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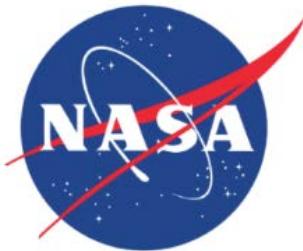
Active Sensing of CO₂ Emissions over Nights, Days, and Seasons (ASCENDS) Mission

Science Mission Definition Study Executive Summary Draft

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1 Executive Summary

2 Improved remote sensing observations of atmospheric CO₂ are critically needed to quantify,
3 monitor, and understand the Earth's carbon cycle and its evolution in a changing climate. The
4 processes governing ocean and terrestrial carbon uptake remain poorly understood, especially in
5 dynamic regions with large carbon stocks and strong vulnerability to climate change, for
6 example, the tropical land biosphere, the northern hemisphere high latitudes, and the Southern
7 Ocean. Because the passive spectrometers used by GOSAT and OCO-2 require sunlit and cloud-
8 free conditions, current observations over these regions remain infrequent and are subject to
9 biases. These shortcomings limit our ability to understand the processes controlling the carbon
10 cycle on regional to global scales.

11 In contrast, active CO₂ remote-sensing techniques allow accurate measurements to be taken day
12 and night, over ocean and land surfaces, in the presence of thin or scattered clouds, and at all
13 times of year. Because of these benefits, the National Research Council recommended the NASA
14 Active Sensing of CO₂ Emissions over Nights, Days, and Seasons (ASCENDS) mission in the
15 2007 report Earth Science and Applications from Space: National Imperatives for the Next
16 Decade and Beyond. The ability of ASCENDS to collect low-bias observations in these key
17 regions is expected to address important gaps in our knowledge of the contemporary carbon
18 cycle.

19 The ASCENDS ad hoc Science Definition Team (SDT), comprised of carbon cycle modeling
20 and active remote sensing instrument teams throughout the U.S., has worked to develop the
21 mission's requirements and advance its readiness since 2008. Numerous scientific investigations
22 have been carried out to identify the benefit of active CO₂ remote sensing measurements for
23 improving our understanding of CO₂ sources and sinks. This report summarizes their findings
24 and recommendations to date, based on mission modeling studies, analysis of ancillary
25 meteorological data products, development and demonstration of candidate technologies, and
26 design studies of the ASCENDS mission concept.

27 To date, the ASCENDS modeling studies have demonstrated that:

- 28 1. ASCENDS will resolve statistically significant differences in total column CO₂
29 concentrations, resulting from foreseeable changes in surface flux over the entire globe.
30 These flux changes could include identifying CO₂ emissions from permafrost thaw at
31 high latitudes, shifting patterns in regional fossil fuel emissions, the evolving nature of
32 the Southern Ocean carbon flux, and/or changes to tropical and mid-latitude terrestrial
33 sinks.
- 34 2. ASCENDS will substantially advance our understanding of the carbon cycle through
35 improved flux estimates with reduced uncertainty at global to regional scales. Reduced
36 flux uncertainties at regional scales are necessary for improved understanding of the
37 processes controlling long-term carbon sinks.
- 38 3. ASCENDS measurements also have the potential to reduce biases due primarily to lower
39 susceptibility to errors from atmospheric scattering and changes in illumination
40 geometry. This can contribute significantly towards improving constraints on surface
41 fluxes beyond passive sensors such as GOSAT and OCO-2.

42 During the past decade, NASA has invested in the development of several different Integrated
43 Path Differential Absorption (IPDA) lidar approaches and associated technologies that are
44 candidates for ASCENDS. The IPDA approach measures the range to the scattering surface, and

45 the column abundance and average mixing ratio of atmospheric CO₂ with increased sensitivity
46 throughout the mid- and lower troposphere. Several aircraft field campaigns have already
47 demonstrated that:

- 48 1. Accurate CO₂ column mixing ratios can be retrieved from airborne lidar data.
- 49 2. Evaluation against in situ aircraft observations show that CO₂ column absorption
50 measurements can be made with high precision and low bias over a wide range of surface
51 types and between scattered clouds.
- 52 3. High-quality observations can be made to cloud tops and through thin clouds and aerosol
53 layers.

54 In addition, evaluation of the magnitude of errors in present atmospheric models has helped to
55 clarify the need for ancillary measurements and to define the error budget for the ASCENDS
56 measurements. Statistical analysis of meteorological products from three different atmospheric
57 modeling centers shows that uncertainty in current surface pressure estimates from models is
58 typically less than 0.1% except in high latitudes regions. These findings will be used to evaluate
59 the need and required performance for a coincident oxygen lidar measurement to meet the
60 desired CO₂ mixing ratio accuracy for ASCENDS.

61 These studies and field activities have greatly improved our understanding of the space-based
62 capabilities required for ASCENDS, and represent significant progress toward meeting the
63 demands of an active remote-sensing mission. Integrating results from the measurement
64 campaigns and modeling studies, the ASCENDS SDT has developed a preliminary set of
65 measurement requirements as well as a study of the ASCENDS mission that demonstrates the
66 feasibility of deploying the observatory. The results of this study show that multiple
67 commercially-available spacecraft buses should be able to accommodate an ASCENDS
68 instrument with minor mission-specific modifications. In addition, the Falcon 9 or Atlas V
69 (EELV) launch vehicles can accommodate an ASCENDS observatory with the parameters used
70 in this study.

71 Finally, this report outlines areas where further research is needed. These include but are not
72 limited to:

- 73 1. Modeling studies that incorporate error statistics from the OCO-2 mission, assess the
74 impact of errors in meteorological parameters on flux estimates, and evaluate the impact
75 of different orbit choices and vertical information on flux inference.
- 76 2. Aircraft campaigns targeting observations over high latitudes and forested areas, and also
77 performed to coincide with OCO-2 overpasses.
- 78 3. Technology development focused on demonstrating the required laser power for space,
79 and further improving O₂ lidar capabilities.

80 Such studies are needed to improve traceability from science questions to measurement
81 requirements. The ASCENDS SDT plans to continue working on these activities to advance
82 mission readiness in coordination with the carbon cycle research community.