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

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INTRODUCTION

Weather forecasting has been called the second oldest profession. To do so accurately and with some consistency requires an ability to understand the processes which create the clouds, drive the winds, and produce the ever changing atmospheric conditions. Measurement of basic parameters such as temperature, water vapor content, pressure, windspeed and wind direction throughout the three dimensional atmosphere form the foundation upon which a modern forecast is created. Modern technology in the form of automated observing stations, Doppler radar, and space borne remote sensing have provided forecasters the new tools with which to ply their trade.

One of the latest additions to the forecasters resources is found high over the earth, some in geosynchronous orbits above the equator. The newest of these Geosynchronous Operational Environmental Satellites (GOES) is GOES 8 which will become operational in October of 1994. It has the ability to scan the entire disk of the earth each half hour, producing imagery in both visible and infrared (IR) wavelengths. These images are familiar to anyone with a television, as they are shown during every weather segment of the local news to point out fronts, thunderstorms, and even areas of nice weather. For research scientists and professional meteorologists, imagery from all channels, not just visible, are of importance. The IR channels provide information about the location and amount of such atmospheric variables such as water vapor, ozone, and carbon dioxide. Of particular interest here, is water vapor. It is invisible to the naked eye, as it is to the visible channels of the meteorological satellites. But, water vapor content of the atmosphere is one of the variables that forecasters need to produce accurate forecasts. For example, the orientation, temperature, height and depth of the warm moist region of air flowing into a squall line is used to predict whether or not the squall line will generate severe weather and tornadoes. So, given its invisibility, how can we use satellite imagery to help determine the location and amount of the water vapor in the atmosphere?

THE PLANCK CURVE AND BASIC RADIATIVE TRANSFER

In 1901, Max Planck derived his famous function (the Planck function, of course) which for a blackbody at a given temperature relates radiance to wavelength. If you have a blackbody at a specific temperature, and are interested in the radiance at a particular wavelength, the Planck function gives it to you. If, however, you have the wavelength and the radiance, you can determine the blackbody temperature by manipulating the function.

In this manner, IR data is converted to temperature. Assume for a moment that there were no impediments to 'seeing' the radiance of the earth. Earth has a maximum radiance at about 15 microns because of its average temperature of 255°. So, if we had a sensor which viewed the earth at 15 microns, it would see some given radiance. Knowing the wavelength (15 microns) and the observed radiance, we could compute the skin temperature of the surface of the earth. The lower the radiance, the lower the temperature and vice versa. And this can be done for each wavelength because the relationship between wavelength and temperature is unique.

Unfortunately, there are contaminants in the atmosphere which act as impediments when observing the earth, and the energy which reaches the satellite is diminished by them. The atmosphere will tend to attenuate the radiance of the earth and this will yield artificially low temperatures. The attenuation can be corrected as the atmosphere, with a few noteworthy exceptions, is a fairly consistent mix of gasses. Water vapor is one of those exceptions and it absorbs mightily in the IR regions of the spectrum. There are some windows in this region, though, and sensors on the meteorological satellites take advantage of them. But even in these windows, attenuation due to water vapor occurs. The transmittance, or ability to transmit radiation, varies with the water vapor content: the more water vapor, the more attenuation. This relationship between attenuation and water vapor content, plus the varying effects of the water vapor content at different wavelengths can be used to determine the actual amount of water vapor in the atmosphere.

COLUMN-INTEGRATED WATER CONTENT

Many schemes have been proposed to determine the water content in a column of air as observed from space. One such scheme refined by Jedlovec[1] is known as the Physical Split Window (PSW) method. It makes use of the temperature values found in the 11.2 and 12.0 micron wavelengths, the so called Physical Split Window. While the wavelengths are very close together, they react differently when observing through water vapor. By comparing the resultant temperatures from these wavelengths to a first guess temperature, a determination of the derived column-integrated water content (IWC) can be made. Making use of the PSW method in data gathered experimentally over Florida and over the South Central United States, Guillory and Jedlovec[2] retrieved IWCs over the region, verifying their accuracy with values more conventionally determined.

