Active Optical Remote Sensing Sensors and Instrumentation for NASA’s Future Earth and Space Science Measurements/Missions

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Outline

• Introduction
  – Active Optical Remote Sensing
  – Lidar Techniques
  – Lidar Applications in NASA’s Missions/Measurements

• NASA Sensors and Instrumentation Capability
  – Assessments, findings, and challenges
  – APMC Formal Action Item
  – Active Optical Tiger Team
  – Leveraging National and International Capabilities
  – Active Optical Strategy Formulation, Work Plan and Recommendations

• Conclusions
AORS Strategies

- Laser based instruments are applicable to a wide range of NASA’s Earth Science, Planetary Science, Aeronautics, and Human Explorations and Operation Mission Directorate needs

- Risk in lidar missions can be significantly reduced by progress in a few key technologies

- Modest NASA investment towards proposed strategy will have significant impact on future space-based active remote sensing missions

- Strategic alliance with other government organizations, industry, and academia for leveraging and accelerating advancement of key technologies
LIDAR - Light Detection And Ranging

- LIDAR is an important technique that contributes to NASA’s overall efforts in Earth System Science.
- LIDAR can make unique contributions, especially in terms of high vertical resolution (accurate time measurements -> accurate height measurements!)
- Since LIDAR involves “bring your own signal” (or “create your own”) there is a possibility of obtaining results not available from passive measurements that utilize “the signal nature gives you”
- LIDAR measurements can be important complements and/or validation measurements for those from other approaches.
- LIDAR technology has advanced to the point that deployment from surface, aircraft, and satellites is now possible; continuing advances offer even greater possibilities in the future.
- NASA has strong scientific and technical capability that is applied to development and utilization of LIDAR approaches.
Lidar Techniques

Altimetry Lidar
- Ice Sheet Mass Balance
- Vegetation Canopy
- Land Topography

\[ \text{Range} = \frac{c}{2} T_{\text{arrival}} \]

Backscatter Lidar
- Cloud
- Aerosol

\[ \frac{I_S}{I_T} \]

\[ \text{Density} = \frac{I_S}{I_T} \]

\[ \text{Range} = \frac{c}{2} T_{\text{arrival}} \]

Differential Absorption Lidar (DIAL)
- Ozone
- Carbon Dioxide

\[ \text{Concentration} = \log\left( \frac{I(\lambda_{\text{on}})}{I(\lambda_{\text{off}})} \right) \]

Doppler Lidar
- Wind Fields

\[ \text{Velocity} = \left( \frac{\lambda}{2} \right) f_{\text{Doppler}} \]

\[ \text{Frequency} \]

\[ f_{\text{Doppler}} \]

\[ T_{\text{arrival}} \]

\[ T_{\text{arrival}} \]

\[ T_{\text{arrival}} \]

\[ T_{\text{arrival}} \]
LIDAR is a Multi-Enterprise Need

**NASA Enterprises Needs**

- Science
  - Clouds/Aerosols
  - Tropospheric Winds
  - Ozone
  - Carbon Dioxide
  - Biomass Burning
  - Water Vapor
  - Surface Mapping
  - Laser Altimetry
  - Oceanography
  - Surface Topography
  - Molecular Species
    - \( \text{H}_2\text{O}, \text{CO}_2, \text{Methane} \)

- Aeronautics
  - Turbulence detection
  - Wind shear detection
  - Wake vortices

- Space Exploration
  - Lander Guidance/Control
  - Lander Hazardous Winds/Dust Avoidance
  - Mars Atmospheric Winds
  - Biological Elements (C, N, H, S, P)
  - Optical Communication
  - Spacecraft Automatic Rendezvous/Capture
  - Wind Profiling for Launch Vehicles
Active Optical Measurements in the Earth Sciences

**Weather**
- Tropospheric Winds
- Atmospheric Temperature and Water Vapor
- Cloud Particle Properties
- Cloud System Structure
- Storm Cell Properties

