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SensorWeb Evolution Using the Earth Observing One (EO-1) Satellite as a Test Platform

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ABSTRACT

The Earth Observing One (EO-1) satellite was launched in November 2000 as a one year technology demonstration mission for a variety of space technologies. After the first year, in addition to collecting science data from its instruments, the EO-1 mission has been used as a testbed for a variety of technologies which provide various automation capabilities and which have been used as a pathfinder for the creation of SensorWebs. A SensorWeb is the integration of variety of space, airborne and ground sensors into a loosely coupled collaborative sensor system that automatically provides useful data products. Typically, a SensorWeb is comprised of heterogeneous sensors tied together with a messaging architecture and web services. This paper provides an overview of the various technologies that were tested and eventually folded into normal operations. As these technologies were folded in, the nature of operations transformed. The SensorWeb software enables easy connectivity for collaboration with sensors, but the side benefit is that it improved the EO-1 operational efficiency. This paper presents the various phases of EO-1 operation over the past 12 years and also presents operational efficiency gains demonstrated by some metrics.

INTRODUCTION

EO-1 Satellite was launched from Vandenberg Air Force Base on November 21, 2000, as the first Earth observing platform in NASA's New Millennium Program (NMP). The NMP was envisioned to develop new technologies and strategies that improve the quality of NASA's future space-based observations, while reducing cost and development time. The launch itself was innovative, since the EO-1 was co-manifested with an Argentine Earth observing satellite, the Satellite de Aplicaciones Cientificas-C (SAC-C), marking the first time that two major payloads of dissimilar nature were delivered to their respective orbits through a single Delta-II rocket launch. The purpose of the EO-1 mission was to demonstrate ten new space technologies which included the Advanced Land Imager (ALI), which is a prototype for the Landsat-7 replacement instrument with 30 m spatial resolution (and a 10 m panchromatic band); the Hyperion imaging spectrometer, with 10 nm spectral and 30 m spatial resolutions, and eight other technologies such as the Pulse Plasma thruster. The EO-1 mission exceeded its primary goals by completing the technology validation portion of the mission in less than one year. The EO-1 team then sought to extend the mission by transforming the mission by expanding the user base to include more science users and also by providing EO-1 as a testbed for other technologies. The following sections provide a historical perspective on the various phases and the impact to the mission.

Operational Phases

The evolution of the ground system architecture and procedures is shown in this section. A high level diagram of the original end-to-end ground data system, utilized between November 20, 2000 and early 2003 is provided [**Fig 1**]. During those early mission years, EO-1 operations typically acquired 2-4 images per day, and it typically took 1-2 weeks to receive Level 1 data once the satellite was tasked. The tasking of the EO-1 satellite was a complex task in which a committee comprised of the Deputy Mission Scientist, the Mission Systems Engineer, a USGS representative and the EO-1 Mission planner met daily during the first few months, but ramping that down to weekly over a two to three year period to create the tasking plan for EO-1. Furthermore, these meetings often had to draw in instrument leads, scientists, technologists and other operational personnel to deconflict all the required activities. Operational personnel manned the mission 24 hours per day, 7 days per week. The operational staff included four full time mission planners. The EO-1 operations budget was $10 million during the first year and phased down to $5 million during the third year of operations. Sending the set of commands to the satellite to take an image at a particular location with one of the instruments took 67 steps and was manpower intensive.

[Fig. 2] depicts the first major upgrade to EO-1 operations that occurred in 2003. The Autonomous Sciencecraft Experiment (ASE) which was onboard autonomy software was integrated to work in conjunction with ground software components, enabling automating of many previously manual operations tasks. The effort was conducted as a technology validation project under the New Millennium Program and the effort is further described in [1]. Eventually, once validation was complete, ASE was adapted as an operational element of EO-1 operations. The key feature of the system is an onboard planner, the Continuous Activity Scheduling Planning Execution and Replanning (CASPER) system, which was coupled with a ground based planner, the Automated Scheduling and Planning Environment (ASPEN), to manage user requests for EO-1 images in an automated manner. The result was a reduction of operations costs down to $2.2 million per year. Part of this cost reduction was due to elimination of the night shift with the added automation. Furthermore, the planning staff was significantly reduced.

The ASE onboard software responds to goals and therefore the tasking of EO-1 became less complex with the bundling of the procedures into the process of goal uploads.

