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High-Definition Television (HDTV) Images for Earth Observations & Earth Science Applications

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ACRONYMS

CCD	charge-coupled device
DTO	Detailed Test Objective
ESC	electronic still camera
HDTV	high-definition television
m	meters
NASDA	National Space Development Agency of Japan
NTSC	National Television Systems Committee
ppi	pixels per inch
sec	seconds
SPOT	Satellite pour l'Observation de la Terre
STS	Space Transport System

ABSTRACT

As part of Detailed Test Objective 700-17A, astronauts acquired Earth observation images from orbit using a high-definition television (HDTV) camcorder. Here we provide a summary of qualitative findings following completion of tests during missions STS (Space Transport System)-93 and STS-99. We compared HDTV imagery stills to images taken using payload bay video cameras, Hasselblad film camera, and electronic still camera. We also evaluated the potential for motion video observations of changes in sunglint and the use of multi-aspect viewing to image aerosols. Spatial resolution and color quality are far superior in HDTV images compared to National Television Systems Committee (NTSC) video images. Thus, HDTV provides the first viable option for video-based remote sensing observations of Earth from orbit. Although under ideal conditions, HDTV images have less spatial resolution than medium-format film cameras, such as the Hasselblad, under some conditions on orbit, the HDTV image acquired compared favorably with the Hasselblad. Of particular note was the quality of color reproduction in the HDTV images. HDTV and electronic still camera (ESC) were not compared with matched fields of view, and so spatial resolution could not be compared for the two image types. However, the color reproduction of the HDTV stills was truer than colors in the ESC images. As HDTV becomes the operational video standard for Space Shuttle and Space Station, HDTV has great potential as a source of Earth-observation data. Planning for the conversion from NTSC to HDTV video standards should include planning for Earth data archiving and distribution.

BACKGROUND

The U.S. television standard is in the process of converting from the current National Television Systems Committee format (NTSC, Society of Motion Picture and Television Engineers, 1999) to a newly adopted digital standard (e.g., Advanced Television Systems Committee, 1995; Basile et al., 1995). This conversion will require that NASA make additions and upgrades to its current video equipment (e.g., Gerstenmaier, 1999). In 1998, a Detailed Test Objective (DTO 700-17A, Holland, 1998) was approved to demonstrate the use of a high-definition television (HDTV) camcorder on the Space Shuttle, and a Sony HDW-700 camera (Thorpe et al., 1998, Thorpe, 1999) and lenses were certified for use on board the Space Shuttle. The DTO was scheduled for its first trial during the STS-93 mission, and then scheduled again on STS-99. For STS-93, the DTO was facilitated by a Space Act Agreement between NASA and Sony Electronics, Inc. For STS-99, the DTO was facilitated by an agreement between NASA and NASDA (National Space Development Agency of Japan).

The primary objectives of the DTO included checking for engineering anomalies, obtaining feedback from potential users about the system and its implementation, and comparing the HDTV output to existing NTSC capabilities. Secondary objectives of the DTO included evaluating the potential of HDTV images for use in Earth observation and remote sensing. This report provides preliminary results for the Earth observation portion of these objectives and includes recommendations by the Office of Earth Sciences based on our observations of the imagery acquired.

EARTH SCIENCE OBJECTIVES

DTO 700-17A included a number of objectives proposed by investigators from the Office of Earth Sciences. We began with the knowledge that although video is readily applied to aircraft remote sensing (e.g. Everitt et al., 1990), at human spaceflight altitudes (222–611 km) current NTSC video standards do not provide sufficient detailed information for the majority of Earth observation and Earth science objectives. The Hasselblad camera has been the "workhorse" for orbital photography from the Shuttle (Amsbury and Bremer, 1989), and has proven capabilities for Earth observations and scientific remote sensing applications (e.g., Webb et al., 2000, and citations). The electronic still camera (ESC; a Kodak professional DCS 460C digital camera incorporating a Nikon N-90S body), while providing less detail than Hasselblad photography, has also been proven as a valuable data source for Earth science applications. The enhanced resolution and imaging capabilities of HDTV compared to previous video standards led us to hypothesize HDTV images of Earth from low orbit would provide enough detail for use in remote sensing applications.

Our objectives for the missions fell into three categories: (1) assess the ability of the human-HDTV system to perform types of observations that might be required for remote sensing of the Earth's surface, (2) compare the quality of the images using side-by-side comparisons of HDTV with still camera images of Earth, and (3) attempt to perform types of observations beyond those generally supported by still photography. It was anticipated that orbital characteristics, crew priorities, and sensor system constraints would be limiting factors.

Operational Use of HDTV for Earth Observations

We evaluated operational use of the HDTV camera in two modes: high crew effort to acquire handheld video of narrowly targeted areas and low crew effort to simply mount the camera, turn it on over specific areas, and allow it to capture images unattended. As for all Shuttle missions, a daily message was sent to the crew with information on Earth science photographic opportunities based on the day's orbit tracks. For STS-93 the message was modified to provide suggested opportunities for acquiring imagery pairs using HDTV and Hasselblad cameras. NASDA was a partner with NASA for the repeat of DTO 700-17A on STS-99. On this second flight, we tested the low crew effort model for routine operational use of the HDTV camera on-orbit. The daily message identified one or two orbit tracks that covered regions of scientific interest. The crew mounted the camera in a bracket in the Orbiter window facing Earth, and turned the camera on and off at designated times. On both missions the crew was free to make additional use of the cameras in handheld or bracketed modes, as time permitted.

Comparison of HDTV With NTSC Video, Hasselblad, and ESC

To determine the potential value of HDTV for Earth sciences we needed to compare HDTV to the current methods of image acquisition (Table 1). Our objectives were to capture side-by-side comparisons of HDTV footage with Hasselblad still camera shots, and side-by-side comparisons of HDTV footage with ESC images. In all these comparisons, the goal was to match the fields of view of the two systems by zooming the 15× lens[1] to match the field of view of the Hasselblad camera using the 250-mm lens (the longest focal length lens currently used on orbit). Because the ESC equipment was shared with a secondary payload (EarthKam), we sought HDTV-ESC comparisons on an opportunistic basis, recognizing that fields of view would not be matched. Similarly, we planned to use video of the Earth collected by the payload bay cameras on an opportunistic basis to provide imagery comparative between high-definition and NTSC video.

Table 1. Maximum Possible Digital Resolution (pixel size in m) for Camera Systems Compared in This Study, Based on the Geometry of Altitude, Lens, and Original Image Size

	Image size		*Minimum ground distance represented by 1 pixel, m, as a function of altitude[2]*			
Camera, lens	*mm*	*pixels[3]*	*Minimum altitude (222 km)*	*STS-99 altitude (233 km)*	*STS-93 altitude (284 km)*	*Maximum altitude (611 km)*
Sony HDW-700, 15×	14.8 × 8.31	1920 × 1035				
Min zoom (8 mm)			218	229	279	601
Match Hasselblad FOV			48.8	51.3	62.5	134
Max zoom (120 mm)			14.5	15.3	18.6	40.1
Kodak ESC, 180 mm	27.6 × 18.5	3069 × 2043	11.1	11.7	14.2	30.6
Hasselblad, 250 mm	55 × 55	5198 × 5198	9.40	9.86	12.0	25.9

Note: Calculations assume that Hasselblad film is digitized at 2400 ppi (pixels per inch, 10.6 µm/pixel)

Earth Imaging Applications

Mapping and Remote Sensing

Digitized Hasselblad photographs can be treated as three-band (red, green, blue) remote sensing images and used for land cover mapping and other remote sensing applications (e.g., Webb et al., and citations). We hoped to identify suitable images from HDTV that could be used in a similar remote sensing analysis to establish the potential application of HDTV imagery for land cover mapping.

