

SATELLITE METEOROLOGY APPLICATIONS: A DEMONSTRATION PROJECT FOR REGIONAL METEOROLOGICAL TRAINING CENTRES

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Introduction

Historically, the USA has been a leader in the training of users throughout the world in the application of meteorological satellite data. Over the years, in cooperation with WMO, NOAA's National Weather Service (NWS) and National Environmental Satellite Data and Information Service (NESDIS) have provided a number of successful satellite training courses. As one might expect, the proliferation of meteorologi-

cal satellites and the evolution of multichannel datasets, coupled with users becoming increasingly sophisticated in their ability to display and analyse satellite imagery, has resulted in great demand for advanced training in the use of those data. That increased demand, coupled with a limited number of experts available in the major satellite-operating countries, prompted WMO to develop a new training strategy known as "training the trainers." In November 1995, NESDIS scientists travelled to the Costa Rica Regional Meteorological Training Centre (RMTC) and participated in the first training course under this new strategy. During the course, Dr Donald

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Hinsman (WMO) and the author met with Dr Vilma Castro León (Costa Rica RMTC) and scientists from both the National Meteorological Institute and the University of Costa Rica to explore the possibility of implementing an innovative approach for both training and applied research in satellite data utilization. The collective desire was to demonstrate how an RMTC could develop considerable expertise in the utilization of, and training capability with, digital GOES satellite imagery by participating in a "virtual laboratory" with NOAA's Cooperative Institute for Research in the Atmosphere (CIRA) and Cooperative Institute for Meteorological Satellite Studies (CIMSS).

Background

The effort was undertaken in the spirit of the 45th session of the WMO Executive Council, which recommended that "each satellite operator ... cooperate with at least one of the specialized satellite applications training centres ("centres of excellence") strategically located around the globe with regard to the satellite training programme, facilities and expertise required". In this activity, CIRA, CIMSS and the Costa Rica and Barbados RMTCs are participating in a demonstration project that is designed around the concept of a virtual laboratory. The virtual laboratory is modelled after the highly successful RAMSDIS ("regional and mesoscale meteorology advanced meteorological satellite demonstration interpretation system") program (Molenar *et al.*, 1996). The RAMSDIS program uses Internet for data transfer from a NESDIS server to selected NWS offices, where inexpensive computer technology is used for imagery display, analysis and animation (movie loops). The original purpose of RAMSDIS was to provide half-hourly digital GOES satellite imagery and products to NWS offices for: (a) assessment of data quality; (b) familiarization with digital satellite data and products and establishment of a baseline for training needs; and (c) improvement in the utility of satellite imagery and derived image products. Throughout the programme, CIRA provided the expert guidance for NWS field offices in the use of the data. An electronic bulletin board allowed participants to share experiences in the use of satellite imagery for forecasting, while providing a forum for discussion, questions and answers. Computer-aided learning (CAL) modules were developed by RAMM/CIRA staff (Phillips and Purdom, 1996) and placed on

all RAMSDIS systems. One CAL module, *Introduction to GOES-8*, covers basic capabilities of the new GOES series and includes comparisons with the previous generation GOES; the other, *GOES-8 3.9 Micron Tutorial*, focuses on special uses of the 3.9 μm channel. RAMSDIS has significantly improved the utility of satellite imagery at NWS forecast offices: response from the field has been exceptional and uniformly positive. In addition to meeting its original goals, the RAMSDIS effort has aided in refining advanced GOES products. The effort has expanded in scope to include a number of research-related activities, with applied research activity under way at several NWS forecast offices. Similar to the RAMSDIS program, the RMTC virtual laboratory utilizes inexpensive PC technology and digital tapes, CD-ROMS and Internet for data distribution. Although the goals of the RMTC effort are similar in nature to those of RAMSDIS, they are, however, more aggressive. Because the RMTCs were already specialized satellite applications training centres ("centres of excellence") the major thrust of the virtual laboratory became: (a) familiarization with digital GOES satellite data and products; (b) participation in joint research projects utilizing GOES digital data; and (c) the development of training cases for use by the RMTC.

