NASA ESTO Technologies Investment Strategy Update

2016 Decadal Update

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Earth Science Technology Forum
Annapolis, MD

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NASA Earth Science Technology Office

ESTO 2016 Investment Strategy Update

Objectives:

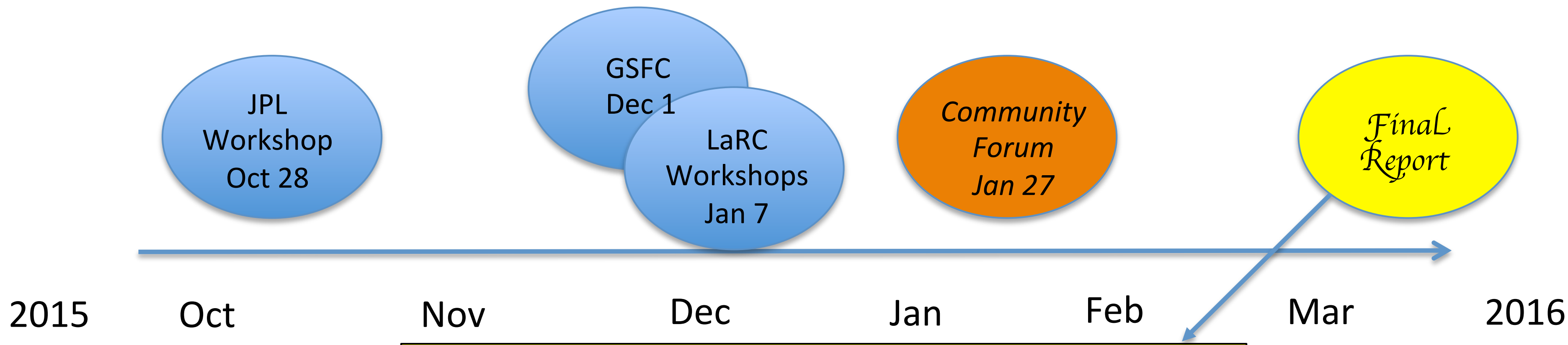
- Survey the 2016 state-of-the-art in active/passive optical and microwave technologies as they pertain to Earth science measurements
  - *Last surveys were done in 2004-2006*

- Identify capability gaps needed to enable Earth science goals

- Adjust investment strategy as needed

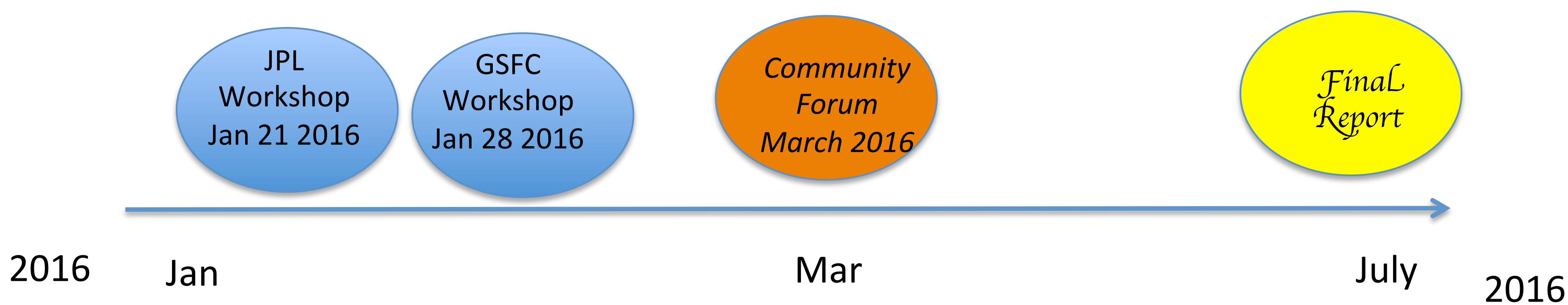
Lidar and Microwave Technologies Survey and Strategy Update

Lidar Survey and Capability Gaps Timeline



https://esto.nasa.gov/LidarStrategies/index.html

Microwave Survey and Capability Gaps Timeline



Passive Optical Technologies Survey Begins September 2016

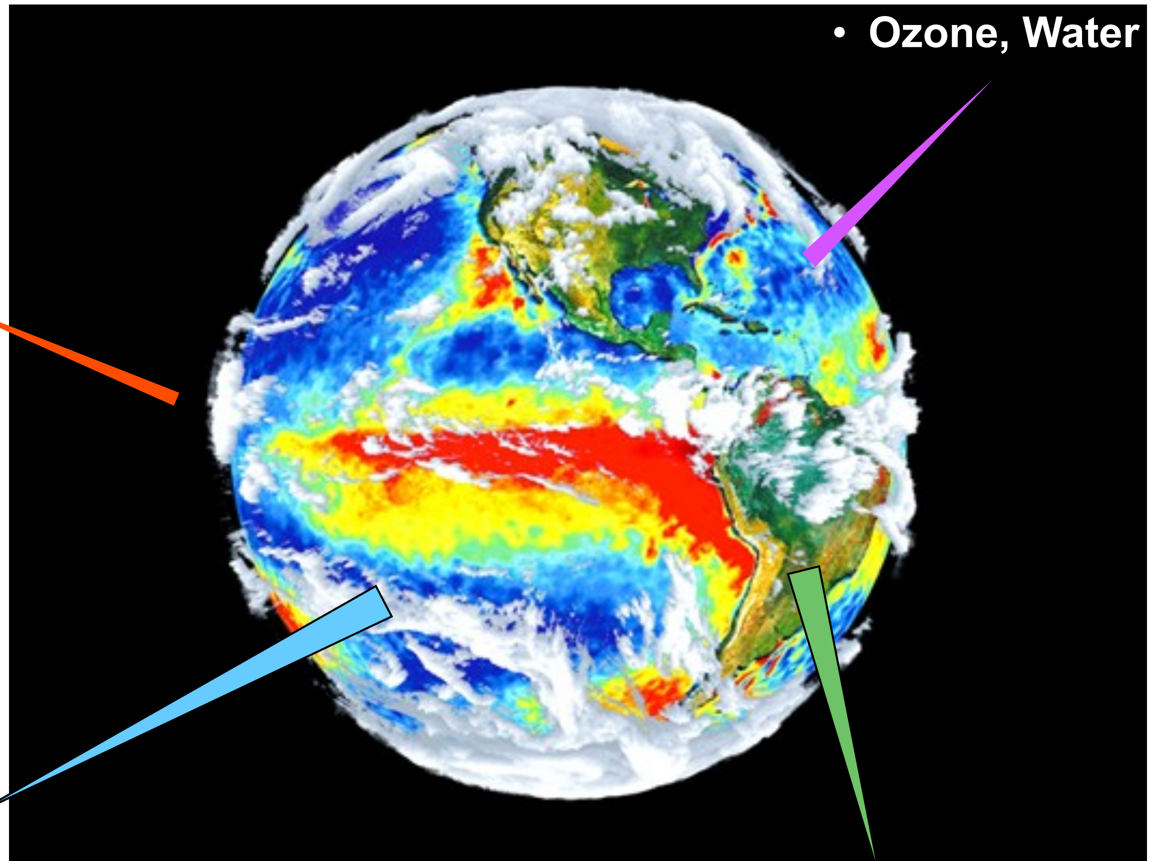
Lidar Technologies Survey and Strategy Update

