CLOUD BASE HEIGHT ESTIMATES FROM A COMBINATION OF A SATELLITE CLOUD CLASSIFICATION AND CEILOMETER-BASED SURFACE REPORTS

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1. INTRODUCTION

The vertical distribution of clouds is of fundamental importance to many areas of atmospheric science. The height of the cloud top and base, along with layering characteristics of clouds, has a significant effect on the global radiation balance. Prediction of cloud ceiling for aviation purposes is another important example. A clear line-of-sight is often required for airborne military and surveillance operations, and the height of the cloud base and top is also a controlling factor. An expanding number of numerical forecast models are beginning to carry clouds explicitly as a prognostic variable. Observations of cloud layers are necessary to validate the cloud fields created by the model. Three-dimensional cloud fields have been constructed by various means and brought into mesoscale models as a proxy for the vertical moisture profile, with a positive impact on the model forecasts (Macpherson et al. 1996; Koch et al. 1997). Scene simulation using realistic clouds (Hembree et al. 1997) also requires cloud base as a primary input. Research on combining surface ceilometer observations with satellite imagery suggests there is much promise to be derived from this approach (Feijt and Van Lammeren, 1996).

2. HYPOTHESIS

The hypothesis we test in this paper is that a satellite-based classification of cloud cover combined with surface reports of cloud base will yield an improvement over estimates of cloud base which use surface reports alone. The problem we consider is how to estimate cloud base at a location where surface observations are not available. Cloud base estimation using only surface observations, hereafter referred to as the NOSAT method, is often based on some rule where distance is a weighting factor (e.g. Macpherson et al. 1996). Since clouds often occur in distinct layers with sharp edges, we expect better performance using a method which preserves the roughness and horizontal contiguity of the cloud field. In our test, we use a cloud classification from visible and infrared satellite data (SAT method) to serve as a mask which preserves the horizontal cloud structure, and compare the results to those obtained from a distance-based NOSAT approach. Our hypothesis is that surface reports within a satellite-derived, horizontally-extended class should be more similar to others within that same class than to those in a different class. We expect this to be true even when the surface-derived reports associated with a different class are spatially closer to the point at which we are trying to predict cloud base.

Figure 1 is a conceptual diagram of our hypothesis. In Fig. 1, the two fill patterns are two classes of cloud derived from satellite. Suppose we wish to predict the cloud base at the location shown in the Fig. 1. Under our hypothesis, the report of 3000 m in the same class is likely to be the cloud base height at the prediction location. The value of 500 m at the nearest station is not used because it is in a different cloud class. The details of the method used to classify clouds on satellite imagery are not important for this study, as long as the method responds to changes in cloud base. For our classifier, we use the visible and infrared histogram classifier method of Porcu and Levizzani (1992). Other types of classifiers using additional spectral information, for instance microwave radiances, could be used in a future classifier.

Figure 2 shows an example of how the infrared and visible images are used as input to create the classified image.

3. DATA

Full-resolution visible and infrared imagery from the Geostationary Operational Environmental Satellite (GOES) - 8 was collected for 23 days during the month of June, 1996 over the central and eastern United States at the Colorado State University Satellite Earthstation. GOES-8 hourly images between 1300 and 2300 UTC were chosen for analysis. These hours were chosen to provide sufficient solar illumination over the study area to use the visible radiances. A total of 235 image pairs were used.

Surface meteorological observations were collected at the Cooperative Institute for Research in the Atmosphere (CIRA), from the U.S. domestic surface-reporting network. Most of these reports are taken at about 10 minutes before the hour. The cloud base height data consists of a combination of Automated Surface Observing Stations (ASOS) ceilometer heights, and human weather observer reports of cloud base height. The upward-looking ceilometer for the ASOS observations only reported clouds below 12000 feet (3650 m).

4. RESULTS AND CONCLUSIONS

Figure 3 shows the detailed procedure used to determine the cloud base estimate using the satellite classification (SAT method) versus a method using a spatially closer surface report without benefit of the satellite classification (NOSAT method). Note that this approach amounts to always giving the NOSAT method the advantage of being spatially closer to the prediction location. So we would expect better performance of the NOSAT method if distance alone was the controlling factor in the accuracy of a cloud base estimate.

Table 1 shows the results obtained by using the SAT and NOSAT methods. The coefficient of determination (r^2) for each method is shown. What is important are the differences between r^2 for the two methods. Results are shown for cloud cover of at least scattered (SCT (1/8 to 4/8)), broken (BKN (5/8 to 7/8)), and overcast (OVC (8/8)). For SCT or greater coverage, the NOSAT method has an r^2 value of 0.350 while the SAT method has a value of 0.400. For BKN or greater coverage, the r^2 values have increased to 0.560 for the NOSAT method versus 0.611 for the SAT method. For OVC conditions, r^2 for the NOSAT method is 0.503 while for the SAT method it is 0.641. The SAT method shows a slightly better fit than the NOSAT method in all conditions, and the best fit is obtained for surface reported cloud cover of at least BKN. It makes sense that the fit of the SAT results should improve as cloud cover increases towards OVC since the misleading effects of partially filled field-of-views in the satellite classification will decrease.

