An Airborne Sensor and Retrieval Project for Geostationary Trace Gas and Aerosol Sensor Optimization for the GEO-CAPE Mission

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***Abstract*- The Geostationary Trace gas and Aerosol Sensor Optimization (Geo-TASO) Instrument Incubator project involves spectrometer development, airborne data campaigns, and algorithm testing - all in support of mission risk reduction for the UV-Vis trace gas and aerosol sensor for the GEO-CAPE mission. A compact, two-channel spectrometer approach for spectral radiance measurements will be built and readied for use on aircraft. The sensor provides a variably oversampled spectral passband to test measurement and retrieval algorithm performance sensitivity to spectral sampling. The ruggedized instrument will be flown to collect real scene data. Both laboratory test data and scene data will be used to test retrieval algorithm performance and retrieval sensitivity to sensor spectral parameters. The goals of the project are to inform the sensor and algorithm system definition for the Geo-CAPE mission, to advance the readiness of the retrieval algorithms, and to demonstrate the compact spectrometer concept.**

I. INTRODUCTION

The NASA Geostationary Coastal and Air Pollution Events (GEO-CAPE) mission, an Earth Science Decadal Survey [1] Tier II mission, will address climate and air quality issues in part by 1) improving estimates of aerosol and trace-gas emissions and their spatial and temporal patterns over those currently observed from LEO, 2) elucidating the influences of weather on the pollutant transport through data assimilation and model evaluation, 3) observing the evolution of the pollutants ozone and aerosols, from formation and transport to losses by chemistry and deposition, and 4) quantifying regional O_3 and aerosol budgets [2, and references therein]. Much of this can be measured using spectral imaging of ultraviolet (UV) and visible backscattered light. A challenge in any remote sensing system observing a complex scene is determining a good sensor-algorithm combination that will indeed make the science measurements at the desired level of uncertainty. This paper outlines the plans for a NASA Instrument Incubator Program (IIP) investigation of a compact spectrometer that will be used to gather real scene data over a range of spectral parameters to determine the sensor configuration that works best with the retrieval algorithms. The collected data will also help refine the algorithms by providing real scene data with which the algorithms can be tested

II. NEW IIP PROGRAM

The Geostationary Trace-gas and Aerosol Sensor Optimization (GEO-TASO) IIP has three goals: advance the technology readiness level (TRL) of an optimally compact GEO-CAPE prototype spectrometer, provide a re-usable tool for addressing GEO-CAPE sensor trades, and test sensor–retrieval system performance over a range of spectral and spatial sampling scales with real scene data. Laboratory and airborne sensor data coupled with retrieval algorithm developments will be studied to determine the optimal spectral sampling and resolution combination for meeting the GEO-CAPE trace gas, ozone, and aerosol measurement objectives.

This IIP will advance the GEO-CAPE wide-area imaging spectrometer technology readiness and validate the mission requirements by exploring the spectral/spatial sampling and resolution trade space. The retrieval algorithms will likewise be advanced closer to mission readiness. This project builds upon the results of a laboratory system designed and fabricated under previous IIP funding, GeoSpec [3]. The proposed work will update the design parameters to take into account the latest GEO-CAPE Science Traceability Matrix (STM) requirements. Our strawman design is a 290 to 510 nm two channel spectrometer with highly dispersed spectra (0.1 nm/pixel in the UV channel, 0.15 nm/pixel in the Vis channel) and variable spectral passbands and sampling (from 2 samples over a 0.2 nm passband to 4 samples within a 0.4 nm spectral passband) through slit selection.

II. TIE TO GEOCAPE MISSION STUDIES

Current space-based instruments have demonstrated measurement capabilities approaching the current STM requirements, but none provide the highly sampled spectral data proposed for the GEO-CAPE sensor. Meeting the stringent STM requirements will rely on careful development of the instrumentation including signal-to-noise ratio, spectral resolution, and spectral sampling value. Studies with variable spectral sampling will demonstrate whether corrections made to GOME, SCIAMACHY, and OMI measurements that are not minimally sampled are sufficient and will help set the spectral sampling requirement for the GEO-CAPE sensor. Comparison of spectral resolution and signal to noise ratio will determine the minimum needed optical throughput of the GEO-CAPE sensor for atmospheric measurements.

