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Visualization of Remotely Sensed Data with 3-D Meteorological Modeling Results

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ABSTRACT

EPA Models-3 system, the third-generation air quality modeling system, is a framework which accommodates new science modules and support their evaluation. One component of the Models-3 system is the Mesoscale Meteorological Model (MM5) which simulates clouds, water-vapor, wind and air deposition. Without comparing simulated data to measurements of real atmospheric data, the quality of the simulated data is completely unknown. There are tremendous amounts of data from satellite and radar which after being combined with geographical information may be compared to the simulated data. Visualization provides a quick and easy tool to present and analyze remote sensing data sets and compare with the modeling results.

Our purpose in this paper is to investigate how we can determine the quality of simulations from MM5 using available software tools to display both simulated and measured data. This capability will help environmental scientists to modify meteorological simulations in the MM5. We will compare the satellite data with model predictions by overlaying the remote sensing satellite imagery with the modeling data using two software tools, the McIDAS and Vis5D. Output from two variations of the MM5 are visualized along with the remotely sensed data imagery from Geostationary Operational Environmental Satellite (GOES) .

1. Introduction

1.1 Overview

Models-3, EPA's third-generation air quality modeling system, is being designed to be user friendly, to overcome known weaknesses in existing modeling systems and to accommodate new science models and evaluation of all components of the modeling systems (Dennis et al., 1996). A meteorological model is a necessary component of Models-3. There are several meteorological models widely used in the environmental community to simulate the required meteorological variables. The first one of these models to be included in the Models-3 system is the Fifth Generation NCAR/Penn State Mesoscale Meteorological Model MM5. Clouds, water-vapor, and wind are some of the variables simulated and output from this model.

One of the critical problems facing environmental scientists is determining how well the model reflects reality. Without proper evaluation, modeling results are open to question. Spatially and temporally dense data are needed for such an evaluation. Fortunately, there is an increasing amount of data being collected from satellite and radar sources which can be combined with the geographical information so that the registration is accurate. Computer visualization enables scientists to look at the model output and to compare effectively with the remote sensing data.

1.2 Project Background

Clouds play a major role in air quality. Cloud properties are critical in the chemical transformations in the atmosphere and precipitation from clouds removes pollutants from the air. Aqueous reactions in clouds differ from gas phase reactions. MM5 simulates various effects of cloud processes and the cloud modeling schemes are crucial to a realistic simulation of mesoscale meteorology and air quality. Therefore, evaluation of MM5 predictions through comparison with satellite cloud imagery is very valuable (LeDuc et al, 1996). Scientific visualization can be used to compare meteorological model results with the satellite imagery on the desktop computer, provides greater insight or understanding of how well the models are approximating reality.

This paper and the related research is a collaboration between US EPA, Lockheed Martin (EPA SVC), and the Earth Science Laboratory of the University of Alabama at Huntsville. It is funded by EPA under the third generation air quality modeling system, Models-3 project. The visualization of the satellite data with the meteorological results are conducted by the EPA Scientific Visualization Center (SVC). The SVC is responsible for the examination of the scientific visualization techniques and tools. Specifically, visible and infrared images obtained from the GOES satellite are compared with MM5 modeling results.

This paper describes how we examined the clouds simulated by the MM5 model using available software tools. This examination determined when simulations were in error and thus provides help to environmental scientists who want to improve the MM5 cloud parameterization. This paper also describes how to compare satellite data with model predictions, by overlaying the remote sensing satellite imagery with the 3D meteorological model MM5 output. The satellite data used are from GOES satellite imagery obtained from the GOES Pathfinder Operation at the University of Wisconsin; and the meteorological modeling results are from MM5. The software chosen for the task includes Vis5D and Man computer Interactive Data Access System (McIDAS). Finally, the MM5 cloud-related information is visualized simultaneously with the GOES remotely sensed imagery.

2. Visualization of the remotely sensed data

2.1 Available Software:

2.1.1 ESRI®ARC/INFO®

ARC/INFO is a leading Geographical Information System (GIS) software marketed by Environmental System Research Institute, Inc. (ESRI). It is designed to process spatial and statistical geographical information datasets. ARC/INFO also provides some limited capabilities of handling remotely sensed data. The software is more widely used by GIS professionals.