During this phase, NASA partnered with US Geological Survey (USGS) to manage the EO-1 imagery and distribute it to the public. The fee for an EO-1 image to the public was $1500 for acquisition requests (i.e., tasking) of EO-1 scenes and $500 to get the data product from their archive.

[Fig. 3] shows Phase 3 which took place between 2005 and 2009, in which Open Geospatial Consortium (OGC) SensorWeb Enablement (SWE) and other web services were added to further automate operations and provide a better user interface both for operations and external users. The OGC compliant web services were integrated both at JPL and GSFC. Furthermore, a commercial cloud was added hosted by Joyent Inc. which in turn was use to host GeoBliki and GeoBPMS. GeoBliki is the service that is the user interface for data products and provides links to those products via RSS feeds. The GeoBPMS is the tasking tool that interacts with the GSFC Sensor Planning Service (SPS) and allows users to submit tasking requests for their area of interest with secure authentication over the open Internet. The user can request an EO-1 image via a map interface and then GeoBPMS notifies the user when the data is available. The user interface makes use of a federated authentication system based on OpenID.

At this point, EO-1 images provided via the USGS, including tasking, was lowered to $750 in 2008 from $2250 per scene and beginning in 2009, became free to all NASA investigators. In addition, excess tasking capacity was used and still is used to serve the public's requests on an "as available" basis. During this timeframe, the total automation of the data production chain was not complete.

[Fig. 4] shows Phase 4 in which cloud computing was added to EO-1 operations. Data processing functionality was moved to a cloud provided by Open Cloud Consortium (OCC) and the Moore Foundation. This cloud, named the Matsu cloud, enabled storage for up to two years of data products and quick access to create higher level data products via an automated data pipeline. With the introduction of the Matsu cloud, users were able to automatically obtain Hyperion and ALI Level 1 Radiometrically corrected data, Level 1 Geometrically Corrected (G) data and Level 1 G Atmospherically Corrected (AC) data. Most of these data products are still available via the USGS, however, the cloud transformed EO-1 into more of a “do-it-yourself” operation. Furthermore, with the addition of the Web Coverage Processing Service (WCPS), users are able to design customized algorithms to run against the L1R, L1G and L1 AC data.

Note that at this point, EO-1 operations is making use of two clouds, the commercial Joyent cloud and the Matsu cloud provided by OCC. For the future, the team may migrate all of the functionality to one cloud. On the other hand, it a may make sense to keep both clouds to add system robustness and eliminate single points of failure.

[Fig. 5] shows the transition from the traditional method to order EO-images via USGS, to the cloud-based, self-service mode for users. Users can choose any of four ways to order images from EO-1; (1) via the USGS web interface, in which case the data products are delivered from USGS (2) via direct request to the EO-1 Mission Science Office in which case the tasking request in somewhat of a manual process with data product delivery either done by the MSO or USGS (3) via the JPL OGC compliant Sensor Planning Service (SPS), in which case there is (TBS delivered products) or (4) via the GeoBPMS with automatic delivery of data products via the cloud.

Metrics:

The EO-1 project attempted to measure the improvement of operational efficiency due o the various upgrades that were infused from the test bedding activities. This included the installation of various flight and ground software highlighted in the previous section. The multiple upgrades to the flight autonomy software was the primary reason that EO-1 has now been able to average 150-160 images per week instead of 120-130 scenes per week previous to 2009 and the 28 images per week at the beginning of the mission. In particular, one of the key new capabilities of the latest flight software upgrade is the capability to image up to 4 different images per orbit whereas the previous version of flight software only allowed up to 2 scenes to be images per orbit.

Another key capability is the expanded methods to request EO-1 imagery and thus more capacity to handle more users. As outlined in figure 5, there are now four ways to request EO-1 images which includes a streamlined internet based method with no interaction required from operational staff.

[Table 1] shows that with the new SensorWeb capabilities and other capabilities added, EO-1 disaster image requests trended up, turn-around time to receive images went down and the cost per scene went down(calculated by dividing the annual cost of operating EO-1 by the total images taken).

