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ANALYSIS OF SIMULATED GOES-R DATA AND PRODUCTS FOR MESOSCALE METEOROLOGY

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1. Introduction

An extensive program is underway to simulate imagery and sounder data from future GOES-R instrumentation. The goal is to assess the potential for new products from GOES-R long before it becomes operational. In spite of the long lead-time needed to design, build, and test this new and complex satellite system, it is time to do the background work needed to prepare for the implementation of GOES-R. Simulations of GOES-R data are being accomplished by utilizing datasets from current operational and experimental satellites. Weather situations under study include applications to forecasting mesoscale weather events, including severe storms, tropical cyclones, lake effect snowstorms and fog outbreaks. The simulations are needed to assess the impact of the increased resolutions available from GOES-R instrumentation. Increases in spatial, temporal, spectral, and radiometric resolution will all be available, the latter two being manifest as both increased number of spectral bands and increased precision for measurements from those bands. One of the approaches being used for these “Risk Reduction” activities is to use data from existing operational and experimental satellites to create subsets of observations that will be available from GOES-R. Then an assessment of the potential applications of these GOES-R data will be made using techniques to manipulate both the multi-spectral imagery and the hyper-spectral sounding data. The image manipulation techniques that will be applied not only pare the data down to its essential components, eliminating redundant information, but also assess the quality and applicability of the data to the weather situations under study. In addition, the data manipulation also has an application toward data compression that will be needed to assure the maximum benefit to the end user while reducing the ever-increasing volume of data that inevitably comes with increased capabilities of new satellite instrumentation.

2. Background

The current Geostationary Operational Environmental Satellite (GOES) series was inaugurated in 1994 with the launch of GOES-8 and will continue with four more satellites past the most recent GOES-12 launched in 2002. The next generation GOES (beginning with GOES-R) will be launched in the 2012 time frame. This new series of satellites will include improved spatial, temporal, spectral, and radiometric resolution. The last two characteristics are manifest by an increased number of spectral bands and increased precision for measurements from those bands. Because of the long lead-time needed to design, build, and test this new and complex satellite system, it is already time to do the background work needed to prepare for the development and implementation of GOES-R (Hillger et al 2004).

Preparations for GOES-R for applications to forecasting mesoscale weather events, including severe storms, tropical cyclones, lake effect snowstorms and fog outbreaks are well underway (Hillger et al 2004). Two approaches are being used for these “Risk Reduction” activities. In the first approach, data from existing operational and experimental satellites are used to create subsets of observations that will be available from GOES-R. In the second approach, numerical cloud models are being coupled with radiative transfer models to create simulated imagery. In this article, GOES-R is briefly reviewed, and some examples of risk reduction activities for mesoscale applications are described.

3. GOES-R Instrumentation

The GOES-R series will include several instruments that will be more advanced than those on the current GOES series. Replacing the current-GOES Imager will be an Advanced

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Baseline Imager (ABI), which will be explained in more detail below. Replacing the current GOES Sounder will be a Hyperspectral Environmental Suite (HES) with both broader spatial coverage and higher spatial resolution. The HES will be designed to give both large-area lower-resolution (10 km infrared) coverage and higher-resolution (4 km infrared) severe-weather/mesoscale capabilities. This portion of the HES will cover both the visible and infrared portions of the spectrum with a very large number of spectral measurements as its hyperspectral name implies.

It is also planned that the HES will include a Coastal Waters imaging instrument that will have much higher spatial resolution (300 m) capabilities in the visible/near-infrared for looking at the coastal ocean environment of great concern and greatly impacted by man. This instrument will also be used to observe other weather-related phenomena such as air quality, flooding, severe weather, and hurricanes.

Additional components of the GOES-R series will be a lightning mapping instrument, and solar/space environmental instrumentation. The solar and space instruments will improve the monitoring of the sun and the electromagnetic environment of the earth that is an important operational aspect of the current GOES series.