The backbone of the RAMSDIS program is an advanced, menu-driven analysis-and-display system developed at CIRA. The system is based on McIDAS-OS2 and uses state-of-the-art Pentium PC technology. The RAMSDIS PCs at the RMTCs are capable of displaying imagery using 256 colours or shades of grey. Images displayed on those systems are 480 by 640 picture elements in size. By utilizing computer memory (RAM), up to 250 frames of image data are available at any time. The ingest systems contain a 1.2 GB hard disk drive, while the research RAMSDIS PCs have larger storage capacity for archived case-study and research datasets.

On the RAMSDIS PCs, real-time GOES-8 satellite data loops (visible, 3.9, 6.7 and 10.7 μm channels) and products can be viewed by simply pressing a function key. A list of the data and associated display resolution and ingest frequency are shown in the table overleaf. Easy-to-use menu-driven satellite data analysis routines are also provided on the system. Applications developed by CIRA include routines to enhance, combine and improve data interpretation and analysis. To enhance satellite imagery, the colour look-up table can be shifted to highlight

<i>Data type</i>	<i>Display resolution</i>	<i>Image frequency</i>	<i>Frames in loop</i>	<i>Comments</i>
Visible	1 x 1 km	30 min	16	Zoom in from 2 x 4 km visible
Visible	2 x 4 km	30 min	16	Internet
3.9 μ m IR	2 x 4 km	30 min	16	Internet
6.7 μ m IR	2 x 4 km	30 min	16	Zoom in from 4 x 8 km 6.7 μ m IR
10.7 μ m IR	2 x 4 km	30 min	16	Internet
10.7 μ m IR	2 x 4 km	2-h averages	16	Average of images from 10.7 ingest
6.7 μ m IR	16 x 16 km	60 min	24	Internet
6.7 μ m IR	4 x 8 km	30 min	16	Internet
Fog product	2 x 4 km	30 min	16	Derived from 3.9 and 10.7 data
Reflectivity product	2 x 4 km	30 min	16	Derived from 3.9 and 10.7 data

specific data features such as cloud-top temperatures. In addition, the cursor can be placed over a cloud top and the minimum, average and maximum temperatures beneath the cursor can be displayed. A time-series of imagery can be averaged into a single product, which can be used to indicate areas of heavy precipitation. Several applications have been developed to determine wind velocity, storm motion and feature arrival time at a specific location. Analysis of a time-series of imagery with the storm motion removed provides the ability to isolate and study flow patterns relative to storm development and decay. Another useful application is the ability to overlay surface and upper-air plots and analysed fields.

The hardware and software capabilities discussed above make the RAMSDIS PC a powerful, easy-to-use, low-cost workstation for the analysis of digital satellite imagery. RAMSDIS provides the ability for remote sites to share software and data on a common platform, which is essential to the success of joint research and training efforts.

Activities during the demonstration year—getting up and running

The first year has been a busy one. Since the summer of 1996, CIRA, CIMSS, and the Costa Rica and Barbados RMTCs have been participating in a virtual laboratory focusing on a familiarization, research and training programme in the use of digital GOES satellite imagery. After receiving funding from the NWS Interagency Activities Office, CIRA purchased and configured two RAMSDIS PC units for each RMTC, with CIMSS providing McIDAS software for each unit. For each RMTC, one RAMSDIS unit was set up for research, while the other was configured for real-time data ingest over Internet. In July

