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Second International Workshop on Space-Based Lidar Remote Sensing Techniques and Emerging Technologies

Many physical phenomena critical to improving our understanding of the Earth and planetary systems can only be practically measured using active optical remote sensing techniques, which can be accomplished with lidar systems. Lidar remote sensing is analogous to radar remote sensing, except lidar employs electromagnetic radiation with wavelengths four to five orders of magnitude shorter than radar. This wavelength difference causes proportionally less beam divergence; results in profound differences in usable targets, atmospheric transmission, and attainable resolution; and requires different beam generation, handling, and detection technologies. The evolution of laser technologies in recent years—including, in particular, advances in diode-pumping technology—has paved the way for high-power, long-lasting space lidar systems.

Researchers urgently need further improvements in laser remote sensing technologies for collecting critical space-based measurements, such as data related to winds, ozone, carbon dioxide, moisture, clouds, aerosols, surface topography, ice thickness, vegetation, trace atmospheric species, biogenic trace gases and materials, and oceanic properties.

NASA has taken on the difficult task of developing spaceborne technologies like these with such space lidar activities as the Lidar In-Space Technology Experiment, the Cloud-Aerosol Lidar and Infrared *Pathfinder* Satellite Observation mission, the Cloud-Aerosol Transport System project, and the Ice, Cloud, and Land Elevation *Satellite-1* and *-2* missions. The European Space Agency (ESA) has conducted its own research in the area with the Aeolus atmospheric dynamics mission. Launching lidar systems into space and achieving long-term operation remain daunting engineering challenges.

For more complex instruments, such as Aladin (part of the Aeolus mission), the technical readiness level (TRL) of the related technologies is still immature, and even post-launch domains, such as material contamination, laser damage, radiation hardening, endurance, and long-term optical component reliability, require further examination and analysis. Various space agencies, as they independently develop technology and plan missions, are finding it difficult to obtain funding.

To address such challenges, the chairs of the IEEE Geoscience and Remote Sensing Society (GRSS) Lidar Working Group on Instrument and Future Technology proposed that the GRSS Administrative Committee hold a second workshop four years after the First International Workshop on Space-Based Lidar Remote Sensing Techniques and Emerging Technologies, which took place in Paris in 2014. This second workshop would assess the status of space-based lidar technology efforts globally and explore whether a framework for collaboration can be developed among various space agencies, industries, and academia to jointly advance space-based laser technologies and techniques for high-priority, active optical remote sensing measurements from space.

The second workshop took place 4–8 June 2018 at the conference center in Milos, Greece (https://www.lidar-workshop-2018.com/). The intent of this workshop was to offer a venue for scientists and technologists from different countries, government agencies, industries, and universities to meet and discuss important issues related to current and planned space lidar missions, techniques, and associated emerging and enabling technologies.

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It was also intended as an opportunity to discuss challenges and common issues and explore ways to increase collaboration among space agencies and organizations and thus stimulate advancements in technologies related to active space-based remote sensing measurements. The event attracted more than 70 participants from 13 countries. The government space agencies represented were NASA, ESA, the Japan Aerospace and Exploration Agency (JAXA), the Centre National d'Etude Spatiale (CNES), and the German Aerospace Center (DLR) (Figure 1). Also attending were representatives from 11 universities and 16 industries. The gathering drew participants with a broad range of expertise in space science, engineering, technology development, program management, and policy formulation, all seeking ways to tackle diverse challenges and find innovative solutions through international partnerships and collaboration (Figure 2).

LIDAR REMOTE SENSING IS ANALOGOUS TO RADAR REMOTE SENSING, EXCEPT LIDAR EMPLOYS ELECTROMAGNETIC RADIATION WITH WAVELENGTHS FOUR TO FIVE ORDERS OF MAGNITUDE SHORTER THAN RADAR.

Following the approach of the first workshop, the venue was open to public, but the planned presentations were primarily invited. This approach aimed to allow the talks to introduce key areas/domains of discussion about important issues related to current and planned space lidar missions and technologies and to explore ways to increase collaboration on future missions. This workshop was cochaired by Dr. Upendra N. Singh (NASA Langley Research Center), Dr. Georgios Tzeremes (ESA Research and Technology Centre), and Dr. Philippe Kechhut [Centre National de la Researche Scientifique (CNRS)]. The workshop was organized by Dr. Tzeremes and the event's sponsoring partners: the GRSS, the ESA, Raymetrics, the U.S. National Oceanic and Atmospheric Administration, Mellon Technologies, and the Laboratoires Atmosphères, Milieux, Observations Spatiales (LATMOS).

The main topics for presentations and discussion were as follows:

- advances in space-based lidar techniques and methodologies for Earth science, planetary science, and lunar and Mars exploration
- science and exploration highlights, observational approaches, technologies, and measurement synergies
- challenges experienced in space lidar missions to date and discussion of approaches to apply lessons learned
- results from or plans for simulations, airborne experiments, and demonstrations as precursors for space missions
- new and emerging space lidar technologies, particularly in lasers, telescopes, and detectors
- space laser reliability factors and effects of the space environment (thermal contamination, optical damage, and radiation)
- risk reduction, mitigation, and readiness efforts for advancing and establishing high TRL levels.