**Earth Surface & Interior**
- Land Surface Topography
- Surface Deformation
- Terrestrial Reference Frame

**Water & Energy Cycle**
- Atmospheric Water Vapor
- River Stage Height

**Climate Variability**
- Ocean Surface Currents
- Deep Ocean Circulation
- Sea Ice Thickness
- Ice Surface Topography

**Atmospheric Composition**
- Aerosol Properties
- Total Aerosol Amount
- Cloud Particle Properties
- Cloud System Structure
- Ozone Vertical Profile & Total Column Ozone
- Surface Gas Concentrates

**Carbon Cycle & Ecosystems**
- Biomass
- Vegetation Canopy
- Fuel Quality & Quantity
- CO₂ & Methane
- Trace Gas Sources
- Land Cover & Use
- Terrestrial & Marine Productivity

**Doppler Altimetry DIAL Backscatter**
S&I Technology Challenges

• Findings:
  – Opportunities for TRL 1-2 Sensor/Instrument development funding are limited
  – Opportunities for academia to participate in basic research to advance capabilities are limited and have shrunk over the years (e.g. GSRP and NASA/ASEE faculty fellowship programs are going away)
  – On-boarding new hires with chances to develop their careers through growing new technologies and applying them to mission concepts is limited
  – Improving methods for crossing the “Valley of Death” will result in reductions in both the rate and the magnitude of cost overruns occurring during mission development.
  – Improved methods for technology maturation will likely require increased technology investment in the early stages of mission development, but will result in significant risk reduction for missions/instruments. In turn, this will reduce both schedule and budget overruns, likely resulting in net savings. Further, it will enable an increased cadence for world-leading science missions.

• Forward Work:
  – Partner with OCT to review current S&I roadmap, review valley of death and assess distribution of TRL funding to work through these challenges
Findings:

- **Active optical (Laser/Lidar)** is critical for future NASA Earth, Planetary Science, and Mars Explorations. Six out of fifteen missions recommended by 2007 NRC Earth Science Decadal Survey require active optical remote sensing for successful mission implementation. Laser/Lidar is also critical for enabling human-rated EDL capabilities for a crewed Mars mission.

- The existing competitive model to fund technologies to develop, mature, advance, and demonstrate TRL advancement in a relevant environment is not working and often results in massive cost growth and schedule slips for Laser/Lidar missions.

- Need to produce more flight-ready Laser/Lidar technologies ready for mission infusion with the accompanying reduction in mission cost, schedule slips, and performance degradation.

- Need to enhance inter-Center collaboration and leveraging between SMD and HEOMD missions.
New Formal Action Item - APMC

• 09-13-2017 Action #7:
  • Charter an Active Optical (Laser/Lidar) tiger team, which includes representation from SMD, STMD and HEOMD to address an increased emphasis on Active Optical technology which is critical for future NASA Earth, Planetary Science and Mars Exploration. Team to provide agency-level strategy and solutions for advancing high-risk Laser/Lidar technologies that are not currently being sufficiently planned or developed or risk reduced to meet NASA missions requirements.

• Assigned to: Sensors/Instruments Capability Lead/Upendra Singh, NASA Tech Fellow S&I
• Due March 2018 (status); September 2018 (completion)
Active Optical Strategy Approach

- Active Optical will be a multi-directorate teaming of the Science Mission, Human Exploration and Operation Mission, Aeronautics Research Mission Directorate and Space Technology Mission representatives to provide the guidance and list of priority measurements requirements to meet their critical future needs.

- An Active Optical Tiger team consisting of MD’s representatives, CLT/TDT leads/co-leads and an external assessment team will work together to seek national and international community inputs to formulate an integrated Agency level strategy.

- An essential part of the augmentation strategy will be to engage with other US Government entities, as well as industry and academia, to leverage common Active Optical interests and complementary skills/expertise resident in those sectors.

- Develop a cross-cutting strategy based on “Lead, Leverage and Collaborate” approach with NASA and external entities, national and international, to meet NASA Science, Aeronautics and Exploration needs.

