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A TECHNIQUE FOR DETERMINING CLOUD FREE VS CLOUD CONTAMINATED PIXELS IN SATELLITE IMAGERY

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INTRODUCTION

Since the first earth orbiting satellite sent pictures of the earth back to them, atmospheric scientists have been focused on the possibilities of using that information as both a forecasting tool and as a meteorological research tool. With the latest generation of Geostationary Operational Environmental Satellites (GOES) now entering service, that view of the earth yields views at a frequency and resolution never before available. These satellites have imagers with a five band multi-spectral capability with high spatial resolution. In addition, the sounder has eighteen thermal infrared (IR) channels plus one low-resolution visible band. With a resolution as small as one kilometer, GOES provides scientists with a powerful eye on the atmosphere. Menzel and Purdom (1994) detail both the imager and sounder capability as well as other systems on the GOES satellites.

Immediately apparent in the visible channel are the patterns of clouds swirling over both oceans and continents. These clouds range in size from huge planetary systems covering thousands of kilometers to puffy fair weather cumulus clouds on the order of half a kilometer in size. With the IR sensors temperature patterns are observed. High clouds appear very cold, while low stratus field show temperatures near that of the surface. The surface, in turn, generally appears warmer than the clouds. It would seem then a simple manner to determine cloud and surface temperature from the imagery, but such is not the case. While most of the atmospheric constituents are well mixed and homogeneous, water vapor is not. The water molecule, because of its unique structure and vibration modes, affects the transmittance of the atmosphere most notably in the infrared regions. There are regions of the IR spectrum where water vapor acts as a strong absorber, and at others it is nearly transparent. The transparent wavelengths are called windows, and one such window occurs at 11.2μm. Adjacent to this window at 12.7μm which is strongly absorbed by water vapor.

These two wavelengths form what is known as a split window, the utility of which was first used by Chesters et al. (1983). Using the linearized form of the radiative transfer equation, they were able to use the split window to determine the amount of water vapor present in the atmosphere. Jedlovec (1987) developed the physical split-window (PSW) technique which determines the integrated water content (IWC). Guillory et al. (1993) used the PSW method using Visible Infrared Spin Scan Radiometer (VISSR) Atmospheric Sounder (VAS) found on the older versions of the GOES satellites. Recently, Jedlovec and colleagues have been attempting to apply the PSW method using full disk IR imagery obtained by the new generation of GOES satellites. IWC is essential for improved analysis and prediction of convective storms which have been observed to develop in regions of both strong and rapidly evolving moisture gradients (Miller 1972). It has also been used in the prediction of clouds and precipitation (Perkey 1976).

CLOUD CLEARING VS. CLOUD FILTERING

Full disk IWC retrievals pose several significant problems. One of these is the requirement for the image pixel be cloud free. Since the method uses upwelling surface radiation in the PSW, it appeared obvious that any cloud contamination would modify the 11.2μm and/or the 12.7μm brightness temperature which would then make IWC retrievals inaccurate. Thus, a method was needed to eliminate the cloudy pixels from the data. There are two approaches to doing this, one called cloud clearing, the other cloud filtering.

Cloud clearing generally employs statistical methods by which clouds are eliminated (cleared). The goal is to modify measured radiances to the 'clear column' values which would be observed from the same atmospheric profile with no cloud contamination. Eyre and Watts (1987) present a fairly comprehensive review of several cloud clearing methods to which the interested reader is invited. This method tends to average the radiances over a partially cloudy area to a significant extent, so to moisture gradients would also be spread over larger areas. Since we are interested in the gradients themselves, modification by the cloud clearing method is not desirable.

