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A SATELLITE DIAGNOSTIC OF GLOBAL CONVECTION

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1. INTRODUCTION

The Aviation Weather Center (AWC) generates High Level Significant Weather forecasts covering 2/3 of the globe which include areas of convective activity that will affect jet aircraft. Verification of these forecasts requires an objective method of global monitoring of convective activity. In addition, a real time diagnostic of thunderstorm convective activity would be of great benefit to aircraft routing decisions. Both the verification of global thunderstorm forecasts and aircraft routing require continual monitoring over the entire globe with update rates of an hour or less. Thunderstorms can be detected directly using radar, remotely sensed lightning detection, and satellite microwave sensors. However, these detection techniques are either not available over the entire globe, or are not continually available. Algorithms for the indirect estimates of thunderstorm existence and intensity have been developed using geostationary satellite images. Over the past 30 years, a number of algorithms have been developed, especially for rainfall estimation. Many of these algorithms use infrared temperature thresholds (such as Arkin (1987) and Vicente (1998)) to determine the existence of thunderstorm clouds. Since cirrus clouds can also have temperatures colder than the thunderstorm's threshold, Rozumalski (2000) has shown that these techniques frequently produce erratic results. Other cloud classification techniques, such as Tag (2000) use a combination of thresholds, texture, and spectral response of various channels. However Shenk (1976) has shown that the ability of these cloud classification techniques to distinguish between thunderstorms and cirrus significantly degrades without the use of the visible channel, such as at night.

At the suggestion of Dennis Chesters (personal communications), the NASA GOES Project Scientist, a new approach to thunderstorm identification using satellite images has been undertaken. This technique uses the difference between the infrared 11 micron channel and the 6.7 micron water vapor channel. Since these two channels are on all the geostationary weather satellites, this technique has the potential for global applications of thunderstorm detection.

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2. THUNDERSTORM DETECTION ALGORITHM

The algorithm is based on the temperature difference between the infrared channel and the water vapor channel.

2.1 Physical Basis of Algorithm

The physical concept behind the algorithm is that thunderstorms lift moisture and cloud particles to the top of the troposphere. Where there is active uplift, the infrared and water vapor channels will have the same temperature. The wind at the thunderstorm top will transport the cloud ice particles and moisture down wind. As the cloud ice particles advect away from the thunderstorm, they will gradually fall because of their size. The water vapor will also advect away from the thunderstorm, but will not fall. Hence in the cirrus clouds down wind of the thunderstorm, there should be a slight temperature difference between the infrared channel sensing the temperature of the cloud particles and the water vapor channel sensing the temperature of the water vapor in the air. In the current algorithm, areas are eliminated where the infrared channel is at least 1 degree C. warmer than the water vapor channel.

2.2 Algorithm Processing

The original version of the global thunderstorm algorithm used differences between the global composites of infrared and water vapor images. While the algorithm showed promise, there were problems in the overlap regions between satellites with false identification of cirrus as thunderstorms. Originally it was thought that these were caused by limb darkening differences between the two channels. However on closer examination it was found that the problems were caused by non-coincident pixels where one satellite was providing the infrared value in the composite and another satellite was providing the water vapor value. The algorithm was changed to first take the differences between the channels in the original satellite image projections, and then to remap and composite the differences into a global composite. This eliminated the false identification problems in the overlap regions.

The global composite is generated by remapping each satellite difference image into a Mercator projection with a parallax correction assuming a 10 km cloud top height. The parallax correction is accomplished by increasing the radius of the earth by 10 km in the navigation subroutines computing coordinate transformations. Image data close to the earth edge beyond approximately 77 degrees from the satellite subpoint are excluded from the composite. Where there is overlap between satellites, the most timely data is selected for the composite.

2.3 Meteosat Overestimation

The requirement for space and time coincident differences of infrared and water vapor images is a problem with the Meteosat satellite. During the day time the visible and infrared channel data must share the same communications bandwidth, with the net result being that the water vapor image is sent only every 3 hours during daylight hours, and every ½ hour during the night hours. The infrared is continually sent every ½ hour. This results in an overestimation of convective cloud extent during the day time. In the areas covered by Meteosat the convective clouds have a 3 hour cycle where the thunderstorm clouds will appear to grow during the 3 hours, and then shrink back when a new water vapor image is obtained. This problem will be corrected in the coming years when a new generation of Meteosat satellites are launched. In the mean time, the decision was made to allow the overestimate of convective cloud extend in the regions covered by Meteosat rather than limit the data update to once every 3 hours.

