# NASA ESTO Lidar Technologies Investment Strategy

*2016 Decadal Update*


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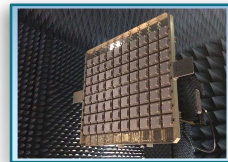
# ESTO Programs

**ESTO manages, on average, 120 active technology development projects. Most are funded through the five primary program lines below. Nearly 700 projects have completed since 1998.**

**Observation**

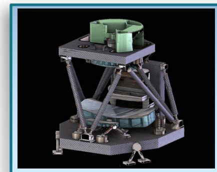
**Instrument Incubator Program (IIP)** Lidar Investment TRL 3-6

Innovative remote sensing instrument development from concept through breadboard and demonstration *(Average award: $1.5M per year over three years)*



**Advanced Component Technologies (ACT)** Lidar Investment TRL 2-5

critical components and subsystems for advanced instruments and observing systems *(average award: $300K per year over three years)*



**Sustainable Land Imaging-Technology (SLI-T)**

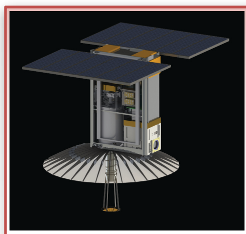
new technologies and reduced costs for future land imaging (Landsat) measurements *First solicitation released in FY16 (average award: TBD)*

**Information**

**Advanced Information Systems Technology (AIST)**

innovative on-orbit and ground capabilities for communication, processing, and management of remotely sensed data and the efficient generation of data products *(average award: $500K per year over two years)*

**Validation**



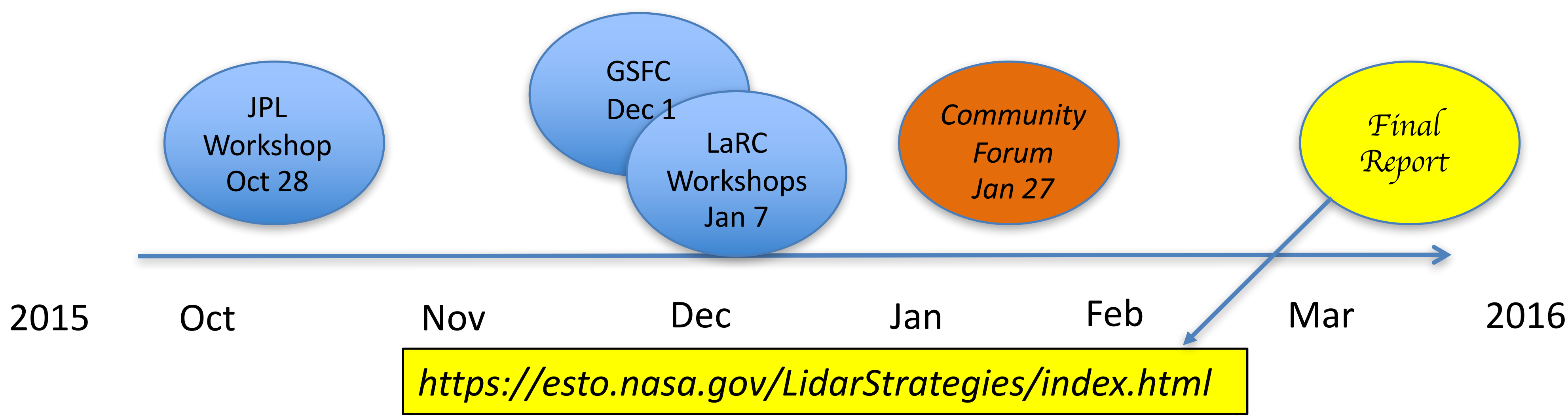
**In-Space Validation of Earth Science Technologies (InVEST)**

on-orbit technology validation and risk reduction for small instruments and instrument systems that could not otherwise be fully tested on the ground or airborne systems *(average award: $1-1.8M per year over three years)*

