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Detection of Deep Convection Around the Globe

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1. INTRODUCTION

Thunderstorms are a hazard for all types of aircraft. The Aviation Weather Center (AWC) generates High Level Significant Weather forecasts covering 2/3 of the globe which include areas of deep 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, lightning detection, and satellite microwave sensors. However, these detection techniques are not continually available over the entire globe.

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 and Meisner (1987) and Vicente et.al. (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 et.al. (2000) use a combination of thresholds, texture, and spectral response of various channels. However 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.

Recently the possibility of using the difference between the 6.7 micron water vapor and the 11 micron infrared channels to identify deep convection has been identified by several groups. Bessho et. al. (2001) has used the technique to identify cumulonimbus clouds in typhoons. Mosher (2001) has proposed using this technique to monitor global convection since these two channels are on all the geostationary weather satellites.

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2. GLOBAL CONVECTIVE DIAGNOSTIC ALGORITHM

The algorithm is based on the temperature difference between the 11 micron infrared channel and the 6.7 micron 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 to the top of the troposphere, 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. The 1 degree threshold was selected because it is the smallest increment of satellites brightness counts using 8 bit satellite images.

2.2 Algorithm Processing

The original version of the global convective diagnostic 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 10 km resolution LatLon

Equidistance 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 65 degrees from the satellite subpoint are excluded from the composite. Where there is overlap between satellites, the most timely data are selected for the composite.

2.3 Requirement for space and time coincident differences

The requirement for space and time coincident differences of infrared and water vapor images is a problem with the Meteosat satellite at 0 degrees longitude. 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. The Indian Ocean Meteosat at 63 degrees longitude provides both infrared and water vapor images every half hour. In overlap regions where both Meteosat data are available, the Indian Ocean satellite is given preference. This problem will be corrected in the coming years when a new generation of Meteosat satellites are launched.

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. 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. The most current AVN run with the forecast times closest to current time (generally the 6 hour forecast) is used to generate the filter. Areas with a positive LI of 1 or greater are eliminated from the composite. The 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. Additional work is planned on other filters, such as the K index and other thresholds.

3. GLOBAL CONVECTIVE DIAGNOSTIC PROCESSING

The Global Convective Diagnostic algorithm is routinely run every half hour at the AWC and is made available to AWC forecasters. An example of the global composite by itself is shown in Figure 1. The best method to display the thunderstorm diagnostic depends upon the user. While a pilot might want to only see the convective areas, meteorologists frequently want to see the Infrared images along with the diagnostic. Figure 2 shows the same Convective Diagnostic combined with the global IR