FIGURES

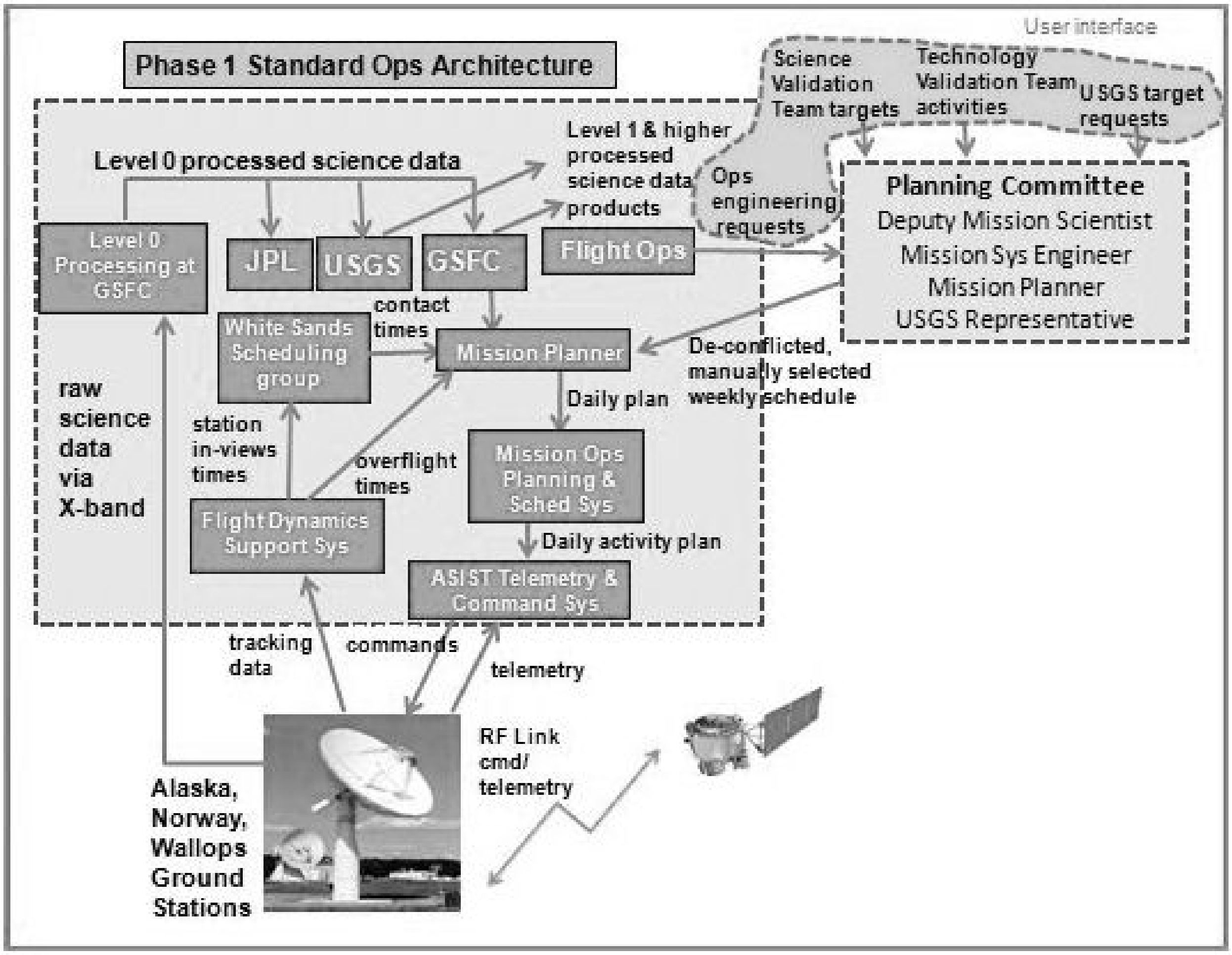

Fig. 1. *In phase one of EO-1 operations, most of the procedures were manpower intensive*

