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ABSTRACT

Tropical cyclone satellite imagery can be used for various applications. Some examples include reanalyzing storm intensity, improving forecast techniques, and training analysts. The Hurricane Satellite (HURSAT) dataset was used to create more than one million satellite images for worldwide tropical cyclones. The imagery derive from infrared, visible and microwave data. Imagery were created using similar color scales as the widely used Navy Research Laboratory (NRL) satellite tropical imagery. Google Earth facilitates the browsing and comparison of all these imagery. The National Climatic Data Center (NCDC) now hosts all imagery online and serves them via Google Earth, which is a freely available data display system. The Keyhole Markup Language (KML) file design allows for simple access to millions of images for more than three thousand tropical cyclones in just a few clicks.

1. Introduction

Technological advances in recent years have made public access to tropical cyclone (TC) satellite data possible. Availability of such information makes a direct impact on TC forecasting, research, and public safety. The Hurricane Satellite (HURSAT) dataset maintained by the National Climatic Data Center (NCDC) is a historical archive of satellite observations from all known TCs that occurred worldwide between 1978 and 2008. Until now, HURSAT had only been available for download on the NCDC website[†] in NetCDF format. However, because the dataset has much value to meteorologists and climatologists, NCDC has been investigating new methods for making the HURSAT data as widely available and easily accessible as possible.

Google Earth (GE), downloadable for free on the internet, was found to be the best option for displaying this data. Other websites, such as the Naval Research Laboratory (NRL) Tropical Cyclone page[‡], have already made use of GE for the display of tropical cyclone

satellite imagery for currently-existing storms. In a similar manner, GE has now been utilized by NCDC for the facilitation and presentation of all HURSAT data. The hope is that this will prove to be a useful commodity for the TC research community.

The following section presents a brief overview of the history and characteristics of the HURSAT dataset itself. Section 3 provides a description of the computer code used to incorporate the data into GE, as well as a summary of the primary imagery display features implemented inside the system. The final section gives a discussion of some of the advantages and disadvantages of displaying HURSAT in GE.

2. HURSAT Data Overview

HURSAT, archived by NCDC for the years 1978 through 2008 (as of this writing) consists of more than 1.4 million polar-orbiting and geostationary satellite observations for TCs worldwide. Table 1 shows a breakdown of these observations by satellite. Made available in NetCDF format, all HURSAT data are easily compatible with most programming languages and accessible among many software interfaces.

The original HURSAT dataset, referred to as HURSAT-B1, initially archived back to 1983 and derived from International Satellite Cloud Climatology Project (ISCCP)[§] B1 data. This original dataset included storm-centered 3-hourly infrared (IR) and visible observations from geostationary satellites having spatial resolutions of ~8km (Knapp and Kossin, 2007). Additional rescued geostationary data have since extended the entire HURSAT-B1 archive back to 1978.

The recent implementation of both Advanced Very High Resolution Radiometer (AVHRR) and microwave (MW) observations from polar-orbiting satellites to the dataset has greatly increased not only its size, but also its use in tropical cyclone research due to the various characteristics of each sensor product. The characteristics of these products are summarized in Table 2. Given the better spatial resolution of AVHRR observations (~4km) compared to those of geostationary satellites, this addition has proved to be a valuable asset to users (Knapp, 2008a). One of the key contributions that the increased spatial resolution brings to TC research pertains to the application of the Dvorak Technique (Dvorak, 1972; 1984). Knowing that

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[†] As of this writing, this website is still in use and can be found at: <http://www.ncdc.noaa.gov/oa/rsad/hursat/>

[‡] <http://www.nrlmry.navy.mil/TC.html>

[§] <http://isccp.giss.nasa.gov/>

storm intensity can be estimated based on satellite imagery, using better resolution imagery such as the AVHRR Basic Dvorak infrared product (AVHRR-IR-BD) will allow for a more effective analysis and application of the Dvorak Technique or the Objective Dvorak Technique (Velden et al., 1998) to these historical storms (Knapp, 2008a).

While the HURSAT dataset does contain such an extensive array of TC observations, several gaps in HURSAT-B1 do exist and are described in Knapp (2008b). Also, MW imagery in the dataset only extend back to 1988, leaving IR and visible observations as the only imagery sources available prior to that time (AVHRR back to 1981 and geostationary back to 1978).

