IMAGERY ASSETS FOR SUPPORTING NUCLEAR EXPLOSION MONITORING RESEARCH AND DEVELOPMENT

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ABSTRACT

The Defense Threat Reduction Agency's (DTRA) Center for Monitoring Research (CMR) maintains a wide range of technical capabilities to support nuclear explosion monitoring research and development. Within the CMR the Research and Development Support System (RDSS) operates as the vehicle to both digest and distribute data and research results of value to both DTRA authorized researchers and the general research community, in particular providing access to processed commercial imagery.

In recent years, commercial products, such as the 1-m-resolution panchromatic products of IKONOS, have enabled the nuclear explosion monitoring research community to benefit from satellite-based imagery acquisition systems. CMR maintains a library of imagery products ranging from the recently acquired, freely available (www.visibleearth.nasa.gov) low-resolution (1-km) composite images of the entire Earth, to 4-m multispectral and 1-m panchromatic (IKONOS) images of selected regions. Supplementing the high-resolution imagery products are 10-m panchromatic (SPOT) and 30-m multispectral (Landsat) images. Even higher resolution (0.7-m) commercial services (Digital Globe) are becoming available and high-resolution images will be acquired by the CMR to extend current holdings.

Within the CMR, research is conducted to determine methodologies for integrating enhanced event location and characterization techniques for nuclear explosion monitoring systems. One aspect of this effort is the utilization of imagery products to provide geographic context for event solutions, and, in some cases, to validate event location hypotheses.

The RDSS makes available selected imagery holdings via http://www.cmr.gov/rdss . Assets include interactive Portable Document Format (PDF) files of annotated images of Novaya Zemlya, Russia; Lop Nor, China; Pakistan; and India. Other imagery assets may be made available to the research community subject to the license agreement of the imagery vendor.

OBJECTIVE

The Defense Threat Reduction Agency (DTRA) sponsors the Center for Monitoring Research's (CMR) effort to improve nuclear explosion monitoring. Within the CMR, the Research and Development Support System (RDSS) (Woodward and North, 2002) supports the DTRA PRDA and general R&D communities with assistance ranging from data and research product dissemination to integration and testing of research and development results. Also within the CMR, the Technical Verification and Analysis Support project provides an environment to demonstrate nuclear explosion monitoring advances applied to generalized conditions. More focused efforts, such as the Lop Nor Advanced Concept Demonstration (Kohl *et al*, 2002), provide environments to develop, integrate and demonstrate advanced techniques applied to specific nuclear explosion monitoring regimes. Despite the broad scope of CMR activities, one common component is the application of imagery assets to the nuclear explosion monitoring research and development effort.

RESEARCH ACCOMPLISHED

The CMR maintains an assortment of imagery products to support research and development. Products range in scale and scope from high-resolution (1-m) geographically registered images (IKONOS) of small regions (~100 sq. km per scene) to low-resolution (1-km) composite images covering the entire Earth. The CMR employs these assets in a variety of ways, including validation and refinement of ground truth locations, event analysis and context visualization, and site identification. Additionally a selection of the imagery assets has been annotated and packaged as interactive Portable Document Format (PDF) documents for use by the general R&D community. In the sections below, each of these areas will be described, and we will close with a summary of planned imagery acquisitions.

Imagery to support ground truth

Many R&D efforts rely on the existence of well-located reference events. Such events, categorized by their absolute location uncertainty in kilometers as GT1 (ground truth, 1 km), GT2, GT5 and so on, are highly valuable for the establishment of regional travel-time corrections and for use as master events when applying Joint Hypocentral Determination (JHD) and Master Event Location techniques. Fisk (2002) demonstrates the advantage of applying high-resolution imagery to the task of establishing ground truth for nuclear explosions at the Lop Nor, China nuclear weapons testing facility.

