The 2011 off the Pacific coast of Tohoku Earthquake (9.0-magnitude) was occurred at off the north-east coast of Japan on Friday, 11 March 2011. There was also a big earthquake at Tsukuba (intensity 6) that caused severe damage to Space Station Integration and Promotion Center (SSIPC) at the Tsukuba Space Center. When the earthquake occurred, Japanese Experiment Module (JEM: KIBO) and H-II Transfer Vehicle 2 (HTV2: KOUNOTORI 2) were under real-time operation and controlled from the SSIPC. SSIPC structure, JEM and HTV ground systems were damaged by the earthquake and Pacific circuit between SSIPC and NASA Johnson Space center was lost by the earthquake as well. The JEM and HTV real-time operation at Mission Control Room, SSIPC was restricted due to above damages for approximately 10 days. During that period, JEM and HTV flight controllers kept monitoring the onboard vehicle with the PC-based telemetry monitoring capability with support of NASA flight controllers. This paper describes how the damage of the JEM and HTV operation systems caused by this earthquake has been recovered. In addition, a countermeasure preparing for large-scale earthquake will be described.

I. Introduction

The 2011 off the Pacific coast of Tohoku Earthquake was caused by a 9.0-magnitude undersea mega thrust earthquake off the north-east coast of Japan that occurred at 14:46 JST on Friday, 11 March (23:46 CST on Thursday, 10 March) 2011. SSIPC/Tsukuba Space Center had a big shake (Intensity 6) and was damaged by the earthquake. The earthquake triggered extremely destructive tsunami waves of up to 37.9 meters (124 ft) high that struck the Tohoku-district about 30 minutes after the quake.

Epicenter of a quake: 38.322N / 142.369E, 130km (81miles)
Depth: 24km (15miles)
Magnitude: 9.0Mw
Duration: 6 min

II. JEM and HTV Operations concept

The first element of Japanese Experiment Modules (JEM) was launched and attached to the International Space Station (ISS) core on March 2008, and Japan’s first human spaceflight ground operation has been started since then. NASA is responsible for overall ISS operation and safety. Space Station Control Center (SSCC) at NASA Johnson Space Center (JSC) is key ground segment for the ISS integrated planning, monitoring, and commanding to ensure the ISS operation integrity. Under the oversight of SSCC, JEM specific planning, monitoring, and commanding as well as experimental payload operation and

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associated trainings are conducted at JAXA SSIPC in Tsukuba Space Center (TKSC), Japan. [1], [2], [3]

Figure 2 shows the viewing of the JEM ground operation at SSIPC.

Under above ISS distributed operations architecture, NASA provides ISS main link to SSCC and Huntsville Operations Support Center (HOSC) using Tracking Data Relay Satellite (TDRS) as NASA link.

JEM OCS interfaces with SSCC for JEM system operations and HOSC for experiment payload operations as depicted in Figure 3.

In conjunction with NASA link, JEM also provides the JAXA unique space-to-ground link called “ICS link” as dedicated link for JEM system back up operations as well as for JEM experiment payloads high rate data transmission.

The ICS link is realized with Inter-orbit Communication System (ICS) installed in JEM onboard and Japanese Data Relay Test Satellite (DRTS).

HTV Operation Control System (HTV OCS) also has interface between SSIPC and JSC for Telemetry and Command operations. In addition HTV OCS has direct link using TDRS to reach the HTV directory. Figure 4 shows the overview of HTV operations.

III. Impacts of the JEM and HTV Operation Systems by the earthquake

Both JEM and HTV operations system as well as SSIPC building structure were extremely damaged as follows.

A. Pacific circuit (submarine cables)
1) SSCC ATM circuit : Both #01, #51 were cut down (Rerouted on March 17th via Hong Kong)
2) HOSC IP circuit : No damage
   JAXA kept telemetry monitoring capability using HOSC connection with reconfiguration. The voice interface used HOSC voice channel with re-assignment as well. It switched back to nominal configuration on March 18th after JSC circuit recovery.)

B. JEM Operations Control System (JEMOCS)
1) New (replaced) OCS servers: No damage occurred.
2) Old servers : Moved and toppled because earthquake-resistant fixed metal fittings came off.
3) Client terminals: Some LCDs were dropped from console.
4) Data storage system (Tape Archiver): power cable cut down.

