Attachment A

AOS BACKGROUND

The Atmosphere Observing System (AOS) was established by the NASA Science Mission Directorate (SMD) Earth Science Division (ESD) to fulfill the science needs proffered in the 2017 Earth Science Decadal Survey (DS) for the combined Designated Observables: Aerosols and Clouds, Convection and Precipitation (ACCP). The AOS mission passed the Key Decision Point (KDP)-A on January 13, 2023, and was authorized to enter Phase A. Note, while the project has entered Phase A, the mission concept is still under formulation study and subject to change. The mission has been directed to pursue an industry-led Doppler radar for the Polar orbit. The respondent may find information on the mission, including architecture, configuration and Science and Applications Traceability Matrix at the AOS website: https://aos.gsfc.nasa.gov/

AOS will make measurements of the aerosol and cloud microphysical properties as well as the vertical air velocity in convection, aerosol distribution, and precipitation to understand the processes that drive the Earth's atmosphere. By employing a multi-instrument, multi-satellite architecture, AOS will be able to cover the relevant temporal and spatial scales, thereby transforming our understanding of this critical part of the Earth System. Through this RFI, the AOS team seeks information on cloud-profiling capable Doppler radar approaches to further refine the payload assignments, spacecraft needs, and mission concept of operations necessary to meet the science objectives.

The current AOS mission concept is illustrated in Figure 1. This architecture encompasses flight assets in two orbit planes: (1) Polar: Sun-synchronous orbit, 450 km, and 1330 ascending node and (2) Inclined: Nominally 55-to-65-degree Inclination, 407 km. Within the AOS constellation, Inclined assets will be launched first to achieve earliest possible science with instruments that will make advancements in the understanding of precipitation, convective storm dynamics, and aerosol and cloud properties on sub-daily to minute time scales. The assets in Polar orbital plane will follow with measurements targeting the seasonal, global-scale microphysical properties of clouds and aerosol and their linkage to atmospheric radiation and longer-term climate change. The constellation targets understanding the dynamics of cloud systems and the transformations and movement of atmospheric particles in the Earth's atmosphere that drive weather and climate change.

While the concept illustrated in Figure 1 accurately reflects the AOS intent, the number of spacecraft in the two orbit planes and the specific instrumentation assignment on the spacecraft remains under study during the Phase A period.