CMR imagery assets covering the tunnel (western) and vertical-borehole (eastern) areas of the Lop Nor facility were analyzed for surface features associated with nuclear explosions. Features such as adits, boreholes, roads, and structures were identified. Subtler features, such as erosional characteristics, were utilized to establish the relative age of the surface features. Using these features, Fisk (2002) determined precise locations for three nuclear explosions. Using these three events as master events, eight other explosions were relocated. Semi-major axis error estimates for these events were less than about 0.65km. Event locations could be associated with observed features to provide an absolute accuracy of 300 m or less – the registration accuracy of the satellite imagery.

Figure 1 demonstrates the clarity of surface features visible in the tunnel region of the Lop Nor facility. The image is a panchromatic (1-m) sharpened, multispectral (4-m) image producing an approximately 1-m-resolution natural color image. This image, covering approximately ¼ of a square kilometer, highlights two (areas 'A' and 'B') of the four tunnel adits described by Fisk (2002). Also visible in the scene are numerous road and support structures. Figure 2 similarly displays the anthropogenic features associated with a portion of the vertical borehole region of the Lop Nor facility.

Using imagery to support the determination of ground truth locations, 11 nuclear explosions, detonated between May 1990 and July 1996 have been relocated and established as GT1 events. These events were utilized during the Lop Nor Advanced Concept Demonstration (Kohl *et al*, 2002) to illustrate the advantage of employing Master Event Location techniques to locate small (mb 2.5-3.5) events.

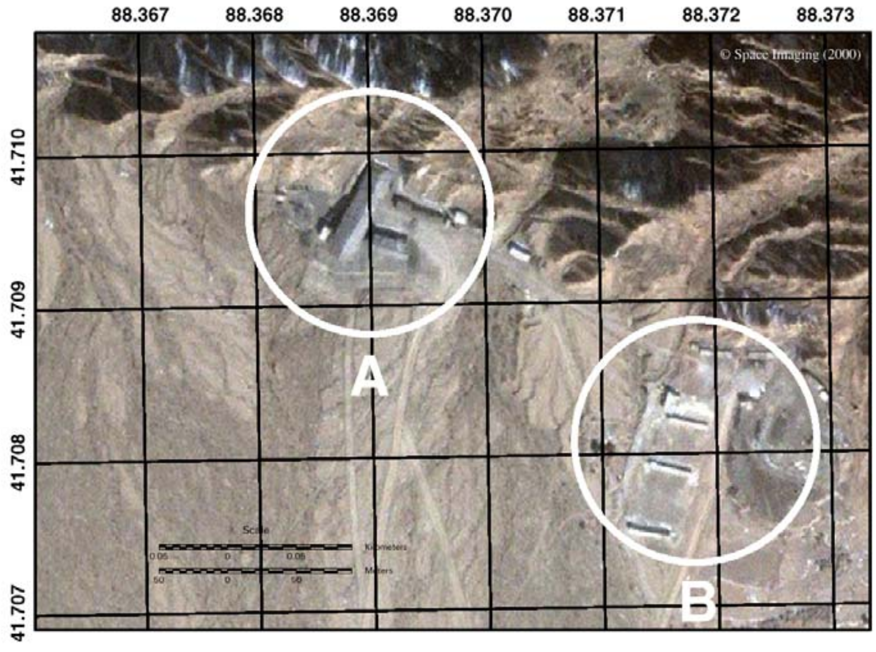

Figure 1. IKONOS imagery from CMR's collection showing two tunnel adits in the Lop Nor complex. The regions labeled 'A' and 'B' correspond to tunnel adits 'A' and 'B' as described by Fisk (2002).