2.1.2 PCI® EASI/PACE®

A commercial package from PCI Remote Sensing Corp.'s remote sensing software family, EASI/PACE, offers a wide range of functionality. EASI/PACE provides extensive capabilities in image classification, geometric correction, orthorectification, enhancement, filtering, vector editing with image backdrop, terrain analysis and visualization, radar image processing, DEM (USGS Digital Elevation Model) extraction, atmospheric correction, and hyperspectral data analysis. EASI/PACE is a modular system. The Image Processing Kit is the core of EASI/PACE, the turnkey solution for the PCI remote sensing software family. Depending on processing requirements, additional software packages may be added.

2.1.3 ENVI®

Environment for Visualizing Images (ENVI) is a robust, easy-to-use image processing system. ENVI provides analysis and visualization of single-band, multispectral, hyperspectral, and radar remote sensing data. ENVI's point-and-click graphical user interface (GUI) makes it easier and faster to learn and utilize the system to process images. ENVI is built on Interactive Data Language (IDL), a structured, array-based programming language that includes flexible image analysis tools.

ENVI's flexible data handling allows most data files to be read directly off the disk (including CD-ROM) without converting them to another format. ENVI uses a generalized raster data format that consists of a simple flat binary file and a small associated ASCII (text) header file. This approach allows reading of almost any image format into ENVI, including those with embedded header information. The ASCII header file provides ENVI with information about the dimensions of the image.

ENVI supports both image-to-image and image-to-map registration through Ground Control Points (GCPs).

2.1.4 ERDAS® IMAGINE®

Another commercial product is available from ERDAS, Inc. It is called IMAGINE and offers total imaging GIS solutions on UNIX-based workstations as well as on PCs. ERDAS IMAGINE is compatible with ARC/INFO. ERDAS IMAGINE actually has ESRI's ARC data model built in.

2.1.5 Lockheed Martin MeteoStar® LEADS

Lockheed Environmental Analysis and Display System (LEADS) is a system for the receipt, integration, and processing of all types of meteorological data, and interactive generation and display of tailored weather support products. It is specifically designed as a meteorological application.

2.1.6 McIDAS and Vis5D

McIDAS (Man computer Interactive Data Access System), under development since 1970 at the Space Science and Engineering Center (SSEC) of the University of Wisconsin-Madison, is a sophisticated, video interactive set of tools for acquiring, managing, analyzing, displaying, and integrating data.

McIDAS generates multicolor composites of conventional and satellite weather data in a variety of displays in two and three dimensions as well as time-lapse sequences of these analyses. Designed to handle large amounts of meteorological imagery and other atmospheric data in a convenient manner, the system is a vast resource of image-processing and applications programs and subroutines. McIDAS hardware and software are used throughout the world.

Vis5D is a system for the interactive visualization of large 5D gridded data sets (3D in space with time sequence and species' concentration) such as those made by numeric weather models. Vis5D was written by the Visualization Project at the University of Wisconsin-Madison Space

Science and Engineering Center (SSEC) by Bill Hibbard and Brian Paul. One can make isosurfaces, contour line slices, colored slices, volume renderings, etc. of data in a 3D grid, then rotate and animate the image in real time. There's also a feature for wind/trajectory tracing, a way to make text annotations for publications, etc.

Vis5D provides superior 3D visualization capability and is free, but does not provide internal geopositioning functionality. McIDAS is used for the geopositioning because it is a standard tool used with meteorological data, including satellite data. Considering the labor, availability of local expertice, and cost of the software, Vis5D and McIDAS was determined to provide the most cost effective solution for us. The flexibility of the software allows us to visualize 3D meteorological modeling results and georeference the satellite map with the model results without writing internal code.

2.2. Methods

The GOES satellite data were obtained from the SSEC, Wisconsin State University GOES Pathfinder Operations. McIDAS is used to pre-process the satellite (GOES) imagery. First, using McIDAS, GOES imagery is projected from native projection to Lambert coordinates. Second, the imagery is subsected to the domain of the model. Finally, Vis5D is used to visualize the meteorological modeling results with the GOES imagery.

Figure 1 shows two satellite images before and after the pre-process from McIDAS. Figure 1a is the original imagery from GOES Pathfinder Operations at the University of Wisconsin. This image is in the original satellite projection (Mercator). Figure 1b is the processed satellite image in Lambert Conformal projection, which is subsected to a domain size identical to the meteorological model (MM5).