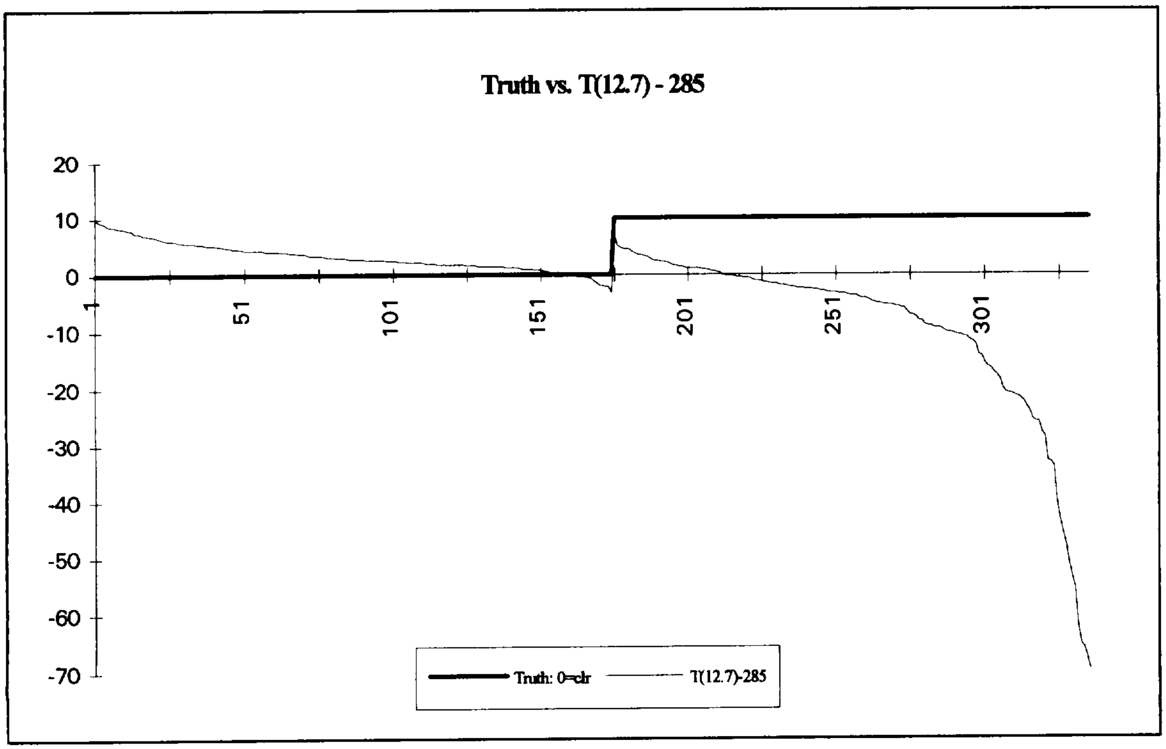
Cloud filtering, on the other hand, does not affect the moisture gradient as the cloud clearing method can. Cloud filtering is simply a method by which cloud contaminated pixels are eliminated entirely from the image so that the retrieval method uses only clear pixels. While cloud filtering might be simple in concept, in practice it is another thing entirely. Again, several methods exist. McMillin (1978) details a method which uses spatial comparisons between a given pixel and its neighbors. McMillin and Dean (1982) describes an operational scheme which makes use of a multi-spectral, multi-step series of tests to determine cloud contamination.

Pieces and parts of each of numerous methods for cloud clearing or filtering were considered for our cloud filtering scheme. But, with the charge of making the scheme as simple, fast and accurate as possible so that ultimately real time GOES data might be used, many were eliminated as being to complicated, computationally difficult and time consuming. We took a new approach in trying to find a simple cloud filtering method.

DATA COLLECTION AND ANALYSIS

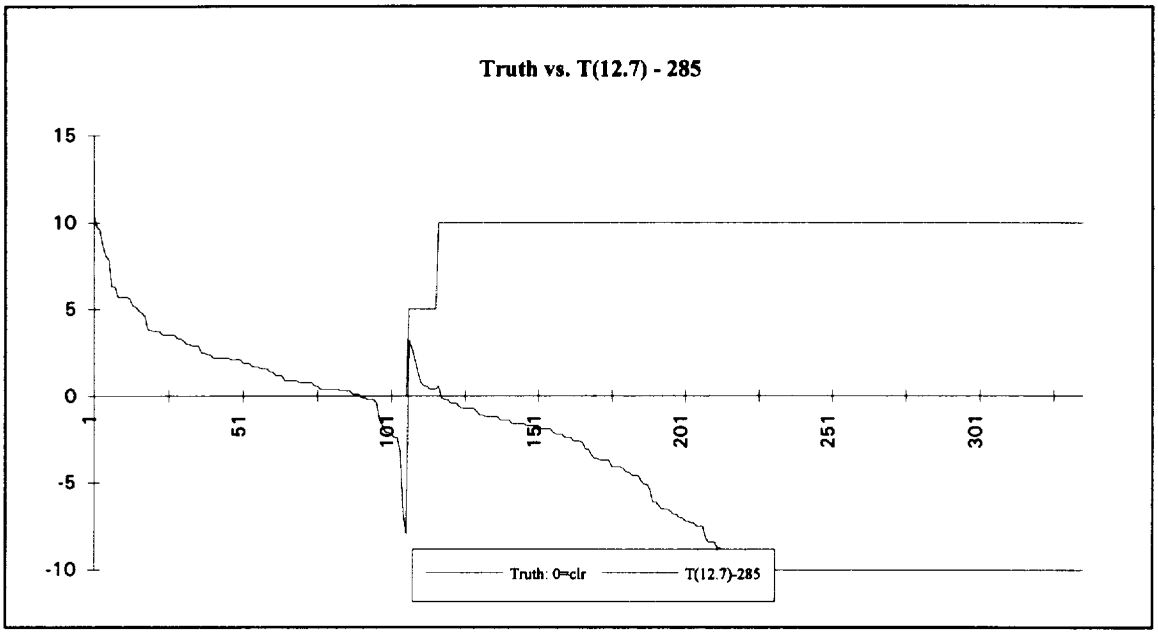
GOES pathfinder data was used to gather radiance information from three sources: 12.7μm and 11.2μm brightness temperatures, and visible brightness counts. The pathfinder dataset provides eight kilometer resolution in all of these wavelengths which are all temporally and spatially correlated. Data was gathered from the odd dates from 19 through 27 August 1988 at both 1500Z and 1800Z using a locally produced program running in the McIdas environment. Each dataset was comprised of an array of pixel information which contained pixel location in both image coordinates and earth coordinates, 11.2μm and 12.7μm radiance, and visible brightness count. There were between 325 and 350 datapoints selected from an image which extended from18°N to 45°N, and from 70°W to 105°W. These data were then imported to a spreadsheet for manipulation, and study.