1996, GOES-8 data covering each RMTC's area of interest was loaded onto the hard drive of the appropriate research RAMSDIS PC, which was then sent to the RMTC: this allowed RMTC staff to become familiar with the RAMSDIS PC functionality prior to specialized training at CIRA. In mid-August 1996, Dr Javier Soley (Costa Rica) and Mr Selvin Burton (Barbados) visited CIRA for training related to RAMSDIS PC and GOES-8. During that week, initial research topics were agreed upon. After the training, they returned to their respective RMTCs and shared their newly acquired knowledge with colleagues about RAMSDIS and its menu-driven applications through demonstrations and hands-on training. An Internet-compatible RAMSDIS PC was shipped to Costa Rica in the late autumn and, through persistent work by the RMTC staff, Internet access problems were solved and the system was running and ingesting data by 13 December 1996. Since that time, near-real-time GOES-8 digital imagery has been provided to the Costa Rica RMTC via Internet from the NESDIS GOES-8 server. During night-time hours, when Internet traffic is light, data flow has been smooth; in the daytime, however, when the traffic is heavy, data flow has at times been interrupted. Current Internet service to the Barbados RMTC is not capable of supporting RAMSDIS PC data flow and until that situation is corrected, CIRA will select datasets for case-study work.

Since the science focal points from each RMTC had visited CIRA during the autumn of 1996, it was both appropriate and necessary that CIRA scientists who would act as the focal point for each RMTC should undertake a reciprocal visit in early 1997. Thus, Bernadette Connell visited Costa Rica during the last week of January 1997 and Carol Vaughn visited Barba-

dos during early March 1997. Those visits had similar purposes, i.e. to: (a) become familiar with the RMTTC operation and its staff; (b) provide further training and troubleshooting in the use of the research RAMSDIS unit, as well as the ingest RAMSDIS at Costa Rica; and (c) continue work on case-studies and refine areas of joint research.

Real-time imagery

The Costa Rica RMTTC is located at the main campus of the University of Costa Rica, with staff from the School of Physics, Department of Atmospheric Science. This provides the opportunity for University scientists and students not directly associated with the RMTTC to have access to digital GOES imagery for both educational purposes and the development of joint projects with RMTTC staff. The Costa Rica system is set up to receive half-hourly digital (8 bit) GOES-8 data from four of the imager's channels, as shown in the table on page 232. The table also shows other image products that are produced on the RAMSDIS PC from the Internet data stream. Each movie loop can be accessed quickly from the function keys on the computer keyboard and toggle keys allow for the comparison of products and imagery from different channels. Surface, international ship and buoy data are ingested every hour and plotted automatically on selected loops. The surface data consist of hourly SAO observations from the USA and portions of the Caribbean islands and Mexico. Radiosonde data over North America at mandatory levels are ingested twice a day, and may be accessed for display on imagery through the menu system.

The 16 km resolution 6.7 μm imagery is used to show broad scale, hemispheric upper-level flow patterns and mesoscale aspects of larger-scale flow features that may influence weather within the RMTTC's area of interest. The imagery can be expanded to a display resolution of 2 x 4 km in a different frame allocation area, allowing those data to be easily compared with the other 2 x 4 km resolution images. The 6.7 μm image is particularly useful when used with the 10.7 μm image for helping discriminate between thick and thin Cirrus cloud. For that reason, the 6.7 μm and 10.7 μm imagery is displayed using the same colour enhancement for cold scene temperatures. Away from the cold temperature range, the 10.7 and 6.7 μm colour enhancements are different: the 10.7 μm

imagery is displayed with normal white (cool) to dark (warm) grey shading, while the 6.7 μm image uses white to dark grey tones to indicate cooler moist regions and orange and red colours for warmer dry regions. For both the 6.7 and 10.7 μm images, the colour bar and a temperature scale are displayed at the bottom of the images. To aid in the analysis of the 10.7 μm imagery, the RAMSDIS PC menu allows the colour bar to be shifted easily to highlight an operator-selected temperature range. This capability makes it much easier to monitor phenomena such as the diurnal heating and cooling cycle of land. Visible images that match the scale of the 6.7 and 10.7 μm imagery are available during daylight hours, while matching 3.9 μm images are available 24 hours a day. From the visible data a close-up image, Figure 1(a), is produced on the RAMSDIS PC for display and analysis. That imagery is useful for following the evolution of clouds associated with mesoscale phenomena such as mountain-induced convection and land and sea-breezes. Once the 10.7 and 3.9 μm data are received by the RAMSDIS PC, derived image products (fog, Figure 1(b) and reflectivity product (Figures 1(c) and 1(d)) are produced for display on the system. Those products are useful for discrimination between ice and water cloud, detection of fires, and monitoring of volcanic ash cloud. An explanation of those products is provided in a CAL module, which resides on the RAMSDIS PC and is available over Internet from the RAMM homepage (RAMM, 1997).