In addition to exploring optimal spectral and temporal sampling parameters, the studies are considering various options for trace gas horizontal spatial resolutions ranging from 8×8 km^2 (threshold) to 4×4 km^2 (baseline). Cloud and aerosol algorithms will likely require 2×2 km^2 or finer resolutions. The question of spatial scale is a key driver in the overall instrument design as it has a large impact on system size.

The proposed GEO-TASO instrumentation will test out the assumptions and conclusions from these investigations. The GEO-TASO spectrometer, with its high spectral and spatial sampling, will validate and inform the selected requirements by providing tangible and relevant data. GEO-TASO measurements will be made in a fashion that permits the optimization of choices in the tradeoff parameter space so that the GEO-CAPE flight instrument will perform as required by the STM.

II. THE GEOTASO SENSOR

The sensor is an Offner spectrometer fed by a 4 mirror telescope. A block diagram representation of the sensor is shown in **Figure 1**. It includes a Time-Domain Polarization Scrambler whose rugged airborne design was developed under a 2009 NASA Advanced Components Technology (ACT) award; this photo-elastic modulator (PEM) depolarizer is expected to improve upon the results obtained with the GeoSpec Lyot depolarizer, where spectral artifacts were found in the VIS/NIR channel. The dichroic beam splitter reflects short wavelengths (290-390 nm) and transmits long wavelengths (410-510 nm); light from each channel originates from different diffractive orders off of a single grating. Optical band filters limit the inter-channel spectral contamination. For each channel the spectrum at each field angle is dispersed over a 1024 by 1024 pixel array to provide spectral and spatial discrimination. All electronics will be rack mounted for easy integration and de-integration from the DC-8 platform that will be used for the flight data collection campaigns.

The design spectral range 290-510 nm includes the likely GEO-CAPE UV-Visible range and achieves the signal to noise ratios needed to retrieve the STM identified trace gases. The Geo-TASO spectrometer achieves very high spectral sampling, 0.1 nm/pixel for the short wavelength channel and 0.15 nm/pixel for the long wavelength channel. With the Offner design form and overlapping orders, image aberrations are minimal [4]. Roughly 2000 spectral samples are collected for each instantaneous field of view (IFOV). With the selection of slit widths, the spectrometer spectral resolution can be varied; **Table 1** lists the planned options for both the short wavelength and long wavelength channels.

TABLE I. Spectral sampling choices with their corresponding passbands for the two channels

Spectral Sampling	Spectral Passband (UV Chan)	Spectral Passband (Vis Chan)
Pix/FWHM	nm	nm
2	0.2	0.3
3	0.3	0.45
4	0.4	0.6

The 4 mirror objective projects the slit into a 45° cross track field. When flying at 40 Kft, this feature generates a ground swath matched to the OMI UV2 channel and facilitates comparison, cross calibration, and validation of the retrievals at the different spectral sampling