- An integrated technology development and investment plan, which will address each directorate agency's requirements in a cross-cutting, synergistic and cost-effective manner, to meet the Agency-level, priority Active Optical space based measurements/missions.
Active Optical Tiger Team

- **S&I Tech Fellow Team** — Upendra Singh, S&I Tech Fellow, Steve Horan, Deputy, TDT and Terence Doiron, Deputy, CLT

- **Active Optical Advisory Tiger Team (AOATT)** — SMD: Michael Seablom (SMD); Prasun Desai (STMD); Jason Crusan, Chris Moore, Phil Liebrecht (HOEMD)

- **Active Optical Assessment and Recommendation Team (AOART)** — S&I TDT Member
  - Dr. Robert T. Menzies, Jet Propulsion Lab (Rtd) — Chair, AOART
  - Dr. T. Y. Fan, MIT Lincoln Lab
  - Dr. Michael Hardesty, Boulder Lidar Associates
  - Dr. David Tratt, Aerospace Corp.
  - Dr. Denis Killinger, SenOptics LLC
AOART Purpose and Scope

• The AOART is an external assessment team to participate in formulating a NASA strategy for laser-based instrument development and usage for scientific and engineering purposes.

• AOART has been directed to assess the status and efficacy of NASA processes and methods for technology development and maturation and recommend actions that prioritize observational needs for the next several years.

• AOART seeks and incorporates opinions and feedback from NASA technologists, NASA mission directorate representatives, Capability Leadership Team leads/co-leads, and others.

• The AOART also seeks and evaluates input from other national agencies, the private sector, and international communities, to use as a basis for making assessments and offering recommendations.
Background: NASA TIM and International Workshop

- The **NASA TIM** (summer, 2018) was a forum to exchange perspectives on the current state of the discipline’s technologies and the direction NASA needs to take to raise the TRL of the measurement technologies to meet these measurement needs in the applications domains.
- The TIM aimed at focusing NASA’s directions to attain the necessary technology TRL levels to meet the Agency-level priority Active Optical measurements in Science, Explorations and Aeronautics and identify capabilities, internal and external to NASA, to lead, leverage and collaborate to meet NASA current and future needs.
- TIM inputs are used in formulating the agency-level strategy and solutions for advancing high-risk Laser/Lidar technologies that are not currently being sufficiently planned, developed, or risk reduced to meet NASA missions requirements.
- The **2018 International Workshop** presents opportunities to incorporate international synergies and collaborative opportunities between NASA and other international space agencies, for consideration in future planning.
NASA TIM on Active Optical Systems

• NASA Technical Interchange Meeting (TIM) on Active Optical Systems for Supporting Science, Exploration, and Aeronautics Measurements Needs

  Chairs: Upendra N. Singh,¹ Steve Horan¹ and Terence Doiron²

  ¹NASA Langley Research Center, USA; ²NASA Goddard Space Flight Centers, USA

– July 31-August 3, 2018 at Universities Space Research Association (USRA) Headquarters, Columbia, MD 21046

– TIM was a forum to exchange perspectives on the current state of the discipline’s technologies and the direction NASA needs to take to meet its future needs.

– >100 attendees from NASA HQ, NASA Centers/JPL, industry, academia, and FFRDCs
  • Plenary Speech by Steve Jurczyk, NASA Associate Administrator
  • Overview presentation by Jack Kaye, Associate Director, ESD; ESTO Program Director, etc
  • Sessions organized and chaired by HQ Program Executives, SMD, HEOMD, STMD and SME’s

– https://www.nasa.gov/nesc/tim-active-optical-systems

• TIM presentations and resulting discussions provide material helpful for assessing the existing capabilities of NASA, Industry, academia and FFRDC, formulating an agency-level strategy and solutions for advancing high-risk laser/lidar technologies that currently receive insufficient planning, development, or risk-reduction to meet NASA mission requirements