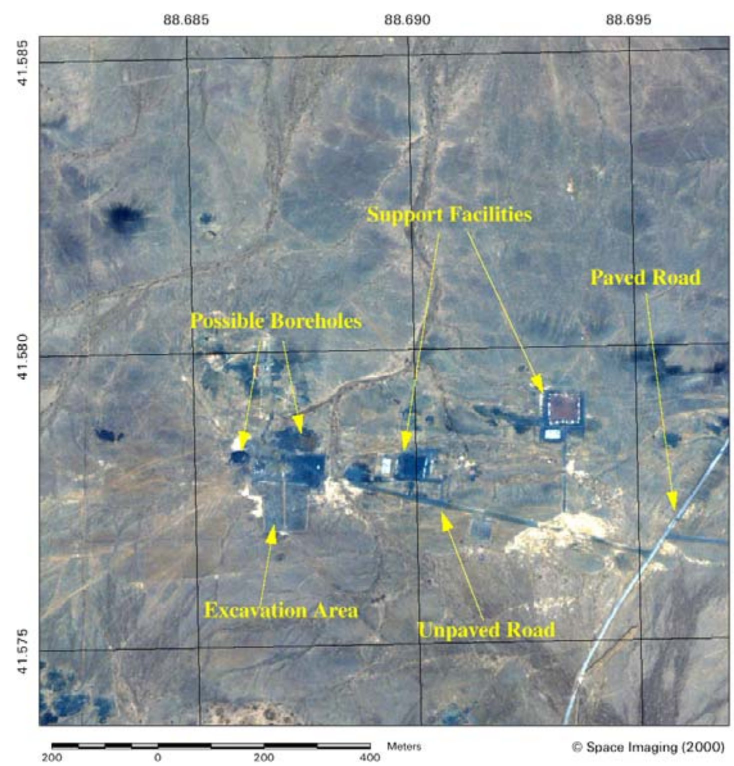

Figure 2. Surface features associated with vertical borehole emplacements in the Lop Nor complex. The IKONOS imagery was acquired, processed and archived by CMR analysts; the annotations are from Fisk (2002).

<u>Imagery to support event analysis and context visualization</u>

Satellite imagery can provide a rich backdrop for conveying information relevant to event analysis or to an event location. High-resolution images such as those shown in Figures 1 and 2 are often required to identify small-scale surface features associated with an event. In some situations, however, broader coverage is desired. Figure 3 shows the Novaya Zemlya, Russia region including several hypothesized locations for a February 23, 2002, seismic event. Also shown, for additional context, are the locations of several historical events of interest (blue triangles) and of underground nuclear explosions (red stars). The larger coverage area provides better visual clues as to the separation of this event from known nuclear tests and places the event in the overall geographic context. Displaying larger coverage areas is neither technically practical nor financially feasible using high-resolution products such as IKONOS. Figure 3 is based on lower resolution (~40 m) MODIS imagery freely available from NASA's Earth images web site (http://visibleearth.nasa.gov).

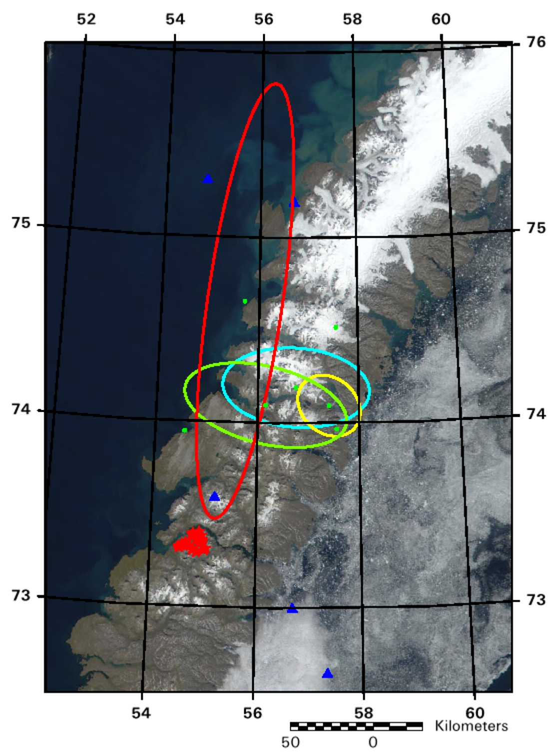

Figure 3. NASA MODIS imagery of Novaya Zemlya, Russia (http://visibleearth.nasa.gov).