2.4 Stability Filter

While thunderstorms are the most common phenomenon lifting clouds to the top of the troposphere, they are not the only lifting mechanisms which generate high clouds. Ageostrophic motions around jet streams cause cirrus clouds. Cyclone lifting mechanisms cause extensive cirrus shields around the mid latitude storms. The channel difference also picks up these cirrus clouds where they are being initially generated. Since these are not associated with thunderstorms, a filter is desired to remove them from the thunderstorm composite. Several meteorological filters have been tried. Warm advection at 250 mb showed some success in identification of jet stream cirrus, and positive vorticity advection at 250 mb showed some success in identification of mid latitude cyclone cirrus. However, a stability index filter appeared to have the most success in elimination of non-convective areas of active uplift. The global AVN forecast model 4 layer Lifted Index (LI) is being used in the current algorithm to eliminate areas not associated with convection. Areas with a positive LI of 1 or greater are eliminated from the composite. The most current gridded AVN model data are converted to an image in the same projection as the satellite image, and then used to eliminate areas not conducive to convection.

The use of the LI filter assumes that the AVN model has captured the state of the atmosphere correctly for the entire globe. Preliminary monitoring of the algorithm for areas incorrectly eliminated by the LI filter has shown few problems. The most common problem has been overrunning convection in the winter near warm fronts. The AVN 4 level LI does not appear to correctly capture the instability associated with these overrunning situations. The AVN model does appear to correctly identify areas of instability over the oceans as well as over land with various mesoscale forcing features.

2.5 Verification

During the development of the algorithm, remotely sensed lightning was used for ground truth of thunderstorm existence. The National Lightning Detection Network (NLDN) as described by Cummins (1998) was augmented with data from the Canadian Lightning Detection Network (CLDN), and network data from Japan, France, and Germany. Global Atmospheric, Inc. (GAI) processed these data with a long range detection algorithm described by Cramer (1999). Nierow (2000) showed these long range data to be useful with range of 2000-4000 km and location accuracy of 16-32 km.

An example of the satellite thunderstorm diagnostic is shown in figure 1. The infrared satellite is shown for the same area in figure 2 with an overlay of the lightning data detected for 60 minutes centered on the satellite data time. The example shows good subjective agreement between the satellite derived product and the lightning data.

A more formal verification is being undertaken utilizing the Real Time Verification System (RTVS) developed by the Forecast Systems Lab (FSL). The ground truth data will be the National Convective Weather Diagnostic (NCWD) described by Magenhardt (2000). Results of this verification study will be available next year.

3. Satellite Thunderstorm Diagnostic

The satellite thunderstorm diagnostic algorithm is routinely run every half hour at the AWC and is made available to AWC forecasters. Sectors are also generated for gif images that are posted to the web. Real time examples of the diagnostic can be seen on the AWC web page at:
http://www.awc-kc.noaa.gov/awc/experimnetal.html.
Sectors for the Atlantic, Pacific, Tropics, and the World are currently available, although other sectors could be generated.