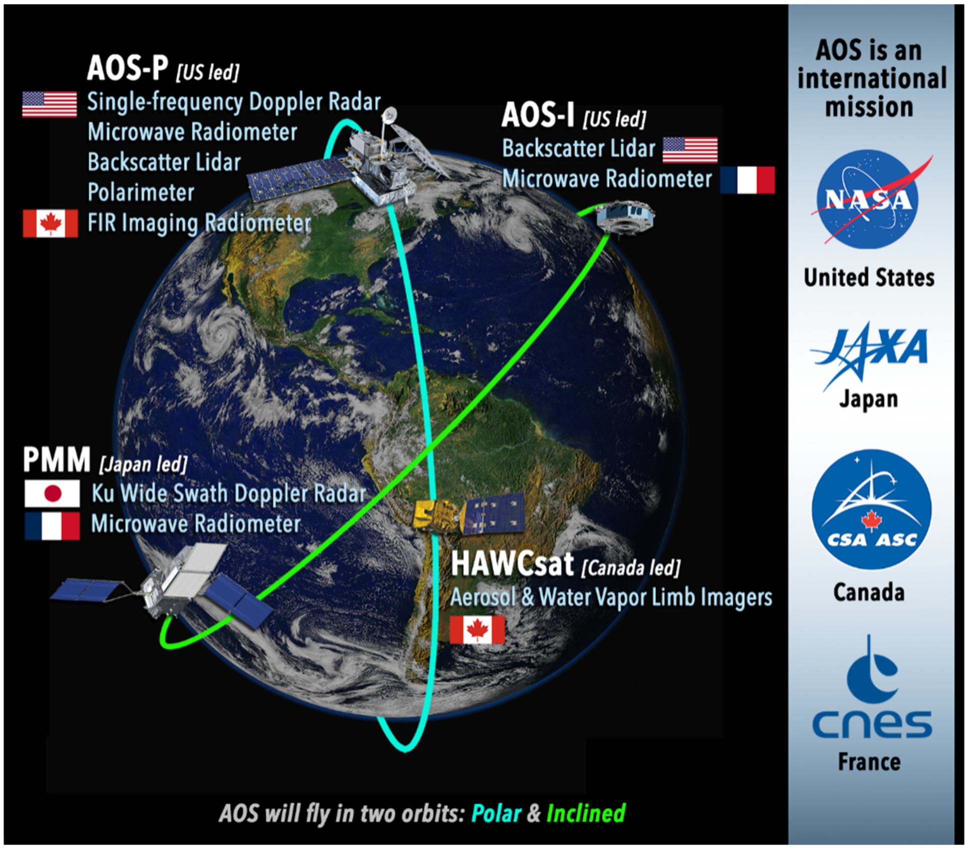

Figure 1 Preferred AOS Architecture Concept

CLOUD-CAPABLE RADAR PERFORMANCE

Radars provide vital information on particles in the Earth's atmosphere. These sensors view backscattered energy from hydrometeors, providing data on clouds, precipitation, and atmospheric motion. Spaceborne atmospheric radars have been used to great effect in the Tropical Rainfall Measurement Mission (TRMM), CloudSat, and Global Precipitation Measurement (GPM) missions.

The NASA study for the combined Aerosols and Clouds, Convection, and Precipitation (ACCP) Designated Observables solicited, through an initial request for information (RFI), hardware concepts for assessing potential architectures to address the science and application objectives defined by ACCP. Based on the responses, feasible accommodations, and the DS guidance, multi-frequency radars containing subsets of Ku-band (nominally 13.6 GHz), Ka-band (nominally 35.55 GHz), and W-band (nominally 94.15 GHz) were indicated by the study as core sensors. The AOS project architecture targets two radars, one for each mission orbit (Polar and Inclined). The target radar for the Inclined Orbit is a wide-swath Ku-band precipitation-sensing radar with Doppler capability at Nadir to be provided by JAXA. The target radar for the Polar Orbit will be a highly sensitive nadir-pointing Doppler radar capable of profiling most clouds. Importantly, AOS targets Doppler capabilities, which have not yet been demonstrated in space.

The Polar Orbit radar (the subject of this RFI) should be a highly sensitive instrument that provides equivalent reflectivity factor and Doppler velocity. Table 1 gives a summary of baseline performance. Minimum capabilities desired for the Polar Radar are shown in Table 2 with changes from the baseline values shown in bold font for clarity. Requirements will not be finalized until the System Requirements Review (SRR) in mid-2024. Brief descriptions and discussions of the fields in Table 1 and Table 2 are provided in the following "DEFINITIONS AND DISCUSSION" section. Responses will be reviewed even if the proposed performance doesn't fully meet the requirements in Table 2.

Table 1: Target Baseline Radar Capabilities for the Polar Orbit

Radar Observable	Altitude	Sensitivity †	Uncertainty §	Horizontal Resolution (sampling)	Vertical Resolution	Swath *
Equivalent Reflectivity Factor (dBZe)	6 to 20 km	-24 dBZe	1.5 dB	2 km (1 km)	500 m	10 km
	2.5 to 6 km	-20 dBZe			500 m	
	1 to 2.5 km	-15 dBZe			300 m	
	0.5 to 1 km	-5 dBZe			300 m	
Doppler Velocity (m/s)	6 to 20 km	Reflectivity SNR>0 dB	0.5 m/s	2 km (1 km)	500 m	Nadir
	2.5 to 6 km				500 m	
	1 to 2.5 km				300 m	
	0.5 to 1 km				300 m	

