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International Space Station Research Benefits for Humanity

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The ISS partnership has seen a substantial increase in research accomplished, crew efforts devoted to research, and results of ongoing research and technology development. The ISS laboratory is providing a unique environment for research and international collaboration that benefits humankind. Benefits come from the engineering development, the international partnership, and from the research results. Benefits can be of three different types: scientific discovery, applications to life on Earth, and applications to future exploration. Working across all ISS partners, we identified key themes where the activities on the ISS improve the lives of people on Earth—not only within the partner nations, but also in other nations of the world. Three major themes of benefits to life on earth emerged from our review: benefits to human health, education, and Earth observation and disaster response. Other themes are growing as use of the ISS continues. Benefits to human health range from advancements in surgical technology, improved telemedicine, and new treatments for disease. Earth observations from the ISS provide a wide range of observations that include: marine vessel tracking, disaster monitoring and climate change. The ISS participates in a number of educational activities aimed to inspire students of all ages to learn about science, technology, engineering and mathematics. To date over 63 countries have directly participated in some aspect of ISS research or education. In summarizing these benefits and accomplishments, ISS partners are also identifying ways to further extend the benefits to people in developing countries for the benefits of humankind.

INTRODUCTION

For more than a decade, the orbiting laboratory known as the International Space Station (ISS) provides a unique environment to conduct scientific research and a platform for technology demonstration. Through the vehicle assembly years and into the Era of Utilizaion[1], the benefits of this international collaboration are coming to fruition.

Many benefits that arise when an achievement as large as the ISS comes into existence. Benefits come from the engineering development, international partnership and research results and can be broken down into three different types of benefits: scientific discovery, application to life on Earth, and application to future exploration.

BENEFITS OF ISS

Three areas of benefits that come from the ISS: engineering development, international partnership, and research results.

Engineering Development The ISS is one of the greatest engineering achievements in aerospace history. The components that form the ISS were built in different countries across the international partnership. The only time these modules were assembled together was in orbit, without issue. Technologies were developed as a result of designing and construction of the vehicle.

International Partnership The ISS is an international collaboration between the Canadian Space Agency (CSA), European Space Agency (ESA), Japan Aerospace Exploration Agency (JAXA), Federal Space Agency of Russia (Roscosmos) and the National Aeronautics and Space Administration (NASA). The partnership has worked together for more than two decades to assemble the ISS, conduct scientific research and for technology demonstration. In many cases, the agencies collaborate on specific research investigations to maximize available resources for optimum results. [2]

Research Results The microgravity environment found on the ISS provides unique laboratory conditions that cannot be reproduced on Earth. Participants from more than 63 countries have participated in ISS research and educational activities.[2] The scientific disciplines studies on the ISS include: biology, Earth science, human research, physical science, technology development and demonstration. Results from each of these disciplines will benefits us on earth, expand our knowledge of the universe and prepare humankind for the next step in exploration.

The research results can be broken down into three areas of benefits: scientific discovery, applications to future exploration, and applications to life on Earth.

Scientific Discovery In 2011, a collaboration between the teams from the JAXA MAXI (Monitoring All-sky X-ray Imager) onboard the ISS and the NASA Swift satellite produced documentation of the first observed super massive black hole consuming a star. The Swift team first reported a gamma-ray burst from Swift J1644+57, however, it was the MAXI instrument that was able to provide observation data several hours prior to the Swift observation. The teams combined the data and co-authored a report in *Nature*[3].

Applications to Future Exploration

Applications to life on Earth Working across all ISS partners, key themes were identified where the activities on the ISS improve the lives of people on Earth – not only within in the partner nations, but also in other nations of the world. These are referred to as the Benefits for Humanity[4].

BENEFITS FOR HUMANITY

Research has been conducted on the ISS for more than a decade. Results of this research are now realized with direct benefits for humankind. While there are many areas a research, Human Health, Earth Observation and Disaster Response, and Global Education are the focus for this paper.

