

## MONITORING FLOODS WITH NASA'S ST6 AUTONOMOUS SCIENCECRAFT EXPERIMENT: IMPLICATIONS ON PLANETARY EXPLORATION

Felipe Ip<sup>1</sup> (felipe@hwr.arizona.edu), J. M. Dohm<sup>1</sup>, V. R. Baker<sup>1</sup>, B. Castano<sup>2</sup>, S. Chien<sup>2</sup>, B. Cichy<sup>2</sup>, A. G. Davies<sup>2</sup>, T. Doggett<sup>3</sup>, R. Greeley<sup>3</sup>, R. Sherwood<sup>2</sup> <sup>1</sup>Dept. of Hydrology and Water Resources, University of Arizona, Tucson, AZ 85721, <sup>2</sup>Jet Propulsion Laboratory, Pasadena, CA 91109-8099, <sup>3</sup>Dept. of Geological Sciences, Arizona State University, Tempe, AZ 85287

**Introduction:** NASA's New Millennium Program (NMP) Autonomous Sciencecraft Experiment (ASE) [1-3] has been successfully demonstrated in Earth-orbit. 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, image formation, and science processing software was uploaded to the Earth Observer 1 (EO-1) spacecraft in early 2004 and has been undergoing onboard testing since May 2004 for the near-real-time detection of surface modification related to transient geological and hydrological processes such as volcanism [4], ice formation and retreat [5], and flooding [6].

Space autonomy technology developed as part of ASE creates the new capability to autonomously detect, assess, react to, and monitor dynamic events such as flooding. Part of the challenge has been the difficulty to observe flooding in real time at sufficient temporal resolutions; more importantly, it is the large spatial extent of most drainage networks coupled with the size of the data sets necessary to be downlinked from satellites that make it difficult to monitor flooding from space. Below is a description of the algorithms (referred to as ASE Floodwater Classifiers) used in tandem with the Hyperion spectrometer instrument on EO-1 to identify flooding and some of the test results.

**ASE Floodwater Classifiers:** The ASE Science Classifiers (including the floodwater classifiers [6]) utilize up to 12 bands of Level 0.5 Hyperion data (226 bands covering 0.4 to 2.5 microns) to classify scenes onboard EO-1 via spectral analysis, identifying water in flood-affected areas. If the number of pixels in a processed scene onboard the spacecraft exceeds the predetermined threshold, then more data are acquired of the target of scientific interest. A trigger leads to the generation of a sequence of observations and rapid return of data flagged as "important" (e.g. data at 3 wavelengths used by the floodwater classifier for identification of 'wet' water pixels).

Commonly used classification assessment techniques were used to make sure that the classifiers performed adequately for the detection of flood waters at various geographical locations. Field data were also used when possible to ground truth the classifications. Adjustments to the classifier thresholds were made depending on geographical and seasonal factors to ensure optimal performance in different conditions. Both ground and onboard testing were done on the floodwater classifiers.

For instance, in February 2004, a rare flooding event along the Australian Diamantina River was captured by EO-1 (Fig 1). In addition, in August 2004 during ASE onboard testing, a Zambezi River scene in Central Africa was successfully triggered by the classifier, and EO-1 responded autonomously by taking a specified scene of another targeted

region, the Ivai confluence of Mato Grosso do Sul in Brazil (Fig. 2a). Yet another successful trigger-response flooding test scenario of the Yellow River in China was captured by ASE on 8/18/04 (Fig. 2b).

**Summary and future work:** Past space missions have been well conceived to take and retrieve pictures of the Earth, as well as other planetary bodies in the Solar System, but they were not designed to respond to natural phenomena. Rather, these previous missions relied on ground-based efforts, which included data processing by numerous technicians, data analysis by multiple scientists, and ultimately the planning of new observations collectively by both engineers and scientists. All these actions required tremendous energy (e.g., human power), time, and cost. As a result, by the time they could all occur, the transient process was all but over.

Onboard testing of ASE science classifiers has successfully demonstrated the ability to autonomously detect and classify floods and other transient processes [4,5,6], and trigger further data acquisition, providing high temporal resolution of dynamic events, as well as tremendous cost savings through (a) reducing data downlink with increased science return of data by filtering no-change/null data and returning only the most useful data (including a savings of onboard data resources such as storage, memory size and processor speed); (b) onboard decision making to overcome communication delays, resulting in improved response time to dynamic events.

ASE has demonstrated how a spacecraft can be controlled by an intelligent computer onboard the orbiting spacecraft to autonomously capture transient flood-related phenomena, which includes the onset of flooding. This effort is paving the way for future smart reconnaissance missions of transient processes on planetary bodies beyond Earth. On Mars, for example, detection, mapping, characterization, analysis, and long-term monitoring of transient scientific phenomena will greatly improve the understanding of current atmospheric, surface, and subsurface conditions (e.g., advance and retreat of water and CO<sub>2</sub> ice, the formation of dust storms, and possible spring-fed aqueous activity).