† Sensitivity targets are defined only for the Nadir beam. Doppler velocity observable uncertainty is defined where the reflectivity signal is significantly above the minimum detectable sensitivity (at approximately 0 dB single-pulse SNR).
§ The uncertainty of the Equivalent Reflectivity Factor is defined at high-SNR. The Doppler Velocity uncertainty includes random noise and non-uniform beam filling. See additional discussion in the DEFINITIONS AND DISCUSSION section.
** A narrow swath of equivalent reflectivity factor is desired to provide horizontal context, enabling precipitation core size estimates and allowing discrimination between convective/stratiform precipitation type.*

*Table 2: Target Minimum Capabilities for the Polar Orbit (changes from baseline are shown in **bold font**)*

Radar Observable	Altitude	Sensitivity †	Uncertainty §	Horizontal Resolution (sampling)	Vertical Resolution	Swath
Equivalent Reflectivity Factor (dBZe)	6 to 20 km	**-20 dBZe**	1.5 dB	**2.5 km (1.25 km)**	500 m	**Nadir**
	2.5 to 6 km	**-13 dBZe**			500 m	
	1 to 2.5 km	**-8 dBZe**			300 m	
	0.5 to 1 km	**+2 dBZe**			300 m	
Doppler Velocity (m/s)	6 to 20 km	Reflectivity SNR>0 dB	**1 m/s**	**2.5 km (1.25 km)**	500 m	Nadir
	2.5 to 6 km				500 m	
	1 to 2.5 km				300 m	
	0.5 to 1 km				300 m	

† Sensitivity targets are defined only for the Nadir beam. Doppler velocity observable uncertainty is defined where the reflectivity signal is significantly above the minimum detectable sensitivity (at approximately 0 dB single-pulse SNR).
§ The uncertainty of the Equivalent Reflectivity Factor is defined at high-SNR. The Doppler Velocity uncertainty includes random noise and non-uniform beam filling. See additional discussion in the DEFINITIONS AND DISCUSSION section.

Potential approaches for achieving cloud-profiling sensitivity identified by the AOS project team include either W-band or Ka-band instrument architectures, but RFI respondents are encouraged to provide potentially relevant information even if it does not fall within one of these concepts. For example, including a second, lower sensitivity wavelength as an option is of interest. Responses are also welcome even if they only address a major subsystem.

<u>Potential W-band architecture</u>

One approach to achieving the target performance is a W-band radar with one or more large, fixed antennas. Doppler could be achieved by using a sufficiently large antenna and estimating the along-track reflectivity gradient to mitigate non-uniform beam filling (NUBF) effects (Kollias et al. 2014; McLinden et al. 2021), or by utilizing the displaced phase center (DPCA) approach with two antennas (Durden et al. 2007, Tanelli et al. 2016). Transmitted peak power would need to be on the order of kilowatts for radars utilizing conventional pulsed continuous-wave (CW) waveforms or one hundred watts for radars utilizing pulse compression and/or frequency diversity (McLinden et al. 2013).

<u>Potential Ka-band architecture</u>

A second approach to achieving the target performance is a Ka-band radar with a single very large deployable antenna. Doppler performance might be achieved by estimating the along-track reflectivity gradient to mitigate NUBF effects. Peak transmit power might be hundreds of watts for a radar utilizing pulse compression and/or frequency diversity, or kilowatts for a radar utilizing CW waveforms.

DEFINITIONS AND DISCUSSION

Altitude is the height above sea level of the observation. The performance targets for sensitivity and vertical resolution vary with altitude at the given levels, but respondents are welcome to provide more detailed or differing information relating instrument performance to the altitude of observations. Improved sensitivity at lower altitudes would provide value if possible without significant cost impact.

Doppler Velocity is defined as the vertical hydrometeor velocity as measured by a nadir-pointing radar. The uncertainty of the Doppler velocity is the combination (as applicable) of spectrum width including that caused by spacecraft motion (Kollias et al. 2014), non-uniform beam filling (Tanelli et al. 2002, Schutgens 2008, Kollias et al. 2018, Sy et al. 2013, Sy et al. 2014), system noise, and other potential factors.

