

PROCEEDINGS OF SPIE

Lidar Remote Sensing for Environmental Monitoring XV

Upendra N. Singh
Nobuo Sugimoto
Achuthan Jayaraman
Mullapudi V. R. Seshasai
Editors

4–7 April 2016
New Delhi, India

Sponsored by
SPIE

Cosponsored by
ISRO—Indian Space Research Organization (India) • Ministry of Earth Sciences (India) •
NASA—National Aeronautics and Space Administration (United States)

Cooperating Organizations
State Key Laboratory of Remote Sensing Science, Chinese Academy of Sciences (China)
RADI—Institute of Remote Sensing and Digital Earth, Chinese Academy of Sciences (China)
JAXA—Japan Aerospace Exploration Agency (Japan)
NICT—National Institute of Information and Communications Technology (Japan)

Local Host
ISRS—Indian Society of Remote Sensing (India)

Published by
SPIE

Volume 9879

Proceedings of SPIE 0277-786X, V. 9879

SPIE is an international society advancing an interdisciplinary approach to the science and application of light.

Lidar Remote Sensing for Environmental Monitoring XV, edited by Upendra N. Singh, Nobuo Sugimoto,
Achuthan Jayaraman, Mullapudi V. R. Seshasai, Proc. of SPIE Vol. 9879, 987901
© 2016 SPIE · CCC code: 0277-786X/16/\$18 · doi: 10.1117/12.2244564

Proc. of SPIE Vol. 9879 987901-1

The papers in this volume were part of the technical conference cited on the cover and title page. Papers were selected and subject to review by the editors and conference program committee. Some conference presentations may not be available for publication. Additional papers and presentation recordings may be available online in the SPIE Digital Library at SPIDigitalLibrary.org.

The papers reflect the work and thoughts of the authors and are published herein as submitted. The publisher is not responsible for the validity of the information or for any outcomes resulting from reliance thereon.

Please use the following format to cite material from these proceedings:

Author(s), "Title of Paper," in *Lidar Remote Sensing for Environmental Monitoring XV*, edited by Upendra N. Singh, Nobuo Sugimoto, Achuthan Jayaraman, Mullapudi V. R. Seshasai, Proceedings of SPIE Vol. 9879 (SPIE, Bellingham, WA, 2016) Six-digit Article CID Number.

ISSN: 0277-786X
ISSN: 1996-756X (electronic)
ISBN: 9781510601208

Published by

SPIE

P.O. Box 10, Bellingham, Washington 98227-0010 USA
Telephone +1 360 676 3290 (Pacific Time) · Fax +1 360 647 1445
SPIE.org

Copyright © 2016, Society of Photo-Optical Instrumentation Engineers.

Copying of material in this book for internal or personal use, or for the internal or personal use of specific clients, beyond the fair use provisions granted by the U.S. Copyright Law is authorized by SPIE subject to payment of copying fees. The Transactional Reporting Service base fee for this volume is \$18.00 per article (or portion thereof), which should be paid directly to the Copyright Clearance Center (CCC), 222 Rosewood Drive, Danvers, MA 01923. Payment may also be made electronically through CCC Online at copyright.com. Other copying for republication, resale, advertising or promotion, or any form of systematic or multiple reproduction of any material in this book is prohibited except with permission in writing from the publisher. The CCC fee code is 0277-786X/16/\$18.00.

Printed in the United States of America.

Publication of record for individual papers is online in the SPIE Digital Library.

SPIE. DIGITAL LIBRARY
SPIDigitalLibrary.org

Paper Numbering: *Proceedings of SPIE* follow an e-First publication model. A unique citation identifier (CID) number is assigned to each article at the time of publication. Utilization of CIDs allows articles to be fully citable as soon as they are published online, and connects the same identifier to all online and print versions of the publication. SPIE uses a six-digit CID article numbering system structured as follows:

- The first four digits correspond to the SPIE volume number.
- The last two digits indicate publication order within the volume using a Base 36 numbering system employing both numerals and letters. These two-number sets start with 00, 01, 02, 03, 04, 05, 06, 07, 08, 09, 0A, 0B ... 0Z, followed by 10-1Z, 20-2Z, etc. The CID Number appears on each page of the manuscript.

