Hyperspectral Data Compression Workshop

May 23, 2003

Nazeeh Aranki

JPL

INTERPLANETARY NETWORK DIRECTORATE

Science Processing & Information Management

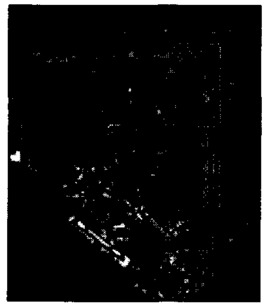
Hyperspectral Data Compression Algorithm and HW Development

- Two related prototype hyperspectral data compression for algorithms based on the reversible integer discrete wavelet transform (DWT).

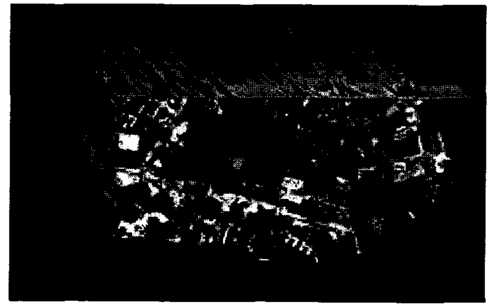
- One algorithm is low complexity, the other is progressive, providing lossless and lossy compression using the same algorithm.

Objective: Develop on-board real-time hyperspectral data compression methods to significantly reduce the data volume necessary to meet science objectives in future deep-space missions

AVIRIS hyperspectral data "cubes"