The Barbados RMTTC, the Caribbean Meteorological Institute (CMI), does not have an Internet service capable of meeting the demands of RAMSDIS data flow. Special focus, therefore, has been placed on the utilization of retrospective datasets for familiarization, as well as for research and training case development. The CMI is affiliated with the University of the West Indies, whose campus is less than 2 km away. The research RAMSDIS is located at the RMTTC, and the datasets on it are shared with colleagues at CMI and the University participating in its meteorology programme.

Use of retrospective data at the RMTTCs

Case-studies have been chosen as the major venue for research activity and training material development. A research RAMSDIS PC was placed at each RMTTC to minimize conflicts between real-time data flow and research activity. Case-stud-



Figure 1(a) — Example of 1 km visible image that is derived from the 2 x 4 km visible data and provides a close-up view centred on the area around San Jose, Costa Rica.

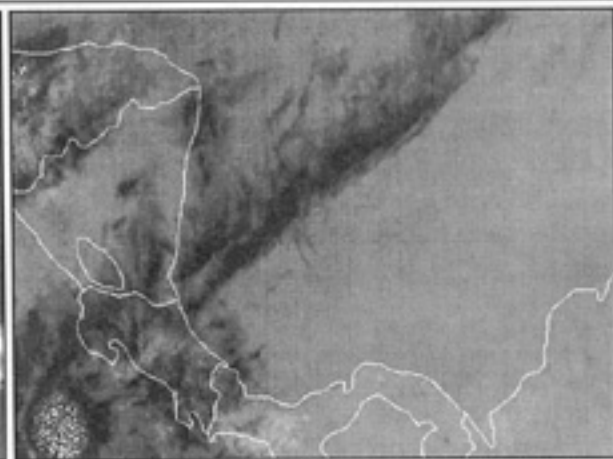


Figure 1(b) — Example of night-time fog product: in tropical regions, this product is useful for distinguishing ice (black) and water (white) clouds at night. It is not a daytime product.

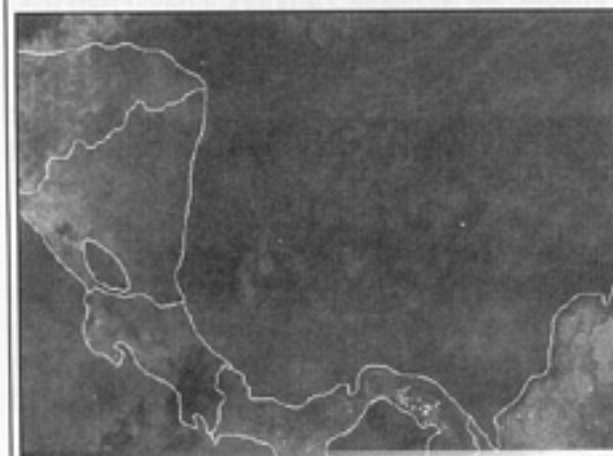


Figure 1(c) — Example of daytime 3.9 μm pseudo-reflectivity product: this product is useful for distinguishing ice and water cloud during daytime and for detecting fires (see close-up in Figure 1(d) and volcanic ash). In tropical areas, however, this capability is dependent on the scattering angle.