Contents

- vii *Authors*
- ix *Symposium Committees*
- xi *Conference Committee*

SESSION 1 SPACE LIDAR I

- 9879 02 **2-micron triple-pulse integrated path differential absorption lidar development for simultaneous airborne column measurements of carbon dioxide and water vapor in the atmosphere (Invited Paper) [9879-1]**
- 9879 03 **Development of Tm: fiber laser-pumped Ho:YLF laser [9879-2]**
- 9879 04 **Wavelength locking to CO₂ absorption line-center for 2- μ m pulsed IPDA lidar application [9879-3]**

SESSION 2 SPACE LIDAR II

- 9879 08 **Overview and status of vegetation lidar mission MOLI [9879-7]**
- 9879 09 **UV lifetime demonstrator for space-based applications [9879-8]**

SESSION 3 WATER VAPOR, WIND, AND OZONE MEASUREMENTS

- 9879 0C **Design of a fused optical fibre bundle-based receiver for low-altitude profiling of water vapour using Raman lidar [9879-11]**

SESSION 4 CLOUDS

- 9879 0F **Lidar measurements of tropical cirrus during monsoon period [9879-14]**
- 9879 0H **Lidar observation of transition of cirrus clouds over a tropical station Gadanki (13.45° N, 79.18° E): case studies [9879-16]**
- 9879 0I **Multi-wavelength dual polarisation lidar for monitoring precipitation process in the cloud seeding technique [9879-17]**

SESSION 5 MIDDLE AND UPPER ATMOSPHERE

9879 0L Lidar application to middle atmospheric dynamics [9879-20]

SESSION 6 VEGETATION CANOPY

9879 0P Demand-based urban forest planning using high-resolution remote sensing and AHP [9879-24]

9879 0Q Random forest regression modelling for forest aboveground biomass estimation using RISAT-1 PolSAR and terrestrial lidar data [9879-25]

9879 0R Performance of laser based optical imaging system [9879-26]

SESSION 7 AEROSOL I

9879 0S Lidar research activities and observations at NARL site, Gadanki, India (Invited Paper) [9879-28]

9879 0T Lidar studies on atmospheric aerosols at a semi-urban station Cheeryal (17.51° N, 78.62° E) near Hyderabad, India [9879-45]

9879 0U Retrieval of mixed layer height (MLH) from lidar using analytical methods and estimation of MLH growth rates over a tropical site Gadanki [9879-31]

9879 0V Dual polarization micropulse lidar observations of the diurnal evolution of atmospheric boundary layer over a tropical coastal station [9879-32]

SESSION 8 AEROSOL II

9879 0Z Measurements of long range transport using two wavelength and polarization lidar over tropical rural site, Gadanki (13.45° N, 79.17° E) [9879-34]

9879 10 Depolarization ratio, SNR estimation, and polarization sensitivity analysis for a commercial Raman depolarization lidar system [9879-35]

9879 12 Development of a high-spectral-resolution lidar for continuous observation of aerosols in South America [9879-37]

POSTER SESSION

9879 19 Experimental investigations on range-resolved refractive index structure parameter C_n^2 , by optical measurements over a 2.0-km free space laser path [9879-46]

9879 1B OPO DIAL lidar for remote measurements of atmospheric gases in the IR range [9879-49]

- 9879 1C **Diameter at breast height estimation in Mt. Makiling, Laguna, Philippines using metrics derived from airborne lidar data and Worldview-2 bands [9879-50]**
- 9879 1D **Addressing lidar overlap for diameter at breast height estimation using a point-cloud processing software [9879-51]**
- 9879 1F **Validation of the separability measure for Rhizophoraceae and Avicenniaceae using point density distribution from lidar [9879-53]**
- 9879 1G **A technique for retrieval of ozone vertical distribution from DIAL measurements [9879-54]**
- 9879 1M **Construction and first atmospheric observations of a high spectral resolution lidar system in Argentina in the frame of a trinational Japanese-Argentinean-Chilean collaboration [9879-60]**

Authors

Numbers in the index correspond to the last two digits of the six-digit citation identifier (CID) article numbering system used in Proceedings of SPIE. The first four digits reflect the volume number. Base 36 numbering is employed for the last two digits and indicates the order of articles within the volume. Numbers start with 00, 01, 02, 03, 04, 05, 06, 07, 08, 09, 0A, 0B...0Z, followed by 10-1Z, 20-2Z, etc.