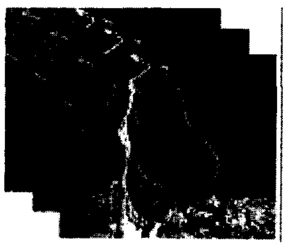


Pearl Harbor, Hawaii

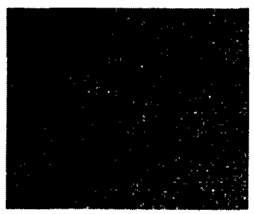


WTC Disaster Site

2D wavelet decomposition with spectral predictive coding

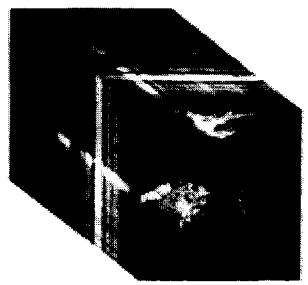


original spectral bands

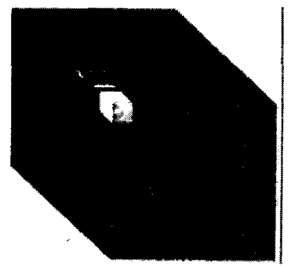


a residual image

3D wavelet decomposition of 244-band data set



original data cube

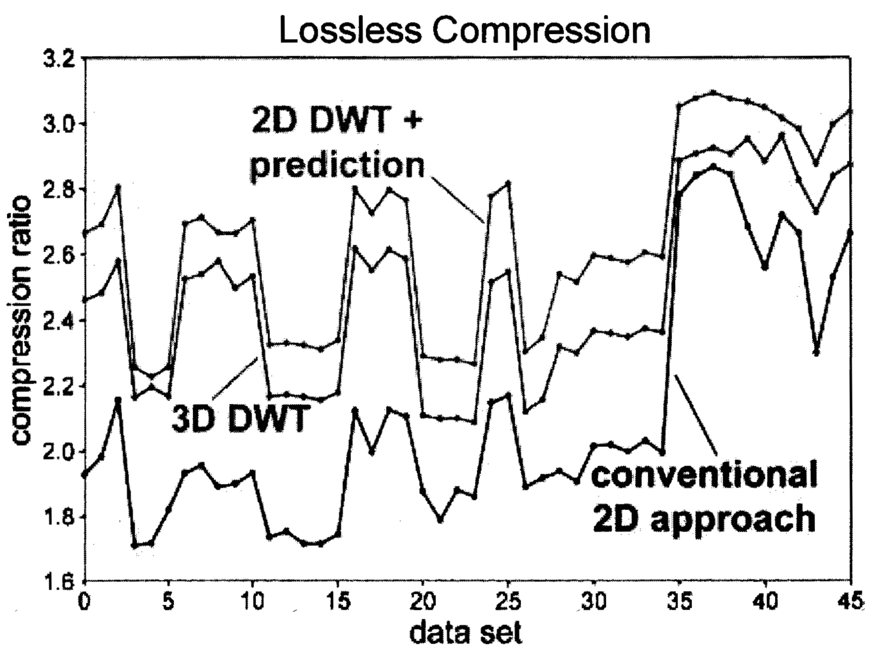


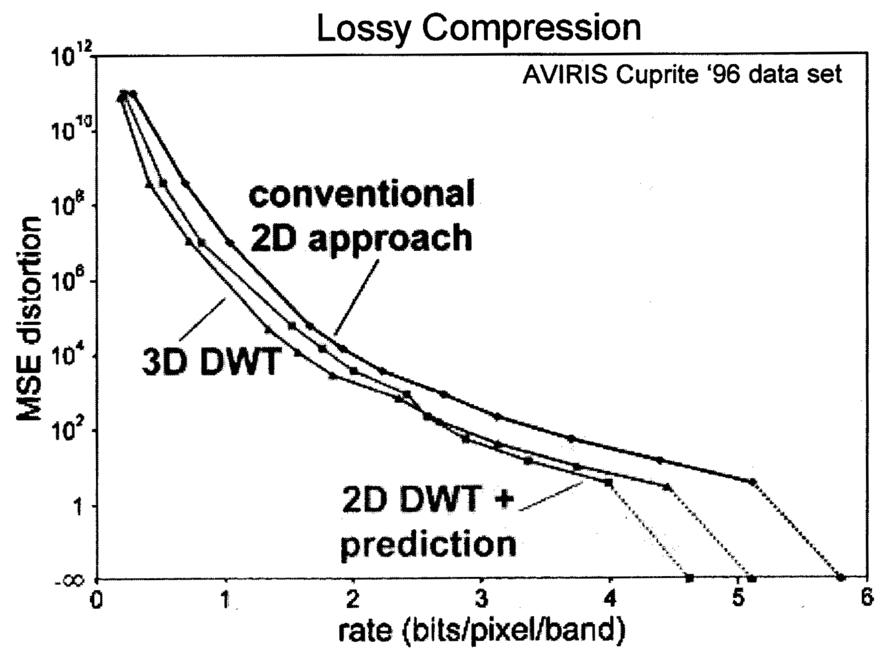
3D DWT of data cube

Hyperspectral Data Compression

- **Compression Approach**
  - 2D wavelet decomposition applied to each spectral band
  - Correlation across spectral band is exploited using one of two methods:
    - Spectral predictive coding (lower complexity)
    - Additional wavelet transform in spectral dimension (progressive).
  - Quantization and entropy coding complete the compression process.

