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Production of Proxy Datasets in Support of GOES-R Algorithm Development

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ABSTRACT

Realistic simulated satellite imagery for GOES-R ABI using state of the art mesoscale modeling and accurate radiative transfer is being produced at the Cooperative Institute for Research in the Atmosphere (CIRA) and used in developing and testing new products.

Products which have been produced in support of the GOES-R Algorithm Working Group (AWG) include 6-hour imagery at 5 minute intervals for 4 GOES-R ABI bands (2.25 µm, 3.9 µm, 10.35 µm, and 11.2 µm) that include fire hotspots. The imagery was initially produced at 400 m resolution and a point-spread function applied on the data to create ABI resolution imagery. Also created was corresponding imagery for current GOES at 2 bands (3.9 µm and 10.7 µm). These fire hotspots were simulated for 4 different cases over Kansas, Central America, and California.

Additionally, high quality imagery for 10 GOES-R ABI bands (3.9 µm and higher) were produced for 4 extreme weather events. These simulations include a lake effect snow case, a severe weather case, Hurricane Wilma, and Hurricane Lili. All simulations for extreme weather events were also performed for current GOES and compared with available imagery for quality control purposes.

Future work focuses on the creation of additional fire proxy datasets including true-color imagery for 3 ABI visible bands. This project also supports the GOES-R AWG Aviation Team in their effort to test their convective initiation algorithm by providing simulated ABI datasets for bands between 2.25 µm and 13.3 µm for a severe weather case. In addition, simulated ABI was generated from MSG infrared (IR) window band imagery and corresponding simulated ABI for the 7 tropical cyclones from 2006-2008 that became hurricanes in the east Atlantic for evaluation of the GOES-R ADT algorithm conducted by the University of Wisconsin Cooperative Institute for Meteorological Satellite Studies (CIMSS).

Keywords: GOES-R, ABI, proxy data, simulations, fires, hurricanes, synthetic-Green, RGB

1. INTRODUCTION

The goal of this project is to develop proxy GOES-R Advanced Baseline Imager (ABI) data for mesoscale weather and hazard events using a sophisticated cloud model and accurate radiative transfer modeling. ABI radiances were provided for different case studies, along with the model fields for "ground truth". The case studies include a severe weather case, a lake effect snow case, and hurricane cases. Also included were simulations of fire hotspots embedded in the severe weather case as well as agricultural fires in the tropics and forest fires in Southern California. AVHRR and MODIS data for tropical cyclone cases were provided as proxy GOES-R data for the tropical cyclone intensity algorithm development.

High quality simulations of satellite radiances provide one of the best ways of testing prototype algorithms for future sensors. These simulations have the advantage of providing ground truth that can be used to verify algorithm performance. It is therefore anticipated that the simulations provide the necessary proxy data to the fire, wind, and cloud algorithm groups for testing proposed algorithms. Therefore the high quality dataset provided by CIRA will lead to better algorithm selection, algorithm refinement, as well as faster implementation after launch.

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2. PROCEDURE

Under the GOES-R Risk Reduction project CIRA has developed the capability to produce radiance fields for GOES-R ABI bands using mesoscale model output. This capability has been developed using the following models.

2.1 Mesoscale model

The CSU Regional Atmospheric Modeling System (RAMS) mesoscale model [1] is a state of the art mesoscale model with unique capabilities for producing cloud properties for various weather events. In particular, the sophisticated cloud microphysical scheme in the model provides more realistic simulated radiances in cloudy regions than would be available from models with simpler schemes. Hydrometeors are predicted with a two-moment bulk microphysical scheme [2]. Mass mixing ratio and number concentration are prognosed for 6 of the 7 hydrometeor types while the mean diameter is diagnosed. Cloud droplet mass mixing ratio, however, is predicted using a one-moment scheme. (Work is ongoing to include cloud droplets into the two-moment scheme.) It should be noted that the liquid water path is the primarily variable influencing radiative transfer in warm clouds with microphysics having a second order effect. The following hydrometeor species are included in a simulation: Cloud droplets, rain droplets, aggregates, graupel, hail, snow, and pristine ice. Both graupel and hail are mixed phased; that is, liquid water may exist on the surface of each particle. Snow and pristine ice are each divided into 5 habit categories: Columns, hexagonal, dendrites, needles, and rosettes. Further, RAMS employs a 2-way interactive nested grid scheme. This allows information from a nested grid to feed back into the coarser grid.

2.2 Radiative transfer model

The radiance computations consist of 3 parts involving the calculation of: (a) atmospheric gas absorption; (b) condensate optical properties; and (c) radiances in the visible, near-infrared, and infrared (IR). OPTRAN was used to compute gaseous absorption in satellite bands, Modified Anomalous Diffraction Theory (MADT [3, 4]) or Ice-scattering tables [5] and Mie tables are used to compute condensate optical properties (asymmetry parameter/phase function, single scattering albedo, and extinction coefficients). Radiances are computed using a Delta-Eddington scheme in the IR and a plane parallel version of the Spherical Harmonics Discrete Ordinate Method (SHDOMPP) for near-IR and visible wavelengths.

As part of our GOES-R Risk Reduction work, GOES-R ABI (3.9 – 13.3 μm) has been produced for severe weather, lake effect snow, and hurricane cases which can be used for verification of GOES-R wind and cloud algorithms. The severe weather case has also being statistically compared with GOES-12 observations that show that the simulations are realistic and significantly similar to the actual occurrence.

