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CLOUD CLIMATOLOGIES CONSTRUCTED FROM SATELLITE IMAGERY

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1. INTRODUCTION

In a previous paper, these same authors (Klitch, et al., 1985) described the results of a study in which full resolution GOES data over Colorado were computer averaged on an interactive processing system. Results included two different types of averages (also called "composites"). The first consisted of a simple PIXEL by PIXEL average of visual imagery from coincident times of day during July and August 1982. The "average images" were constructed for four times -- 1700, 1900, 2100 and 2300 GMT. Additionally, four other VIS composites, consisting of images from severe weather days only, were made for the same times for comparison.

The second type of composite was an average of interactively-altered imagery. In this case, information from both VIS and IR data was combined to identify regions having either 1) deep convection (defined as $\leq$-30°C in the IR and "bright" cloudiness in the VIS), 2) clear skies, or 3) all other type of cloudiness. A new image was created in which the deep convection was colored white, the clear ground black, and the "other cloudiness" regions a deep gray. These images were then averaged together as were the VIS images above.

There were several interesting results to the study. The composites illustrated the potential for developing a highly detailed climatology of topographically controlled convection. The data furnished a much more dense observation network than is typically available. For example, Colorado (CO) has nearly 200 precipitation reporting stations statewide. However, since Colorado covers an area of roughly $2.67(10)^5$ km^2, the average coverage is one observation every 1,335 km^2. GOES pixels range from 2 km^2 (for 1/2 mi VIS) to 80 km^2 (for IR) at the latitude of CO. Consequently, the satellite coverage is between 17 and 668 times more dense than the state-wide precipitation reporting network. This is not to imply that satellite can measure the same variables as surface networks; only that, for what they do measure (i.e., total cloud cover, cloud type, location of deep convection, etc.), the sensor supplies very high resolution measurements.

One of the shortfalls of the study was that, by allowing three categories in the bi-spectrally altered imagery, an ambiguity was introduced which created a problem in making definitive statements. Klitch, et al. (1985) suggested that future work should create bi-modal composites (e.g., cloud/no cloud, convection/no convection, etc.) to avoid these problems. It was further suggested that more data were needed before such averages could become significant in any statistical sense. Finally, it was stated that the Summer 1982 study was merely a first step in what they hoped would become many, larger based climatological studies over different regions of the country (especially where geographic features force repetitive convective cycles).

Following the 1982 project, a study utilizing similar cloud compositing techniques was completed by another group at Colorado State University (McQueen and Pielke, 1985). That study investigated deep convective cloud patterns over southern Florida on synoptically undisturbed days. The authors subdivided their data into the four most common local wind flow regimes. Composite results were compared to a three dimensional mesoscale model (Pielke, 1974; Pielke and Mahrer, 1978) which incorporates sea breeze forcing, synoptic flow patterns, and ground characteristics. The composited data helped interpret model results in relation to general convective behavior patterns.

The summer of 1985 marked the beginning of a new phase to the cloud climatology project. The current plan includes utilizing data collected during July and August 1985 to design new composite types -- then to run these composites for June-August, 1986 and 1987.

The first phase of the project is now complete, and prototype composites are available. This paper discusses the interactive compositing methodology and meteorological significance of the results.

2. New Composites

As noted above, one of the lessons learned in the first compositing study was that

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ambiguities were easy to come by. Thus, one of the primary concerns was to formulate determinate averages. This was accomplished by altering the data to a bi-modal form (such as cloud/no cloud) whenever possible. A second concern was to present the averaged data in a precise, clear format. That is, even though the averaged arrays give an accurate, point by point frequency count, the subjective appearance of the image is often confusing. It may not look like a satellite image, and may not, therefore, be the best product from the user standpoint. To solve this problem, a set of secondary images was constructed. For these, a completely cloud-free satellite image of the study area was collected. The interactive, image processing system described in Klitch, et al. (1985) was then used to replace pixels in the clear image wherever the frequency exceeded a chosen threshold. The combination of the two made the frequency data appear to represent clouds as in a normal satellite image.

There are three types of composite illustrated here. The first is a simple average of all of the VIS images for the entire data collection period. It encompasses all brightnesses, from whatever cause, and may include regions of repetitively bright ground as well as those regions having frequent clouds. The resulting composite for 1700 GMT is shown in figure 1. It is purposely left in its original format to illustrate the potential for confusion. For example, the bright areas in eastern CO are actually "mostly clear" areas where the ground has a high albedo, while the bright regions in western and central CO result from frequent cloudiness. The method whereby this distinction was made will not be discussed here. Suffice it to say that the interpretation is ambiguous, and may even be misleading to forecasters.