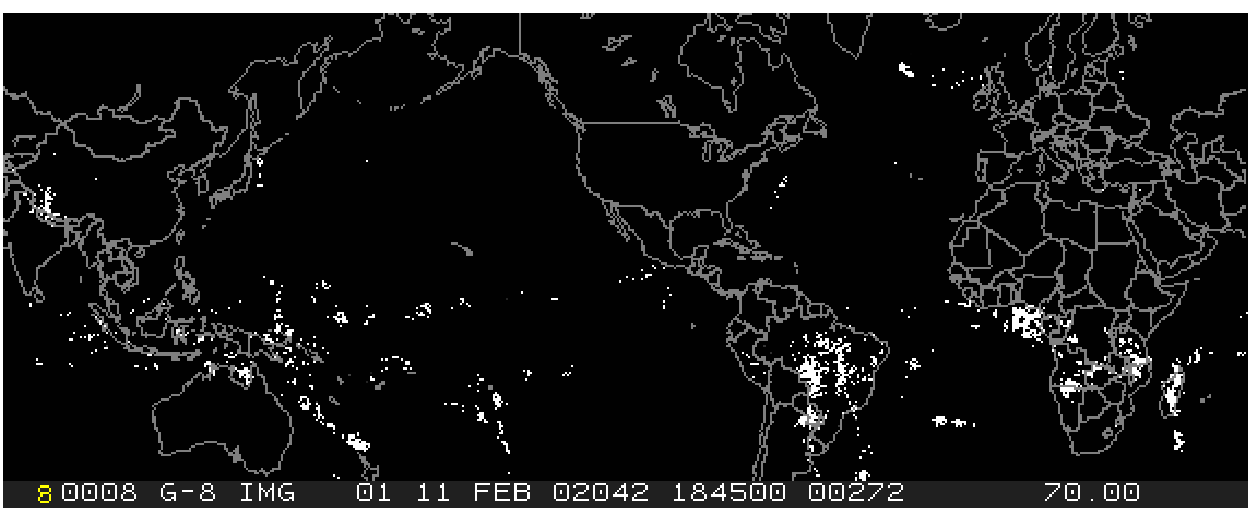

Figure 1. Example of Global Convective Diagnostic on February 11, 2002 at 1845 GMT.

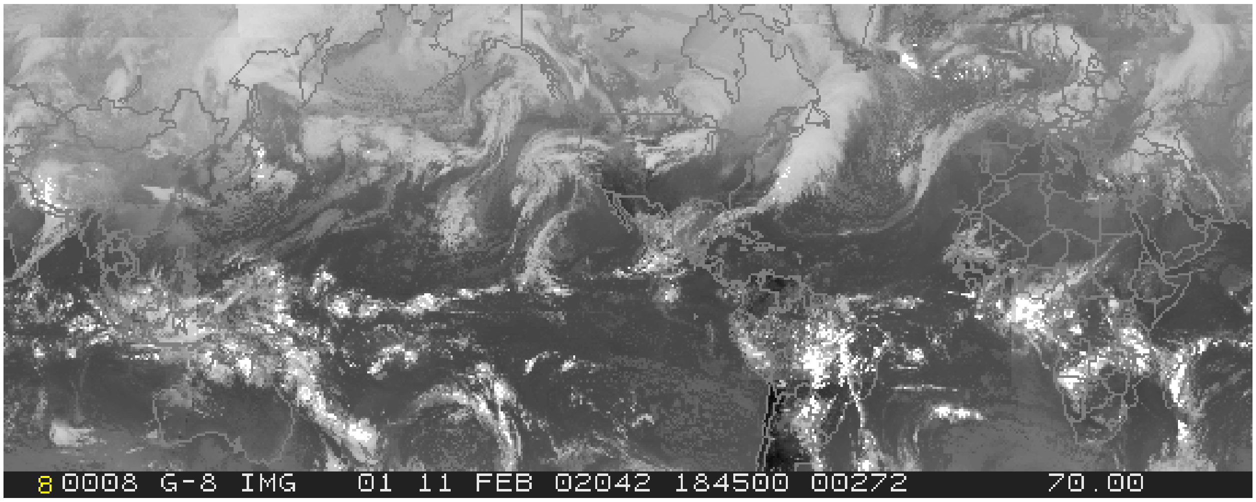

Figure 2. Global IR composite combined with Global Convective Diagnostic (white) of Figure 1.

composite. 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: http://www.aviationweather.noaa.gov . From the home page click on the experimental products for convection. Sectors for the Atlantic, Pacific, Indian Ocean, Tropics, South America, Africa, Asia, Australia, Europe, and the World are currently available.

3.1 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 et.al. (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 and Cummins (1999). Nierow et.al. (2000) showed these long range data to be useful with range of 2000-4000 km and location accuracy of 16-32 km.