2.3 Other

Also under the GOES-R Risk Reduction project at CIRA, data sets from existing satellites have been collected for a variety of mesoscale events, including severe weather and tropical cyclones. Further details of the CIRA GOES-R Risk Reduction project are available at http://rammb.cira.colostate.edu/projects/goes_r/

3. TROPICAL CYCLONE DATASET ARCHIVE

A GOES-R proxy dataset consisting of AVHRR, MODIS, and GOES IR (window band) images was collected and archived covering more than 350 tropical cyclone scenes from 11 storms. The CIRA/RAMM Digital Dvorak Tropical Cyclone Intensity calculation was applied to this dataset as a preliminary test of the impact of horizontal resolution on the intensity estimates. The National Hurricane Center (NHC) best track maximum sustained surface wind estimates were linearly interpolated to the image times for use as ground truth.

The simulated GOES-R proxy dataset (AVHRR, MODIS, and GOES) has also been made available on the web. To simulate resolutions similar to what will be available from GOES-R the imagery resolution is degraded (remapped) from 1 to 2 km (for GOES-R ABI) and from 1 to 4 km (for comparison to the current GOES). The reduced resolutions are displayed next to the full 1 km IR imagery at http://rammb.cira.colostate.edu/projects/awg

Eleven tropical cyclones were selected for this archive. There are a minimum of 8 and a maximum of 66 individual "scenes" (imagery at a certain date and time) for these storms. Each scene includes the following:

- Polar (AVHRR or MODIS) full resolution imagery
- time-matching (as close as possible) full resolution GOES IR
- AVHRR or MODIS IR remapped to 1 km
- reduced resolution polar IR 2 km (resembling the GOES-R footprint)
- reduced resolution polar IR 4 km (resembling the current GOES footprint)
- GOES IR remapped 4 km

The above scenes are available in McIDAS and in GIF format. For the sectorized images, the domain for the 1, 2, and 4 km re-maps are always the same as the large domain for the GOES data. The GIFs use a smaller domain, consistent with what a 1 km image at 640x480 resolution would have.

We collected a total of 357 individual scenes from 11 tropical cyclones, which occurred between 2002 and 2006. Each of the polar images uses the full resolution IR image data from MODIS or AVHRR and remaps it to a tropical-cyclone-centered Mercator projection image with 1 km resolution. The reduced resolution images are then produced at 2 and 4 km from those images using sub-sampling. No pixel averaging was used in creating the reduced resolution images.

It should be pointed out that because the proxy data are from polar satellites, the time resolution is much coarser than is available from the current GOES or will be available from GOES-R. The images are usually between 3 and 6 hours apart, but larger gaps are also present for some storms. The intensity estimation techniques take advantage of the time resolution through time averaging, but this will not be possible with the proxy dataset.

3.1 Tropical cyclone website

The tropical cyclone website URL is http://rammb.cira.colostate.edu/projects/awg

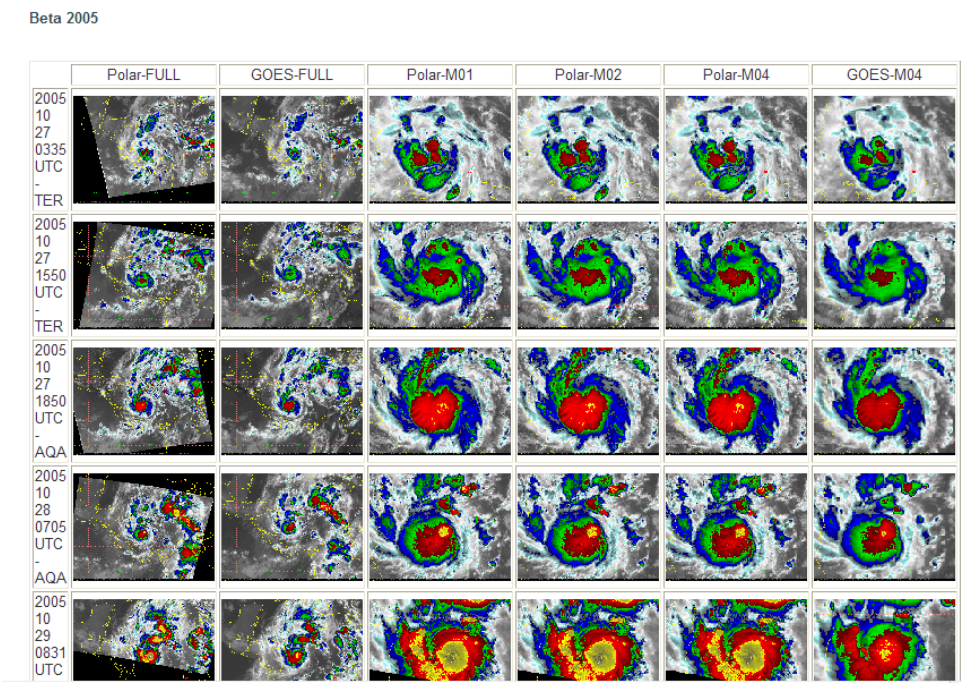

Fig. 1. The Tropical Cyclone website displaying the Hurricane Beta data page.

3.2 Tropical cyclone ground truth dataset

The ground truth for the intensity estimate algorithms is determined from the National Hurricane Center (NHC) best track. The NHC best track includes the maximum sustained surface winds, minimum sea-level pressure, and the latitude and longitude of the storm center at 6 h intervals. This 6 hourly data was linearly interpolated to the date/time of each of the 357 cases.