4. GOES-R ABI

The main instrument on the GOES-R will be the ABI. The exact configuration of spectral bands has not been fixed, but the spatial resolution will be improved (0.5 km visible, 2 km infrared) over the current geostationary imaging (1 km visible, 4 km infrared). Table 1 shows the proposed spectral bands for the ABI compared to the current GOES bands, showing the more complete spectral coverage of the ABI. The current-GOES Imager is limited to only 5 of the 6 numbered spectral bands on any satellite. The ABI, with 16 bands, will have three times the spectral coverage as the current-GOES Imager as well as improved radiometric capabilities (such as precision and signal-to-noise) for those bands.

Table 1: Proposed GOES-R ABI Bands

GOES-R ABI Band	Central Wavelength (μm)	Current GOES band
1	0.47	
2	0.64	1
3	0.86	
4	1.38	
5	1.61	
6	2.26	
7	3.9	2
8	6.185	
9	6.95	3
10	7.34	
11	8.5	
12	9.61	
13	10.35	4
14	11.2	
15	12.3	5
16	13.3	6

5. Case Study Database

The GOES-R activities are focused on mesoscale weather events. For the initial phase of this research, five cases studies were chosen as listed in Table 2. The cases were chosen because of their meteorological interest, and the availability of satellite and in situ observations that can be used to simulate subsets of GOES-R observations.

Table 2: Case Studies for First Phase of GOES-R Research

Case	Region	Study Dates
Hurricane Lili Landfall	Gulf of Mexico	30 September - 4 October 2002
Hurricane Isabel Near Peak Intensity	Central Atlantic	12 September 2003
Severe Weather Outbreak	Oklahoma, Kansas	8 - 9 May 2003
Lake-Effect Snow	Western New York	12 - 14 February 2003
Fog Outbreak	California, Utah, Colorado	11 January 2004

Much of the initial emphasis has been on gathering the various satellite data and making it available to multiple researchers involved in this study. For this purpose, a mass-storage device is being used which involves uniquely-linked hard disks that are capable of redundancy and failure recovery. All the satellite data, as well as derived products and numerical model output from these cases, are being saved on this mass-storage device. Observations being collected for these cases include those from the current GOES and POES satellites, and data from the 36-band MODIS (Moderate-resolution Imaging Spectrometer) and the hyper-spectral AIRS (Advanced Infrared Sounder) instrument on the EOS-series polar-orbiting satellites called Aqua and Terra. Conventional observations and the initial fields from the NCEP Eta model are also being collected. For the hurricane cases, GPS soundings in the storm environments obtained from the NOAA Gulfstream jet are also being obtained to help evaluate atmospheric profiles from the AIRS instrument.

The chart in Figure 1 shows the bands from the proposed GOES-R ABI, NPOESS Visible/Infrared Imager/Radiometer Suite (VIIRS), as well as those from currently available satellite systems. The spectral range will be covered more completely by GOES-R than by current GOES instrumentation.