Human Health Many different aspects of human health are studied in the unique environment of the ISS. The applications of the research benefits range from new surgical equipment to vaccine development to potential treatments for disease.

The technology developed by CSA for the Canada Arm 2 and Special Purpose Dexterous Manipulator (SPDM), used on the ISS, has found an application in operating rooms. The neuroArm is the world's first robot capable of performing surgery inside magnetic resonance machines. This robotic arm is used for difficult surgeries that may have been considered impossible previously. [4] (Figure 1)

Figure 1: neuroArm with Dr. Garnette Sutherland the team lead for developing this new innovative surgical device. (Image credit: Ken Bendiksten)

Bone health is an issue that is shared on Earth as well as in space. Each of the international partners conducts research on this topic. The research examines all aspects of bone health including nutrition, exercise countermeasures and therapeutic supplements such as

Bisphosphonate. From the nutritional aspect, a study from ESA is evaluating sodium intake and how it affects bone health. The body retains sodium affecting the acid balance of the body and bone metabolism which may lead to accelerated bone loss. [4]

In a study conducted by JAXA and NASA, crewmembers are evaluated on multiple countermeasures to protect against bone loss. These countermeasures include using the therapeutic supplement, Bisphosphonate - well known osteoporosis treatment on Earth. Early results of this study indicate that crewmembers can reduce the risk of bone loss by proper intake of nutrients such as calcium and vitamin D, an effective exercise program and minimal amounts of medication. [4]

The microgravity environment is conducive to growing high quality protein crystal on board the ISS. An investigation conducted by JAXA examined protein crystal growth of the HQL-79 (human hematopoietic prostaglandin D2 synthase inhibitor) protein. This protein is a candidate treatment in inhibiting the effects of Duchenne's muscular dystrophy. The crystals grown in microgravity allowed researchers to more accurately determine the three-dimensional structure of HQL-79 which led to the development of a more potent form of the protein (Figure2). [1][4][5]

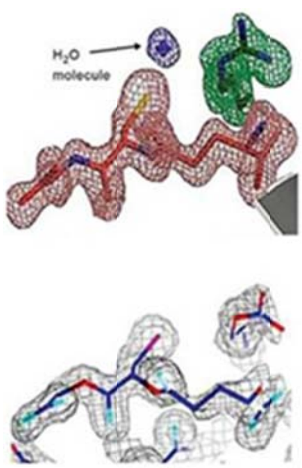

Figure 2 : Electron Density Maps of HQL-79 crystals grown in space show a more detailed three-dimensional structure (top) as compared to those grown on Earth (bottom), which also uncovered the presence of a newly identified water molecule. Figures courtesy of Yoshihiro Urade.

ESA is evaluating the amount of nitrogen monoxide (NO) that crewmembers exhale which is measured by a lightweight device. Inflammation in the airway adds to the amount NO exhaled; by measuring the amount of NO, it is possible to evaluate possible airway inflammation and take the appropriate steps before it becomes a health problem. ESA and Aerocrine AB developed the handheld device known as NIOX MINE®. This device is used in health centers to monitor asthma in patients and to evaluate the efficiency of medication, allowing for more accurate dosing and reduction of asthma attacks. [4]

ISS is being used as a platform for vaccine development by two different teams. Astrogenetix, Inc., has used ISS assembly missions for a microgravity model of virulence to help in the screening of potential vaccines for *Salmonella* food poisoning and for methicillin-resistant *Staphylococcus aureus* (MRSA). Arizona State University Biodesign Institute has conducted spaceflight tests aimed at improving the effectiveness of a vaccine for pneumonia that is currently in clinical trials. [2][4]

Technology to allow remotely-guided ultrasound to be performed by non-specialist operators[6] continues to be applied around the world. This approach has been used in remote areas of Africa to identify pregnant women in need of transport to neonatal care facilities before they go into labor, decreasing the risk to both mother and child. The approach has also been adopted by the American College of Surgeons as a training tool for residents. [4][5]