C. HTV Operations Control System (HTVOCS)
1) Client terminals: Some LCDs were broken.

D. SSIPC building structure
1) 1F Mission Control Room (MCR) / User Operation Area (UOA) : No damage occurred.
2) 4F corridor (where JEM/HTV OCS server’s harnessed): Ceiling panels fell down, but the power cables of the JEM/HTV OCS servers Figure 2. JEM Operation Overview at SSIPC ©JAXA.

Figure 3. Overview of JEM Operation Systems.
were barely safe with support of air conditioner’s ducts assembly.
3) 4F computer room: Bookshelves and Ceiling lights were fell down, old JEMOCS servers were moved, client terminals were fell from the desks
4) 4F MCR2: Client terminals fell from the desks
5) 4F warehouse: Documents and spare equipments were scattered

IV. JEM and HTV Real-Time Operations just after the Earthquake

JEM and HTV telemetry data and voice communication was received via BCC-HOSC after reconfiguration because the pacific circuits for JSC were cut down.

JEM and HTV flight controllers had the real time operation in a conference room at the other building as the temporary operation room (only 8hours / during daylight).

Operations during night time (from 17:00 to 8:00JST) were supported by Tsukuba support group in Houston (TSG) and JFCT who flew to Houston in order to continue JEM operations.

For the temporal JEM and HTV operations, some web based tools were temporarily provided from NASA.
JFCTs had minimum operations using web-based telemetry monitoring tool “MCC DPS” and web based voice loop monitoring capability “MCC Audio” in the temporary operation room. And commanding capability was supported by Houston Flight Control Team under JEMFCT monitoring.

JEM and HTV OCS were reconfigured to establish telemetry, command and C&W interface with MCC-H since JSC-SSIPC Pacific circuit was recovered on March 17th, via Hong Kong and returned to nominal operation on March 22nd, 2011.

V. Lessons Learned from the Earthquake

We were fortunate to recover JEM and HTV operations quickly, and were able to completed HTV2 mission after the earthquake due to ...

1) No human damage nor injured
2) SSIPC building structure itself was safe
3) No damage at power equipment at SSIPC
4) No damage at air conditioning system at SSIPC
5) The quick recovery of Pacific circuit with re-routing
6) Several JFCTs were in Houston at that time and were able to support the real time operation from Houston.
7) Pacific circuit between SSIPC and MSFC was already changed from ATM to IP based circuit which was no impacted.

A. Web based Telemetry / Voice monitoring tool.
NASA provided web-based telemetry and voice monitoring capabilities were very useful for us under circumstances like this time.
JFCTs made a request to use the tools for the preparation of future disaster.

B. Power source redundancy
Last March, we were lucky to keep power
source for the HTV and JEM operation system servers located in Ops building 4th floor. However, some electrical leakage happened in the building. Therefore, JAXA decided to install an additional power cable to the servers from different building to make power redundancy. An additional power interface will be installed in Japanese fiscal year 2012 (From April 1st to March 31st).

C. Back up control center (BCC) development
   As a lessons learned from the huge earthquake struck during HTV2 mission, JAXA made a decision to develop the Back-up HTV operation room in Astronauts Training Facility (ATF) in Tsukuba Space Center.
   Installation of BCC function for HTV operation was completed on March 3rd, 2012 except for voice system. (Voice system will be available at the end of May, 2012)
   BCC function for JEM system and payload operations is also under development phase. Detail status of BCC development is described in section VI.

D. TSG commanding certification
   TSG is a team which supports JEM operations from Houston. Usually they are supporting JEM operations with their console for checking JEM down linked telemetry but they do not have command sending capability. For the lessons learned from the earthquake, JAXA made a plan to train them to get certification for sending commands to JEM in case SSIPC is down.
   Some software modifications of TSG console in NASA asset will be necessary as well.

