人工衛星による地球観測：現状と将来計画の課題
Satellite Earth Observation: Current status and Future Planning issues

*中島 映至[1]
*Teruyuki Nakajima[1]

1.宇宙航空研究開発機構
1.Japan Aerospace Exploration Agency

It is necessary to construct effective and sustainable satellite observation systems for monitoring the earth under pressure of climate change and environmental problems. The world satellite operators are in the process of program constructing for future satellite programs in the horizon of 2020 to 2040. There are also projects of related data analyses, like European Copernicus Program and US NOAA Big Data Project, which maximize the utility of satellite data by various services like climate service and others. Japanese contributions are also large with GOSAT, GCOM/W, GPM, ALOS-2, and the first third generation geostationary satellite Himawari-8. I like to discuss the status of these satellite programs and issues for future earth observation planning.

キーワード：地球観測、人工衛星
Keywords: Earth observation, satellite

NASA’s Earth Science Program and Cooperation With Japan
NASA’s Earth Science Program and Cooperation With Japan

*Freilich Michael[1]
*Michael Freilich[1]

1.Earth Science Div. NASA Headquarters
1.Earth Science Div. NASA Headquarters

This presentation will highlight NASA’s current and planned Earth observing capabilities, the resulting science and applications,and NASA’s long-standing partnership with Japan. NASA and the Japan Aerospace Exploration Agency (JAXA) have a long history of collaboration on satellite missions. The two agencies worked together on the highly successful 17-year Tropical Rainfall Measuring Mission (TRMM). TRMM’s success contributed in part to further cooperation between NASA and JAXA on the Global Precipitation Measurement (GPM) Core spacecraft, launched in 2014. Meanwhile, Japan has also been an active partner in two of NASA’s Earth Observing System “flagship” missions: Terra and Aqua. Both the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) onboard Terra and Advanced Microwave Scanning Radiometer for EOS (AMSR-E) onboard Aqua were built by and are operated by JAXA. NASA and JAXA have partnered for the last several years on calibration and validation activities associated with JAXA’s Greenhouse Gases Observing Satellite (GOSAT) and NASA’s Orbiting Carbon Observatory (OCO0-2) missions. And in 2012, JAXA’s Global Change Observation Mission ? Water (GCOM-W1)
satellite joined Aqua and other NASA missions as part of the international Afternoon Constellation (A-Train). The results from these (and other) Earth observing missions are expanding our knowledge of the current state of the Earth system and our ability to predict how it may change in the future. These data also enable a wide range of practical applications that benefit society.

キーワード：TRMM、GPM、GOSAT、ASTER、AMSR-E、A-Train
Keywords: TRMM, GPM, GOSAT, ASTER, AMSR-E, A-Train

ISAS space science in 2020s
ISAS space science in 2020s

*常田 佐久[1]
*Saku Tsuneta[1]

1.宇宙航空研究開発機構・宇宙科学研究所
1.Japan Aerospace Exploration Agency Institute of Space and Astronautical Science

Space Policy Commission under the Cabinet Office intends to guarantee predetermined steady annual budget for space science and exploration to be performed by ISAS/JAXA. This policy is clearly stated in the “Basic Plan on Space Policy” recently revised and approved by the Government of Japan. This document is our legitimate backbone that allows ISAS/JAXA to have stable and regular launch cadence with newly-defined mission lines,
long-term planning on missions and enabling technology development and early commitment to international programs. Three distinct mission categories (or pillars) are strategic Large mission (3 launces in 10 years) with H3 vehicle, competitively-chosen Medium-size focused missions (comparable to NASA’s SMEX) launched approximately every other year with Epsilon rocket, and missions of opportunity (S-class) for participation to foreign agency-led large missions.
The latest L-mission is the JAXA-NASA X-ray astronomy satellite Hitomi (ASTRO-H launched in 2016). Our provisional decadal plan for L-class is articulated around the Martian Moons eXplorer (MMX, 2022) and the
far-infrared mission with ESA (SPICA, 2027-2028). L-class candidates for the 2025 slot include LiteBIRD for Cosmic Microwave Background B-mode polarization detection and Solar Power Sail mission for Trojan
exploration. M-class missions in orbit and development phase include Hisaki (UV planet observations, launched in 2013), ERG (van Allen probe to be launched in JFY 2016) and SLIM (lunar-lander to be launched in JFY
2019). Candidates for 4th and 5th M-class missions are being selected.
S-class projects in development/planning phase include ESA-led BepiColombo, JUCE, X-ray astronomy mission Athena and NASA-led WFIRST.
Our enabling technology for astrophysics and fundamental physics missions in 2020s include cryogenic systems as represented by Hitomi,SPICA and LiteBIRD, and those for 2020s~ 2030s planetary science are two-fold; (1) landing on planet/satellite starting with pathfinder mission SLIM, (2) sample & return technology as represented by Hayabusa,Hayabusa2 and MMX. We desire to participate in foreign-agency-led large astrophysics missions and missions to distant planets in 2020s~2030s.
ISAS has benefitted from intimate collaboration with NASA over past 30 years especially in X-ray astronomy, solar physics, and magnetospheric science. We could not make Hitomi happen without the tremendous contribution from NASA. We have been looking forward to new substantial collaboration following ASTRO-H with NASA. ISAS/JAXA ongoing and planned missions for 2020s are scientifically attractive. These mission candidates are ambitious but will be feasible if we have early coordination and stable relationship with our international partners. We hope that these missions pave the way to even more ambitious joint plans for 2030s space science.