3. Keyhole Markup Language (KML) Access

While some HURSAT data are publically accessible in NetCDF format and usable in many different types of software, a need has arisen for a more interactive and widely available medium to view the data with the ability to process large amounts of information for storm analysis. One medium that fits this description and has the shown the capacity to handle such processing is GE. Available free to the public in a basic version via the internet, and sold commercially in a professional version, GE is a virtual map and geographic data display system. It provides the average user with the ability to manually explore almost any region of the globe using the software's interactive features.

The computer code utilized by GE is the Keyhole Markup Language (KML)^{**}. Incorporating the format standards of the widely used Extensible Markup Language (XML), KML uses a tag-based schema which combines coordinates of specific locations with graphical display features and is able to exhibit these locations in a virtual fashion in GE. For example, the free downloadable version of GE makes available high-resolution aerial photography, political boundary information, road positions, and much more, all of which are superimposed onto the globe through KML according to their actual real-life locations. Some of these files can become very large and may be compressed into zipped KML (KMZ) files.

In order to incorporate the HURSAT data into GE, the observations from the dataset were used to create more than one million IR, visible, and microwave images using standard color schemes and tables provided by the NRL. The next step was to generate KML files for each storm. It was realized that by creating files that could read the HURSAT imagery and determine their coordinates, GE would be able to display these images at their exact locations on Earth at the time the images were taken.

An Interactive Data Language (IDL) program was developed for the purpose of reading the HURSAT data,

determining location of each image with respect to the Earth, and writing the KML files to display the data. Both these files and the imagery files, which were created in PNG format, were originally stored on a local FTP server to open up access to the public. Since many files were written – one for each of the 3,000+ storms within the period – a portal was launched on the NCDC website with individual links to the FTP for the KML files of each storm. The portal organizes the links first by year, and then by the ocean basin in which the storm was located. For display purposes, each link is colorized based on the maximum lifetime intensity of the storm.

When a file is loaded into GE, many features are immediately obvious. A storm track, marked with colorful cyclone icons correlating to storm intensity, is visible on the screen from startup. The icons, positioned at 6-hourly intervals along the track, are all clickable and bring up a table with links to all satellite imagery for the storm during the respective time interval (Figure 1). The track information was incorporated using information from the International Best Track Archive for Climate Stewardship (IBTrACS), a project orchestrated by NCDC. IBTrACS is essentially a collection of all available post-storm analysis best track data for all observed TCs occurring as far back, in some cases, as 1848. These analyses were provided by various TC forecast agencies across the world (Knapp et al., 2010). The table from each icon also provides the storm intensities as reported by the various agencies.

The user is also able to view imagery in a sensor-specific manner simply by controlling the folders in the "Places" panel on the left. By opening the folder for the desired sensor, GE loads all imagery within and allows the user to loop through the images at different speeds. This will be useful for documentation of storm progression and intensification. There is also a folder listing collective imagery from all sensors chronologically, much in the same manner as in the cyclone icons.

As a means to speed up the display of imagery inside GE, the vast majority of information for each storm was contained in the single storm KML file. The exceptions were the image files themselves, which were stored on the FTP, and the image links in the cyclone icon tables, which connected to individual KML files that call the imagery. These individual files were also stored on the FTP. The large quantity of information inside the storm KML files caused the files to eventually become fairly large, so they were all converted to KMZ format in an effort to reduce the size.

Another IDL program was written to create a file that can plot all of the annual storm tracks of TCs, complete with the icons, for each of the years 1978-2008 (see Figure 2). However, instead of the icons linking to satellite imagery, they link to the main KMZ file for their respective TC. As a result, users can open

^{**} <http://code.google.com/apis/kml/>

this “global” file and select the year of interest in the Places panel on the left. This loads all of the storm tracks for that individual year, allowing users to click on a storm track link on the globe and quickly open that storm’s KMZ file – all from within GE.

4. Discussion

The implementation of HURSAT into GE brings several advantages to the realm of TC research and analysis. The first, and most obvious, is the simplified accessibility of the data. The dataset’s infrared, visible, and microwave imagery are all now more widely available than ever before. Overlaying these imagery on the GE globe (see Figure 3) allows for an alternative approach to the study of historical tropical cyclones.