Vis5D is used here for the visualization of the output of the NCAR/Penn State Mesoscale Meteorological Model (MM5). Figure 2 shows the rendering of the isosurfaces of the cloud water (the blue volume) and the rainwater (the white yellow volume). They are overlaid with the corresponding satellite images and other information. The United States map is superimposed on the top of the satellite imagery.

3. Results and Discussions

3.1 Comparing Model Prediction with Satellite Data

Shown in Fig 3 is the GOES satellite imagery infrared band overlaid with the MM5 results. The period modeled is on 08/02/88. The MM5 modeling results shown are at a 54 km grid size. Clouds and rainwater are visualized as isosurfaces and normalized by humidity, the interiors of which have a normalized water contents greater than 0.01.

The infrared information from GOES indicates temperature, which can be compared to model-predicted temperature wherever clouds are present. This is accomplished by projecting the model-simulated temperature onto the isosurface of the cloud water. In the infrared band, clouds that are highest are also the coldest. Therefore, when the infrared band is projected onto the Earth's surface, the highest clouds appear the whitest. The model's predicted isosurfaces are translucent so the infrared cloud projections can be viewed on the surface. White areas on the surface are clouds detected by infrared sensors on GOES; they correspond to the model-predicted clouds with coldest temperatures.

3.2 Side-by-Side Comparison of the Two Model Runs

Two MM5 model outputs with different grid resolutions (80km and 54km) are compared side-by-side in Figure 4. The grid resolution is not the only difference as the internal equations have different assumptions regarding the hydrostatics. This allows examination of cases in which one model configuration (resolution and hydrostatics) does a better simulation than another model configuration based on the comparison to satellite imagery. Observed satellite data offer good spatial and temporal resolution and provide the opportunity to gain additional insight in inter-model comparisons.

3.3 Velocity Fields Predicted by Model

Vertical wind information is displayed in Figure 5 and shows the detailed physics of the model and the structure of convective events. Note the shafts with upward motion, associated with large clouds. High, cold cloud tops should exist in these convective areas. The infrared satellite information is added for comparison, with white representing the coldest clouds.

4. Summary

In this paper, we described how we can examine certain output from a meteorological model using software tools and thus help environmental scientists to improve their meteorological models. Satellite data were from GOES and were obtained from the GOES Pathfinder Operations at the University of Wisconsin. The meteorological modeling data were from MM5. We described how we compared the satellite data with model predictions by overlaying the 3D scientific modeling data over the remote sensing satellite imagery using software tools, McIDAS and Vis5D. Other software were discussed, but were not used in the comparison. The technical issue, the geoposition of the data with the maps, the cost, the local expertise, and the labor were the reasons we chose the approach using McIDAS and Vis5D.

Finally, three-dimensional output simulated in MM5, including cloud water, relative humidity and velocity, were visualized simultaneously with the remotely sensed data imagery (GOES). Observed satellite data provide the opportunity to gain additional insight in inter-model comparisons. Satellite-observed clouds offer good spatial and temporal resolution for this kind of comparison. Through an improved understanding gained in using visualization tools, satellite data can be incorporated into model predictions. Improved analytic tools for directly assessing the accuracy of spatial predictions offer additional challenges and opportunities.

5. Acknowledgment

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6. Disclaimer

This paper has been reviewed in accordance with the U.S. Environmental Protection Agency's peer and administrative review policies and approved for presentation and publication. Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

7. References

ARC/INFO: http://www.esri.com/

Dennis, R.L., D.W. Byun, J.H. Novak, K.J. Galluppi, C.J. Coats and M.A. Vouk (1996): The Next Generation of Integrated Air Quality Modeling: EPA's Models-3, *Atmospheric Environment*, **30**, n12, 1925-1938.

ENVI: http://www.envi-sw.com/

ERDAS IMAGINE: http://www.erdas.com/

LeDuc S., J. Pleim, Y.Q. Zhang and J. Wang (1996):GOES Visible and Infrared Channels to Evaluate Cloud Processes in Air Quality Models, *Second International Symp. and Spatial Accuracy Assessment in Natural Resources and Environmental Sciences*, May 21-23, 1996, Fort Collins, CO, USA.

