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Unique Offerings of the ISS as an Earth Observing Platform

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The International Space Station offers unique capabilities for earth remote sensing. An established Earth orbiting platform with abundant power, data and commanding infrastructure, the ISS has been in operation for twelve years as a crew occupied science laboratory and offers low cost and expedited concept-to-operation paths for new sensing technologies. Plug in modularity on external platforms equipped with structural, power and data interfaces standardizes and streamlines integration and minimizes risk and start up difficulties. Data dissemination is also standardized. Emerging sensor technologies and instruments tailored for sensing of regional dynamics may not be worthy of dedicated platforms and launch vehicles, but may well be worthy of ISS deployment, hitching a ride on one of a variety of government or commercial visiting vehicles. As global acceptance of the urgent need for understanding Climate Change continues to grow, the value of ISS, orbiting in Low Earth Orbit, in complementing airborne, sun synchronous polar, geosynchronous and other platform remote sensing will also grow.

I. INTRODUCTION

The International Space Station offers a Low Earth Orbiting (LEO) space laboratory, environment or vantage point for virtually any field of science or space exploration. Most investigations focus on weightlessness or exploring and developing human presence, operations, and technology for the long duration space missions of the future, while some other investigations leverage the vantage point of LEO as a platform for viewing the universe, solar system, or sun, or looking back at earth. The physics and biological investigations which depend on weightlessness typically exhibit macro phenomena which actually are reflections of processes in weightlessness at the molecular or cellular level. For example, BCAT, FLEX, Resist Wall and Triple Lux … (XXX references will be provided in final copy). The ISS is an excellent laboratory and environment for studying the effects of, and developing countermeasures against the undesirable effects of long duration weightlessness on the human body. The Nutrition (XXX reference) experiment which recently completed documented the effects of various types of exercise protocols as countermeasures to the problem of elevated rates of bone loss for long duration crew members. Not only do physiological changes occur, but neuronal, perceptual and even cognitive changes to long duration crew members (XXX reference). ISS use for the development of hardware and operations technology which will be needed for further space exploration typically involves developmental or prototype hardware and or operations for those anticipated needs. For example, Amine Swingbed, Robonaut, and Robotic Refueling Mission, XXX References… . And the ISS also provides an orbital vantage point for sensors looking away from earth or toward earth. In efforts to further understand the origins and evolution of the universe and our solar system, outward looking sensors and instruments collect high energy spectrum X-Ray and gamma ray both in the local (CALET reference) and distant universe (CREAM, AMS, MAXI reference). Sun viewing instruments (SOLAR reference) document spectral variations of irradiance as the sun cycles though its 11 year solar cycle. All of these investigations and uses of ISS, over broad spectra of science fields and preparations for further space exploration, have been underway since the first crew launch in November, 2000. Although the numbers of investigations and crew hours spent on science were low in the early years, with the ISS assembly complete as of 2010, ISS science and utilization has basically tripled.

In the field of Earth Science, the ISS offers a unique vantage point due to its orbit characteristics. The ISS orbits earth at an inclination relative to the equatorial plane, of 51.6 degrees. Its altitude fluctuates through the range of 375 to 435 km as it cycles through slowly descending periods, due to orbital drag, and is then reboosted, within seconds, with engines and propellant from the near monthly arriving Progress, ATV, and HTV vehicles provided by Russian, European, and Japanese space agencies, respectively. The station attitude will also vary over the course of the mission, particularly the pitch bias with which the ISS flies will vary depending on the combinations of visiting vehicles and their berthing sites. Although varying altitude and attitude are not ideal conditions for remote sensing satellites, these characteristics can be accommodated.

The ISS orbit inclination results in orbit tracks which are advantageous to many earth remote sensing approaches. Even though altitude cycles through a range of slow decay and reboost, and even though attitude adjustments occur for visiting vehicles, the ISS altitude and attitude vectors are constantly available with high accuracy for real time adjustments to remote sensing data and/or pointing commands.

Most non remote sensing investigations are located internally as the internal environment is not as harsh as the external environment, crew installation, tending and trouble shooting is available, and the desired environment, typically weightlessness, is also present. Other investigations are located externally on the collection of external sites designed into the ISS. Some payloads may require external installation because they are robotic based, require the radiation or plasma environment of the external ISS, or, as with most external payloads, have viewing requirements that cannot be met with an internal installation.

Of the externally mounted, earth viewing payloads, this paper describes three such payloads and highlights the ISS characteristics that make ISS attractive to the science objectives of these three sensors. In some cases the science objectives were designed around ISS capabilities.