As Doppler velocity observations have not been demonstrated in space, respondents are encouraged to discuss the approach to overcoming the challenges associated with this observable, including large antenna sizes, along-track reflectivity gradient estimation (Kollias et al. 2014; McLinden et al. 2021), and potentially displaced phase center antenna (DPCA) techniques (Durden et al. 2007; Tanelli et al. 2016).

Equivalent Reflectivity Factor in units of dBZe is a measure of the volume backscatter from hydrometeors. The equivalent reflectivity factor is defined as in Smith (1984) and Doviak and Zrnic (1993) as

$$\mathrm{dBZe} = 10\log_{10}\left(\frac{\eta\lambda^4 10^{18}}{\pi^5|K_w|^2}\right), \qquad \log_{10}\left[\frac{\mathrm{mm}^6}{\mathrm{m}^3}\right] \tag{1}$$

where η is the radar cross section per unit volume and λ is the wavelength. The term $|K_w|^2$ is defined by convention as 0.93 at Ku-band and Ka-band, and as 0.75 at W-band (Stephens et al. 2008).

Horizontal Resolution is defined for the AOS radar as the major axis of the ellipse defined by the -6 dB contour of the horizontal weighting function (two-way antenna pattern) projected on the Earth's surface after pulse integration. The horizontal resolution as defined here is only required at nadir in the case of a scanning radar. Note that the horizontal resolution (width of the weighting function) is defined separately from the horizontal sampling (radar observable record density) and that neighboring samples need not be independent (McLinden et al. 2015).

Horizontal Sampling is defined as the horizontal space between neighboring records of radar observables and is targeted at two samples per horizontal resolution to maintain near-Nyquist sampling of the observable fields. Due to the increased density of this approach compared to contiguous sampling (non-overlapping footprints), neighboring samples need not be independent and running averages of pulses are expected after ground processing.

Sensitivity is defined at the estimated received power equal to the standard deviation of the thermal noise after averaging multiple pulses to the target resolution in horizontal distance and subtracting the mean noise. The sensitivity target is specified only for the nadir beam of a multi-beam radar. Non-nadir beams may have reduced sensitivity to provide for additional averaging and sensitivity at Nadir.

In the case that sensitivity is limited by **pulse compression** range sidelobes from surface clutter, please provide the estimated range sidelobe levels and what surface normalized radar cross section (NRCS) would cause the sidelobe level to meet the noise-equivalent thresholding levels. For reference, Battaglia (2017) provides a summary of wind speed and surface NRCS over ocean and Tanelli et al. (2008) provides surface NRCS measurements from CloudSat over a variety of surface types. If the radar utilizes pulse compression, respondents are encouraged to provide information on the time-bandwidth product and assumed phase noise.

To compare responses and instrument performance, the AOS project requests respondents provide both the single-pulse noise-equivalent (0 dB SNR) sensitivity and the sensitivity after pulse averaging.

Swath is defined as the cross-track distance of the outermost beam centers of a multi-beam radar. While a narrow swath at one frequency was identified in the SATM as an enhancement, it is highly desired to provide necessary horizontal context (stratiform/convection discrimination) and convective core size estimates. Cross-track sampling of ½ the beam footprint is desired, but contiguous cross-track sampling may be acceptable.

Vertical Resolution is defined as the distance between the -6 dB edges of the range weighting function of the radar pulse after receiver filtering.

Vertical Sampling is defined as the distance between neighboring records of radar observables within a profile and is targeted at two samples per vertical resolution to maintain near-Nyquist sampling of the observable fields.

RADAR RESOURCE ALLOCATION TARGETS

The AOS team has developed target spacecraft resource allocations, detailed in Table 3 below, for the cloud-profiling radar based on information gathered during the AOS Mission Concept Study Phase, including information gathered from previous Instrument Requests for Information submitted during the earlier ACCP study. The Respondent should provide both their Current Best Estimate and Maximum Expected Value resource needs in the attached AOS_Radar_RFI spreadsheet, Attachment B, "4 Spacecraft Accommodation" tab. Exceedance of the allocation values below should be described in your response. Concepts that exceed specific allocations with reasonable justifications will be reviewed.