Sunglint Observations

Observations of sunglint are significant because they provide unique descriptions of surface structure and circulation patterns within the ocean. Sunglint on water surfaces is difficult to image because observations are generally represented by a single exposure setting. As a result the brightest area is often saturated, with no detail depicted within, and the darkest layers are

[1] The 15 × 8 lens for the Sony HDW-700 camcorder has a focal length range of 8–120 mm, zoom ratio of 15:1, horizontal field of view of 61.8–4.6 deg, and vertical field of view of 37.2–2.6 deg.
[2] Altitudes shown are minimum, median and maximum through STS-89 (January 1998, N = 84 missions).
[3] Actual pixels for ESC, otherwise assumed digitization at 2400 ppi (pixels per inch), equal to 10.6µm / pixel.

underexposed so that no patterns are discernable, limiting the area of coverage. The sunglint observation test was to determine if HDTV could acquire multiple levels of exposure over the variably illuminated scenes where sun reflects off water surfaces. The goal was to combine several frames into a mosaic to provide detailed description of the water surface for a much larger area.

We had two objectives for imaging sunglint: (1) to acquire sunglint near the coast with automatic gain control off, 75% zoom, and aperture small, and while observing the sunglint open the aperture from small to wide over a period of 3–5 sec; and (2) to acquire sunglint over open ocean under similar conditions.

Multiple Aspect Viewing for Aerosol Detection

Atmospheric aerosols can be mapped by imaging a region through different viewing (aspect) angles. Images record variable reflectance due to the scattering phase angle. Imaging aerosols using Hasselblad photography with multiple aspect views was tested in May 1989 (STS-30, Helfert et al., 1990). Digitization, registration, and differencing these views resulted in an apparent mapping of the spatial distribution of atmospheric aerosols as a result of the scattering phase angle of the aerosols. HDTV has the potential of providing a more precise description of aerosol distribution due to the rapid frame rate (30 frames/sec instead of several seconds between each still frame) and more accurate digitization.

Our aerosol imaging objective was for a crewmember to image a point of reference on the Earth in front of the spacecraft track and attempt to hold the scene in view for 60 sec, recording continuously. Other criteria included (1) a solar elevation angle at time of observation greater than 30 deg, with local afternoon preferred over local mornings, (2) sufficient land area in the scene to allow registration of images (coastal cities were planned as the ideal targets), and (3) less than 25% cloud cover over the scene.

DATA COLLECTED

The STS-93 crew captured a total of approximately 75 min of Earth-looking footage, all using the 15× lens. According to the crew, most Earth-looking tape time was at ~73–75% zoom. The STS-99 crew captured a total of approximately 210 min of Earth-looking footage, all using the 15× lens. For STS-99, most of the Earth-looking tape time was at minimum zoom, however several targets were chosen for recording the range of detail from minimum to maximum zoom.

Using images from STS-93, we were able to match 20 frames of Hasselblad photographs to still images from the HDTV tapes for future comparative analysis (fields of view were approximately matched). We also matched approximately 60 sec of HDTV with NTSC video from the payload bay cameras, and produced four HDTV-NTSC still image comparisons. The ESC was operated by EarthKam on STS-99, and we identified four opportunistic comparisons where the HDTV and ESC cameras had imaged the same areas (fields of view were not matched).

High-oblique sunglint observations were acquired over open ocean at low sun elevation angle on both STS-93 and STS-99. The period of aperture opening and closing was of the order of tens of seconds. Additional orbital passes with sunglint in evidence were also obtained during both missions, allowing illustration of the movement of the areas of sunglint in accord with spacecraft motion.

For testing aerosol detection, Santo Domingo, Dominican Republic, was acquired and viewed for approximately 40 sec during STS-93. Another coastal site was viewed for approximately the same time period. Sun angle was less than 30 deg in both cases but cloud cover was within the desirable range. The crew was able to maintain the 40-sec viewing duration only with considerable difficulty due to the camera size.

Data from this study are archived and available to the public. Copies of video can be obtained from the Johnson Space Center (JSC) Video Repository (details of title and tape numbering are shown in Table 2). Still images extracted from HDTV video have been assigned NASA archive numbers and have been cataloged with the same data fields used for film photography.

Table 2. HDTV Tapes From DTO 700-17A as Archived in the Video Repository, and NASA Numbers of Extracted Still Images as Archived and Cataloged by the Office of Earth Sciences

Title	*Original Tape Number*	*Still Image Numbers*
STS-93 HDCAM ONBOARD ID# 001	800745	
STS-93 HDCAM ONBOARD ID# 002	800746	S93e5133 to S93e5141
STS-93 HDCAM ONBOARD ID# 003	800747	S93e5142 to S93e5144
STS-93 HDCAM ONBOARD ID# 004	800748	
STS-93 HDCAM ONBOARD ID# 006	800749	
STS-93 HDCAM ONBOARD ID# 007	800750	S93e5145 to S93e5188
STS-93 HDCAM ONBOARD ID# 008	800751	S93e5189 to S93e5212
STS-99 HDCAM ONBOARD ID# 001	800761	S99e8004 to S99e8018
STS-99 HDCAM ONBOARD ID# 002	800762	S99e8019 to S99e8022
STS-99 HDCAM ONBOARD ID# 003	800763	
STS-99 HDCAM ONBOARD ID# 004	800764	S99e8023 to S99e8029
STS-99 HDCAM ONBOARD ID# 005	800765	S99e8030 and S99e8031
STS-99 HDCAM ONBOARD ID# 006	800766	S99e8032 and S99e8033
STS-99 HDCAM ONBOARD ID# 007	800767	S99e8034
STS-99 HDCAM ONBOARD ID# 008	800768	S99e8035 to S99e8050

Data on these images can be searched on line at the gateway for all astronaut photography of Earth provided by the Office of Earth Sciences, (http://eol.jsc.nasa.gov/sseop/). The raw images (which have not been de-interlaced) can also be downloaded from that location. For STS-93, 80 still images are available, and are numbered 93e5133 through 93e5212l; for STS-99, 47 still images are available, and are numbered 99e8004 through 99e8050 (Table 2).

RESULTS

The HDTV camera was used successfully in both operational modes. Crewmembers targeted specific sites of interest in handheld mode (Figure 1), and recorded the ground track along orbital passes in bracketed mode. When handheld, the video was bumpier in appearance, but still images could be successfully extracted from handheld and bracket-mounted video.

Figure 1. Crew use of the Sony HDW-700 camera while in orbit (STS093-320-37).

HDTV vs. ESC, Field of View Not Matched

The ESC and HDTV cameras use different methods for recording color on the CCD (charge-coupled device) sensor. The ESC employs a 3060 × 2036 pixel CCD (M-6 sensor; Eastman Kodak Company, 1993). The individual pixels employ color filters with rows of alternating red- and green-sensitive pixels interspersed with rows of alternating blue- and green-sensitive pixels. Values are interpolated within the 3060 × 2036 array to assign values of red, green, and blue to each pixel. The HDTV camera employs three separate optically registered CCDs to record three color planes in a component format. This method provides better color reproduction and registration as compared to single-CCD imaging systems. Compared to the ESC, we expected the HDTV camera to have truer color reproduction and fidelity. Because of the color interpolation of the ESC, we could not predict which camera system would provide better spatial resolution if fields of view were matched. Unfortunately, we did not obtain HDTV and ESC imagery with matched fields of view; thus we cannot compare spatial resolution from the two cameras. In addition, the expected improvement in color registration cannot be tested because of the malfunction of the ESC. A sample ESC frame, processed using the standard EarthKam methods, has excessive magenta tones in the image (Figure 3) due to the malfunction. In Figure 3, some of the spatial information in the ESC image has been discarded to facilitate a comparison of color representation. Contrast enhancement has been performed on both detailed images.