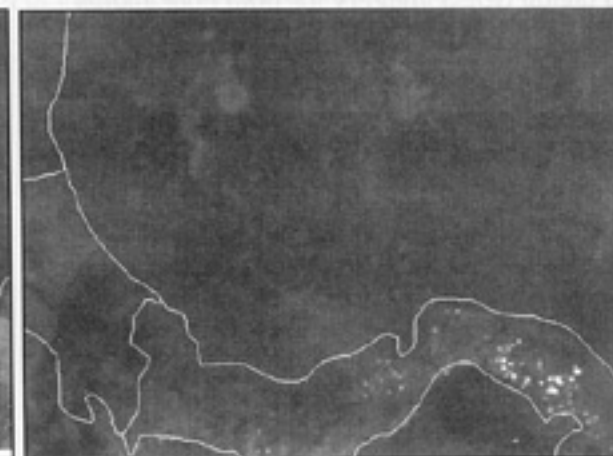


Figure 1(d) — Example of fires during daytime in 3.9 μm reflectivity product. The fires appear as numerous bright spots in Panama.

ies allow for in-depth exploration of the capabilities of digital satellite imagery, encourage interaction within the virtual laboratory environment, and lead to the development of training materials that can be used at the RMTc. To encourage interaction within the virtual laboratory, CIRA established an electronic "mailing group" for discussion purposes. To facilitate the case-study activity and take advantage of the CIRA satellite data-collection and archival capability, CIRA scientists routinely capture cases of interesting meteorological activity over each RMTc's region of responsibility. Unlike the real-time data flow, those datasets contain full resolution data for the visible, 3.9, 6.7 and 10.7 μm imagery and cover an area larger than the nominal 480 x 640 image size. Those special data are transferred to either CDS or digital tapes and sent to the

appropriate RMTc for study on their research RAMSDIS system. A number of interesting cases have been shared with the RMTcs, including one-minute interval imagery of hurricanes, various cycles of convective development over land and water, strong wind events, tropical storms and heavy precipitation. Both RMTcs are studying hurricane Cesar during different portions of its life.

Two research activities are under way at the Costa Rica RMTc. One focuses on the development of rainfall algorithms for satellite imagery from Cesar. Those estimates will be compared with ground-based measurements. Work has also started on the development of GOES-8 satellite-based cloud climatologies with data ingested on the RAMSDIS system. An example from the mesoscale cloud climatologies is shown in Fig-

ures 2(a) and 2(b). Figure 2a shows the minimum and maximum brightness count derived from visible imagery at 1915 GMT for the last two weeks in November and the first two weeks in December 1996. Note that during both periods, there are cloudy areas over the mountains in the minimum images, while, in the maximum imagery for November, clouds appear over the entire image while the December 1996 imagery has cloud-free areas. Figure 2b, a 4-panel of average imagery for 1315, 1515, 1715 and 1915 GMT for the last two weeks in November 1996, shows a portion of the diurnal cycle with the development of clouds in mountainous areas, particularly over Costa Rica. Climatologies of this type have great potential for use in training and helping understand topographic influences on cloud development. They also have a broad variety of potential applications that range from agricultural activity to solar power.

Exciting research is also under way in Barbados. The genesis of hurricanes Cesar and Dolly, which both impacted Barbados, are being studied. Similar to Costa Rica, Barbados is studying heavy rainfall events; in particular, an October 1996 late season tropical wave which,

in combination with an upper trough, produced heavy rainfall and severe flooding in St Lucia; 200 mm of rain fell on the island during one six-hour period. Series of three-hour averages of 10.7 μm images, such as those from from that study, may be of use in defining locations of maximum rainfall.