NASA-JAXA Heliophysics Observation Partnerships

NASA-JAXA Heliophysics Observation Partnerships

*Clarke Steven[1]
*Steven W Clarke[1]

1.NASA Headquarters
1.NASA Headquarters

NASA and JAXA have been successful partners in unlocking the mysteries of the universe, including those related to our own star, the Sun, and it’s effects on our solar system. Through collaborations on previous space-based observations, such as Geotail, Hinode, and last summer’s sounding rocket launch of CLASP, NASA and JAXA have enabled the heliophysics science community to obtain critical observational data for over 20 years. These data have helped to answer many compelling science questions and initiate additional ones. NASA and JAXA continue to investigate future opportunities to further heliophysics science. This long-standing partnership between NASA and JAXA will continue to provide significant benefits to the global heliophysics science community and more broadly, society as a whole.

Asteroid sample return missions: The collaboration between OSIRIS-REx and Hayabysa2

Asteroid sample return missions: The collaboration between OSIRIS-REx and Hayabysa2

*橘 省吾[1]、Connolly, Jr. Harold[2]、Lauretta Dante[3]、吉川 真[4]
*Shogo Tachibana[1], Harold C. Connolly, Jr.[2], Dante S. Lauretta[3], Makoto Yoshikawa[4]

1.北海道大学大学院理学研究院自然史科学専攻地球惑星システム科学分野、2.City University of New York、3.University of Arizona、4.宇宙航空研究開発機構
1.Department of Natural History Scieces, Hokkaido University, 2.City University of New York, 3.University of Arizona, 4.JAXA

The Origins Spectral Interpretation, Resource Identification, and Security-Regolith Explorer (OSIRIS-REx) is scheduled to launch on September 8, 2016 as the NASA’s third New Frontiers mission. OSIRIS-REx will arrive at the target (101955) Bennu [1], which is a B-type asteroid spectroscopically similar to carbonaceous chondrites, in August 2018. With detailed engineering and scientific mapping, OSIRIS-REx will sample the surface regolith of Bennu late 2019. The amount of sample is expected to be up to 2 kg. The samples will be delivered to the Earth in September 2023. The surface regolith from Bennu will be pristine samples with a record of the Solar System history. They also record the recent dynamical evolution and surface geological processes on Bennu [2]. Another asteroid explorer, JAXA’s Hayabusa2, is now heading for a C-type asteroid (162173) Ryugu, also spectroscopically similar to carbonaceous chondrites, after its successful Earth swing-by on December 3, 2015. Hayabusa2 will get to Ryugu in June, 2018, obtain surface samples from Ryugu nominally at three different locations, and return to the Earth in December 2020. The samples from Ryugu are also expected to record the Solar System evolution [3] and recent surface geological activities [2].

This is the first since the Apollo and Luna era that two sample return missions operated by different space agencies are occurring at the same time. Therefore intimate collaboration between the two missions will enhance the mutual scientific return. NASA and JAXA signed a Memorandum of Understanding (MOU) for official collaboration between the missions in 2014. In addition to the MOU, the two missions will have a Joint Project Implementation Plan (JPIP), with meeting the provisions of the MOU, for the scientific collaboration during the cruise phase, the asteroid proximity operation phase, the sampling phase, and the sample analysis phase. The JPIP includes the agreement of having three co-investigators from the other mission (Dante S. Lauretta, Olivier Barnouin, and Harold C. Connolly Jr. as Hayabusa2 Co-I’s from OSIRIS-REx and Sei-ichiro Watanabe, Makoto Yoshikawa, and Shogo Tachibana as OSIRIS-REx Co-I’s from Hayabusa2). The JPIP also includes the agreement of participation of OSIRIS-REx (Hayabusa2) team members in the preliminary examination and curation of the Hayabusa2 (OSIRIS-REx) returned samples. The intimate collaboration between the two missions defined by the JPIP will maximize the scientific return from both missions and help to establish long lasting collaborations within the science, engineering, and space exploration communities.