Table 3: Cloud Profiling Radar Target Resource Allocations

Resource	Units	Target Instrument Allocation
Mass	kg	410
Operational Power (Orbit Average)	W	500
Envelope Dimensions in Stowed Configuration (L x W x H). See Figure 2.	cm	450 x 225 x 100
Data Rate (Peak*)	bits/second	4.0×10^7
*Peak data rate is the nominal rate while the instrument is in its acquisition mode.		

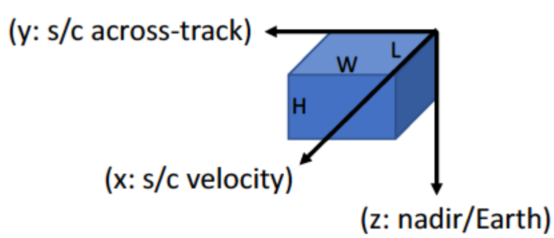

Figure 2 Instrument reference coordinate system.

INSTRUMENT MATURITY

The respondent is encouraged to use the narrative section of the response to describe the technical maturity and supporting basis for the instrument use in spaceflight. In addition to the narrative, the respondent should address the itemized requests within the spreadsheet, tab "6 TRL" on technology readiness assessment.

Suitable instrument candidates must be no less than Technology Readiness Level (TRL) 5 at spaceflight radar contract award and TRL 6 by the radar Preliminary Design Review (PDR). TRL definitions can be found in the NASA Systems Engineering Handbook, Appendix G and Appendix E of the Systems Engineering Processes & Requirements, NPR 7123.1 (see references), and they apply to the relevant, intended environment (e.g., airborne instrument demonstrated in that environment would be considered TRL 6, but would not be considered TRL 6 if they were intended for a spaceflight environment for AOS). The TRL focus is on elements and subsystems.

If the candidate instrument elements and subsystems are not currently at TRL 6 for the intended environment, the response should include the following:

a) An estimate of current TRL, using the TRL definitions in Appendix G of the NASA Systems Engineering Handbook (NASA SP-2016-6105 Rev. 2, 2016).
b) A technology maturation plan and needs that outlines the approach and timeline to achieve TRL 6
c) If existing, identification of the external funding source(s) supporting the effort to achieve TRL 6 and qualify the hardware for the intended environment

POTENTIAL AOS CONTRACT ACTIVITY

The AOS project has released this RFI to aid in evaluating industry capabilities in preparation for a potential flight radar solicitation. The intention of the AOS project is to issue an RFP or RFQ in the spring of 2023 to competitively award multiple study contracts to assist in developing more detailed instrument requirements. Based on the outcome of those study contracts, AOS could release a spaceflight hardware procurement RFP as soon as early 2024.

MISSION ASSUMPTIONS AND SPACECRAFT INTERFACE ASSUMPTIONS

When developing their response, the respondent should consider the following Mission and Spacecraft Interface assumptions detailed in Table 4. The respondent should elaborate in the narrative if there are any issues with any of these assumptions.

Table 4: Mission and Spacecraft (MSC) Interface Assumptions

Identifier	Category	Mission Parameters and Spacecraft Interface: Driving/Key Assumptions
MSC1	Orbit	450 km ± 10 km altitude, Sun Synchronous Polar Orbit, Ascending Node: 1330 ± 15 minutes
MSC4	Instrument Design Life	Minimum 3 Years, accommodate 5 years for any consumable.
MSC5	Instrument Risk Classification	Risk Class C per NASA 8705.4A
MSC6	Launch Vehicle	Assume environment envelope of the following launch vehicles: Falcon 9, Blue Origin New Glenn, and ULA Vulcan Centaur.
MSC7	Launch Orientation	The instrument design and mounting to the spacecraft will allow for launch in any orientation with respect to the launch velocity direction.
MSC8	Deployments	Deployments for initial instrument configuration are acceptable. and should be noted by the vendor. For example, this might include protective aperture covers or release mechanisms for a system locked during launch.
MSC9	Orbital Debris Reduction	The instrument shall retain any deployed hardware. No hardware is to be released into orbit.