HDTV vs. Hasselblad, Field of View Matched

Figure 4 illustrates the comparison of an HDTV image with a digitized Hasselblad photograph. The images are shown both in their original size, and enlarged to a common scale for comparison. The original HDTV image is much smaller than the film original, but zooming the HDTV lens to match the fields of view partly compensates for the effect of original image size on resolution. The HDTV image is also shown enlarged to match the scale of the Hasselblad original.

Hasselblad photographs were digitized at 2400 ppi from second-generation film, producing images that were approximately 5100 × 5100 pixels. Digitizing at this resolution produces a loss of some spatial information compared to the resolving power of the film. If fields of view were matched, we would expect greater spatial resolution in the Hasselblad image compared to the 1920- × 1035-pixel HDTV image (Table 1). In the comparison in Figure 4, the HDTV image did have slightly less ground resolution than its Hasselblad counterpart. This is evidenced by the reduced detail in land use patterns in the lower right of the image.

The HDTV image also shows some advantages over the Hasselblad image. (1) Colors appear to be truer in the HDTV image. (Note the bluish cast to the original Hasselblad image in Figure 4, and the fact that even after color correction, the clouds appear blue-green in the detailed Hasselblad image.) Vibrant colors compared to typical film products were notable in all the HDTV video. This is especially noticeable when viewing the HDTV on a monitor, since the monitor has a wider color gamut (range of display for color) than does either color transparency film or color prints. Our early assessment is that the white and black balancing of the HDTV camera under orbital lighting conditions allowed better capture of true colors than other camera systems and films. Several crewmembers expressed belief that the HDTV images better represented their memory of the Earth's coloration as seen from orbit. Color correction of films designed for lighting conditions on the Earth's surface has been a continuing challenge for Earth Observations, and may be obviated in this camera system.

(2) Vignetting is reduced in the HDTV image compared to the Hasselblad. This can be seen in Figure 4 by comparing the 5.4-cm-wide HDTV image with the original-size Hasselblad image. The dark areas around the edges of the Hasselblad image (especially the corners) are a result of vignetting or scattering of light within the lens. Although Hasselblad lenses are chosen to reduce this impact, vignetting cannot be entirely eliminated from orbital photography. We were surprised by the lesser degree of vignetting using the HDTV camera.

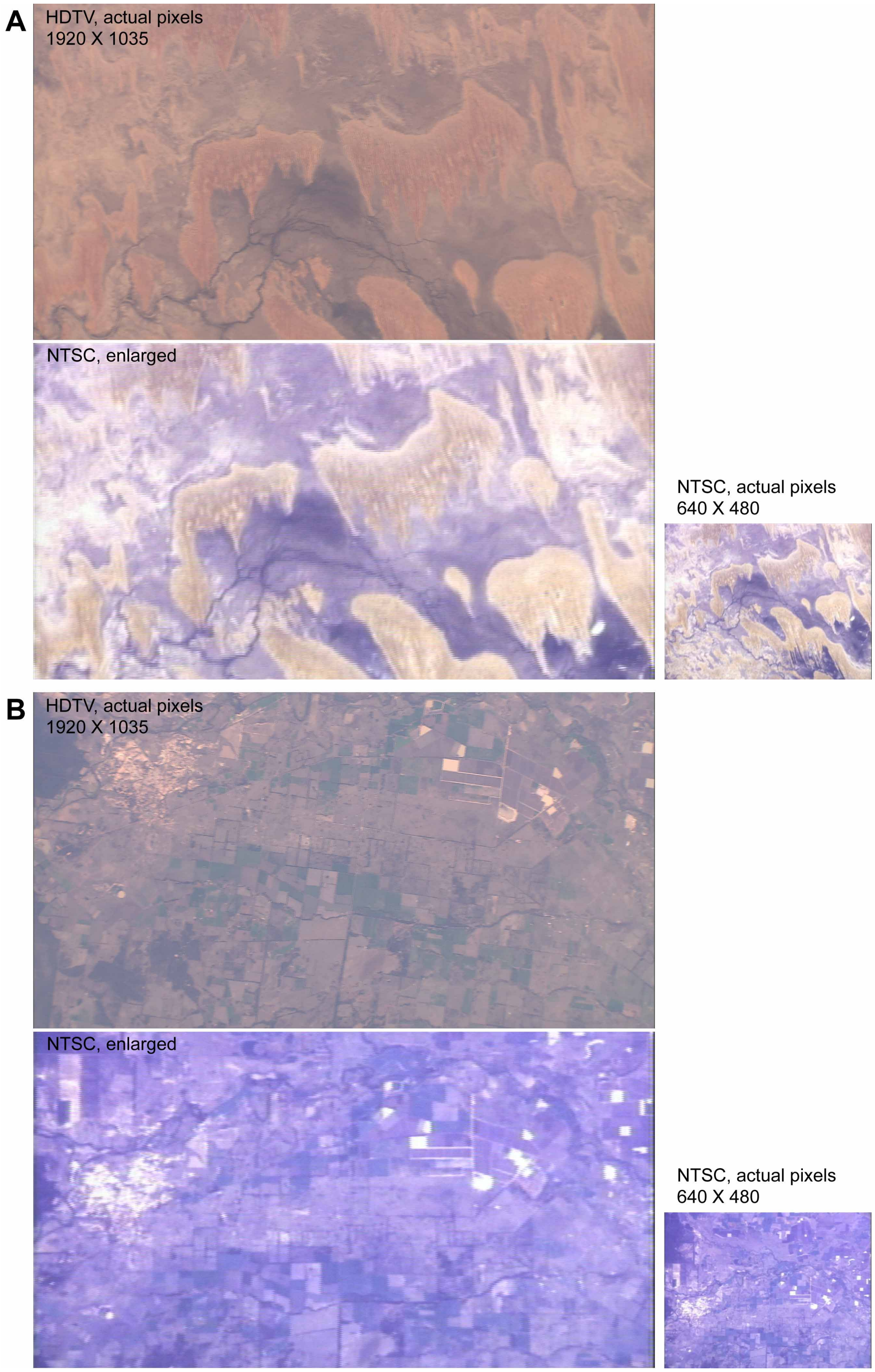


Figure 2. Comparing HDTV and NTSC video cameras. Still images extracted from HDTV (S93e5189 and S93e5193, STS-93 Tape 800751, 18:49:01:23 and 18:51:26:08) and NTSC video (STS-93 Tape 617219, 23:19:16:28 and 23:21:41:11) over southern Australia.

