NASA SBIR 2004 Phase I Solicitation

Earth Science

Instruments for Earth Science Measurements Topic E1

NASA's Earth Science Enterprise (ESE) is studying how our global environment is changing. Using the unique perspective available from space and airborne platforms, NASA is observing, documenting, and assessing large-scale environmental processes with emphasis on atmospheric composition, climate, carbon cycle and ecosystems, the Earth's surface and interior, the water and energy cycles, and weather. A major objective of the ESE instrument development programs is to implement science measurement capabilities with small or more affordable spacecraft so development programs can meet multiple mission needs and therefore, make the best use of limited resources. The rapid development of small, low cost remote sensing and in situ instruments is essential to achieving this objective. Consequently, the objective of the Instruments for Earth Science Measurements SBIR topic is to develop and demonstrate instrument component and subsystem technologies that reduce the risk, cost, size, and development time of Earth observing instruments, and enable new Earth observation measurements. The following subtopics are concomitant with this objective and are organized by measurement technique.

Sub Topics:

E1.01 Passive Optics

Lead Center: LaRC

Participating Center(s): ARC, GSFC

The following technologies are of interest to NASA in the remote sensing subtopic “passive optics.” Passive optical remote sensing generally requires that deployed devices have large apertures and large throughput. NASA is interested primarily in instrument technologies suitable for aircraft or space flight platforms, and these inherently also prefer low mass, low power, fast measurement times, and a high degree of robustness to survive vibrations in flight or at launch. Wavelengths of interest range from ultraviolet through the far infrared. Development of techniques, components and instrument concepts that can be developed for use in actual deployed devices and systems within the next few years is highly encouraged.

Technologies and components that are not clearly suitable for use in high throughput remote sensing instruments are not applicable to this subtopic. Technical and scientific leads at NASA have given careful consideration to the technology areas described below, and responses are solicited for these topics.

1) Stiff actuator technology designed to produce precisely controlled motion of large (> 1.0 cm diameter) optical elements intended for use in tunable Fabry-Perot and Fourier Transform Spectrometer (FTS) instruments. Motion ranges of particular interest include 20–60 µm, 1–2 mm, and 3–5 cm. Techniques applicable to very cold temperature (~20–60 µm, 1–2 mm, and 3–5 cm. Techniques applicable to very cold temperature (~
2) Technology leading to significant improvements in capability of large format (> 1 inch diameter), very narrow band (-1 full-width at half-maximum), polarization insensitive, high throughput infrared (0.7–15 µm) optical filters.

3) Large format (> 1 inch diameter) high-transmission far infrared filters. Technology and techniques leading to filters operating at wave numbers between 500 and 5 cm\(^{-1}\) with FWHM less than 2 cm\(^{-1}\) are of immediate interest, though technology leading to very high transmission edge filters (long and short pass) is also solicited. The filters must be capable of operating in a vacuum at cryogenic temperatures.

4) High performance four-band two-dimensional (2-D) arrays (128x128 elements) in the 0.4 – 2.5 µm wavelength range with high quantum efficiencies (60%–80% or higher) in all spectral bands, low noise, and ambient temperature operation.

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**E1.02 Lidar Remote Sensing**

*Lead Center: LaRC*

*Participating Center(s): GSFC*

High spatial resolution, high accuracy measurements of atmospheric parameters from ground-based, airborne, and spaceborne platforms require advances in the state-of-the-art lidar technology with emphasis on compactness, reliability, efficiency, low weight, and high performance. Innovative technologies that can expand current measurement capabilities to airborne, spaceborne, or Unmanned Aerial Vehicle (UAV) platforms are particularly desirable. Development of techniques, components, and instrument concepts that can be used in actual deployed systems within the next few years is highly encouraged. Technologies and components that are not clearly suitable for effective lidar remote sensing or field deployment are not applicable to this subtopic. This subtopic considers components, subsystems, and complete instrument packages addressing the following specific measurement needs:

- Molecular species (ozone, water vapor, and carbon dioxide);
- Cloud and aerosols with emphasis on aerosol optical properties;
- Wind profiles using direct-detection lidar, or coherent-detection (heterodyne) lidar, or both; and
- Land topography (vegetation, ice, and land use).

In addition to instrument systems, innovative component technologies that directly address the measurement needs above will be considered. Technical and scientific leads at NASA have given careful consideration to the component technologies described below, and responses are solicited for these technology areas.
1. Novel laser materials and components for high efficiency solid state lasers operating at 1 and 2 µm wavelength regions. The laser components include:

   - Rugged, compact fiber lasers and fiber amplifiers for use at 1.5 and 1 µm;
   - Low voltage (Efficient and reliable high power, quasi-CW, pump diodes operating at 792 nm and 808 nm in fiber-coupled or free-space configuration; and
   - Laser crystals for generating 2 µm radiation with high thermal conductivity and small variation of the index of refraction with temperature.

2. High damage-resistant, efficient, inorganic and birefringent nonlinear optical materials for generation of ultraviolet and mid-infrared radiation.

3. Thermally efficient conductively-cooled head for solid-state lasers with side-pumped rod configuration, and thermally and mechanically stable optical bench.

4. Frequency-agile, semiconductor lasers operating in 1 to 2 µm wavelength region with spectral linewidth less than 200 kHz over 1 ms and optical power greater than 20 mW.

5. Scanning or scanable lightweight telescopes with an optical quality better than 1/6 wave at 632 nm, mass density less than 12 kg/m², and aperture diameters from 0.5–1.0 m.

6. Laser beam steering and scanning technologies operating at 0.355, 1.06, or 2.05 µm with 5–25 cm aperture diameter for airborne and 0.5–1.0 m for spaceborne instruments, meeting the following minimum requirements:
   - 60° field of regard
   - 90% optical throughput
   - wave single pass optical quality at 632 nm

7. Shared aperture angle-multiplexed holographic or diffractive optical elements having several fields of view, each with angular resolution of 50 µrad or better for the Nd:YAG or Nd:YLF laser harmonics, and diffraction limited resolution for the Ho:YLF fundamental wavelength. Wide, flat, focal planes with low off-axis aberrations is of importance to terrain and vegetation mapping lidar applications. Hybrid designs using both 2053 nm or 1064 nm and 355 nm simultaneously are needed for dual wavelength Doppler wind lidar applications. Materials and technologies are needed that can be scaled up to 1 m apertures and larger, and space qualified. Designs using lightweight materials, such as composites or membranes and deployable folded architectures, are also desired to decrease system size and weight.
8. High gain, low noise photon counting detectors that operate without the use of cryogens are needed. Other desirable properties are linearity over a large dynamic range, saturation count rates over 100 MHz, reasonable active area size (>200 µm), 250–2200 nm response wavelengths, and high clocking and readout rates with low read noise. High-speed (500 Msamples per second or greater) waveform digitizers are also of interest for operation with integrated pulse-finding capability suitable for continuous operation and capable of locating more than 200,000 individual pulses per second.

9. Narrow band optical filters with 75% throughput, with minimum 1 inch clear aperture.

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**E1.03 In Situ Sensors**

**Lead Center:** GSFC

**Participating Center(s):** ARC, JPL

Proposals are sought for the development of *in situ* measurement systems that will enhance the scientific and commercial utility of data products from the Earth Science Enterprise program and that will enable the development of new products of interest to commercial and governmental entities around the world. Technology innovation areas of interest include:

- Autonomous Global Positioning System (GPS)-located platforms (fixed or moving) to measure and transmit to remote terminals upper ocean and lower atmosphere properties including temperature, salinity, momentum, light, precipitation, and biogeochemistry.
- Dynamic stabilization systems for small instruments mounted on moving platforms (e.g., buoys and boats) to maintain vertical and horizontal alignment. Systems capable of maintaining a specified pointing with respect to the Sun are preferred.
- Small, lightweight instruments for measuring clouds, liquid water, or ice content (mass) designed for use on radiosondes, dropsondes, aerosondes, tethered balloons, or kites.
- Wide-band microwave radiometers capable of high-speed characterization of cloud parameters, including liquid and ice phase precipitation, which can operate in harsh environmental conditions (e.g., onboard ships and aircraft).
- Autonomous GPS-located airborne sensors that remotely sense atmospheric wind profiles in the troposphere and lower stratosphere with high spatial resolution and accuracy.
- Systems for *in situ* measurement of atmospheric electrical parameters including electric and magnetic fields, conductivity, and optical emissions.
- Systems to measure line- and area-averaged rain rate at the surface over lines of at least 100 m and areas of at least 100x100 m.
- Lightweight, low-power systems that integrate the functions of inertial navigation systems and GPS receivers for characterizing and/or controlling the flight path of remotely piloted vehicles.
- Low-cost, stable (to within 1% over several months), portable radiometric calibration devices in the
shortwave spectral region (0.3 to 3 µm) for field characterization of radiance instruments such as sun photometers and spectrometers.

- Miniaturized, low power (12V DC) instruments especially suited for small boat operations that are capable of adequately resolving, at the appropriate accuracy, the complex vertical structure (optical, hydrographic, and biogeochemical) of the coastal ocean (turbid) water column. Sensors that can be easily integrated within a digital (serial) network to measure the apparent and inherent optical properties of seawater are preferred.

**E1.04 Passive Microwave**

**Lead Center: GSFC**

Proposals are sought for the development of innovative passive microwave technology in support of Earth System Science measurements of the Earth's atmosphere and surface. These microwave radiometry technology innovations are intended for use in the frequency band from about 1 GHz to 1 THz. The key science goal is to increase our understanding of the interacting physical, chemical and biological processes that form the complex Earth system. Atmospheric measurements of interest include climate and meteorological parameters including temperature, water vapor, clouds, precipitation, and aerosols; air pollution; and chemical constituents such as ozone, NOₓ, and carbon monoxide. Earth surface measurements of interest include water, land, and ice surface temperatures, land surface moisture, snow coverage and water content, sea surface salinity and winds, and multispectral imaging.

Technology innovations are sought that will provide the needed concepts, components, subsystems, or complete systems that will improve these needed Earth System Science measurements. Technology innovations should address enhanced measurement capabilities such as improved spatial or temporal resolution, improved spectral resolution, or improved calibration accuracies. Technology innovations should provide reduced size, weight, power, improved reliability, and lower cost. The innovations should expand the capabilities of airborne systems (manned and unmanned), as well as next generation spaceborne systems. Highly innovative approaches that open new pathways are an important element of competitive proposals under this solicitation.

Specific technology innovation areas include:

- Imaging radiometers, receivers or receiver arrays on a chip, and flux radiometers.
- Large aperture, deployable antenna systems suitable for highly reliable space deployment with root mean square (RMS) surface accuracy approaching 1/50th wavelength. Such large apertures can be real or synthetic apertures. Of key importance is the ability for a highly compact launch configuration, followed by a highly reliable erection and resultant surface configuration.
- Focal plane array modules for large-aperture passive microwave imaging applications.
- Wideband and ultra-wideband sensors with >15dB cross-pole isolation across the bandwidth.
Sensors with low surface currents enabling scanning up to +/-50° without grating lobes, and collimation in one direction with low side lobes for 1-D aperture synthesis.

Bi-static GPS receiving systems for application as altimeters and scatterometers.

Enhanced onboard data processing capabilities that enable real-time, reconfigurable computational approaches which enhance research flexibility. Such approaches should improve image reconstruction, enable high compression ratios, improve atmospheric corrections, and the geolocation and geometric correction of digital image data.

Techniques for the detection and removal of Radio Frequency Interference (RFI) in microwave radiometers are desired. Microwave radiometer measurements can be contaminated by RFI that is within or near the reception band of the radiometer. Electronic design approaches and subsystems are desired that can be incorporated into microwave radiometers to detect and suppress RFI, thus insuring higher data quality.

New technology calibration reference sources for microwave radiometers that provide greatly improved reference measurement accuracy. High emissivity (near-black-body) surfaces are often used as onboard calibration targets for many microwave radiometers. NASA seeks ways to significantly reduce the weight of aluminum core target designs, while reliably improving the uniformity and knowledge of the calibration target temperature. NASA seeks innovative new designs for highly stable noise-diode or other electronic devices as additional reference sources for onboard calibration. Of particular interest are variable correlated noise sources for calibrating correlation-type receivers used in interferometric and polarimetric radiometers.

New approaches, concepts and techniques are sought for microwave radiometer system calibration over or within the 1–300 GHz frequency band, which provide end-to-end calibration to better than 0.1°, including corrections for temperature changes and other potential sources of instrumental measurement drift and error.

Microwave and millimeter wave frequency sources are sought as an alternative to Gunn diode oscillators. Compact (3) self contained oscillators with output frequency between 40 GHz and 120 GHz, low phase noise 100 mW are needed.

Low noise (3) heterodyne mixers requiring low local oscillator drive power (L)

Low power lightweight microwave radiometers are desired which are able to operate stably over long periods, with DC power consumption of less than 2 W and preferably less than 1 W, not including any mechanisms.

Monolithic microwave integrated circuit (MMIC) low noise amplifier (LNA) for space-borne microwave radiometers, covering the frequency range of 165 to 193 GHz, having a noise figure of 6.0 dB or better (and with low 1/f noise).

NASA is developing satellite systems that will use passive and active microwave sensing at L-band and other frequencies to measure sea surface salinity, and soil moisture to a depth of ~10 cm. In support of these global research efforts, the following ancillary measurement systems are required:

Inexpensive approaches to ground sensors are desired that are capable of measuring areas at least 100,000 km$^2$ with a spatial resolution of 20 km. These ground sensors will be needed to validate those space-borne measurements. Measurement of ground-wave propagation characteristics of radio signals from commercial sources may satisfy that need. Although absolute values of soil moisture are desirable, they are not required if the technique can be calibrated frequently at suitable sites. Cost per covered area, autonomous operation, anticipated accuracy, and depth resolution of the soil moisture measurement will be considerations for selection.

Autonomous GPS-located ocean platforms are needed which can measure upper ocean and lower
atmosphere properties including temperature, salinity, momentum, light, precipitation, and biology, and can communicate the resultant data and computational or configuration instructions to and from remote terminals. Similar sensor packages are desired for use onboard ships while underway. This includes the development of intelligent platforms that can change measurement strategy upon receipt of a message from a command center.

- Autonomous low-cost systems are desired that can measure Earth and ocean surface and lower atmospheric parameters including soil moisture, precipitation, temperature, wind speed, sea surface salinity, surface irradiance, and humidity.