The Stratospheric Aerosol and Gas Experiment III-ISS (SAGE III-ISS) measures the composition of the earth's middle and lower atmosphere with an externally mounted spectrometer. The ISS orbit provides a perfect vantage point from which to acquire measurements of this region of the atmosphere. The Cloud-Aerosol Transport System (CATS) measures cloud and aerosol layer heights with an externally mounted LiDAR. The ISS orbit covers many of the primary aerosol transport paths, provides cloud and aerosol vertical profiles, and will characterize the diurnal variability of this information. The ISS-RapidScat payload measures ocean wind vectors with an externally mounted radar scatterometer. The ISS orbit allows characterization of the diurnal dynamics of ocean winds. Additionally, because the ISS orbit track intersects the near-polar orbit tracks of most other currently operating scatterometers, a cross calibration can be achieved among the individual satellites of the scatterometer constellation.

While the orbit of the ISS is attractive to all three of these programs, and even though the ISS orbit offers track and coverage characteristics which are difficult, if not impossible, to achieve with existing remote sensing systems, other ISS laboratory features are also attractive. Launch to orbit services and on-orbit resource infrastructure are part of the ISS program (XXX reference). Launch of external payloads is currently offered by the ISS program as part of the SpaceX Dragon vehicle, which has a "trunk" for external cargo. Once on-orbit, installation is typically accommodated with robotics. After installation on standard external interfaces on EXPRESS Logistics Carrier (ELC) Adapters distributed along the truss or external sites on the ESA and JAXA modules, resources include power (as much as 6 KW on the JAXA sites) and data (as much as 43 Mbps shared among the JAXA sites).[2] It is the combination of ISS orbit characteristics with launch services and on-orbit infrastructure that not only makes ISS a unique and attractive platform, but the platform of choice for the above mentioned, and other, earth remote sensing payloads.

Sun-Synchronous Orbit

A sun-synchronous orbit is an orbit in which the satellite's orbital plane is at a fixed orientation to the sun, i.e., the orbit plane through the center of the Earth precesses (rotates) about the Earth at the same rate that the Earth orbits the sun. This orbit combines altitude and inclination in such a way that an object in a sun-synchronous orbit ascends or descends over any given Earth latitude at the same local mean solar time. This has the effect that the surface illumination angle will be nearly the same for each fly over, and this consistent lighting is a useful characteristic for remote sensed imaging so that lighting variations due to sun angle changing will not mask or confuse the ability to identify long term trends.

Typical sun-synchronous orbits are about 600–800 km in altitude, with periods in the 96–100 minute range, and inclinations of around 98°. Hence, a sun-synchronous orbit is nearly a polar orbit.

Drawbacks

Although the ISS has been designed to accommodate a large number (> 140) of ongoing investigations, it was not designed exclusively for remote sensing payloads. As a crew occupied vehicle with rotating machinery, the ISS has a jitter spectrum that is not ideal for sensors pointed at distant targets. Also, contamination may be a concern for some sensors. So, the ISS is not an ideal platform for earth remote sensing. Nevertheless, the attractive and unique offerings outweigh these downsides for these three and other earth viewing payloads.

Sensor Types

The three sensors chosen for this paper span a wide range of passive and active sensor types.

II. SAGE III-ISS

The Stratospheric Aerosol and Gas Experiment (SAGE) III-ISS is a spectrometer which uses an energy occultation method to measure the vertical structure of atmospheric ozone, aerosols and gases based on their absorption spectra in the instrument's bandwidth. The 76 kg payload is planned for launch on SpX-6 in December, 2014.

This SAGE instrument represents the third generation in a lineage of remote sensing instruments that study the Earth's atmosphere and protective ozone layer. SAGE I and II, launched in 1979 and 1984, respectively, and were in 56° and 57° orbits, respectively; whereas SAGE III-METEOR, launched in 2001 on the Russian METEOR-3M satellite, and was in a near-polar, 99° orbit. The geographic location of the measurements from an occultation instrument is determined by the orbit of the host spacecraft. Since SAGE III METEOR was in a high inclination orbit, it provided measurements only at high latitudes. From the 51.6° ISS orbit, SAGE III-ISS will provide measurements with a near-global seasonal and latitudinal sampling very similar to that from SAGE I and SAGE II. The data collected on SAGE I and SAGE II were critical to the discovery of the Earth's ozone hole and the creation of 1987 Montreal Protocol, which banned ozone-depleting substances, such as chlorofluorocarbon (CFC). The ISS mid-plane orbit inclination is actually ideal for the SAGE III-ISS science objectives because it maximizes the coverage area while maintaining the system's performance requirements.

SAGE III sensor assembly consists of pointing and imaging subsystems and a UV/visible spectrometer. The pointing and imaging systems are employed to acquire light from either the Sun or Moon by vertically scanning across the object. The SAGE III-ISS sensor is a grating spectrometer measuring ultraviolet and visible energy between 290 and 1030 nm. An 800 element CCD linear array provides continuous spectral coverage over this range. Additional aerosol information is provided by a discrete photodiode at 1550 nm. This configuration enables SAGE III to make multiple measurements of absorption features of target gaseous species and multi-wavelength measurements of broadband extinction by aerosols.