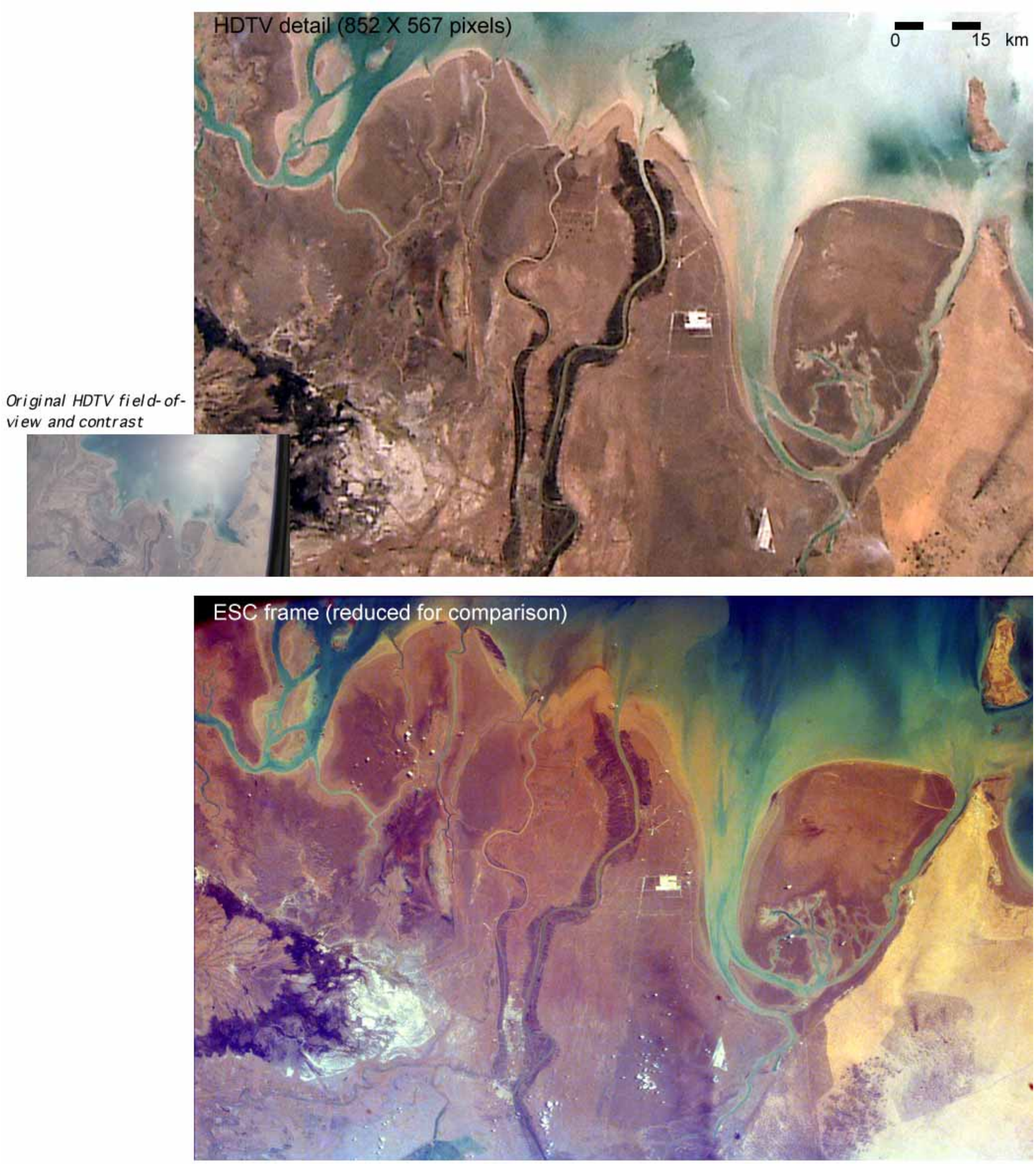
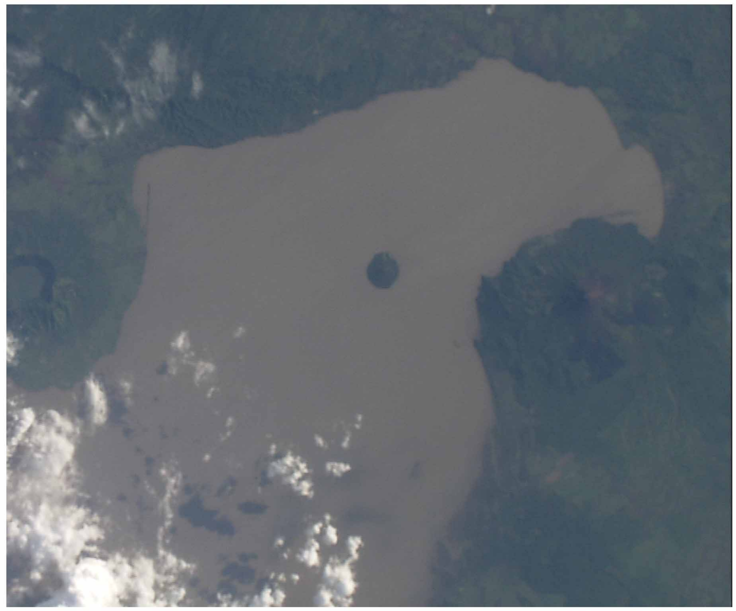


Figure 3. Comparing HDTV and ESC. HDTV still image (S99e8018, STS-99 Tape 800761, 14:15:55:01) and ESC image (EarthKam number 99E02142909, NASA number S99e5504) of the mouths of the Tigris and Euphrates rivers acquired during STS-99. The original HDTV field of view (see inset) was much larger than the ESC, and has been de-interlaced and contrast-enhanced. The ESC image was contrast-enhanced following standard protocols for the EarthKam payload. The ESC experienced a color malfunction during the mission, leading to excess magenta.

A. HDTV still

Original size:
1920 x 1035 pixels
1.48 x 0.831 cm

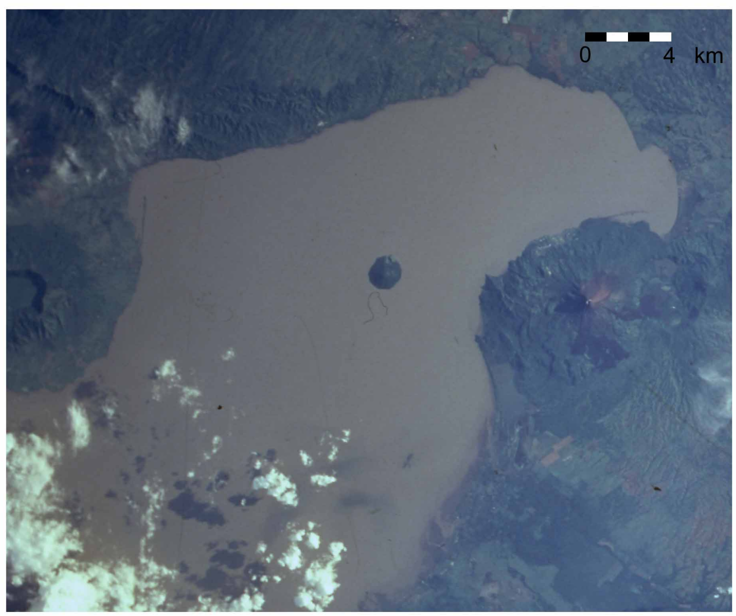
Enlarged to 5.4 x 2.9 cm



Comparative detail: 1220 x 1023 pixels

B. Hasselblad film frame

Original size:
5052 x 5052 pixels
5.4 x 5.4 cm



Comparative detail: 1827 x 1514 pixels

Figure 4. Comparing image detail between HDTV and Hasselblad film cameras with field of view held constant. Images show a portion of Lake Managua, Nicaragua. A. HDTV still image (S93e5169, STS-93 Tape 800750, 17:50:44:00). B. Hasselblad film frame (STS093-714-39) digitized at 2400 ppi, shown original size and color and with color adjusted to match HDTV image.

(3) The HDTV image did not require hand digitization. Currently Hasselblad film must be digitized by hand before it can be used for digital Earth science applications. Although every effort is made to clean the negatives before digitization, small errors such as dust spots, hairs, and scratches are reproduced. These can be seen in the detailed Hasselblad image. These problems are avoided in the all-digital HDTV product.

Maximum Detail From HDTV Camera

The detail available by using the HDTV camera with a 15× lens at maximum zoom can be seen qualitatively in Figure 5. The two still images of the same area were captured 15 sec apart, one with the lens at minimum zoom and one with the lens at maximum zoom. In the lower image, very fine features can be discriminated, including the center and pivot line in the central-pivot irrigation fields, roads, and the town[4]. The resolvable features on the ground are in accord with the optimal ground sampled area for each pixel (15.3 m, Table 1). All of these images were captured using 1/500th-sec electronic shutter speed, and show no evidence of smearing due to ground motion.