- Novel approaches to beam steering for these very large aperture antenna systems are also desired: 1) lightweight, electronically steerable, dual-polarized, phased-array antennas; 2) shared aperture, multi-frequency antennas; 3) high-efficiency, high power, low-cost, lightweight, phase-stable transmit/receive modules; 4) advanced antenna array architectures including scalable, reconfigurable and autonomous antennas; 5) sparse arrays, digital beamforming techniques, time domain techniques, phase correction techniques; 6) distributed digital beamforming and onboard processing technologies; and 7) brightness temperature/scatter co-registration data processing algorithms, data reduction, and merging techniques.

Ground-based microwave radiometer instrumentation, subsystems, and techniques for validating space-borne precipitation measurements. Passive microwave instrumentation, or subsystems, capable of ground-based retrievals of precipitation. The instrumentation, or subsystems, shall operate in inclement weather conditions without the interfering affects of liquid water accumulation on the aperture or field-of-view obstructions. Capabilities for volumetric scanning of the atmosphere and autonomous operation are of great interest.

**E1.05 Active Microwave**

**Lead Center:** JPL  
**Participating Center(s):** GSFC

Active microwave sensors have proven to be ideal instruments for many Earth science applications. Examples include global freeze and thaw monitoring and soil moisture mapping, accurate global wind retrieval and snow inundation mapping, global 3-D mapping of rainfall and cloud systems, precise topographic mapping and natural hazard monitoring, global ocean topographic mapping, and glacial ice mapping for climate change studies. For global coverage and the long-term study of Earth’s eco-systems, space-based radar is of particular interest to Earth scientists. Radar instruments for Earth science measurements include Synthetic Aperture Radar (SAR), scatterometers, sounders, altimeters and atmospheric radars. The life-cycle cost of such radar missions has always been driven by the resources—power, mass, size, and data rate—required by the radar instrument, often making radar not cost competitive with other remote sensing instruments. Order-of-magnitude advancement in key sensor components will make the radar instrument more power efficient, much lighter weight, and smaller in stow volume, leading to substantial savings in overall mission life-cycle cost by requiring smaller and less expensive spacecraft buses and launch vehicles. Onboard processing techniques will reduce data rates sufficiently to enable global coverage. High performance, yet affordable, radars will provide data products of better quality and deliver them to the users more frequently and in a timelier manner, with benefits for science, as well as the civil and defense communities. Technologies that may lead to advances in instrument design, architectures, hardware, and algorithms are the focused areas of this subtopic. In order to increase the radar remote sensing user community, this subtopic will also consider radar data applications and post-processing techniques.

The frequency and bandwidth of operation are mission driven and defined by the science objectives. For SAR applications, the frequencies of interest include UHF (100 MHz), P-band (400 MHz), L-band (1.25 GHz), X-band (10 GHz) and Ku-band (12 GHz). The required bandwidth varies from a few megahertz to 20 MHz to 300 MHz to
achieve the desired resolution; the larger the bandwidth, the higher the resolution. Ocean altimeters and scatterometers typically operate at L-band (1.2 GHz), C-band (5.3 GHz) and Ku-band (12 GHz). Ka-band (35 GHz) interferometers have applications to river discharge. The atmospheric radars operate at very high frequencies (35 GHz and 94 GHz) with only modest bandwidth requirements on the order of a few megahertz.

The emphasis of this subtopic is on core technologies that will significantly reduce mission cost and increase performance and utility of future radar systems. There are specific areas in which advances are needed.

- SAR for surface deformation, topography, soil moisture measurements:
  - Very large aperture L-band antennas (20 m x 20 m) for Medium Earth Orbit (MEO) or 30m diameter for Geosynchronous SAR applications.
  - Shared aperture, multi-frequency antennas (P/L-band, L/X-band).
  - Lightweight, deployable antenna structures and deployment mechanisms.
  - Rad-hard, high-efficiency, high power, low-cost, lightweight L-band and P-band T/R modules.
  - High-power transmitters (L-band, 50-100 kW).
  - L-band and P-band MMIC single-chip T/R module.
  - Rad-hard, high-power, low-loss RF switches, filters, and phase shifters.
  - Digital true-time delay (TTD) components.
  - Thin-film membrane compatible electronics. This includes: Reliable integration of electronics with the membrane, high performance (>1.2 GHz) transistor fabrication on flex material including identifying new materials, process development, and techniques that have the potential to produce large-area passive and active flexible antenna arrays.
  - Advanced transmit and receive module architectures such as optically-fed T/R modules, signal up/down conversion within the module and novel RF and DC signal distribution techniques.
  - Advanced radar system architectures including flexible, broadband signal generation and direct digital conversion radar systems.
  - Advanced antenna array architectures including scalable, reconfigurable, and autonomous antennas; sparse arrays; and phase correction techniques.
  - Distributed digital beamforming and onboard processing technologies.

- SAR data processing algorithms and data reduction techniques.
- SAR data applications and post-processing techniques.
- Low-frequency SAR for subcanopy and subsurface applications:
• Lightweight, large aperture (30 m diameter) reflector and reflectarray antennas.

• Large electronically scanning P-band arrays.

• Shared aperture, dual-polarized, multiple low-frequency (VHF through P-band, 50–500 MHz) antennas with highly shaped beams.

• Lightweight, low frequency, low loss antenna feeds (VHF through P-band, 50–500 MHz).

• High-efficiency T/R modules and transmitters (50–500 MHz, 10 kW).

• Lightweight deployable antenna structures and deployment mechanisms.

• Data applications and post-processing techniques.

• Polarimetric ocean/land scatterometer:

  • Multi-frequency (L/Ku-band) lightweight, deployable reflectors.

  • Large, lightweight, electronically steerable Ku-band reflectarrays.

  • Lightweight L-band and Ku-band antenna feeds.

  • Dual-polarized antennas with high polarization isolation.

  • Lightweight, deployable antenna structures and deployment mechanisms.

  • High efficiency, high power, phase stable L-band and Ku-band transmitters.

  • Low-power, highly integrated radar components.

  • Calibration techniques, data processing algorithms and data reduction techniques.

  • Data applications and post-processing techniques.

• Wide swath ocean and surface water monitoring altimeters:

  • Shared aperture, multi-frequency (C/Ku-band) antennas.

  • Large, lightweight antenna reflectors and reflectarrays.

  • Lightweight C-band and Ku-band antenna feeds.

  • Lightweight deployable antenna structures and deployment mechanisms.

  • High efficiency, high power (1–10 kW) C-band and Ku-band transmitters.

  • Real-time onboard radar data processing.

  • Calibration techniques, data processing algorithms and data reduction techniques.

• Ku-band & Ka-band interferometers for snow cover measurement over land (Ku-band) and wetland and river monitoring (Ka-band):
- Large, stable, lightweight, deployable structures (10–50 m interferometric baseline).
- Ka-band along and across-track track interferometers with a few centimeters of height accuracy.
- Ku-band interferometric polarimetric SAR.
- Phase-stable Ku-band and Ka-band electronically steered arrays and multibeam antennas.
- Lightweight deployable reflectors (Ku-band and Ka-band).
- Shared aperture technologies (L/Ku-band).
- Phase-stable Ku-band and Ka-band receive electronics.
- High-efficiency, rad-hard Ku-band and Ka-band T/R modules or >10 kW transmitters.
- Ku-band and Ka-band antenna feeds.
- Calibration and metrology for accurate baseline knowledge.
- Real-time onboard radar data processing.
- Data applications and post-processing techniques.

- Atmospheric radar:
  - Low sidelobe, electronically steerable millimeter wave phased-array antennas and feed networks.
  - Low sidelobe, multi-frequency, multi-beam, shared aperture millimeter wave antennas (Ka-band and W-band).
  - Large (~300 wavelength), lightweight, low sidelobe, millimeter wave (Ka-band and W-band) antenna reflectors and reflectarrays.
  - Lightweight deployable antenna structures and deployment mechanisms.
  - High power (10 kW) Ka-band and W-band transmitters.
  - High-power (>1 kW, duty cycle >5%), wide bandwidth (>10%) Ka-band amplifiers.
  - High-efficiency, low-cost, lightweight Ka-band and W-band transmit/receive modules.
  - Advanced transmit/receive module concepts such as optically-fed T/R modules.
  - Onboard (real-time) pulse compression and image processing hardware and/or software.
  - Advanced data processing techniques for real-time rain cell tracking, and rapid 3-D rain mapping.
  - Lightweight, low-cost, Ku/Ka band radar system for ground-based rain measurements.
  - High power, low sidelobe (better than -30 dB) scanning phase array flat plate antenna (X, Ku, Ka, or W-band) for high altitude operation (65,000 feet).
E1.06 Passive Infrared - Sub Millimeter

Lead Center: JPL

Many NASA future Earth science remote sensing programs and missions require microwave to submillimeter wavelength antennas, transmitters, and receivers operating in the 1-cm to 100-µm wavelength range (or a frequency range of 30 GHz to 3 THz). General requirements for these instruments include large-aperture (possibly deployable) antenna systems with RMS surface accuracy of

For these systems, advancement is needed in primarily three areas: (1) the development of frequency-stabilized, low phase noise, tunable, fundamental local oscillator sources covering frequencies between 160 GHz and 3 THz; (2) the development of submillimeter-wave mixers in the 300–3000 GHz spectral region with improved sensitivity, stability, and IF bandwidth capability; (3) the development of higher-frequency and higher-output-power MMIC circuits.

Specific innovations or demonstrations are required in the following areas:

- Heterodyne receiver system integration at the circuit and/or chip level is needed to extend MMIC capability into the submillimeter regime. MMIC amplifier development for both power amplifiers and low noise amplifiers at frequencies up to several hundred GHz is solicited. Integration of a local oscillator multiplier chain, mixer, and intermediate frequency amplifier is one example. There is also a specific need to demonstrate array radiometer systems using MMIC radiometers from 60 GHz, to approximately 500 GHz.

- Solid-state, phase-lockable local-oscillator sources with flight-qualifiable design approaches are needed with >10 mW output power at 200 GHz and >100 µW at 1 THz; source line widths should be

- Stable local-oscillator sources are needed for heterodyne receiver system laboratory testing and development.

- Multi-channel spectrometers that analyze intermediate frequency signal bandwidths as large as 10 GHz with a frequency resolution of

- Compact and reliable millimeter and submillimeter imaging instrumentation that produces images simultaneously in multiple spectral bands.

- Schottky mixers with high sensitivity at T = 100 K and above.

- Low noise superconducting HEB mixers and SIS mixers.

- Receivers using planar diode or alternative reliable local oscillator technologies in the 300–3000 GHz spectrum.

- Lightweight and compact radiometer calibration references covering 100–800 GHz frequency range.

- Lightweight, field portable, compact radiometer calibration references covering frequencies up to 200 GHz. The reference must be temperature stable to within 1 K with a minimum of three temperature settings between 250 and 350 K.

- Low cost special purpose ground-based receivers to detect signals radiated from active satellites that are in orbit, for estimating rain rate, water vapor, and cloud liquid water.
• Calibrated radiometer systems that can achieve accuracy and stability of 0.1 K.

• Astrophysics receiver-detector technology proposals are also solicited, specifically under topic S2.01, Sensors and Detectors for Astrophysics.

E1.07 Thermal Control for Instruments

Lead Center: GSFC
Participating Center(s): ARC, JPL, MSFC

Future instruments and platforms for NASA's Earth Science Enterprises will require increasingly sophisticated thermal control technology.

1. Instrument optical alignment needs, lasers, and detectors require tight temperature control, often to better than +/- 1°C.

2. Heat flux levels from lasers and other high power devices are increasing, with some projected to go as high as 100 W/cm².

3. Cryogenic applications are becoming more common. Large, distributed structures, such as mirrors and antennae, will require creative techniques to integrate thermal control functions and minimize weight.

4. The push for miniaturization also drives the need for new thermal technologies towards the micro-electromechanical system (MEMS) level.

5. The drive towards ‘off-the-shelf’ commercial spacecraft, and reconfigurable spacecraft presents engineering challenges for instruments, which must become more self-sufficient.

Innovative proposals for thermal control technologies are sought in the following areas:

• Miniaturized heat transport devices, especially those suitable for cooling small sensors, devices, and electronics.

• Highly reliable, miniaturized Loop Heat Pipes and Capillary Pumped Loops that allow multiple heat load sources and multiple sinks.

• Advanced thermoelectric coolers capable of providing cooling at ambient and cryogenic temperatures.

• Inexpensive passive radiative coolers for low Earth orbit.

• Technologies for cooling very high flux (>100 W/cm²) heat sources, including spray and jet impingement cooling.

• Advanced thermal control coatings, such as variable emittance surfaces and coatings with a high emissivity
at ambient and cryogenic temperatures.

- High conductivity materials to:
  - Minimize temperature gradients, especially for optical benches and structures,
  - Provide jitter isolation links between cryocoolers and sensors, and
  - Provide high efficiency light-weight radiators.

- Advanced analytical techniques for thermal modeling, focusing on techniques that can be easily integrated into existing codes.

- Thermal control systems that actively maintain optical alignment for very large structures at both ambient and cryogenic temperatures.

- Single and two-phase pumped fluid loop systems, which accommodate multiple heat sources and sinks.

- Long life, lightweight pumps for single and two-phase fluid loop systems.

- Efficient, lightweight vapor compression systems for cooling up to 2 kW.

Platform Technologies for Earth Science Topic E2

NASA is fostering innovations that support implementation of the Earth Science (ES) Enterprise program, an integrated international undertaking to study the Earth system. ES uses the unique perspective available from orbit to study land cover and land use changes, short and long term climate variability, natural hazards, and environmental changes. Additionally, ES uses terrestrial and airborne measurements to complement those acquired from Earth orbit. ES has a parallel development effort to these platforms that includes the largest ground and data system ever undertaken, which will provide the facility for command and control of flight segments and for data processing, distribution, storage, and archival of vast amounts of Earth science research data. The Earth Science Program defines platforms as the host systems for ES instruments, i.e., they provide the infrastructure for an instrument or suite of instruments. Traditionally, the term 'platform' would be synonymous with 'spacecraft,' and it certainly does include spacecraft. 'Platform,' however, is intended to be much broader in application than spacecraft and is intended to include non-traditional hosts for sensors and instruments such as airborne platforms (piloted and unpiloted aircraft, balloons, and drop sondes), terrestrial platforms, sea surface and subsurface platforms, and even surface penetrators. These application examples are given to illustrate the wide diversity of possibilities for acquiring ES data consistent with the future vision of the Earth Science Program and indicate types of platforms for which technology development is required.