[1] D. S. Lauretta et al. (2014) Meteorit. Planet. Sci. 50, 834-849.
[2] H. C. Connolly, Jr. et al. (2015) Earth Planets Space 67, 1-6.
[3] S. Tachibana et al. (2014) Geochemical J. 48, 571-587.

「いぶき」(GOSAT)による温室効果ガス観測に関する国際研究協力

International research collaboration in GOSAT-based greenhouse gas observation

*横田 達也[1]、GOSATプロジェクト メンバー[1,2]
*Tatsuya Yokota[1], Members of GOSAT_Project[1,2]

1.国立研究開発法人国立環境研究所、2.国立研究開発法人宇宙航空研究開発機構
1.National Institute for Environmental Studies, 2.Japan Aerospace Exploration Agency

More than seven years have passed since the Greenhouse gases Observing SATellite (GOSAT) was launched. Over those years, many international research groups mutually collaborated in validating GOSAT data, estimating carbon fluxes, and conducting other related studies. Thus far, the GOSAT Project, promoted by the Ministry of the Environment of Japan, the Japan Aerospace Exploration Agency (JAXA), and the National Institute for Environmental Studies (NIES), issued GOSAT Research Announcement (RA) ten times, and adopted 123 research proposals (http://www.gosat.nies.go.jp/en/reserchannouncement_4.html). Among them, 46 studies were already completed (some of the final reports submitted) or finished, and 77 are still in progress. These studies are categorized in the following four research fields:
(1) Data processing algorithms: developing algorithms for retrieving carbon dioxide (CO_2) and methane (CH_4) concentrations from GOSAT data, detecting light interfering clouds and aerosols, and computing solar-induced fluorescence,
(2) Data validation: monitoring GHG phenology, developing instrument prototypes for GHG measurement, inter-comparing several GOSAT GHG data, evaluating vegetation indices, and comparing GOSAT GHG data with model simulations,
(3) Carbon balance estimation and atmospheric transport modeling: estimating surface CO_2 and CH_4 fluxes from GOSAT GHG data,
(4) Data application: researching GOSAT-based NDVI, CO_2 and CH_4 distribution relationships, monitoring wildfires and volcanic activities, and understanding relationships between vegetation activities and atmospheric CO_2 and CH_4.
We hold annual GOSAT RA meeting to facilitate research collaboration through the exchange of new research findings.
Further, the members of the GOSAT Project at JAXA and NIES collaborate closely with those of the NASA OCO-2 team (previously the Atmospheric CO_2 Observations from Space (ACOS) team) through frequently exchanging latest information and research findings during bi-weekly teleconferences, field campaigns, and annual workshops.
In Europe, the European Space Agency is leading GHG-Climate Change Initiative (GHG-CCI, http://www.esa-ghg-cci.org/), promoting long-term GHG emission estimation using SCIAMACHY data and GOSAT data.
We herein explain the above international collaborative activities and also report the progress of the ongoing GOSAT Project.

キーワード：温室効果ガス、二酸化炭素、メタン、校正・検証、導出手法、炭素収支推定
Keywords: greenhouse gas, carbon dioxide, methane, calibration and validation, retrieval algorithm, carbon flux estimation

Watching the Earth Breath –Measuring carbon dioxide with the Japanese GOSAT and NASA OCO-2

*David Crisp[1]

1.Jet Propulsion Laboratory, California Institute of Technology

Space based remote sensing provides new tools for quantifying carbon dioxide (CO_2) emissions from fossil fuel combustion, biomass mass burning, and other human activities. These measurements are also essential for monitoring changes in the emission and absorption of CO_2 by the land biosphere and ocean as the natural carbon cycle responds to climate change. High resolution spectra of reflected sunlight within near infrared CO_2 and molecular oxygen (O_2) absorption bands are well suited for this application because they can be analyzed to estimate the column-averaged CO_2 dry air mole fraction, X_{CO2}. These X_{CO2} estimates can be assimilated into chemical transport models to infer the spatial distribution of surface CO_2 fluxes over the globe. This is a particularly challenging space based measurement, however, because the even the largest human and natural emission sources and natural absorbers produce only small (< 0.25%) changes in the background X_{CO2} field. High precision is essential to resolve the small variations and high accuracy is needed because small biases in the retrieved X_{CO2} distribution could be misinterpreted as spurious CO_2 fluxes.