Secondly, and as mentioned earlier, application of the Dvorak Technique for re-analysis of past storm intensities now becomes possible primarily with the use of IR-BD imagery (c.f. Figure 3). It has been theorized that some storms within the HURSAT record were originally underestimated with regard to their intensities (Landsea et al., 2006). The hope is that this new way to look at the data will facilitate re-analysis of storm intensities.

Finally, thanks to the interactive nature of GE, users are able to pick and choose from inside the interface the year, basin, storm, time, satellite sensor, and image that they would like to examine. It is believed that this will also help to increase the efficiency of future studies involving historical TCs by cutting down on time spent slowly sifting through NetCDF files.

One small issue that was encountered during the processing of the KML files involved the geostationary observations. Because HURSAT makes use of all available geostationary imagery, some storms were bound to have identical observation times from multiple geostationary satellites. This only presented a problem when it came time to create the image loops as multiple observations from the same exact time were unnecessary. The issue was resolved by setting the IDL program to only recognize the observations with the better (smaller) zenith angles for any multiple geostationary images taken during the same time period. This forced the KML file to display only the images with the best pixel quality in the loops. However, elsewhere in the file, the lower-quality images were retained and then italicized in order to contrast them with the higher-quality images.

Another issue that arose dealt with storms which crossed the International Dateline. One downside of GE is that upon initially loading a file, if the storm track in the file is plotted across the Dateline, GE automatically zooms in on the Prime Meridian and not the track. The reason for this is unclear; although the thought is that the problem is related to an averaging of storm track coordinates performed by GE. Nonetheless, this should

not be detrimental to file use or navigation and should not inhibit the access to imagery.

Future GE-related work is highly dependent on the HURSAT dataset itself. Annual updates to the archive will be performed as new imagery become available. Also, implementing observations from additional satellites may be a possibility, although the usefulness of such data would need to be considered.

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Table 1 – Number of HURSAT Observations by Sensor Type

	IR	IR-BD	VIS	WV	Microwave	Total
B1	251,013	251,013	179,650	160,318	----	841,994
AVHRR	88,075	88,075	51,993	----	----	228,143
MW	----	----	----	----	355,845	355,845
Total	339,088	339,088	231,643	160,318	355,845	1,425,928

Table 2 - Summary of various HURSAT products (Knapp 2008a)

Product	HURSAT-B1	HURSAT-AVHRR	HURSAT-MW	HURSAT-Basin
Temporal span	1978-present	1978-present	1988-present	1978-present
Spatial span	Storm-centric: 10.5° from center for all global TCs	Storm-centric: 10.5° from storm for all global TCs	Storm-centric: 10.5° from center for all global TCs	Basin wide
Temporal resolution	3 hourly	Varying (6-12 hourly)	Varying (6-12 hourly)	3 hourly
Gridding resolution	8km	4km	8km ^{††}	8km
Data source	ISCCP B1	AVHRR GAC	DMSP SSM/I	ISCCP B1
Channels available^{‡‡}	IRWIN (11µm) IRWVP (6.7µm) VIS (0.65µm)	All AVHRR channels	All SSM/I channels	IRWIN (11µm) IRWVP (6.7µm) VIS (0.65µm)
Calibration	Clim. ^{§§} – IRWIN, ISCCP – IRWVP, VIS	Climate calibrated.	Operational calibration.	Clim. – IRWIN, ISCCP – IRWVP, VIS
Yearly Size (GB)	<6.5	40-60	4	<20
Format	NetCDF	NetCDF	NetCDF	NetCDF
Current Version	3.0	Beta	Beta	Beta
Imagery	Movies ^{***}	BD Imagery	Imagery ^{†††}	Planned

^{††} While the original SSM/I data have a coarse resolution (ranging from 25-70km), the SSM/I gridded data are remapped to a resolution identical to the B1 for ease of display and analysis. However, the original SSM/I swaths are provided for further quantitative analysis. The swath data have various footprint sizes and two native sampling resolutions (referred to as the A and B scans).

^{‡‡} IRWIN = Infrared Window, IRWVP = Infrared Water Vapor and VIS = visible channels.

^{§§} “Clim.” and “climate” refers to a climate quality re-calibration. In the case of B1 data, a reanalysis of the ISCCP calibration using an independent instrument as a reference. For AVHRR, it relies on the work performed at NOAA/STAR. “ISCCP” refers to the absolute calibration provided by ISCCP.