Sub Topics:

**E2.01 Guidance, Navigation and Control**

Lead Center: GSFC
Future ES architectures will include platforms of varying size and complexity in a number of mission trajectories and orbits. These platforms will include spacecraft, sounding rockets, balloons, and Unmanned Aerial Vehicles (UAVs). Advanced Guidance Navigation and Control (GN&C) technology is required for these platforms to address high performance and reliability requirements while simultaneously satisfying low power, mass, and volume resource constraints. A vigorous effort is needed to develop guidance, navigation and control methodologies, algorithms, and sensor–actuator technologies to enable revolutionary Earth science missions. Of particular interest are highly innovative GN&C technology proposals directed towards enabling ES investigators to exploit new vantage points, develop new sensing strategies, and implement new system-level observational concepts that promote agility, adaptability, evolvability, scalability, and affordability. Novel approaches for the autonomous control of distributed ES spacecraft and/or the management of large fleets of heterogeneous and/or homogeneous ES assets are desired. Specific areas of research include:

**GN&C System Technologies**

Innovative GN&C solutions for ES instrument pointing and stabilization. Advanced GN&C solutions for the Microsat attitude determination and control problem. Of special interest are low cost (at high production volumes) and highly integrated Microsat GN&C subsystems suitable for enabling both spin stabilized and three-axis stabilized Microsats. GN&C proposals that exploit and combine recent advances in miniature spacecraft subsystem architectures, spacecraft attitude determination and control theory, advanced electro-mechanical packaging, MEMS technology, ultra-low power microelectronics are encouraged. Proposals of special interest are ones that address the technologies needed to implement closed-loop spacecraft control system architectures which provide the "Drag-Free" precision orbit determination and maintenance capabilities needed for future ES Low Earth Orbit (LEO) formation-flying applications. Technology solutions are encouraged that employ Drag-Free sensors (similar to accelerometers), high specific impulse (Isp) thrusters, and low-cost processors with appropriate closed-loop filtering and control algorithms to implement a complete Drag-Free spacecraft control system module.

Vision-based GN&C system concepts, subsystems, hardware components, and supporting algorithms/flight software. Applications of interest are of high performance video image processing technology to provide alternative solutions to challenging GN&C problems such as spacecraft relative range and attitude determination while in close formation and/or during proximity operations.

Advanced GN&C solutions for balloon-borne stratospheric science payloads, including sub-arc second pointing control, sub-arcssecond attitude knowledge determination and trajectory guidance for individual balloon-borne payloads. Innovative techniques are of interest for modeling, simulating, and analyzing the inherent dynamics and control of balloon-borne payloads. Also of interest are innovative concepts, strategies, techniques, and methods for modeling, simulating, and analyzing formations, constellations, and/or networks of multiple balloon-borne stratospheric science payloads.

**GN&C Sensors and Actuators**

Advanced sensors and actuators with enhanced capabilities and performance, as well as reduced cost, mass, power, volume, and reduced complexity for all spacecraft GN&C system elements. Emphasis is placed on improved stability, accuracy, and noise performance. Nontraditional multifunctional sensor/actuator technology proposals are of particular interest.

Innovations in Global Positioning System (GPS) receiver hardware and algorithms that use GPS code and carrier...
signals to provide spacecraft navigation, attitude, and time. Of particular interest are GPS-based navigation techniques that may employ Wide Area Augmentation System (WAAS) corrections.

Novel approaches to autonomous sensing and navigation of multiple distributed space platforms. Of particular interest are specialized sensors and measurement systems for formation sensing and navigations functions.

**E2.02 Command and Data Handling**

*Lead Center: GSFC*

Advancing science with reduced levels of mission funding, shorter mission development schedules and reduced availability of flight electronic components creates new requirements for spacecraft Command and Data Handling (C&DH) systems. There are specific areas for which proposals are being sought.

**Onboard Processing**

- General purpose data processing: higher levels of spacecraft autonomy require higher levels of general purpose CISC (Complex Instruction Set Computer) and RISC (Reduced Instruction Set Computer) processing with fault tolerance and error correction (system and application).

- Special purpose data processing: higher levels of automated onboard science data processing to complement the data gathering capabilities of future instruments. Reduce the processed data volume to remain within the limits of spacecraft to Earth communications.

- Reconfigurable computing hardware: achieving pure hardware processing capabilities with the flexibility of reprogrammability to allow different science objectives to be met with the same hardware platform. Development of technologies such as radiation hardened Field Programmable Gate Arrays (FPGAs) and similar components for data communications and processing.

- Low-power electronics: in order to provide higher capabilities on smaller and/or less expensive spacecraft. Electronics that consume less power decrease overall thermal load, and decrease battery size and solar panel size.

**Command and Data Transfer**

- Subsystem data transfer: communications between various spacecraft subsystems in order to realize higher autonomy. Development of technologies and architectures that increase the rate of data transfer above 20 Mbits/s are necessary to achieve the self-diagnosis, autonomous control, and science data transfer requirements.

- Intra-system data transfer: communications within the spacecraft subsystem, between cards within a box to replace the conventional passive backplanes.
Protocols and Architectures

- Internet-based protocol modules and extensions that will support seamless connectivity between terrestrial and aerospace platforms by mitigating variable latencies and bit error rates among distributed air and spacecraft to terrestrial gateways.

- Novel methodologies for performing medium to large-scale simulations of space Internet architectures, protocols, and applications.

- Network security technologies to assure integrity and authentication of data from the public Internet to protected space-based networks.

- Ad hoc and innovative, lightweight networking protocols to support spacecraft constellation, formation flying, satellite clusters, proximity, and sensor based networks.

E2.03 Advanced Communication Technologies for Near-Earth Missions

Lead Center: GSFC

Participating Center(s): GRC

Programmable Analog Devices

A technology is desired to provide a software programmable analog component. This “programmable analog array” would consist of basic elements including filters, amplifiers, couplers and mixers whose frequency of operation, bandwidths and gains can be changed by software command. The signal flow in the component itself will be reconfigurable by software and firmware loads in a manner similar to that of Field Programmable Gate-Array (FPGA) digital devices. Desired components will be capable of operating in the S- and Ku-bands. Maximum flexibility in configuration is also desired with the goal of producing a generic “sea of elements” rather than an integrated system on a chip.

Low-Overhead Software-Defined Radio (SDR) Implementations

NASA is interested in SDR architectures and implementations that optimize flexibility and interoperability between different SDRs, but are based on extremely efficient core architectures and low processor overheads. Algorithms that can be implemented in current space flight capable hardware are especially encouraged.

RF Component Technology

A wide variety of general advances in component, material and manufacturing technologies are required to support future NASA mission requirements. These technologies include innovative approaches to enable higher frequency, miniature, power efficient Traveling Wave Tube Amplifiers (TWTAs) operating at millimeter wave frequencies and at data rates of 10 Gbps or higher. Wide band-gap semiconductor (WBGS) based devices for high power, high efficiency microwave and millimeter wave solid-state power amplifiers (SSPAs), as well as low noise amplifiers in the same ranges. MEMS-based RF switches are needed for use in reconfigurable antennas, phase shifters,
amplifiers, oscillators and in-flight reconfigurable filters. Frequencies of interest include S-, Ku-, Ka-, and V-band (60 GHz).

**Bandwidth Efficient Channel Coding**

To support extremely high data rates in a limited frequency spectrum, bandwidth-efficient channel coding is required. NASA is interested in algorithms that provide lossless data compression and efficient error correction at data rates greater than 1 Gbps for links between Earth orbit and Earth ground stations.

**RF Materials and Structures**

NASA is interested in materials that can be efficiently manufactured and effectively used in the construction and deployment of thin-film based RF antenna systems. Methods for deploying very large, lightweight, aperture structures on-orbit are needed. Inflatable structures, as well as “shape memory” alloy-based implementations, capable of withstanding launch and deployment forces are encouraged.

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**E2.04 Onboard Propulsion**

**Lead Center:** GRC

**Participating Center(s):** GSFC, JSC, MSFC

This subtopic seeks technologies that will significantly increase capabilities and reduce costs for Earth science spacecraft. Propulsion functions include orbit insertion, orbit maintenance, constellation maintenance, precision positioning, in-space maneuvering, and de-orbit. Propulsion technologies are sought that will provide platforms with larger scientific payloads, longer-life missions, and increased operational flexibility during missions. To accomplish these goals, innovations are needed in low-thrust chemical and low-power electric propulsion technology, including thruster components, advanced propellants, power processing units, and feed system components. Of particular interest are innovations in propulsion technology that lead to smaller-sized, integrated, autonomous spacecraft. The following specific areas are of interest:

**Miniature and Precision Propulsion**

Propulsion technologies for miniature (less than 10 kg) spacecraft and for high-precision (impulse bit

**Thruster Technology**

Electric and chemical propulsion technologies that provide increased capability (mass and volume) and/or flexibility (duty cycle and life) for small, power-limited spacecraft, including:

- Electrostatic and electromagnetic propulsion technologies;
- High-performance (specific impulse > 250 s), high-density monopropellant thruster technology;
• High-performance (specific impulse > 350 s), space storable bipropellant thruster technology; and

• Propellant gelation technology.

**Propulsion System Components**

Innovative electric and chemical propulsion system components for small spacecraft are sought including:

• Materials compatible with high-temperature, oxidizing, and reactive environments;
• Components for fluid isolation, pressure and mass flow regulation, relief quick disconnect, and flow control;
• Technologies for metering, injection, and ignition of fluids in combustion devices;
• Gaseous storage and pressurization system; and
• Components for xenon storage and flow control.

**E2.05 Energy Storage Technologies**

**Lead Center:** GRC

**Participating Center(s):** GSFC, JPL, JSC, MSFC

Advanced energy storage technologies are required for Earth science observation platforms. These platforms are defined as host systems that include traditional spacecraft, airborne platforms, such as piloted and unpiloted aircraft and balloons, terrestrial platforms, micro-spacecraft, and surface penetrators.

The energy storage technologies solicited include both primary and secondary batteries, primary and regenerative fuel cells, and flywheels. The desired technology advances common to all of the storage devices of interest include the following elements:

• Improvements in energy density and specific energy;
• Improvement in cycle life, run time, and calendar life;
• Performance over a wide temperature range;
• Reduction in device size, to the micro-scale;
• Reduction in system complexity; and
• Integration into, and with, other spacecraft structures.
A vigorous effort is needed to develop energy storage technologies that will enable the revolutionary ES missions.

Specific technology advances that contribute to achieving the following performance goals are of interest.

**Advanced Battery Technology**

- Specific energy: >150 Wh/kg for secondary batteries >400 Wh/kg for primary batteries
- Low-Earth-Orbit (LEO) cycle life >60,000 cycles for secondary batteries
- Calendar life >15 years
- Operating temperature range -100°C to 100°C
  - Systems capable of delivering 30–50% of the capacity available at ambient temperatures at temperatures as low as -100°C

Primary and rechargeable lithium-based batteries with advanced anode and cathode materials and advanced liquid and polymer electrolytes are of particular interest. Proposals addressing structural and microbatteries are sought.

**Fuel cell (FC) and Regenerative Fuel Cell (RFC) Technologies**

- Specific energy: FC >1500 W/kg, RFC >600 Wh/kg
- Efficiency: FC>70% at 1500 W/kg, RFC >60% at 600 Wh/kg
- Life FC >10,000 hours, RFC > 1500 cycles

Advances to PEM, Direct methanol and solid oxide fuel cell systems are of particular interest.

**Flywheel Energy Storage**

- Specific energy > 100 Wh/kg
- LEO cycle life > 60,000 cycles

Micro-flywheels with a high number of watt hours per kilogram and highly integrated components are of particular interest.
Earth science observation missions will employ spacecraft, balloons, sounding rockets, surface assets, and piloted and robotic aircraft and marine craft. Advanced power technologies are required for each of these platforms that address issues of size, mass, capacity, reliability, and operational costs. A vigorous effort is needed to develop energy conversion technologies that will enable the revolutionary Earth science missions. Exploiting innovative technological opportunities, developing power systems for adverse environments, and implementing system-wide techniques that promote scalability, adaptability, flexibility, and affordability are characteristic of the technological challenges to be faced and are representative of the type of developments required beyond the current state-of-the-art.

The energy conversion technologies solicited include photovoltaics, Brayton, Rankine, Stirling, and thermophotovoltaic, as well as related technologies such as concentrators and thermal technologies. Specific areas of interest follow.

- Photovoltaic cell and array technologies with significant improvements in efficiencies, cost, radiation resistance, and wide operating conditions are solicited. Potential concepts include rigid arrays, concentrator configurations, and ultra-lightweight array technologies that exploit the properties of lightweight, flexible thin-film photovoltaic cells. Photovoltaic cell and array technologies for extreme environments such as high- or low-temperature operation are solicited. Technologies for electrostatically-clean spacecraft solar arrays are also of interest.

- Future micro-spacecraft require distributed power sources that are integrated with microelectronics devices/instruments. These microelectronic devices/instruments integrate energy conversion and storage into a hybrid structure.

- Thermal power conversion technologies for Earth orbiting spacecraft and/or orbit transfer vehicles are sought.

- Advances may be in solar concentrators (rigid or inflatable, primary or secondary) and receivers to improve specific power and reduce mass.

- Topics of interest in power conversion include heat cycles (Brayton, Rankine, and Stirling), compact heat exchangers, advanced materials and fabrication techniques, and control methods, as they relate to life, reliability and manufacturability.

- Thermal technology areas include heat rejection, composite materials, heat pipes, pumped loop systems, packaging and deployment, including integration with the power conversion technology. Highly integrated systems are sought that combine elements of the above subsystems to show system level benefits.
Earth science missions employ spacecraft, balloons, sounding rockets, surface assets, aircraft, and marine craft as observation platforms. Advanced technologies are required for the electrical components and systems on these platforms to address the issues of size, mass, efficiency, capacity, durability, and reliability. Advancements are sought in power electronic materials, devices, components, packaging, and coatings.

Power Electronic Materials and Components

Advanced magnetic, dielectric, semiconductor, and superconductor materials, devices, and circuits are of interest. Proposals must address improvements in energy density, speed, or efficiency. Candidate devices and applications include transformers, inductors, semiconductor switches and diodes, electrostatic capacitors, current sensors, and cables.