E. Satellite phone
   The first action for a big earthquake is to evacuate outside of the building. However it sometime takes a long time to go back to the building because of safety inspection. On the other hand, JEM requires real time operations for 24 hours and HTV requires more critical operation especially in rendezvous phase. Therefore, it is important to have communication capability even if Flight controllers are evacuated outside. Having satellite phone (such as Iridium) is one of option to secure communication capability in evacuation phase. It must be useful when communication lines (telephone, cellular phone) are unstable during under disaster.

VI. Backup Control Center (BCC) development status
   When the earthquake attacked Japan, all servers of JEM/HTV Operations system were working well. However operators and flight controllers were kept out from the Operations building for their safety. As lessons learned of the earthquake, JAXA decided to develop the Backup Control Center in Astronaut Training Facility (ATF). ATF is located about 200m from JEM operations building in Tsukuba Space Center (TKSC). (Figure 6).
   There are three backup control rooms in the BCC-ATF. JEM system, JEM payload and HTV operations are conducted in each backup room in case of disaster.

A. Precondition for BCC development
   To develop the BCC-ATF development, JAXA set preconditions for disaster damage as follows;
1) JEM OCS servers themselves are operating normally. (Same as March 2011)
2) Restricted access to JEM Operation Building. (Same as March 2011)
3) Minimum system operations and PL safing are required for short time period.
4) System operations and minimum PL operations are required for long time period.
5) The meeting room will be used as the HTV-BCC for HTV mission phase.
6) JEM-BCC will be kept for 7 days /week. (For external monitoring capability.)

B. Design concept
The design concept of BCC installation is as follows;
1) Keep JEMOCS and HTVOCS main servers on Operation building 4th floor.
2) Install JEM system operation room, JEM payload operation room and HTV operation room individually.
3) Install system client terminals for minimum operation, voice communication terminals and video terminals.
4) Use dark fiber between JEM Operations building and ATF.
5) Install new fiber cable for HTVOCS and payload GSE (IPU-G)

C. Schedule
Figure 8 shows a BCC development schedule. HTV backup control room development was completed at end of March 2012 except for voice terminals. JEM backup control room in ATF will be completed by end of October 2012. The voice terminals will be installed by end of May, 2012.

VII. Conclusion
Since we are conducting JEM and HTV operation in Japan, we cannot ignore the risk of influence caused by the earthquakes and other natural disasters.
It is said that the March 11th earthquake is a great disaster once in 1,000 years, and nobody can predict when the next giant earthquake occurs. It is important to prepare for the earthquake similar this time to mitigate impact to JEM and HTV operations in the future.
## Appendix A
### Acronym List

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<tr>
<th>Acronym</th>
<th>Definition</th>
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<tbody>
<tr>
<td>ATF</td>
<td>Astronaut Training Facility</td>
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<td>ATM</td>
<td>Asynchronous Transfer Mode</td>
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<td>BCC-HOSC</td>
<td>Backup Control Center - HOSC</td>
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<tr>
<td>DRTS</td>
<td>Data Relay Test Satellite</td>
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<td>GSE</td>
<td>Ground Support Equipment</td>
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<tr>
<td>HOSC</td>
<td>Huntsville Operations Support Center</td>
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<td>HTV</td>
<td>H-II Transfer Vehicle</td>
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<tr>
<td>ICS</td>
<td>Inter-orbit Communication System</td>
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<td>IP</td>
<td>Internet Protocol</td>
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<tr>
<td>ISS</td>
<td>International Space Station</td>
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<td>JAXA</td>
<td>Japan Aerospace Exploration Agency</td>
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<td>JEM</td>
<td>Japanese Experiment Module</td>
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<td>JFCT</td>
<td>JEM Flight Control Team</td>
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<td>JSC</td>
<td>Johnson Space Center</td>
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<td>LCD</td>
<td>Liquid Crystal Display</td>
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<td>MSFC</td>
<td>Marshall Space Flight Center</td>
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<td>SSCC</td>
<td>Space Station Control Center</td>
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<td>SSIPC</td>
<td>Space Station Integration and Promotion Center</td>
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<td>TDRS</td>
<td>Tracking Data Relay Satellite</td>
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<tr>
<td>TKSC</td>
<td>Tsukuba Space Center</td>
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<tr>
<td>TSG</td>
<td>Tsukuba Support Group in Houston</td>
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References

Reports, Theses, and Individual Papers