Of first concern was the generation of a 'truth' value for each pixel, that is, a binary type value which described the pixel as clear or cloudy. This was done in a gross manner in the selection program run under McIdas, and fine tuned by individually examining pixels in all three wavelengths for final determination of their clear or cloudy status. This examination considered the relationship of the individual pixel value to neighboring values. For example, if a visible brightness count was 65 (a rather low value) it might indicate a clear pixel if over land, but could show a cloud contaminated pixel over water. By comparing it to the adjacent pixels, it can usually be determined to be clear or cloudy. If the pixel was determined to be clear, it was assigned a truth value of 0, if cloudy, 10. Once 'truth' was determined with a high degree of certainty, a data manipulation was performed. The data were sorted by 'truth' (from low to high) and secondarily sorted by the 12.7μm brightness temperature. Additionally, 285 was subtracted from the 12.7μm brightness temperature to lower the curve to the y-axis for plotting, as shown below. The number 285 was chosen after careful consideration of many data sets, as it provided a good first guess at determining clear versus cloudy.



It is apparent that there are four categories of pixels in this chart. The first are pixels which are identified as clear (true clear), and that where the T(12.7)-285 line is above the heavy 'Truth" line. Second are false cloudy- those pixels which are colder than 285 which indicates cloudy, but are actually clear. Next are those pixels whose temperature is greater than 285, but are in fact cloudy (false clear) and finally are the true cloudy pixels. The statistics for this data, 15Z 25 Aug. 1988, show that of 336 pixels total, 175 were clear, and 161 were cloudy. The selection method found 158 of the clear and 128 of the cloudy which are 90.29% and 79.5% respectively. There were 17 false cloudy and 33 false clear (9.71% and 20.5%).

A close examination of the tabular data showed that for all cases, the false clear pixels were due to one major factor, that being the small cumuliform clouds over warm gulf water. False cloudy results were made for several reasons: cold water, mountain tops, and pixels near the limb. If it were possible to somehow reduce the false clear pixels, then the result would be to increase the correct selection of cloudy pixels while losing the pixels which yielded false cloudy results. Another day was examined with the thought of accepting the cumulus over water, and initial results seem to indicate that while these clouds show up very brightly in the visible spectrum because of the very dark background of the ocean, they are almost nonexistent in the IR channels because they are both shallow, small in horizontal extent, and very nearly ocean temperature. Re-evaluating the data for the 19th at 15Z, and changing the 'truth' value from 10 to 5 and resorting as above, we found that almost all of the false clear pixels were eliminated. This, once again, assumes that the small cumulus over water may be treated as clear pixels. The results are as follows:



The false clear values all appear below the 'step' in the 'truth' line, and the statistics for the dataset bear out the fact that 99.55% of the cloudy pixels are selected correctly using this simple algorithm. In fact, this selection process, using the 12.7μm channel is more successful than the more commonly used 11.2μm channel under conditions limited to the constraints of these data sets as mentioned above. The success comes at no expense to the true clear pixels, but it does not save those points which were deemed cloudy by the cutoff temperature, so the percentage of all clear pixels correct does not greatly improve, only (on this date) increasing from 84.91% to 86.21% with 13.79% still false cloudy. Data from the remaining days has yet to be analyzed, but following an initial evaluation it is anticipated that the by accepting the small cumuliform clouds over the ocean as clear (given that the assumption of no contamination in the IR channels under these conditions is substantiated) an increase in correct cloudy pixels will increase to the 95% level or above.

CONCLUSION

It has been rather surprising to find that a first cut scheme for discriminating between clear and cloudy pixels should be so effective. That method being to set a threshold of 285K in the 12.7μm channel as a cloud/no cloud cutoff. Integrating 11.2μm and even visible data does not appreciably affect the results.

RECOMMENDATIONS

Continued exploration of the cumuliform clouds over the gulf is highly recommended in light of the promising developments in that area. As these data sets are very restricted in latitude, an analysis of latitude dependence is needed, with expectations being that there be some modification to the threshold cutoff varying with latitude. Similarly, seasonal effects are anticipated for constant times, as well as variations due to the solar angle. These might be accurately modeled as some sinusoidal function of time of day and day of year once information from datasets for the entire year are developed. Limb effects were examined in a very cursory manner in this study, but once again, a mathematical relationship between satellite zenith angle and limb darkening/brightening should be possible.

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