One of the weather stratifications used for this pilot study separates "monsoon" from "non-monsoon" cases. A brief explanation is in order before going on to figure 2. CO receives its moisture for summer thunderstorms from at least two sources--easterly upslope Gulf moisture (or evaporated rain), or advection of Pacific moisture from the west or southwest. The latter has been labeled "monsoon flow" (after Hales, 1974). A monsoon situation normally results from several days of southwesterly 700 mb through 500 mb geostrophic flow. In most years, monsoon flow accounts for about a third of the convective days in CO. For the 1985 data period the ratio was nearly 50 percent. Thus, the decision to separate cases of monsoon/non-monsoon flow days. A "monsoon day" was defined as days having a moist southwesterly flow at 700 mb and/or 500 mb.

Figure 2 is a composite of monsoon day images from 1700 GMT. Before averaging, each image was interactively altered. Each cloudy pixel was transformed to absolute white, each non-cloudy pixel, absolute black. The average of all such images represents the frequency of cloudiness, at each point, over the entire sample period. We have shown only points that had cloudiness 50 percent of the time or more. For the rest of the image, the "clear ground" image was substituted as described earlier. Note the sharp contrast between figure 2 and

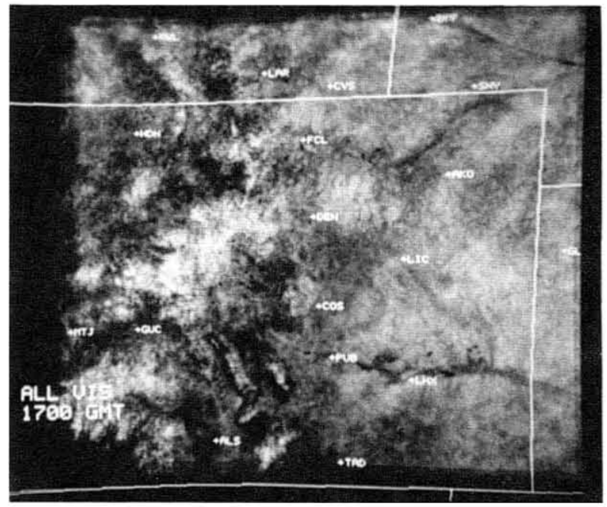

Fig. 1. Computer average of all VIS imagery collected at 1700 GMT, daily, between 13 July 1985 and 23 August 1985.

figure 3 (which is the same type of composite for non-monsoon days). Monsoon days generally "look" much more moist and careful scrutiny of cloud streaks in relation to the wind flow reveals a direct relationship of cloudiness out over the plains in eastern CO and WY, to terrain features (figure 4) over in the mountains.

The lack of activity on non-monsoon days in northern Colorado raises an intriguing question in light of findings in the earlier paper. Klitch, et al. (1985) showed that Colorado severe thunderstorm days differed from non-severe days by the amount of convective activity in northern Colorado and southeastern Wyoming. The results showed enhanced convective development in those areas on severe days. In the current study, development to the north is found only on "monsoon" days. One is tempted to speculate on the relationship between mid-level monsoon flow, and severe weather on the high plains. While significant weather reports (Storm Data, 1985) don't fully support this speculation, there was enough of a tendency to warrant further investigation. For example, defining a "significant thunderstorm" as one producing tornadoes, hail $\geq$ 0.5", damaging winds, or 15 min. rain rates of $\geq$ 1.5"/hr, we found that significant storms occurred on 88 percent of the monsoon days, but only 28 percent of the non-monsoon cases. Similarly, 56 percent of the monsoon case days produced severe thunderstorms (tornadoes, hail $\geq$ 0.75", or winds $\geq$ 50 kts), compared to only 24 percent for the non-monsoon cases. These statistics lend some weight to the speculation, but the data set is small and strong inferences are not possible. This relationship will be further investigated with 1986-87 cloud composite and synoptic data.