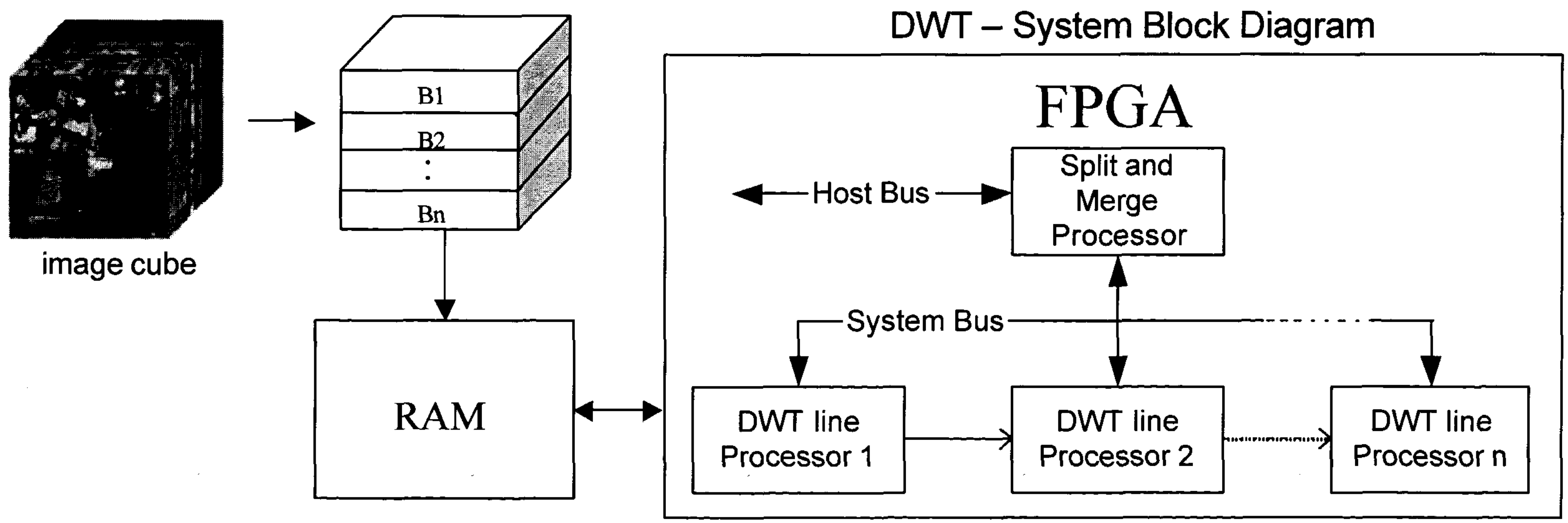
- **Benchmarks of hyperspectral compressor software prototype**
  - Demonstrated ~ 30% improvement in lossless compression, and 20% to 40% improvement in lossy compression effectiveness on AVIRIS data sets when compared to conventional application of a two-dimensional wavelet-based image compressor to each spectral band independently (see graphs below)
  - Similar results were obtained for the several Hyperion data sets just obtained.





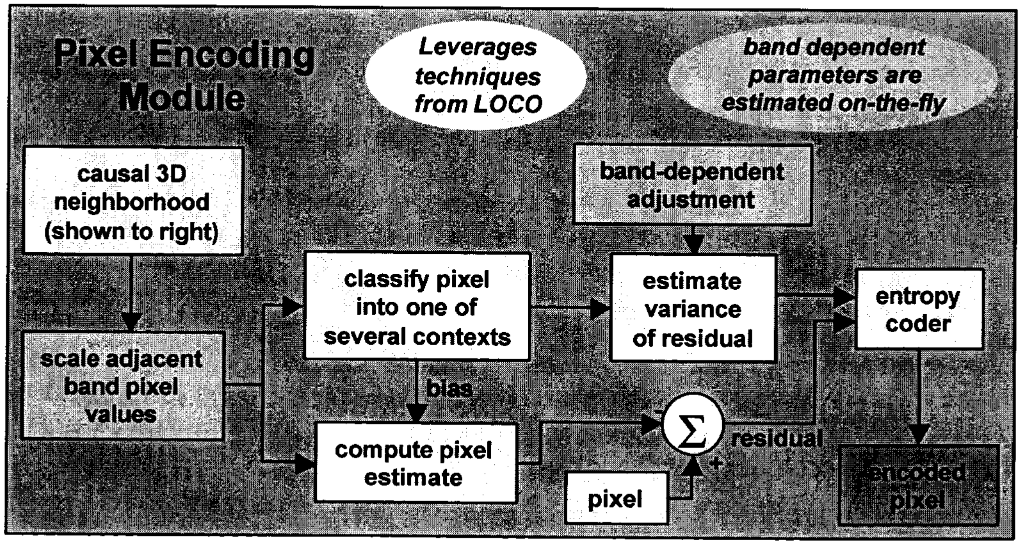
Each AVIRIS data set consists of 224 spectral bands, 16 bits/pixel/spectral band