The NHC best track data are somewhat smoothed in time so the position estimates are not always representative of the storm center at a given time. In addition, the navigation on some of the archived polar images was not completely accurate. Therefore, when possible, the storm center was also estimated manually directly from the imagery, using the NHC best track position as a first guess. The manual centers are referred to as "McIDAS" centers. The McIDAS centers were determined for 218 of the 357 cases.

4. RAMS-MODEL BASED SIMULATED GOES-R ABI BANDS FOR MESOSCALE WEATHER AND HAZARD EVENTS

Simulated GOES-R ABI (radiances, brightness temperatures, and verification fields) were produced for the 10 upper bands from 3.9 μm to 13.3 μm for a variety of different mesoscale weather and fire events.

To simulate the different observed mesoscale weather or hazard events, the RAMS forecast model ran with up to 4 nested grids and with horizontal grid spacing as small as 400 m. Ben Rustin from the Navy Research Laboratory provided us with satellite-derived emissivity data. The RAMS output was used as input to an observational operator. In conjunction with OPTRAN code and radiative transfer models the simulated radiances and brightness temperatures were produced for the 10 GOES-R ABI wavelengths (3.9 μm to 13.3 μm) with a footprint size of 400 m. An approximated point spread function considering latitude and longitude of the data points was applied to create the GOES-R ABI simulated imagery at the appropriate footprint. In a last step McIDAS and GIF imagery was created for all datasets.

List of RAMMB/CIRA Simulated ABI Proxy Datasets:

1) Severe Weather over Kansas – 8 May 2003
2) Lake Effect Snow storm – 12 February 2003
3) Hurricane Lili – October 2002
4) Hurricane Wilma – October 2005
5) Fire case I: Fires embedded into Kansas Severe Weather Event – 8 May 2003
6) Fire case II: Agricultural fires in Central America – 24 April 2004
7) Fire case III: Lightning-caused fires in Southern California – 23 October 2007
8) Fire case IV: Lightning-caused fires in Southern California – 26 October 2007

4.1 Severe Weather over Kansas - 8 May 2003

The figure below depicts the map of the United States along with boundaries of Grids 1 through 4 that were used for the 8 May 2003 severe weather simulation.

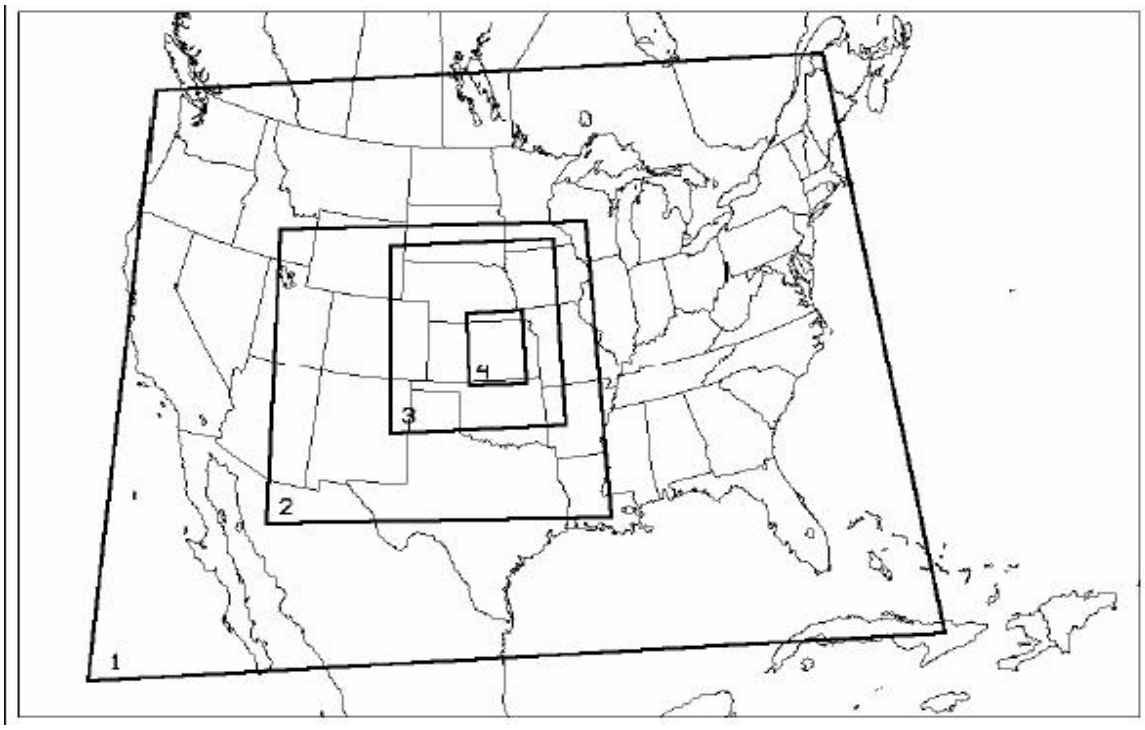

Fig. 2. The horizontal grid spacing for this nested grid forecast run was: Grid 1: 90 x 66 points with 50 km spacing; Grid 2: 192 x 162 points with 10 km spacing; Grid 3: 502 x 522 points with 2 km spacing; and Grid 4: 852 x 1027 points with 400 m spacing.

