JP1.5 A DEMONSTRATION OF REAL-TIME TRANSMISSION AND DISPLAY OF GOES IMAGERY ABOARD THE NOAA P-3 AIRCRAFT DURING THE 2002 HURRICANE SEASON

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1. INTRODUCTION

NOAA's two WP-3 aircraft are the primary tools for the annual hurricane field program of the Hurricane Research Division (HRD). The WP-3 aircraft are also used for operational reconnaissance missions to supplement the flights of the U.S. Air Force Reserve, which operates out of Kessler Air Force Base in Mississippi. During the hurricane off-season, the WP-3 aircraft are used for many other atmospheric research missions throughout the world. The WP-3 aircraft are instrumented to collect flight-level atmospheric data, can release dropwindsondes to obtain vertical profiles of atmospheric parameters, and have on-board Doppler radars. However, the WP-3s currently do not have the capability to display or animate on-board satellite imagery in real-time because the aircraft are limited by the bandwidth of the communications system. However, the capability to display and animate satellite imagery would significantly aid the operational missions providing additional information that will support reconnaissance duties and data collection.

Because of the potential beneficial impacts of satellite data upon WP-3 data collection activities, a demonstration project was undertaken during the 2002 hurricane season to display and animate real-time GOES satellite data aboard these aircraft. This project combines the efforts currently underway at HRD to increase the communication capabilities of the WP-3s using cell-phone and Internet technology, GOES satellite data and recent advances in data compression technology being developed at NOAA's Forecast Systems Laboratory (FSL). Even with the recent WP-3 to ground communication improvements, the bandwidth is still very limited (maximum rate of 2400 baud), although it is a large improvement over what was previously available. To accomplish the goals of this demonstration project, advanced wavelet transform techniques are applied to GOES satellite imagery that allow the transmission of large data volumes associated with satellite data over the very limited bandwidths available for communication with the WP-3 aircraft.

This paper discusses details of the this demonstration project including what datasets are compressed and transmitted, how the data are compressed, how the data are displayed and animated and the overall performance of the system.

2. WP-3-TO-GROUND COMMUNICATIONS

The communications to and from the WP-3 aircraft and the ground is provided through INMARSAT satellite communications (SATCOM), which currently provides voice communications and data transmission rates of 2400 baud via ftp. This enables the transmission of a limited amount of real-time data. For instance, during the NOAA's 2002 Hurricane Field Experiment the SATCOM demonstrated the capability to transmit a 42 kilobyte (kb) Joint Photographic Experts Group (JPEG) satellite image in approximately two and a half minutes (see Figure 1). While the current data transmission rates would easily enable the transmission of half-hourly GOES data to the WP-3 aircraft, faster data transmission is still desired.

The capabilities of SATCOM continue to improve to data transfer rates greater than 9600 baud, but computer and data collection technology are far outpacing this improvement. The desire to share information gathered on the ground with the WP-3 and visa versa suggest that other ways to improve the data transmission should be explored. One of these ways is the use of advanced data compression techniques, which is utilized in this demonstration project.

Figure 1. Picture of a laptop displaying the 42 kb water vapor JPEG image that was downloaded during a WP-3 flight into Tropical Storm Hanna on September 13, 2002. It took approximately 2 minutes to down load the image. Also shown in Mike Black of HRD and one of the flight crew of NOAA-43.

3. DATA COMPRESSION

The choice of compression techniques for this project is based upon a tradeoff between compression ratio and image quality. For example, JPEG format is a commonly available image compression technique. While JPEG compression achieves the compression needed for this project, the fidelity of the decoded image is far from satisfactory. JPEG-compressed images usually exhibit some blocky effects at a compression ratio as low as 10:1.

A similar compression problem arose during the development of FX-Net[1] (Wang and Madine 1998) at FSL. After testing a variety of compression methods, the wavelet transform was chosen as the approach to image compression for FX-Net. The wavelet transform was introduced in the early 1990s and has remained a cutting edge technology in image compression research (Akansu 1992, Prasad 1997). Like the Fourier transform, the wavelet transform relies on a particular set of basis functions. However, the set of basis functions that the wavelet transforms uses is localized in both space and frequency, whereas a Fourier transform only contains frequency information. The ability of the wavelet transform to contain some spatial information, in addition to the frequency information, allows it to achieve excellent compression of meteorological images.