Although it was not an objective of the DTO, some of the comparative images captured had a narrower field of view for HDTV than for Hasselblad. In essence, these comparisons serve as a preliminary test of levels of zoom on the adjustable HDTV lens that exceed the detail available in the 250-mm Hasselblad lens.

At least under some conditions for orbital photography, the HDTV camera can capture more detail than is available in the equivalent Hasselblad image captured with a 250-mm lens (Figure 6). Figure 6 compares a complete HDTV frame with the equivalent portion of a digitized Hasselblad frame. Even though the Hasselblad detail contained more pixels than did the HDTV still, there is far more resolving power in the HDTV image.

The poorer performance of the Hasselblad in this case may be due to the Hasselblad focus (focus over ocean regions is difficult) or to the challenges of setting exposure when photographing ocean environments. If the exposure is read in an area where there are many clouds and a subsequent frame has few clouds, then the film is underexposed. If the exposure is determined in an area of open ocean with no clouds, then when reefs and islands are imaged, they are slightly overexposed.

Effect of Interlacing on Data Contained in HDTV Images

The objectives of the DTO required that the HDTV camera be handheld for part of the time that video was taken. In the orbital environment, the magnification of small movements makes it extremely difficult to hold the camera still during the 1/30th of a second it takes for each frame to be captured. This appears as fuzziness (Figure 7, top) because odd-numbered lines (first

[4] The largest central-pivot irrigation circles in the image are 48–51 pixels in diameter, measured horizontally (the direction of the least distortion due to obliquity). Using the scaling relationships between focal length, altitude, and CCD size, this would correspond to 730–780 m in diameter for a perfect nadir view.

field) in the image are captured in the first 1/60th of a second and even-numbered lines (second field) in the second 1/60th of a second. This general phenomenon in videography is known as inter-field jitter.

In selecting frames for still extraction, a frame with little or no jitter can often be selected (Figure 7, bottom). However, that image may not be the ideal one for a particular imaging objective. Therefore we evaluated whether using post-processing algorithms to interpolate and de-interlace produced an image product comparable to the case where no post-processing was required.

There is slightly less information present in the de-interlaced image. In Figure 7, a comparison of the smallest dark islets at the top the atoll in the de-interlaced (middle) image and the image without jitter (bottom), shows that some detail has been lost. However, the de-interlaced image is still superior to the Hasselblad comparative for this scene (Figure 6). It appears that de-interlacing is a suitable option for removing effects of camera jitter, whether caused by the need for a human to hold the camera, or by other aspects of the orbital environment that might cause the camera to move even when mounted on a bracket[5].

Earth Imaging Applications

HDTV Images for Remote Sensing

HDTV has sufficient resolution and dynamic range to capture images that may be used as digital remote sensing data. These data can be used for such applications as identifying land use and land cover, and for mapping shallow marine environments.

HDTV images and digitized Hasselblad film images were included in an ongoing study evaluating the ability of different types of remote sensing data to map and classify coral reefs. An HDTV image of Amanu Atoll, Tuamotu Archipelago, and a SPOT (Satellite pour l'Observation de le Terre) satellite multispectral image were each used to map coral reefs. HDTV classification used three CCD bands (red, green, and blue). Although the superior spatial and spectral resolution of SPOT images would generally be preferred for remote sensing, it is often difficult to obtain complete coverage due to cloud cover. By choosing a site where both images were available, we could determine the level of information that can be obtained from HDTV images when SPOT data are not available. The spatial resolution of this HDTV image was 27.7 m, while the spatial resolution of the SPOT image was 20 m.

Figure 8 shows four examples of different rim types in Amanu Atoll (rim typology from Andréfouët et al., in press). Rim type 3 (Figure 8, A) is dominated by shallow water (blue-green in the SPOT image) with a large intertidal domain (brown in the SPOT image) and small accumulations of coral rubble (white in the SPOT image). Rim type 5 (Figure 8, C) is

[5] NASA plans to employ HDTV camcorders that can be switched between interlaced and progressive (non-interlaced) acquisition mode on future flights.

dominated by small vegetated islets (red in the SPOT image), with a narrow intertidal area located at the interface between the reef flat (blue-green in the SPOT image), and the area of conglomerate/coral rubble (gray-white in the SPOT image). Rim type 8 (Figure 8, C) is dominated by conglomerate/coral rubble (gray-white in the SPOT image) with small vegetated islets (red in the SPOT image) and an intertidal domain (orange-brown in the SPOT image) located at the interface between the reef flat (blue-green) and the lagoon.

Classifications were performed for each rim type using an algorithm based on Mahalanobis distance (see Andréfouët et al., in press), for five classes: shallow water, deep water, conglomerate/rubble, intertidal, and vegetation.

Overall classification accuracies for HDTV were systematically lower than SPOT (as expected given the higher spatial and spectral resolution of the satellite data). However, the HDTV results were very good, with average performances of nearly 80% for all the rim types. HDTV captured the areas of vegetation and conglomerate coral rubble (Table 3). HDTV also identified shallow water and intertidal zones, except when these were very narrow zones (rim type 5). When the reef flat is larger, it is better identified in HDTV images (Figure 8, C). The HDTV image provides information on depth variation (area labeled *A* vs. *B* and *C* in Figure 8, B), but did not clearly distinguish hard and soft bottom.

HDTV images were also used to provide a multitemporal perspective—reef pinnacles within the lagoon can be difficult to distinguish from small clouds when using a single image. However, by referring to an HDTV image taken at a different time, pinnacles could be distinguished from transient clouds.

From these results it is clear that imagery captured with the HDTV camera taken from Space Shuttle or Space Station has great potential as a remote sensing data source. Its primary value will likely be for cases where suitable imagery is not available from other sources, or as multitemporal reference data.