- Tech Development Statistics
  - Science Measurement Areas
  - TRL Advancements
- Lidar Technologies State of the Art
- Airborne
- Space
- Lidar Technologies Capability Gaps

Laser Remote Sensing Applications and Techniques

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

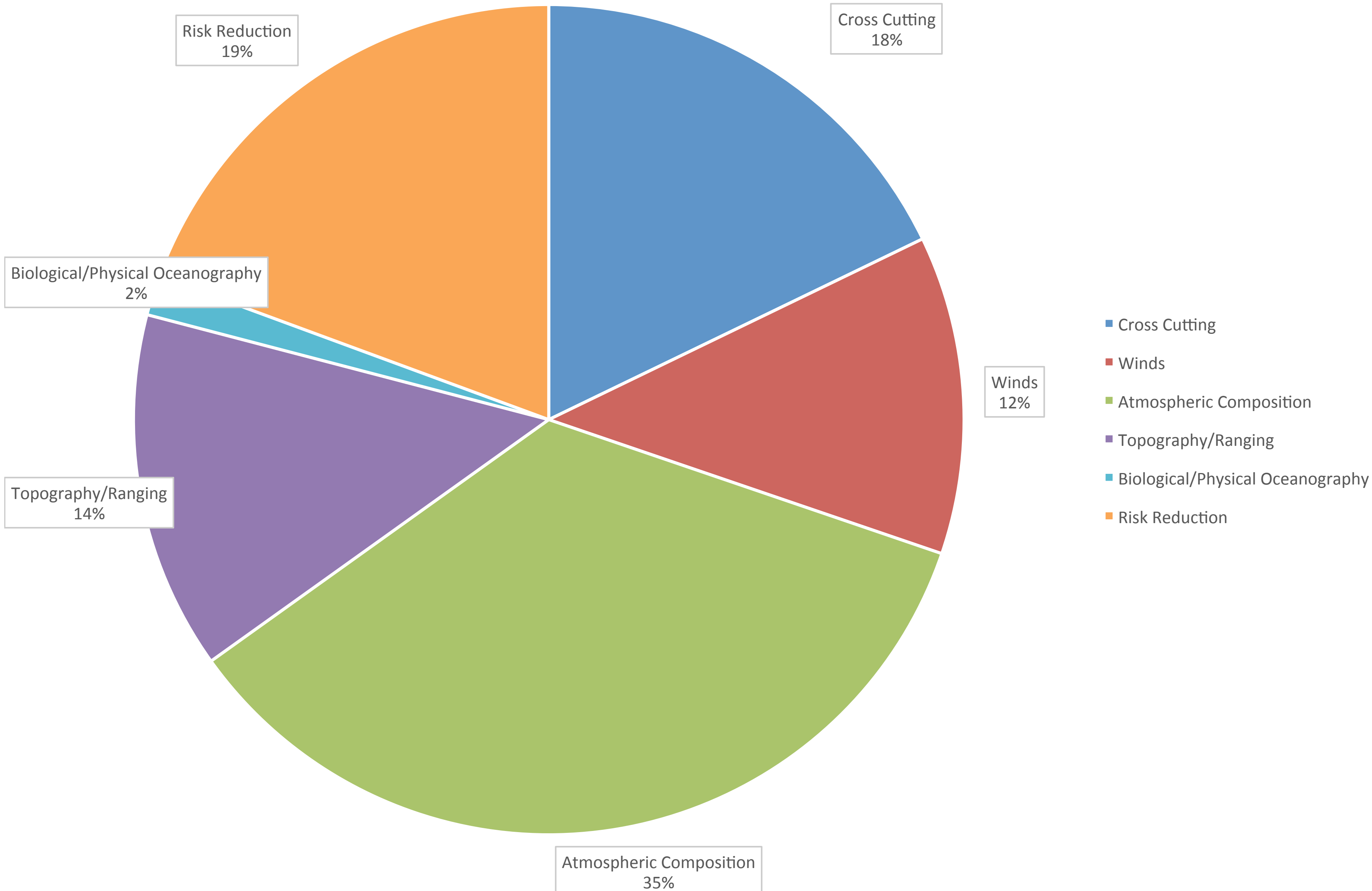
Doppler Lidar
- Wind Field



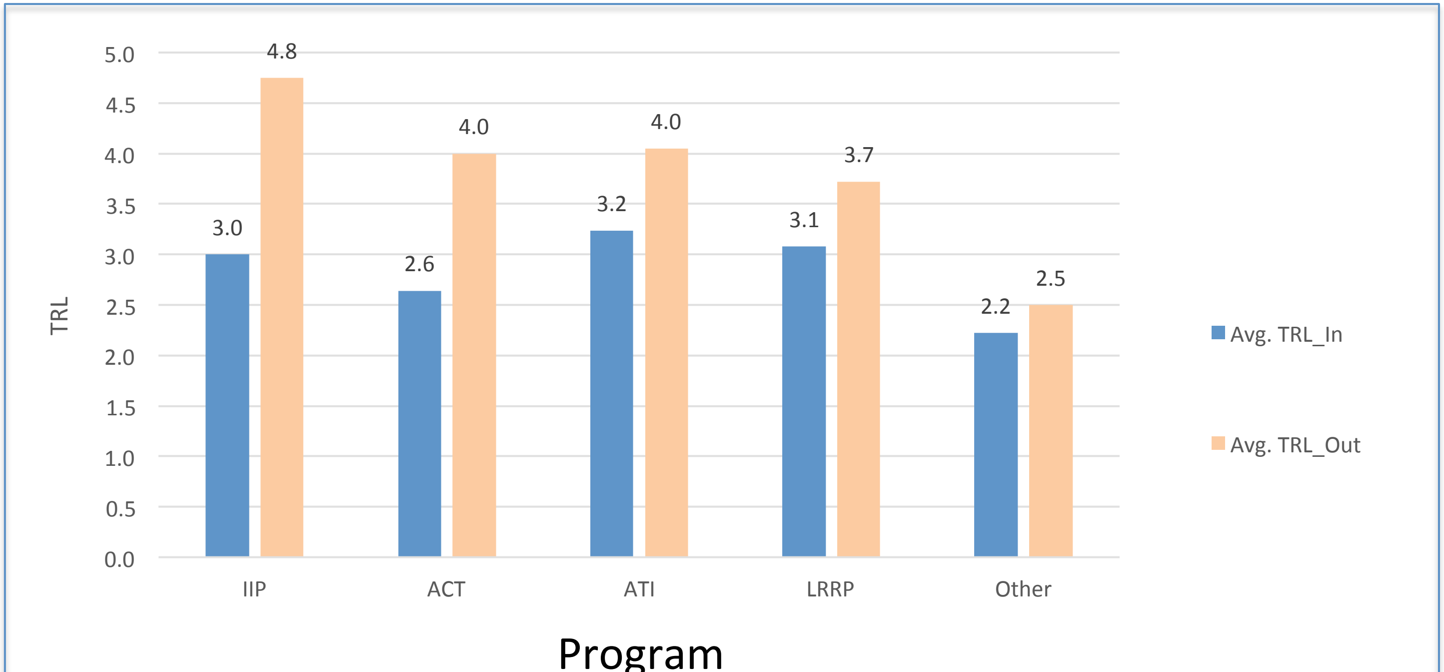
Backscatter Lidar
- Clouds
- Aerosols
- Phytoplankton Physiology
- Ocean Carbon/Particle Abundance

