AUTONOMOUS SCIENCECRAFT EXPERIMENT (ASE) TEST OPERATIONS IN 2003. S. Chien[1], A. G. Davies[1,a], V. Baker[2], B. Castano[1], B. Cichy[1], T. Doggett[3], J. M. Dohm[2], R. Greeley[3], R. Sherwood[1] and K. Williams[4] [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]Center for Earth and Planetary Studies National Air and Space Museum, Smithsonian Institution, Washington DC 20560-0315.

Introduction: NASA has identified the development of an autonomously operating spacecraft as a necessity for an expanded program of missions exploring the Solar System. 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. ASE is scheduled to fly on the US Air Force Research Laboratory (AFRL) Techsat-21 constellation in 2006. TechSat-21 consists of three satellites flying in a variable-geometry formation in Earth orbit. Each satellite is equipped with X-band Synthetic Aperture Radar, yielding high spatial resolution images (~3 m) of the Earth's surface. The constellation will fly at an altitude of 550 km, in a 35.4° inclination circular orbit, yielding exact repeat-track observations every 13 days. Prior to full deployment, elements of the versatile ASE spacecraft command and control software, image formation software and science processing software will be utilized and tested on two very different platforms in 2003: AirSAR and EO-1 (described below).

Advantages of Autonomous Operations: ASE [1, 2] will demonstrate advanced autonomous science data acquisition, processing, and product downlink prioritization, as well as autonomous spacecraft command and control, and fault detection. The advantages of spacecraft autonomy are to future missions include: (a) making the best use of reduced downlink; (b) the overcoming of communication delays through decision-making *in situ*, enabling fast reaction to dynamic events; (c) an increase of science content per byte of returned data; and (d) an avoidance 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. The basic concept is as follows: First, the spacecraft makes a science observation of a target of interest: for example, a frozen lake, or a volcano. Onboard Science Software forms the image (which may be radar, visible, or infrared: any formed image can be processed) and compares it to previous images to detect whether thawing of the frozen lake or a new lava flow has been emplaced (that is, if new open water or new flows are observed). If an event is detected the science module quantifies the change and requests new observations centered on the change region, to monitor the process. 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. The cluster management software and execution management software ensures correct implementation of the new observation plan. Data and science are down-linked at the first available opportunity.

ASE Science Algorithms: Currently there are three ASE science analysis algorithms.

Change detection. 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.

Feature identification: The Feature Identification experiment uses the DiamondEye software developed by JPL (Burl *et al.*, 2001). The algorithms are trained to identify geomorphological features such as impact craters on Mars, volcanic cones sand dunes and flood features, using scalable templates. DiamondEye identifies the location and sizes of each template pattern. Comparison with previously obtained images identifies new features: a new impact crater, for example, would be a site of potentially high scientific return.

Discovery: The Discovery Algorithm identifies those areas of an image that are statistically different from the average image brightness. In this way, those 'interesting' areas can be selectively returned for closer scrutiny and tagged for further, more detailed imaging. The Discovery Algorithm will be run on all datasets collected by ASE.

Science-driven planning and "Rapid Response" observations: An important facet of this mission is demonstrating how onboard science analysis can drive mission operations. For example, on making a successful detection of change, ASE can request, 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 rapid response observation may be obtained on the next available orbit, and certainly within 48 hours. This is to monitor an event already identified by ASE as active.

Versatility of ASE: The ASE algorithms run on any formed image. Currently, we are testing the algorithms on images formed from radar, visible and infrared datasets (Shuttle X-SAR, SIR-C, AirSAR, ERS-1, Galileo NIMS and SSI, EO-1, MGS-MOC, Themis). In 2003 we will be carrying out deployment of ASE on the JPL AirSAR DC8 and the EO-1 (Earth Observer) spacecraft.

AirSAR deployments in 2003: In September 2002 we obtained C, L and P band SAR data of selected targets in the SW United States with the JPL AirSAR DC-8. Targets included Death Valley, CA, Silverton, CO and Cameron, AZ. Exact repeat-track observations of these and other targets will be obtained in March and July 2003, and ASE will be run on these data to detect: (1) the formation and retreat of ice on lakes; (2) change in surface and near-surface water content, and possibly (3) topographic change due to erosion over the winter (primarily at fire-scars). We will be carrying the ASE change detection algorithm onboard the AirSAR DC-8 and by tapping into the data stream the AirSAR data can be analysed by ASE in real time to search for change. If change is successfully detected 'rapid response' planning can be carried out in shadow mode.

EO-1 deployment in 2003: Elements of ASE software will fly onboard the Earth Observer-1 (EO-1) spacecraft in April 2003 as part of a pilot experiment to evaluate ASE technology. 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 per pixel resolution. A section of an ALI image of Kilauea, Hawai'i, is shown in Figure 1. ASE can process up to six separate wavelengths from each hyperspectral product. Also onboard EO-1 is *ALI*, the Advanced Land Imager, which has 10 wavelengths covering the same range as Hyperion, but includes a PAN band that yields 10 m per pixel resolution.

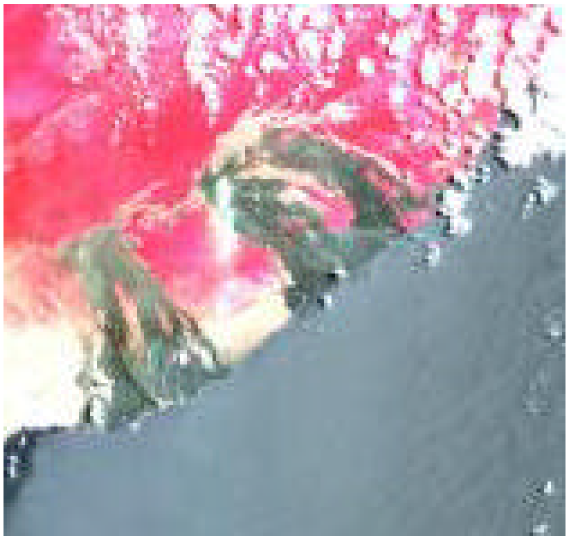

Figure 1. A section of an ALI observation of Kilauea, Hawai'i (obtained 23/05/2001). The plume from Pu'U O'o can be seen. Other images show areas of new lava emplacement and the plume from the ocean entry. ALI swathe width is 37 km, Hyperion 7.7 km.

Target Selection: EO-1 targets are selected for processes with extraterrestrial analogues. Examples include active volcanism (targets include Kilauea, HI, and Etna, Sicily, with the extraterrestrial analogue being Io), ice formation and retreat (Bering Sea, high altitude lakes in Colorado and the Himalayas, catastrophic flooding (targets may include areas inundated and modified by monsoon-, typhoon-, and Hurricane-induced flooding such as in Central India, China, and central America, respectively), and aeolian features such as sand dunes, for testing ASE feature identification. In addition to daytime observations, nighttime observations will be made of selected volcanoes. Thermal emission from active volcanism is more easily identified at night at EO-1 instrument wavelengths, where there is no reflected solar component to the observed spectra.

References: [1] Chien, S. *et al*. (2001) I-SAIRAS, 6th Symp. on Artificial Intelligence, Robotics and Automation in: Space. Montreal, Canada, June 2001. [2] Davies A. G. *et al*. (2001) ASC Science Study Report, available from http://ASE.jpl.nasa.gov. [3] Burl, M. C. *et al*. (2001) Automated Detection of Craters and Other Geological Features. Intl. Symp. Artificial Intelligence Robotics & Automation in Space, Montreal, Canada, June 2001.