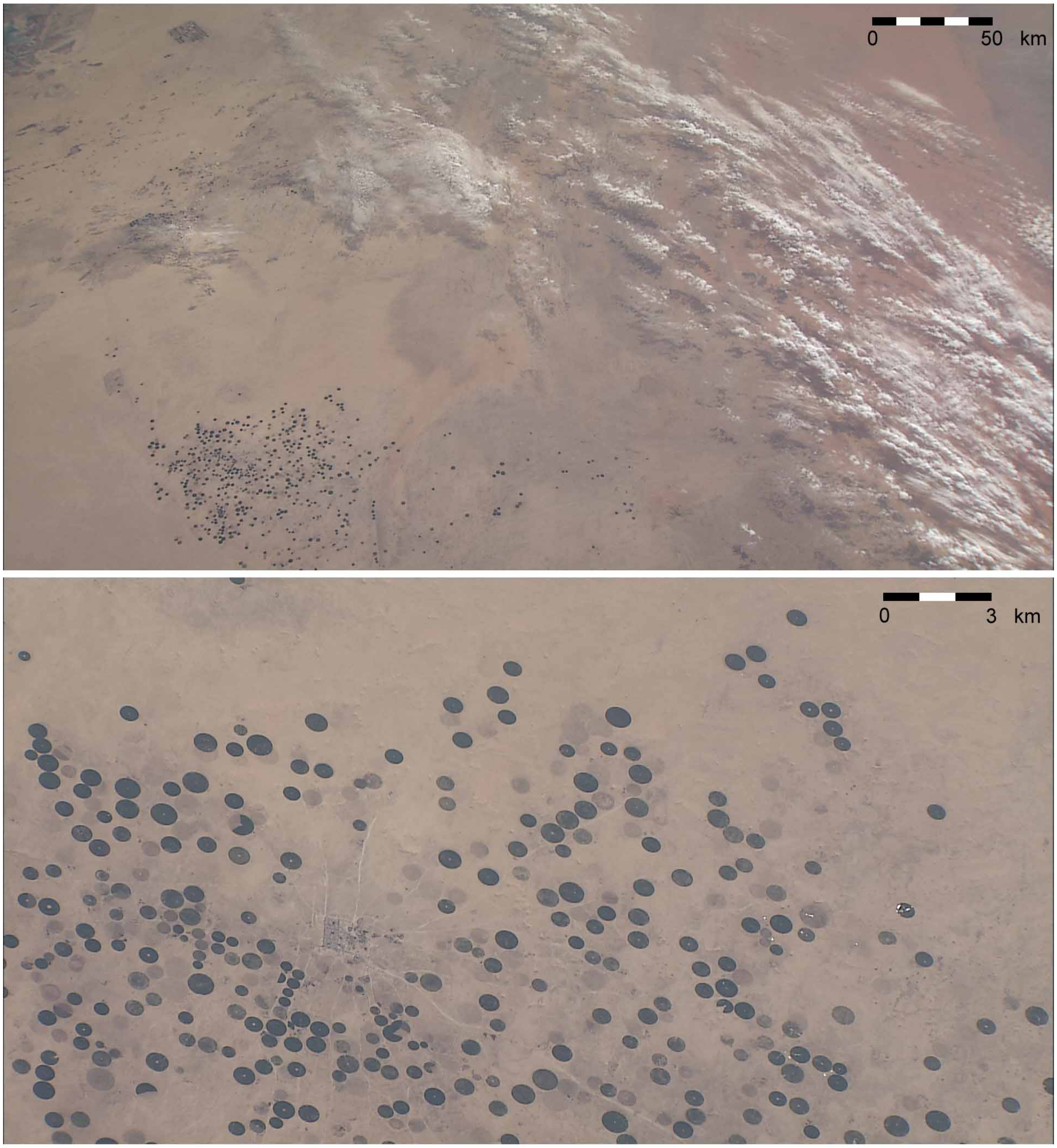


Figure 5. The range of detail obtainable using the HDTV camera with a 15× lens and zooming from minimum to maximum. Area shown is a region of central-pivot irrigation in northern Saudi Arabia. Sunglint can be seen reflecting off of standing water in the right side of the detailed view. De-interlaced HDTV still images (S99e8011 and S99e8012, STS-99 Tape 800761, 14:15:08:23 and 14:15:23:26); scales approximate.

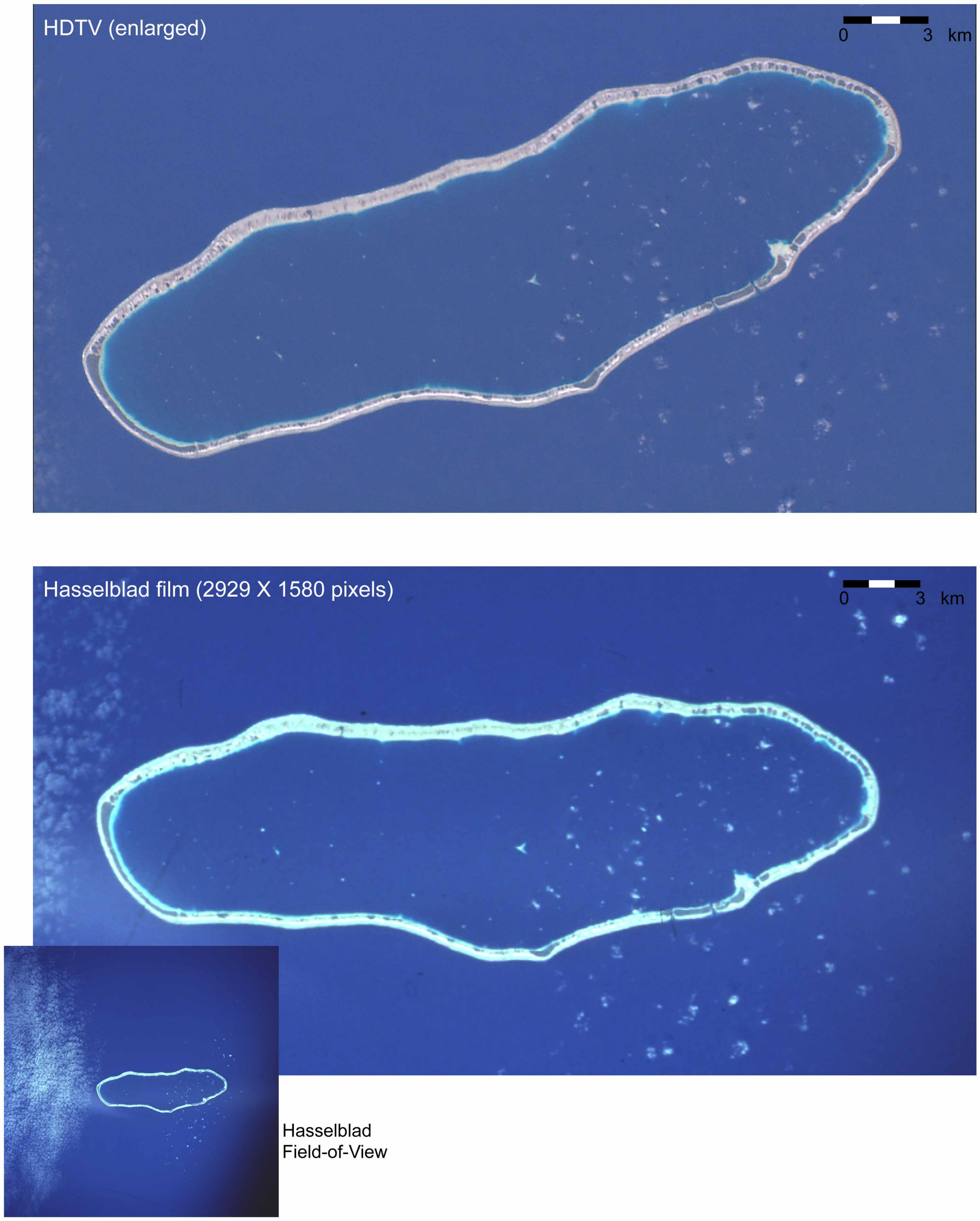


Figure 6. Comparing image detail between HDTV and Hasselblad. In these images of Amanu, Tuamotu Archipelago, the field of view for the HDTV camera was narrower as shown in the inset. HDTV still image (S93e5166, STS-93 Tape 800750, 17:34:13:26) has been de-interlaced with interpolation, and enlarged from 1920 × 1035 pixels to match the scale of the Hasselblad frame. Hasselblad film (STS093-714-32) was digitized at 2400 ppi, and a detail section is shown. Even though there are more pixels in the Hasselblad frame, photographic conditions produced an image with less sharpness and contrast.