McIDAS: http://www.ssec.wisc.edu/software/mcidas.html

PCI EASI/PACE: http://www.pci.on.ca

Vis5D: http://www.ssec.wisc.edu/~billh/vis5d.html

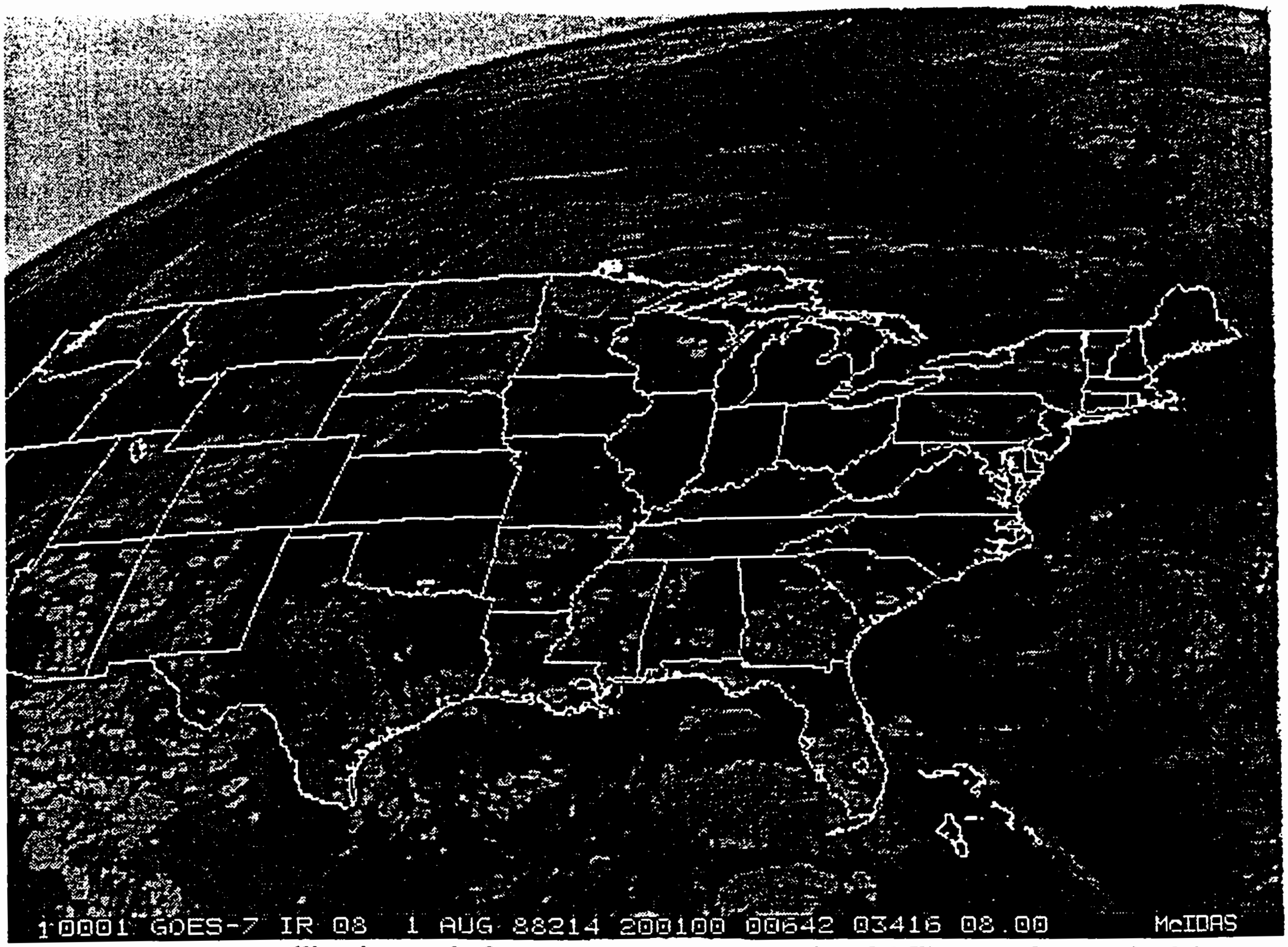

Figure 1a: GOES satellite image before the "pre-process" using McIDAS software, in Mercator projection.