The wavelet data compression usually consists of three steps: transform, quantization, and entropy encoding. The transform step is done through a fast discrete wavelet transform algorithm. The quantization step finds the "best" representation of the image for the specified compression ratio by minimizing the mean square error in the coefficient domain. The last step, entropy encoding, further reduces the size of the compressed data set, in lossless fashion.

In our implementation, we use filter bank convolution to obtain the wavelet analysis and synthesis (Mallat 1989), a zerotree-like quantizer for the coefficients quantization and dequantization (Shapiro, 1993), and an arithmetic codec with finite context model for entropy encoding and decoding (Bell et al. 1990).

Examples of the images resulting from wavelet image compression routines with various compression ratios are shown in Figure 2. For comparison the GIF and JPEG (quality = 30) renditions of the same image (date time) are shown in Figure 3. The images decoded from the wavelet compression show an ever-decreasing degree of higher frequency detail with increasing compression ratio. However, the resulting images are still far superior to the JPEG image, which actually has a larger file size.

4. THE DEMONSTRATION PROJECT

To demonstrate the ability to transmit, and animate satellite imagery aboard the WP-3 aircraft, two UNIX scripts were used to automate 1) the process of acquiring, compressing and serving the satellite data on the ground and 2) the process getting compressed files (via ftp), decompressing them, and looping the resulting imagery on the plane.

With the ideal of improving reconnaissance and data collection capabilities aboard the WP-3 aircraft only a fraction of currently available satellite data is utilized. Using UNIX shell scripts three spectral channels of the Geostationary Operational Environmental Satellite (GOES) were acquired from the NESDIS severs for this purpose. Visible, 11 μm (IR4), and 6.7 μm (water vapor) imagery were remapped to Mercator projections at 2 km, 4 km, and 8 km resolutions, respectively using MCIDAS software (MCIDAS resulting in three 500 x 500 pixel, 1-byte datasets with navigation, calibration, and time information with a size of (251 kb)

From the resulting raw data files (MCIDAS AREA Files) the 1 – byte image information was extracted to create a data file (225 kb) and from the navigation and time information a minimum set of information was extracted and put in a navigation file (52 bytes). The navigation file contains 13 integer words, the number of points in the x-direction, the number of points in the y-direction, upper-left latitude, upper-left longitude, lower-right latitude, lower-right longitude, base latitude for the Mercator projection, Julian Day, UTC hour, minute, and second. These two files along with the compression ratio provided input to the wavelet compression algorithms that output a file containing the encoded wavelet transform information and the navigation information (WLT). This file is then made available to the plane via ftp.

[1] FX-Net is an Internet-based meteorological workstation with an AWIPS-like user interface, which operates with only modest communications and computing capability.

A UNIX shell script on the WP-3's computers then contacts the ftp site to look for new WLT files. If newly created WLT files exist they are transmitted via ftp to the plane, and decoded into GIF satellite images. Each of the three image products is then sorted with respect to time and made available to three separate HTML based JavaScript programs that loop the image products in almost any HTML browser.

Examples of what the browser loops of the three satellite products looked like when Hurricane Isidore as it was approaching the Louisiana coast on 25 September are shown in Figure 4. Currently, four hours of half-hourly imagery is displayed for each product or eight frames. The JavaScript also enables the exclusion of bad images and control of the looping speed.

5. SUMMARY AND FUTURE PLANS.

During the 2002 Atlantic Hurricane Season a system was developed to transmit real-time GOES satellite imagery via SATCOM to the NOAA WP-3 aircraft. First tests of transmission of JPEG images proved successful, but time consuming. Luckily advanced image compression technology in the form of wavelet compression allows better quality satellite imagery to be transmitted in a fraction of the time required for JPEG images. This technology has been utilized to speed the transmission of this imagery, which is severely limited by bandwidth (2400 baud) associated with current SATCOM data transmission. Combining existing software (MCIDAS, UNIX, JavaScript) along with these wavelet compression techniques GOES imagery capabilities now exist to transmit, update, display and animate real-time GOES imagery on the NOAA WP-3 aircraft.