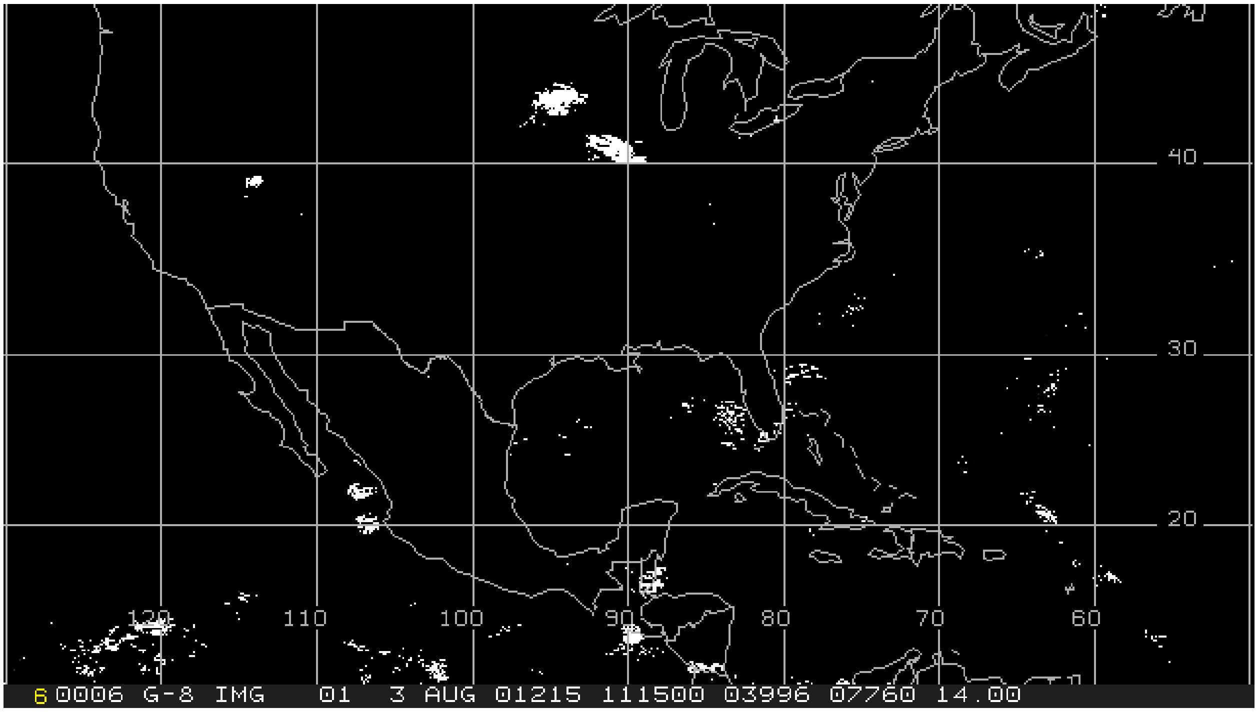

Figure 1
Satellite convective diagnostic showing sector over the US and adjacent ocean areas for August 3 at 11:15 UTC. Areas in white are active thunderstorms.

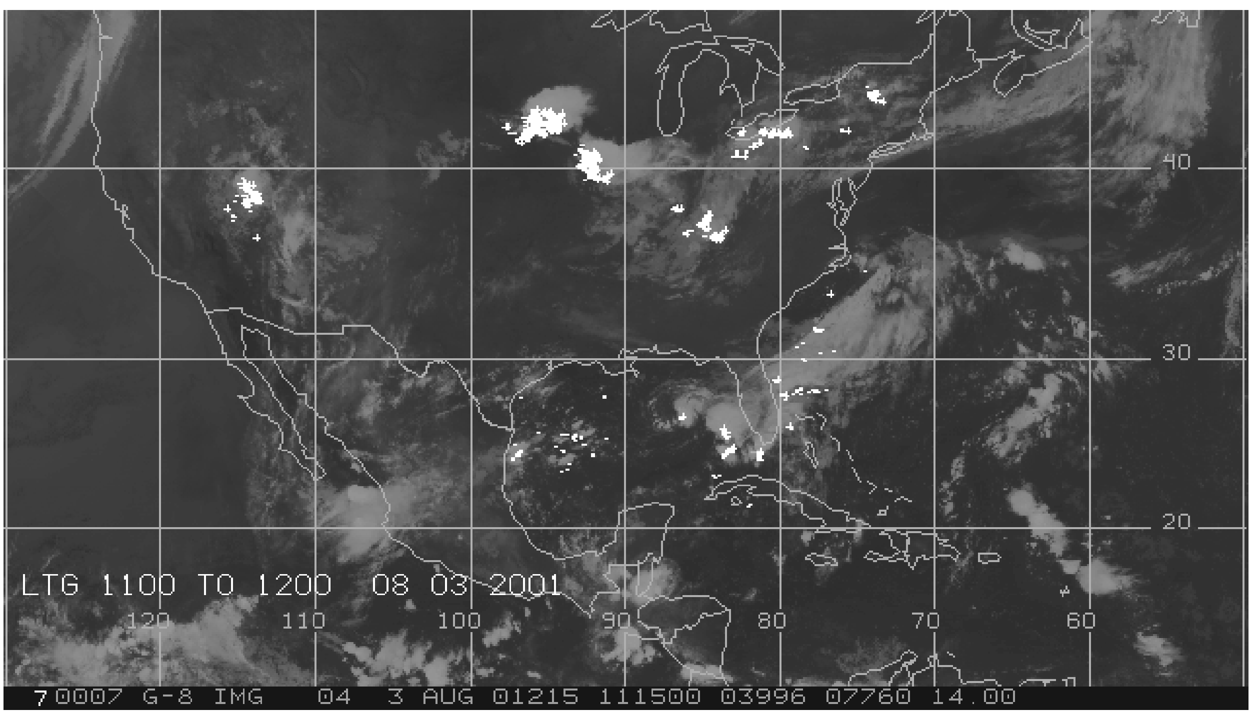

Figure 2
Infrared satellite image with lightning overlay in white. The lightning is for the one hour period centered on the time of the satellite image.

4. Summary

A global satellite based thunderstorm detection diagnostic has been developed using the temperature difference between the infrared and water vapor channels from geostationary satellite images. The physical concept behind the algorithm is that in areas of active uplift, the temperature of the clouds detected by the infrared channel will be the same as the temperature of the water vapor detected by the 6.7 micron channel. As the clouds advect away from the areas of uplift, the cloud particles will slowly fall, but the water vapor will not. This will result in the infrared channel being slightly warmer than the water vapor channel. In the current algorithm, pixels which have temperature differences of 1 degree C. or warmer are eliminated as non-thunderstorm. The temperature differences are remapped and combined into a global composite with a parallax correction of 10 km. Data beyond approximately 77 degrees from the satellite subpoint are eliminated from the composite. Where two satellites have overlap, the data from the more recent image is used in the composite. Since other phenomenon, such as ageostrophic motions around jet streams, can cause cloud formation at the top of the atmosphere, a filter of the AVN Lifted Index (LI) was applied to the data. Areas with a positive LI of 1 or greater are eliminated from the composite. Verification efforts have been started.

5. References

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