Since GOES 8 carries sensors which observe in the same wavelengths, one should be able to use the same technique to determine IWC over large areas. Typically, water vapor content is determined from radiosonde data. However, the radiosonde launch rates are decreasing yearly due to budget constraints. Additionally, there are huge regions of the earth's surface which are covered by ocean that rarely if ever are probed by radiosondes. Using the PSW technique, reliance upon radiosonde data is greatly reduced. Because GOES 8 can produce soundings every half hour, IWC retrievals can be made almost anytime, anywhere.

Almost, because the PSW method requires clear cloud free line of sight from the sensor to the ground. Cloud contamination is a significant problem for several reasons. Thick clouds result in IWC retrievals from the top of the cloud to the top of the atmosphere (TOA), instead of from the ground to the TOA. Secondly, thin cirrus clouds absorb radiance from the ground, and radiate at colder temperature, artificially decreasing the radiance seen by the sensor. This in turn yields erroneous IWC values. Low fair weather cumulus fields whose clouds are smaller than sensor resolution produce erroneous values, but their deviation from actual values is not well known.

CLOUD FILTERING AND DATA COLLECTION

A scheme was needed to filter those cloud pixels from the image. Early in the research, we decided that only satellite data could be used, that is, no temperature fields (forecast or actual) were allowed in the cloud filtering method.

In a paper by Hayden[3], a method for cloud filtering was suggested and was used as a starting point for the scheme. But first, data had to be gathered. Using McIdas, imagery from several days was examined. Values for temperatures were made in three IR wavelengths: 3.9, 11.2 and 12.0 microns, the split window wavelengths. The first, 3.9 microns, is much less affected by the water vapor content of the atmosphere than are the split window wavelengths of 11.2 and 12.0 microns so can better give a reasonable surface temperature. In addition to the IR channel data, brightness counts in the visible channel were made. These data were collected at one hundred locations in the image and stored in a data file. The data file was then loaded into a spread sheet program, and examination began. In all, nine separate samples were made, three each from 26 July 1994 at 15Z, 18Z and 21Z.

RESULTS

After much manipulating and messaging, the data began to yield a pattern. It was noticed that the cirrus clouds could be detected if 11.2 micron temperature was less than 265°K. Mid level clouds could be found by using the difference in temperature between the 11.2 and the 12.0 microns, and applying an empirically derived threshold value. Finally, values were calculated for the difference between the temperature at 3.9 and 11.2 microns, and 3.9 and 12.0 microns. The difference of these values was related to the presence of cloud.

These data are represented in figure 1 below.

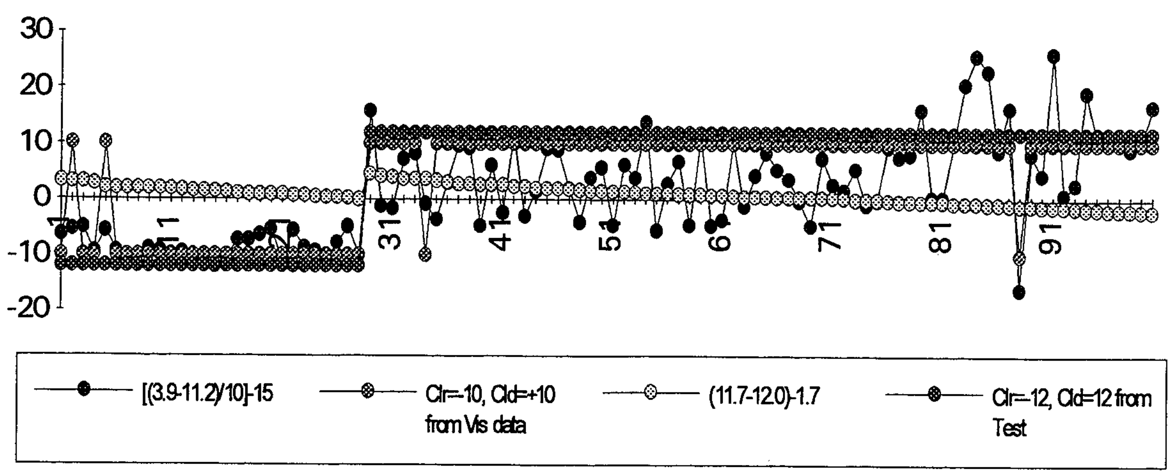

Figure 1.