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

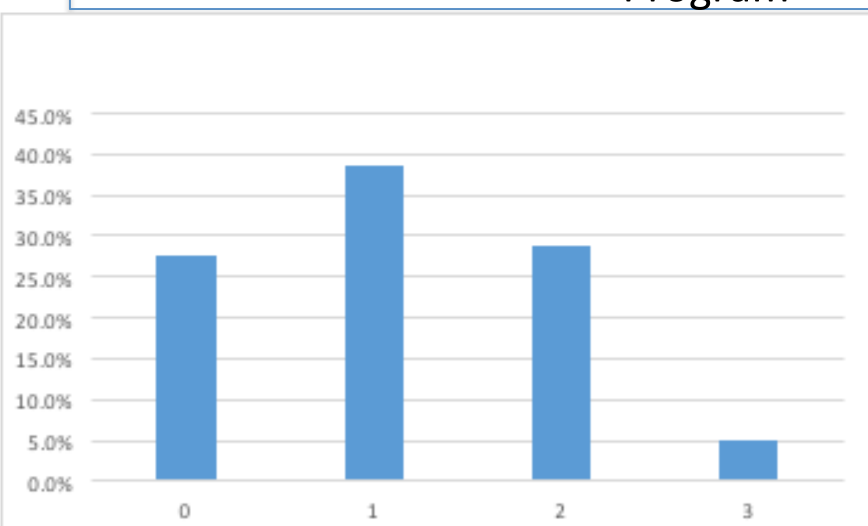
Project Distribution According to Science Measurement