Other activities fostered by the virtual laboratory venture

It is satisfying to see that the goals set up at the beginning of this effort are being met. Other benefits of the virtual laboratory effort, however, make this doubly exciting. In Barbados, Selvin Burton is using some of the data for demonstration in a satellite meteorology course offered at the University (e.g. satellite winds, relative motion, 3.9 μm data interpretation and its use). Students have shown a keen interest in the capabilities afforded by digital satellite imagery and are excited about the prospects of using RAMSDIS and information available through the virtual laboratory to help improve their knowledge and use of satellite imagery. Selvin has been joined by his twin brother, Horace, in investigations at the RMTc using the digital

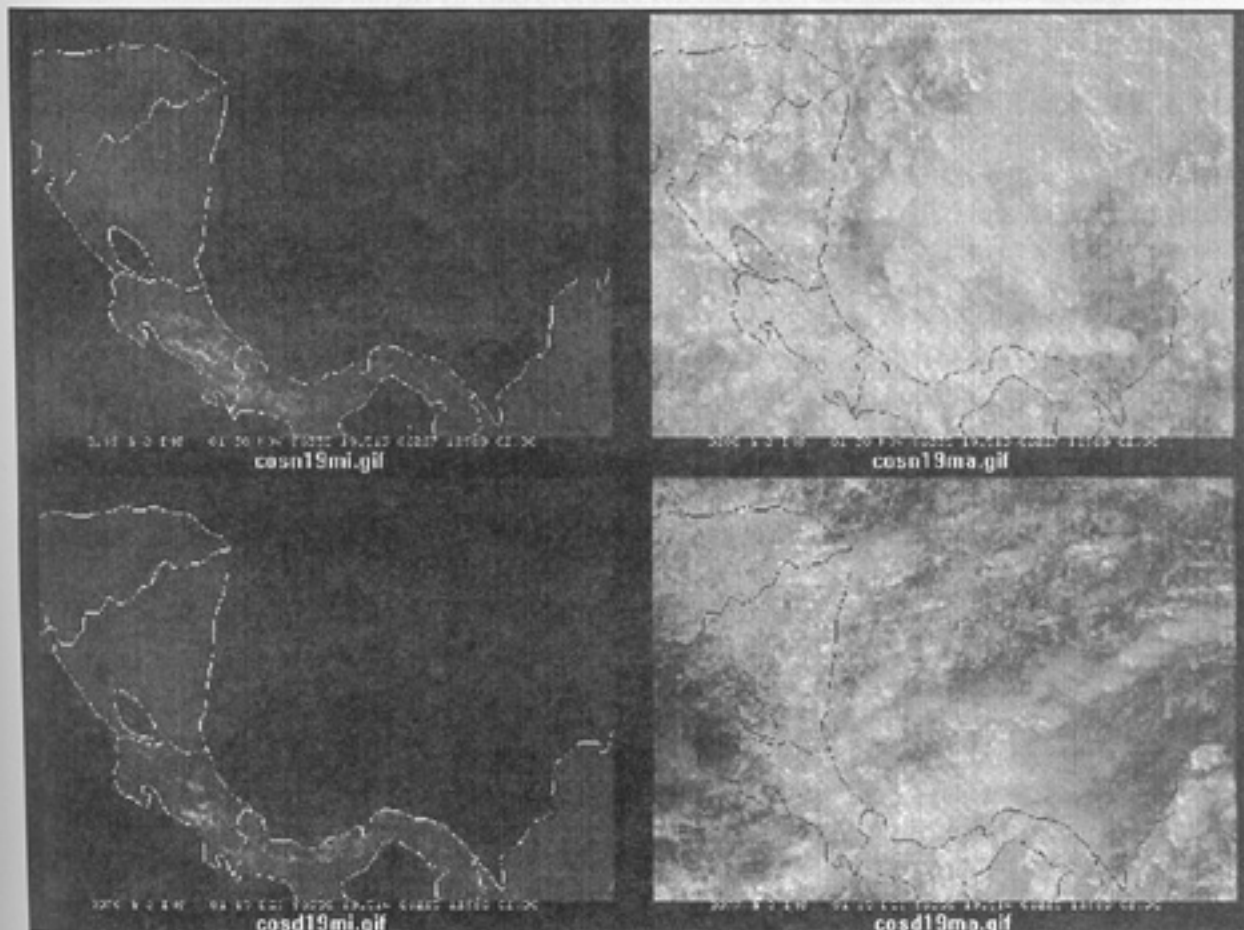


Figure 2(a) — Minimum (*left*) and maximum (*right*) brightness at 1915 GMT for two-week periods in November (*top*) and December (*bottom*) 1996