By defining "convection" as points having bright clouds on the VIS, and an IR temperature of less than -12C (about 20,000 feet in summer in CO), we were able to construct black/white images representing convection/no convection. Figure 5 is a "convection/no convection average" of images for the cloud/no cloud data shown in figure 2. Note what a small percentage of the cloudiness at 1700 GMT is actually deep

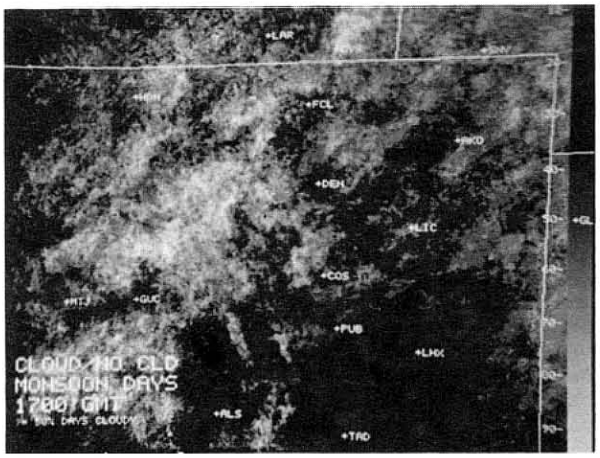

Fig. 2. Computer average of interactively altered VIS images collected at 1700 GMT, daily, between 13 July 1985 and 23 August 1985 on "monsoon" days (see text). Before averaging, cloudy pixels were turned pure white, and non-cloudy pixels black.

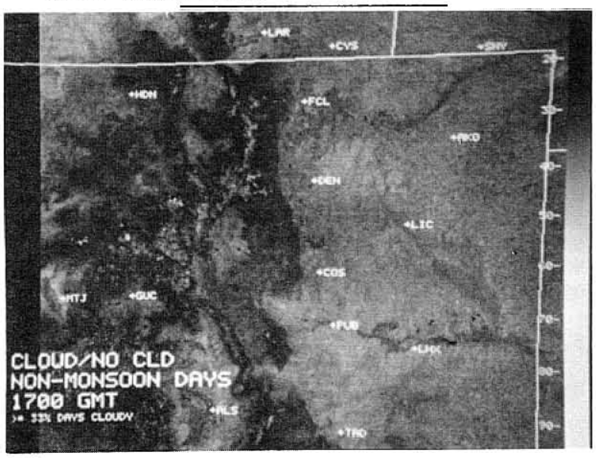

Fig. 3. Same as figure 2, except for non-monsoon days.

Fig. 4. Colorado topographic image. Brightest regions are the high ranges of the Rocky Mountains.

convection. Most of the other cloudiness turns out to be a shallow, mid-level deck.

For completeness, figures 6-9 are included to show the subsequent evolution of the monsoon/non-monsoon days. The last time period collected for the sample set was 2100 GMT. Actually, for both cases, the 2300 GMT composites find much more development in the Denver to Colorado Springs region than appears by 2100 GMT, but particularly for the non-monsoon case.

3. CONCLUDING REMARKS AND PLANS FOR FUTURE RESEARCH

The new project will include data from several orographically and non-orographically forced regions. The targeted areas include data from the Great Lakes, Colorado, Alabama, southern Florida/Caribbean Islands, Gulf of Mexico/Central America, and the southeastern US centered on Georgia. Presently, the primary stratification categories planned are 1) averages of all data, 2) a monsoon/non-monsoon breakdown, and 3) severe versus non-severe thunderstorm days. Subsets planned for each stratification will include a) cloud/no cloud images, b) convection/no convection, and c) stratiform versus "other" types. Additionally, half minute resolution, topographic data over the study area will be remapped and matched for direct comparison.

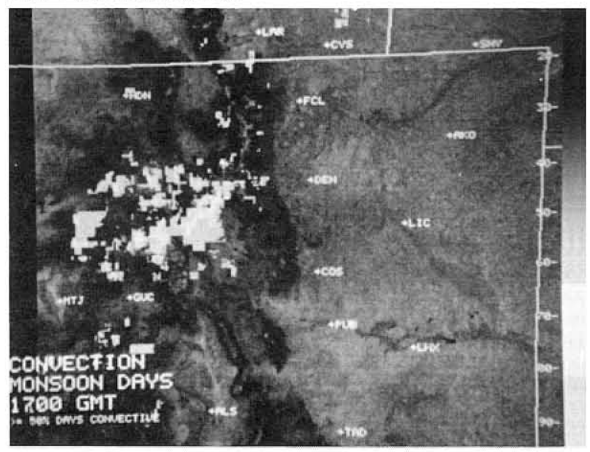

Fig. 5. Computer average of interactively altered satellite imagery collected at 1700 GMT, daily, between 13 July 1985 and 23 August 1985 on "monsoon" days. Before averaging, convective pixels (see text) were turned pure white, and non-convective pixels black.