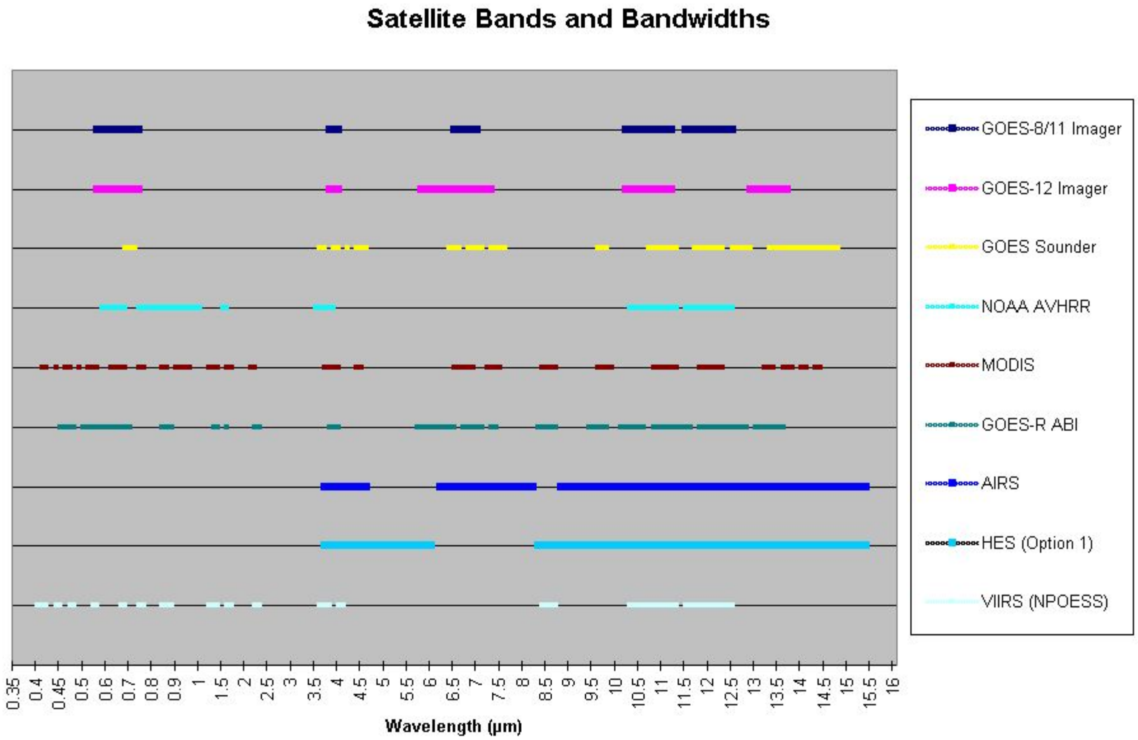

Figure 1: Spectral bands for the proposed ABI, VIIRS, and those from existing operational and experimental satellites.

6. Sample of Initial ABI Capabilities

Some of the initial work in preparation for GOES-R has been to simulate the capabilities of the increased spectral resolution of the ABI using MODIS data. With 16 rather than 5 bands, the ABI will provide increased capability to discriminate various features within an image, such as better differentiation between various types of cloud, atmospheric, and surface properties. Simple spectral band differencing works well when only a few bands are available. More sophisticated techniques are needed to handle the increased number of spectral bands, as there are limits on the ability to randomly combine the spectral bands to learn all the capabilities that will be available. Once the GOES-R ABI data are simulated, image combination techniques are being employed to learn the capabilities of the ABI.

Two of the preliminary image products generated from this study are shown in Figures 2 and 3, for the severe weather and fog cases, respectively. These three-color images are combinations of various image products that arose from multiple image differencing techniques normally applied to multi-spectral data (Hillger and Clark 2002a and 2002b, Hillger and Ellrod 2003). These techniques are designed to remove the redundant information in the imagery and to emphasize the image differences so that important cloud, atmospheric, and surface properties can be seen.

The image in Figure 2 contains two potentially-severe storms that formed along a dryline extending from Texas into Oklahoma on this day. Low-level moisture appears greener to the east and drier to the west of this dryline. Note also that surface features are also more easily seen through the drier air than through the moist air. High cloud tops are colored red along with thinner cirrus cloud, whereas lower-level and feeder-cloud bands related to the individual storms are colored blue.