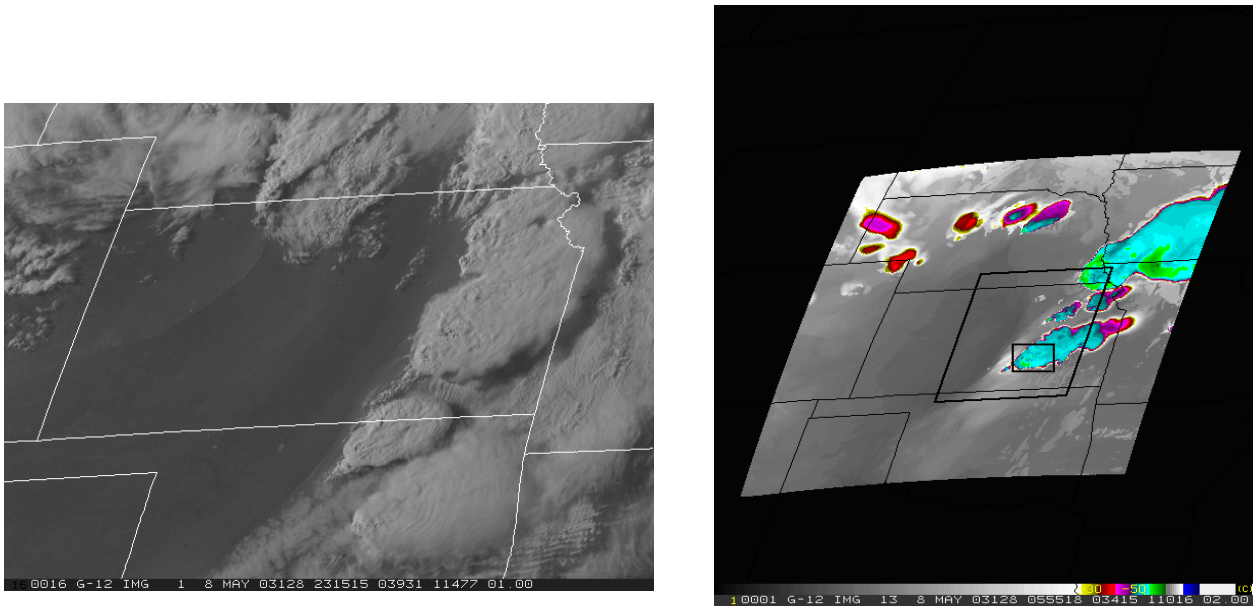

Fig. 3. An example frame of our 8 May 2003 simulated proxy data. To the left is a 1 km GOES-12 visible image at 2315 UTC, and to the right is the corresponding simulated GOES-R ABI satellite image (2 km at 10.35 μm at 2000 UTC).

4.2 Lake Effect Snow Storm – 12 February 2003

Simulated imagery was also produced for a 12 February 2003 Lake Effect Snow event. For this case, the RAMS model forecast used 3 nested grids.

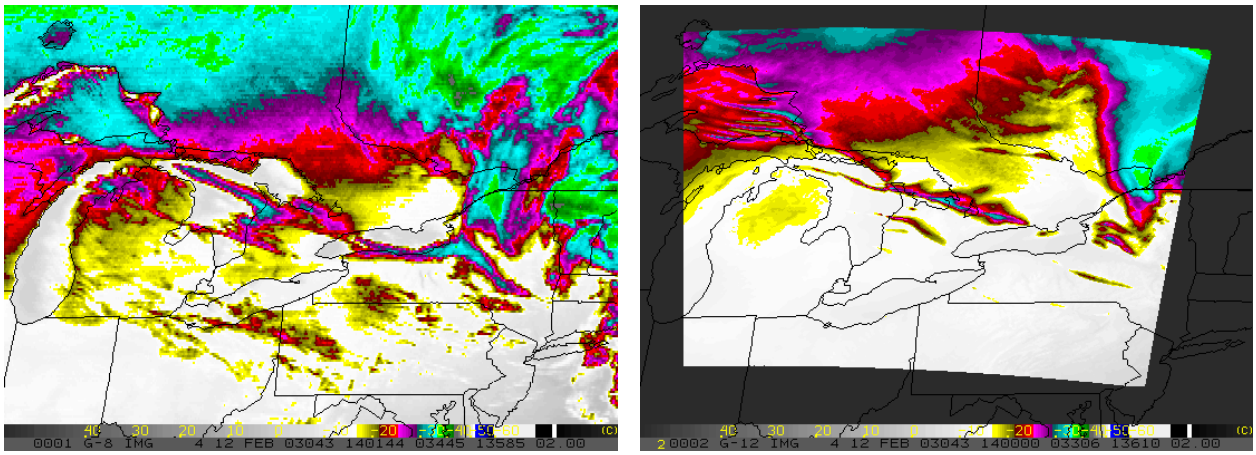

Fig. 4. Left: GOES-8 IR Image: 4 km 10.7 µm for 12 Feb 2003 at 1400 UTC; Right: Simulated GOES-R imagery: 2 km at 10.35 µm for 12 Feb 2003 at 1400 UTC.

4.3 Hurricane Lili – 2 October 2002

RAMS simulated GOES-R imagery was produced for a 6 hour time period (output every 5 minutes) for the 10 upper ABI wavelengths. An example of this dataset can be seen below.

