described in this paper would lend itself perfectly to software that would allow a user to point and click at the desired location on a map and instantly display the climatological data through hypertext links, like those used on Web pages.

In this study we demonstrated the importance of including the spatial pattern of cloud surrounding the target in creating conditional probabilities. A second level of sophistication would be to include a temporal pattern of cloud. For instance, the initial condition could be composed of 3–6 h of cloud data at a target pixel or in a region surrounding a point of interest.

Currently, researchers at the Cooperative Institute for Research in the Atmosphere (CIRA) at Colorado State University (CSU) are developing techniques to extract layered cloud information from the CHANCES database. A paper on their results was presented at the 1996 Battlespace Atmospherics Conference (Forsythe et al. 1996). The location of the bases and heights of clouds are of great importance in a military target forecast. Stratifying the data in terms of meteorological variables such as wind direction and air mass would make the climatology even more reliable. The level of sophistication is virtually limitless.

The potential military and civilian forecasting applications of very high resolution satellite cloud climatologies are exciting. With a single observation, the forecaster could quickly access climatological forecast aids such as the forecast matrix developed in this study using a personal computer. With the global coverage of meteorological satellites, high-resolution climatological cloud forecast tools for airfields and remote locations anywhere in the world are within our grasp.

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