Power Conversion, Protection, and Distribution

Technologies that provide significant improvements in mass, size, power quality, reliability, or efficiency in electrical power conversion and protective switchgear components are of interest. Candidate applications include solar array regulators, battery charge and discharge regulators, power conversion, power distribution, and fault protection.

Environmentally Durable Technologies

Technologies that enable materials, surfaces, coatings, and components to be durable in a space environment, in atomic oxygen, soft x-ray, electron, proton, ultraviolet radiation, and thermal cycling environments are of interest to NASA. Environmentally durable coatings for radiators and lightweight electromagnetic shielding are sought.

Electrical Packaging

Thermal control technologies are sought that are integral to electrical devices with high heat flux capability and advanced electronic packaging technologies which reduce volume and mass or combine electromagnetic shielding with thermal control.
Advanced Information Systems Technology For Earth Science Topic E3

The objectives of the Advanced Information System Technology (AIST) Topic are to develop innovative technologies that enable new, or enhance existing, mission and science measurement capabilities for problems closely aligned to the NASA Earth Science Enterprise and, upon completion, provide these capabilities to the broadest set of NASA missions across the agency. The Earth Science Enterprise acquires, processes and delivers very large (gigabyte to terabyte) volumes of remote sensing and related data to public and government entities that apply this information to understand and solve problems in Earth Science. Currently, NASA’s Earth Science Enterprise (ESE) operates 18 orbiting platforms with 80 sensors making scientific measurements of the complex Earth system. Information technology is currently employed throughout ESE’s space and ground systems and the AIST Topic is soliciting technologies that apply to the end-to-end system functions. Target capabilities fall into five major themes: Data Collection and Handling, Transmission and Dissemination, Search, Access, Analysis and Display, and Systems Management.

Results from the AIST Topic will:

- Reduce the risk, cost, size, and development time of NASA’s ESE space-based and ground-based information systems,
- Increase the accessibility and utility of Earth science data,
- Enable new Earth observation measurements and information products, and
- Develop information technologies that enable planetary scale observing systems in support of NASA’s exploration and discovery vision.

Sub Topics:

**E3.01 Automation and Planning**

**Lead Center:** ARC  
**Participating Center(s):** GSFC

The Automation and Planning Subtopic solicits proposals that allow either spacecraft or ground systems to robustly perform complex tasks given high-level goals with minimal human direction. Technology innovations include, but are not limited to: 1) automation and autonomous systems that support high-level command abstraction; 2) efficient and effective techniques for processing large volumes of data (commonly available on the Internet) into useful information; 3) intelligent search of large, distributed data archives, and data discovery through searches of heterogeneous data sets and architecture; and 4) automation of routine, labor intensive tasks that either increase reliability or throughput of current processes. Specific areas of interest include the following:

- Search agents that support applications involving the use of NASA data;
- Methods that support the robust production of data products given a set of high-level goals and constraints;
- Autonomous data collection including the coordination of space or airborne platforms while adhering to a set of data collection goals and resource constraints;
• Autonomous data logging devices (software, or hardware and software) supporting a variety of weather and climate sensors, capable of ground-based operation in a wide variety of environmental conditions; such systems would probably be solar powered with accurate time stamping;

• Planning and scheduling methods related to Earth Science Mission objectives;

• System and subsystem health and maintenance, both space- and ground-based;

• Distributed decision making, using multiple agents, and/or mixed autonomous systems;

• Automated software testing;

• Verification and validation of automated systems;

• Automatic software generation and processing algorithms;

• Control of Field Programmable Gate-Arrays (FPGA) to provide real-time products.

E3.02 Distributed Information Systems and Numerical Simulation

Lead Center: ARC

Participating Center(s): GSFC

This subtopic seeks advances in tools, techniques, and technologies for distributed information systems and large-scale numerical simulation. The goal of this work is to create an autonomous information and computing environment that enables NASA scientists to work naturally with distributed teams and resources to dramatically reduce total time-to-solution (i.e., time to discovery, understanding, or prediction), vastly increase the feasible scale and complexity of analysis and data assimilation, and greatly accelerate model advancement cycles. Areas of interest follow below.

Distributed Information Systems

• Core services (autonomous software systems) for automated, scalable, and reliable management of distributed, dynamic, and heterogeneous computing, data, and instrument resources. Services of interest (which may be based on Open Grid Service Infrastructure) include those for authentication and security, resource and service discovery, resource scheduling, event monitoring, uniform access to compute and data resources, and efficient and reliable data transfer.

• Higher level services, including those for job management, resource brokering, workflow management, portlet (i.e., application-specific graphical user interface) building, and collaboration.

• Services for management of distributed, heterogeneous information, including replica management, intuitive interfaces, and instantiation on demand or “virtualized data.” These services would be used, for example, to access and manipulate NASA’s wealth of geospatial and remote sensing data.
• Science portals for cross-disciplinary discovery, understanding, and prediction, encapsulating services for single sign-on access, semantic resource and service discovery, workflow composition and management, remote collaboration, and results analysis and visualization.

• Tools for rapidly porting and hosting science applications in a distributed environment. These applications were written for an integrated, or workstation, environment using standard programming languages or tools such as Matlab, Interactive Data Language (IDL), or Mathematica.

Large-Scale Numerical Simulation

• Tools for automating large-scale modeling, simulation, and analysis, including those for managing computational ensembles, performing model-optimization studies, interactive computational steering, and maintaining progress in long-running computations in spite of unreliable computing, data, and network resources.

• Tools for computer system performance modeling, prediction, and optimization for real applications.

• Techniques and tools for application parallelization and performance analysis.

• Tools for effective load balancing, and high reliability, availability, and serviceability (RAS) in commodity clusters and other large-scale computing systems.

• Novel supercomputing approaches using FPGAs, graphics processors, and other novel architectures and technologies.

E3.03 Geospatial Data Analysis Processing and Visualization Technologies

Lead Center: SSC
Participating Center(s): GSFC

Proposals are sought for the development of advanced technologies in support of scientific, commercial, and educational application of ESE and other remote sensing data. Focus areas are to provide tools for processing, analysis, interpretation, and visualization of remotely sensed data sets. ESE benchmarks practical uses of NASA-sponsored observations from remote sensing systems and predictions from scientific research and modeling. Specific interest exists in the development of technologies contributing to decision support systems, and model development and operation. For more information on decision support models under evaluation, please visit http://earth.nasa.gov/eseapps/index.html [1]. Areas of specific interest include the following:

• Unique, innovative data reduction, rapid analysis and data exploitation methodologies and algorithms of information from remotely sensed data sets, e.g., automated feature extraction, data mining, etc.;

• Algorithms and approaches to enable the efficient production of data products from active imaging systems, e.g., multipoint data resampling, digital elevation model creation, etc.;

• Data merge and fusion software for efficient production and real-time delivery of digital products of ESE
Mission and other remote sensing data sets, e.g., weather observation and land use and land cover data sets;

- Innovative approaches for incorporation of GPS data into *in situ* data collection operations with dynamic links to spatial databases including environmental models
- Image enhancement algorithms for improving spatial, spectral, and geometric image attributes;
- Innovative approaches for the querying and assimilation of application-specific datasets from disparate and distributed databases from government, academic and commercial sources into a common framework for data analysis
- Innovative approaches for querying of application-specific data sets from disparate, distributed databases in government, academic, and commercial data warehouses into a common framework for data analysis; and
- Innovative visualization technologies contributing to the analysis of data through the display and visualization of some or all of the above data types including providing the linkages and user interface between the cartographic model and attribute databases.

**E3.04 Data Management and Visualization**

**Lead Center: GSFC**

This subtopic focuses on innovative approaches to managing and visualizing large collections of Earth science data in a highly distributed and networked environment.

- Develop technologies that support long term data management, storage, search, and retrieval of very large, distributed, geospatial Earth science data sets, including the development of object based storage devices, file systems that promote long term data maintenance and recovery from user errors, and global compression techniques that optimize data backup operations.
- Develop techniques to manage and locate data in a distributed metadata catalog environment and provide tools to create, use, and then tear down wide area high speed Storage Area Network (SAN) access to remote data sets.
- Develop tools and techniques that enable high bandwidth scientific collaboration in a distributed environment, and allow data viewing, real-time data browse, and general purpose rendering of multivariate geospatial scientific data sets using georectification, data overlays, data reduction, and data encoding across widely differing data types and formats.
- Design and implement 3-D virtual reality environments for scientific data visualization that will enable users to 'fly' through the data space to locate specific areas of interest, and make use of novel 3-D presentation techniques which minimize or eliminate the need for special user devices such as goggles or helmets.
Current sensors can collect more data than is possible to transmit to the ground for analysis. One solution is to incorporate intelligence in the sensor or platform to prioritize or summarize the data and send down high priority or synoptic data. In the future, a sensor-web capability will demand this remote onboard autonomy and intelligence about the kind and content of data being collected to support rapid decision-making and tasking. This subtopic is interested in developing new methods to autonomously understand ES data in support of making rapid decisions and taking actions under two themes:

**Onboard Satellite Data Processing and Intelligent Sensor Control**

Software technologies that support the configuration of sensors, satellites, and sensor webs of space-based resources. Examples include capabilities that allow the reconfiguration or retargeting of sensors in response to user demand or significant events. Also included in this category is onboard processing of sensor data through the use of processing architectures and reconfigurable computing environments, as well as technologies that support or enable the generation of data products for direct distribution to users.

**Onboard Satellite Data Organization, Analysis, and Storage**

Software technologies that support the storage, handling, analysis, and interpretation of data. Examples include innovations in the enhancement, classification, or feature extraction processes. Also included are data mining, intelligent agent applications for tracking data, distributed heterogeneous frameworks (including open system interfaces and protocols), and data and/or metadata structures to support autonomous data handling, as well as compaction (lossless) or compression of data for storage and transmission.

**Applying Earth Science Measurements Topic E4**

The Earth Science Enterprise (ESE) continues to strive to better understand how the global environment is changing, predict change and understand how these changes affect the human and economic condition. In this Topic, the ESE wants innovative companies to propose technology and techniques to accomplish two goals.
1. Goal 1: Accelerate the deployment of NASA science data and understanding into existing decision support tools used by managers concerned with stewardship of the Earth’s resources. This goal addresses the development of innovative technology solutions that allow the routine use of Earth science results in automated decision support tools already in use by a broad user community. Management decision support tools of interest are used daily in the management of land and biota, air, water, education, and emergency issues.

2. Goal 2: Inspire and motivate students to pursue careers in science, technology, engineering, and mathematics.

Sub Topics:

E4.01 Innovative Tools and Techniques Supporting the Practical Uses of Earth Science Observations

Lead Center: SSC
Participating Center(s): MSFC

Technical innovation and unique approaches are solicited for the development of new technologies and technical methods that make Earth science observations both useful and easy to use by practitioners. This subtopic seeks proposals that support the development of operational decision support tools that produce information for management or policy decision makers. Proposed applications must use NASA Earth Observations (see http://gaia.hq.nasa.gov/ese_missions/ [2]) Other remote sensing data and geospatial technologies may also be employed in the solution.

This subtopic focuses on the systems engineering aspect of application development rather than fundamental research. Offerors are, therefore, expected to have the documented proof-of-concept project in hand. Topics of current interest to the Earth Science Applications Directorate may be found at http://www.esa.ssc.nasa.gov [3]. Innovation in processing techniques, include, but are not limited to, automated feature extraction, data fusion, and parallel and distributed computing which are desired for the purpose of facilitating the use of Earth science data by the nonspecialist. Ease of use, fault tolerance, and statistical rigor and robustness are required for confidence in the product by the nonspecialist end user.

Promotion of interoperability is also a goal of the subtopic, so Federal data standards, communication standards, Open Geographic Information Systems (GIS) standards, and industry-standard tools and techniques will be strongly favored over proprietary ‘black-box’ solutions. Endorsement by the end user of both system requirements and the proposed solution concept is desirable. While the proposed application system may be specific to a particular end user or market, techniques and tools that have broad potential applicability will be favored. An objective assessment of market value or benefit/cost will help reviewers assess the relative potential of proposed projects.

E4.02 Advanced Educational Processes and Tools

Lead Center: GSFC
This subtopic focuses on innovation in effective applications related to classroom- or museum-ready software tools for display and/or analysis of Earth science information for learners in both formal and informal settings, and tools for organization and dissemination of NASA's Earth science educational materials to a wide array of educational audiences. The Earth science educational program covers a wide range of audiences from students to adults in both classroom settings, such as public schools or continuing education venues, to all matter of informal learning settings such as radio, television, museums, parks, scouts, and the Internet. In these venues, the learning focuses on the scientific discoveries by the ESE, the technology innovations and the applied use of these discoveries and technologies for improved decision making by all.

The areas of interest (described below) cross-cut the three programmatic areas within the ESE program (formal, informal, and professional development) and hence, are anticipated to have utility in at least two of these areas and most likely in all three areas.

The first area of interest focuses on innovation in the application of digital library technologies to educational materials and audiences. NASA's Earth Science Education Program currently collaborates with the Digital Library for Earth System Education (DLESE). The successful proposal must be able to integrate with, or be integrated into, existing educational digital library efforts within NASA and/or make contributions to DLESE. These proposals will advance the use and usability of globally distributed, networked information resources, and encourage existing and new communities to focus on innovative applications areas. Collaboration between Earth scientists, formal or informal education community professionals, and computer scientists is required for these proposals to demonstrate useful results. Areas of interest include:

- Extend the current Joined Digital Library (JOIN) effort by developing additional Jini applications. (JOIN is a collection of tools based on Sun's Jini technology used to implement efficient, decentralized, and distributed computing systems and follows "the network is the computer" philosophy.)
- Development of formal and informal education audience-specific interfaces (e.g., specific interfaces for students, park interpreters, TV producers, curriculum developers, etc.).
- Development of interfaces to promote diversity within educational audiences (e.g., age, ethnicity, cultural, urban/rural, etc.).
- Development of accessibility tools for disabled users to interact and search digital libraries.
- Development and access to educational materials including new resources for science, mathematics, and engineering education at all levels.
- Development of interoperability tools to integrate dissimilar library archives.
- Development of tools to administer and manage end-user expectations and satisfaction.
- Develop applications that enhance the general functionality of existing digital libraries by providing new general-purpose tools for archive management, metadata ingestion, intelligent search, and retrieval.
- Tools to support online community interaction, which could include new means for gathering, interacting, and communicating with other library users.