NASA maintains a substantial catalog that CMR staff utilize to identify images of potential value to nuclear explosion monitoring research and development. Also available from NASA (http://visibleearth.nasa.gov) are low-resolution (1-km) composite images covering the entire Earth. CMR has acquired this collection of images and is currently assembling relevant regional composite images.

CMR's usage of imagery also includes sophisticated visualization techniques such as imagery draping. Figure 4 illustrates the technique. The region shown in Figure 1 is draped over digital terrain elevation data to produce a three-dimensional (3-D) transformation of IKONOS imagery. This specific example shows non-exaggerated surface elevation features associated with two of the adits in the western portion of the Lop Nor, China, nuclear weapons testing facility. Of particular note is the extent of the overburden provided by the ridge. The extent and relative isolation of the overburden is further illustrated through the creation of "flyby" animations. Two such animations were constructed to support the Lop Nor Advanced Concept Demonstration (Kohl *et al*, 2002). One such animation toured the western tunnel region; the second illustrated the features around the vertical borehole complex in the eastern portion of the Lop Nor facility.

Figure 4. IKONOS imagery of the region shown in Figure 1 draped over terrain data.

Imagery for site identification

Supporting the efforts of ground truth determination and event context visualization is an effort to maintain imagery holdings for regions of particular interest. Recent imagery acquisitions can obviously aid research and development by providing the most up-to-date view possible of surface features in a region of interest. However, other benefits, such as resolving surface features obscured by clouds or shadows, can also be realized through routine acquisition of imagery.

Most sites of interest are best imaged by acquisitions in mid to late summer. These times provide high sun angles and minimize cloud and snow cover. For this reason, most images commissioned by CMR have acquisition dates of July, August, and September (images of sites in the northern hemisphere dominate current holdings). The subtle changes in acquisition date and time can be beneficial for altering sun angles, but often the more overt changes seen year-to-year are the most interesting.

Identification of changes can be highly valuable for tasks such as establishment of ground truth. Fisk (2002) used substantially more subtle features, such as relative erosional characteristics, to establish the relative age of various components of the Lop Nor, China, facility. Clear changes observed in sequential images, such as those illustrated in Figure 5, can provide substantially better temporal information than can be inferred by interpretation of erosional features. The region highlighted with the white box in Figure 5 illustrates the substantial development that occurred in the 14 months between the acquisition dates of July 2000 and September 2001 of high-resolution (~1 m) IKONOS imagery and illustrate the advantage of maintaining and refreshing imagery holdings.