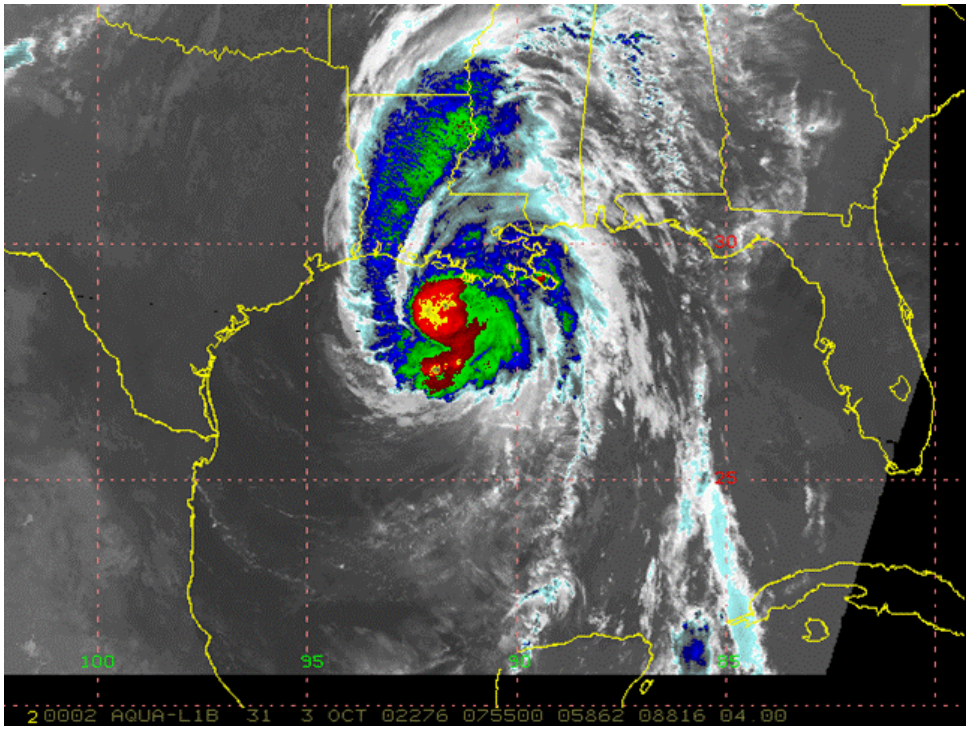

Fig. 5. MODIS longwave IR image of Hurricane Lili for 3 October 2002 at 0755 UTC.

4.4 Hurricane Wilma – October 2005

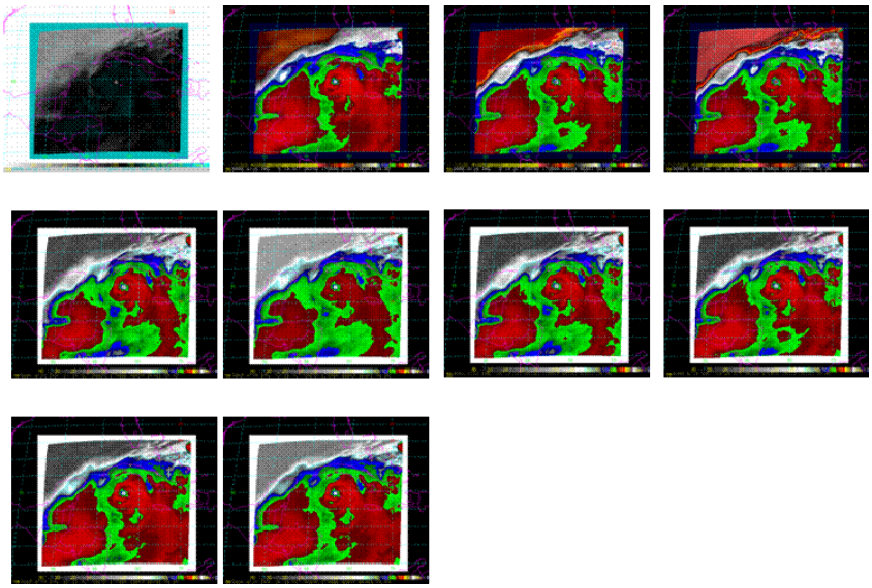

Fig. 6. Simulated imagery for the 10 upper ABI bands for Hurricane Wilma for 19 October 2005 at 1705 UTC.

4.5 Fire cases

The 4 fire cases are discussed in the following section.

5. RAMS AND WRF MODEL BASED SIMULATED GOES-R ABI FIRE PROXY DATASET PRODUCTION

Use the CSU RAMS forecast model (nested grids) to simulate an observed mesoscale weather with horizontal grid spacing as small as 400 m. For simulated fires, equally-distributed artificial fire hotspots were added to the simulated mesoscale event. For real fires, CIMSS ABBA retrieved datasets (based on GOES-11/12) for location and fire temperature information were inserted as fire hotspots into the simulated mesoscale event.