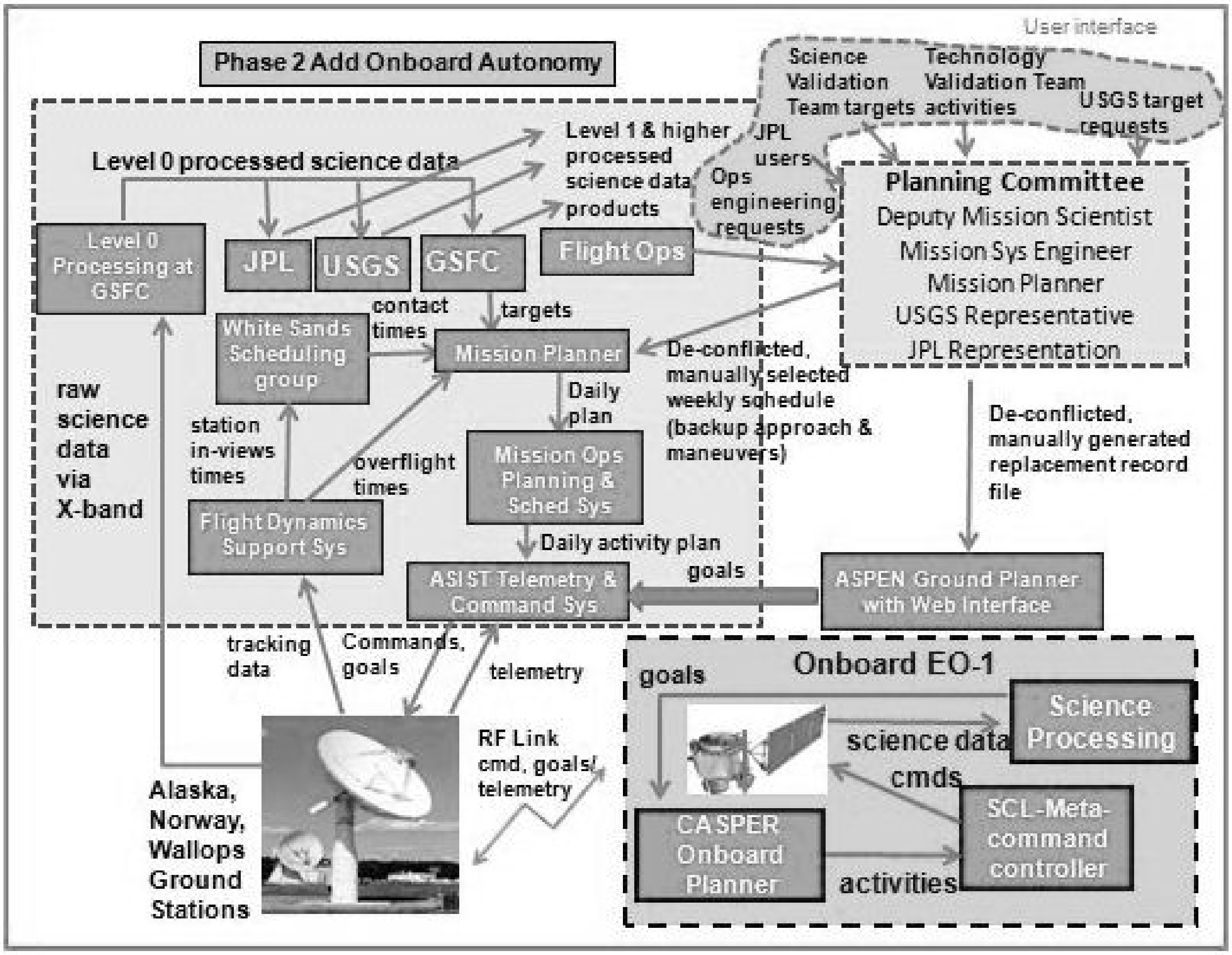

Fig. 2. *In phase 2, onboard autonomy software was added which reduced the effort for planning and thus the planning committee reduced their meetings to once a week*