Early detection of immune changes help in preventing painful symptoms associated with the varicella zoster virus (VZV), commonly known as shingles (Figure 3). VZV is one of eight herpes viruses that may reside in an inactive state in the human body. When the human body experiences increased stress (i.e. psychological, emotion, physical), it may cause the virus to reactive. Researchers evaluated saliva collected from ISS crewmembers to determine if the Epstein-Barr virus (EBV), an early indicator of VZV, was present; thus indicating reduced cellular immunity. New technology was developed for a method of rapid detection that uses small samples of saliva. Studies on Earth and on-orbit, led to an early diagnosis and treatment of VZV, preventing the Earth bound patient from experiencing lesions and pain associated with VZV. [4][7]

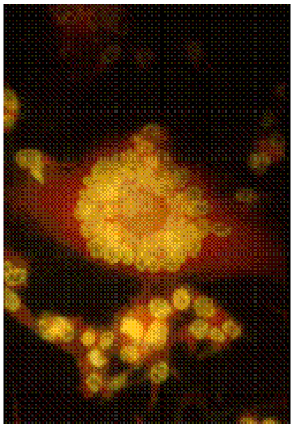

Figure 3: VZV infected MeWo cells showing typical herpes-virus-induced multinucleated giant cells. Cultures are stained with acrydine orange to identify RNA (red) in the cytoplasm. (Image credit: NASA)

Microencapsulation techniques are being used in the oncology community as an approach to treating cancer. With microencapsulation, anti-tumor drugs are delivered directly to the tumor via liquid filled, biodegradable micro-balloons. Research conducted on the ISS in 2002 has improved microencapsulation technology that is used on Earth. The microgravity environment was used to modify the fluid mechanics, interfacial behavior, and biological processing methods when compared to terrestrial methods. This research led to the development of the Pulse Flow Microencapsulation System (PFMS), an Earth-based system that can replicate the quality of the microcapsules created on the ISS. The system combines two immiscible fluids where surface tension forces, rather than fluid shear, dominated at the interface of the fluids. The technologies and method used in this research are now to create micro-balloons that provide sustained release of drugs over a 12 to 14 day period. Clinical trails using this method in conjunction with NuVue Technologies, Inc developed therapies are to be conducted at MD Anderson Cancer Center in Houston, TX and the Mayo Clinic Cancer Center in Scottsdale, AZ. [4][[8][9]

Clean water is essential to maintaining proper health on Earth and in space. The Water Recovery System (WRS) onboard the ISS recycles water for the crewmembers. The filtration technology in the WRS uses iodinated resin to control microbial growth in water. This technology has been used to develop filtration systems for use on Earth in regions that lack clean water.[4]

Earth Observation and Disaster Response The ISS provides a platform for Earth remote sensing through multiple autonomous instruments and crew photography. The data collected from these different avenues are used to study atmospheric changes, weather systems such as hurricanes/typhoons, environmental changes, in addition to natural and human made disasters.

The Crew Earth Observations (CEO) program on the ISS has collected more than 600,000 images since the first crew arrived in the year 2000. The ISS orbit is unlike the traditional remote sensing satellites in that the ISS orbit is not sun-synchronous; oscillating between 52° N and 52° S latitude, it orbits the Earth every 90 minutes under varying illumination conditions. CEO imagery is used in various areas of Earth observation from coral reef studies to evaluating lagoon health to capturing devastation from natural disasters.[4]

Several years ago, the scientific community identified a need to monitor the health of the Earth's coral reefs which are being threatened by climate change, over fishing and heavy tourisim. Through this effort, it was acknowledged that there was a deficit in detailed mapping of the coral reefs. To overcome this dficit, remote sensing satellites in conjunction with CEO imagery was to used to create detailed maps of coral reefs. CEO imagery is an important contribution in this effort. The images captured from the ISS are unique as they have higher resolution (5-6m) than some remote sensing data, nearly no cloud cover, and cover areas that traditional remote sensing instruments do not image. [2][4] (Figure 4)