^{***} <http://www.ncdc.noaa.gov/oa/rsad/hursat/movie.php>

^{†††} <http://www.ncdc.noaa.gov/oa/rsad/hursat/index.php?name=mw-imagery>

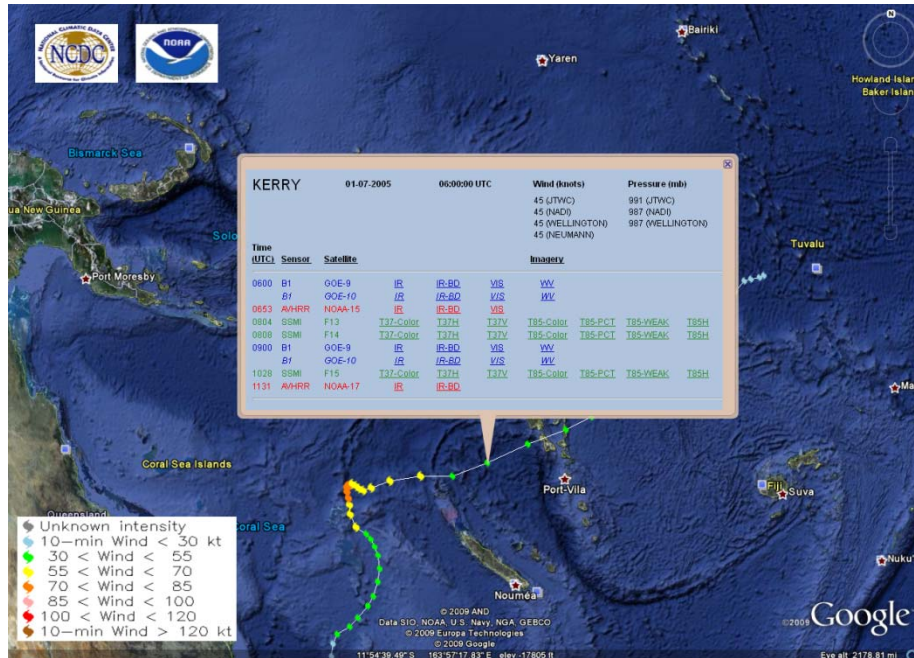


Figure 1 – Google Earth representation of Tropical Cyclone Kerry storm track as determined by IBTrACS data (Knapp et al., 2009) Colorized dots are storm icons placed at 6-hourly intervals. An imagery table appears when a storm icon is clicked on. Information from table includes the storm name, date and beginning time of 6-hour period, wind speeds and central pressures from all IBTrACS TC forecast agencies, and links to satellite imagery. Geostationary links are colored in blue, AVHRR links in red, and MW links in green.

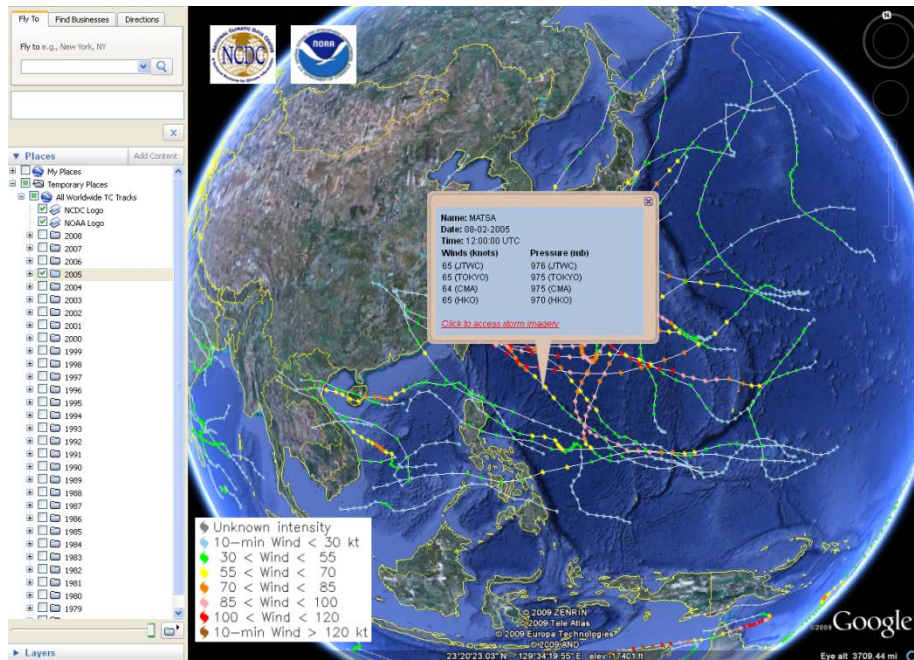


Figure 2 – Global storm tracks file from 2005 for Western Pacific Ocean basin. Table links to respective storm file instead of imagery.