Identifier	Category	Mission Parameters and Spacecraft Interface: Driving/Key Assumptions
MSC10	Thermal Interface	Instrument is responsible for its own thermal management, including any cryocoolers, operational heaters, thermal radiators, thermal straps, and heat pipes. Assume that spacecraft will accommodate field of view for instrument radiators with view to a 'cold side' of the spacecraft. Conductive heat transfer between instrument and mounting interface will be restricted.
MSC11	Survival Power	Spacecraft will provide dedicated, unswitched power feed for survival heaters from nominal 28 V DC power service. Instrument is responsible for its own survival heaters and control (e.g., thermostats).
MSC12	Operational Power Service	Assume nominal 28 V DC power service from spacecraft battery system, notionally 26 V to 34 V DC range of variation.
MSC13	Spacecraft Attitude Control System	The spacecraft will maintain a fixed nadir-pointing attitude during operations.
MSC14	Science Data Management	Instrument need not provide its own data storage system. Assume spacecraft will provide adequately sized data recorder to store instrument science, telemetry, housekeeping for periodic spacecraft downlinking.
MSC15	Science Data Management	Data Rate values provided in the targeted resource allocation are for uncompressed data. Assume that the spacecraft will not implement any data compression on the instrument science data. The instruments may wish to implement data compression (lossy or lossless) algorithms prior to transfer to the spacecraft.

DATA SECURITY

The information provided will be maintained on GSFC-maintained secure servers, and accessed only by civil servants, or contractors that have signed Non-Disclosure Agreements (NDAs) that preserve vendor proprietary and competition sensitive data. A sanitized summary of all the responses will be shared with the AOS Science and Applications Leadership Team, AOS and NASA senior leadership, and a technical review board to assist in further development of AOS science goals and mission architectures.

It is not NASA's intent to publicly disclose vendor proprietary information obtained during this solicitation, including any cost estimates provided. To the full extent that it is protected pursuant to the Freedom of Information Act and other laws and regulations, information identified by a respondent as "Proprietary or Confidential" will be kept confidential. Note that marking information as "Proprietary or Confidential" may limit the ability for the submitted material to be reviewed and considered.

The North American Industry Classification System (NAICS) code for this procurement is 336419, Other Guided Missile and Space Vehicle Parts and Auxiliary Equipment Manufacturing, with a size standard of 1,000 employees.

RESPONSE CONTENT REQUEST

This RFI is to solicit specific capability information from any experienced source and promote collaboration and competition. The RFI seeks responses that provide the technical resource footprint, science performance, and vendor capability statements for the radar. Additionally, the RFI seeks a high-level development schedule with key milestones (PDR, CDR, AI&T date & delivery date) identified. For any hardware that is currently at a maturity level less than TRL 6, the vendor should provide a TRL maturation plan for achieving TRL 6. The description of the Radar should include any relevant laboratory, sub-orbital, or spaceflight information regarding the hardware configuration as previously demonstrated and the science returned, as well as the instrument calibration and data validation methods.