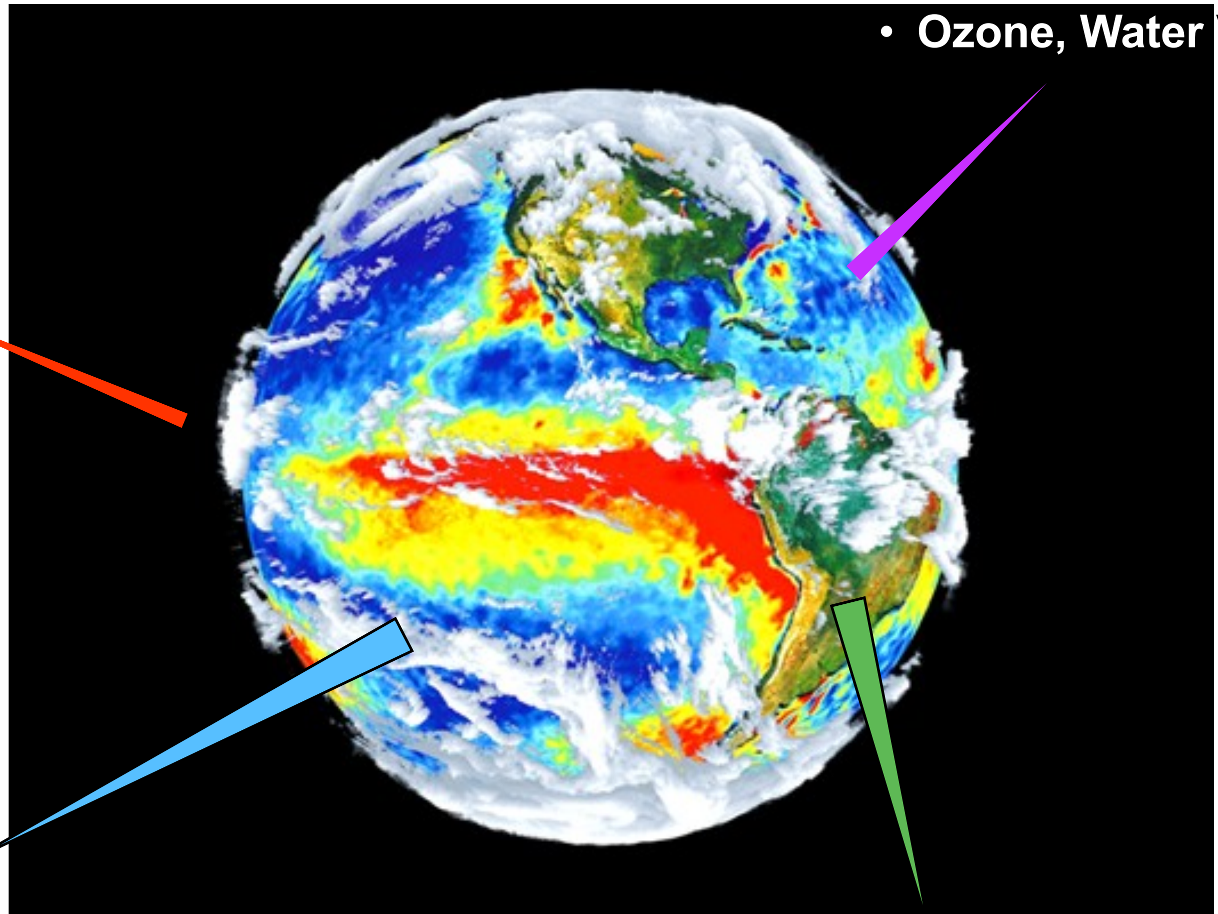
# ESTO 2016 Lidar Investment Strategy Update

## *Objectives:*

- Survey the 2016 state-of-the-art in lidar technology as it pertains to Earth science measurements
  - *Last survey was done in 2006*
- Identify capability gaps needed to enable Earth science goals
- Adjust investment strategy as needed