The scientific objective of SAGE III-ISS is to measure global, high-resolution, vertical profiles of key components of atmospheric composition and their long term variability. The most important of these are ozone, which shields the Earth's surface from harmful ultraviolet radiation, and aerosols, which play an essential role in the radiative and chemical processes that govern the Earth's climate. Additionally, SAGE III-ISS measures temperature in the stratosphere and mesosphere and profiles of trace gases such as water vapor and nitrogen dioxide that play significant roles in atmospheric radiative and chemical processes.

III. CATS

The Cloud-Aerosol Transport System (CATS), planned for launch in 2014 on JAXA's HTV-5, is a lidar remote sensing instrument that will provide range-resolved profile measurements of atmospheric aerosols and clouds. The CATS payload is based on existing instrumentation built and operated on the high-altitude NASA ER-2 aircraft.[3] The instrument consists of a high repetition rate Nd:YVO4 laser operating at three wavelengths (1064, 532, and 355 nm) that generates signal photons, a receiver subsystem with a 60 cm diameter telescope to collect photons that backscatter from the atmosphere, and a data system to provide timing of the return photon events. Data from CATS will be used to derive properties of cloud/aerosol layers including: layer height, layer thickness, backscatter, optical depth, extinction, and depolarization-based discrimination of particle type. The instrument will be installed on the Japanese Experiment Module – Exposed Facility (JEM-EF) and is intended to operate on-orbit for at least six months, and up to three years. The CATS payload is designed to provide a combination of long-term operational science, in-space technology demonstration, and technology risk reduction for future Earth Science missions.

The measurements of atmospheric clouds and aerosols provided by the CATS payload will be used for two main science objectives. One important aspect of the CATS on-orbit science will be to provide real-time observations of aerosol vertical distribution as inputs to global models. Current models tend to agree on total aerosol loading but tend to disagree on the vertical distribution of the loading and the type of aerosols present.[4] The vertical distribution of aerosols is highly important to studies of cloud-aerosol interactions.[5] As a result, the impact of clouds and aerosols on global energy balance and climate feedback mechanisms is not yet fully understood.[6] Obtaining a better understanding of cloud and aerosol coverage and properties is critical for understanding of the Earth system and climate feedback processes. The vertical profile information obtained by CATS, particularly at multiple wavelengths and with depolarization information, provides height location of cloud and aerosol layers, as well as information on particle size and shape.

Another important aspect of the CATS on-orbit science will be to extend the space-based lidar record for continuity in the lidar climate observations. The Cloud-Aerosol Lidar Infrared Pathfinder Satellite Observations (CALIPSO[7]) satellite was successfully launched in April 2006 and has provided the first continuous global lidar measurements of clouds and aerosols from space. The CATS instrument will provide similar measurements of cloud and aerosol profiles, filling in the data gap, so this information can continually be used to improve climate models and our understanding of the Earth system and climate feedback processes. The ISS orbit is particularly suited to this measurement, because the ISS tracks over and along primary aerosol transport paths. The ISS orbit also permits study of diurnal (day to night) changes in aerosol and cloud effects, something not achieved with other Earth Science satellite orbits.

IV. ISS-RAPIDSCAT

The ISS-RapidScat, planned for launch in 2014 on SpaceX-4, is a rotating pencil beam radar scatterometer (geometry shown in Fig. 1) that will provide ocean vector winds (OVW) for ice-free oceans in XXX % of the earth. The hardware consists of a refurbished engineering model of the SeaWinds scatterometer, which was launched in 1999 on the QuickScat satellite. However, the antenna sub-system has been modified, and a digital interface to the ISS Columbus module has been developed for ISS-RapidScat. Due to accommodation constraints of the launch vehicle and the ISS mounting site the antenna diameter is set to 0.75 m, which is slightly smaller than that of QuikSCAT (1m). The instrument is expected to be in operation for 24 months after installation.

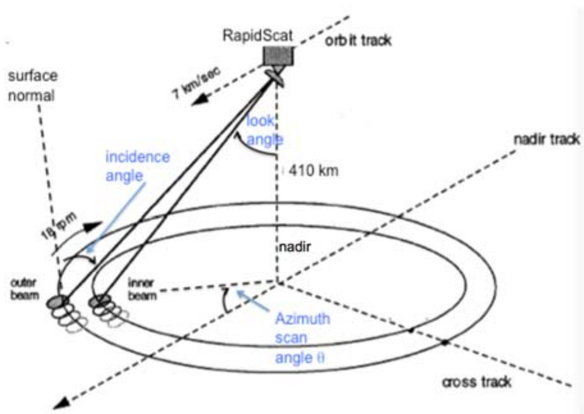

Fig. 1 ISS-RapidScat rotating pencil beam scatterometer geometry.