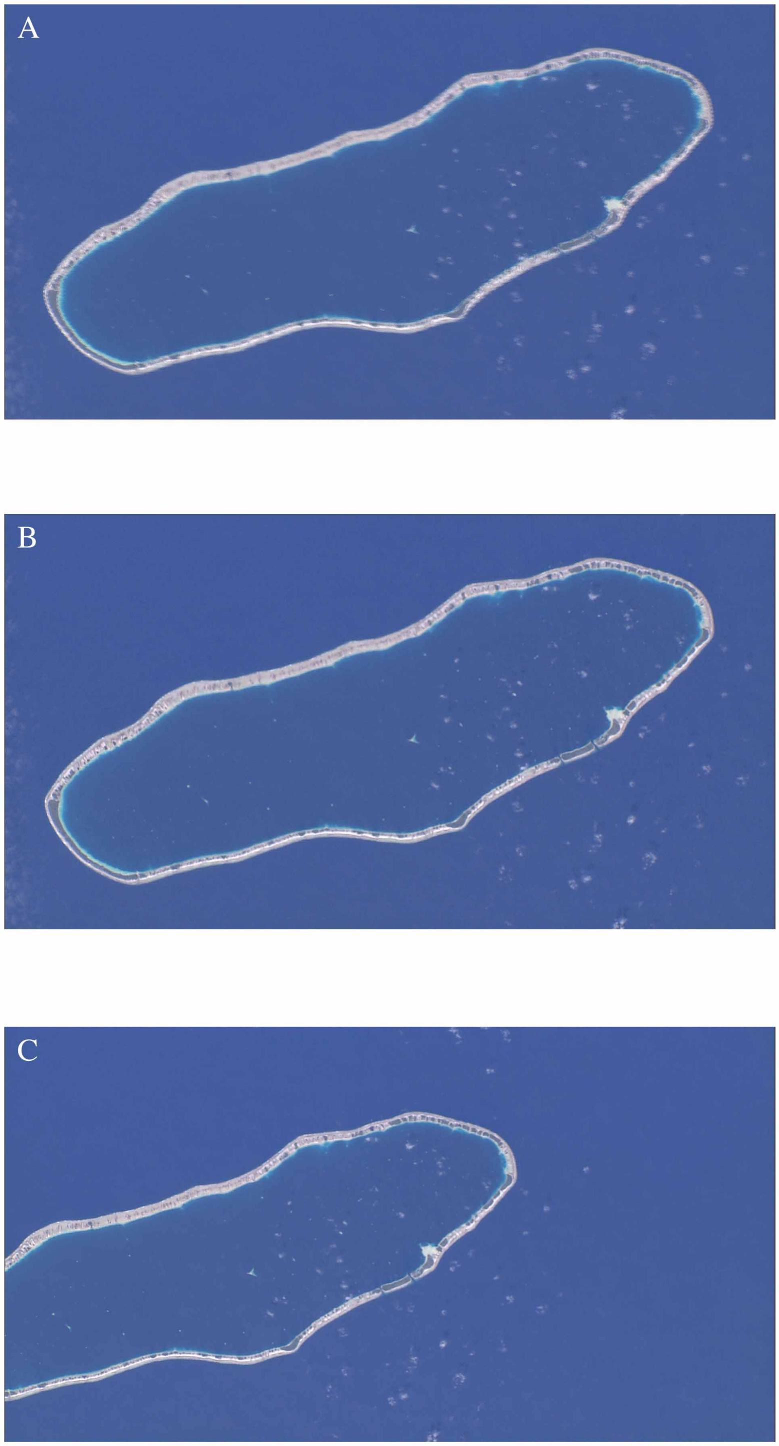


Figure 7. Effect of interlacing on resolution of still images extracted from HDTV. A. Movement of camera during frame capture produces blur in the still image. B. Image processing to de-interlace frame reduces blur but some information is lost. C. Extracted image with minimal movement during frame acquisition is sharp without any post-processing. HDTV still images (A and B, S93e5166, STS-93 Tape 800750, 17:34:13:26; C, S93e5165, STS-93 Tape 800750, 17:34:12:05).

Table 3: Classification Results for Three Rim Types, Amanu Atoll, Tuamotu Archipelago (French Polynesia).

				User Accuracy (%)		*Producer Accuracy (%)*	
Classes	*Sensor*	*SPOT*	*HDTV*	*SPOT*	*HDTV*	*SPOT*	*HDTV*
Rim type 3 (Figure 8, A)							
Overall Accuracy		89.39%	90.12%				
Kappa Coefficient		0.8549	0.8640				
Shallow Water				99.44	89.89	95.72	88.40
Conglomerate/Rubble				81.67	85.11	98.00	75.47
Intertidal				100.00	86.41	95.56	92.71
Vegetation				83.33	100.00	100.00	61.90
Rim type 5 (Figure 8, B)							
Overall Accuracy		72.59%	61.96%				
Kappa Coefficient		0.6662	0.5172				
Shallow Water				79.17	59.52	80.28	44.64
Conglomerate/Rubble				76.60	93.94	97.30	100.00
Intertidal				76.09	36.90	47.30	51.67
Vegetation				80.52	78.83	100.00	74.48
Rim type 8 (Figure 8, C)							
Overall Accuracy		82.00%	73.47%				
Kappa Coefficient		0.7680	0.6615				
Shallow Water				95.31	84.42	64.21	79.27
Conglomerate/Rubble				93.59	89.06	98.65	96.61
Intertidal				31.03	75.00	54.55	50.00
Vegetation				81.82	74.34	92.31	62.69