• TIM presentation materials and strategic inputs are being synthesized by the NASA Active Optical Tiger Team and will be presented to the NASA APMC with a suggested strategy to address the Agency’s needs in a cross-cutting, synergistic and cost-effective manner
Mission I - To Understand and Protect our Home Planet
Earth Science Foci

- **Atmospheric Composition** sounding measurements in the troposphere including aerosol and cloud properties and profiling, water vapor profiling, and Planetary Boundary Layer height
- **Earth’s Surface & Interior** via geodetic imaging including wide-swath laser altimetry
- **Climate Effect Monitoring** including ice mass changes, global ice characterization, snow depth, and snow-water equivalent measurements
- **Weather** including global tropospheric lidar wind measurements for planetary boundary layer energy, momentum, and mass exchanges; forecasting; convection; fluxes of heat, momentum, water vapor and other gases; and model validation and improvement
- **Carbon, Ecosystems, & Biogeochemistry** including measurements of CO$_2$ and CH$_4$ fluxes and trends, vegetation 3D structure, biomass, and disturbance, ocean mixing layer
Mission II - To Explore the Universe and Search for Life
Planetary and Exploration of Mars, Lunar and Outer Planets foci

- **Lunar Exploration** including landing navigation and hazard avoidance, and surface exploration and characterization
- **Jovian Moons** including surface features and characterization, and tidal signatures
- **Jovian Environment** including atmospheric cloud and wind structure, atmospheric composition
- **Mars Exploration** including atmospheric winds, density, and dust profiling, surface topography, surface exploration and characterization, search for organic signatures, moisture distribution, and cloud characterization
- **Martian Mission Support** including precision landing, navigation, and hazard avoidance, sample return rendezvous and capture, atmospheric characterization to support entry, descent, and landing
- **Titan and Venus** including balloon-borne active optical instrumentation
- **Situational awareness** of space weather phenomena
- **Laser interferometry**, active – optical sensing of telescope and satellite swarm elements to enable observations
Mission III: Active Optical for Aeronautics

- Detection of turbulence (current activities by Boeing and JAXA)
- Detection of and situational awareness for atmospheric hazards (e.g., volcanic ash, ice, snow)
- Sense and avoidance for autonomous UAVs and future autonomous urban mobility aircraft
- LIDARs on airport ground to control taxing, takeoff, and landing of aircraft (e.g., wake vortices)
- Imagery of various targets using UAVS
- Miniaturized, low power active optical sensors and instrumentation for Unmanned and Personal Air Vehicles for sensing and avoiding hazards in the National Air Space
Mission Area I: Earth Science
   Session 1: Clouds, Aerosols and Ocean
   Session 2: Greenhouse and Trace Gases Measurements
   Session 3: Wind Measurements
   Session 4: Topography, Cryosphere and Biomass

Mission Area II: Space Science and Exploration
   Session 5: Planetary Science
   Special: Automotive Lidar
   Session 6: EDL Technologies
   Session 7: Exploration

Mission Area III: Aeronautics
   Session 8: Aeronautics – Turbulence Detection, Hazard, Autonomous UAV

Mission Area IV: Innovations
   Session 9: Innovations

Panel Discussions of the Session Chairs and AOTT and AOART
https://www.nasa.gov/nesc/tim-active-optical-systems
International Workshop on Space-based Lidar

- Second International IEEE-GRSS Workshop on Space-based Lidar Remote Sensing Techniques and Emerging Technologies
  
  **Chairs: Upendra N. Singh¹ and Georgios Tzeremes²**
  
  ¹NASA Langley Research Center, USA; ²European Space Agency, ESA/ESTEC, The Netherlands

- **June 4-8, 2018** at Milos Conference Center, Adamas, Milos Island, Cyclades, Greece

- Workshop brought together ~100 active optical experts from NASA, ESA, JAXA, CNES, and DLR, including policy makers and experts from various agencies engaged in advancing space missions/measurements in active optical sensing for science and exploration

  - Plenary speeches from Jean-Yves Le Gall, President, CNES; Phillippe Gaudy, Head, Earth Observation, ESA; Toshiyoshi Kimura, Director, Sensors, JAXA; etc.,
  