- FPGA-based DWT hardware module
  - The architecture allows in-place transformation resulting in low-memory requirements
  - The number of co-processors can be scaled depending on system performance requirements and available hardware resources.
  - Initial performance estimates indicate that the FPGA implementation, at <100MHz, is more than two orders of magnitude faster than a C software implementation on a 200MHz Sun Ultra Sparc II.
- The implementation is high performance, fully parallel, low-power, and scalable.
- Targets Xilinx Virtex II and Virtex II pro FPGAs.



Fast Lossless Hyperspectral Data Compression

- Objective: State-of-the-art lossless compression, with low complexity (i.e., fast)
- Completed design of pixel encoding module (see box below)
  - Uses *predictive compression* with *context modeling* (see boxes at right)
  - Several components leverage LOCO lossless image compressor
  - 3D context model accounts for different prediction accuracy in the different spectral bands (due to different noise levels)



Predictive Compression

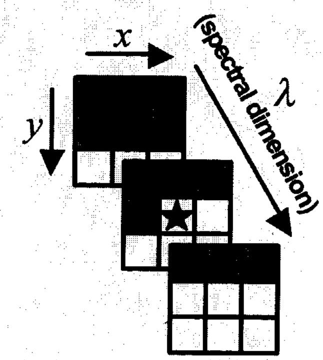
- Encodes pixels one-at-a-time, typically in raster scan order
- Estimates pixel value probability distribution from previously encoded pixels. These estimates are used to efficiently encode the pixel value.

Context Modeling

- Classifies pixels to be encoded into one of several *contexts* based on nearby pixels already encoded
- Maintains statistics for each context to determine estimated distributions of pixel values

3D neighborhood for prediction and contexts

- Pixel scan order: x, λ, y
  - Accommodates band-interleaved-pixel (BIP) or band-interleaved-line (BIL) acquisition
- Causal neighborhood contains 13 pixels (shaded)
- Restricted to two adjacent bands to keep complexity low



Region-of-Interest (ROI) Compression of Hyperspectral Data

- Selected 3D wavelet transform for first application of ROI algorithms for hyperspectral data
  - 3D transform is fully progressive and fits the prioritized buffer management model
  - 3D wavelet coefficients can be scaled to reflect priorities in the same way as 2D wavelet coefficients for 2D images

Hyperspectral ROI Compression

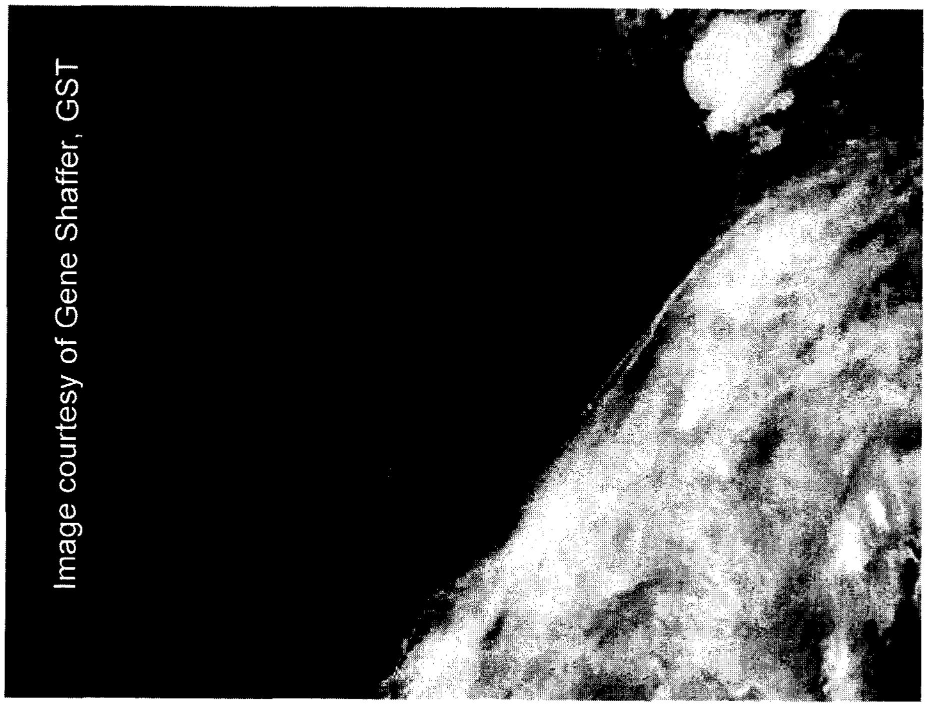
- Aims to allocate compressed bits to produce highest-fidelity reconstructions in identified high-priority regions of interest
- Based on 2D ROI image compression system developed under Earth Science AIST program.
- Works like non-ROI compression except that transform coefficients are scaled to reflect priorities
- Map of priority values must be transmitted and adds overhead cost