Albert, Michael, 09
Anfill, Charles W., 04
Argamosa, Reginald Jay L., 1C, 1D, 1F
Asai, Kazuhiro, 03, 08
Avdikos, George, 10
Banerjee, Arup, 0R
Bantayan, Nathaniel C., 1C
Biswas, Amiya, 0R
Burlakov, V. D., 1G
D., Ramakrishna Rao, 0I, 0T, 19
Dolgii, S. I., 1G
Dutt, Ashutosh, 0R
E., James Jebaseelan Samuel, 0U, 0Z
Faelga, Regine Anne G., 1C, 1D, 1F
Fitzpatrick, Fran, 09
Georgoussis, George, 10
Hovis, Floyd, 09
Ibañez, Carlyn Ann G., 1C, 1D, 1F
Imai, Tadashi, 08
Ishii, Shoken, 03
Jin, Yoshitaka, 12, 1M
Jones, Darrell, 09
Kharchenko, O. V., 1B, 1G
Kimura, Toshiyoshi, 08
Kolanuvada, Srinivasa Raju, 0P
Krishnaiah, M., 0H
Krishnan, Vani, 0P
Kumar, Shashi, 0Q
Kurulkar, Amit, 0R
Litvinovitch, Slava, 09
Machavaram, V. R., 0C
Malabanan, Matthew V., 1C, 1D
Mangla, Rohit, 0Q
Mariappan, Muneeswaran, 0P
Mishra, Manoj Kumar, 0V
Mizuno, Akira, 12, 1M
Mizutani, Kohei, 03
Murooka, Jumpei, 08
Murti, M. V. R., 0F
N., Sangeetha, 0C
Nandy, Subrata, 0Q
Nevzorov, A. A., 1G
Nevzorov, A. V., 1G
Nishizawa, Tomoaki, 12, 1M
Otero, Lidia, 12, 1M
P., Sudhakar, 0I, 0T, 19
Papandrea, Sebastian, 12, 1M
Paringit, Enrico C., 1C, 1D, 1F
Patel, Naimesh, 0R
Perez, Gay Jane P., 1F
Petros, Mulugeta, 02, 04
Posilero, Mark Anthony V., 1C, 1D, 1F
Puffenburger, Kent, 09
Quel, Eduardo, 12, 1M
R., Vishnu, 0U, 0Z
Rajeev, K., 0V
Ramesh, K., 0L
Rao, C. Dhananjaya, 0H
Refaat, Tamer F., 02, 04
Ristori, Pablo, 12, 1M
Romanovskii, O. A., 1B, 1G
Roy, Subhajit, 0F
Rudd, Joseph, 09
Sadovnikov, S. A., 1B
Sakaizawa, Daisuke, 08
Sato, Atsushi, 03
Satyanarayana, Malladi, 0I, 0T, 19
Schum, Tom, 09
Shah, Dhruv S., 0R
Sheela, K. Anitha, 0I, 0T, 19
Shumskii, V. K., 1B
Sijikumar, S., 0V
Singh, Upendra N., 02, 04
Sinha, P. R., 0U
Sridharan, S., 0L
Srinivasan, M. Arunachalam, 0H
Sugimoto, Nobuo, 12, 1M
Sunilkumar, S. V., 0V
T., Narayana Rao, 0U
Tandoc, Fe Andrea M., 1C, 1D, 1F
Vora, Anup, 0R
Yakovlev, S. V., 1B
Y., Bhavani Kumar, 0C, 0F, 0S, 0U, 0Z
Yu, Jirong, 02, 04
Zaragosa, Gio P., 1C, 1D, 1F

Symposium Committees

Symposium Chairs

Upendra Singh, NASA Langley Research Center (United States)
Vinay Dadhwal, Indian Space Research Organisation (India)
KJ Ramesh, Ministry of Earth Sciences (India)

Symposium Co-chairs

Toshio Iguchi, National Institute of Information and
Communications Technology (Japan)
Jiancheng Shi, Institute of Remote Sensing and Digital Earth
(China)

Honorary Symposium Chairs

A. S. Kiran Kumar, Indian Space Research Organisation (India)
Charles F. Bolden, National Aeronautics and Space
Administration (United States)
Jean-Yves Le Gall, Centre National d'Études Spatiales (France)
Naoki Okumura, Japanese Aerospace Exploration Agency
(Japan)
Dazhe Xu, China National Space Administration (China)
Madhavan N. Rajeevan, Ministry of Earth Sciences (India)
Guanhua Xu, Ministry of Science and Technology (China)
Alain Ratier, EUMETSAT (Germany)

Symposium Technical Program Chairs

George J. Komar, National Aeronautics and Space
Administration (United States)
Kohei Mizutani, National Institute of Information and
Communications Technology (Japan)
Tapan Misra, Indian Space Research Organisation (India)
S.S.C. Shenoi, Ministry of Earth Sciences (India)
Xiaohan Liao, China National Remote Sensing Center (China)

Symposium International Organizing Committee

Michael H. Freilich, *Chair*, National Aeronautics and Space
Administration (United States)
Jack A. Kaye, National Aeronautics and Space Administration
(United States)
Clayton P. Turner, NASA Langley Research Center (United States)

David F. Young, NASA Langley Research Center (United States)
Y. V. N. Krishnamurthy, Indian Space Research Organisation (India)
M. Annadurai, Indian Space Research Organisation (India)
Saroj K. Jha, National Hydrographic Centre (India)
E. N. Rajagopal, National Centre for Medium Range Weather Forecasting (India)
M. Ravichandran, National Centre for Antarctic and Ocean Research (India)
Teruyuki Nakajima, Japan Aerospace Exploration Agency (Japan)
Toshiyoshi Kimura, Japan Aerospace Exploration Agency (Japan)
Akimasa Sumi, National Institute for Environmental Studies (Japan)
Haruhisa Shimoda, Tokai University (Japan)
Peng Gong, Tsinghua University (China)
Shunling Liang, Beijing Normal University (China)