# Scope of the Survey: Laser Remote Sensing Applications &Techniques



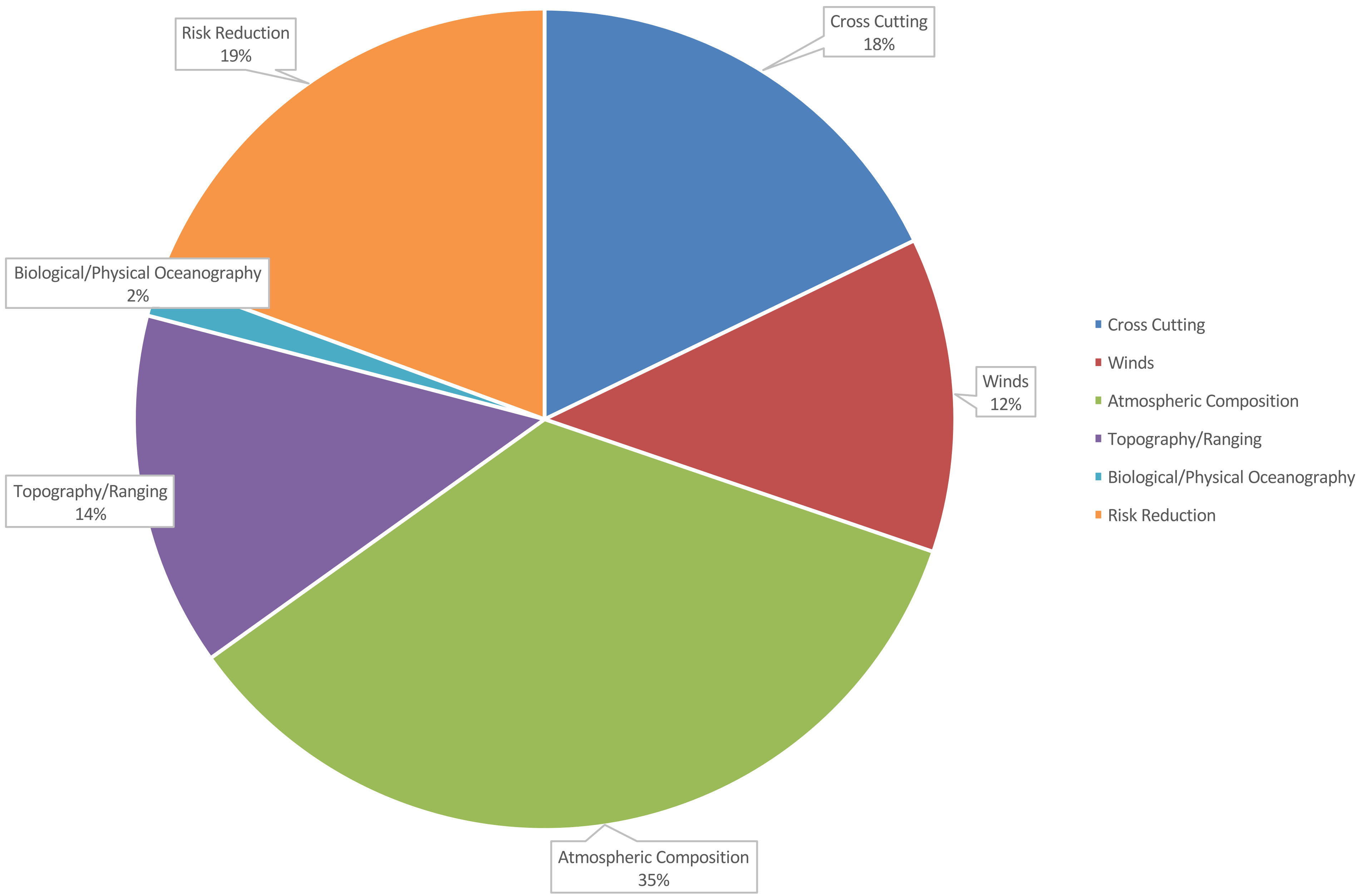
**Differential Absorption Lidar (DIAL)**
- Carbon Dioxide
- Ozone, Water Vapor

**Doppler Lidar**
- Wind Field

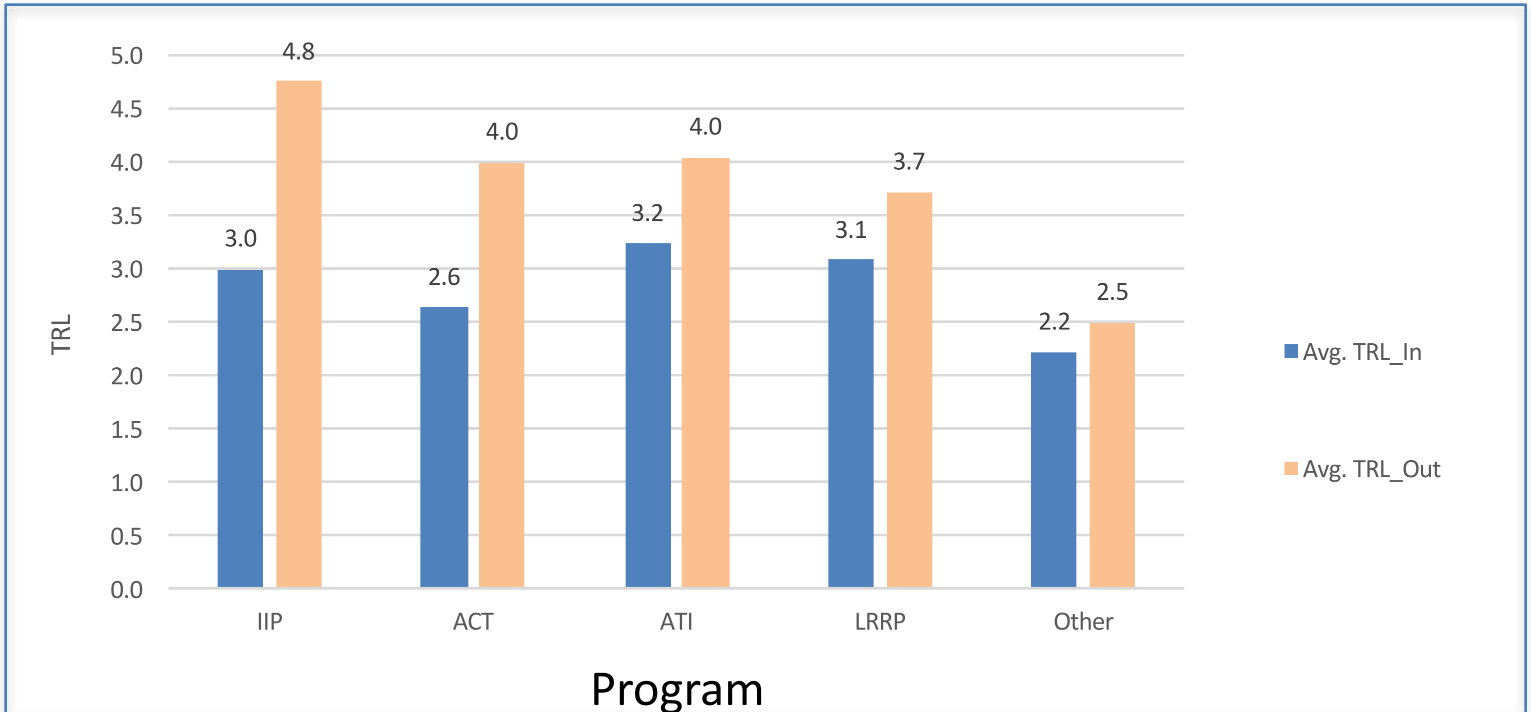
**Backscatter Lidar**
- Clouds
- Aerosols
- Phytoplankton Physiology
- Ocean Carbon/Particle Abundance