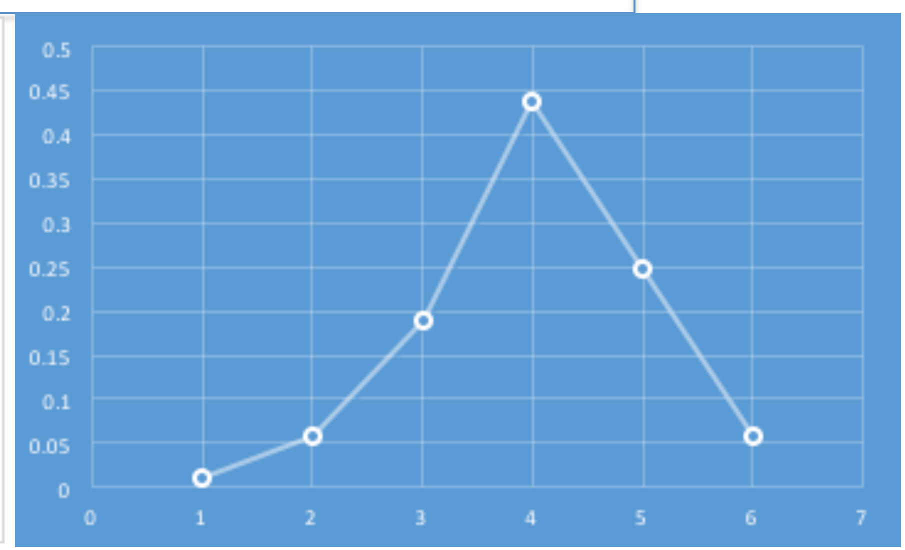


TRL Advancement for Completed Laser Related Tasks



Percentage of Tasks

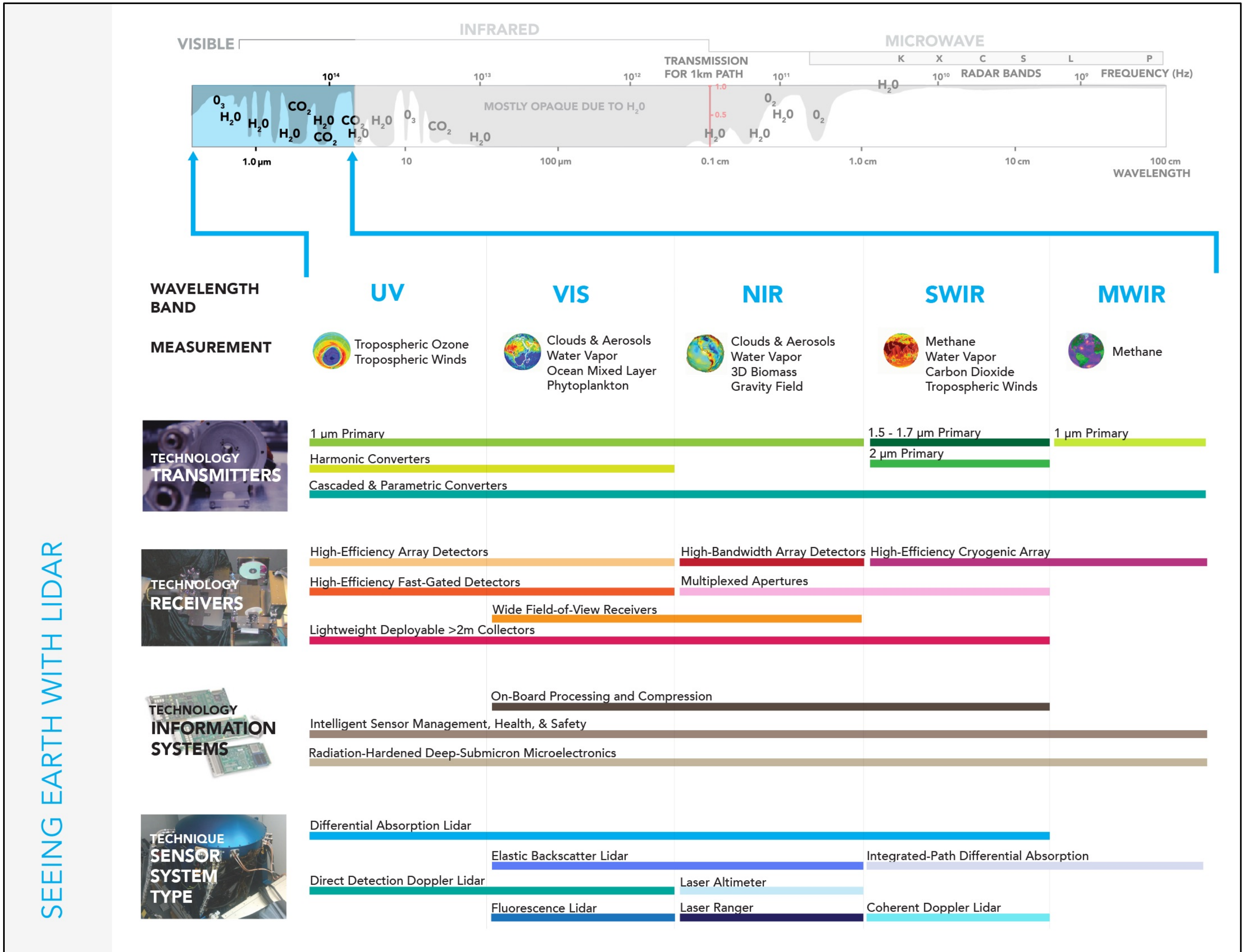




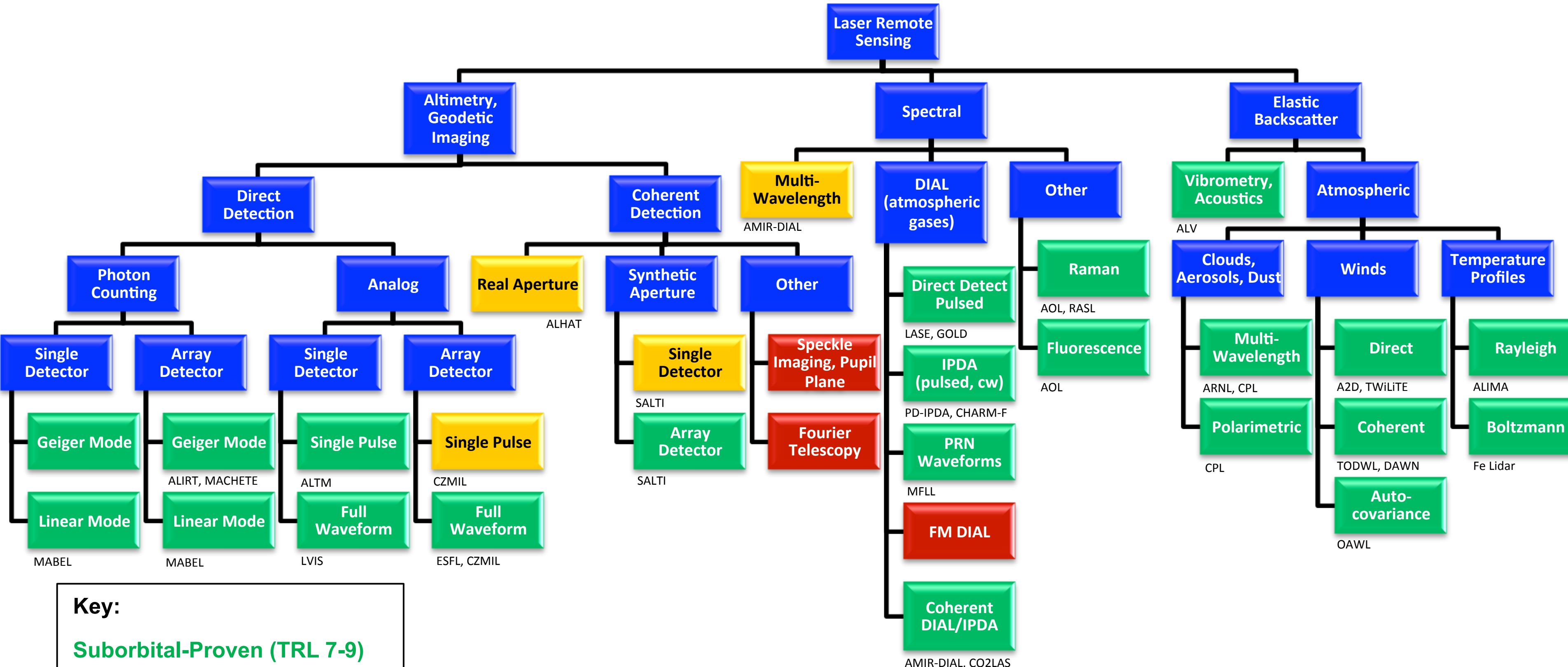
TRL Advancement

Final TRL

The Lidar Technology Needs Landscape



Laser Remote Sensing Taxonomy: Suborbital

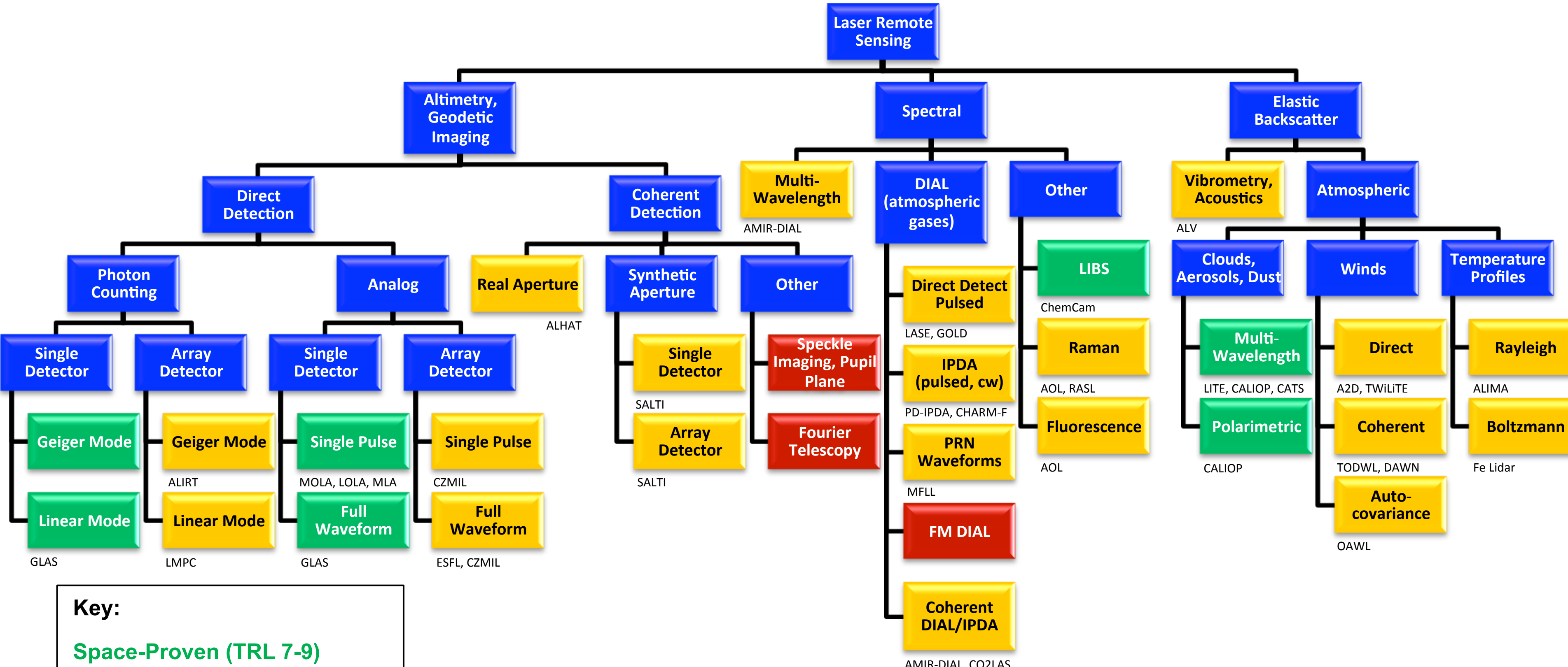


Key:

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



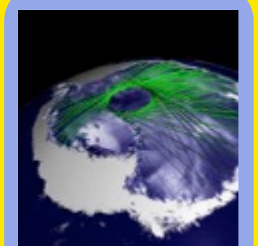
Key:

Space-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).