The display of such data will significantly impact reconnaissance and research missions flown by the NOAA WP-3. At the time this article was written testing of this system was continuing. Such testing will likely continue through the 2002 Hurricane season with hopes that real-time satellite imagery should be routinely available on the WP-3 aircraft at the beginning of the 2003 hurricane season.

It is anticipated that this type of data compression can be used for a variety of different applications on different platforms. For instance, similar software could be employed to transmit information gathered during missions from the WP-3 to the National Hurricane Center. Another possible application could be to transmit satellite information to the Air Force Reserve Hurricane Hunter aircraft to aid in their reconnaissance missions. These possibilities will also be investigated in the coming year.

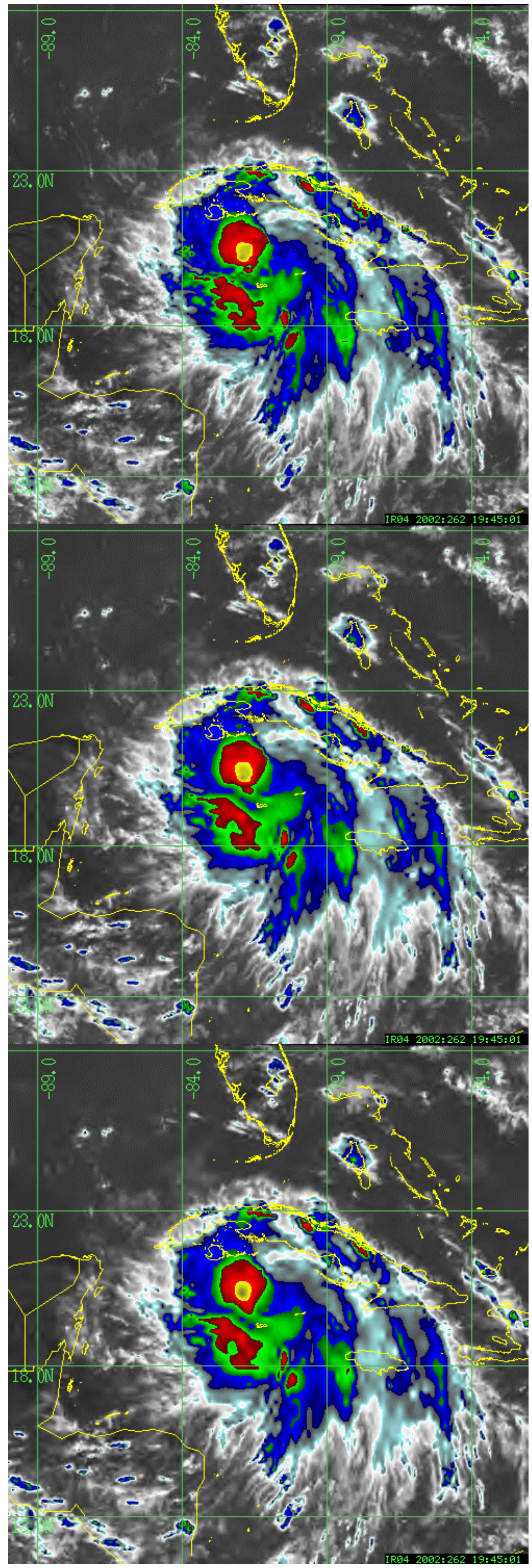

Figure 2. Examples of Images resulting from wavelet compression using compression ratios of 10:1,25kb (top), 20:1,12.5kb (middle), and 30:1, 8.3kb (bottom).