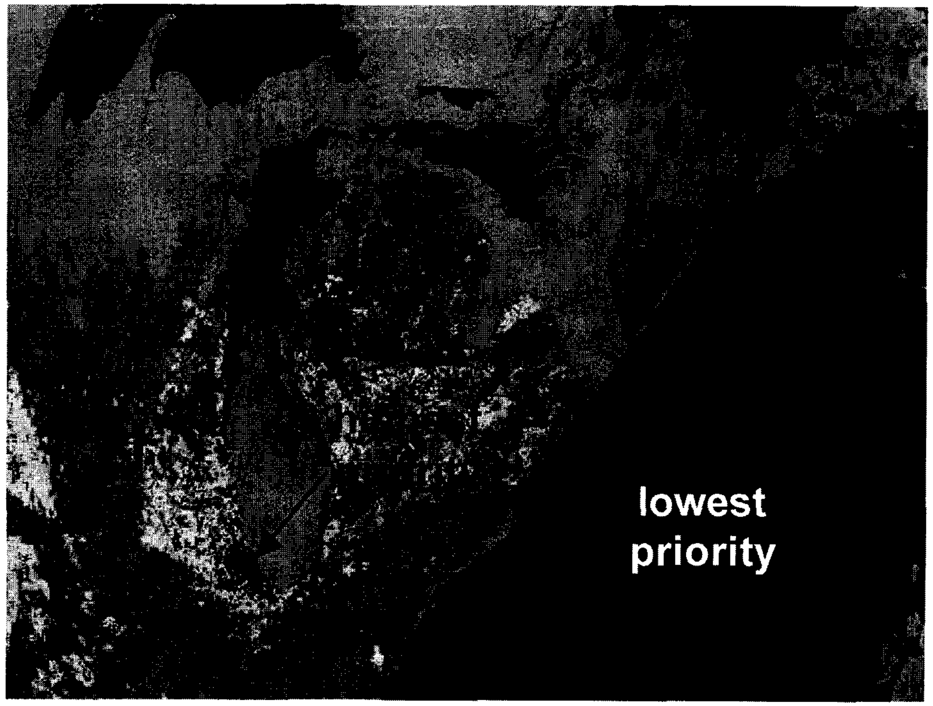
- Improved techniques to compress priority maps
  - New software uses specialized algorithm for lossless compression of priority map, based on
    - Interleaved entropy coding
    - Predictive compression with context modeling
  - Limited tests with new software have yielded priority map overheads of about
    - 0.05 bits/pixel ± 50% for priority maps with broad priority areas
      - 5 to 10 times reduction in overhead compared to old (non-specialized) software that used plain ICER to compress priority maps
    - 2 to 4 times more overhead is required for priority maps with many fine detail areas
      - Too much detail on priority maps can hurt overall compression performance