NASA Earth Science 2007 Decadal Survey Missions

1 µm laser altimeter

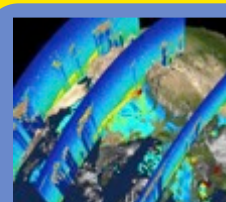


Ice, Cloud,and land Elevation Satellite II **(ICESat-II)**

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

1.57 or 2.06 µm column lidar

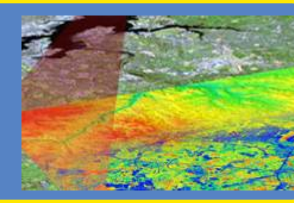
Multibeam cross-track dual-wavelength lidar



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

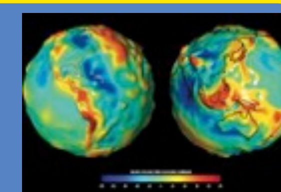
Mapping laser altimeter system

LIDAR Surface Topography **(LIST)**



Laser satellite-to-satellite interferometer

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



Snow and Cold Land Processes (SCLP)

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

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

Lasers

2007 Decadal Survey Technology Capability Gaps

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

New Measurement Concept (since 2007) Capability Gaps

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

Receiver Technologies

- 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)

<u>Emerging Technologies</u>

- **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.

- Tech Development Statistics
  - Science Measurement Areas
  - TRL Advancements
- Microwave Technologies State of the Art
- Microwave Technologies Capability Gaps

Radar Remote Sensing Techniques & Applications

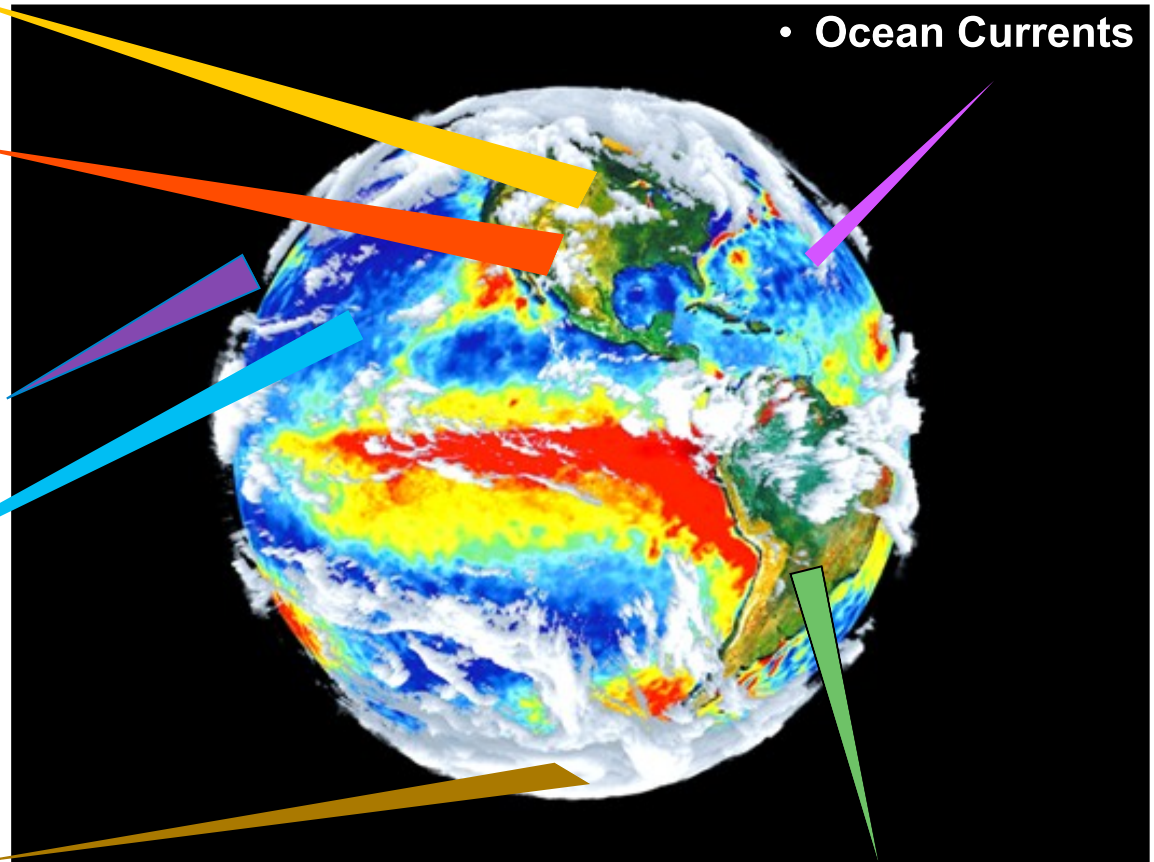
Radiometry
- Salinity, soil moisture, snow
- SoOp/GPS

Repeat Pass Interferometry
- Surface deformation
- Seismology and hazards
- Damage assessment

Doppler and Profiling
- Cloud, Ice, Precipitation

Altimeters/single pass interferometry/GPS
- Sea surface height
- Topography
- Surface water
- Ice thickness

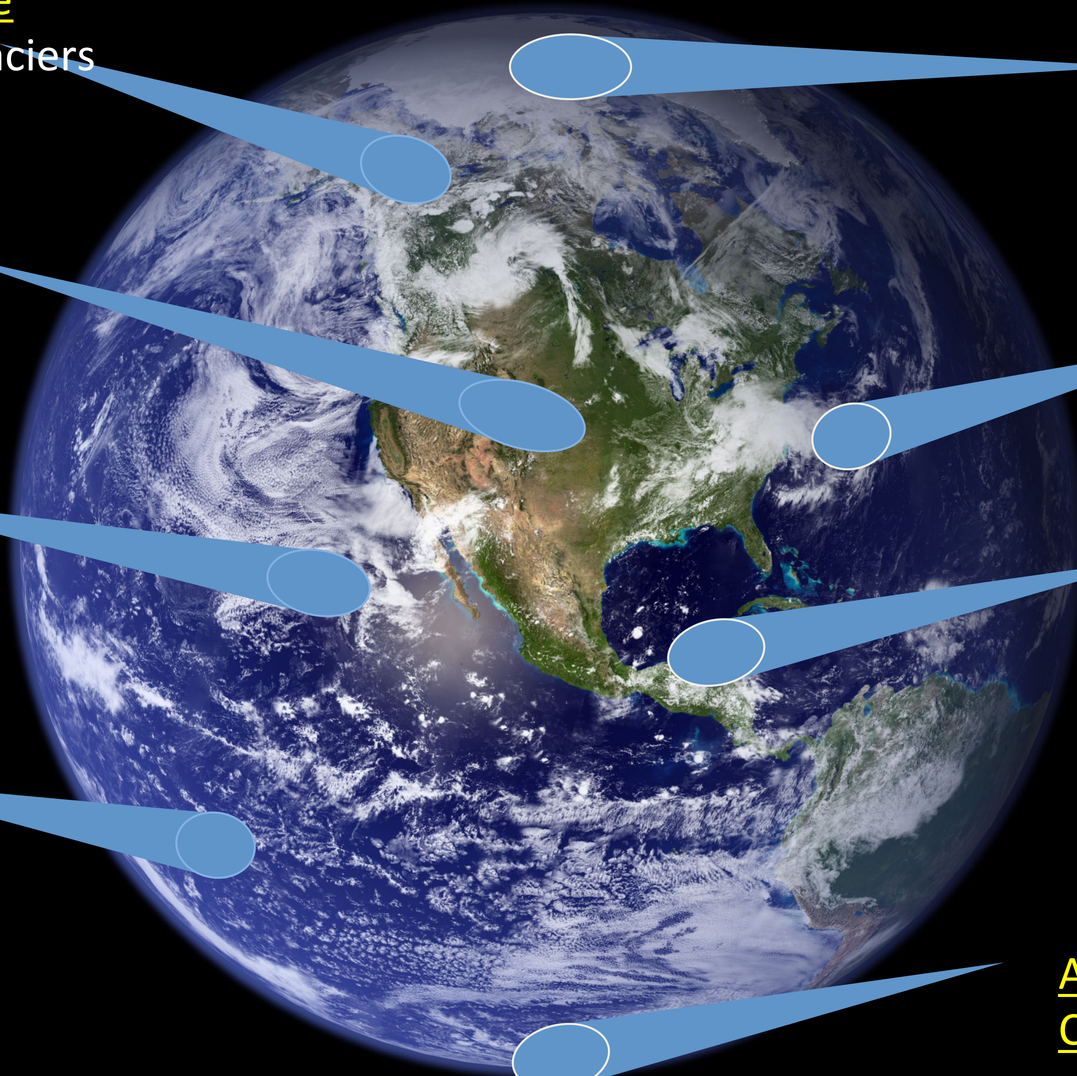
Scatterometers
- Ocean Winds
- Ocean Currents