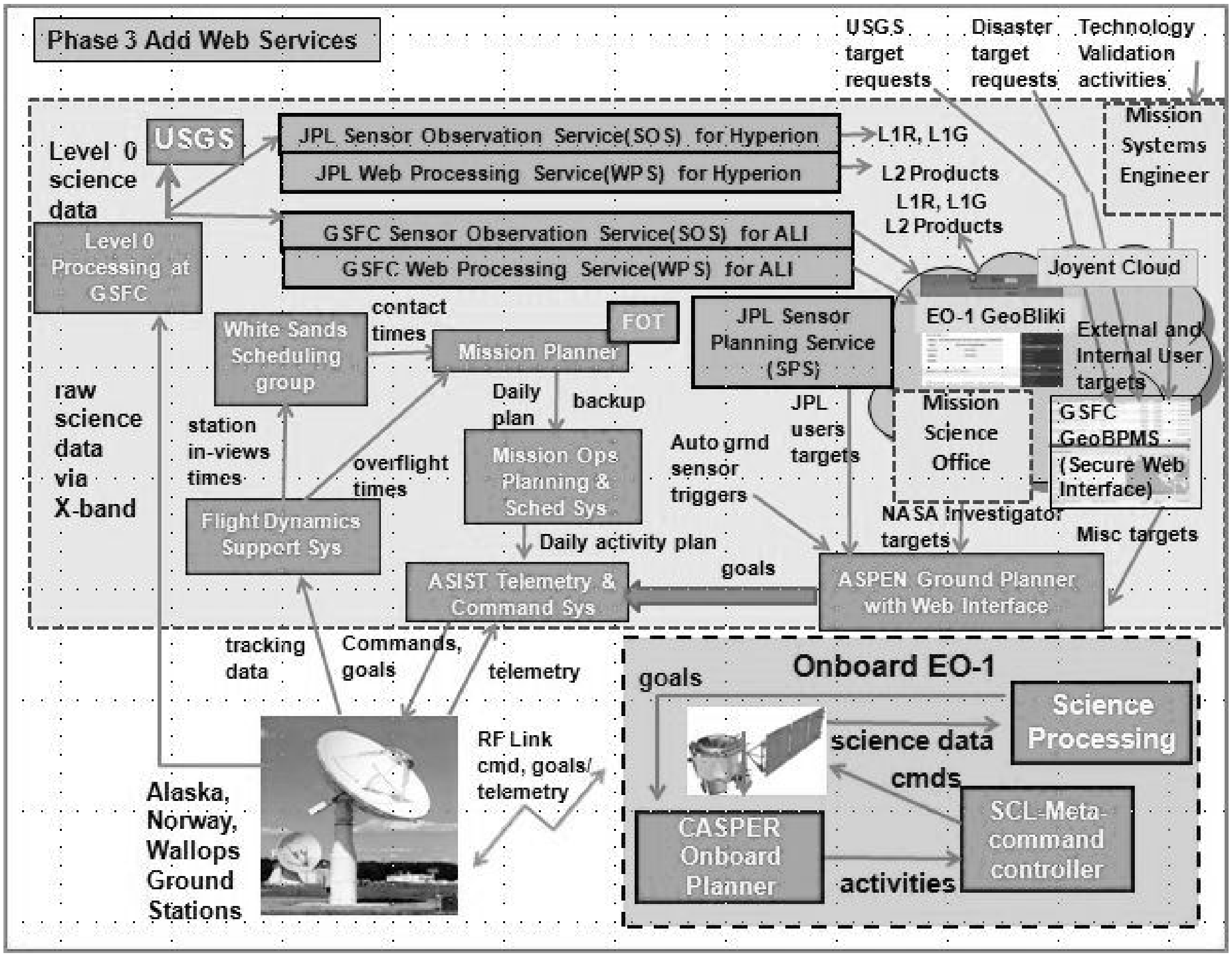

Fig. 3. *In phase 2, OGC compliant web services were added at both GSFC and JPL to create a more user friendly interface to EO-1 and thus decrease complexity of obtaining EO-1 data products.*