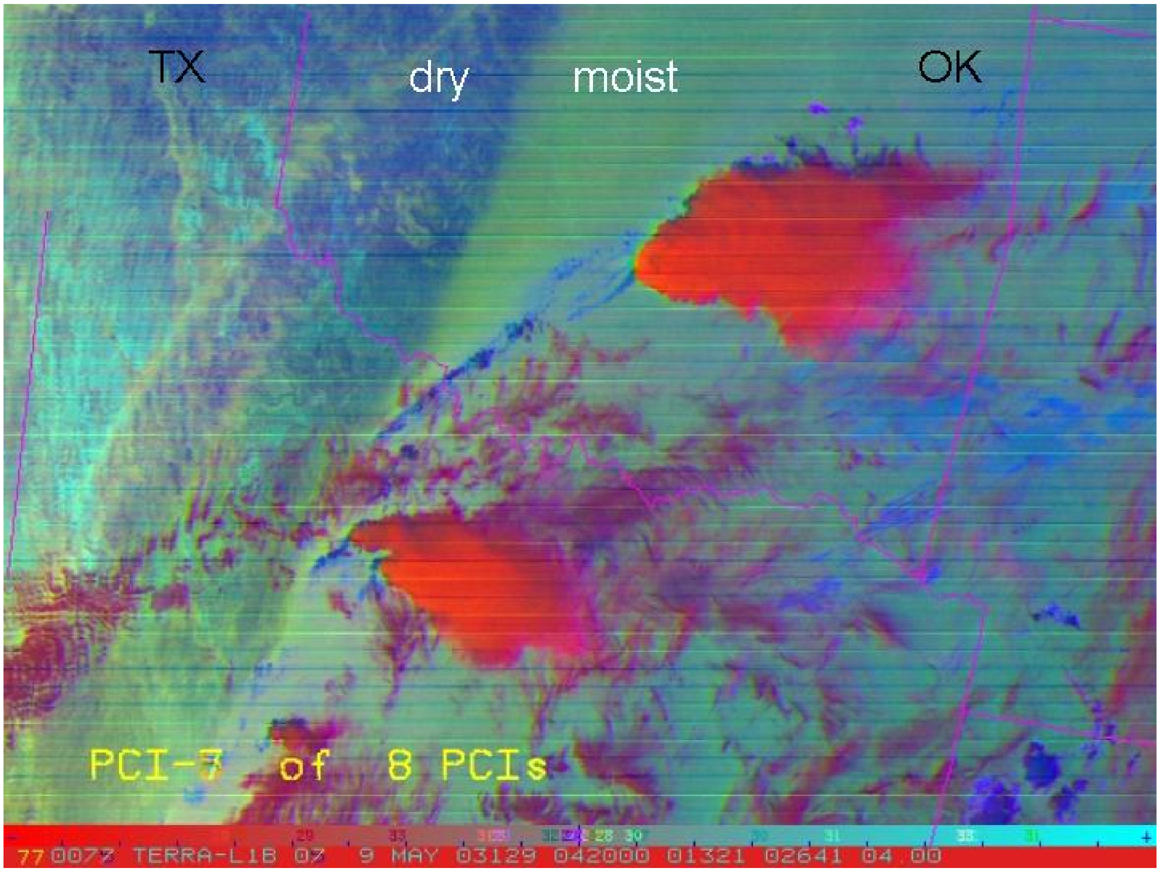

Figure 2: Three-color composite image for a severe weather case. Colors denote various types and heights of clouds (high clouds are red, low clouds are blue) as well a more subtle variations in the low-level moisture seen along a dryline in Texas and Oklahoma.

The image in Figure 3 is a fog detection case where valley fog is clearly differentiated from both dry terrain and surrounding snow-covered mountain peaks. This case is an event from Utah and Colorado where valley fog is often hard to discern from other image features with normal visible imagery alone.