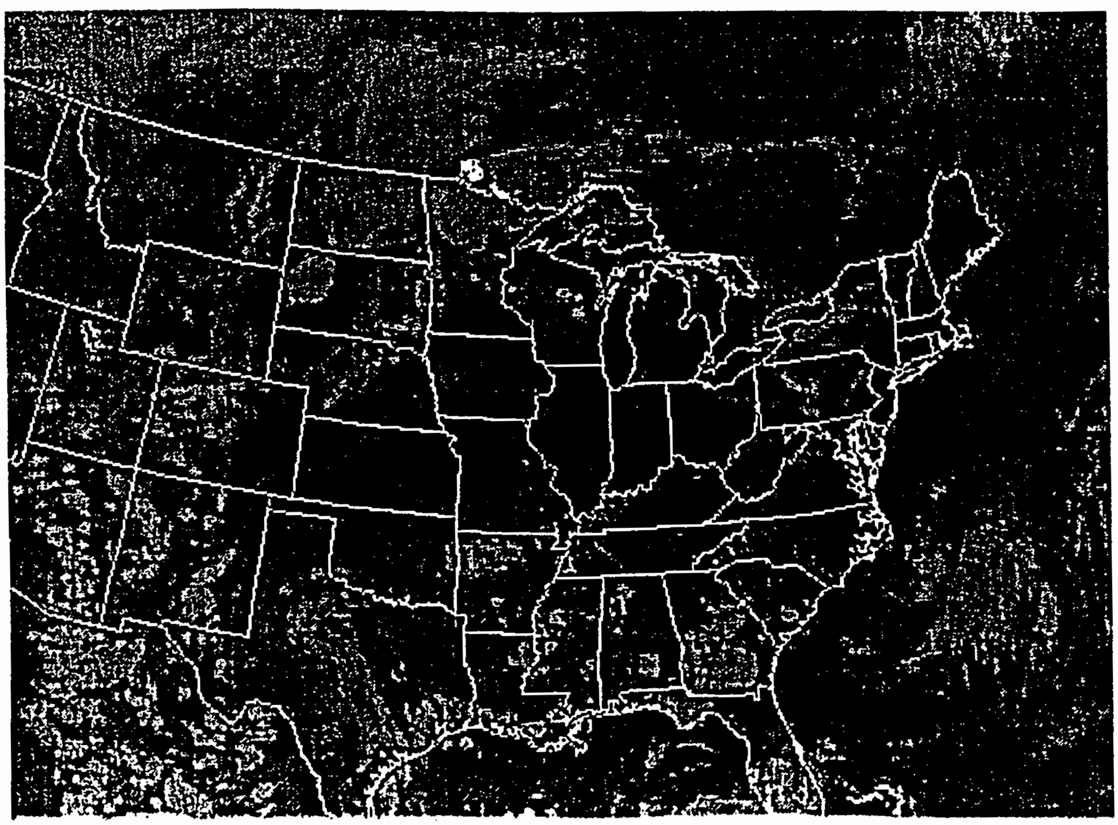

Figure 1b: GOES satellite image after the "pre-process" using McIDAS software, in Lambert Conformal projection.