**References:** [1] Chien et al. (2003) Proc. I-SAIRAS 2003, Montreal. [2] Sherwood, R., et al. (2004) Preliminary Results of the Autonomous Sciencecraft Experiment, Proceedings of the IEEE Aerospace Conference, Big Sky, MT, March 2004. [3] Davies A. G. et al. (2001) ASE Science Study Report, available from <http://ASE.jpl.nasa.gov>. [4] Davies et al. (2005) Maximizing Mission Science Return through use of Spacecraft Autonomy: Active Volcanism and the Autonomous Sciencecraft Experiment, this volume [5] Doggett et al. (2005) submitted to Rem. Sens. Env. [6] Ip et al. (2005) sub. Rem. Sens. Env.

**Acknowledgements:** We are grateful to the City of Tucson and Tucson Water for their critical cooperation in this activity.

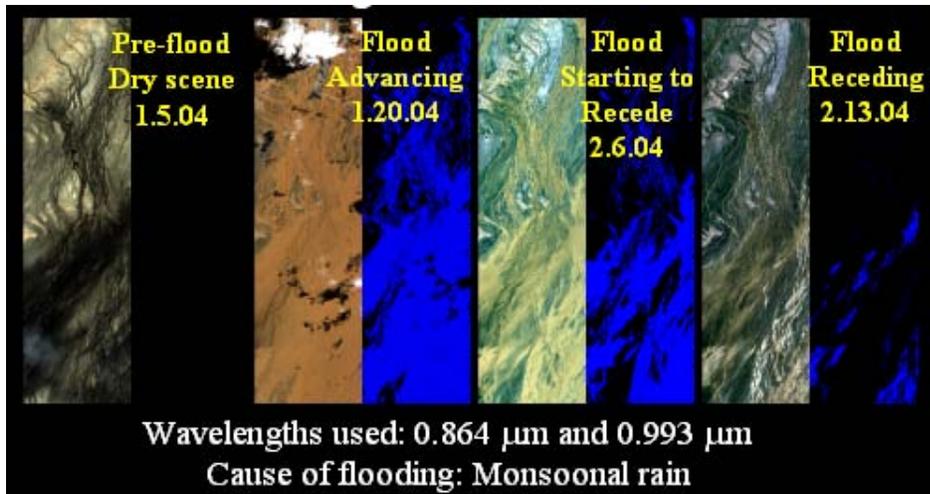
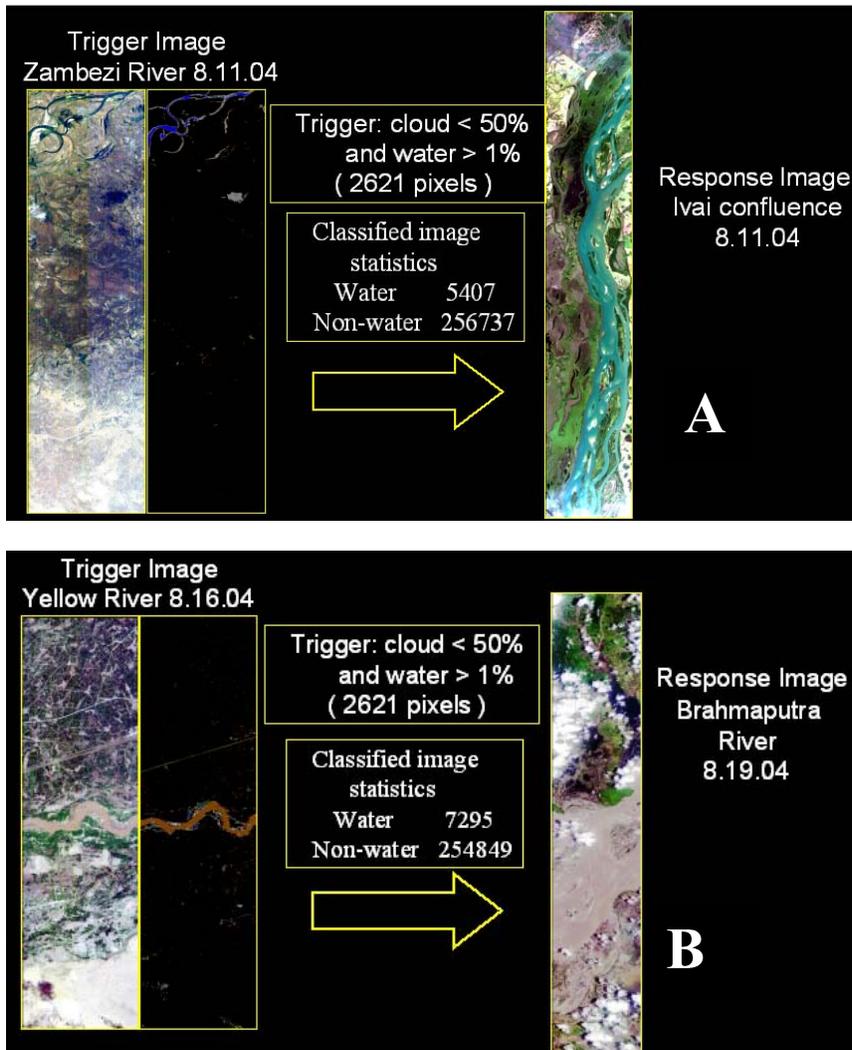


Figure 1. Detection of a rare major flood on Australia's Diamantina River using the ASE floodwater classifiers.



Figures 2a, 2b. Examples of successful ASE triggers and responses onboard EO-1 (note that the triggered responses were specified scenes of different targeted regions).