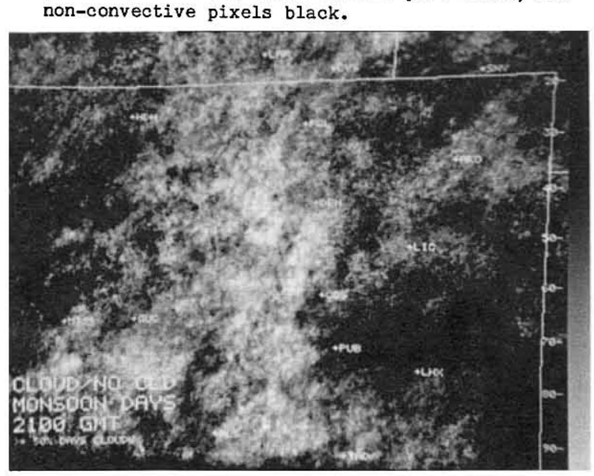

Fig. 6. Same as figure 2, except composite is for 2100 GMT.

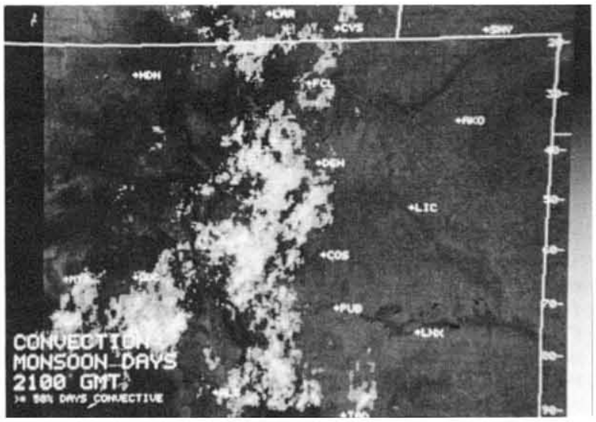

Fig. 7. Same as figure 5, except composite is for 2100 GMT.

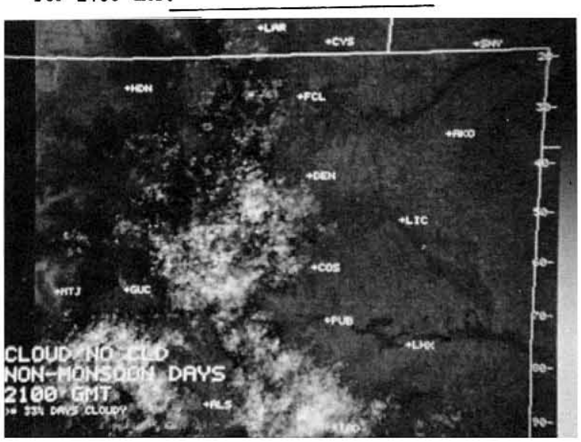

Fig. 8. Same as figure 3, except composite is for 2100 GMT.

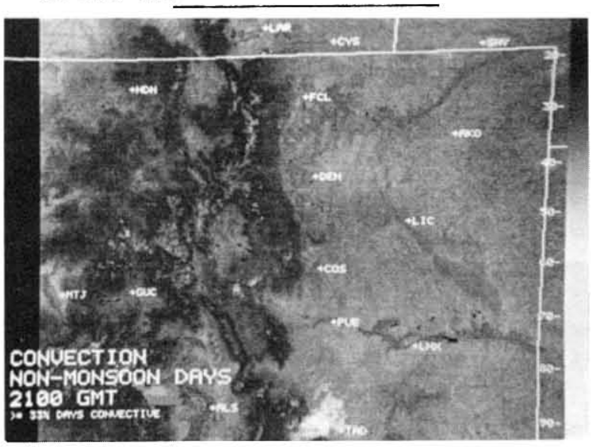

Fig. 9. Same as figure 5, except composite is for non-monsoon cases at 2100 GMT.

The generation of climatologies for these areas will assist in the development of short range cloud forecasting techniques. The composites will provide a basis for the first guess estimation of cloud development and motion. Empirical studies relating the derived composites to the dynamics of the cloud field will assist in the forecasting of the subsequent cloud field through the weighting of parameters used in dynamic estimation models.

The high resolution digital character of the composites provides a basis for image combination studies. The purpose is to generate a climatological estimate of the cloud field for a particular date and time with as much resemblance as possible to an actual satellite image. This will provide direct image combination capabilities with the real-time imagery for estimating the probabilities of extreme events.

Finally, a complementary climatological data set depicting the spatial and temporal character of the clear areas versus clouds is planned. By emphasizing the clear area climatology and combining it with the cloud climatologies and mesoscale models, we hope to gain insight into the dynamic effects of differential heating and the extent of subsident motions related to cloud types and geographic regions.

4. ACKNOWLEDGMENTS

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