Sounders
- Interior structures such as Ice thickness & aquifer depth

Synthetic Aperture Radar (SAR)
- Sea ice
- Ecology
- Hydrology
- Rapid response (e.g. oil spills, forest fire)
- Land Classification
- Oceanography

Radiometer Applications in Earth Science



Land Cryosphere
Snow Water, glaciers
Ku-Ka

Soil Moisture
P-X band
STAR Radiometers

Clouds and Precip
mm-THz imagers
constellations

Oceans
K- band wind
vector
SST C-K band
Altimetry
correction
L-band salinity

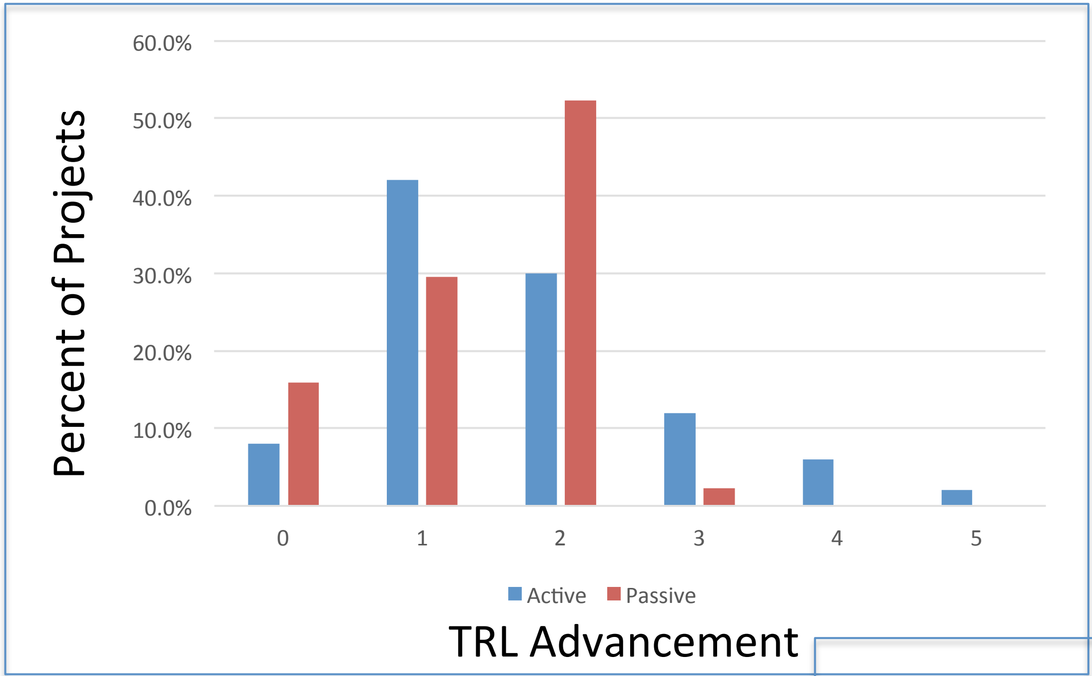
Sea Ice
P/L band
X-Ka-Band

Tropospheric Winds
Repeat pass
water-vapor
radiometry

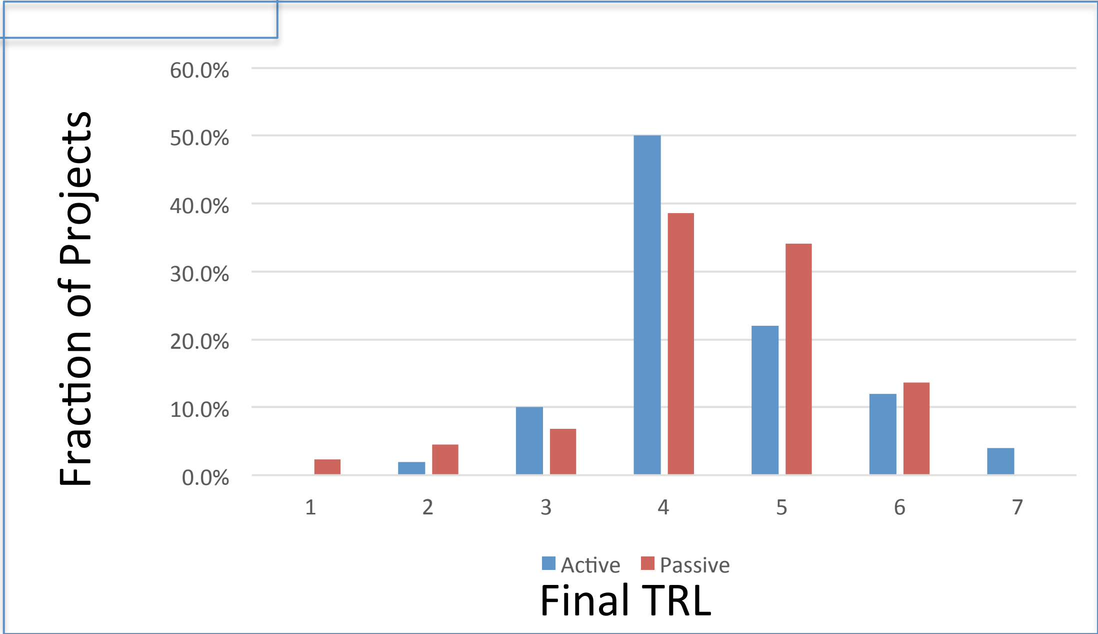
Weather
K-G-band LEO
imager/sounder
constellations
Geostationary
Imager/Sounder