The second area of interest focuses on innovation in effective software and related development techniques, and in highly practical methods for maintaining and disseminating software for use by educational audiences engaged in teaching or learning about Earth science. The specific areas of greatest interest are highly-portable, classroom-
ready software for analysis, visualization, and processing of Earth science satellite data, and methods to provide long-term support and viability for educational software. Collaboration between Earth scientists, educators, computer scientists, and "business" model experts is required for these proposals to demonstrate useful results. Areas of interest include:

- Extend the current Image 2000 effort by developing additional plug-in applications and modifying core software if necessary. Image 2000 is a Java/Java Advanced Imaging (JAI)-based image processing package being developed at GSFC.

- User-friendly, extensible, Earth science satellite image processing software for multiple operating systems, for educational use in K–12, undergraduate and continuing education venues.

- Techniques and software for integrating vector and raster data for the visualization and analysis of geo-spatial Earth science data.

- Tutorials geared toward the use of image processing software for visualization and analysis of Earth science related satellite imagery.

- Infrastructure and startup of an Internet based user-supported support and development network, in the spirit of "Open-Source," to ensure continued maintenance and development of Earth science satellite image processing software and tutorials for educational audiences.

### E4.03 Wireless Technologies for Spatial Data, Input, Manipulation and Distribution

**Lead Center:** SSC

Technical innovation is solicited for the development of wireless technologies for field personnel and robotic platforms to send and receive digital and analog data from sensors such as photography cameras, spectrometers, infrared and thermal scanners, and other sensor systems to collection hubs. The intent of this new innovation is to rapidly, in real time, ingest data sequentially from a variety of input sensors, provide initial field verification of data, and distribute the data to various nodes and servers at collection, processing, and decision hub sites. Data distribution should utilize state-of-the-art wireless, satellite, land carriers, and local area communication networks. The technologies' operating system should be compatible with commonly available systems. The operating system should not be proprietary to the offeror. The innovation should include biometric capability for password protection and relational tracking of data to the field personnel inputting the data and/or sensors and platforms sending information. The innovation should contain technologies that recognize multiple personnel and other sources (robotics) so that several personnel and platforms can use the same unit in the field. Biometric identification can be fingerprint, retina scans, facial, or other methods. The innovation should include geospatial technologies to use digital imagery and have Global Positioning System (GPS) location capabilities. The innovation should be able to display with sufficient size and resolution the rendering of vector and raster data and other sensor data for easy understanding. The field capability of the innovation must be fully integrated end to end with computing capabilities that range from mobile computers to servers at distant locations. Field personnel and robotic platforms providing information and support to science investigations, resource managers, and community planners will use the innovative wireless technology. First responders to natural, human-made disasters and emergencies will also be users of this innovation.
Passive Optics Topic E1.01

The following technologies are of interest to NASA in the remote sensing subtopic “passive optics.” Passive optical remote sensing generally requires that deployed devices have large apertures and large throughput. NASA is interested primarily in instrument technologies suitable for aircraft or space flight platforms, and these inherently also prefer low mass, low power, fast measurement times, and a high degree of robustness to survive vibrations in flight or at launch. Wavelengths of interest range from ultraviolet through the far infrared. Development of techniques, components and instrument concepts that can be developed for use in actual deployed devices and systems within the next few years is highly encouraged.

Technologies and components that are not clearly suitable for use in high throughput remote sensing instruments are not applicable to this subtopic. Technical and scientific leads at NASA have given careful consideration to the technology areas described below, and responses are solicited for these topics.

1) Stiff actuator technology designed to produce precisely controlled motion of large (> 1.0 cm diameter) optical elements intended for use in tunable Fabry-Perot and Fourier Transform Spectrometer (FTS) instruments. Motion ranges of particular interest include 20–60 µm, 1–2 mm, and 3–5 cm. Techniques applicable to very cold temperature (...

2) Technology leading to significant improvements in capability of large format (> 1 inch diameter), very narrow band (-1 full-width at half-maximum), polarization insensitive, high throughput infrared (0.7–15 µm) optical filters.

3) Large format (> 1 inch diameter) high-transmission far infrared filters. Technology and techniques leading to filters operating at wave numbers between 500 and 5 cm⁻¹ with FWHM less than 2 cm⁻¹ are of immediate interest, though technology leading to very high transmission edge filters (long and short pass) is also solicited. The filters must be capable of operating in a vacuum at cryogenic temperatures.

4) High performance four-band two-dimensional (2-D) arrays (128x128 elements) in the 0.4 – 2.5 µm wavelength range with high quantum efficiencies (60%–80% or higher) in all spectral bands, low noise, and ambient temperature operation.
Sub Topics:
Lidar Remote Sensing Topic E1.02

High spatial resolution, high accuracy measurements of atmospheric parameters from ground-based, airborne, and spaceborne platforms require advances in the state-of-the-art lidar technology with emphasis on compactness, reliability, efficiency, low weight, and high performance. Innovative technologies that can expand current measurement capabilities to airborne, spaceborne, or Unmanned Aerial Vehicle (UAV) platforms are particularly desirable. Development of techniques, components, and instrument concepts that can be used in actual deployed systems within the next few years is highly encouraged. Technologies and components that are not clearly suitable for effective lidar remote sensing or field deployment are not applicable to this subtopic. This subtopic considers components, subsystems, and complete instrument packages addressing the following specific measurement needs:

- Molecular species (ozone, water vapor, and carbon dioxide);
- Cloud and aerosols with emphasis on aerosol optical properties;
- Wind profiles using direct-detection lidar, or coherent-detection (heterodyne) lidar, or both; and
- Land topography (vegetation, ice, and land use).

In addition to instrument systems, innovative component technologies that directly address the measurement needs above will be considered. Technical and scientific leads at NASA have given careful consideration to the component technologies described below, and responses are solicited for these technology areas.

1. Novel laser materials and components for high efficiency solid state lasers operating at 1 and 2 µm wavelength regions. The laser components include:

   - Rugged, compact fiber lasers and fiber amplifiers for use at 1.5 and 1 µm;
   - Low voltage (Efficient and reliable high power, quasi-CW, pump diodes operating at 792 nm and 808 nm in fiber-coupled or free-space configuration; and
   - Laser crystals for generating 2 µm radiation with high thermal conductivity and small variation of the index of refraction with temperature.

2. High damage-resistant, efficient, inorganic and birefringent nonlinear optical materials for generation of ultraviolet and mid-infrared radiation.

3. Thermally efficient conductively-cooled head for solid-state lasers with side-pumped rod configuration, and thermally and mechanically stable optical bench.
4. Frequency-agile, semiconductor lasers operating in 1 to 2 µm wavelength region with spectral linewidth less than 200 kHz over 1 ms and optical power greater than 20 mW.

5. Scanning or scanable lightweight telescopes with an optical quality better than 1/6 wave at 632 nm, mass density less than 12 kg/m², and aperture diameters from 0.5–1.0 m.

6. Laser beam steering and scanning technologies operating at 0.355, 1.06, or 2.05 µm with 5–25 cm aperture diameter for airborne and 0.5–1.0 m for spaceborne instruments, meeting the following minimum requirements:
   - 60° field of regard
   - 90% optical throughput
   - wave single pass optical quality at 632 nm

7. Shared aperture angle-multiplexed holographic or diffractive optical elements having several fields of view, each with angular resolution of 50 µrad or better for the Nd:YAG or Nd:YLF laser harmonics, and diffraction limited resolution for the Ho:YLF fundamental wavelength. Wide, flat, focal planes with low off-axis aberrations is of importance to terrain and vegetation mapping lidar applications. Hybrid designs using both 2053 nm or 1064 nm and 355 nm simultaneously are needed for dual wavelength Doppler wind lidar applications. Materials and technologies are needed that can be scaled up to 1 m apertures and larger, and space qualified. Designs using lightweight materials, such as composites or membranes and deployable folded architectures, are also desired to decrease system size and weight.

8. High gain, low noise photon counting detectors that operate without the use of cryogens are needed. Other desirable properties are linearity over a large dynamic range, saturation count rates over 100 MHz, reasonable active area size (>200 µm), 250–2200 nm response wavelengths, and high clocking and readout rates with low read noise. High-speed (500 Msamples per second or greater) waveform digitizers are also of interest for operation with integrated pulse-finding capability suitable for continuous operation and capable of locating more than 200,000 individual pulses per second.

9. Narrow band optical filters with 75% throughput, with minimum 1 inch clear aperture.

Sub Topics:
In Situ Sensors Topic E1.03
Proposals are sought for the development of in situ measurement systems that will enhance the scientific and commercial utility of data products from the Earth Science Enterprise program and that will enable the development of new products of interest to commercial and governmental entities around the world. Technology innovation areas of interest include:

- Autonomous Global Positioning System (GPS)-located platforms (fixed or moving) to measure and
transmit to remote terminals upper ocean and lower atmosphere properties including temperature, salinity, momentum, light, precipitation, and biogeochemistry.

- Dynamic stabilization systems for small instruments mounted on moving platforms (e.g., buoys and boats) to maintain vertical and horizontal alignment. Systems capable of maintaining a specified pointing with respect to the Sun are preferred.

- Small, lightweight instruments for measuring clouds, liquid water, or ice content (mass) designed for use on radiosondes, dropsondes, aerosondes, tethered balloons, or kites.

- Wide-band microwave radiometers capable of high-speed characterization of cloud parameters, including liquid and ice phase precipitation, which can operate in harsh environmental conditions (e.g., onboard ships and aircraft).

- Autonomous GPS-located airborne sensors that remotely sense atmospheric wind profiles in the troposphere and lower stratosphere with high spatial resolution and accuracy.

- Systems for \textit{in situ} measurement of atmospheric electrical parameters including electric and magnetic fields, conductivity, and optical emissions.

- Systems to measure line- and area-averaged rain rate at the surface over lines of at least 100 m and areas of at least 100x100 m.

- Lightweight, low-power systems that integrate the functions of inertial navigation systems and GPS receivers for characterizing and/or controlling the flight path of remotely piloted vehicles.

- Low-cost, stable (to within 1% over several months), portable radiometric calibration devices in the shortwave spectral region (0.3 to 3 µm) for field characterization of radiance instruments such as sun photometers and spectrometers.

- Miniaturized, low power (12V DC) instruments especially suited for small boat operations that are capable of adequately resolving, at the appropriate accuracy, the complex vertical structure (optical, hydrographic, and biogeochemical) of the coastal ocean (turbid) water column. Sensors that can be easily integrated within a digital (serial) network to measure the apparent and inherent optical properties of seawater are preferred.

Sub Topics:
Passive Microwave Topic E1.04

Proposals are sought for the development of innovative passive microwave technology in support of Earth System Science measurements of the Earth's atmosphere and surface. These microwave radiometry technology innovations are intended for use in the frequency band from about 1 GHz to 1 THz. The key science goal is to increase our understanding of the interacting physical, chemical and biological processes that form the complex Earth system. Atmospheric measurements of interest include climate and meteorological parameters including temperature, water vapor, clouds, precipitation, and aerosols; air pollution; and chemical constituents such as ozone, NO\textsubscript{X}, and carbon monoxide. Earth surface measurements of interest include water, land, and ice surface temperatures, land surface moisture, snow coverage and water content, sea surface salinity and winds, and multispectral imaging.

Technology innovations are sought that will provide the needed concepts, components, subsystems, or complete systems that will improve these needed Earth System Science measurements. Technology innovations should address enhanced measurement capabilities such as improved spatial or temporal resolution, improved spectral
resolution, or improved calibration accuracies. Technology innovations should provide reduced size, weight, power, improved reliability, and lower cost. The innovations should expand the capabilities of airborne systems (manned and unmanned), as well as next generation spaceborne systems. Highly innovative approaches that open new pathways are an important element of competitive proposals under this solicitation.

Specific technology innovation areas include:

- Imaging radiometers, receivers or receiver arrays on a chip, and flux radiometers.
- Large aperture, deployable antenna systems suitable for highly reliable space deployment with root mean square (RMS) surface accuracy approaching 1/50th wavelength. Such large apertures can be real or synthetic apertures. Of key importance is the ability for a highly compact launch configuration, followed by a highly reliable erection and resultant surface configuration.
- Focal plane array modules for large-aperture passive microwave imaging applications.
- Wideband and ultra-wideband sensors with >15dB cross-pole isolation across the bandwidth.
- Sensors with low surface currents enabling scanning up to +/-50° without grating lobes, and collimation in one direction with low side lobes for 1-D aperture synthesis.
- Bi-static GPS receiving systems for application as altimeters and scatterometers.
- Enhanced onboard data processing capabilities that enable real-time, reconfigurable computational approaches which enhance research flexibility. Such approaches should improve image reconstruction, enable high compression ratios, improve atmospheric corrections, and the geolocation and geometric correction of digital image data.
- Techniques for the detection and removal of Radio Frequency Interference (RFI) in microwave radiometers are desired. Microwave radiometer measurements can be contaminated by RFI that is within or near the reception band of the radiometer. Electronic design approaches and subsystems are desired that can be incorporated into microwave radiometers to detect and suppress RFI, thus insuring higher data quality.
- New technology calibration reference sources for microwave radiometers that provide greatly improved reference measurement accuracy. High emissivity (near-black-body) surfaces are often used as onboard calibration targets for many microwave radiometers. NASA seeks ways to significantly reduce the weight of aluminum core target designs, while reliably improving the uniformity and knowledge of the calibration target temperature. NASA seeks innovative new designs for highly stable noise-diode or other electronic devices as additional reference sources for onboard calibration. Of particular interest are variable correlated noise sources for calibrating correlation-type receivers used in interferometric and polarimetric radiometers.
- New approaches, concepts and techniques are sought for microwave radiometer system calibration over or within the 1–300 GHz frequency band, which provide end-to-end calibration to better than 0.10°, including corrections for temperature changes and other potential sources of instrumental measurement drift and error.
- Microwave and millimeter wave frequency sources are sought as an alternative to Gunn diode oscillators. Compact (3) self contained oscillators with output frequency between 40 GHz and 120 GHz, low phase noise 100 mW) are needed.
- Low noise (3) heterodyne mixers requiring low local oscillator drive power (
- Monolithic microwave integrated circuit (MMIC) low noise amplifier (LNA) for space-borne microwave radiometers, covering the frequency range of 165 to 193 GHz, having a noise figure of 6.0 dB or better (and with low 1/f noise).