List of RAMMB/CIRA Simulated ABI Proxy Datasets:

1. Simulated fire hot spots embedded in severe weather case over Kansas (8 May 2003) for 3 GOES-R ABI bands (3.9 µm, 10.35 µm, 11.2 µm) and 3 different scenarios:
   - Constant fire temperature without clouds
   - Flickering fire temperature without clouds
   - Constant fire temperature with clouds

2. Real agricultural fires in Central America from 24 April 2004
Simulated imagery based on a RAMS (and a WRF) model forecast was produced for
ABI bands (3.9 µm, 10.35 µm, 11.2 µm)

3. Wild fire event in Southern California from 23 October 2007
Simulated imagery based on a RAMS model forecast was produced for
ABI bands (3.9 µm, 10.35 µm, 11.2 µm, and reflective ABI band at 2.25 µm)

4. Wild fire event in Southern California from 26 October 2007
Simulated imagery based on a RAMS model forecast was produced for
ABI bands (3.9 µm, 10.35 µm, 11.2 µm)

5.1 Artificial fire hot spots embedded in severe weather event Kansas - 8 May 2003

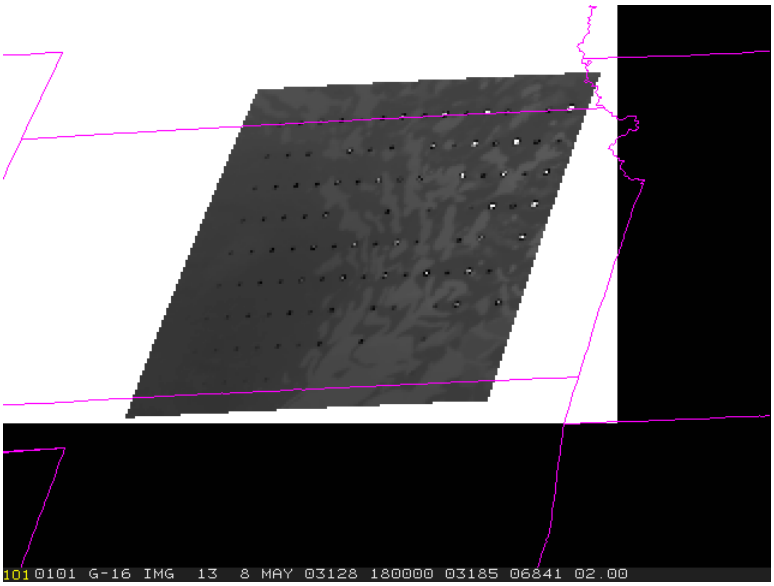

Fig. 7. Simulated 10.35 µm image of Grid 4 with constant fires and with clouds for 8 May 2003.

5.2 Central America – 24 April 2004 Agricultural Fires in Mexico, Guatemala, and Belize

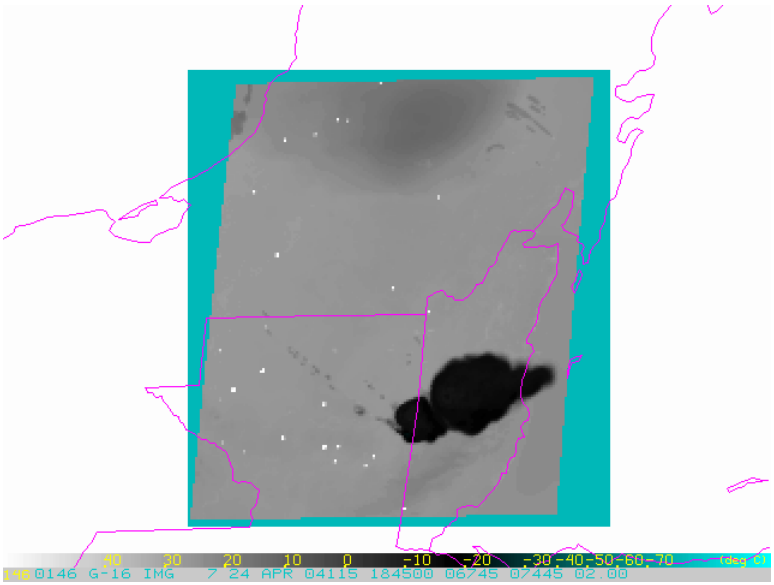

Fig. 8. Simulated GOES-R ABI 3.9 µm for 24 April 2004. Simulations extend from 1840 to 2100 UTC (with a 5 min interval).

5.3 Southern California Fires – 23 October 2007

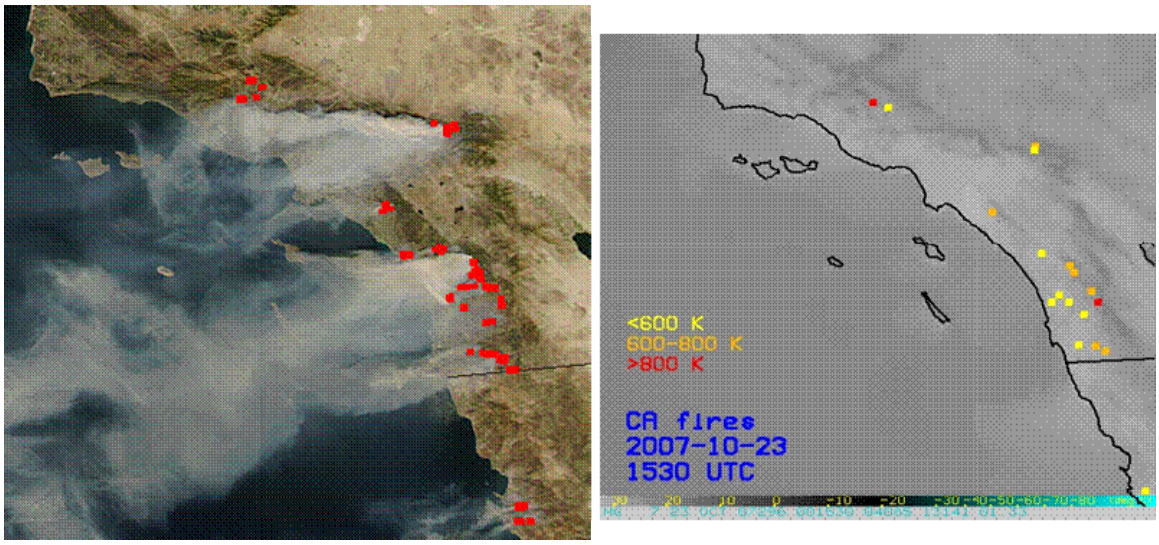

Fig. 9. Left: MODIS Aqua 1 km true-color image for 23 October 2007 (created by NASA); Right: Simulated ABI 3.9 µm image produced for 23 October 2007 at 1530 UTC.