Related Research – ROI compression

Example of ROI compression of multispectral/hyperspectral data

- Sample multispectral MODIS image of Great Lakes area
- One of 16 IR (emissive) bands at 1-km resolution shown below





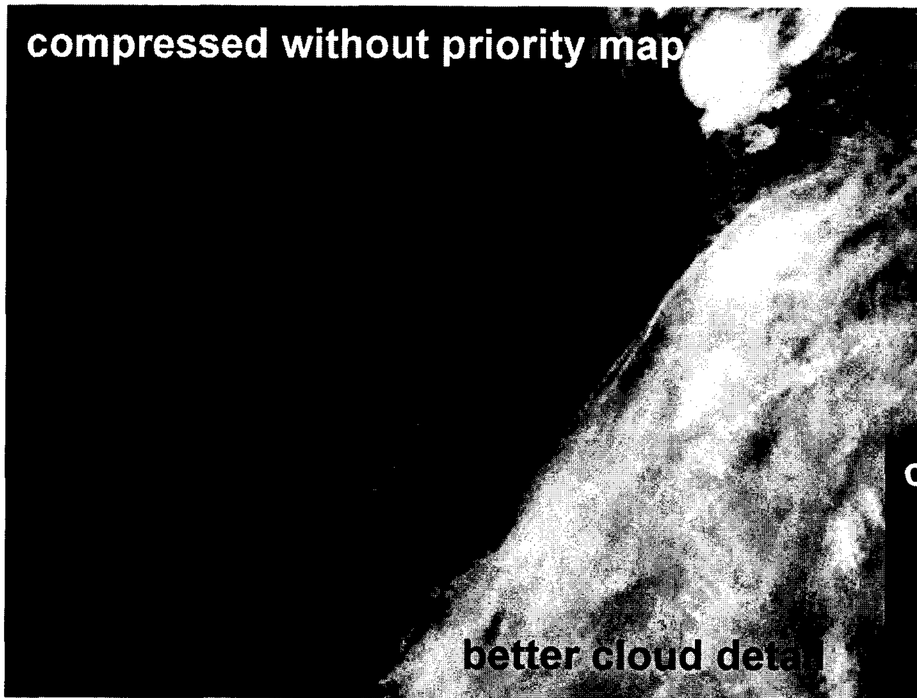
Sample Priority Map

- Rudimentary classifier determines whether spectrum resembles Chicago or Lake Michigan. Highest priority given to Chicago-like regions.
- Classification (and resultant priority map) are based on all 16 IR (emissive) bands at 1-km resolution

Related Research – ROI compression

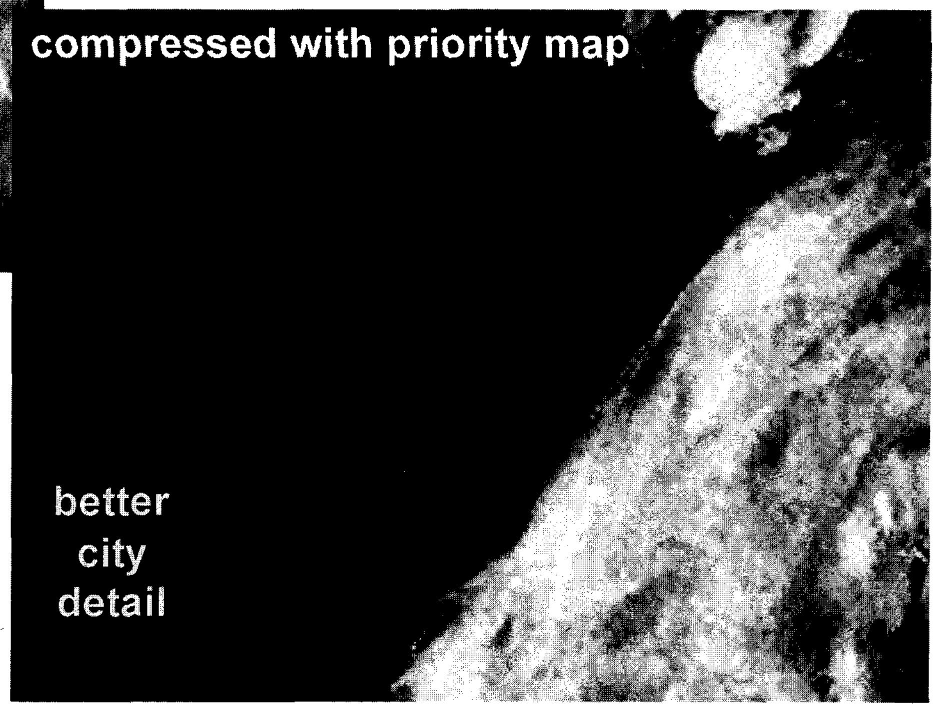
Example of ROI Compression of MODIS Dataset