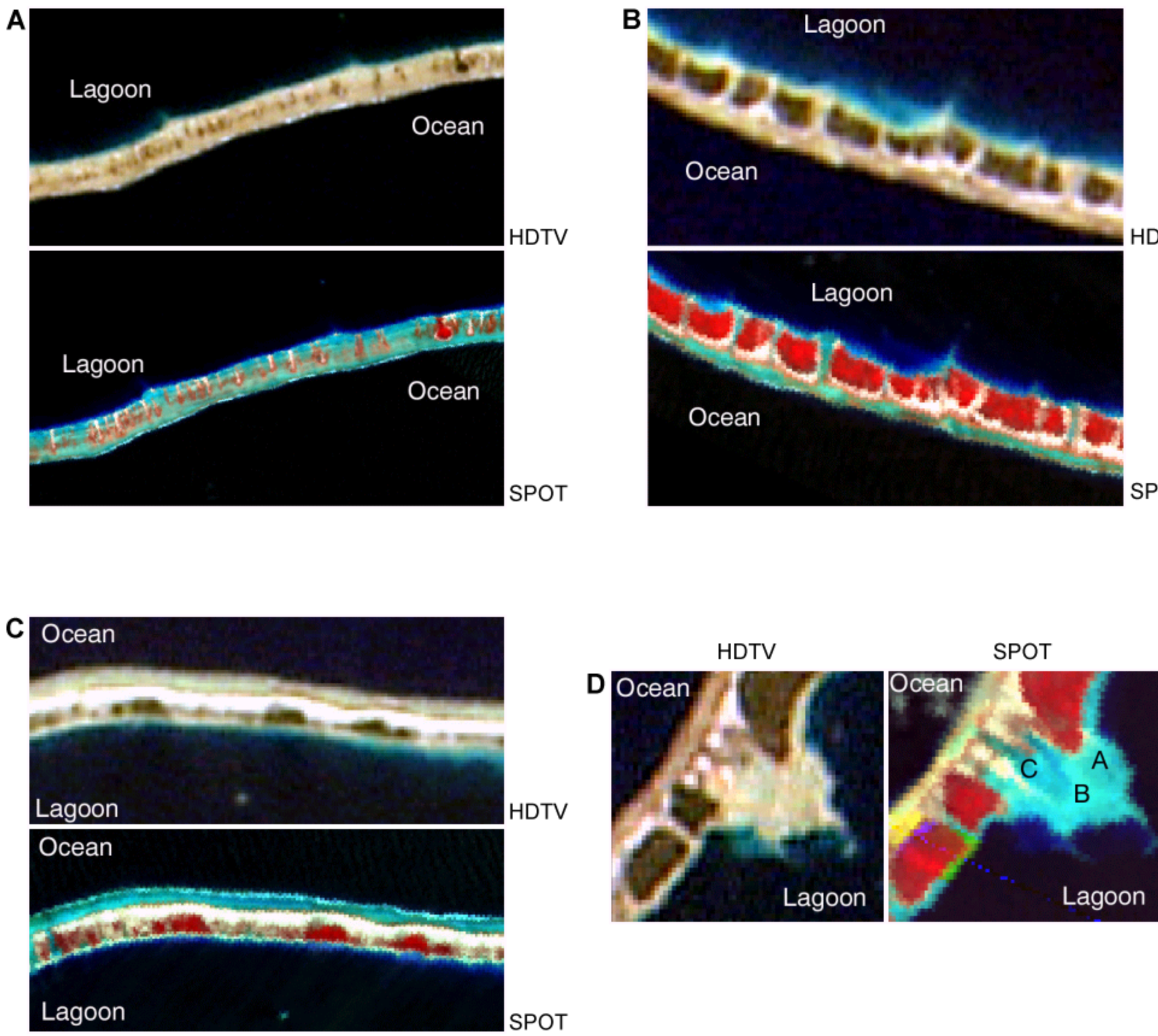


Figure 8. A comparison of SPOT and HDTV images of coral reef features, Amanu, Tuamotu Archipelago. HDTV still image used was the same de-interlaced image shown in Figures 6 and 7 (S93e5166, STS-93 Tape 800750, 17:34:13:26). Colored composition of SPOT data is band XS1=blue, band XS2=green and band XS3=red. A. Atoll rim of type Rim 3 (Andréfouët et al., in press). B. Atoll rim of type Rim 5. C. Atoll rim of type Rim 8. D. Area with large inner reef flat. Areas of the reef flat that can be distinguished on the SPOT image are labeled on the image and include *A* deeper channels, *B* shallow water with soft bottom, and *C* shallow water with more living structure and hard bottom.

HDTV Images for Sunglint Observations

The format of the output lends itself well to standard image-processing techniques. Histograms derived from sample frames showed that as the aperture was opened, red saturated faster than green, which saturated faster than blue. Saturation of a part of the image did not noticeably affect the remainder of the scan. To fully meet the objectives, additional observations will be required.

Multiple Aspect Viewing With HDTV Images for Aerosol Detection

HDTV has sufficient resolution and dynamic range to perform multi-aspect viewing in which rectification and registration are required. A more compact camera body or a detached head (such as the Sony DXC-H10) would provide more flexibility in viewing geometry. To fully meet the aerosol detection objectives, additional observations are desirable.

CONCLUSIONS AND RECOMMENDATIONS

Under some circumstances, the HDTV camera can provide digital image data on the Earth that meets or exceeds the standards from other cameras (ESC, 35-mm film, and Hasselblad film). Comparison of still images extracted from HDTV showed that they compared favorably with Hasselblad photographs, although under optimal conditions the Hasselblad will provide higher spatial resolution. On HDTV imagery, contrast in all colors was exceptional. While it is unlikely HDTV can compete in spatial resolution with film in ideal environments, given the constraints on observations from orbit, HDTV comes close to film observations. HDTV has some potential advantages over film formats in the amount of information acquired (30 frames/sec instead of 1 image every few seconds), making frame selection by investigators possible (rather than frame selection by the astronauts on orbit), and because images are captured in digital form. Technical problems such as vignetting, ground smear, and soft focus were no more pronounced in the HDTV footage than in images captured by film cameras, and vignetting appeared to be reduced. White-balance and color renditions of HDTV were more true than colors in Hasselblad film. A study of signal-to-noise ratio of the HDTV camera system compared to the Hasselblad film system would be valuable for adding quantitative information to the qualitative analysis presented here.

The comparison of HDTV with ESC was limited because images acquired did not have matched fields of view, and because of a malfunction in the ESC. Further investigation would be necessary to fully compare these two digital forms of image acquisition.

With data collected as part of this DTO, we were able to conduct remote sensing identification of rim features in the Tuamotu Archipelago (French Polynesia). This illustrates and confirms the data collection potential of this camera when used from orbit.

Difficulties from HDTV camera motion when handheld probably can be reduced in applications where the camera is bracket-mounted. When necessary, post-processing to de-interlace the image had excellent results for improving image quality with relatively small loss of information content.

The bulk (size and mass) of the camera appeared to limit its utility. A more compact model could be employed. Such a camera would be easier to use when handheld and would also fit more easily in a window bracket.

Problems in cataloging and remote screening of Earth-observing HDTV video are also important issues that would need to be resolved before HDTV can be considered a routine tool for orbital remote sensing. During this mission the time code build in to the camera was used to record time. However, this time drifted relative to official time, and could only be used to get an approximate position of the orbiter when the images were recorded. A more accurate and updated time code that would synchronize tightly with orbital telemetry would provide more accurate prediction of the area on the ground recorded by the camera, and could be used to reduce the amount of human scene-listing needed. Developing geospatial technologies such as geographic positioning systems may make further improvements possible. For remote sensing, a camera ideally would record more than an accurate time. Other parameters of interest include the camera position within the spacecraft, the lens used, and zoom level employed, making it possible to automatically catalog and georeference digital images.

A final aspect of the use of HDTV as a tool for acquiring Earth observations remains to be addressed—data storage and distribution. Extracting still images from HDTV tapes requires expensive editing equipment that is not currently available at JSC, and that is not available readily to scientists hoping to use HDTV Earth images in their research. Each extracted image is nearly 6 Mbytes in size and the 30-frame/sec acquisition rate of the HDTV camera would preclude storage of all but a small percentage of available HDTV images as stills.

However, commercial and technological advances relating to broadcast use of HDTV is likely to alleviate many of these problems. Hardware for HDTV frame capture is already more broadly available than when this DTO was completed and is likely to decrease in price substantially over the next few years. Although remote screening of HDTV may be difficult, tape duplication costs are far lower than the costs of duplicating mission film.

With current technology, an HDTV camera could be mounted in a window of the Orbiter or International Space Station, be turned on by astronauts and obtain HDTV video that can be time-reconciled with ground location from the spacecraft nadir data. Digital clones of the original tapes could be distributed to scientists and the public for screening. Those users that need still frames captured for specific studies will soon have access to the necessary hardware. NASA's future DTOs include HDTV downlink, which will develop the possibility of using HDTV for real-time downlink of images of scientific and public interest. It is easy to imagine that an HDTV camera permanently mounted on the International Space Station will be a source of immediate detailed information on storms, hurricanes, volcanic eruptions, and wildfires; and an archive of data on land cover and shallow water features around the globe.

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13. ABSTRACT *(Maximum 200 words)*
As part of Detailed Test Objective 700-17A, astronauts acquired Earth observation images from orbit using a high-definition television (HDTV) camcorder. Here we provide a summary of qualitative findings following completion of tests during missions STS (Space Transport System)-93 and STS-99. We compared HDTV imagery stills to images taken using payload bay video cameras, Hasselblad film camera, and electronic still camera. We also evaluated the potential for motion video observations of changes in sunglint and the use of multi-aspect viewing to image aerosols. Spatial resolution and color quality are far superior in HDTV images compared to National Television Systems Committee (NTSC) video images. Thus, HDTV provides the first viable option for video-based remote sensing observations of Earth from orbit. Although under ideal conditions, HDTV images have less spatial resolution than medium-format film cameras, such as the Hasselblad, under some conditions on orbit, the HDTV image acquired compared favorably with the Hasselblad. Of particular note was the quality of color reproduction in the HDTV images. HDTV and electronic still camera (ESC) were not compared with matched fields of view, and so spatial resolution could not be compared for the two image types. However, the color reproduction of the HDTV stills was truer than colors in the ESC images. As HDTV becomes the operational video standard for Space Shuttle and Space Station, HDTV has great potential as a source of Earth-observation data. Planning for the conversion from NTSC to HDTV video standards should include planning for Earth data archiving and distribution.

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