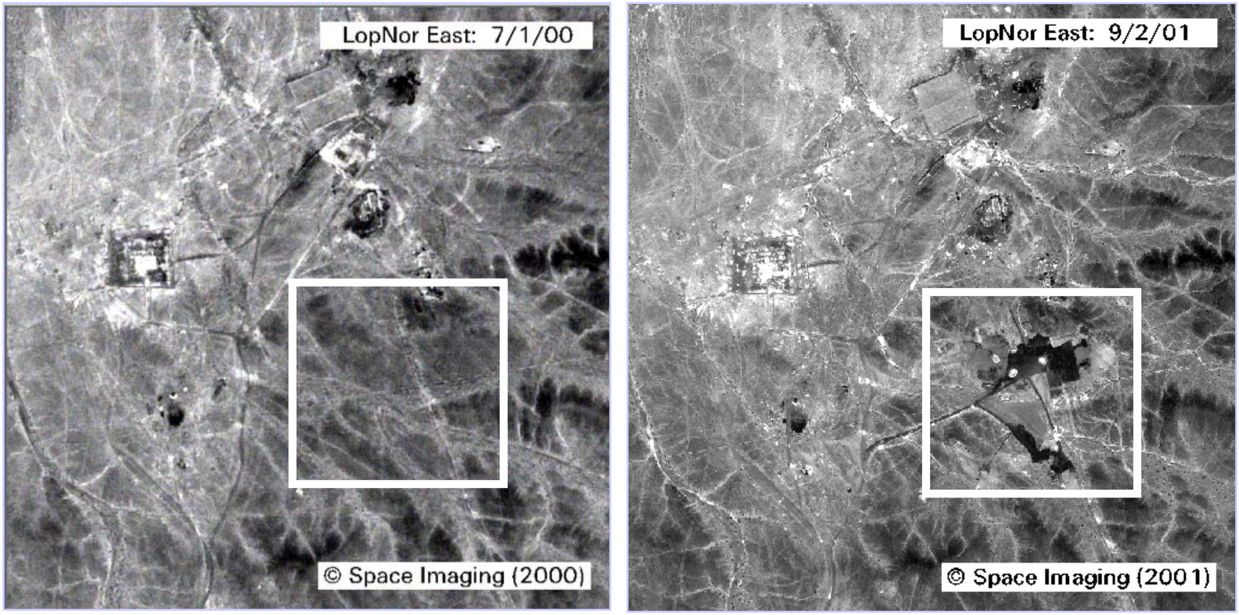

Figure 5. Two IKONOS images of Lop Nor, China taken approximately 14 months apart illustrating the substantial observable changes occurring at the site.

Detailed analysis of the changes has not been conducted; however, current plans include the acquisition of higher-resolution (~0. 7-m) Digital Globe imagery for this site in 2002. A more detailed study may be initiated pending the initial analysis of new imagery and a determination of need.

Imagery for the research community

CMR provides annotated satellite imagery products for use by the research community. Subject to the end user license agreement of the image provider, selected imagery is packaged in PDF format and made available from the RDSS portion of the CMR web site at http://www.cmr.gov/rdss . The PDF documents provide mechanisms to zoom on features of interest and navigate the region. Figure 6 shows a snapshot of the portion of the RDSS web content that provides a high-level view of the Novaya Zemlya, Russia, region. Annotations include structures, roads and rivers, as well as features more directly related to nuclear weapons testing, such as tailings and subsidence craters. The images viewable directly on the web site are reduced resolution; however, the PDF format documents available for download provide full resolution versions of the imagery.

Currently available imagery includes a mosaic of three images of Novaya Zemlya, Russia, (Figure 6), two images of Lop Nor, China, showing both the tunnel and vertical borehole regions, one image of the site of the May 5, 1974, and May 11, 1998, underground nuclear tests in India, and two images of the test facility in Pakistan, including the site of the May 28, 1998, underground nuclear test. Each of these is available via the CMR web site. Also available are examples of typical features associated with nuclear weapons testing, such as support infrastructure and collapse features. The main entry point for the CMR web site may be accessed at http://www.cmr.gov .