Figure 4: Îles Glorieuses (îles Eparses archipelago, Indian Ocean). These islands are protected because of their importance for sea turtles and seabird nesting. (ISS002-E-6913)

Since 2010, CEO images of the Lagoon of Venice have been used in the Atlante della laguna (Atlas of the Lagoon[10]) project. As part of this collaboration, the Lagoon of Venice has become an official viewing site for CEO. Through these up-to-date images, the ecological health is monitored.[4]

In March of 2011, CEO captured the aftermath of the tsunami that devastated northern Japan. Quick response from CEO and the ISS crewmembers resulted capturing useful images of the flooding in residential and agricultural areas. The crew also acquired images of oil slicks in Ishinomaki Bay caused by earthquake damaged oil refineries. The crew was able to use sun glints off the water to capture the oil slicks, which were difficult to see from the ground.[4][11]

The Roscosmos sponsored Uragan program uses digital photography to study natural phenomenon and monitoring disasters both natural and human-made. The images captured by ISS crewmembers are used by government agencies, scientists, and others to evaluate the effects of disasters. One human-made disaster is oil pollution in the Caspian Sea. Images helped researchers in identifying three major areas of pollution: northeast coast of Kazakhstan, southeastern Turkmenistan and the Absheron region of Azerbaijan. In these areas, there are water-oil lakes ranging in size from several meters to 12 km. In order to decrease contamination of nearby areas, walls have been erected to contain the water-oil lakes.[4]

In September 2002, Kolka, a small glacier, unexpectedly released ice and snow causing an avalanche in the Caucasus Mountains. The Uragan program captured an image of the glacier a month prior to the event. Analysis of this image showed clear signs of the initial phase of the avalanche in motion. The color of the ice-soil mixture of the glacier indicated that the inner layers of the glacier were melting.[4]

The International Space Station Agricultural Camera (ISSAC) is a relatively new addition to the ISS suite of remote sensing devices. ISSAC was developed by students and faculty at the University of North Dakota with the objective of collecting imagery data of agricultural areas in the U.S. Midwest. Data collected by ISSAC is used in conjunction with remote sensing satellite data so that farmers can evaluate crop health, climate patterns and weather systems. [4]

Mounted outside of the *Kibo* module on the Japanese Exposed Facility, the HICO and RAIDS Experiment Payload-Hyperspectral Imager for Coastal Ocean (HREP-HICO) scans coastal areas with a spectral imager. HREP-HICO uses a visible to near-infrared wavelength spectrometer to characterize the coastal zones and mapping of geophysical features. Data on bathymetry, water clarity and other water optical properties is used by other agencies such as the National Oceanic and Atmospheric Administration (NOAA). [4] (Figure 5)

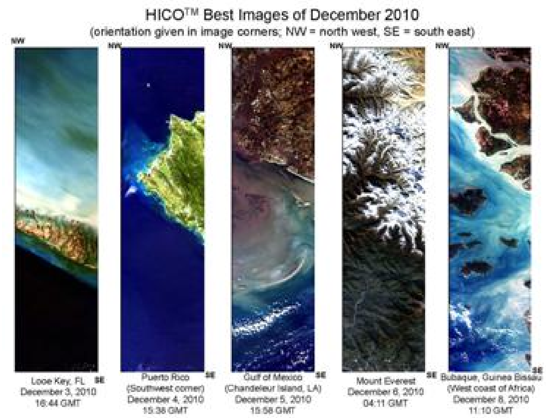

Figure 5: The above image compilation is an annotated representation of the best pictures taken during the December 2010 investigation of HICO. (Image courtesy of NASA)