The analysis to this point has revealed a slight increase in estimation skill by using the SAT method over the NOSAT method, even though the NOSAT method has been given an advantage by using closer stations. We now examine if there are certain circumstances where the SAT method more clearly outperforms the NOSAT method. The particular situation we examine is when the clouds along a straight line between the CONTROL site and the SAT site are in the same class from the two-dimensional histogram as the CONTROL and SAT site points. The prior analysis only required a 5 x 5 area around the CONTROL and SAT points to be in the same class and made no examination of what might lie spatially in between these sites. Physically, requiring the class to remain constant along a ray drawn between the SAT and CONTROL sites means that we expect the character of the clouds to remain consistent along that path, assuming the SAT classification has some sensitivity to changes in cloud base. The exact cloud properties have not been inferred from the bispectral classification, but if the satellite-derived classes are meaningful we expect that the clouds will be essentially the same at the CONTROL and SAT site if the class in between is contiguous. The NOSAT sites are still given the advantage of being spatially closer to the CONTROL site than the SAT site, and we continue to require that the NOSAT points are not in the same class as the SAT points in order to test the impact of the classification.

Using the class consistency test, the r^2 values shown in Table 2 from the SAT classification show a marked improvement. For SCT or greater coverage, r^2 has increased from 0.400 to 0.623. For BKN or greater coverage, r^2 has increased from 0.611 to 0.874, and for OVC conditions it has increased from 0.641 to 0.867. The pattern of improved fit with broken and overcast conditions holds. The NOSAT correlations for the same cases also show some increase for all coverages as compared to their coverage in Table 1. For SCT or greater coverage, r^2 has increased from 0.350 to 0.532. For BKN or greater, r^2 has increased from 0.560 to 0.706, and for OVC conditions it has increased from 0.503 to 0.535. As in Table 1, the SAT method cloud bases have better correlation than the NOSAT results at all coverages. In particular, the SAT method with a check for class consistency between observations clearly outperforms the NOSAT method when the surface reports indicate coverage of BKN or greater. The check for consistency of class also increases the r^2 values of the SAT method for BKN and OVC conditions by over 0.20 versus simply finding the nearest in class without any measure of variability in between. This increase in skill by using the class consistency check can be seen by comparing Table 1 with Table 2. The result of better performance obtained by using the class consistency check can be used to intelligently spread point measurements of cloud base over large geographic regions with a satellite classification controlling the spatial structure of the field.

In summary, Tables 1 and 2 show that the SAT method outperforms the NOSAT method. Results indicate that fusion of the satellite cloud classification with surface cloud base height reports yields a superior estimation of cloud base height versus an estimate using only interpolated surface data. This is true even though we gave the surface-only method the advantage of always being spatially closer to the control site. Performance improvement is more significant for broken and overcast conditions. In addition, the use of a simple textural measure, derived from the satellite cloud classification, causes the satellite-assisted method to outperform the surface-only method by an even wider margin. These results point the way towards improved three-dimensional cloud field estimation using surface and satellite observations.

5. ACKNOWLEDGMENTS

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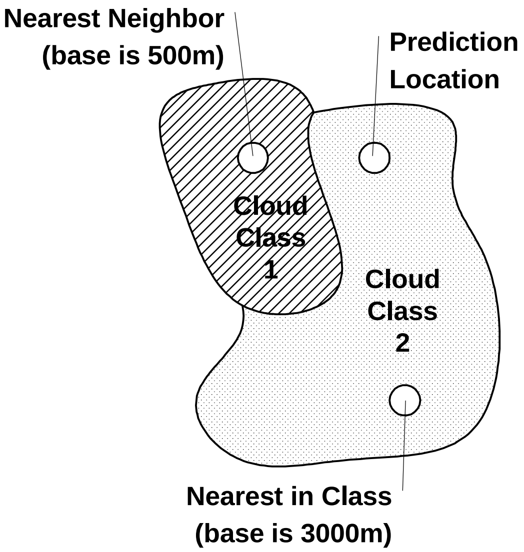

Figure 1. Conceptual diagram indicating two satellite-derived cloud classes and surface cloud base observations used in this study.

