AUTONOMOUS SCIENCECRAFT EXPERIMENT (ASE) OPERATIONS ON EO-1 IN 2004.

A. G. Davies[1,a], V. Baker[2], R. Castaño[1], S. Chien[1], B. Cichy[1], T. Doggett[3], J. M. Dohm[2], R. Greeley[3], R. Lee[4], R. Sherwood[1] [1]Jet Propulsion Laboratory-California Institute of Technology, ms 183-601, 4800 Oak Grove Drive, Pasadena, CA 91109-8099 ([a]tel 818-393-1775, email Ashley.Davies@jpl.nasa.gov), [2]Dept. of Hydrology and Water Resources, University of Arizona, Tucson, AZ 85721, [3]Dept. of Geological Sciences, Box 81704, Arizona State University, Tempe, AZ 85287, [4]Geology Department, Trinity University, San Antonio, TX.

Introduction: The Autonomous Sciencecraft Experiment (ASE) has been selected for flight demonstration by NASA's New Millennium Program (NMP) as part of the Space Technology 6 (ST6) mission. NASA has identified the development of an autonomously operating spacecraft as a necessity for an expanded program of missions exploring the Solar System. The versatile ASE spacecraft command and control software, image formation software, and science processing software will be uploaded to the Earth Observer 1 (EO-1) spacecraft in early 2004 to detect surface modification related to volcanism, ice formation and retreat, and flooding.

Advantages of Autonomous Operations: ASE [1, 2, 3] demonstrates advanced autonomous science data acquisition, processing, and product downlink prioritization, as well as autonomous spacecraft command and control, and fault detection. Spacecraft autonomy will be advantageous to future missions by (a) making the best use of reduced downlink; (b) overcoming communication delays through decision-making *in situ*, enabling fast reaction to dynamic events; (c) increasing science content per byte of returned data; and (d) avoiding the of return of null (no-change/no feature) datasets: if there is no change detectable between two scenes of the same target, there is no need to return the second dataset.

Operations and basic operational plan. Science-driven goals will evolve during the ASE mission through *onboard replanning* software that will generate low-level command sequences based on reformulation of science goals from the onboard science software. *Cluster management* software will enable the elements of the distributed spacecraft constellation to work as a single virtual instrument in several possible configurations. An example of the basic concept is presented in the following sequence: (1) the spacecraft makes a science observation of a target of interest (e.g., a frozen lake, or volcano). (2) Onboard *Science software* forms the image and runs data classifiers, looking for a specific surface type or spectral signature. (3) The software then compares this analysis to previous images to detect whether thawing of the frozen lake or a new lava flow has been emplaced. (4) If an event is detected the science module quantifies the change and requests new observations centered on the region of change, to monitor the process. (5) The onboard planner is tasked to fulfill this request and develops a plan to allocate resources and image the site on the next repeat orbits. (6) The spacecraft management software and execution management software ensures correct implementation of the new observation plan; and (7) data and science are down-linked at the first available opportunity after acquisition.

ASE deployment in 2004: The ASE software will fly onboard the Earth Observer-1 (EO-1) spacecraft in early 2004. EO-1 is in a 705-km altitude, highly inclined orbit. The main instrument of interest onboard is *Hyperion***,** a hyperspectral imager with 226 wavelengths from 0.6 to 2.4 microns, yielding 30 m/pixel resolution. Science analysis onboard EO-1 is limited by available processing power. ASE will process up to twelve separate wavelengths from each hyperspectral product, six of which are used by the Cloud Detection algorithm. It should be noted that the Cloud Detection algorithm, designed by Lincoln Labs [4] for fully-calibrated Level 1 Hyperion data, has been modified for the Level 0.5 Hyperion data ASE has access to onboard EO-1. The science algorithms are designed to use up to six additional bands, but are generally limited to two or three bands each so that algorithms can be stacked to further sub-classify an already classified scene.

ASE Science Algorithms: The first set of ASE science classifiers to be uploaded to EO-1 in early 2004 include:

Thermal Classifier: Detection of pixels with a strong thermal component, characterized in most cases with an increase in thermal emission towards longer wavelengths. This is used for the detection of volcanic thermal emission, and can be applied to both day and night-time observations (see Figure 1).

Snow-Water-Ice Land (SWIL) classifier: Classifies surface as either snow, water, ice or land, and is used to monitor formation and retreat of sea and lake ice, and separates water/ice from land for subsequent sub-classification of land (see *Stacking of Algorithms*).

Flood classifier: monitors river systems for change in total area covered in water, even sediment-laden water. Used for detecting and monitoring seasonal flood events and inundations [5].

Vegetation classifier. Using the 'red-edge' spectral feature, an algorithm has been developed for identification of pixels containing vegetation [6]. Can be used in specific cases where there is sufficient denudation of vegetation, such as extensive volcanic activity and wild fires, and flood activity.