Values which have a visible brightness counts greater than a threshold value of 80 are assumed cloudy, while those less than 80 are assumed clear. The cloudy pixels are given a value of 10, while the clear pixels are valued at -10 (the second data points). The difference temperatures between 3.9 and 11.2 microns (first points in the key) vary greatly ranging from -15 to +25, while the difference temperatures between 11.2 and 12.0 (third set of data points) vary only slightly between about -3 to +4. Note that the key indicates that there is an arbitrarily selected scalar subtracted from each of these difference temperature values. This shifts the curve downwards in the graph for esthetic reasons so that the clear/cloudy determination follows the convention of the visible brightness values- that is clear is negative, cloudy positive.

The last set of points is the test selection criteria using the cloud filtering scheme. The test works as follows:

> The pixel is determined to be a cloud if any of the following are true:
> - Temperature at 11.2 microns is colder than 275°K
> - Difference between 3.9 and 11.2 micron temperature > -5
> - Difference between 11.2 and 12.0 micron temperature is <0
>
> Otherwise, the pixel is clear.

These values are depicted as the last data point, and given a value of -12 if clear, and +12 if cloudy.

Once the test was applied to the data in the spreadsheet, any conflicts between what the test determined and what the visible imagery said was clear or cloud was examined in the original imagery. Pixel addresses were saved along with data, and these allowed a close inspection of the data point in question. Occasionally, some of the visible imagery data was determined to be clear or cloudy contrary to the brightness value cutoff of 80. For example, thin cirrus over the water was rarely seen as cloudy at that cutoff value, because the underlying water was very dark. This had the effect of darkening the thin cirrus. In these cases, correct values (+10 or -10) were inserted into the database overruling the automatic cloud determination mechanism.

The test worked correctly in 96 of the 100 cases for this date and time group. This was consistent with the other eight cases. Errors occurred primarily in the ability of the test to determine low cumulus fields. The small cumulus clouds are quite frequently smaller than the resolution size of the imagery, which has the effect of raising its brightness count above the threshold value of 80. Since the cloud is low, the temperature in all of the IR channels is very close to that of the surface, and consequently is not selected in the test. Examination of figure 1 shows two such cases- visible data says that point 2 and point 5 are cloudy, while the test shows it to be clear. On the other hand, the test excelled in selecting cirrus clouds. Of all of the 'corrections' inserted into the original database, by far the greatest number were for cirrus and thin cirrus. The test correctly selected each case of thin cirrus clouds.

CONCLUSION AND FURTHER CONSIDERATIONS

The test seems to be able to determine clear or cloudy pixels with a consistency greater than 94% for these cases. By carefully selecting threshold values for use in the test it appears that automatic cloud filtering is possible.

Additional data needs to be examined, as there is a variability in the threshold values which appears dependent upon solar angle and consequently surface heating. This would also indicate that there should be significant seasonal variations for northern (southern) latitudes where solar insolation varies most extremely. Thus, seasonal data sets as well as different time of day data sets should be collected so that those threshold values can be determined.

Once those values are determined and verified to an acceptable level, construction may begin on a map which would act as a mask to overlay an image. This could allow a determination of areas which are clear or cloudy. Since a version of the PSW routine has been written for use with McIdas, integration of such a mask in the routine could allow the retrieval of IWC without the need for careful time consuming individual pixel examination as is now required.

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For the 30th consecutive year, a NASA/ASEE Summer Faculty Fellowship Program was conduct at the Marshall Space Flight Center (MSFC). The program was conducted by the University of Alabama a MSFC during the period May 31, 1994 through August 5, 1994. Operated under the auspices of the Americ Society for Engineering Education, the MSFC program, as well as those at other NASA centers, was sponsored l the Higher Education Branch, Education Division, NASA Headquarters, Washington, D.C. The basic objectives the programs, which are in the 31st year of operation nationally, are (1) to further the professional knowledge qualified engineering and science faculty members; (2) to stimulate an exchange of ideas between participants a NASA; (3) to enrich and refresh the research and teaching activities of the participants' institutions; and (4) contribute to the research objectives of the NASA centers.

The Faculty Fellows spent 10 weeks at MSFC engaged in a research project compatible with the interests and background and worked in collaboration with a NASA/MSFC colleague. This document is compilation of Fellows' reports on their research during the summer of 1994. The University of Alabama presen the Co-Directors' report on the administrative operations of the program. Further information can be obtained l contacting any of the editors.

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