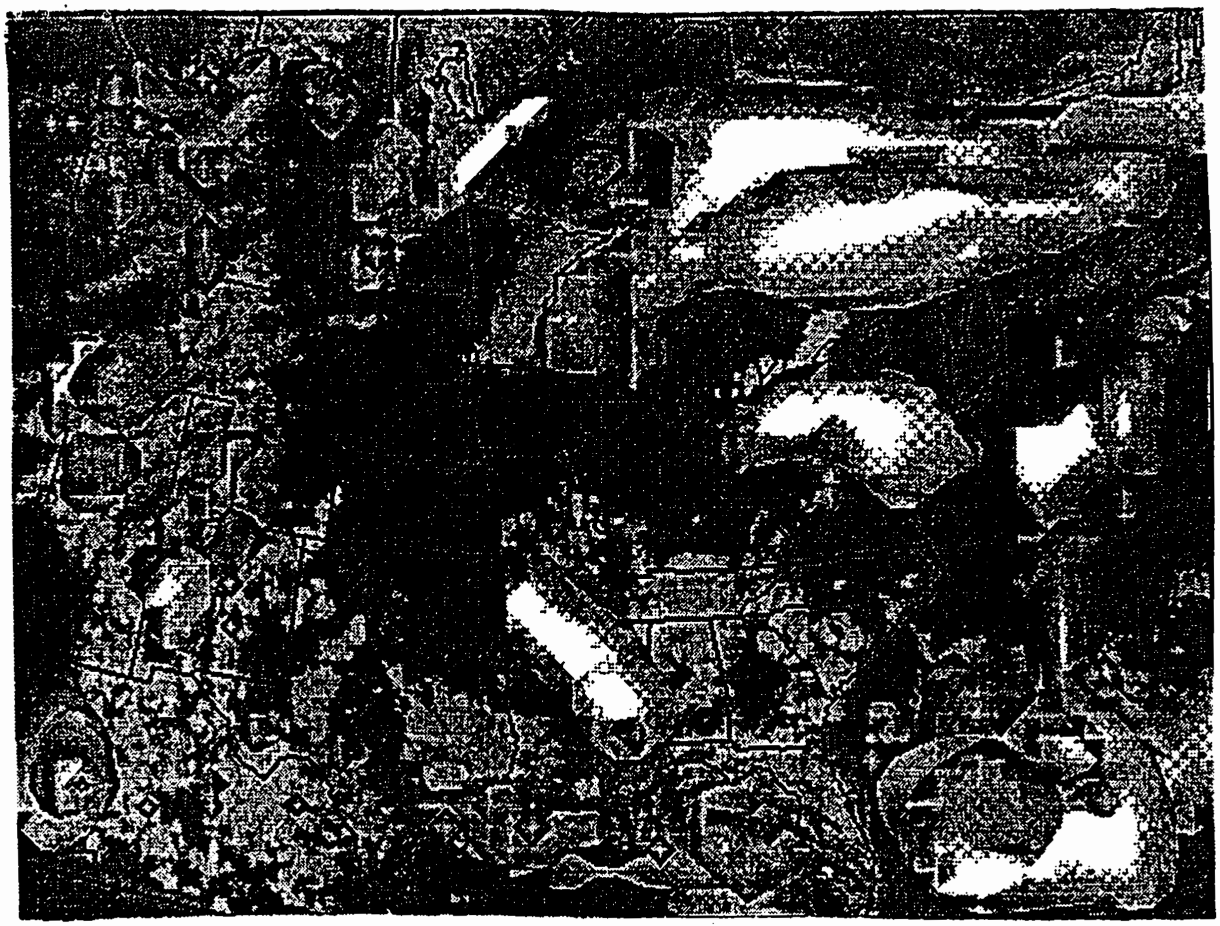

Figure 2: Rendering image of the isosurfaces of the cloud water. They are overlaid with corresponding satellite image.

