1. EXECUTIVE SUMMARY AND RECOMMENDATIONS

The 2007 Decadal Survey (DS) included the recommendation for the Geostationary Coastal and Air Pollution Events (GEO-CAPE) mission to launch in 2013–2016 to advance the science of both coastal ocean biophysics and atmospheric-pollution chemistry. In 2009 the NASA Earth Science Division (ESD) initiated study activities for GEO-CAPE and 8 other near- to medium-term missions to help determine the readiness of these conceptual missions to begin the formulation phase. In FY15 the GEO-CAPE mission study team completed a white paper summarizing the results of the pre-formulation work accomplished to date: https://geo-cape.larc.nasa.gov/pdf/GEO-CAPE_2009-2015_SummativeWhitePaper.pdf The team was directed to complete a final report in FY18. This document, prepared as an addendum to the FY15 white paper, serves as the GEO-CAPE final report and focuses only on FY16-18 activities and on summarizing the final state.

GEO-CAPE fully matured during the 2010–2018 pre-formulation study activities. Early studies confirmed that the mission as recommended in the 2007 DS was at a high level of technology readiness, with launch feasible by 2015, but also found that the 2007 DS cost estimate of $550 million for a dedicated geostationary mission was low by a factor of 2 to 3. Therefore, the study team developed a novel mission implementation strategy featuring commercial hosting of GEO-CAPE instruments on one or more geostationary satellites. This strategy was estimated to reduce mission risk and potentially total mission cost, but most importantly to provide programmatic flexibility by allowing smaller components of the mission to be individually initiated as NASA funding profiles allowed. The team completed all other pre-formulation objectives (including developing science traceability matrices to express measurement requirements, conducting field campaigns and other science studies to affirm and refine these requirements, and maturing enhancing technologies) and advanced mission readiness via multiple synergistic activities with ESD research, applications, technology, and flight programs. In parallel, team members also started pursuing Earth Venture (EV) opportunities as the only means of initiating GEO-CAPE satellite observations in a constrained budgetary environment.

The selection of the Tropospheric Emissions: Monitoring of Pollution (TEMPO) mission through the EV Instrument (EVI) 1 solicitation is viewed as a step toward the GEO-CAPE distributed implementation strategy. TEMPO is likely to meet many of the GEO-CAPE atmospheric science objectives and is a pathfinder for the hosted payload mission strategy. The principal remaining atmospheric measurement objectives can be met by an instrument of comparable cost to TEMPO that makes measurements in infrared wavelengths, as defined in the GEO-CAPE atmospheric science traceability matrix, and use of data from the Advanced Baseline Imagers on the GOES-R/S series satellites. The GeoCARB mission selected December 2016 via the EV Mission 2 solicitation has potential to partially meet remaining GEO-CAPE atmospheric science

requirements associated with infrared measurements, pending its final configuration and observing strategy, and also demonstrates an alternative partnering strategy for a commercial hosted payload mission. The coastal waters science objectives can be met by a variety of instrument concepts within an instrument cost range of $100–200 million. This statement is supported by the evaluations of the GLIMR proposal submitted to the EVI-4 solicitation. Full mission cost estimates for a hosted payload implementation strategy ultimately depend on the commercial market for hosting this class of instruments. At this time, it appears there are fewer geostationary launch opportunities in the 2020-2023 period for new satellites viewing the Americas than originally forecast, due to a combination of factors. It is unclear whether this is a secular business change or a shorter-term market fluctuation, but the TEMPO and GeoCARB experiences to date indicate that a hosted payload implementation strategy remains viable.