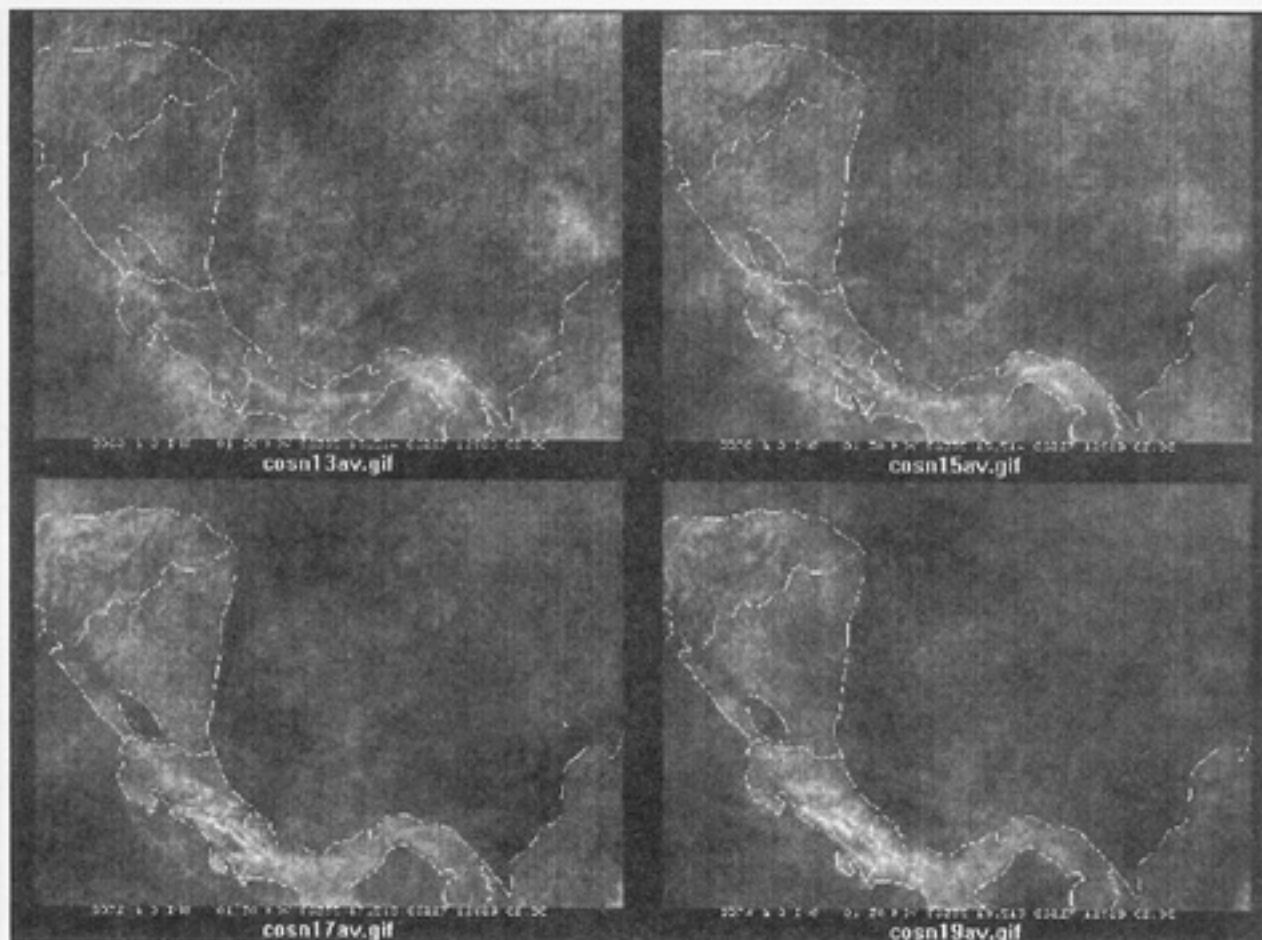


Figure 2b — Average images at 1315, 1515, 1715 and 1915 GMT for last two weeks in November 1996