The Japanese Greenhouse Gases observing SATellite, GOSAT (nicknamed “Ibuki”) and the NASA Orbiting Carbon Observatory (OCO) were the first two satellites designed specifically to exploit this measurement approach. OCO used high resolution imaging grating spectrometers to measure the absorption by CO_2 near 1.61 and 2.06 microns and O_2 near 0.765 microns. GOSAT used a Fourier transform spectrometer to observe the same O_2 and CO_2 bands, as well as the methane (CH_4) band near 1.67 microns. GOSAT was successfully launched in January 2009, and has been returning measurements of X_{CO2} and X_{CH4} since April 2009. OCO was lost in February 2009 when its launch vehicle malfunctioned. It was replaced by OCO-2, which was successfully launched in July 2014 and has been returning measurements of X_{CO2} since September 2014.

While these to pioneering missions each have unique capabilities, the GOSAT and OCO teams realized early in their development that their scientific benefits could be improved if their measurements could combined to produce a uniform climate data record. The two teams formed a close collaboration to cross calibrate the GOSAT and OCO measurements and cross-validate their retrieved X_{CO2} estimates against internationally recognized standards. Early in the GOSAT mission, this collaboration accelerated the development of calibration methods, retrieval algorithms, and validation techniques. Since the OCO-2 launch, these methods have been applied to both missions.

Near-simultaneous observations of the vicarious calibration site at Railroad Valley, Nevada, U.S.A. indicate that a small (5%) radiometric offset between the OCO-2 and GOSAT 0.765 and 1.61 micron bands that is currently under investigation. Comparisons of GOSAT and OCO-2 X_{CO2} estimates with results from the ground-based Total Carbon Column Observing Network (TCCON) indicate that both are yielding X_{CO2} estimates with accuracies better than 0.5%.

The approach used to cross calibrate and cross validate the OCO-2 and GOSAT results has become a model for future greenhouse gas missions. Its extension to GOSAT-2 and OCO-3, both expected to launch in 2018, has been formalized through a Memorandum of Understanding between NASA and the GOSAT-2 partners. Similar collaborations have also been discussed for the European Space Agency’s CarbonSat mission and French Space Agency (Centre national d'études spatiales, CNES) MicroCarb mission. If implemented, this approach could yield a continuous X_{CO2} record that extends from 2009 through the early 2020’s.

Keywords: Carbon dioxide, Greenhouse Gases, Remote Sensing

GCOM-W1/AMSR-2 Status and Utilization at NOAA

*Paul Chang[1], Zorana Jelenak[1], Ralph Ferraro[1]

1.NOAA/NESDIS Center for Satellite Applications and Research

Multi-channel passive microwave radiometry is a special application of microwave communications technology for the purpose of collecting Earth’s electromagnetic radiation. With the use of radiometers onboard polar-orbiting satellites, scientists are able to monitor the Earth’s environment on both short- and long-term temporal scales with near global coverage.
The Global Change Observation Mission (GCOM) is part of the Japanese Aerospace Exploration Agency (JAXA) broader commitment toward a global and long-term observation of the Earth’s environment. It consists of two polar-orbiting satellite series [GCOM-W (Water) and GCOM-C (Climate)] nominally with a 1-year overlap between each satellite in the series to allow for inter-calibration. As payloads for these missions, two instruments were selected to cover a wide range of geophysical parameters: the Advanced Microwave Scanning Radiometer –2 (AMSR-2) on GCOM-W, and the Second-Generation Global Imager (SGLI) on GCOM-C. The AMSR2 instrument, follow-on to the AMSR-E, will perform observations related to the global water and energy cycle, whereas the SGLI will conduct surface and atmospheric measurements related to the carbon cycle and radiation budget.
The National Oceanic and Atmospheric Administration (NOAA) GCOM-W1/AMSR-2 product development and validation project is providing NOAA’s users access to critical geophysical products derived from AMSR-2. These products, detailed in NOAA’s Joint Polar Satellite System (JPSS) Level 1 Requirements Document Supplement [1], include: calibrated microwave brightness temperature (MBT), total precipitable water (TPW), cloud liquid water (CLW), precipitation type/rate (PT/R), sea surface temperature (SST), and Sea Surface Wind Speed (SSW). An overview of the status and achievements of GCOM-W1/AMSR-2 at NOAA will be presented.