NASA is developing satellite systems that will use passive and active microwave sensing at L-band and other frequencies to measure sea surface salinity, and soil moisture to a depth of ~10 cm. In support of these global research efforts, the following ancillary measurement systems are required:

- Inexpensive approaches to ground sensors are desired that are capable of measuring areas at least 100,000 km$^2$, with a spatial resolution of 20 km. These ground sensors will be needed to validate those space-borne measurements. Measurement of ground-wave propagation characteristics of radio signals from commercial sources may satisfy that need. Although absolute values of soil moisture are desirable, they are not required if the technique can be calibrated frequently at suitable sites. Cost per covered area, autonomous operation, anticipated accuracy, and depth resolution of the soil moisture measurement will be considerations for selection.

- Autonomous GPS-located ocean platforms are needed which can measure upper ocean and lower atmosphere properties including temperature, salinity, momentum, light, precipitation, and biology, and can communicate the resultant data and computational or configuration instructions to and from remote terminals. Similar sensor packages are desired for use onboard ships while under way. This includes the development of intelligent platforms that can change measurement strategy upon receipt of a message from a command center.

- Autonomous low-cost systems are desired that can measure Earth and ocean surface and lower atmospheric parameters including soil moisture, precipitation, temperature, wind speed, sea surface salinity, surface irradiance, and humidity.

- Novel approaches to beam steering for these very large aperture antenna systems are also desired: 1) lightweight, electronically steerable, dual-polarized, phased-array antennas; 2) shared aperture, multi-frequency antennas; 3) high-efficiency, high power, low-cost, lightweight, phase-stable transmit/receive modules; 4) advanced antenna array architectures including scalable, reconfigurable and autonomous antennas; 5) sparse arrays, digital beamforming techniques, time domain techniques, phase correction techniques; 6) distributed digital beamforming and onboard processing technologies; and 7) brightness temperature/scatter co-registration data processing algorithms, data reduction, and merging techniques.

Ground-based microwave radiometer instrumentation, subsystems, and techniques for validating space-borne precipitation measurements. Passive microwave instrumentation, or subsystems, capable of ground-based retrievals of precipitation. The instrumentation, or subsystems, shall operate in inclement weather conditions without the interfering affects of liquid water accumulation on the aperture or field-of-view obstructions. Capabilities for volumetric scanning of the atmosphere and autonomous operation are of great interest.

Sub Topics:

Active Microwave Topic E1.05

Active microwave sensors have proven to be ideal instruments for many Earth science applications. Examples include global freeze and thaw monitoring and soil moisture mapping, accurate global wind retrieval and snow inundation mapping, global 3-D mapping of rainfall and cloud systems, precise topographic mapping and natural hazard monitoring, global ocean topographic mapping, and glacial ice mapping for climate change studies. For global coverage and the long-term study of Earth's eco-systems, space-based radar is of particular interest to Earth scientists. Radar instruments for Earth science measurements include Synthetic Aperture Radar (SAR), scatterometers, sounders, altimeters and atmospheric radars. The life-cycle cost of such radar missions has always
been driven by the resources—power, mass, size, and data rate—required by the radar instrument, often making radar not cost competitive with other remote sensing instruments. Order-of-magnitude advancement in key sensor components will make the radar instrument more power efficient, much lighter weight, and smaller in stow volume, leading to substantial savings in overall mission life-cycle cost by requiring smaller and less expensive spacecraft buses and launch vehicles. Onboard processing techniques will reduce data rates sufficiently to enable global coverage. High performance, yet affordable, radars will provide data products of better quality and deliver them to the users more frequently and in a timelier manner, with benefits for science, as well as the civil and defense communities. Technologies that may lead to advances in instrument design, architectures, hardware, and algorithms are the focused areas of this subtopic. In order to increase the radar remote sensing user community, this subtopic will also consider radar data applications and post-processing techniques.

The frequency and bandwidth of operation are mission driven and defined by the science objectives. For SAR applications, the frequencies of interest include UHF (100 MHz), P-band (400 MHz), L-band (1.25 GHz), X-band (10 GHz) and Ku-band (12 GHz). The required bandwidth varies from a few megahertz to 20 MHz to 300 MHz to achieve the desired resolution; the larger the bandwidth, the higher the resolution. Ocean altimeters and scatterometers typically operate at L-band (1.2 GHz), C-band (5.3 GHz) and Ku-band (12 GHz). Ka-band (35 GHz) interferometers have applications to river discharge. The atmospheric radars operate at very high frequencies (35 GHz and 94 GHz) with only modest bandwidth requirements on the order of a few megahertz.

The emphasis of this subtopic is on core technologies that will significantly reduce mission cost and increase performance and utility of future radar systems. There are specific areas in which advances are needed.

- SAR for surface deformation, topography, soil moisture measurements:
  - Very large aperture L-band antennas (20 m x 20 m) for Medium Earth Orbit (MEO) or 30m diameter for Geosynchronous SAR applications.
  - Shared aperture, multi-frequency antennas (P/L-band, L/X-band).
  - Lightweight, deployable antenna structures and deployment mechanisms.
  - Rad-hard, high-efficiency, high power, low-cost, lightweight L-band and P-band T/R modules.
  - High-power transmitters (L-band, 50-100 kW).
  - L-band and P-band MMIC single-chip T/R module.
  - Rad-hard, high-power, low-loss RF switches, filters, and phase shifters.
  - Digital true-time delay (TTD) components.
  - Thin-film membrane compatible electronics. This includes: Reliable integration of electronics with the membrane, high performance (>1.2 GHz) transistor fabrication on flex material including identifying new materials, process development, and techniques that have the potential to produce large-area passive and active flexible antenna arrays.
  - Advanced transmit and receive module architectures such as optically-fed T/R modules, signal up/down conversion within the module and novel RF and DC signal distribution techniques.
- Advanced radar system architectures including flexible, broadband signal generation and direct digital conversion radar systems.
- Advanced antenna array architectures including scalable, reconfigurable, and autonomous antennas; sparse arrays; and phase correction techniques.
- Distributed digital beamforming and onboard processing technologies.

- SAR data processing algorithms and data reduction techniques.
- SAR data applications and post-processing techniques.
- Low-frequency SAR for subcanopy and subsurface applications:
  - Lightweight, large aperture (30 m diameter) reflector and reflectarray antennas.
  - Large electronically scanning P-band arrays.
  - Shared aperture, dual-polarized, multiple low-frequency (VHF through P-band, 50–500 MHz) antennas with highly shaped beams.
  - Lightweight, low frequency, low loss antenna feeds (VHF through P-band, 50–500 MHz).
  - High-efficiency T/R modules and transmitters (50–500 MHz, 10 kW).
  - Lightweight deployable antenna structures and deployment mechanisms.
  - Data applications and post-processing techniques.

- Polarimetric ocean/land scatterometer:
  - Multi-frequency (L/Ku-band) lightweight, deployable reflectors.
  - Large, lightweight, electronically steerable Ku-band reflectarrays.
  - Lightweight L-band and Ku-band antenna feeds.
  - Dual-polarized antennas with high polarization isolation.
  - Lightweight, deployable antenna structures and deployment mechanisms.
  - High efficiency, high power, phase stable L-band and Ku-band transmitters.
  - Low-power, highly integrated radar components.
  - Calibration techniques, data processing algorithms and data reduction techniques.
  - Data applications and post-processing techniques.

- Wide swath ocean and surface water monitoring altimeters:
  - Shared aperture, multi-frequency (C/Ku-band) antennas.
- Large, lightweight antenna reflectors and reflectarrays.
- Lightweight C-band and Ku-band antenna feeds.
- Lightweight deployable antenna structures and deployment mechanisms.
- High efficiency, high power (1–10 kW) C-band and Ku-band transmitters.
- Real-time onboard radar data processing.
- Calibration techniques, data processing algorithms and data reduction techniques.

- Ku-band & Ka-band interferometers for snow cover measurement over land (Ku-band) and wetland and river monitoring (Ka-band):
  - Large, stable, lightweight, deployable structures (10–50 m interferometric baseline).
  - Ka-band along and across-track track interferometers with a few centimeters of height accuracy.
  - Ku-band interferometric polarimetric SAR.
  - Phase-stable Ku-band and Ka-band electronically steered arrays and multibeam antennas.
  - Lightweight deployable reflectors (Ku-band and Ka-band).
  - Shared aperture technologies (L/Ku-band).
  - Phase-stable Ku-band and Ka-band receive electronics.
  - High-efficiency, rad-hard Ku-band and Ka-band T/R modules or >10 kW transmitters.
  - Ku-band and Ka-band antenna feeds.
  - Calibration and metrology for accurate baseline knowledge.
  - Real-time onboard radar data processing.
  - Data applications and post-processing techniques.

- Atmospheric radar:
  - Low sidelobe, electronically steerable millimeter wave phased-array antennas and feed networks.
  - Low sidelobe, multi-frequency, multi-beam, shared aperture millimeter wave antennas (Ka-band and W-band).
  - Large (~300 wavelength), lightweight, low sidelobe, millimeter wave (Ka-band and W-band) antenna reflectors and reflectarrays.
  - Lightweight deployable antenna structures and deployment mechanisms.
  - High power (10 kW) Ka-band and W-band transmitters.
  - High-power (>1 kW, duty cycle >5%), wide bandwidth (>10%) Ka-band amplifiers.
- High-efficiency, low-cost, lightweight Ka-band and W-band transmit/receive modules.
- Advanced transmit/receive module concepts such as optically-fed T/R modules.
- Onboard (real-time) pulse compression and image processing hardware and/or software.
- Advanced data processing techniques for real-time rain cell tracking, and rapid 3-D rain mapping.
- Lightweight, low-cost, Ku/Ka band radar system for ground-based rain measurements.
- High power, low sidelobe (better than -30 dB) scanning phase array flat plate antenna (X, Ku, Ka, or W-band) for high altitude operation (65,000 feet).

Sub Topics:
Passive Infrared - Sub Millimeter Topic E1.06

Many NASA future Earth science remote sensing programs and missions require microwave to submillimeter wavelength antennas, transmitters, and receivers operating in the 1-cm to 100-µm wavelength range (or a frequency range of 30 GHz to 3 THz). General requirements for these instruments include large-aperture (possibly deployable) antenna systems with RMS surface accuracy of...

For these systems, advancement is needed in primarily three areas: (1) the development of frequency-stabilized, low phase noise, tunable, fundamental local oscillator sources covering frequencies between 160 GHz and 3 THz; (2) the development of submillimeter-wave mixers in the 300–3000 GHz spectral region with improved sensitivity, stability, and IF bandwidth capability; (3) the development of higher-frequency and higher-output-power MMIC circuits.

Specific innovations or demonstrations are required in the following areas:

- Heterodyne receiver system integration at the circuit and/or chip level is needed to extend MMIC capability into the submillimeter regime. MMIC amplifier development for both power amplifiers and low noise amplifiers at frequencies up to several hundred GHz is solicited. Integration of a local oscillator multiplier chain, mixer, and intermediate frequency amplifier is one example. There is also a specific need to demonstrate array radiometer systems using MMIC radiometers from 60 GHz, to approximately 500 GHz.

- Solid-state, phase-lockable local-oscillator sources with flight-qualifiable design approaches are needed with >10 mW output power at 200 GHz and >100 µW at 1 THz; source line widths should be
- Stable local-oscillator sources are needed for heterodyne receiver system laboratory testing and development.

- Multi-channel spectrometers that analyze intermediate frequency signal bandwidths as large as 10 GHz with a frequency resolution of
- Compact and reliable millimeter and submillimeter imaging instrumentation that produces images simultaneously in multiple spectral bands.

- Schottky mixers with high sensitivity at T = 100 K and above.
- Low noise superconducting HEB mixers and SIS mixers.
- Receivers using planar diode or alternative reliable local oscillator technologies in the 300–3000 GHz
spectrum.

- Lightweight and compact radiometer calibration references covering 100–800 GHz frequency range.
- Lightweight, field portable, compact radiometer calibration references covering frequencies up to 200 GHz. The reference must be temperature stable to within 1 K with a minimum of three temperature settings between 250 and 350 K.
- Low cost special purpose ground-based receivers to detect signals radiated from active satellites that are in orbit, for estimating rain rate, water vapor, and cloud liquid water.
- Calibrated radiometer systems that can achieve accuracy and stability of 0.1 K.
- Astrophysics receiver-detector technology proposals are also solicited, specifically under topic S2.01, Sensors and Detectors for Astrophysics.

Sub Topics:
Thermal Control for Instruments Topic E1.07

Future instruments and platforms for NASA's Earth Science Enterprises will require increasingly sophisticated thermal control technology.

1. Instrument optical alignment needs, lasers, and detectors require tight temperature control, often to better than +/- 1°C.
2. Heat flux levels from lasers and other high power devices are increasing, with some projected to go as high as 100 W/cm².
3. Cryogenic applications are becoming more common. Large, distributed structures, such as mirrors and antennae, will require creative techniques to integrate thermal control functions and minimize weight.
4. The push for miniaturization also drives the need for new thermal technologies towards the micro-electromechanical system (MEMS) level.
5. The drive towards ‘off-the-shelf’ commercial spacecraft, and reconfigurable spacecraft presents engineering challenges for instruments, which must become more self-sufficient.

Innovative proposals for thermal control technologies are sought in the following areas:

- Miniaturized heat transport devices, especially those suitable for cooling small sensors, devices, and electronics.
- Highly reliable, miniaturized Loop Heat Pipes and Capillary Pumped Loops that allow multiple heat load sources and multiple sinks.
- Advanced thermoelectric coolers capable of providing cooling at ambient and cryogenic temperatures.
- Inexpensive passive radiative coolers for low Earth orbit.
- Technologies for cooling very high flux (>100 W/cm^2) heat sources, including spray and jet impingement cooling.

- Advanced thermal control coatings, such as variable emittance surfaces and coatings with a high emissivity at ambient and cryogenic temperatures.

- High conductivity materials to:
  - Minimize temperature gradients, especially for optical benches and structures,
  - Provide jitter isolation links between cryocoolers and sensors, and
  - Provide high efficiency light-weight radiators.

- Advanced analytical techniques for thermal modeling, focusing on techniques that can be easily integrated into existing codes.

- Thermal control systems that actively maintain optical alignment for very large structures at both ambient and cryogenic temperatures.

- Single and two-phase pumped fluid loop systems, which accommodate multiple heat sources and sinks.

- Long life, lightweight pumps for single and two-phase fluid loop systems.

- Efficient, lightweight vapor compression systems for cooling up to 2 kW.