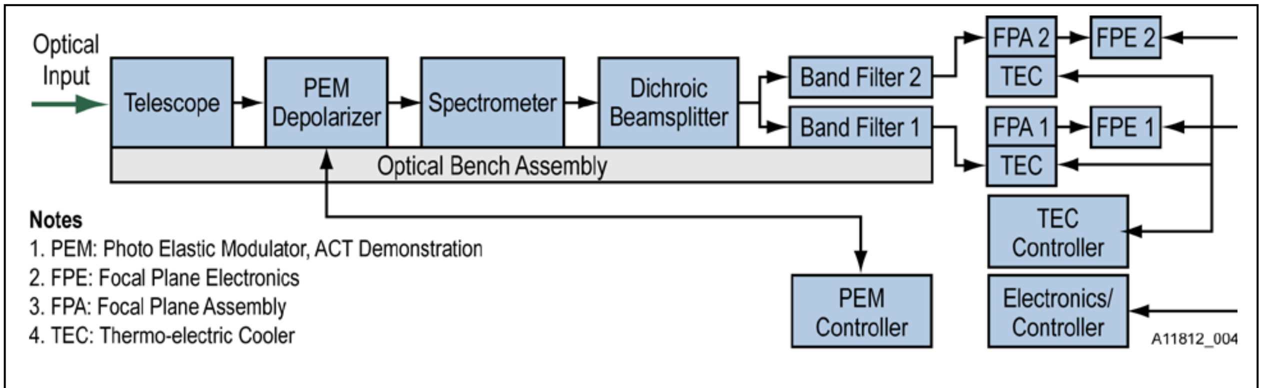

Figure 1. Block diagram for the GEO-TASO compact two channel spectrometer designed to raise the TRL of GEO-CAPE sensor designs, validate instrument requirements, and provide spectral data similar to that expected from the GEO-CAPE UV-Vis spectrometer.

scales. Exact values for the spatial resolution in both the crosstrack and along track directions will be determined during the initial sensor trade studies.

II. The GEOTASO Program Plan

The proposed 3-year effort follows a typical development flow: mission and system requirements definition, sensor assembly, integration and performance testing, environmental testing, and two NASA DC-8 campaigns. Calibrated laboratory and flight data will be used in state of the art trace gas retrievals to assess the coupled sensor and algorithms ability to achieve the GEO-CAPE measurement objectives. The entry TRL is 3 and the exit will be 6 for airborne. The airborne sensor will advance the TRL of a spaceflight sensor as well by proving out the multi-order approach for making a compact spectrometer. We intend the hardware to be available for further GEO-CAPE associated trade studies and data needs, continuing to inform the mission requirements definition.

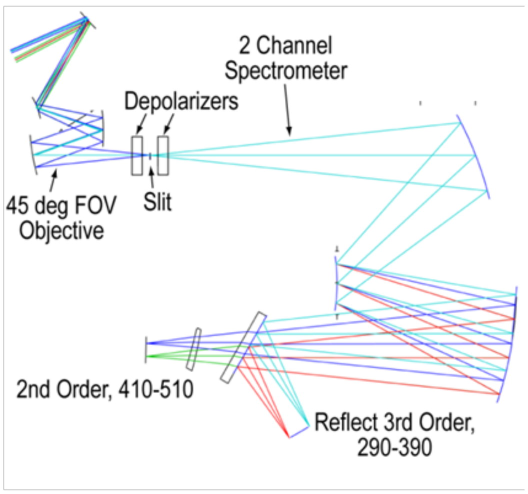

Figure 1 The GEO-TASO Offner spectrometer uses multiple diffraction orders to achieve high spectral sampling and spectral range in a small space. The compactness comes from the spatial overlap of the different orders.

The retrieval algorithms will also be advanced in their readiness level. Sensor data will be used to check the validity of algorithm sensitivities to instrument parameters that have been derived from simulations. Real scene data will provide an authentic test of the retrieval algorithms' capability to measure trace gases and aerosols in the presence of clouds, varying surface reflectivities and other natural effects.

II. Conclusions

The sensor and algorithm work outlined here addresses a key need for Geo-CAPE: a test of the proposed measurement scheme for many of the trace gases and aerosol parameters that are in the GEO-CAPE STM. The project will demonstrate a spectrometer that is based on use of multiple overlapping diffraction orders to deliver the needed spectral resolution and range in a compact package. The laboratory and airborne measurement data from the sensor will be used to measure the retrieval algorithm sensitivity to spectral parameters and fine spatial scale real scene data. The testing of the sensor and the algorithms together will provide a higher fidelity estimate of expected on-orbit performance of GEO-CAPE as well as supplying a recommended set of sensor parameters that best meet the GEO-CAPE science requirements.

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