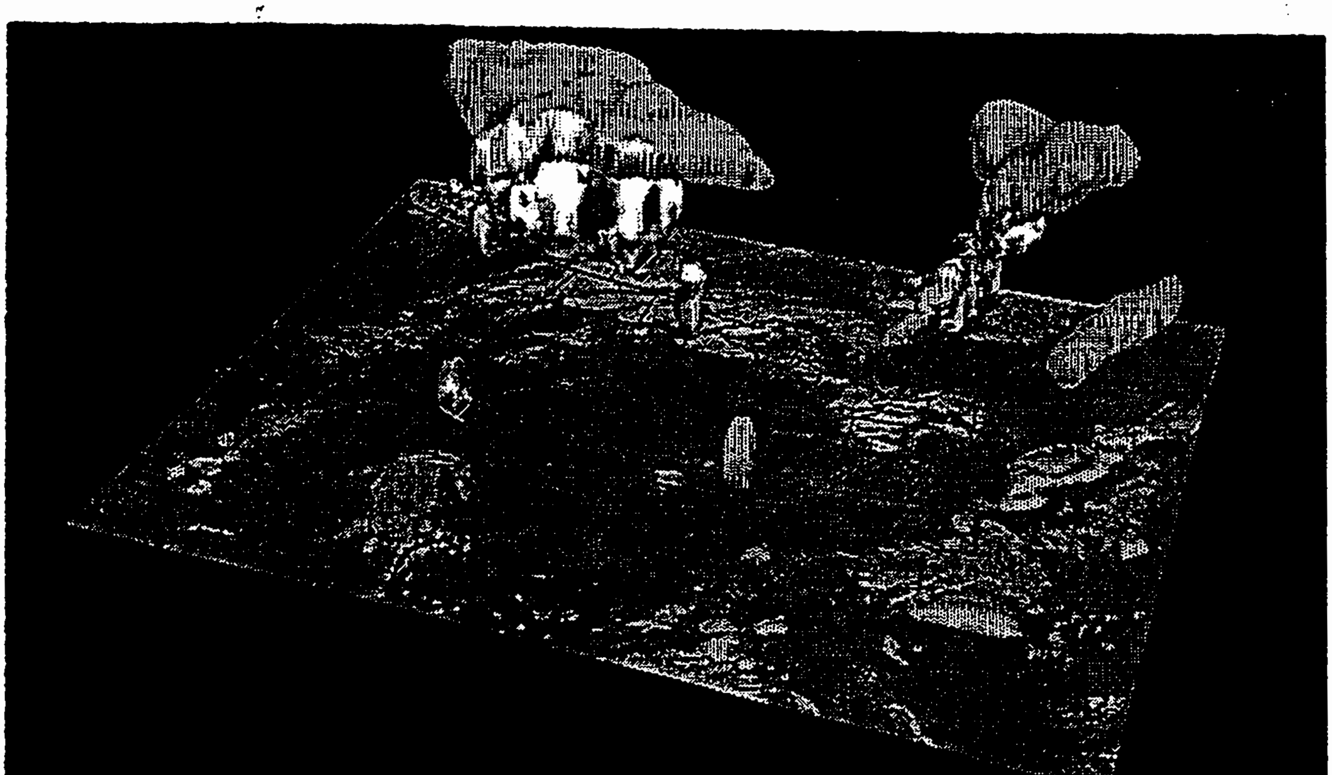

Figure 3: GOES satellite imagery infrared band overlaid with the MM5 modeling results. The temperature can be mapped (in color) onto the cloud isosurface.