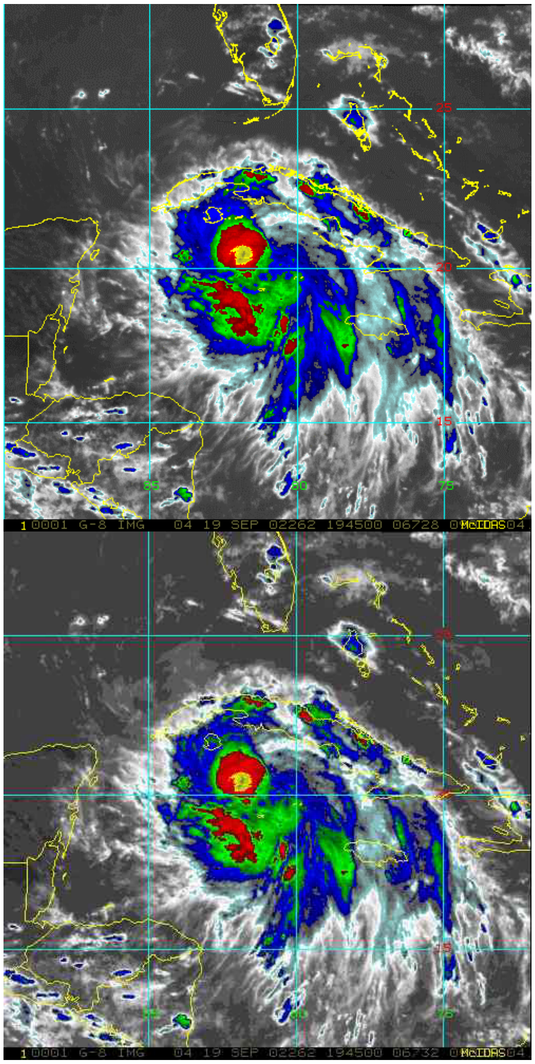

Figure 3. Examples of the same image as in Figure 2, but as a GIF image with a size of 88kb (top) and a JPEG image with a quality flag of 30 and a size of 36kb (bottom).

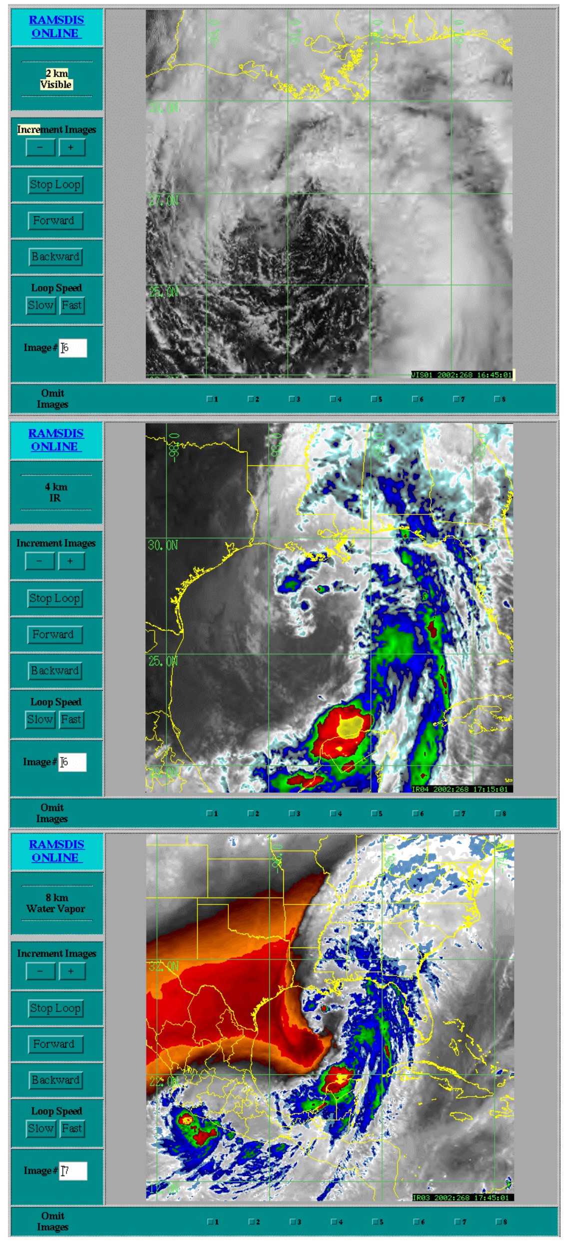

Figure 4. Shown are examples of the satellite image products available during Hurricane Isidore on 25 September 25, 2002. The products are 2 km Visible (top), 4km IR (middle) and 8 km Water vapor (bottom). Note that there are eight images in each product loop. Also this figure displays three different times at 16:45 UTC (visible), 17:15 UTC (IR) and 17:45 UTC (water vapor), respectively.

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