Local Organizing Committee

Shibendu S. Ray, Mahalanobis National Crop Forecast Centre (India)
Mahendra Bhutiyani, Defence Terrain Research Laboratory (India)
Vivek Singh, Indian Space Research Organisation (India)
Shiv Prasad Aggarwal, Indian Space Research Organisation (India)
Sameer Saran, Indian Space Research Organisation (India)
Jagvir Singh, Ministry of Earth Sciences (India)
Rishi Kumar, Ministry of Earth Sciences (India)
Rabi N. Sahoo, Indian Agricultural Research Institute (India)
Jai K. Garg, Guru Gobind Singh Indraprastha University (India)
Pawan Kumar Joshi, Jawaharlal Nehru University (India)
Madan M. Kimothi, Mahalanobis National Crop Forecast Centre (India)

Conference Committee

Conference Chairs

Upendra N. Singh, NASA Langley Research Center (United States)
Nobuo Sugimoto, National Institute for Environmental Studies (Japan)
Achuthan Jayaraman, National Atmospheric Research Laboratory
(India)
Mullapudi V. R. Seshasai, National Remote Sensing Center (India)

Conference Program Committee

Makoto Abo, Tokyo Metropolitan University (Japan)
Weibiao Chen, Shanghai Institute of Optics and Fine Mechanics
(China)
Panuganti C. S. Devara, Indian Institute of Tropical Meteorology
(India)
Takashi Fujii, Central Research Institute of Electric Power Industry
(Japan)
John P. George, National Center for Medium Range Weather
Forecasting (India)
Parminder Ghuman, NASA Goddard Space Flight Center
(United States)
Yongxiang Hu, NASA Langley Research Center (United States)
Shoken Ishii, National Institute of Information and Communications
Technology (Japan)
Dong Liu, Anhui Institute of Optics and Fine Mechanics (China)
Philippe L. Keckhut, LATMOS (France)
Sang-Woo Kim, Seoul National University (Korea, Republic of)
D. Preveen Kumar, National Center for Medium Range Weather
Forecasting (India)
Thomas J. McGee, NASA Goddard Space Flight Center
(United States)
Kohei Mizutani, National Institute of Information and Communications
Technology (Japan)
Fred Moshary, The City College of New York (United States) and
NOAA-CREST (United States)
Kunjukrishnapillai Rajeev, Vikram Sarabhai Space Center (India)
Tamer F. Refaat, NASA Langley Research Center (United States)
Soma Senroy, India Meteorological Department (India)
Tetsu Sakai, Meteorological Research Institute (Japan)
Daisuke Sakaizawa, Japan Aerospace Exploration Agency (Japan)
Takashi Shibata, Nagoya University (Japan)
Tatsuo Shiina, Chiba University (Japan)

Georgios Tzermes, European Space Research and Technology
Centre (Netherlands)
Bhavani Kumar Yellapragada, National Atmospheric Research
Laboratory (India)
Fan Yi, Wuhan University (China)
Jirong Yu, NASA Langley Research Center (United States)

Session Chairs

Opening Ceremony and Plenary Session

Upendra N. Singh, NASA Langley Research Center (United States)

- 1 Space Lidar I
George J. Komar, NASA Headquarters (United States)
Upendra N. Singh, NASA Langley Research Center (United States)
- 2 Space Lidar II
George J. Komar, NASA Headquarters (United States)
Ramesh K. Kakar, NASA Headquarters (United States)
- 3 Water Vapor, Wind, and Ozone Measurements
Kohei Mizutani, National Institute of Information and Communications
Technology (Japan)
Junpei Murooka, Japan Aerospace Exploration Agency (Japan)
- 4 Clouds
Fred Moshary, The City College of New York (United States) and
NOAA-CREST (United States)
Floyd E. Hovis, Fibertek, Inc. (United States)
- 5 Middle and Upper Atmosphere
Achuthan Jayaraman, National Atmospheric Research Laboratory
(India)
Bhavani Kumar Yellapragada, National Atmospheric Research
Laboratory (India)
- 6 Vegetation Canopy
Philippe L. Keckhut, LATMOS (France)
Mulugeta Petros, NASA Langley Research Center (United States)
- 7 Aerosol I
Nobuo Sugimoto, National Institute for Environmental Studies (Japan)
Edwin Eloranta, University of Wisconsin-Madison (United States)

- 8 Aerosol II
Mullapudi V. R. Seshasai, National Remote Sensing Center (India)
Yongxiang Hu, NASA Langley Research Center (United States)
- 9 Aerosol III
Parminder Ghuman, NASA Goddard Space Flight Center
(United States)
Tamer F. Refaat, NASA Langley Research Center (United States)