Atmospheric Chemistry mm-wave/THz limb
sounders

TRL Advancement for Completed Microwave Related Tasks

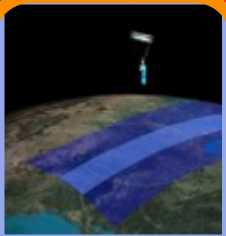


Passive Microwave projects show greater TRL advancement

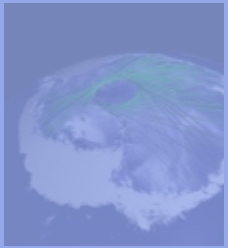


Passive Microwave projects complete at higher TRL

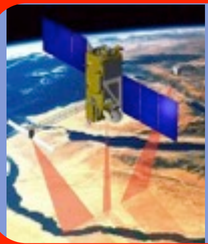
NASA Earth Science Decadal Survey Measurements



Soil Moisture Active Passive **(SMAP)**

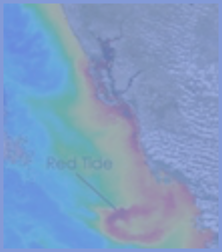


Ice, Cloud, and land Elevation Satellite II **(ICESat-II)**



Surface Water and Ocean Topography **(SWOT)**

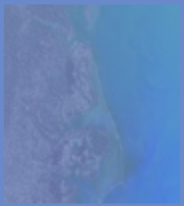
Pre-Aerosol - Cloud - Ecosystems ***(PACE)***



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

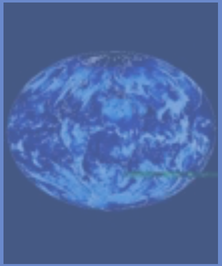
Hyperspectral Infrared Imager **(HYSPIRI)**

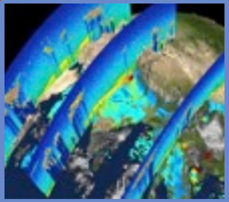
Geostationary Coastal and Air Pollution Events **(GEO-CAPE)**



Deformation, Ecosystem Structure and Dynamics of Ice (Radar) **(DESDynI -R)**

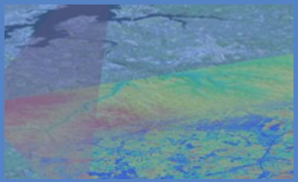
Climate Absolute Radiance and Refractivity Observatory **(CLARREO)**





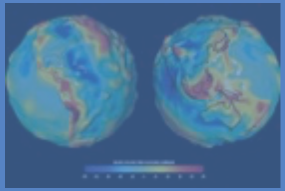
Aerosol - Cloud - Ecosystems **(ACE)**

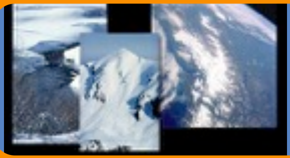
LIDAR Surface Topography **(LIST)**



Precipitation and All-Weather Temperature and Humidity **(PATH)**

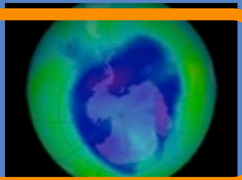
Gravity Recovery and Climate Experiment - II **(GRACE - II)**





Snow and Cold Land Processes **(SCLP)**

Global Atmospheric Composition Mission **(GACM)**

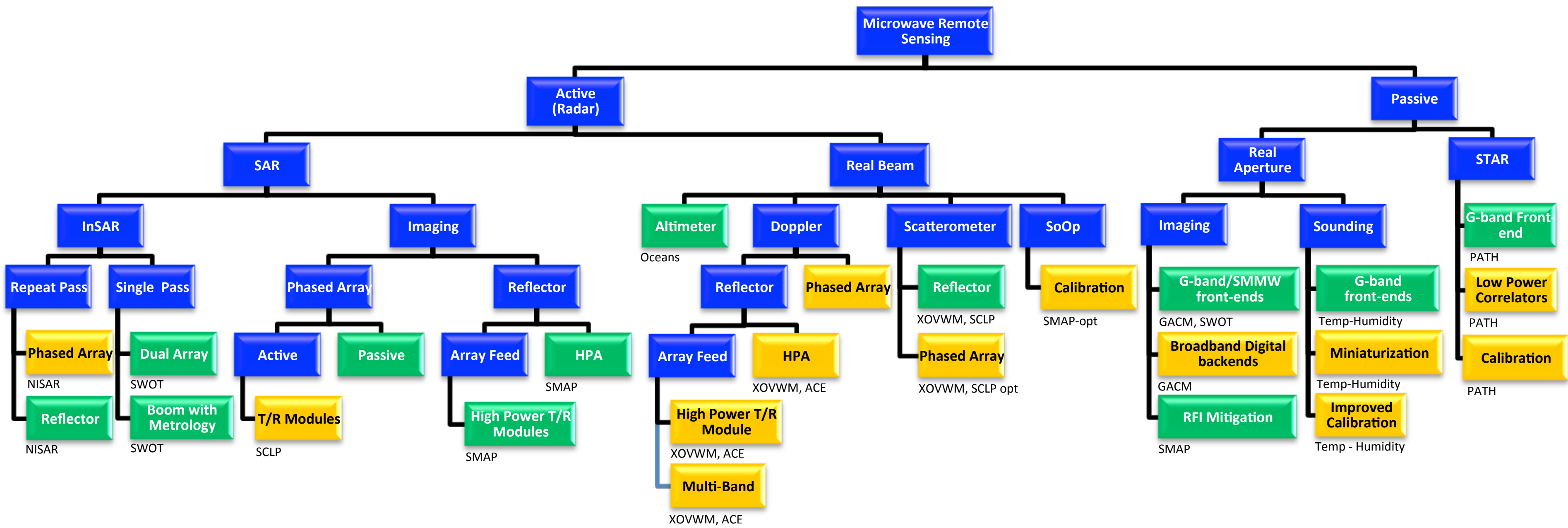


Three-Dimensional Winds from Space Lidar **(3D-Winds)**

Radars

Passive Microwave

Microwave Remote Sensing State of the Art (2007 DS Missions)



Key:

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

Microwave remote sensing taxonomy identifying technology developments generally required to complete the remaining tiered 2007 NRC decadal survey missions carrying microwave sensors.

Active Microwave Technology Needs Landscape

Band	VHF/P	L	C	X	Ku	Ka	W	G
Measurement	soil moisture							
			ocean wind vector					
					surface water topo			
								humidity
	ice							
				snow				
						hydrometeor		
	biomass							
		surface deformation						
						weather		
						precipitation		
						clouds		
Antenna	large lightweight structures							
						dual/multi band array feed		
		single-chip MMIC T/R module						
						single-chip MMIC T/R module		
	DBF							
							lightweight reflectors	
Amplifier							HPAs – lighter, smaller, higher efficiency	
						GaN SSPA for higher efficiency		
Payload Electronics	space-qualified, high bandwidth & nbits, integrated digital subsystems							
System	explore measurement enhancements from using lightweight phased arrays							
	applying cubesat technology to larger sats							
	SoOp systems							

Passive Microwave Technology Needs Landscape

Band	P L C X K K_a V W G smmW
Measurement	Soil Moisture; Ocean Wind Vector; Atmospheric Comp Salinity; Snow Cover/Depth; Cloud Ice / Trop Proc Precipitation; Precipitation Cloud Liquid; Cld lqd Temp; Humidity
Antenna Feeds and Reflectors	Integrated active/passive multi-band front-ends / FPAs Deployable 2m class (10m) Large reflectors (7m)
Receiver Electronics	Miniaturization (Integration: Active / FPA); Miniaturization (SWaP-C) LP LO; Performance
Calibration	Distributed Correlators; UAV; Direct SI-Traceability
System	Distributed Correlators; Correlators; Correlators Formation flying / STAR; EPBR Polarimetry Constellation Management

Preliminary Microwave Technologies Summary

- The state of microwave technologies is a lot more mature relative to that of lidar technologies.
- Cost is currently the biggest challenge in implementing the microwave related Decadal Survey (2007) missions.
- Technologies to improve the SWAP to decrease the total cost of missions are needed.
- Model-Based Systems Engineering (MBSE) should be investigated to improve feasibility of implementation with current technology. JPL has been using MBSE for NiSAR and SWOT.
- Final microwave technology report will be available in July 2016.