The 2017 DS contains clear statements of the ongoing importance of GEO-CAPE objectives and recommends accomplishing them via a range of existing and new missions. The importance of GEO-CAPE's atmospheric science goals is highlighted in 2017 DS "Weather and Air Quality" and "Climate Variability and Change" priorities. Air quality is a "Most Important" Science and Applications Priority (Table 3.3, Question W-5) and part of two other "Most Important" priorities (Questions W-1, W-2). Methane measurements similar to those of GEO-CAPE are part of the "Most Important" priorities for greenhouse gas measurements (Questions C-2d, E-3a, and E-4a). Disposition of Targeted Observables aligned with these priorities is via the Program of Record (including TEMPO, GeoCARB, MAIA, and partner space agency missions), the Designated Mission for aerosols, and Explorer missions for greenhouse gases and ozone/trace gases. Coastal ocean color is associated with three "Most Important" Priorities (Questions E-1b, E-1c, E-3a) reflected in the Aquatic Biogeochemistry Targeted Observable (TO). Though not presently allocated to a Flight Program Element, the Aquatic Biogeochemistry TO is well positioned for Earth Venture opportunities given favorable reviews of the EVI-4 submission.

Given the progress of GEO-CAPE and related projects, and the recommendations of the 2017 DS, the opportunity exists to fulfill all GEO-CAPE objectives in a cost-effective manner by completing NASA missions in the Program of Record (TEMPO, GeoCARB), investing in fused data products using observations from these missions and those of NOAA and international space agencies, and capturing future Earth Venture and Explorer opportunities. It has become evident that the value of GEO-CAPE observations will be amplified by being embedded within an integrated observing strategy featuring similar geostationary observations from missions over other parts of the globe combined with low Earth orbit observations to provide full global context. GEO-CAPE study team members remain key participants in international activities to implement this potential under the auspices of the Committee on Earth Observation Satellites (CEOS), and as members of mission science teams in Europe and Korea. Data harmonization activities featuring common validation strategies will be essential for providing truly

interoperable data products from these satellite constellations. GEO-CAPE study activities have helped define and begin to build the modeling capabilities necessary for realizing these visions.

Specific recommendations follow.

1. Fulfill the Program of Record for the atmospheric composition missions in development (TEMPO, GeoCARB, MAIA) and maintain close coordination among them and partner missions in operation (GOES ABI, Sentinel-5 Precursor TROPOMI, S-NPP, JPSS, EPS) to meet the science and applications priorities expressed in the 2017 DS. In particular, ensure that measurements of CO and CH_4 consistent with GEO-CAPE science traceability matrix requirements are available from GeoCARB or other means.
2. Prepare to fully exploit these data for improved monitoring of air quality over North America by sustaining ongoing activities to improve retrieval algorithms, chemical data assimilation capabilities, inverse modeling capabilities for constraining emissions estimates, and integrated observing system frameworks (such as observation system simulation experiments). In particular, synergistic aerosol retrievals using geostationary observations from TEMPO, ABI, and potentially GeoCARB should be invested in.
3. Continue to support scientific investigations that exploit data from the Korean GOCI and GOCI-II sensors and collaborations with KIOST to advance NASA capabilities for accomplishing 2017 DS science and applications priorities (E-1a, E-1c, E-2a, E-3a, and C-2d) and Targeted Observable 3, Aquatic Biogeochemistry.
4. Remain receptive to opportunities to begin formulation of a coastal ecosystems mission to conduct GEO-CAPE coastal waters science, potentially through a targeted EV opportunity.
5. Continue collaborations with partners such as the U.S. EPA and regional air quality organizations to further implement and maintain long-term ground sites combining continuous *in-situ* and remote-sensing (Pandora, lidar) measurements many times per hour. Data from such sites are critical for validation of the geostationary measurements, science and applications data utilization, and stakeholder uptake of the satellite data.
6. Continue to mature mechanisms for engaging end-users to aid early adoption of TEMPO and other GEO-CAPE related observations, including participation in collaborative regional field campaigns.
7. Create formal Constellation Science Teams for Air Quality and Ocean Color, supported by stable funding for U.S. members, to collaborate with national and international partners in order to mature harmonized, consistent, well-validated interoperable data products from the constellations of geostationary and low-Earth orbit satellites now coming into existence.
8. Given that highly time-resolved observations are the next frontier of Earth science from space, build on the lessons learned from the communal GEO-CAPE study activities by continuing to work with all stakeholders to jointly identify priorities and develop advocacy for sustainable future highly time-resolved observations.