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Active Sensing of CO_2 Emissions over Nights, Days, and Seasons (ASCENDS) Mission

Science Mission Definition Study

Executive Summary Draft

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Executive Summary

Improved remote sensing observations of atmospheric CO_2 are critically needed to quantify, monitor, and understand the Earth's carbon cycle and its evolution in a changing climate. The processes governing ocean and terrestrial carbon uptake remain poorly understood, especially in dynamic regions with large carbon stocks and strong vulnerability to climate change, for example, the tropical land biosphere, the northern hemisphere high latitudes, and the Southern Ocean. Because the passive spectrometers used by GOSAT and OCO-2 require sunlit and cloud-free conditions, current observations over these regions remain infrequent and are subject to biases. These shortcomings limit our ability to understand the processes controlling the carbon cycle on regional to global scales.

In contrast, active CO_2 remote-sensing techniques allow accurate measurements to be taken day and night, over ocean and land surfaces, in the presence of thin or scattered clouds, and at all times of year. Because of these benefits, the National Research Council recommended the NASA Active Sensing of CO_2 Emissions over Nights, Days, and Seasons (ASCENDS) mission in the 2007 report Earth Science and Applications from Space: National Imperatives for the Next Decade and Beyond. The ability of ASCENDS to collect low-bias observations in these key regions is expected to address important gaps in our knowledge of the contemporary carbon cycle.

The ASCENDS ad hoc Science Definition Team (SDT), comprised of carbon cycle modeling and active remote sensing instrument teams throughout the U.S., has worked to develop the mission's requirements and advance its readiness since 2008. Numerous scientific investigations have been carried out to identify the benefit of active CO_2 remote sensing measurements for improving our understanding of CO_2 sources and sinks. This report summarizes their findings and recommendations to date, based on mission modeling studies, analysis of ancillary meteorological data products, development and demonstration of candidate technologies, and design studies of the ASCENDS mission concept.

To date, the ASCENDS modeling studies have demonstrated that:

1. ASCENDS will resolve statistically significant differences in total column CO_2 concentrations, resulting from foreseeable changes in surface flux over the entire globe. These flux changes could include identifying CO_2 emissions from permafrost thaw at high latitudes, shifting patterns in regional fossil fuel emissions, the evolving nature of the Southern Ocean carbon flux, and/or changes to tropical and mid-latitude terrestrial sinks.
2. ASCENDS will substantially advance our understanding of the carbon cycle through improved flux estimates with reduced uncertainty at global to regional scales. Reduced flux uncertainties at regional scales are necessary for improved understanding of the processes controlling long-term carbon sinks.
3. ASCENDS measurements also have the potential to reduce biases due primarily to lower susceptibility to errors from atmospheric scattering and changes in illumination geometry. This can contribute significantly towards improving constraints on surface fluxes beyond passive sensors such as GOSAT and OCO-2.

During the past decade, NASA has invested in the development of several different Integrated Path Differential Absorption (IPDA) lidar approaches and associated technologies that are candidates for ASCENDS. The IPDA approach measures the range to the scattering surface, and the column abundance and average mixing ratio of atmospheric CO_2 with increased sensitivity throughout the mid- and lower troposphere. Several aircraft field campaigns have already demonstrated that:

1. Accurate CO_2 column mixing ratios can be retrieved from airborne lidar data.
2. Evaluation against in situ aircraft observations show that CO_2 column absorption measurements can be made with high precision and low bias over a wide range of surface types and between scattered clouds.
3. High-quality observations can be made to cloud tops and through thin clouds and aerosol layers.

In addition, evaluation of the magnitude of errors in present atmospheric models has helped to clarify the need for ancillary measurements and to define the error budget for the ASCENDS measurements. Statistical analysis of meteorological products from three different atmospheric modeling centers shows that uncertainty in current surface pressure estimates from models is typically less than 0.1% except in high latitudes regions. These findings will be used to evaluate the need and required performance for a coincident oxygen lidar measurement to meet the desired CO_2 mixing ratio accuracy for ASCENDS.

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

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

1. Modeling studies that incorporate error statistics from the OCO-2 mission, assess the impact of errors in meteorological parameters on flux estimates, and evaluate the impact of different orbit choices and vertical information on flux inference.
2. Aircraft campaigns targeting observations over high latitudes and forested areas, and also performed to coincide with OCO-2 overpasses.
3. Technology development focused on demonstrating the required laser power for space, and further improving O_2 lidar capabilities.

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