**High-Precision Ranging & Altimetry**
- Geodetic Imaging
- Vegetation Structure/Biomass
- Earth Gravity Field

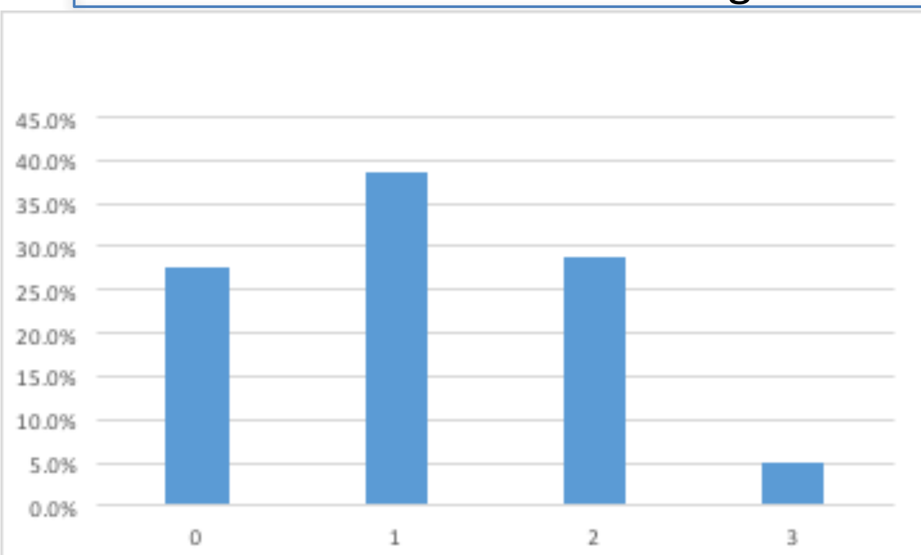
# ESTO Projects Distribution According to Science Measurement