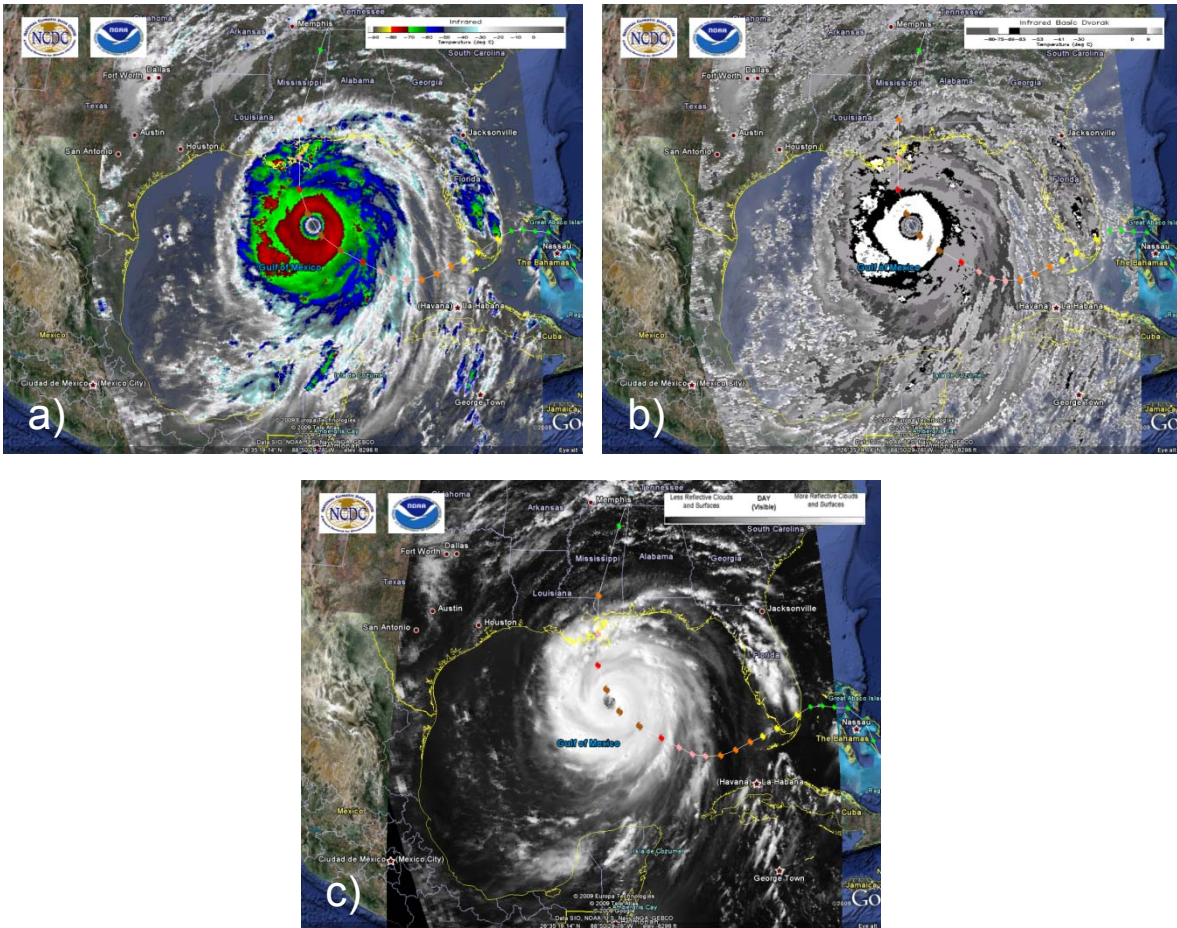


Figure 3 – Examples of HURSAT-AVHRR imagery for Hurricane Katrina in 2005. Imagery from a) infrared, b) Dvorak infrared, and c) visible shown for 28 August 2004 UTC.