  - Researchers and technologists from ESA, NASA, JAXA, CNES, and DLR; European and US industry leaders engaged in building active optical flight systems for space and academia
  
  - Four day of interactive technical sessions and panel discussions. Presentation materials and Papers


- **Workshop discussions** identified potential international synergies and collaboration opportunities between NASA and other international space agencies for consideration in future planning of active optical missions
Listing of Inherited Findings/Tenets

1) Active Optical is critical for future recommended missions
2) Modest NASA investment in Active Optical can have significant impact on future mission planning.
3) Risk in lidar missions can be significantly reduced by advancement and maturation of a few key technologies.
4) The existing competitive model to fund technologies to develop, mature, advance, and demonstrate TRL advancement in a relevant environment is not working and often results in massive cost growth and schedule slips for Laser/Lidar missions.
5) The current means for TRL advancement have a poor track record of successfully advancing to system-level TRL6 or TRL7, at which point further advancement would be implemented by space-flight projects.
6) Inter-Center collaboration is a means to reach the desired outcomes. (Finding from the Capability Leadership Team Assessment: “Need to enhance inter-Center collaboration and leveraging between SMD and HEOMD missions.”) NASA can benefit from engaging in collaborative opportunities with other U.S. agencies and international space agencies.
7) Leveraging between SMD and HEOMD is advantageous for implementing their roadmap priorities.
8) TRL 1-2 (research) opportunities are limited.
9) Participation of academia in Active Optical R&D that is relevant to NASA has been dwindling over the years.
10) There are limited opportunities for [attracting/developing] new hires.
National and International Community Inputs

- NASA Technical Interchange Meeting (TIM) on Active Optical Systems for Supporting Science, Exploration, and Aeronautics Measurements Needs

  **Chairs: Upendra N. Singh, Steve Horan and Terence Doiron**
  1NASA Langley Research Center, USA; 2NASA Goddard Space Flight Centers, USA

  - July 31-August 3, 2018
  - Universities Space Research Association (USRA) Headquarters, Columbia, MD 21046
  - TIM will bring together Active Optical experts from NASA Centers, NASA HQ, Industry, Academia, National Labs, and DoD who are engaged in developing concepts and systems to support NASA measurements needs
    [https://www.nasa.gov/nesc/tim-active-optical-systems](https://www.nasa.gov/nesc/tim-active-optical-systems)

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  - Workshop will bring together Active Optical Experts from NASA, ESA, JAXA, CNES, and DLR policymakers and experts from various agencies engaged in advancing Space missions/measurements in Active Optical area for Science and Exploration
Active Optical Work Plan Flow Chart

- Decadal Survey Review
- Key Questions for Workshop, and TIM
- Technology Interchange Meeting (TIM)
- Develop Critical Measurements and Technologies Drivers
- International Workshop
- Synthesize Inputs and Assessments
- Develop Assessment Report
- Present Assessment Report and Recommendations to HQ
- Active Optical Assessment Report
- Present Assessment Report and Recommendations to HQ
- Briefing/Presentation to AO Tiger Team and Mission Directorate
- NOV/DEC, 2018

Centers Input
FFRDC Input
OGA Input
Academia Input
NASA HQ Input
Industry Input

ESA
DLR
NASA
JAXA
CNES

EMB/APMC
March, 2018

NOV/DEC, 2018
Conclusions

- Active optical remote sensing is making significant contributions to NASA’s Earth Science, Planetary Science and being targeted for future Mars and Lunar explorations space-based observations.
- The integration of active optical remote sensing with other observing approaches is providing new knowledge in a broad set of disciplines.
- An Agency level active optical strategy effort will align NASA efforts for Science, Exploration and Aeronautics.
- Industry, academia, OGA and international partners are key contributors in advancing the active optical capability.
- Active optical remote sensing can be expected to play an increasing role in the future and will benefit from investments in lidar technology by NASA and our industry, interagency and international partners.
Questions?