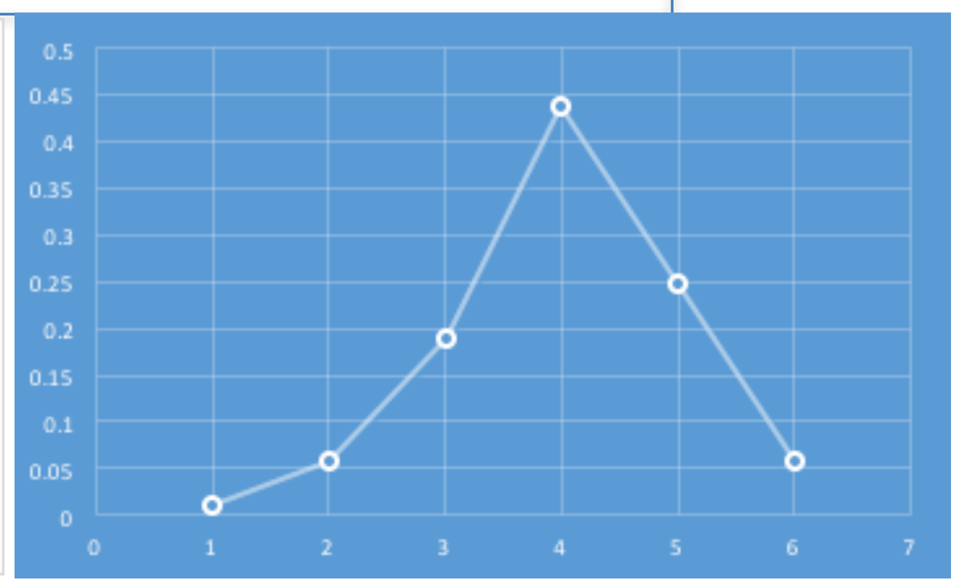


# TRL Advancement for Completed Laser Related ESTO Tasks




Percentage of Tasks

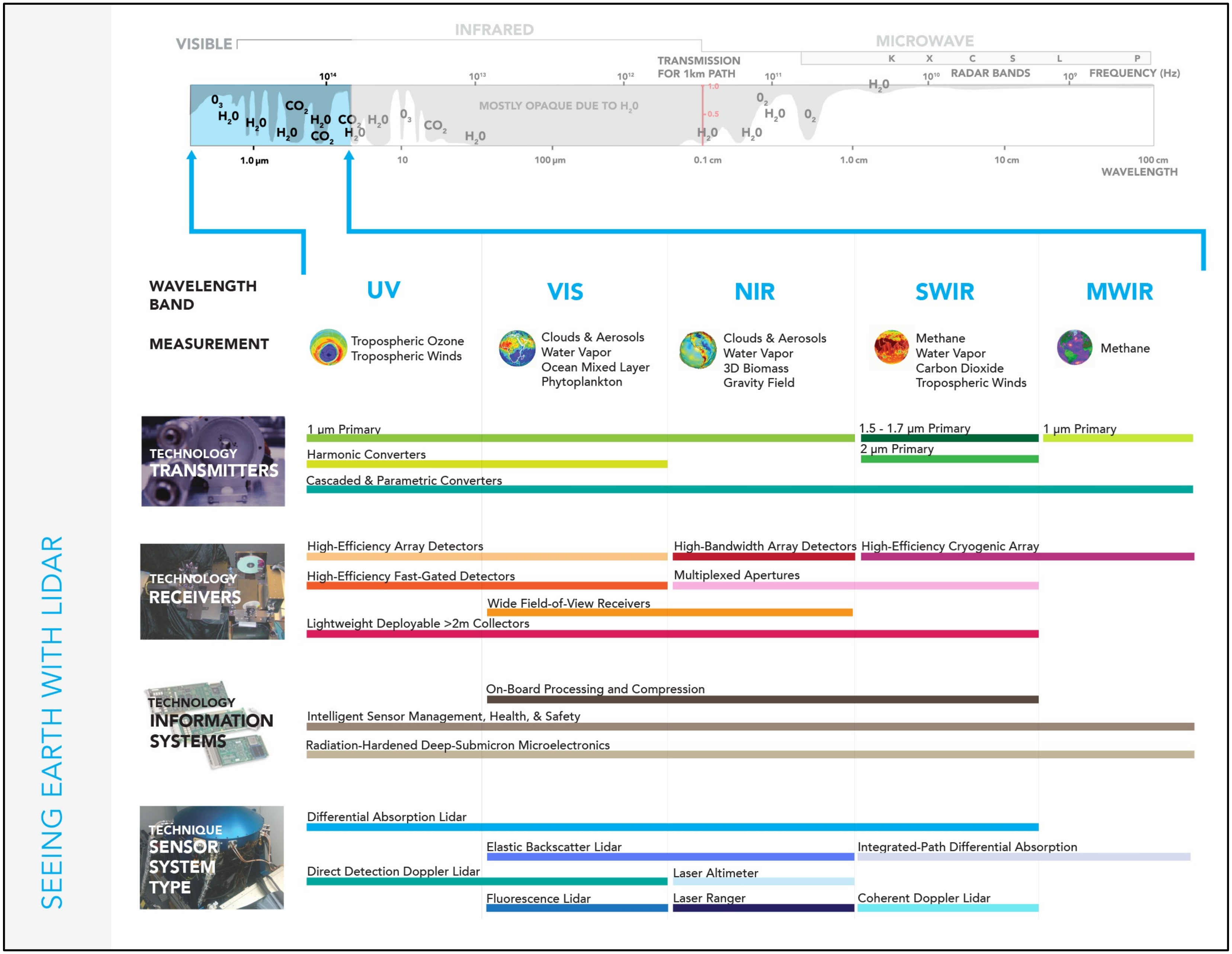


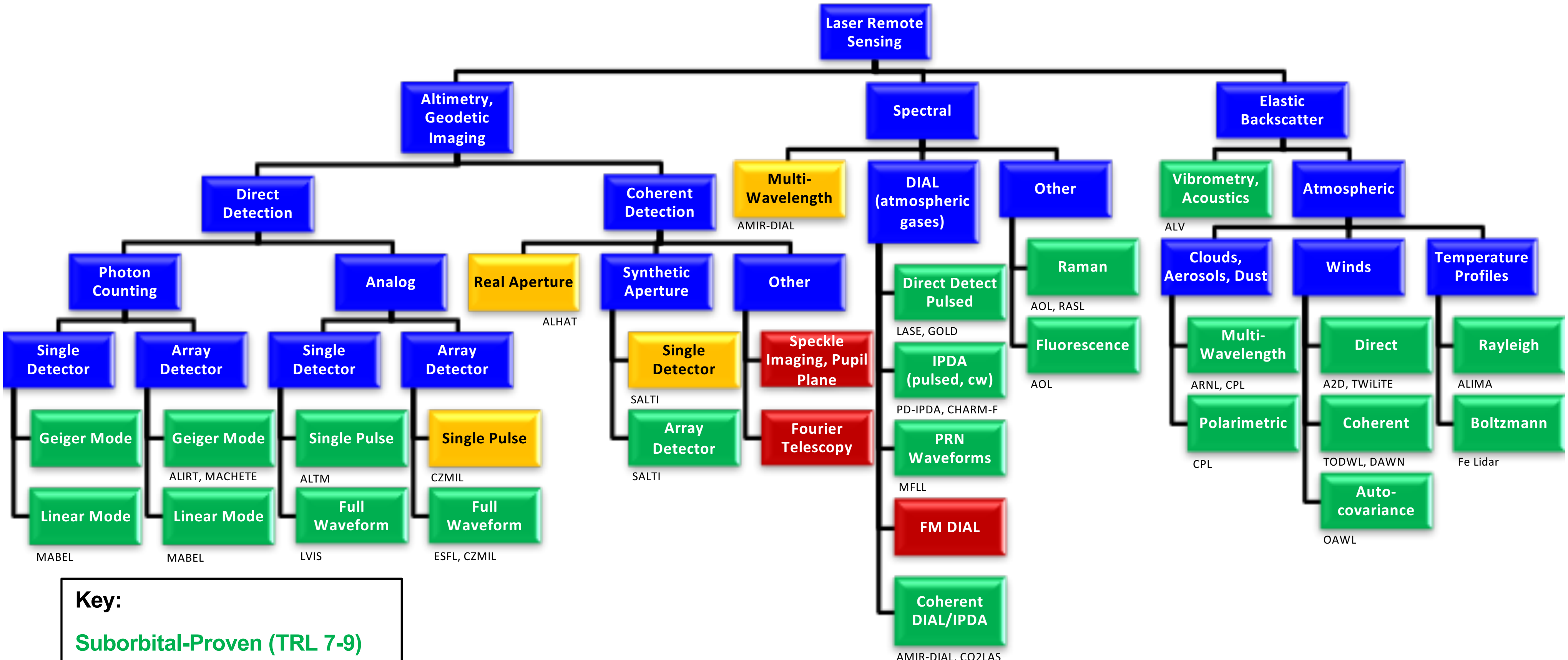

TRL Advancement

Final TRL

# The Lidar Technology Needs Landscape



# Laser Remote Sensing Taxonomy: Suborbital

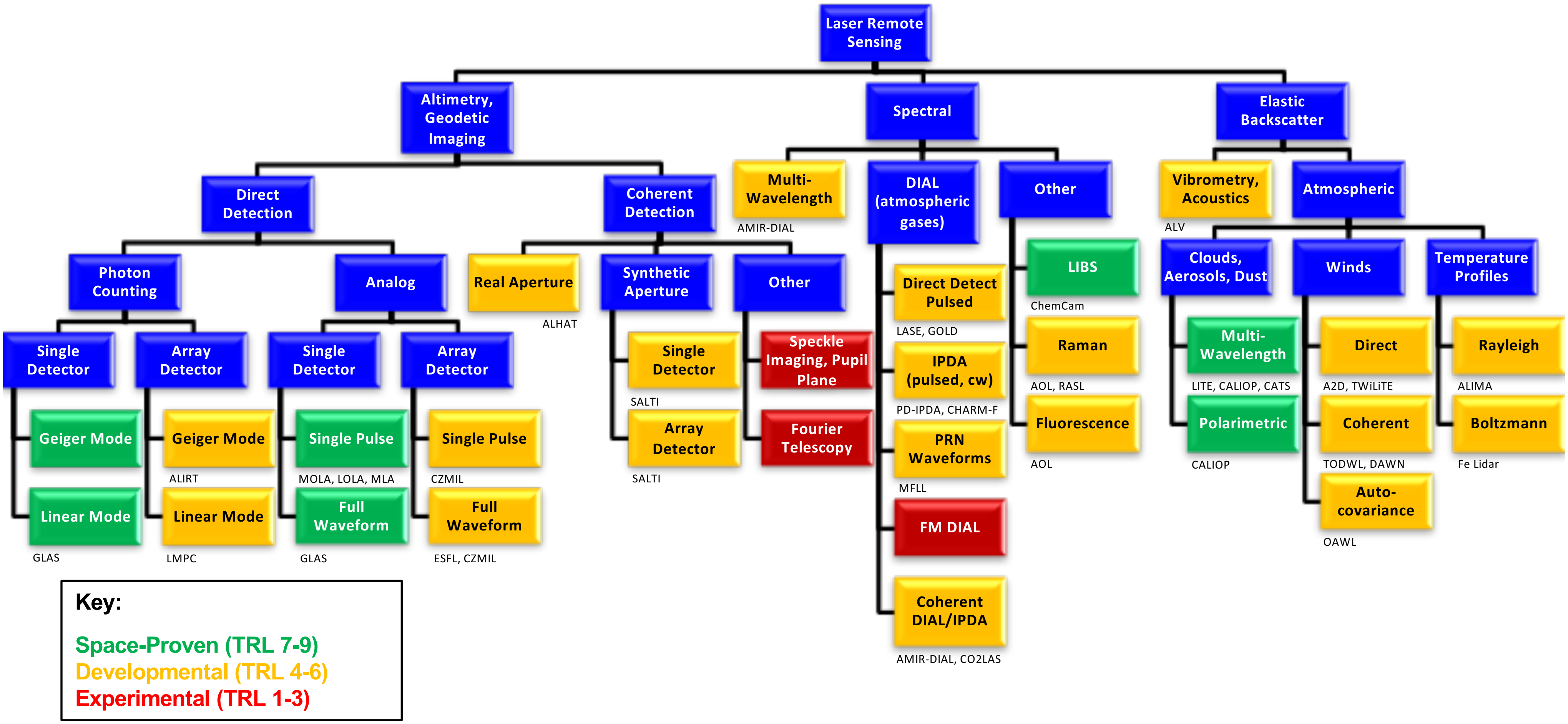



**Key:**

Suborbital-Proven (TRL 7-9)
Developmental (TRL 4-6)
Experimental (TRL 1-3)