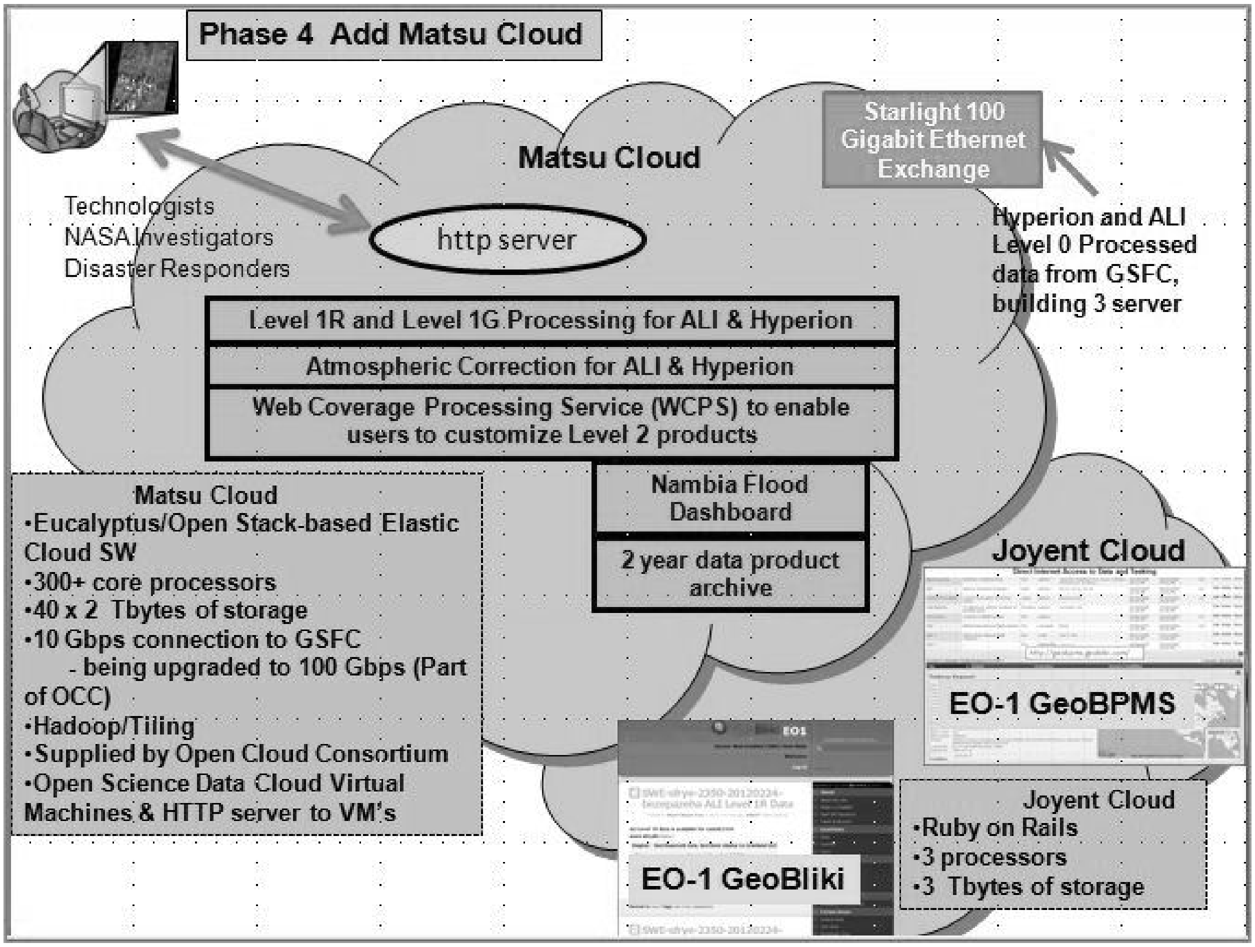

Fig 4. *In phase 4, cloud computing was added to enable handling of large data sets and many users*