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 is the radar/lightning based National Convective Weather Diagnostic (NCWD) described by Magenhardt et.al.(2000). A US sector with 20 km grid spacing is

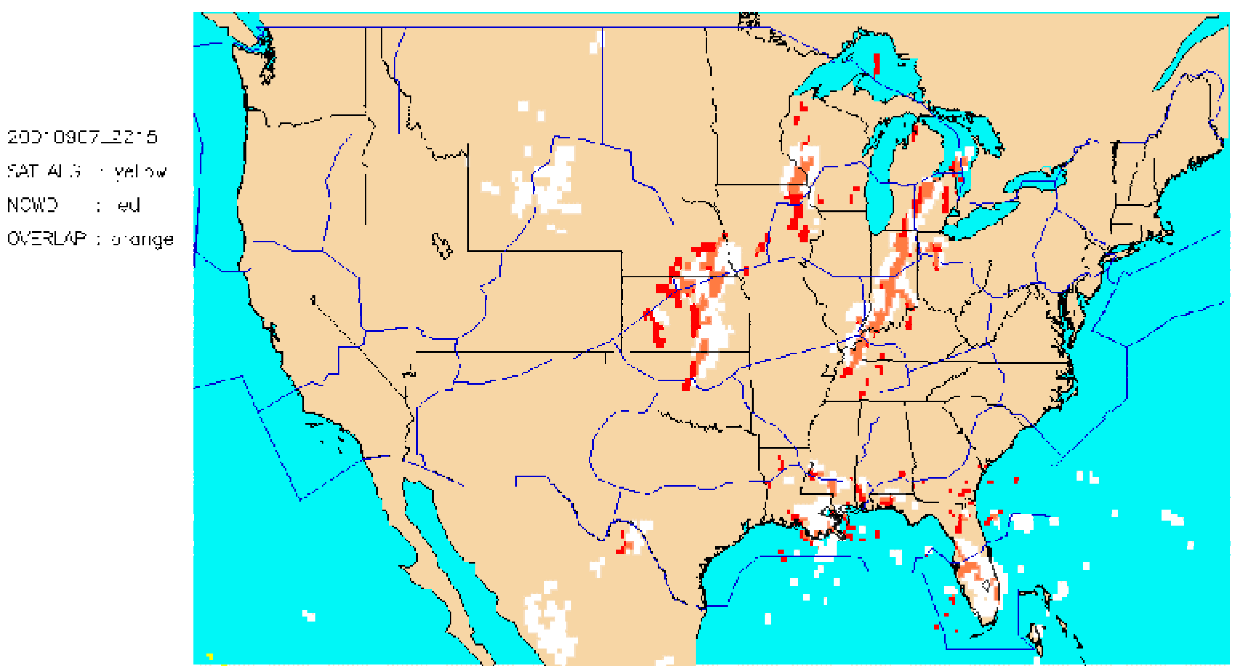

Figure 3. Verification example for Sept. 7, 2001 at 22:15 GMT of the Global Convective Diagnostic (white) with the radar/lightning based NCWD (light and dark gray). Dark gray is for NCWD that are outside the area defined by the Global Convective Diagnostic.

generated for the verification effort. The methods used for convective verification are described by Mahoney (2000). Figure 3 shows an example from Sept. 7, 2001 at 2215 GMT NCWD with the Global Convective Diagnostic. The figure shows reasonable agreement, except for Wyoming where there was decaying convection and Mexico which was outside the range of the NCWD.

Verification statistics are available from Sept. 7, 2001 to Feb 5, 2002. The Probability of Detection yes (PODy) was .39, the Probability of Detection no (PODn) was .99, the True Skill Statistic (TSS) was .39 and the bias was 2.94. To show the comparative level of skill (even though it is for a different product and a different period of observations), the Convective SIGMET verification for the initial time of the forecast period for April 2001 to Feb. 6, 2002 had a PODy =.44, PODn=.99, TSS=.43 and Bias=1.39. The verification shows that the Global Convective Diagnostic has a reasonable level of skill, but that the Diagnostic overestimates the area of convection.

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 to the top of the troposphere, 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 are eliminated as non-thunderstorm which have temperature differences of 1 degree C. or warmer. The temperature differences are remapped and combined into a global composite with a parallax correction of 10 km. Data beyond approximately 65 degrees from the satellite subpoint are eliminated from the composite. Where two satellites have overlap, the data from the more recent image are 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 show the diagnostic to have reasonably good skill (True Skill Statistic= .39) in detecting areas of convection, but to overestimate the areal extent (Bias=2.94).

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