5.4 Southern California Fires – 26 October 2007

This case is similar to the 23 October 2007 fire case but with fewer fires and very different wind conditions. In this case the winds were onshore, as opposed to offshore, resulting in suppressed fire activity compared to 3 days earlier.

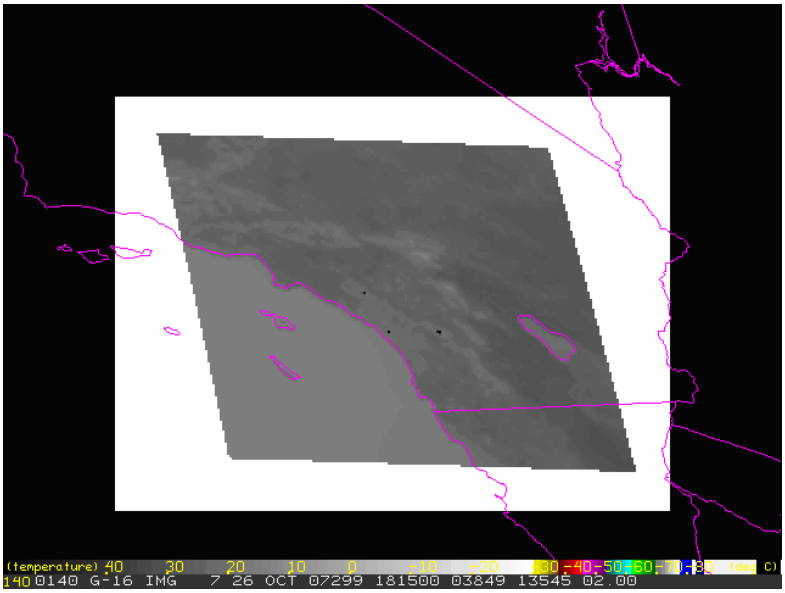

Fig. 10. Example of a simulated ABI 3.9 µm image for Southern California for 26 October 2007.

6. SIMULATED ABI REFLECTIVE BAND IMAGERY

Simulated imagery for 3 ABI reflective bands: 0.47 µm (blue), 0.64 µm (red), and 0.86 µm (near-IR) were produced of the Southern California 23 October 2007 wildfire case. A true-color (Red, Green, and Blue (RGB)) image was created by building an ABI synthetic-Green (0.55 µm) image based on a MODIS LUT as well as synthetic-RGB (true-color) image.

The simulations are based on 16-day albedos from MODIS for land surfaces. Results of the ABI simulations are quite good, with the ABI RGB comparing more favorably to the MODIS RGB than even to the MODIS synthetic RGB which is computationally more similar to the ABI product.

The following two figures explain the process of generating synthetic-Green and synthetic-RGB images for future ABI applications.

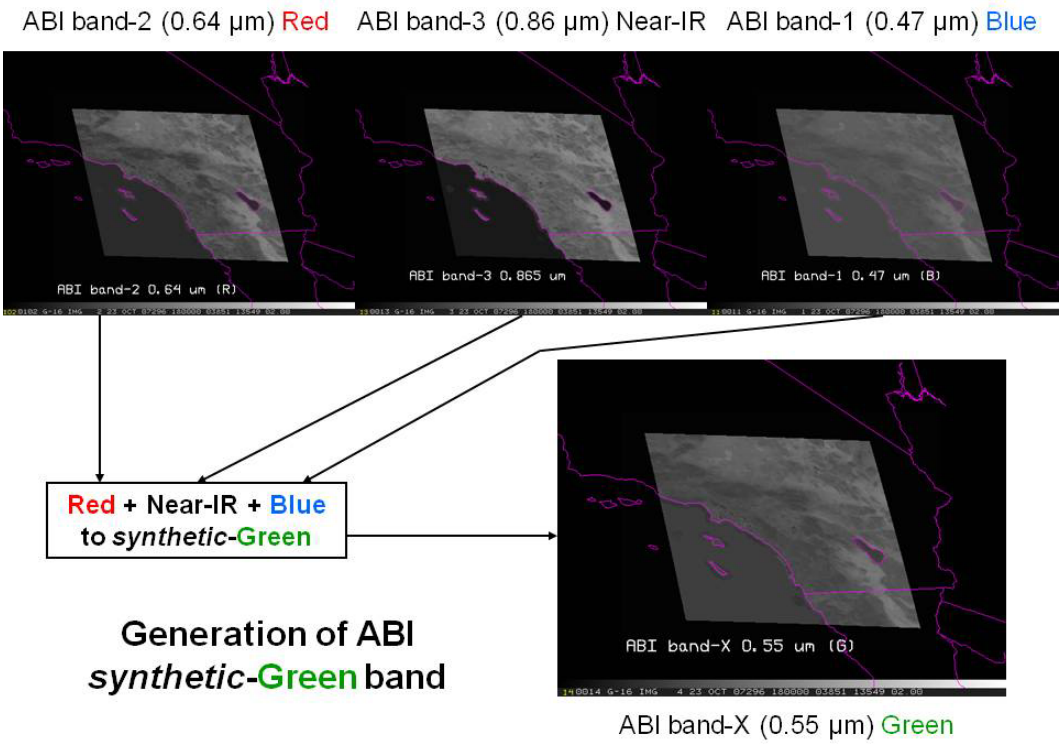

Fig. 11. Production of ABI synthetic-Green (0.55 µm) image for Southern California for 23 October 2007.