- Current compression is band-by-band independently



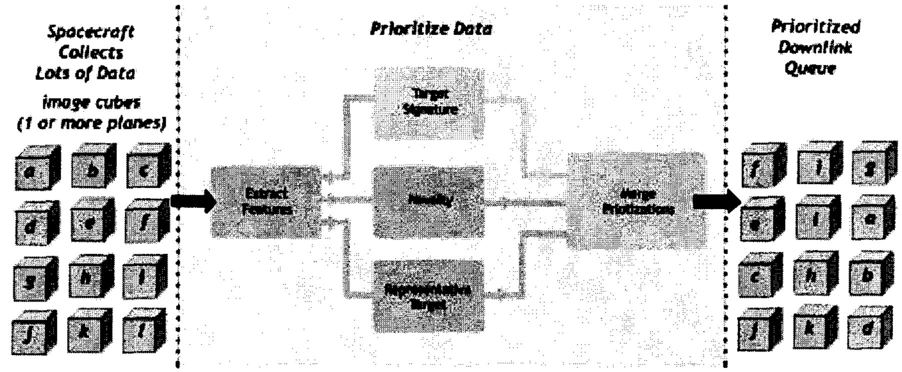
One IR band reconstructed from 10 (of 170 total) packets of data when compressed without priority map

One IR band reconstructed from 10 (of 183 total) packets of data when compressed with priority map

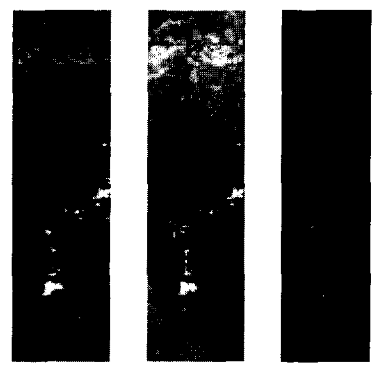


Autonomous Onboard Hyperspectral Data Evaluation and Prioritization

- **Algorithm merges the results of three different prioritization techniques.**
  - **Combining the three separate prioritizations is necessary to produce a single prioritized queue for downlink**
- **Integrated algorithm into data analysis system.**
  - **Applied the algorithm to a set of grayscale images to provide a proof-of-concept for prioritization of hyperspectral images**
- **Reached agreement with Earth-Observing-1 (EO1) Autonomy Experiment (scheduled for second half of FY03) to flight validate hyperspectral classifier/event recognizers on the EO1 Mission.**
  - **Hyperspectral classifier/event recognizer successfully detected events (such as fresh lava flows) in tests on Hyperion data in the infra red wavelength range.**
  - **Pursuing further access to Hyperion data to test additional key target signature algorithm (carbonate detector) for use in downlink prioritization.**



overall system assigns science-based priorities to hyperspectral data for transmission



Hyperion data illustrating a volcanic eruption. The middle image (infra-red) shows a number of new lava flows. The last image is the output of our target signature software