**Adapted and updated from:** *Laser Radar: Progress and Opportunities in Active Electro-Optical Sensing* (NRC, 2014).

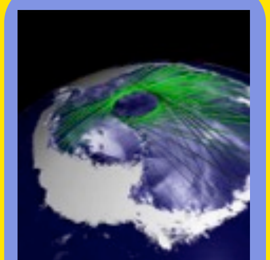
# Laser Remote Sensing Taxonomy: Space




**Adapted and updated from:** *Laser Radar: Progress and Opportunities in Active Electro-Optical Sensing* (NRC, 2014).

# NASA Earth Science 2007 Decadal Survey Missions

1 µm laser altimeter

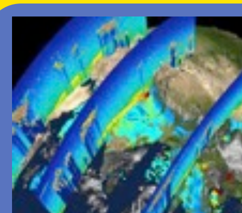


Ice, Cloud,and land Elevation Satellite II **(ICESat-II)**

Active Sensing of CO2 Emissions **(ASCENDS)**

1.57 or 2.06 µm column lidar

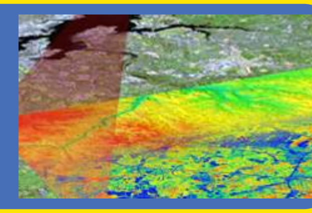
Multibeam cross-track dual-wavelength lidar



Aerosol - Cloud - Ecosystems **(ACE)**

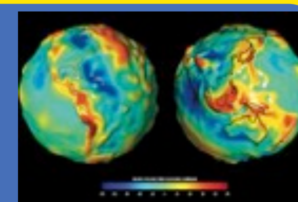
Mapping laser altimeter system

LIDAR Surface Topography **(LIST)**



Laser satellite-to-satellite interferometer

Gravity Recovery and Climate Experiment - II **(GRACE - II)**



Coherent and/or direct detection Doppler wind lidar(s)