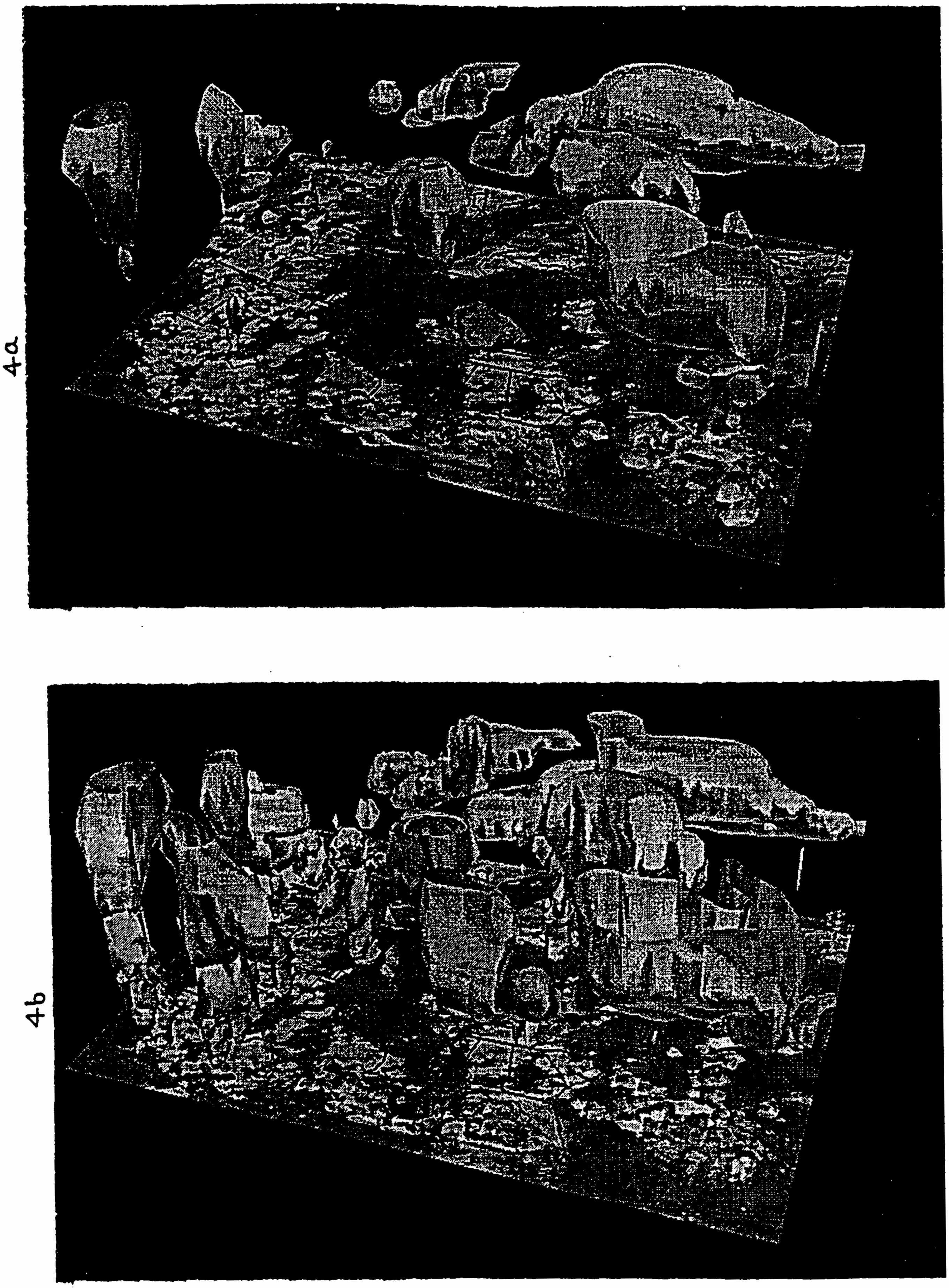

Figure 4: Side-by-side comparison of two MM5 model outputs, 4a: 80km grid resolution; 4b: 54 km grid resolution..

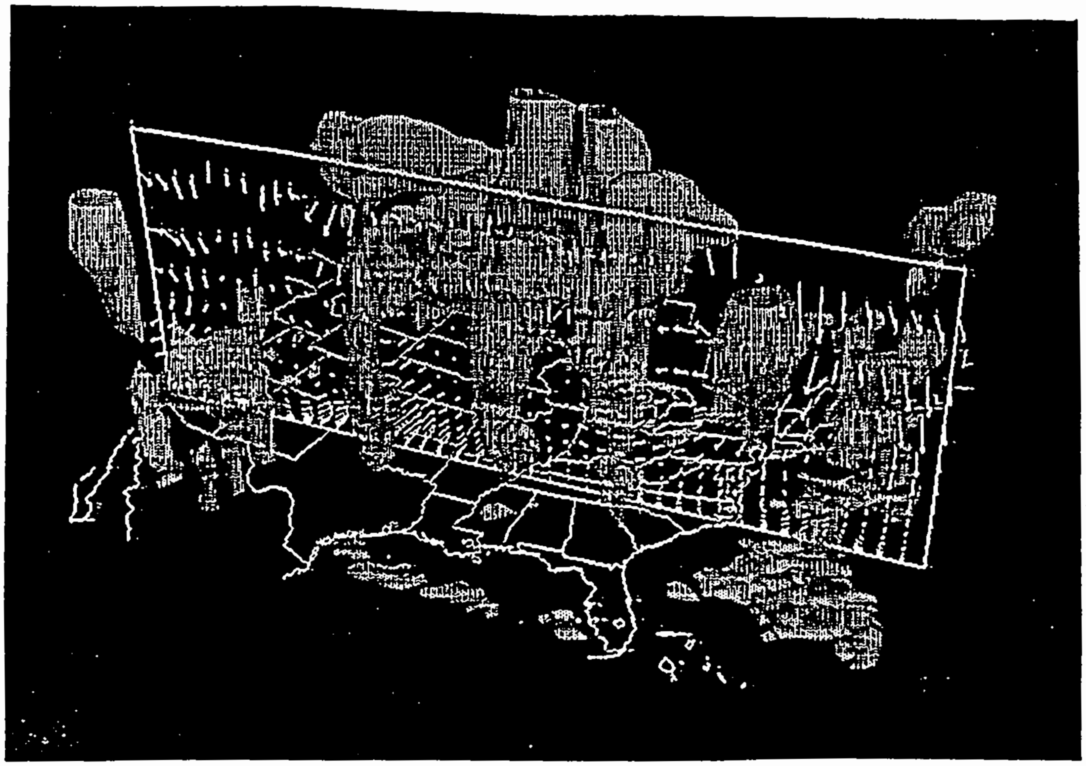

Figure 5:Vertical wind shows the detailed physics of the model and the structure of convective events.

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16. ABSTRACT

The EPA Models-3 system, a third-generation air quality modeling system, is a framework which accommodates new science modules and supports their evaluation. One component of the Models-3 system is the mesoscale meteorological model (MM5) which simulates clouds, water-vapor, wind and air deposition. Without comparing simulated data to measurements of real atmospheric data, the quality of the simulated data is completely unknown. There are tremendous amounts of data from satellite and radar which, after being combined with geographical information, may be compared to the simulated data. Computer visualization provides a quick and easy tool to present and analyze remote sensing data sets and compare with the modeling results.

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