The average altitude of the ISS is approximately half the orbit altitude of QuikSCAT. Both the attitude and altitude variations of the ISS require timing modifications to the engineering hardware that will be accomplished before launch as well as changes in day-to-day operations of the radar.

Since the hardware is essentially the same as SeaWinds on QuikSCAT, the ground processing software for QuikSCAT will be used to process the RapidScat data, with modifications to handle the increased altitude and attitude variability and to flag and remove data occasionally impacted by the presence of the ISS solar arrays within the RapidScat beam. The calibration accuracy goal for RapidScat is the same as for its predecessors; however, the variability in ISS platform parameters will likely make calibration more challenging. Data loss due to various ISS activities will also impact the data quality.

ISS-RapidScat's science objectives are threefold: Cross-calibration among various existing scatterometers, diurnal Ocean Vector Winds variation, and improved marine storm forecasting. Providing an improved cross-calibration platform for OVW will increase the validity of the QuikSCAT data and stability. Ocean Vector Winds are currently measured by a constellation of near-polar orbiting scatterometers, including ASCAT, OSCAT, and SeaWinds shown in Table 1. SeaWinds provides a stable radar cross-section reference along a narrow swath. In 2009 the rotating ability of the SeaWinds (operating since 1999) dish antenna was lost, but its ability to measure radar backscatter at a fixed azimuth angle continues today. QuickScat continues to provide a stable radar cross-section reference along a narrow (since it is no longer rotating) swath. This remaining, stable reference has resulted in QuikSCAT being able to provide invaluable mitigation for the failure of the Ku-band OSCAT calibration loop. However, due to the fact that the two systems are in a different sun-synchronous orbit, with different time of day revisits, it is not possible to get a geographical map of the wind vector biases between the two systems. Also ASCAT has no temporally coincident observations with QuickScat, so there is little QuickScat can do in its current mode to serve as the calibration standard for ASCAT.

Since the ISS is on a mid-inclination non-sun-synchronous orbit, there will be an intersection with the orbits of each scatterometer in the constellation once every revolution.. Furthermore, since the orbit periods of RapidScat and the constellation scatterometers are relatively brief (~90 minutes and ~99 minutes, respectively), the intersections will be nearly temporally coincident.

Sponsor	Scatterometer/Satellite
European Organization for the Exploitation of Meteorological Satellites (EUMETSAT)	Advanced Scatterometer (ASCAT) on MetOp-A and MetOp-B
Indian Space Research Organization (ISRO)	OSCAT/Oceansat-2
NASA JPL	SeaWinds/QuickScat

Table 1 Current Scatterometer Constellation

For the current scatterometers, intersections only occur at very high latitudes, limiting coverage to either land or the Southern Ocean, and this is not sufficient for cross calibration among the current scatterometers. So for the joint use of ISS-RapidScat and QuickScat, intersections of those two will yield a cross calibration such that the then calibrated ISS-RapidScat may be used as a "golden" standard to develop bias corrections for the other instruments in the constellation. In this manner, all instruments in the constellation, plus ISS-RapidScat may produce a consistent winds data set.

Diurnal Variation

It is well known that ocean winds vary throughout the day, but this is not well characterized by current instruments. It was more important to characterize the global ocean winds with consistent time-of-day sampling, a virtue of sun-synchronous, polar orbit, and this priority meant that multiple samplings throughout the day at the same spot would not be possible. The ISS orbit, on the other hand, visits all points at latitudes smaller than 51.6° at all times of day over a period of roughly 2 months. This will allow, over a period of two years, the estimation of the semi-diurnal wind components from the RapidScat data alone. Additionally, since radar scatterometers are able to detect terrestrial evaporation by virtue of the vegetation dielectric constant, ISS-RapidScat will similarly allow semi-diurnal characterization of terrestrial evapo-transpiration cycles at latitudes smaller than 51.6° at all times of day over a period of roughly 2 months.

Improved Forecasting

The 900 km swath of the rotating RapidScat pencil beam is approximately equal to that of the fixed wide beam ASCAT scatterometer. By combining the two systems, the space-time sampling is greatly improved, leading to a finer space-time resolution for marine storm modelling and forecasting.

V. CONCLUSION

The ISS offers unique attractions for Earth Remote Sensing payloads. There are some aspects of ISS that are not ideal for remote sensing payloads, however ISS orbit characteristics and launch and on-orbit resource infrastructure can often result in system which can extend the data available to Earth scientists for modelling Earth's complex exchanges of energy, in mechanical, chemical and other forms, between its oceans and atmosphere

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