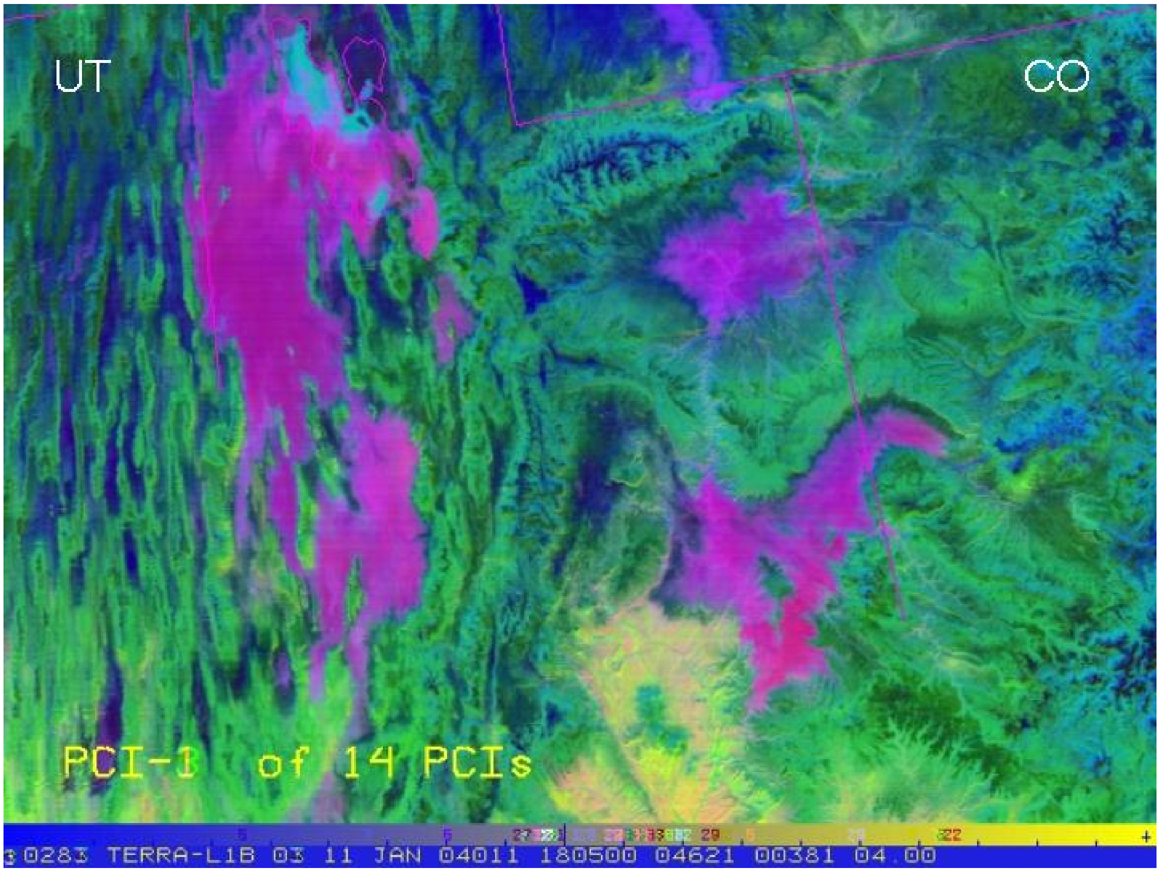

Figure 3: Three-color composite image for a fog case in Utah and western Colorado. Magenta colors denote fog in patterns determined by the terrain. Changes in the thickness of the fog are seen in the variations of color, and surface- type differences are noted by more subtle changes in greens and yellows.

7. Hurricane Intensity and Structure

Two of the case studies chosen for intensive analysis involve hurricanes. Although tropical cyclones (hurricanes) are large features there are still many high-resolution details that will benefit from increased spatial resolution imagery in both the visible and infrared. GOES-R will have numerous applications to tropical cyclone diagnostics. The impact of the higher spatial resolution is being investigated using AVHRR and MODIS imagery.

The top image in Figure 4 shows an infrared image of Hurricane Isabel at 4 km resolution as taken from the current Imager on GOES-12. The bottom image is a 2 km resolution image of Isabel obtained from MODIS. Both images are remapped into a Mercator projection to aid their comparison. The increased spatial resolution shows more detail of both the spiral and transverse bands within the cloud tops of the hurricane as well as more structure in the eye and eyewall.