The JAXA sponsored Superconducting Submillimeter-Wave Limb-Emission Sounder (SMILES) measures stratospheric and mesospheric chemistry. SMILES is the first onboard mechanically cooled superconducting mixer and high resolution system used for measuring atmospheric components. During its 6 months of operation, one of the SMILES observations was ozone depletion and the related change in the amount of chlorine compounds at the North Pole. In the winter of 2010, in the higher latitudes of the stratosphere, a sudden temperature increase of 40°C over a period of several days. During the temperature increase, levels of hydrochloric acid (HCL) decreased while at the same time, solar radiation activated chlorine chemistry resulting in high levels of chlorine monoxide resulting in ozone damage. [4] (Figure 6)

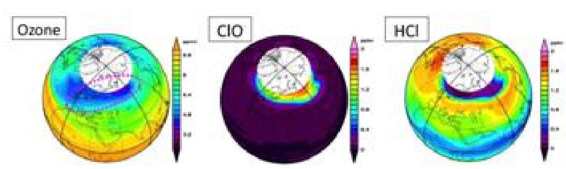

Figure 6: Ozone destruction was activated with ClO and HCl on Jan. 23, 2010. In the high ClO region, O3 destruction has occurred (left). The high ClO region (center). The area where HCl concentration is low suggests the region of polar vortex (right). (Courtesy of Kyoto University)

The ISS also assists in keeping track of maritime traffic through the ESA Vessel ID System. Using a ship-detection system based on the Automatic Identification System (AIS), ship traffic is monitored over the Earth. International vessels, cargo vessels above a certain weight and passenger vessels of all sizes, are equipped with AIS transponders that transmits location, identity, speed, course, cargo and voyage information. This system has limited horizontal range (74km) on Earth, thus making it difficult to monitor open ocean traffic from shore. AIS signals travel much further vertically, therefore the signal can be tracked from space. Initial reports of the ISS maritime tracking have been favorable; on an average day, roughly 400,000 ship position reports are received from 22,000 ships. One report, after approximately 16 months of operation, shows that the total number of position reports exceeded 110 million messages from more than 82,000 different ship ID numbers.[4] (Figure 7)

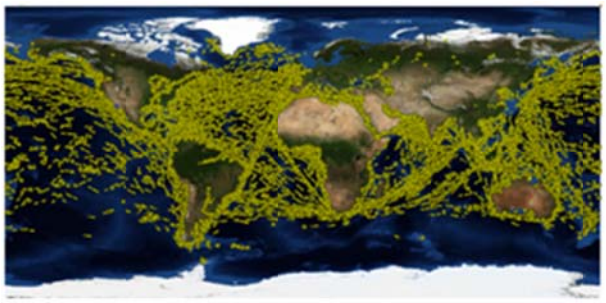

Figure 7: Ship position reports received with the NORAIS Receiver during 24 hours, 29th June 2010. (Credit: FFI)

Global Education A common goal of the ISS partnership is one of inspiration to future generations. Engaging students in science, technology, education and mathematics (STEM) and cultural activities, peaks interest in pursuing careers in these areas. The scientific and engineering accomplishments from ISS afford opportunities for educational outreach.

Students, teachers, parents and communities from around the world are able to speak directly with ISS crewmembers using ham radio through the Amateur Radio on the International Space Station (ARISS) investigation. The primary goal of ARISS is spark interest in science and mathematics. Students prepare for the contact by writing questions for the crewmembers, learn about the ISS and how amateur radio works. More than 600 ARISS contacts have been accomplished with students from around the work. [2][4]

Educating students on proper health practices is an important part of their education. Mission-X, a program designed to inspire students to participate in physical activity, was launched in 2010 through NASA's Human Research Program Education and Outreach (HRPEO). In the Mission-X program, students ages 8-12 years old are encouraged to train like and astronaut. Through the training, students are educated on the science behind the activities, including nutrition and bone health. This program is available in six languages for participants in 10 countries. During the pilot program, approximately 3700 students participated in 40 cities around the Earth. [2][4]