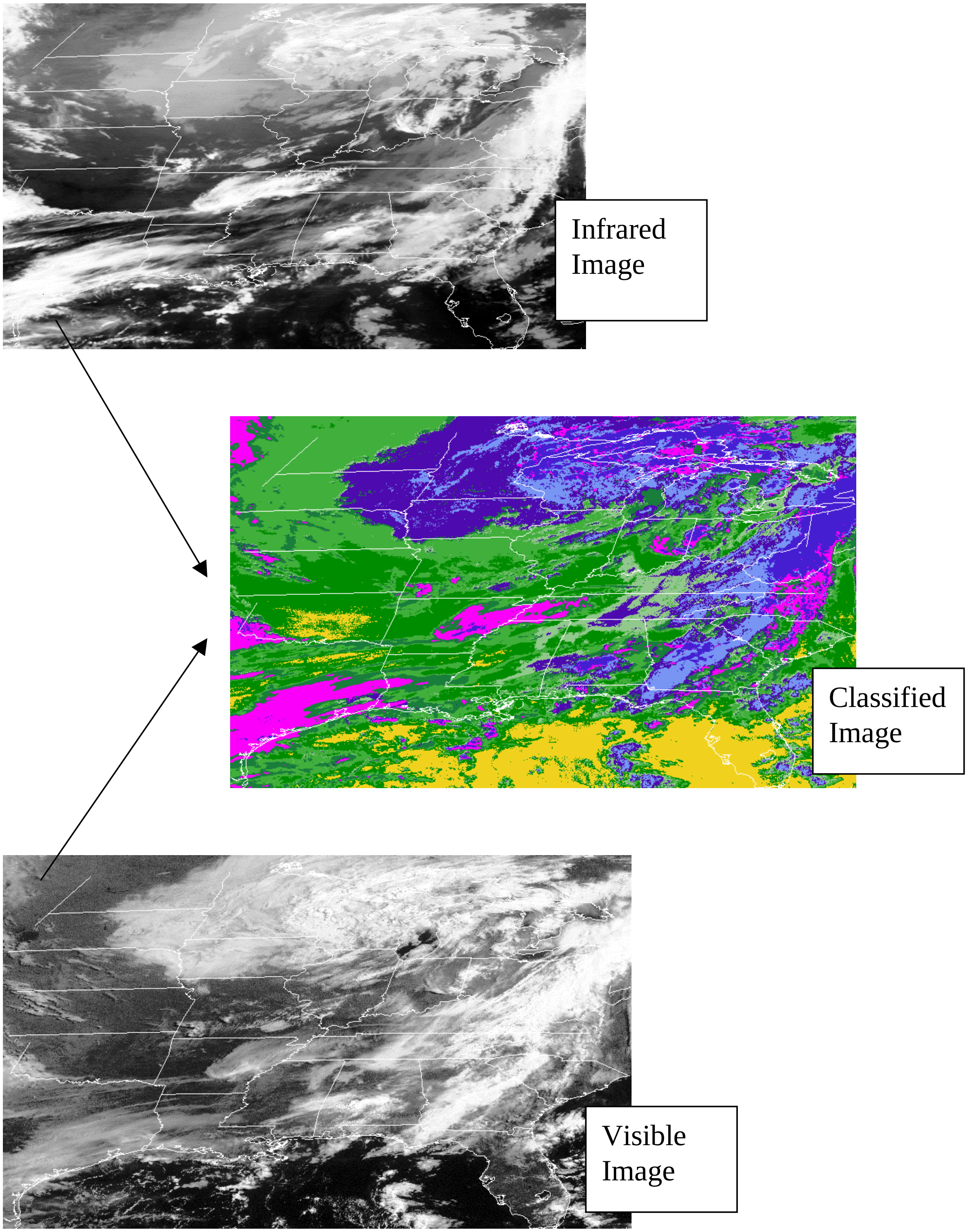

Figure 2. Example of infrared and visible images being used to create a classified image. Images are from June 3, 1996 1301 UTC over the eastern United States.

PROCESS TO COMPARE SAT AND NOSAT METHODS

- For each of the 235 paired visible and infrared images in our study, perform a cloud classification using the 2-dimensional visible / infrared histogram from the image radiance.
- Examine the surface cloud observations and make a list of all reports within a half hour of the satellite observation which report at least scattered (1/8 to 4/8) cloud cover.
- Loop through the surface reports and withhold one station at a time (the CONTROL). Determine the class from the satellite classification to which the CONTROL belongs. We require a 5 x 5 pixel (20 x 20 km) area around the station to consist of the same class, otherwise the station is discarded for comparison purposes (implying that the point does not belong to just one of our satellite classes). Then go through the remaining surface cloud height observations and find:
- The nearest report which is in the same class (the SAT site) and
- A report which is located closer to the CONTROL site than the SAT site, but which is in a different class (the NOSAT site).
- From these three reports (the CONTROL, SAT, NOSAT) go through the surface reports from each and find the layers which give the minimum difference in cloud base between CONTROL versus SAT and CONTROL versus NOSAT. Compare the CONTROL report, NOSAT prediction, and SAT prediction.

Figure 3. Process to compare SAT and NOSAT methods

Coverage	r^2 NOSAT	r^2 SAT	# Obs
SCT	0.350	0.400	667
BKN	0.560	0.611	256
OVC	0.503	0.641	140

Table 1: The coefficient of determination (r^2) values for the SAT and NOSAT cases are shown for scattered, broken, and overcast surface-reported cloud conditions.

Coverage	r^2 NOSAT with class consistency test	r^2 SAT with class consist-ency test	# Obs
SCT	0.532	0.623	138
BKN	0.706	0.874	68
OVC	0.535	0.867	47

Table 2: Same as Table 1 except using the class consistency test.