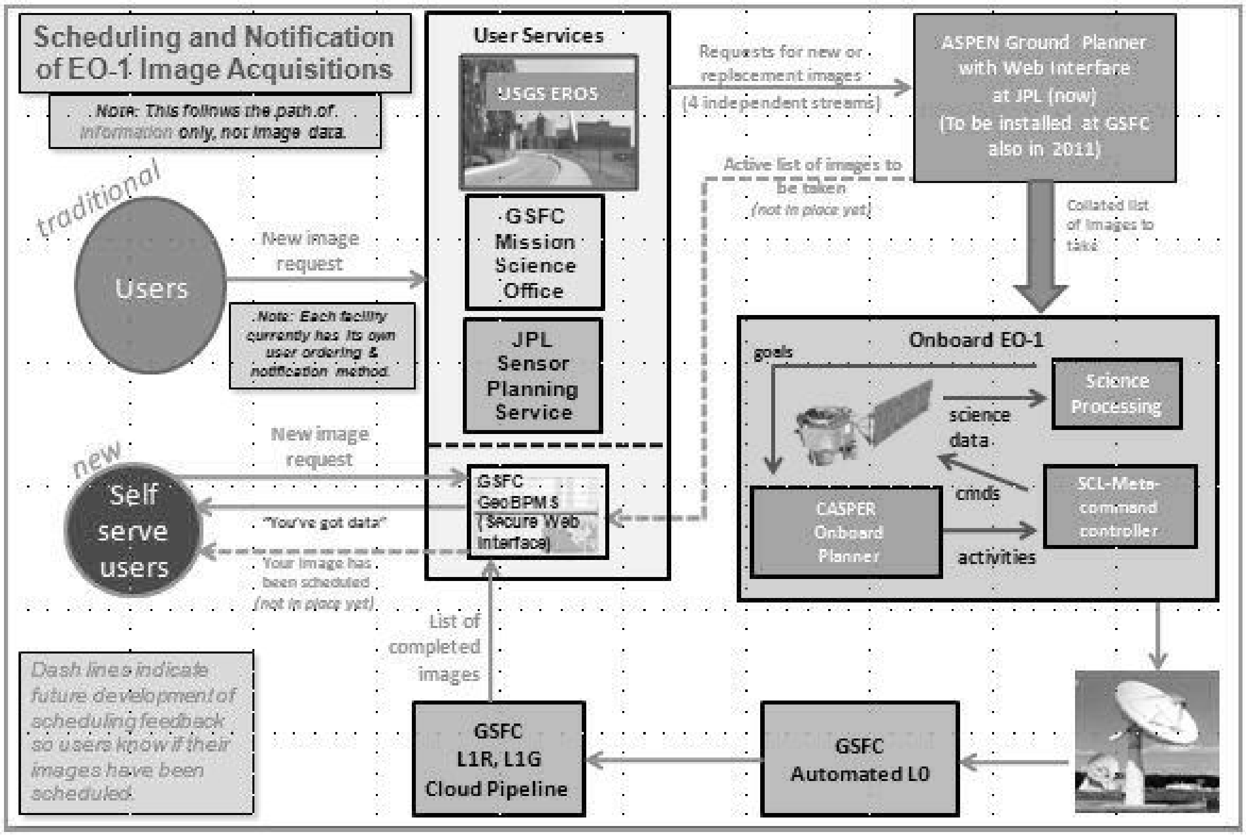

Fig. 5. *Shows transition of traditional tasking to the automated, cloud-based, self-service method to order EO-1 images*

Time Range	Total Scenes per week	Total Disaster Requests	Minimum Time to execute a target replacement	Minimum time to deliver data after acquisition	Cost per scene	Comments
Launch - 2004	28-60	One per quarter	7-10 days	10-21 days	$7500	No Automation
2005-2007	80-100	One per month	24 hours	10-21 days	$3500	SGM/ASE R1
Jan-Jun 2008	100-130	2-3 per month	24 hours	24 hours	$1500	EDOS/GEOBLIKI
Jul-Dec 2008	100-130	One per week	16 hours	16 hours	$750	GEOBPMS/ASE R3

Jan-Jun 2009	130-160	3 per week	8 hours	12 hours	$500	JAVA Client
Jul-Sep 2009	160-200	5 per week	5 hours	8 hours	$200	ASE R5/OpenID

[Table 1] *This table demonstrations the improvement of EO-1 operational efficiencies due to the addition of SensorWeb and other technologies into operations*

REFERENCES:

[1] Mandl, D., "Matsu: An Elastic Cloud Connected to a SensorWeb for Disaster Response", GSAW, Los Angeles, CA, March 2, 2011

[2] Cappelaere, P., Stu Frye, Dan Mandl, "Flow-Enablement of the NASA SensorWeb using RESTful (and Secure) Workflows", IEEE Aerospace Conf 2009, March 2009, Big Sky, Montana

[3] Mandl, D., Rob Sohlberg, Stu Frye, Pat Cappelaere, Steve Ungar, Steve Chien, and Danny Tran, "An Updated Status of the Experiments with Sensor Webs and OGC Service Oriented Architectures to Enable Global Earth Observing Systems of Systems," GSAW 2007, March 27-29, 2007, Manhattan Beach, CA.

[4] Mandl, D., "A Service Oriented Architecture to Enable Sensor Webs," 2006 AGU Fall Meeting, San Francisco, CA, December 11-15, 2006.

[5] Mandl, D., "Challenges in Transforming Space Missions Into Service Oriented Architectures," 58th OGC Technical Committee Meeting, Tyson's Corner, VA, October 4, 2006.

[6] Mandl, D., Stuart Frye, and Pat Cappelaere, "Transforming Space Missions Into Service Oriented Architectures," 18th Global Grid Forum – GGF18/GridWorld, Washington, DC, September 12, 2006.

[7] Cappelaere, Pat, and Linda Derezinski, "EO-1 Geo-Bliki – OGC Sensor Web Enabled Data Node," FOSS4G2006, Lausanne, Switzerland, September 11-15, 2006.