In 2012, high school students from Europe and the U.S. participated in a competition using satellites onboard the ISS. For this competition, students develop algorithms to test on the ISS using bowling-ball size satellites that are part of the Synchronized Position Hold, Engage, Reorient, Experimental Satellites (SPHERES) Zero-robotics. Through the process of developing the algorithms, students work with local experts to establish problem solving skills, design thought process, operations experience, and teamwork. For this competition, teams compete in elimination rounds on the ground under realistic microgravity conditions. Once the two finalists are determined, the winners' algorithm is uploaded to the SPHERES on ISS for the final round of competition. [4] (Figure 8)

Figure 8: View of the Synchronized Position Hold, Engage, Reorient, Experimental Satellites (SPHERES) floating in the Destiny laboratory module as seen by the Expedition 14 crew. Flight Engineer Thomas Reiter is visible in the background. Image credit: NASA.

As part of the United Nations Educational, Scientific, and Cultural Organization (UNESCO) and the International Union of Pure and Applied Chemistry (IUPAC) 2011 International Year of Chemistry initiative, students sampled local water to learn about the chemistry associated with water and the Earth. Results from this effort will be used to create an interactive, global water data map. Students also learn about how the ISS recycles water and the fundamental technologies associated with this effort. The water system onboard the ISS uses iodinated resin in the filtration system in an effort to control microbial growth. This technology has been applied to in areas on Earth that are in need of clean drinking water.

Every year, the JAXA sponsored Ucyu Renshi (space poem chain) invites students to participate in a poetry event that connects the ISS to people on Earth. For this event, 24 poems short poems are collected; half from the public and the remaining from famous poets. Poems that are linked together with thoughts of imagining space, Earth and daily lives. The poems are recorded digitally and uploaded to the ISS. Ucyu Renshi is being used in Japanese classrooms to teach students about creating poems, collaboration and the ISS.[4]

Middle school students from all over the world use the Earth Knowledge Acquired by Middle School Students (EarthKAM) to learn about orbital mechanics, space operations, and geography. Students determine geographic targets to capture through imagery from the EarthKAM camera onboard the ISS. Commands are sent to the camera from students via the online EarthKAM program. Once the images are acquired, students and teachers annotate the images and discuss geographic matters. [4]

Tomatosphere Project is a jointly sponsored endeavor of CSA, University of Guelph, Agriculture and Agro-Food Canada, the Ontario Centres of Excellence, Heinz Canada and Stokes Seed designed to get students involved in space related agricultural activities. Students are furnished tomato seeds that have been exposed to the space environment as well as ground control seeds. Students and educators investigate the germination rate of the seeds and learn about various botany topics. [4] (Figure 9)

Figure 9: During a previous Tomatosphere program, students studied the growth of their tomato plants in Miss Smith's grade three class at Langley Fundamental Elementary, Vancouver, British Columbia, Canada. The students took their plants home to grow in their gardens over the summer. (Image credit: Tomatosphere.)

Roscosmos sponsors a variety of educational activities associated with investigations on the ISS. The Coulomb Crystal investigation evaluates the structural properties of Coulomb clusters. Students are invited to conduct similar investigations in their classrooms. Two communication investigations, Shadow-Mayak and MAI-75, utilize video and ham radio equipment onboard the ISS to communication with students on Earth. Great Start is an investigation that encourages participation from the general public. Through a questionnaire, the public can express their position on human space flight as well as learn about current ISS operations.[4]

ISS partners are currently conducting a comprehensive survey of the many different educational activities on the ISS, as well as the educational content extended from many other research projects. A summary of these impacts is expected to be published in fall of 2012.[2]

CONCLUSION

For more than a decade, research has been conducted on the ISS and the benefits of that research are being realized. There are many aspects of benefits that range from engineering achievement, international collaboration, and research results.

ISS research covers a large breadth scientific disciplines and educational activities. This research has applications on Earth, applications for space exploration, and for advancement of scientific discoveries. To date over 63 countries have directly participated in some aspect of ISS research or education. In summarizing these benefits and accomplishments, ISS partners are also identifying ways to further extend the benefits to people in developing countries for the benefits of humankind.

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