GOES case-study data. Other members of staff at the CMI, though not involved in the research, have shown an interest in the RAMSDIS system. The results of the research being undertaken jointly by the CMI and CIRA staff, particularly the heavy rainfall event in St Lucia, are expected to be published. In Costa Rica, the ingest RAMSDIS is being used daily for weather briefings attended and presented by both students and staff. Dr Vilma Castro León is using RAMSDIS and information available through the virtual laboratory to provide students with examples that relate to information presented to them in classes on dynamic and synoptic meteorology, cloud physics, and meteorological observations. Dr Walter Fernández (University of Costa Rica) and Rosario Alfaro (National Meteorological Institute) are looking into satellite-derived rainfall estimates during hurricane Cesar and use of this derived rainfall algorithm for operational purposes. Staff members are excited about developing cloud climatologies and their potential in identifying repetitive meteorological patterns. These last two research efforts will result in collaborative publications between CIRA and the University.

Conclusions and future activity

The RAMSDIS program may be looked upon as one of the first ventures into the world of virtual laboratories. The experience has been valuable in bringing to fruition a demonstration project that is showing how an RMTc can develop into a specialized satellite applications training centre by participating in a virtual laboratory environment. Familiarization and specific applied research tasks are being performed at each RMTc using digital satellite imagery. Based on the activities at each RMTc, training cases are being developed as a joint effort with CIRA for use at the RMTc. Results have far exceeded expectations.

Near-real-time GOES-8 digital imagery will continue to be provided to the RMTcs via Internet using the NESDIS GOES-8 server. A satellite dish for Internet connections is being installed at the University of Costa Rica. This will provide a smoother daytime data flow. Efforts are forging ahead at the CMI for the provision of an Internet connection which is capable of meeting the demands of the RAMSDIS data flow. CIRA scientists will continue to collaborate with the staff at each RMTc in the development of case-

studies that highlight the use of GOES-8 imagery in that RMTC's area of interest. CIMSS scientists will begin to interact with the RMTCs on the use of GOES sounder data and products. Interaction will continue on the application of satellite rainfall algorithms. Archival and analysis of climatology imagery will continue in Costa Rica and will expand to cover Barbados. Besides the focus on the "larger" research projects, effort will be directed towards producing "mini" examples of the use of satellite imagery, such as locating fires and land and sea breezes, cloud streets developing downwind of islands and windy-versus-calm conditions highlighted by sun glint. These and other projects will provide the RMTCs with useful training materials applicable to local conditions.

Acknowledgments

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with the RMTCs in the areas mentioned in the body of this article. In Costa Rica, Dr Vilma Castro León, Coordinator of the Department of Atmospheric Physics, and Dr Javier Soley Alfaro, Director, Centre for Geophysical Research, have been instrumental in assuring the success of the virtual laboratory. Their efforts were made possible by the strong support of Mr Hugo Hidalgo Ramirez, Director, National Meteorological Institute, the past and present rectors of the University of Costa Rica, Dr Luis Garita Bonilla and Dr Gabriel Macaya Trejos, respectively, as well as Dr Yamileth González García, Director, Vice-presidency for Research, and Dr Guy de Teramond Peralta, Director, CRNet, who is the administrator of Internet for Costa Rica. In Barbados, Mr Selvin Burton, meteorologist at CMI, has been instrumental in assuring the success of the virtual laboratory. His twin brother, Horace, Chief Meteorologist at CMI, is now playing a key role in research and case-study development. The effort in Barbados was made possible through the strong support of Dr Colin Depradine, Principal, CMI, and the excellent support of CMI staff. □

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