Three-Dimensional Winds from Space Lidar **(3D-Winds)**

Lasers

# 2007 Decadal Survey Technology Capability Gaps

| Measurement | Capability Gap | TRL | "Greatest Challenge" TRL |
|---|---|---|---|
| $CO_2$ (ASCENDS) | Maturity and readiness of tunable lasers meeting measurement requirements | 3-4 | 1.57-µm power amplifier |
| $CO_2$ (ASCENDS) | High-efficiency detectors in 1.5-2 µm range | 5 | Space qualification/ radhard assurance |
| Aerosol/Clouds/Ecosystems (ACE) | Readiness of laser systems | 4-5 | Space qualification |
| Aerosol/Clouds/Ecosystems (ACE) | Field-widened interferometric receiver | 4 | Wavefront error |
| 3D Biomass (NISAR/GEDI, formerly DESDynI) | Readiness of laser systems<br>High-bandwidth, high-sensitivity detector arrays | 4-5 | Space qualification |
| Topography (LIST in 2007 Decadal) | Multiple aperture transmitter | 4-5 | Multiple aperture system |
| Topography (LIST in 2007 Decadal) | Multiple aperture/beam receiver | 3 | Large-area detector with high readout bandwidth |
| 3D Winds | Reliable 355-nm transmitters meeting measurement requirements; 2-µm technology readiness and reliability | 3-4 | Laser reliability, readiness |
| 3D Winds | Single telescope supporting multiple look angles | 3 | Large-aperture receive optics (HOE/DOE, interferometer) |

# New Measurement Concept (since 2007) Capability Gaps

| Measurement | Capability Gap | TRL | TRL Assessment; Greatest TRL Challenge |
|---|---|---|---|
| Phytoplankton | Blue-green laser technology readiness | 3 | 2: Robust and reliable laser and frequency conversion system |
| Phytoplankton | Detector performance | 2 | Dead-time, afterpulsing |
| Ocean Mixed Layer | Blue-green laser technology readiness | 2 | Robust and reliable laser and frequency conversion system |
| Ocean Mixed Layer | Detector performance | 2 | Dead-time, afterpulsing |
| Non-$CO_2$ Greenhouse Gases | Tunable laser transmitter for $CH_4$ IPDA | 4-5 | 3-4: Er:YAG and seed sources |
| Non-$CO_2$ Greenhouse Gases | Low-noise, few-photon-sensitive detector array | 5 | Space qualification |
| Ozone | Robust UV laser transmitter | 2 | 2: Robust and reliable UV generation 290-320 nm |
| Ozone | Large-aperture collector; detector efficiency | 4 | Deployability |
| Water vapor profiles | Multi-wavelength NIR laser transmitter readiness | 2 | 2: Robust and reliable 720-nm, 820-nm sources |
| Water vapor profiles | Detector performance | 4 | Low-noise, few-photon-sensitive detector array |

# Summary of the Findings (1 of 3)

<u>**Transmitter Technologies**</u>

- Since the last Decadal, ***fiber-laser average power capability now rivals that of traditional bulk solid-state systems*** and may be used in more of the science measurement scenarios. Fiber lasers have the distinct advantage of being compact, immune to misalignment, and offer higher WPE. **Fiber/bulk solid-state hybrid laser technologies present potential solutions to difficult performance and wavelength requirements.**
- **Emerging laser materials** (*e.g.*, Cr:ZnSe) and improvements in nonlinear optical (NLO) materials have ***expanded options for wavelength generation in near-UV, SWIR/MWIR***. ***Dramatic improvements in pump laser-diode electrical efficiency*** **have significantly improved the WPE** of both bulk solid-state and fiber-based lasers.
- **High power lasers and adequate thermal systems are among biggest challenges**. High conductivity thermal materials are needed.

# Summary of the Findings (2 of 3)

**<u>Receiver Technologies</u>**

- There remains ***a need*** **for** ***improved detector performance***, particularly in the area of radiation-hardened multi-element architectures with high quantum efficiency, low noise, low timing jitter, and low afterpulsing.
- Greatest challenge is in the area of under 1 micron in detector performance.
- Reduction in size and weight for receiver telescopes benefit all measurement scenarios.
- Deployable apertures could relax requirements on transmitter technologies and enable measurement scenarios from smaller satellite platforms.
- ***Need to develop and mature U.S. industrial base*** required for critical system components in the area of: detectors and nonlinear conversion material.

# Summary of the Findings (3 of 3)

## Emerging Technologies

- **New technologies in the area of detectors, lightweight apertures, as well as second and third harmonic generation at lower TRLs** are coming to market that could benefit from further exploration.
- SmallSats have emerged onto the scene in the last decade and demand greater attention to miniaturization. Cross-cutting emerging technologies such as ***integrated photonics circuitry and deep-submicron microelectronic architectures can prove enabling for SmallSat-based lidar missions and significant SWAP improvements.***
- **Model –based systems engineering (MBSE)** should be more effectively employed as an arbitrator between evolving technology options, by enabling parametric trades between aperture size, detector efficiency, laser power, waveform diversity, *etc*. that could circumvent technological hurdles.
- **MBSE requires robust, high-fidelity modeling and simulation capabilities** in both the environmental and sensor performance domains, which will require strengthening and further development of concurrent engineering tool.