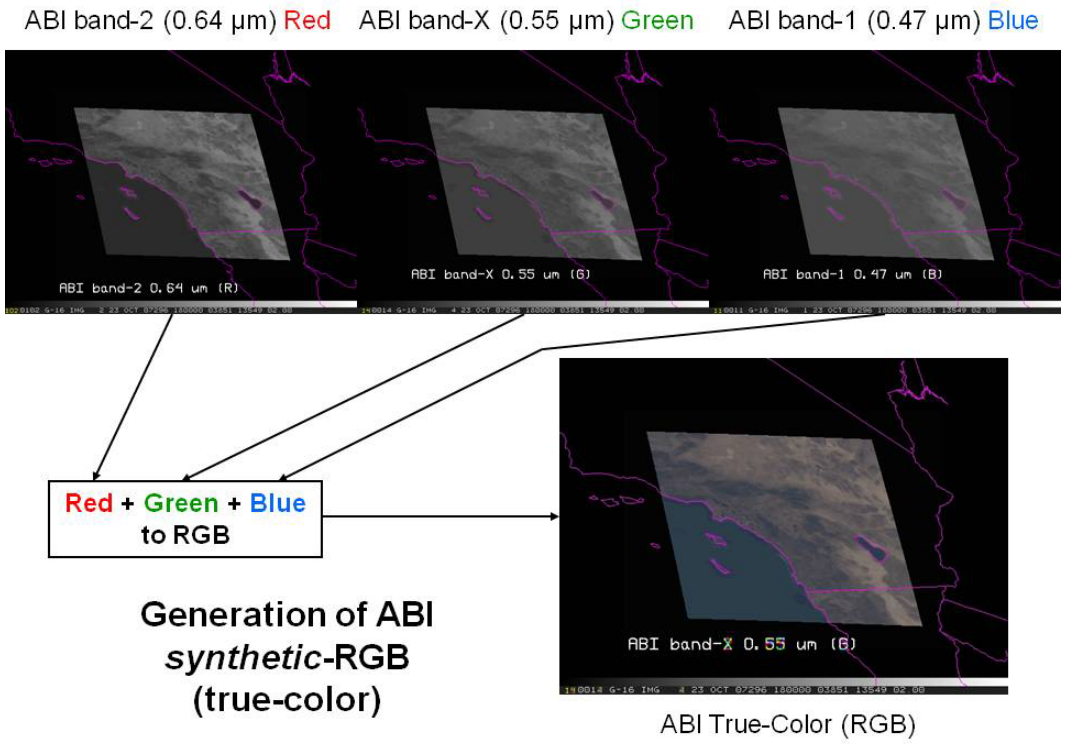

Fig. 12. Production of ABI synthetic-RGB (true-color) image for Southern California for 23 October 2007.

6.1 Simulations with Added Smoke

A true-color (RGB) image with a "dark" dissipating-fire smoke plume was created using the Southern California dataset just discussed. Work on adding aerosols such as smoke, volcanic ash and dust are only beginning as this document is being prepared.

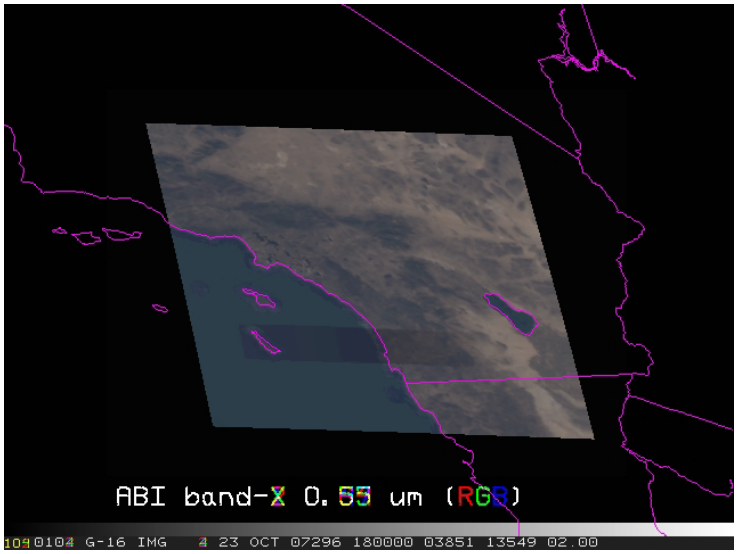

Fig. 13. ABI synthetic-RGB (true-color) image for case above with a modeled patch of "dark" smoke added.

7. SUMMARY AND BIBLIOGRAPHY

All datasets are available on-line on our GOES-R Study Dataset website
http://rammb.cira.colostate.edu/projects/goes_r/

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