Sub Topics:
Guidance, Navigation and Control Topic E2.01

Future ES architectures will include platforms of varying size and complexity in a number of mission trajectories and orbits. These platforms will include spacecraft, sounding rockets, balloons, and Unmanned Aerial Vehicles (UAVs). Advanced Guidance Navigation and Control (GN&C) technology is required for these platforms to address high performance and reliability requirements while simultaneously satisfying low power, mass, and volume resource constraints. A vigorous effort is needed to develop guidance, navigation and control methodologies, algorithms, and sensor–actuator technologies to enable revolutionary Earth science missions. Of particular interest are highly innovative GN&C technology proposals directed towards enabling ES investigators to exploit new vantage points, develop new sensing strategies, and implement new system-level observational concepts that promote agility, adaptability, evolvability, scalability, and affordability. Novel approaches for the autonomous control of distributed ES spacecraft and/or the management of large fleets of heterogeneous and/or homogeneous ES assets are desired. Specific areas of research include:

**GN&C System Technologies**

Innovative GN&C solutions for ES instrument pointing and stabilization. Advanced GN&C solutions for the Microsat attitude determination and control problem. Of special interest are low cost (at high production volumes) and highly
integrated Microsat GN&C subsystems suitable for enabling both spin stabilized and three-axis stabilized Microsats. GN&C proposals that exploit and combine recent advances in miniature spacecraft subsystem architectures, spacecraft attitude determination and control theory, advanced electro-mechanical packaging, MEMS technology, ultra-low power microelectronics are encouraged. Proposals of special interest are ones that address the technologies needed to implement closed-loop spacecraft control system architectures which provide the “Drag-Free” precision orbit determination and maintenance capabilities needed for future ES Low Earth Orbit (LEO) formation-flying applications. Technology solutions are encouraged that employ Drag-Free sensors (similar to accelerometers), high specific impulse (Isp) thrusters, and low-cost processors with appropriate closed-loop filtering and control algorithms to implement a complete Drag-Free spacecraft control system module.

Vision-based GN&C system concepts, subsystems, hardware components, and supporting algorithms/flight software. Applications of interest are of high performance video image processing technology to provide alternative solutions to challenging GN&C problems such as spacecraft relative range and attitude determination while in close formation and/or during proximity operations.

Advanced GN&C solutions for balloon-borne stratospheric science payloads, including sub-arc second pointing control, sub-arcsecond attitude knowledge determination and trajectory guidance for individual balloon-borne payloads. Innovative techniques are of interest for modeling, simulating, and analyzing the inherent dynamics and control of balloon-borne payloads. Also of interest are innovative concepts, strategies, techniques, and methods for modeling, simulating, and analyzing formations, constellations, and/or networks of multiple balloon-borne stratospheric science payloads.

**GN&C Sensors and Actuators**

Advanced sensors and actuators with enhanced capabilities and performance, as well as reduced cost, mass, power, volume, and reduced complexity for all spacecraft GN&C system elements. Emphasis is placed on improved stability, accuracy, and noise performance. Nontraditional multifunctional sensor/actuator technology proposals are of particular interest.

Innovations in Global Positioning System (GPS) receiver hardware and algorithms that use GPS code and carrier signals to provide spacecraft navigation, attitude, and time. Of particular interest are GPS-based navigation techniques that may employ Wide Area Augmentation System (WAAS) corrections.

Novel approaches to autonomous sensing and navigation of multiple distributed space platforms. Of particular interest are specialized sensors and measurement systems for formation sensing and navigations functions.

Sub Topics:
Command and Data Handling Topic E2.02

Advancing science with reduced levels of mission funding, shorter mission development schedules and reduced availability of flight electronic components creates new requirements for spacecraft Command and Data Handling (C&DH) systems. There are specific areas for which proposals are being sought.
Onboard Processing

- General purpose data processing: higher levels of spacecraft autonomy require higher levels of general purpose CISC (Complex Instruction Set Computer) and RISC (Reduced Instruction Set Computer) processing with fault tolerance and error correction (system and application).

- Special purpose data processing: higher levels of automated onboard science data processing to complement the data gathering capabilities of future instruments. Reduce the processed data volume to remain within the limits of spacecraft to Earth communications.

- Reconfigurable computing hardware: achieving pure hardware processing capabilities with the flexibility of reprogrammability to allow different science objectives to be met with the same hardware platform. Development of technologies such as radiation hardened Field Programmable Gate Arrays (FPGAs) and similar components for data communications and processing.

- Low-power electronics: in order to provide higher capabilities on smaller and/or less expensive spacecraft. Electronics that consume less power decrease overall thermal load, and decrease battery size and solar panel size.

Command and Data Transfer

- Subsystem data transfer: communications between various spacecraft subsystems in order to realize higher autonomy. Development of technologies and architectures that increase the rate of data transfer above 20 Mbits/s are necessary to achieve the self-diagnosis, autonomous control, and science data transfer requirements.

- Intra-system data transfer: communications within the spacecraft subsystem, between cards within a box to replace the conventional passive backplanes.

Protocols and Architectures

- Internet-based protocol modules and extensions that will support seamless connectivity between terrestrial and aerospace platforms by mitigating variable latencies and bit error rates among distributed air and spacecraft to terrestrial gateways.

- Novel methodologies for performing medium to large-scale simulations of space Internet architectures, protocols, and applications.

- Network security technologies to assure integrity and authentication of data from the public Internet to protected space-based networks.

- Ad hoc and innovative, lightweight networking protocols to support spacecraft constellation, formation flying, satellite clusters, proximity, and sensor based networks.
A technology is desired to provide a software programmable analog component. This “programmable analog array” would consist of basic elements including filters, amplifiers, couplers and mixers whose frequency of operation, bandwidths and gains can be changed by software command. The signal flow in the component itself will be reconfigurable by software and firmware loads in a manner similar to that of Field Programmable Gate-Array (FPGA) digital devices. Desired components will be capable of operating in the S- and Ku-bands. Maximum flexibility in configuration is also desired with the goal of producing a generic “sea of elements” rather than an integrated system on a chip.

Low-Overhead Software-Defined Radio (SDR) Implementations

NASA is interested in SDR architectures and implementations that optimize flexibility and interoperability between different SDRs, but are based on extremely efficient core architectures and low processor overheads. Algorithms that can be implemented in current space flight capable hardware are especially encouraged.

RF Component Technology

A wide variety of general advances in component, material and manufacturing technologies are required to support future NASA mission requirements. These technologies include innovative approaches to enable higher frequency, miniaturized, power efficient Traveling Wave Tube Amplifiers (TWTAs) operating at millimeter wave frequencies and at data rates of 10 Gbps or higher. Wide band-gap semiconductor (WBGS) based devices for high power, high efficiency microwave and millimeter wave solid-state power amplifiers (SSPAs), as well as low noise amplifiers in the same ranges. MEMS-based RF switches are needed for use in reconfigurable antennas, phase shifters, amplifiers, oscillators and in-flight reconfigurable filters. Frequencies of interest include S-, Ku-, Ka-, and V-band (60 GHz).

Bandwidth Efficient Channel Coding

To support extremely high data rates in a limited frequency spectrum, bandwidth-efficient channel coding is required. NASA is interested in algorithms that provide lossless data compression and efficient error correction at data rates greater than 1 Gbps for links between Earth orbit and Earth ground stations.

RF Materials and Structures

NASA is interested in materials that can be efficiently manufactured and effectively used in the construction and deployment of thin-film based RF antenna systems. Methods for deploying very large, lightweight, aperture structures on-orbit are needed. Inflatable structures, as well as “shape memory” alloy-based implementations, capable of withstanding launch and deployment forces are encouraged.

Sub Topics:
Onboard Propulsion Topic E2.04

This subtopic seeks technologies that will significantly increase capabilities and reduce costs for Earth science spacecraft. Propulsion functions include orbit insertion, orbit maintenance, constellation maintenance, precision positioning, in-space maneuvering, and de-orbit. Propulsion technologies are sought that will provide platforms with larger scientific payloads, longer-life missions, and increased operational flexibility during missions. To accomplish these goals, innovations are needed in low-thrust chemical and low-power electric propulsion technology, including...
thruster components, advanced propellants, power processing units, and feed system components. Of particular interest are innovations in propulsion technology that lead to smaller-sized, integrated, autonomous spacecraft. The following specific areas are of interest:

**Miniature and Precision Propulsion**

Propulsion technologies for miniature (less than 10 kg) spacecraft and for high-precision (impulse bit

**Thruster Technology**

Electric and chemical propulsion technologies that provide increased capability (mass and volume) and/or flexibility (duty cycle and life) for small, power-limited spacecraft, including:

- Electrostatic and electromagnetic propulsion technologies;
- High-performance (specific impulse > 250 s), high-density monopropellant thruster technology;
- High-performance (specific impulse > 350 s), space storable bipropellant thruster technology; and
- Propellant gelation technology.

**Propulsion System Components**

Innovative electric and chemical propulsion system components for small spacecraft are sought including:

- Materials compatible with high-temperature, oxidizing, and reactive environments;
- Components for fluid isolation, pressure and mass flow regulation, relief quick disconnect, and flow control;
- Technologies for metering, injection, and ignition of fluids in combustion devices;
- Gaseous storage and pressurization system; and
- Components for xenon storage and flow control.

**Sub Topics:**

**Energy Storage Technologies Topic E2.05**

Advanced energy storage technologies are required for Earth science observation platforms. These platforms are defined as host systems that include traditional spacecraft, airborne platforms, such as piloted and unpiloted aircraft and balloons, terrestrial platforms, micro-spacecraft, and surface penetrators.

The energy storage technologies solicited include both primary and secondary batteries, primary and regenerative fuel cells, and flywheels. The desired technology advances common to all of the storage devices of interest include the following elements:
Improvements in energy density and specific energy;

Improvement in cycle life, run time, and calendar life;

Performance over a wide temperature range;

Reduction in device size, to the micro-scale;

Reduction in system complexity; and

Integration into, and with, other spacecraft structures.

A vigorous effort is needed to develop energy storage technologies that will enable the revolutionary ES missions.

Specific technology advances that contribute to achieving the following performance goals are of interest.

### Advanced Battery Technology

- Specific energy: >150 Wh/kg for secondary batteries >400 Wh/kg for primary batteries
- Low-Earth-Orbit (LEO) cycle life >60,000 cycles for secondary batteries
- Calendar life >15 years
- Operating temperature range -100°C to 100°C
  - Systems capable of delivering 30–50% of the capacity available at ambient temperatures at temperatures as low as -100°C

Primary and rechargeable lithium-based batteries with advanced anode and cathode materials and advanced liquid and polymer electrolytes are of particular interest. Proposals addressing structural and microbatteries are sought.

### Fuel cell (FC) and Regenerative Fuel Cell (RFC) Technologies

- Specific energy: FC >1500 W/kg, RFC >600 Wh/kg
- Efficiency: FC>70% at 1500 W/kg, RFC >60% at 600 Wh/kg
- Life FC >10,000 hours, RFC > 1500 cycles

Advances to PEM, Direct methanol and solid oxide fuel cell systems are of particular interest.
Flywheel Energy Storage

- Specific energy > 100 Wh/kg
- LEO cycle life > 60,000 cycles

Micro-flywheels with a high number of watt hours per kilogram and highly integrated components are of particular interest.

Sub Topics:

- Energy Conversion for Space Applications Topic E2.06

Earth science observation missions will employ spacecraft, balloons, sounding rockets, surface assets, and piloted and robotic aircraft and marine craft. Advanced power technologies are required for each of these platforms that address issues of size, mass, capacity, reliability, and operational costs. A vigorous effort is needed to develop energy conversion technologies that will enable the revolutionary Earth science missions. Exploiting innovative technological opportunities, developing power systems for adverse environments, and implementing system-wide techniques that promote scalability, adaptability, flexibility, and affordability are characteristic of the technological challenges to be faced and are representative of the type of developments required beyond the current state-of-the-art.

The energy conversion technologies solicited include photovoltaics, Brayton, Rankine, Stirling, and thermophotovoltaic, as well as related technologies such as concentrators and thermal technologies. Specific areas of interest follow.

- Photovoltaic cell and array technologies with significant improvements in efficiencies, cost, radiation resistance, and wide operating conditions are solicited. Potential concepts include rigid arrays, concentrator configurations, and ultra-lightweight array technologies that exploit the properties of lightweight, flexible thin-film photovoltaic cells. Photovoltaic cell and array technologies for extreme environments such as high- or low-temperature operation are solicited. Technologies for electrostatically-clean spacecraft solar arrays are also of interest.

- Future micro-spacecraft require distributed power sources that are integrated with microelectronics devices/instruments. These microelectronic devices/instruments integrate energy conversion and storage into a hybrid structure.

- Thermal power conversion technologies for Earth orbiting spacecraft and/or orbit transfer vehicles are sought.

- Advances may be in solar concentrators (rigid or inflatable, primary or secondary) and receivers to improve specific power and reduce mass.

- Topics of interest in power conversion include heat cycles (Brayton, Rankine, and Stirling), compact heat exchangers, advanced materials and fabrication techniques, and control methods, as they relate to life, reliability and manufacturability.
• Thermal technology areas include heat rejection, composite materials, heat pipes, pumped loop systems, packaging and deployment, including integration with the power conversion technology. Highly integrated systems are sought that combine elements of the above subsystems to show system level benefits.

Sub Topics:
Platform Power Management and Distribution Topic E2.07
Earth science missions employ spacecraft, balloons, sounding rockets, surface assets, aircraft, and marine craft as observation platforms. Advanced technologies are required for the electrical components and systems on these platforms to address the issues of size, mass, efficiency, capacity, durability, and reliability. Advancements are sought in power electronic materials, devices, components, packaging, and coatings.

**Power Electronic Materials and Components**
Advanced magnetic, dielectric, semiconductor, and superconductor materials, devices, and circuits are of interest. Proposals must address improvements in energy density, speed, or efficiency. Candidate devices and applications include transformers, inductors, semiconductor switches and diodes, electrostatic capacitors, current sensors, and cables.

**Power Conversion, Protection, and Distribution**
Technologies that provide significant improvements in mass, size, power quality, reliability, or efficiency in electrical power conversion and protective switchgear components are of interest. Candidate applications include solar array regulators, battery charge and discharge regulators, power conversion, power distribution, and fault protection.

**Environmentally Durable Technologies**
Technologies that enable materials, surfaces, coatings, and components to be durable in a space environment, in atomic oxygen, soft x-ray, electron, proton, ultraviolet radiation, and thermal cycling environments are of interest to NASA. Environmentally durable coatings for radiators and lightweight electromagnetic shielding are sought.