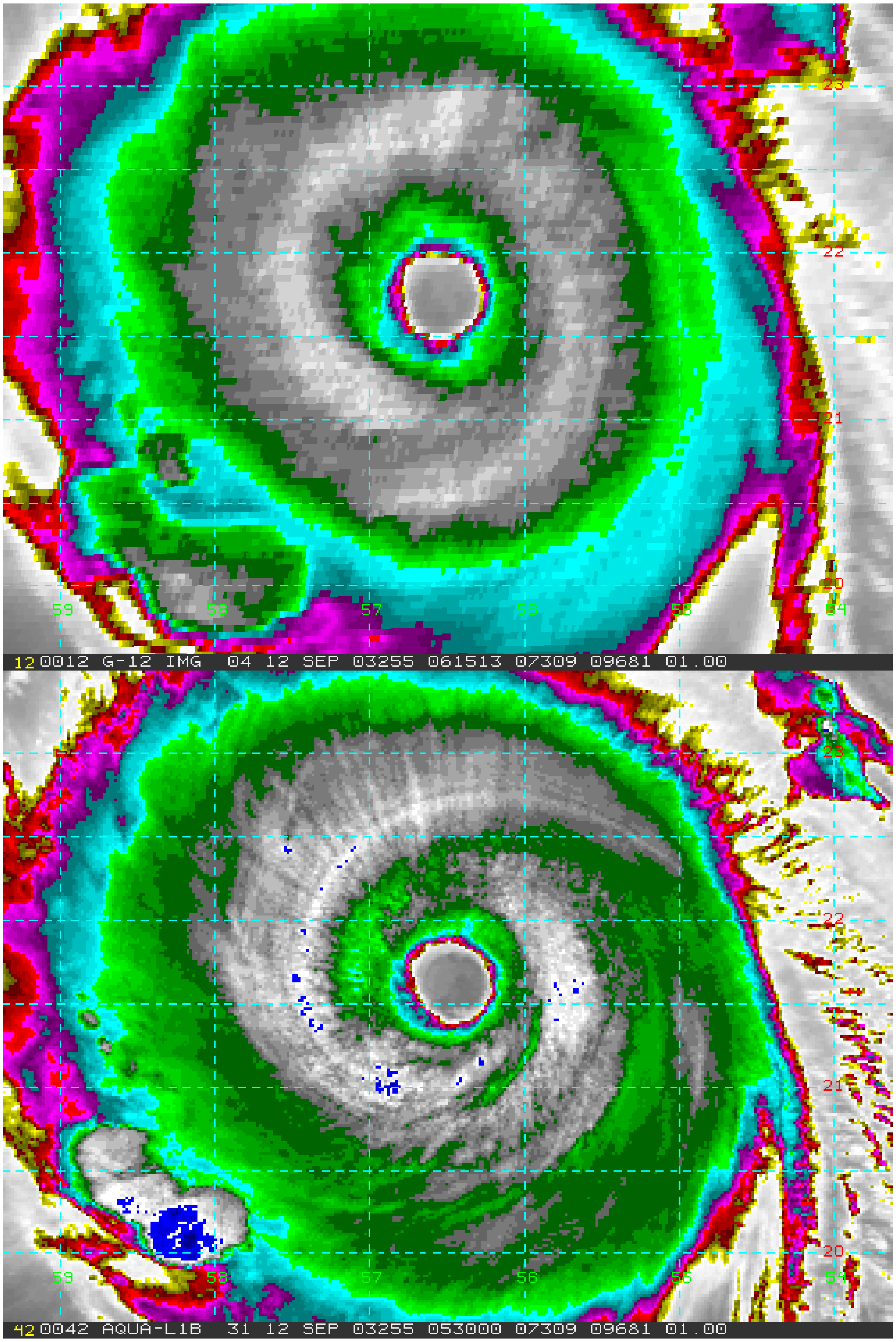

Figure 4: Images of Hurricane Isabel mapped into a Mercator projection. Top image is a GOES-12 infrared image at 4 km resolution. Bottom image is a MODIS infrared image at 2 km resolution, the spatial resolution expected of the GOES-R ABI.

A quantitative analysis of the imagery from Isabel, Lili and several other Atlantic storms is being performed to estimate the improvements in the ability to estimate the eye and eyewall temperatures, which are crucial parameters for intensity estimation (Velden et al 1998). The feasibility of obtaining eye soundings from the GOES-R HES is also being evaluated using this data.

8. Evaluation of Hyperspectral IR Soundings in Hurricane Environments

The utility of hyperspectral IR soundings is being evaluated by comparing AIRS temperature and moisture soundings with aircraft GPS soundings in the environments of Hurricanes Lili and Isabel. The soundings from the NCEP Eta model are also included in the comparison to determine if the AIRS sounding add value to what is already available. The purpose of this study is to provide motivation for the assimilation of GOES-R Sounder data in tropical cyclone models. Figure 5 shows the locations of where aircraft GPS soundings were available on one surveillance mission into hurricane Lili. There were four of these missions for Lili and four for Isabel. See the accompanying paper by DeMaria et al (2004) for a comparison of soundings for these hurricane cases.