Keywords: passive microwave, AMSR-2

GCOMによる包括的な気候観測
Toward Comprehensive Climate Observations - Global Change Observation Mission (GCOM)

*沖 大幹[1]、可知 美佐子[2]、村上 浩[2]
*Taikan Oki[1], Misako Kachi[2], Hiroshi Murakami[2]

1.東京大学生産技術研究所、2.宇宙航空研究開発機構第一宇宙技術部門地球観測研究センター
1.Institute of Industrial Science, The University of Tokyo, 2.Earth Observation Research Center, Japan Aerospace Exploration Agency

The Global Change Observation Mission (GCOM) is planned as the comprehensive observation system of the Earth System's essential variables of atmosphere, ocean, land, cryosphere, and ecosystem (Imaoka *et al.*, 2010). The mission is designed to find out the traces of human-induced environmental changes, such as deforestations, forest fires, air and water quality changes to distinguish the human-induced changes and the natural cyclic changes, as well as to contribute to the climate studies and operational applications.

GCOM consists of two medium sized satellites to provide comprehensive information of the Essential Climate Variables (ECV) of atmosphere, ocean, land, cryosphere, and ecosystem. The GCOM-W (Water) or "SHIZUKU" satellite that is carrying the Advanced Microwave Scanning Radiometer 2 (AMSR2), which was launched from JAXA Tanegashima Space Center on May 18, 2012 (JST); and GCOM-C (Climate) satellite that will be carrying the Second Generation Global Imager (SGLI), which is scheduled to be launched in Japanese Fiscal Year of 2016.

AMSR2 on board the GCOM-W satellite is multi-frequency, total-power microwave radiometer system with dual polarization channels for all frequency bands. AMSR2 is a successor of JAXA's Advanced Microwave Scanning Radiometer for EOS (AMSR-E) on the NASA's Aqua satellite, which was launched in May 2002, and completed its operation in December 2015. Basic concept of AMSR2 is almost identical to that of AMSR-E. Because of various experiences and heritages from AMSR-E, AMSR2 standard products, including brightness temperature and eight geophysical parameters that related to water cycle, have been introduced to many operational and science applications quickly. AMSR2 standard products are available from the GCOM-W1 Data Providing Service (https://gcom-w1.jaxa.jp/). In addition to those standard products, eight research products are defined to expand possible utilization of AMSR2 data in new fields. Those are all-weather sea surface wind speed (ASW), high-resolution sea surface temperature (10-GHz SST), land temperature, vegetation water content, high-resolution sea ice concentration, sea ice thickness, sea ice moving vector, and soil moisture and vegetation water content based on the data assimilation methodology. AMSR2 ASW research product is distributed to public through the GCOM-W web site (http://suzaku.eorc.jaxa.jp/GCOM_W/) and 10-GHz SST research product is included in AMSR2 standard SST product from product version 2 to provide complimentary information. Other products except data assimilation product are being integrated and evaluated at JAXA for future release. JAXA also planning to produce consistent dataset of water-related parameters between AMSR-E and AMSR2 for global water cycle and climate change studies in 2016.

SGLI on board the GCOM-C satellite is a versatile, general purpose optical and infrared radiometer system covering the wavelength region from near ultraviolet to infrared. Two major new features are added to SGLI, they are 250 m spatial resolution for 11 channels and polarization/multidirectional observation capabilities. The 250m spatial resolution will provide enhanced observation capability over land and coastal areas where the influences of human activity are most obvious. The polarization and multidirectional observations will enable us to retrieve aerosol information over land. Precise observation of global aerosols is a key for improving climate-prediction models. Further information of the GCOM-C and SGLI can be found at the GCOM-C web site (http://suzaku.eorc.jaxa.jp/GCOM_C/).

[1] K. Imaoka, M. Kachi, H. Fujii, H. Murakami, M. Hori, A. Ono, T. Igarashi, K. Nakagawa, T. Oki, Y. Honda, and H. Shimoda, “Global Change Observation Mission (GCOM) for monitoring carbon, water cycles, and climate change,” Proc. of the IEEE, vol. 98, pp.717-734, 2010.

キーワード：地球観測、水循環、気候変動
Keywords: earth observation, hydrological cycle, climate change