Backup

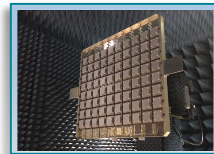
ESTO Programs

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

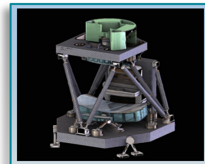
Instrument Incubator Program (IIP) TRL 3-6

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



Advanced Component Technologies (ACT) 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) TRL 2-6

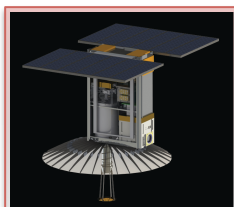
new technologies and reduced costs for future land imaging (Landsat) measurements *First solicitation released in FY16 (average award: TBD)*

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)*

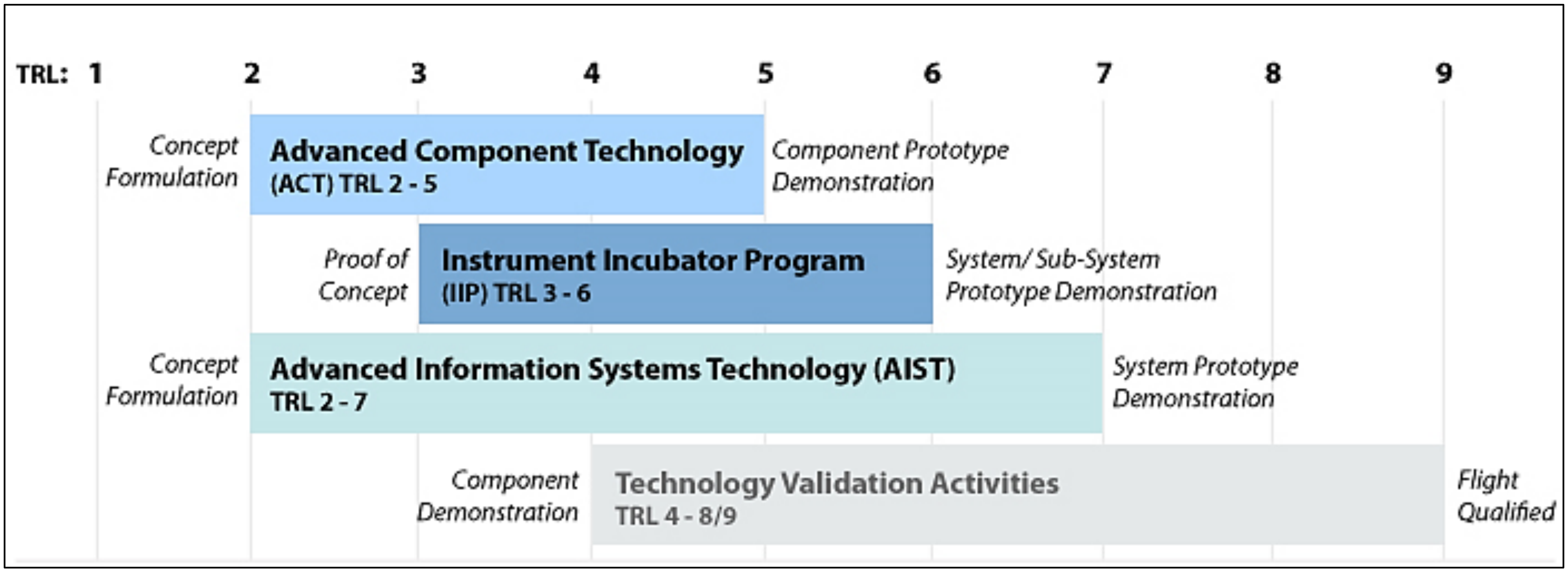
Validation



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 Portfolio



TRL Definitions

TRL	Definition	Hardware Description	Software Description	Exit Criteria
1	Basic principles observed and reported	Scientific knowledge generated underpinning hardware technology concepts/applications.	Scientific knowledge generated underpinning basic properties of software architecture and mathematical formulation.	Peer reviewed publication of research underlying the proposed concept/application.
2	Technology concept and/or application formulated	Invention begins, practical applications is identified but is speculative, no experimental proof or detailed analysis is available to support the conjecture.	Practical application is identified but is speculative; no experimental proof or detailed analysis is available to support the conjecture. Basic properties of algorithms, representations, and concepts defined. Basic principles coded. Experiments performed with synthetic data.	Documented description of the application/concept that addresses feasibility and benefit.
3	Analytical and experimental critical function and/or characteristic proof-of- concept	Analytical studies place the technology in an appropriate context and laboratory demonstrations, modeling and simulation validate analytical prediction.	Development of limited functionality to validate critical properties and predictions using non-integrated software components.	Documented analytical/experimental results validating predictions of key parameters.

TRL Definitions (cont.)

TRL	Definition	Hardware Description	Software Description	Exit Criteria
4	Component and/or breadboard validation in laboratory environment.	A low fidelity system/component breadboard is built and operated to demonstrate basic functionality and critical test environments, and associated performance predictions are defined relative to final operating environment.	Key, functionality critical software components are integrated and functionally validated to establish interoperability and begin architecture development. Relevant environments defined and performance in the environment predicted.	Documented test performance demonstrating agreement with analytical predictions. Documented definition of relevant environment.
5	Component and/or breadboard validation in relevant environment.	A medium fidelity system/component brassboard is built and operated to demonstrate overall performance in a simulated operational environment with realistic support elements that demonstrate overall performance in critical areas. Performance predictions are made for subsequent development phases.	End-to-end software elements implemented and interfaced with existing systems/simulations conforming to target environment. End-to-end software system tested in relevant environment, meeting predicted performance. Operational environment performance predicted. Prototype implementations developed.	Documented test performance demonstrating agreement with analytical predictions. Documented definition of scaling requirements.

TRL Definitions (cont.)

TRL	Definition	Hardware Description	Software Description	Exit Criteria
6	System/sub-system model or prototype demonstration in a relevant environment.	A high fidelity system/component prototype that adequately addresses all critical scaling issues is built and operated in a relevant environment to demonstrate operations under critical environmental conditions.	Prototype implementations of the software demonstrated on full-scale, realistic problems. Partially integrated with existing hardware/software systems. Limited documentation available. Engineering feasibility fully demonstrated.	Documented test performance demonstrating agreement with analytical predictions.