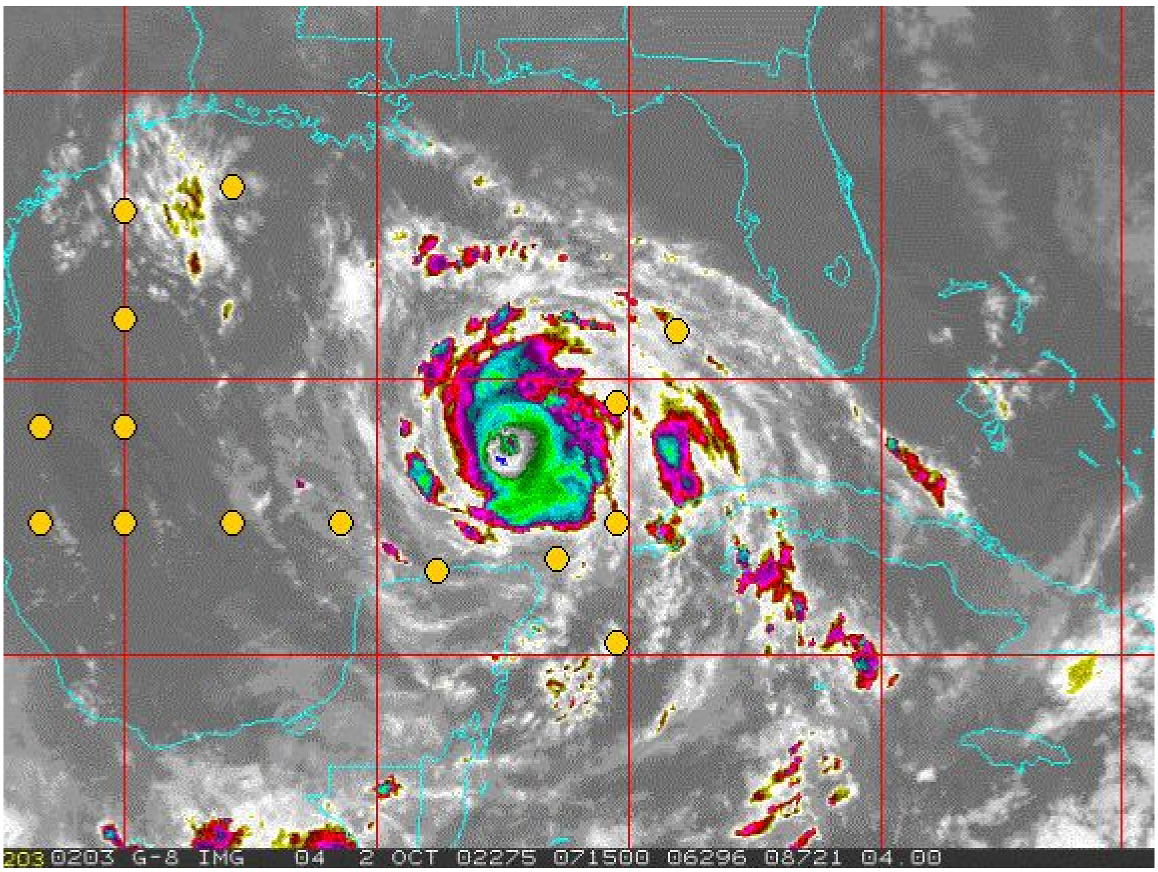

Figure 5: The yellow circles indicate the locations of GPS soundings from an aircraft surveillance mission into Hurricane Lili on 2 Oct 2002.

9. Simulated GOES-R Imagery from Numerical Cloud Models

As shown in the examples above, it is possible to simulate some aspects of GOES-R using currently available observations (primarily from polar-orbiting satellites). However, until the launch of GOES-R it will not be possible to simulate observations with the temporal resolution that will be possible from a geostationary platform. For this reason, numerical model runs are being coupled with radiative transfer models to produce synthetic ABI observations (Grasso and Sengupta, 2004).

10. Future Plans

Data gathering and preliminary analysis of some of the weather cases chosen for analysis have characterized the beginnings of this multi-year study in preparation for GOES-R operations. Additional research on these cases will be done with a mind to developing the new capabilities of the ABI instrument, especially the capabilities that are not available from the current-GOES Imager.

The research studies described above will continue. In addition, plans are underway to develop a severe weather now-cast tool that combines large-scale analyses and high spatial resolution imagery. In the longer term, experimental analysis and forecast products will be developed based upon the results of the case studies. These experimental products will evolve into real-time products that will be ready for testing when GOES-R comes on line early in the next decade.

Acknowledgements

Funding for this study is made available through NOAA Grant NA67RJ0152. The views, opinions, and findings contained in this article are those of the author(s) and should not be construed as an official National Oceanic and Atmospheric Administration or U.S. Government position, policy, or decision.

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