The vendor's response should address the following:

1. Abstract: Provide a brief summary of the radar concept, and developmental and organizational approach.
2. Organization capabilities, facilities, experience and expertise related to this RFI. Include any partnerships that might be proposed
3. Specific radar concept details:
    - Instrument performance as specified in Table 1 (vendor details provided in Attachment B)
    - Instrument Mass & Volume, including points instrument size, weight and power (SWaP) changes significantly with performance
    - Instrument Power Requirements (operational, peak, survival)
    - Instrument Thermal Constraints (operating temperature, survival temperature, interface heat transfer)
    - Instrument View Constraints (field of view, field of regard, keep-out zones)
    - Instrument Data (rates, latency, interfaces)
    - Instrument Pointing (accuracy, knowledge, jitter, stability)
    - Instrument Accommodation constraints (such as FoV, thermal interface constraints, expected data & power interfaces, etc.)
    - Calibration activities
4. Development schedule estimate (major milestones) assuming a start of Q2 CY2025.
5. Planned technology readiness level (TRL) at start and TRL maturation plan (see NPR 7123.1C Appendix E for TRL definitions). Subsystem/element TRL 6 is required by Instrument PDR.
6. Description of key technical, schedule and cost drivers, identifying options for mitigating cost, including technical trades, redundancy, etc.

Interested offerors/vendors having the required specialized capabilities to meet the intended application should submit a capability statement indicating the ability to perform all aspects of the effort described herein. Responders are invited to submit a narrative and to fill out the attached AOS_Radar_RFI spreadsheet. Science publications and other relevant information can be referenced in the narrative to provide examples of the source's expertise, facilities, and prior work, especially regarding hardware and/or test results for atmospheric or spaceflight radar. The respondent is encouraged to use the narrative to include an instrument functional block diagram, technology readiness assessment basis, identification of any long-lead components or subsystems, and any potential risks (cost, technology, or schedule) envisioned for the radar based on the AOS schedule and flight architecture.

The attached AOS_Radar_RFI spreadsheet offers a convenient and concise means of addressing the anticipated radar performance, spacecraft resource, and mission operational concept needs. The spreadsheet includes the technical information necessary to support Mission Concept development/pre-formulation. The spreadsheet includes separate tabs for General Information, Radar Performance, Supplemental Information, Spacecraft Accommodation, Orbit and Attitude, and TRL. Please complete one spreadsheet for each candidate instrument submitted.

Because the AOS Constellation is cost-constrained, the project seeks to understand the rough-order-of-magnitude estimate of the total cost. If respondents choose to provide an estimate, please do so in real year (RY$) dollars. For purposes of cost estimation and planning, the respondent should consider award of the instrument hardware contract NET March 2025. The respondent should assume that:

- The instrument is delivered to the AOS spacecraft provider for integration and testing at the observatory level
- Integration & test support at the vendor's facility and at the launch site will be required
- Up to 90 days of launch & on-orbit checkout support will be required

Responses must also include the following: name and address of firm, size of business; average annual revenue for past 3 years and number of employees; ownership; whether they are large, small, small disadvantaged, 8(a), Woman-owned, Veteran Owned, Service-Disabled Veteran Owned, Historically Underutilized Business Zone and Historically Black Colleges and Universities/Minority Institutions and number of years in business. Also include any affiliate information: parent company, joint venture partners, potential teaming partners, prime contractor (if potential sub) or subcontractors (if potential prime), list of customers covering the past five years (highlight relevant work performed, contract numbers, contract type, dollar value of each procurement; and point of contact - address and phone number).

This synopsis is for information and planning purposes and is not to be construed as a commitment by the Government nor will the Government pay for information solicited. Respondents will not be notified of the results of the evaluation.

All questions should be directed to: Andres Castro, andres.c.castro@nasa.gov and Craig Keish, craig.f.keish@nasa.gov

Interested offerors shall address the requirements of this RFI in written format as described in the previous paragraphs by electronic mail to Andres Castro, andres.c.castro@nasa.gov and Craig Keish, craig.f.keish@nasa.gov by March 31, 2023. Responses can be submitted via email or contact us for other secure transmission options. The subject line of the submission should be "RFI for AOS Polar Radar," and attachments should be in Microsoft WORD, POWERPOINT, EXCEL or PDF format. The email text must give a point-of-contact and provide the point of contact's name, address, telephone/fax numbers, and email address.