FIGURE 1. Space agency representatives with local chairs: (from left) Dr. Toshiyoshi Kimura, JAXA; Philippe Goudy, ESA; Christoduolos Protopappas, European Launcher Development Organisation; Jean-Yves Le Gall, CNES; Dr. Upendra N. Singh, NASA; and Dr. Georgios Tzeremes, ESA.

FIGURE 2. Participants at the Second International Workshop on Space-Based Lidar Remote Sensing Technique and Emerging Technologies at the entrance to the Milos Conference Center, Greece.

This workshop included two additional topics/sessions that were not part of the first workshop. One was about the Laser Interferometer Space Antenna, and the other focused on orbiting lidar, flash and navigational lidar, and Mars and Lunar Rover lidars. These topics involve many critical lidar applications and numerous activities supported and advanced by several space agencies.

The eight space lidar sessions/topical areas were as follows:

1) Topography, Cryosphere, and Biomass (chair: Dr. Toshiyoshi Kimura, JAXA)
2) Greenhouse and Trace Gases (chair: Pierre Flamant, LATMOS)
3) Clouds, Aerosols, and Oceans (chair: Arnaud Hélière, ESA)
4) Winds (chair: Dr. Upendra Singh, NASA)
5) Entry, Descent, and Landing for Exploration (Orbiting Lidar), Precision Landing and Hazard Avoidance for Exploration (Flash and Navigational Lidar), Mars and Lunar Rover Lidars for Surface, Atmosphere, and Mineralogical Studies (chair: Dr. Georgios Tzeremes, ESA)
6) Laser Technology Developments for ESA's Laser Interferometer Space Antenna (chair: Dr. Azita Valinia, NASA)
7) New and Emerging Space Lidar Technology (chair: Frank Peri, NASA)
8) Space Environmental Effects, Lidar Reliability and Lifetime Issues (chairs: Wolfgang Riede, DLR, and Floyd Hovis, Fibertek).

Three or four invited talks were presented during each session, followed by panel discussion, summary, and conclusions. This approach facilitated open discussion for each session area and provided time for the exchange of ideas. Participants liked the discussion format and favored adopting it in future meetings.

On the opening day of the workshop, participants were welcomed by the local organizer, Dr. Tzeremes, and the workshop chairman, Dr. Singh, who drafted the overview of the workshop objectives and session chair assignments. Following the opening, representatives of the key space agencies took the podium in a plenary session and presented the space lidar strategies of their respective organizations: Jean-Yves Le Gall (CNES president) (Figure 3), Dr. Kimura (director, Sensor System Research Group Research and Development, JAXA), Dr. Singh (technical fellow for sensors and instrumentation, NASA) (Figure 4), and Philippe Goudy (head of Earth Observations Programs, ESA).

FIGURE 3. CNES President Jean-Yves Le Gall, delivering his plenary speech.

The workshop program, which followed the plenary session, included two topic areas per day, with sessions from 8:30 a.m. to 5:35 p.m. In the first session, representatives of the big three space agencies made presentations: NASA's presentation was about the Global Ecosystem Dynamics Investigation and the Ice, Cloud, and Land Elevation *Satellite-2* mission; JAXA's presentation was about the

(a) (b)

FIGURE 4. (a) Dr. Singh (right) with Dr. Tzeremes. (b) Dr. Kimura presents JAXA's vision for space lidars.

(a) (b)

FIGURE 5. Collaborative and networking opportunities at the workshop in Greece. (a) A group reception and (b) lunch on the pavilion.

Multifootprint Observation Lidar and Imager mission; and the ESA's presentation dealt with the BepiColombo laser altimeter. In the second session, the CNES offered a presentation about the Methane Remote Sensing mission. This session focused on the maturity of the technologies needed to trace greenhouse gasses. The session on clouds, aerosols, and oceans included presentations by the ESA ("Earth Clouds, Aerosols, and Radiation Explorer"), CNRS ("Monitoring the Evolving State of Clouds and Aerosol Layers"), and NASA ("Cloud-Aerosol Lidar with Orthogonal Polarization," concerning the longest operating lidar in space). In the session on winds, the ESA made a presentation about Aeolus concerning ways to measure wind speed from space, while NASA and JAXA made presentations about wind lidar developments. In the domain of miniaturized lidars for exploration, six different concepts/missions were presented, demonstrating the potential for this type of system. The Laser Interferometer Space Antenna was discussed in Session 6. Sessions 7 and 8 focused on new technologies and the reliability of lidar systems in space.

The Second International Workshop on Space-Based Lidar Remote Sensing Techniques and Emerging Technologies promoted collaboration (Figure 5) that will be strengthened by the establishment of international working groups in appropriate topical areas (including science, technology, data, and program formulation). Planning activities at the space agencies will be enhanced. Plans are underway to hold the third workshop in two years.

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