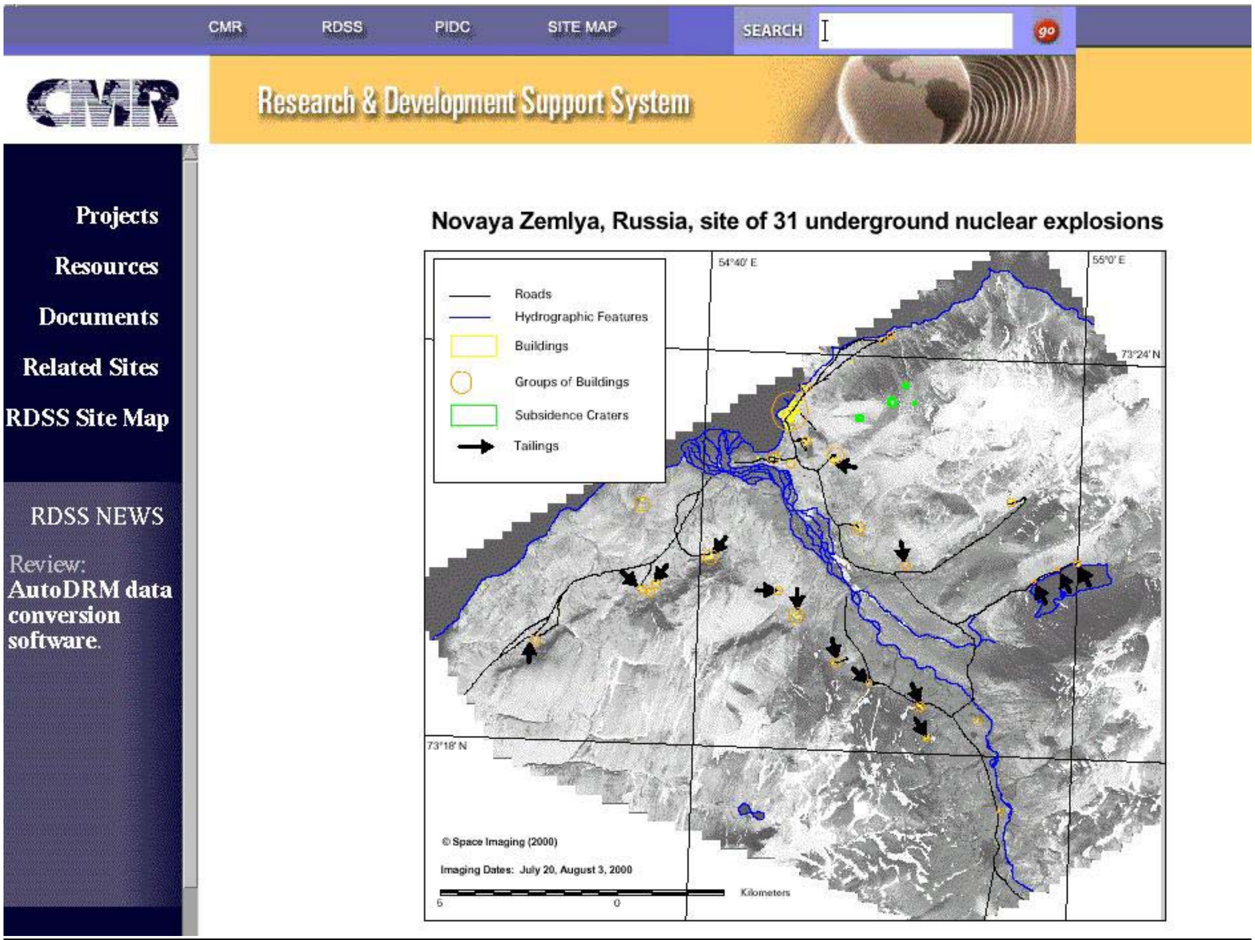

Figure 6. Screenshot of a portion of the CMR web site showing one of the images (Novaya Zemlya, Russia) available from the RDSS.

Planned 2002 acquisitions

As of this writing, the Technical Verification and Analysis Support component of CMR has initiated imagery acquisitions for 2002. Pending the outcome of the price quote process, CMR is considering new acquisitions for four regions of interest. For all sites, CMR is considering the acquisition of higher-resolution panchromatic (0.7-m) Digital Globe products. Multispectral images may be acquired for selected sites. Two images covering the Novaya Zemlya, Russia, test facility are being considered. Three new images of the Lop Nor, China, region are being considering, including one of the western (tunnel) area, one of the eastern (vertical borehole) area including the altered region identified in Figure 5, and possibly an image of the region southwest of this complex where two tests are reported to have been conducted many years ago. Also under consideration are updates to the imagery holdings for India and Pakistan.

CONCLUSIONS AND RECOMMENDATIONS

CMR's imagery acquisition program has proven a valuable aid to efforts such as the establishment of ground truth locations and for the visualization of research and development results. Additional, commercial, high-resolution imagery will be acquired on a periodic basis to ensure CMR's imagery holdings remain current. These commercial products will be supplemented with freely available products whenever possible.

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