Contracting Office Address:
NASA/Goddard Space Flight Center
Greenbelt, Maryland 20771

Primary Points of Contact:
Andres Castro
andres.c.castro@nasa.gov
Craig Keish
craig.f.keish@nasa.gov

References

Battaglia, Alessandro, et al. "Characterization of surface radar cross sections at W-band at moderate incidence angles." *IEEE Transactions on Geoscience and Remote Sensing* 55.7 (2017): 3846-3859.

Doviak, Richard J. *Doppler radar and weather observations*. Dover Publications, 1993.

Durden, Stephen L., P. R. Siqueira, and Simone Tanelli. "On the use of multiantenna radars for spaceborne Doppler precipitation measurements." *IEEE Geoscience and Remote Sensing Letters* 4.1 (2007): 181-183.

Kollias, Pavlos, et al. "Evaluation of EarthCARE cloud profiling radar Doppler velocity measurements in particle sedimentation regimes." *Journal of Atmospheric and Oceanic Technology* 31.2 (2014): 366-386.

Kollias, Pavlos, et al. "The EarthCARE cloud profiling radar (CPR) doppler measurements in deep convection: challenges, post-processing, and science applications." *Remote sensing of the atmosphere, clouds, and precipitation VII*. Vol. 10776. International Society for Optics and Photonics, 2018.

McLinden, Matthew L., et al. "Utilizing versatile transmission waveforms to mitigate pulse-compression range sidelobes with the HIWRAP radar." *IEEE Geoscience and Remote Sensing Letters* 10.6 (2013): 1365-1368.

McLinden, Matthew L., et al. "Reduced Image Aliasing with Microwave Radiometers and Weather Radar Through Windowed Spatial Averaging." *IEEE Transactions on Geoscience and Remote Sensing* 53.12 (2015): 6639-6649.

McLinden, Matthew L. Walker, et al. "Application of Nonuniform Beam Filling (NUBF) Doppler Velocity Error Correction on Airborne Radar Measurements." *IEEE Geoscience and Remote Sensing Letters* 19 (2021): 1-5.

Schutgens, N. A. J. "Simulated Doppler radar observations of inhomogeneous clouds: Application to the EarthCARE space mission." *Journal of atmospheric and oceanic technology* 25.1 (2008): 26-42.

Smith, Paul L. "Equivalent radar reflectivity factors for snow and ice particles." *Journal of Climate and Applied Meteorology* 23.8 (1984): 1258-1260.

Stephens, Graeme L., et al. "CloudSat mission: Performance and early science after the first year of operation." *Journal of Geophysical Research: Atmospheres* 113.D8 (2008).

Sy, Ousmane O., et al. "Simulation of EarthCARE spaceborne Doppler radar products using ground-based and airborne data: Effects of aliasing and nonuniform beam-filling." *IEEE transactions on geoscience and remote sensing* 52.2 (2013): 1463-1479.

Sy, Ousmane O., et al. "Application of matched statistical filters for EarthCARE cloud Doppler products." *IEEE Transactions on Geoscience and Remote Sensing* 52.11 (2014): 7297-7316.

Tanelli, Simone, et al. "The effects of nonuniform beam filling on vertical rainfall velocity measurements with a spaceborne Doppler radar." *Journal of Atmospheric and Oceanic Technology* 19.7 (2002): 1019-1034.

Tanelli, Simone, et al. "CloudSat's cloud profiling radar after two years in orbit: Performance, calibration, and processing." *IEEE Transactions on Geoscience and Remote Sensing* 46.11 (2008): 3560-3573.

Tanelli, Simone, Stephen L. Durden, and M. P. Johnson. "Airborne demonstration of DPCA for velocity measurements of distributed targets." *IEEE Geoscience and Remote Sensing Letters* 13.10 (2016): 1415-1419.

NPR 7123.1C, NASA Systems Engineering Processes and Requirements: https://nodis3.gsfc.nasa.gov/displayDir.cfm?t=NPR&c=7123&s=1C

NASA Systems Engineering Handbook: https://www.nasa.gov/connect/ebooks/nasa-systems-engineering-handbook