Cloud detection: The cloud detection algorithm is used to identify clouds before applying Flood, SWIL and Vegetation classifiers. For example, observations with more than 50% cloud cover can be passed over. Determination of cloud cover also aids evaluation of daytime thermal classification.

Stacking of algorithms: The ASE science classifiers can be stacked to enable sub-classification. For example, a scene will firstly be classified to identify and remove from further classification areas of cloud. Then SWIL separates sea from land, and Vegetation classifies remaining land areas as vegetated or non-vegetated [6]. Independent of this, the thermal classifier detects pixels with a hot component.

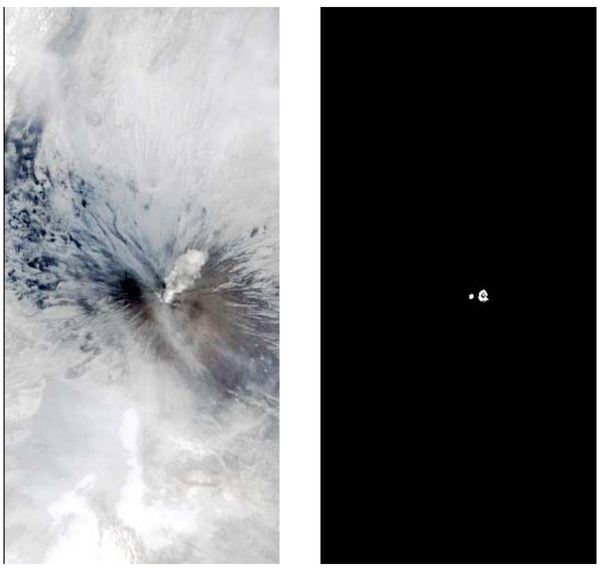

Figure 1. Identification of thermal pixels (white pixels, right image) in Hyperion data of Kliuchevskoi volcano, Kamchatka, using ASE Thermal Detector. Data obtained on 2003-Oct-08. Left image is 7.7 km wide.

Detecting change with ASE. The change detection algorithm searches for change by comparing a current image with a previous observation. In the event of severe downlink restrictions, and depending on the process being observed, it may only be necessary to return segmented outlines of changed areas, or the total area of change, or only the rate of change (of flooding, for example). These are all products with very high science content per returned byte. For cases of volcanism, for example, the intensities and locations of individual hot pixels can be returned, without the need to return the entire dataset.

Science-driven planning and reaction observations: An important facet of this mission is demonstrating how onboard science analysis can drive mission operations. On making a successful detection of change or initial activity, ASE requests, via the onboard planner, additional observations of a specific target, or even an observation of a nearby location to determine the extent of the process (flooding, for example). The new observation is designated as high priority and the planner decides if the observation is possible and allocates resources accordingly. Whereas ASE change detection currently operates on data obtained on an exact repeat track orbit (every 16 days), a reaction observation may be obtained on the next available orbit. Combined nadir and oblique (1 and 2 rows over, East and West) observations allows a total of 5 observations within 16 days.

Target Selection: EO-1 targets are selected for processes with extraterrestrial analogues. Examples include different active effusive and explosive volcanism (targets include Kilauea, HI, and Erta'Ale, Ethiopia, with the extraterrestrial analogue being Io); ice formation and retreat (Beaufort Sea, Antarctica, lakes in Minnesota, Colorado and the Tibetan Plateau); and catastrophic flooding. Targets may include areas inundated and modified by storm-induced flooding (in Central India, China, and Central America, for example). In addition to daytime observations, nighttime observations will be made of selected volcanoes. Thermal emission from active volcanism is more easily identified at night with Hyperion, where there is no reflected solar component to the observed spectra.

Future use of ASE Technology: ASE can contribute to future Mars missions in the search for changes in variable features, such as wind streaks, and other dynamic processes, and for JIMO in the search for changes on Jovian satellites Europa, Ganymede and Io. Indeed, elements of ASE are being uploaded to Mars Odyssey *Themis* in 2004 (see [7]).

Acknowledgements: Part of this work was carried out at the Jet Propulsion Laboratory-California Institute of Technology, under contract to NASA.

References: [1] Chien, S. *et al.* (2001) I-SAIRAS, 6th Symp. on Artificial Intelligence, Robotics and Automation in: Space. Montreal, Canada, June 2001. [2] Chien, S. *et al.* (2004) Preliminary Results from the autonomous Sciencecraft Experiment, submitted to IEEE Conference [3] Davies A. G. *et al.* (2001) ASC Science Study Report, available from http://ASE.jpl.nasa.gov. [4] Griffin, M. *et al.*, (2003) proceedings of 17th SPIE AeroSense 2003 Conference. [5] Ip, F. *et al.* (2004) *LPSC35* abstract, this volume. [6] Lee, R. *et al.*, (2004) *LPSC35* abstract #1615. [7] Chien, S. *et al.* (2003) *LPSC34* abstract #1458.