**Electrical Packaging**
Thermal control technologies are sought that are integral to electrical devices with high heat flux capability and advanced electronic packaging technologies which reduce volume and mass or combine electromagnetic shielding with thermal control.
Sub Topics:
Automation and Planning Topic E3.01

The Automation and Planning Subtopic solicits proposals that allow either spacecraft or ground systems to robustly perform complex tasks given high-level goals with minimal human direction. Technology innovations include, but are not limited to: 1) automation and autonomous systems that support high-level command abstraction; 2) efficient and effective techniques for processing large volumes of data (commonly available on the Internet) into useful information; 3) intelligent search of large, distributed data archives, and data discovery through searches of heterogeneous data sets and architecture; and 4) automation of routine, labor intensive tasks that either increase reliability or throughput of current process. Specific areas of interest include the following:

- Search agents that support applications involving the use of NASA data;
- Methods that support the robust production of data products given a set of high-level goals and constraints;
- Autonomous data collection including the coordination of space or airborne platforms while adhering to a set of data collection goals and resource constraints;
- Autonomous data logging devices (software, or hardware and software) supporting a variety of weather and climate sensors, capable of ground-based operation in a wide variety of environmental conditions; such systems would probably be solar powered with accurate time stamping;
- Planning and scheduling methods related to Earth Science Mission objectives;
- System and subsystem health and maintenance, both space- and ground-based;
- Distributed decision making, using multiple agents, and/or mixed autonomous systems;
- Automated software testing;
- Verification and validation of automated systems;
- Automatic software generation and processing algorithms;
- Control of Field Programmable Gate-Arrays (FPGA) to provide real-time products.

Sub Topics:
Distributed Information Systems and Numerical Simulation Topic E3.02

This subtopic seeks advances in tools, techniques, and technologies for distributed information systems and large-scale numerical simulation. The goal of this work is to create an autonomous information and computing environment that enables NASA scientists to work naturally with distributed teams and resources to dramatically reduce total time-to-solution (i.e., time to discovery, understanding, or prediction), vastly increase the feasible scale and complexity of analysis and data assimilation, and greatly accelerate model advancement cycles. Areas of interest follow below.
Distributed Information Systems

- Core services (autonomous software systems) for automated, scalable, and reliable management of distributed, dynamic, and heterogeneous computing, data, and instrument resources. Services of interest (which may be based on Open Grid Service Infrastructure) include those for authentication and security, resource and service discovery, resource scheduling, event monitoring, uniform access to compute and data resources, and efficient and reliable data transfer.

- Higher level services, including those for job management, resource brokering, workflow management, portlet (i.e., application-specific graphical user interface) building, and collaboration.

- Services for management of distributed, heterogeneous information, including replica management, intuitive interfaces, and instantiation on demand or “virtualized data.” These services would be used, for example, to access and manipulate NASA’s wealth of geospatial and remote sensing data.

- Science portals for cross-disciplinary discovery, understanding, and prediction, encapsulating services for single sign-on access, semantic resource and service discovery, workflow composition and management, remote collaboration, and results analysis and visualization.

- Tools for rapidly porting and hosting science applications in a distributed environment. These applications were written for an integrated, or workstation, environment using standard programming languages or tools such as Matlab, Interactive Data Language (IDL), or Mathematica.

Large-Scale Numerical Simulation

- Tools for automating large-scale modeling, simulation, and analysis, including those for managing computational ensembles, performing model-optimization studies, interactive computational steering, and maintaining progress in long-running computations in spite of unreliable computing, data, and network resources.

- Tools for computer system performance modeling, prediction, and optimization for real applications.

- Techniques and tools for application parallelization and performance analysis.

- Tools for effective load balancing, and high reliability, availability, and serviceability (RAS) in commodity clusters and other large-scale computing systems.

- Novel supercomputing approaches using FPGAs, graphics processors, and other novel architectures and technologies.

Sub Topics:

Geospatial Data Analysis Processing and Visualization Technologies Topic E3.03

Proposals are sought for the development of advanced technologies in support of scientific, commercial, and educational application of ESE and other remote sensing data. Focus areas are to provide tools for processing, analysis, interpretation, and visualization of remotely sensed data sets. ESE benchmarks practical uses of NASA-sponsored observations from remote sensing systems and predictions from scientific research and modeling. Specific interest exists in the development of technologies contributing to decision support systems, and model development and operation. For more information on decision support models under evaluation, please visit [http://earth.nasa.gov/eseapps/index.html](http://earth.nasa.gov/eseapps/index.html) [1]. Areas of specific interest include the following:
• Unique, innovative data reduction, rapid analysis and data exploitation methodologies and algorithms of information from remotely sensed data sets, e.g., automated feature extraction, data mining, etc.;

• Algorithms and approaches to enable the efficient production of data products from active imaging systems, e.g., multipoint data resampling, digital elevation model creation, etc.;

• Data merge and fusion software for efficient production and real-time delivery of digital products of ESE Mission and other remote sensing data sets, e.g., weather observation and land use and land cover data sets;

• Innovative approaches for incorporation of GPS data into in situ data collection operations with dynamic links to spatial databases including environmental models

• Image enhancement algorithms for improving spatial, spectral, and geometric image attributes;

• Innovative approaches for the querying and assimilation of application-specific datasets from disparate and distributed databases from government, academic and commercial sources into a common framework for data analysis

• Innovative approaches for querying of application-specific data sets from disparate, distributed databases in government, academic, and commercial data warehouses into a common framework for data analysis; and

• Innovative visualization technologies contributing to the analysis of data through the display and visualization of some or all of the above data types including providing the linkages and user interface between the cartographic model and attribute databases.

Sub Topics:
Data Management and Visualization Topic E3.04
This subtopic focuses on innovative approaches to managing and visualizing large collections of Earth science data in a highly distributed and networked environment.

• Develop technologies that support long term data management, storage, search, and retrieval of very large, distributed, geospatial Earth science data sets, including the development of object based storage devices, file systems that promote long term data maintenance and recovery from user errors, and global compression techniques that optimize data backup operations.

• Develop techniques to manage and locate data in a distributed metadata catalog environment and provide tools to create, use, and then tear down wide area high speed Storage Area Network (SAN) access to remote data sets.

• Develop tools and techniques that enable high bandwidth scientific collaboration in a distributed environment, and allow data viewing, real-time data browse, and general purpose rendering of multivariate geospatial scientific data sets using georectification, data overlays, data reduction, and data encoding across widely differing data types and formats.

• Design and implement 3-D virtual reality environments for scientific data visualization that will enable users
to ‘fly’ through the data space to locate specific areas of interest, and make use of novel 3-D presentation techniques which minimize or eliminate the need for special user devices such as goggles or helmets.

Sub Topics:
On-Board Science for Decisions and Actions Topic E3.05

Current sensors can collect more data than is possible to transmit to the ground for analysis. One solution is to incorporate intelligence in the sensor or platform to prioritize or summarize the data and send down high priority or synoptic data. In the future, a sensor-web capability will demand this remote onboard autonomy and intelligence about the kind and content of data being collected to support rapid decision-making and tasking. This subtopic is interested in developing new methods to autonomously understand ES data in support of making rapid decisions and taking actions under two themes:

Onboard Satellite Data Processing and Intelligent Sensor Control

Software technologies that support the configuration of sensors, satellites, and sensor webs of space-based resources. Examples include capabilities that allow the reconfiguration or retargeting of sensors in response to user demand or significant events. Also included in this category is onboard processing of sensor data through the use of processing architectures and reconfigurable computing environments, as well as technologies that support or enable the generation of data products for direct distribution to users.

Onboard Satellite Data Organization, Analysis, and Storage

Software technologies that support the storage, handling, analysis, and interpretation of data. Examples include innovations in the enhancement, classification, or feature extraction processes. Also included are data mining, intelligent agent applications for tracking data, distributed heterogeneous frameworks (including open system interfaces and protocols), and data and/or metadata structures to support autonomous data handling, as well as compaction (lossless) or compression of data for storage and transmission.

Sub Topics:
Innovative Tools and Techniques Supporting the Practical Uses of Earth Science Observations Topic E4.01

Technical innovation and unique approaches are solicited for the development of new technologies and technical methods that make Earth science observations both useful and easy to use by practitioners. This subtopic seeks proposals that support the development of operational decision support tools that produce information for management or policy decision makers. Proposed applications must use NASA Earth Observations (see http://gaia.hq.nasa.gov/ese_missions/ [2]) Other remote sensing data and geospatial technologies may also be employed in the solution.
This subtopic focuses on the systems engineering aspect of application development rather than fundamental research. Offerors are, therefore, expected to have the documented proof-of-concept project in hand. Topics of current interest to the Earth Science Applications Directorate may be found at [http://www.esa.ssc.nasa.gov](http://www.esa.ssc.nasa.gov). Innovation in processing techniques, include, but are not limited to, automated feature extraction, data fusion, and parallel and distributed computing which are desired for the purpose of facilitating the use of Earth science data by the nonspecialist. Ease of use, fault tolerance, and statistical rigor and robustness are required for confidence in the product by the nonspecialist end user.

Promotion of interoperability is also a goal of the subtopic, so Federal data standards, communication standards, Open Geographic Information Systems (GIS) standards, and industry-standard tools and techniques will be strongly favored over proprietary ‘black-box’ solutions. Endorsement by the end user of both system requirements and the proposed solution concept is desirable. While the proposed application system may be specific to a particular end user or market, techniques and tools that have broad potential applicability will be favored. An objective assessment of market value or benefit/cost will help reviewers assess the relative potential of proposed projects.

Sub Topics:
- Advanced Educational Processes and Tools Topic E4.02

This subtopic focuses on innovation in effective applications related to classroom- or museum-ready software tools for display and/or analysis of Earth science information for learners in both formal and informal settings, and tools for organization and dissemination of NASA's Earth science educational materials to a wide array of educational audiences. The Earth science educational program covers a wide range of audiences from students to adults in both classroom settings, such as public schools or continuing education venues, to all matter of informal learning settings such as radio, television, museums, parks, scouts, and the Internet. In these venues, the learning focuses on the scientific discoveries by the ESE, the technology innovations and the applied use of these discoveries and technologies for improved decision making by all.

The areas of interest (described below) cross-cut the three programmatic areas within the ESE program (formal, informal, and professional development) and hence, are anticipated to have utility in at least two of these areas and most likely in all three areas.

The first area of interest focuses on innovation in the application of digital library technologies to educational materials and audiences. NASA's Earth Science Education Program currently collaborates with the Digital Library for Earth System Education (DLESE). The successful proposal must be able to integrate with, or be integrated into, existing educational digital library efforts within NASA and/or make contributions to DLESE. These proposals will advance the use and usability of globally distributed, networked information resources, and encourage existing and new communities to focus on innovative applications areas. Collaboration between Earth scientists, formal or informal education community professionals, and computer scientists is required for these proposals to demonstrate useful results. Areas of interest include:

- Extend the current Joined Digital Library (JOIN) effort by developing additional Jini applications. (JOIN is a
collection of tools based on Sun's Jini technology used to implement efficient, decentralized, and distributed computing systems and follows "the network is the computer" philosophy.

- Development of formal and informal education audience-specific interfaces (e.g., specific interfaces for students, park interpreters, TV producers, curriculum developers, etc.).

- Development of interfaces to promote diversity within educational audiences (e.g., age, ethnicity, cultural, urban/rural, etc.).

- Development of accessibility tools for disabled users to interact and search digital libraries.

- Development and access to educational materials including new resources for science, mathematics, and engineering education at all levels.

- Development of interoperability tools to integrate dissimilar library archives.

- Development of tools to administer and manage end-user expectations and satisfaction.

- Develop applications that enhance the general functionality of existing digital libraries by providing new general-purpose tools for archive management, metadata ingestion, intelligent search, and retrieval.

- Tools to support online community interaction, which could include new means for gathering, interacting, and communicating with other library users.

The second area of interest focuses on innovation in effective software and related development techniques, and in highly practical methods for maintaining and disseminating software for use by educational audiences engaged in teaching or learning about Earth science. The specific areas of greatest interest are highly-portable, classroom-ready software for analysis, visualization, and processing of Earth science satellite data, and methods to provide long-term support and viability for educational software. Collaboration between Earth scientists, educators, computer scientists, and "business" model experts is required for these proposals to demonstrate useful results. Areas of interest include:

- Extend the current Image 2000 effort by developing additional plug-in applications and modifying core software if necessary. Image 2000 is a Java/Java Advanced Imaging (JAI)-based image processing package being developed at GSFC.

- User-friendly, extensible, Earth science satellite image processing software for multiple operating systems, for educational use in K–12, undergraduate and continuing education venues.

- Techniques and software for integrating vector and raster data for the visualization and analysis of geospatial Earth science data.

- Tutorials geared toward the use of image processing software for visualization and analysis of Earth science related satellite imagery.

- Infrastructure and startup of an Internet based user-supported support and development network, in the spirit of "Open-Source," to ensure continued maintenance and development of Earth science satellite image processing software and tutorials for educational audiences.

Sub Topics:
Technical innovation is solicited for the development of wireless technologies for field personnel and robotic platforms to send and receive digital and analog data from sensors such as photography cameras, spectrometers, infrared and thermal scanners, and other sensor systems to collection hubs. The intent of this new innovation is to rapidly, in real time, ingest data sequentially from a variety of input sensors, provide initial field verification of data, and distribute the data to various nodes and servers at collection, processing, and decision hub sites. Data distribution should utilize state-of-the-art wireless, satellite, land carriers, and local area communication networks. The technologies' operating system should be compatible with commonly available systems. The operating system should not be proprietary to the offeror. The innovation should include biometric capability for password protection and relational tracking of data to the field personnel inputting the data and/or sensors and platforms sending information. The innovation should contain technologies that recognize multiple personnel and other sources (robotics) so that several personnel and platforms can use the same unit in the field. Biometric identification can be fingerprint, retina scans, facial, or other methods. The innovation should include geospatial technologies to use digital imagery and have Global Positioning System (GPS) location capabilities. The innovation should be able to display with sufficient size and resolution the rendering of vector and raster data and other sensor data for easy understanding. The field capability of the innovation must be fully integrated end to end with computing capabilities that range from mobile computers to servers at distant locations. Field personnel and robotic platforms providing information and support to science investigations, resource managers, and community planners will use the innovative wireless technology. First responders to natural, human-made disasters and emergencies will also be users of this innovation.

Sub Topics: