National Oceanic and Atmospheric Administration
Oceanic and Atmospheric Research

NOAA CHEMICAL SCIENCES LABORATORY

NOAA Chemical Sciences Laboratory Science Review 23-25 February 2021

Response to Panel Review Recommendations

Submitted by:

Dr. David W. Fahey,

Director of the NOAA Chemical Sciences Laboratory

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Introduction

Laboratory science reviews are conducted every five years to evaluate the quality, relevance, and performance of research conducted in the National Oceanic and Atmospheric Administration (NOAA) Office of Oceanic and Atmospheric Research (OAR) laboratories. This review is for internal OAR/NOAA use for planning, programming, and budgeting, and external interests. It helps the Laboratory in its strategic planning of future research directions. These reviews are also intended to ensure that OAR laboratory research is linked to NOAA Research mission and priorities, and other relevant strategic plans, is of high quality as judged by preeminence criteria, and is carried out with a high level of performance.

The 2021 Chemical Sciences Laboratory Science Review (CSL) took place virtually 23-25 February 2021. The review covered research conducted by CSL from 2015 through 2020. The research themes for the review were: (1) Air Quality, (2) Climate, and (3) the Stratosphere. In addition to these three research themes, the CSL Science Review also covered Research Strategy and Leadership and Contributions to the Scientific Community. All documents, presentations, and StoryMaps for 2021 CSL Science Review can be found at csl.noaa.gov/reviews/2021.

In this report, each actionable recommendation provided by the Science Review Panel is italicized and followed by the Chemical Sciences Laboratory's response. A table summarizing the actions with timelines for completion is included below. Detailed responses can be found in the Appendix.

Recommendations, Responses, and Action Plans

CSL Science Review Action Sheet				
Recommendation		**Action**	**Champion(s)**	**Target Start & Completion Dates**
1. General Recommendations				
1.1	*CSL needs to improve the diversity of its leadership and staff.*	CSL is developing a Diversity, Equity, & Inclusion (DE&I) Implementation Plan to address how CSL will implement the strategic plans of DOC, NOAA, OAR, ESRL, and cooperative institute partners, e.g., CIRES. Currently, CSL is actively increasing the diversity of its leadership and staff, including have a working group on inclusive hiring practices. CSL is also increasing its interactions and collaborations with Cooperative Science Centers (CSCs) through the ESRL/CSC engagement series and engaging with other minority serving institutions/organizations. It would be beneficial for OAR to be the primary line office for a CSC. CSL has a grassroots Working group on Equity & Inclusion that is working directly with the Director's Office to create a strong culture of diversity and inclusion.	Megan Melamed; Ann Thorne; Matt Coggon	Start Date: June 11th, 2021 Completion Date: June 30th, 2022
1.2	*The CSL Research Strategy which encourages a high level of integration between field campaigns, laboratory studies, modeling, and instrument development across all research foci leads to outstanding research and should be actively nurtured and maintained.*	Agreed. CSL will continue to nurture its Research Strategy of integration between field campaigns, laboratory studies, modeling, and instrument development across air quality, climate, and the stratosphere research themes.	Megan Melamed; Program Leaders	Ongoing

1.3	*NOAA OAR should continue to entrust CSL leadership with the management of the Laboratory's research funds and scientific direction.*	Agreed. CSL will continue to take actions that instill trust in OAR to allow the laboratory manage its funding and scientific direction.	David Fahey	Ongoing
2. Air Quality Recommendations				
2.1	*CSL research could better integrate environmental justice in considering how to prioritize scientific topics.*	Consideration of environmental justice science will be integrated into field campaign planning, data analysis, and modeling at CSL.	Megan Melamed; Chelsea Thompson; Brian McDonald	Start Date: July 1st, 2021 Completion Date: August 31st, 2023
2.2	*CSL scientists should continue to play an active role in defining the components and preparing for NOAA's Geostationary and Extended Orbits (GEO-XO) satellite system.*	Agreed. CSL will continue its leadership role in informing the design of NOAA's next-generation geostationary satellite mission, GeoXO, by developing improved understanding and new applications of existing geostationary products.	Greg Frost	Ongoing
2.3	*CSL modeling efforts should be expanded to include support for development of improved operational air quality predictions at national, global, and regional scales.*	CSL will continue to support development of NOAA operational air quality models at global and regional scales in particular through evaluation of model processes using aircraft data.	Greg Frost; Becky Schwantes	Start Date: September 1st, 2021 Completion Date: September 30th, 2023
2.4	*Improve CSL's data management of air quality datasets by providing data in a timely manner and adopting open data policies.*	CSL will create a data management plan in accordance with NOAA Administrative Order (NAO) 212-15, Management of Environmental Data and Information.	Jenny Fox; Cathy Rasco	Start Date: July 1st, 2021 Completion Date: September 30th, 2022
2.5	*Continue to develop and support a collection of state-of-the-science instrumentation to allow for both rapid and repeated deployment.*	Agreed. CSL will continue to prioritize and support state-of-the-science instrument development.	Shuka Schwarz, Dan Murphy, Steve Brown, Alan Brewer	Ongoing

2.6	*CSL should continue collaborations with scientists at academic institutions and other agencies to continue to maximize impact and catalyze research beyond NOAA.*	Agreed. CSL will continue Collaborations with scientists at academic institutions and other agencies.	Megan Melamed; Program Leaders	Ongoing
2.7	*Seek strategic collaborations to implement the air quality health effect link early in the research value chain.*	Strategic collaborations will be considered in order to incorporate air quality health effects in CSL research.	Jim Roberts; Megan Melamed;	Start Date: September 1st, 2021 Completion Date: August 31st, 2023
2.8	*Continue efforts to make efficient use of satellite products and prepare for full utilization through additional in-house expertise.*	Agreed. CSL will continue to evaluate the scientific expertise required in the laboratory to help develop and use satellite products efficiently and effectively to advance atmospheric chemistry and climate research as well as meet user needs.	Greg Frost; Karen Rosenlof; other program leaders	Ongoing
3. Climate Recommendations				
3.1	*Consider repeating the systematic sampling of the remote atmosphere similar to the recent ATom field campaign.*	CSL will promote the scientific value of the ATom campaign to scientists and program managers to increase interest in conducting similar airborne campaigns in the future.	Chuck Brock; Steve Brown	Start Date: June 1st, 2021 Completion Date: December 31st, 2025
3.2	*CSL climate science should also consider focusing on solutions and reducing risk.*	CSL conducts policy-relevant science that informs possible climate solutions and risk reduction.	Dan Murphy	Ongoing
3.3	*Continue to use the CLS LES ensemble simulations to develop low-order, simplified models.*	Agreed. CSL will continue to use CLS LES ensemble simulations to develop low-order, simplified models.	Graham Feingold	Ongoing
3.4	*Given the importance of the TOAR effort, CSL should consider adding a new scientist with expertise in the retrieval of tropospheric ozone from satellite sensors.*	See 2.8	Greg Frost	

4. Stratosphere Recommendations				
4.1	*Moving forward CSL should continue to focus on the impact of replacements for CFCs and observational strategies to continue ensuring a consistent long term record of the evolution of stratospheric composition.*	Agreed. CSL will continue laboratory studies to quantify the atmospheric chemistry and climate metrics of CFC replacements and improve stratospheric observational strategies and capabilities.	Jim Burkholder; Shuka Schwarz; Dan Murphy; Karen Rosenlof	Ongoing
4.2	*CSL should continue to expand the budget for POPS Balloon Baseline Stratospheric Aerosol Profiles (B2SAP) project, particularly with the new focus on climate intervention studies.*	Agreed. CSL will continue and expand balloon borne measurements.	Shuka Schwarz; Karen Rosenlof; Lizzy Asher	Start Date: October 1st, 2020 Completion Date: September 30th, 2025
4.3	*CSL should leverage the potentially short-term ERB funding to support activities that will build strengths and skills in CSL that can be continued beyond the ERB lifetime.*	Agreed. CSL will leverage ERB funding to develop scientific capabilities (instrumentation, models, and expertise) that will enhance its broader mission to advance scientific understanding of the chemical and physical processes that affect Earth's atmospheric composition and climate.	David Fahey	Start Date: March 6th, 2020 Completion Date: Ongoing
4.4	*The CSL chemistry-climate group, which has recently lost two modelers, should be a high priority for both the long-term retention of current modelling expertise and the potential location for a new hire.*	Maintain staffing within the CSL Chemistry and Climate Processes program to support modeling studies related to stratospheric composition and stratosphere/troposphere interactions.	Karen Rosenlof	Start Date: July 1st, 2021 Completion Date: November 30th, 2021

5. Research Strategy Recommendations				
5.1	*CSL should ensure stable base funding of it's instrument engineering staff and plan ahead by developing viable succession plans for each staff member, because this team is critical to the continued success of CSL's integrated research strategy.*	CSL's top-flight cadre of engineers and support scientists are critical to the laboratory's success, and CSL is currently developing plans to ensure continuity of this support.	Steve Brown; Dan Murphy; Alan Brewer; Shuka Schwarz	Start Date: September 1st, 2021 Completion Date: September 30th, 2023
5.2	*CSL should aspire to make their research enterprise more open by adopting Open Data and Open Source Software policies.*	CSL is working on implementing Open Data and Open Software policies. Currently, it is difficult to obtain NOAA DOIs for datasets, but CSL is part of a NOAA working group to address this issue.	Jenny Fox; Cathy Rasco	Start Date: October 1st, 2020 Completion Date: December 31st, 2023
5.3	*CSL should purposefully reach out to better incorporate Historically Black Colleges and Universities (HBCUs) into their research and development enterprise.*	See R1.1	Megan Melamed; Ann Thorne	
5.4	*CSL should complement their laboratory studies with theoretical chemistry expertise through strategic collaborations and partnerships.*	CSL will continue to interpret complex chemical systems that are important to atmospheric chemistry and NOAA's research goals through the powerful combination of expert laboratory studies with theoretical chemical methods.	Jim Burkholder	Start Date: January 1st, 2018 Completion Date: March 1st, 2026
5.5	*CSL should reinvest in and reestablish their heterogeneous chemistry expertise.*	The understanding of the chemical and physical processes that drive changes in atmospheric air quality, stratospheric ozone, and climate change will remain a CSL priority.	Jim Burkholder; Steve Brown; Ann Middlebrook	Start Date: Janaury 1st, 2021 Completion Date: March 1st, 2026
5.6	*CSL should continue to invest in the development of machine learning.*	Agreed. CSL has developed expertise in machine learning and will expand on these activities by applying them to a range of problems.	Graham Feingold; Karen Rosenlof; Greg Frost	Ongoing

6. Leadership Recommendations				
6.1	*More effective communication between CIRES and CSL leadership regarding career advancement opportunities.*	CSL will continue to work with CIRES to encourage science advisors and CIRES supervisors to make clear what success looks likes in the employee's position.	John Daniel; Christoph Senff	Start Date: September 1st, 2021 Completion Date: March 1st, 2026
6.2	*CSL leadership should work hard to create a strong culture of diversity and inclusion throughout the organization.*	See R1.1	Megan Melamed; Ann Thorne	
6.3	*Ensure support for CSL scientists to take on leadership roles within future IPCC assessments.*	The CSL Director will continue to support the involvement of CSL scientists in international assessments and organizations.	David Fahey	Start Date: September 1st Completion Date: March 1st, 2026
6.4	*Continue to support and promote CSL scientists as leaders of activities within the World Climate Research Programme (WCRP).*	See R6.3	David Fahey	
6.5	*CSL needs to continue its leadership and important role in the national discussion on research of climate interventions.*	Agreed. The CSL Director and senior scientists will continue to seek opportunities to contribute to the national and international discussion of climate intervention research.	David Fahey; Greg Frost; Graham Feingold	Ongoing

Appendix - Detailed Response

General Recommendations

***R1.1:** CSL needs to improve the diversity of its leadership and staff.*

R5.3: **CSL should purposefully reach out to better incorporate Historically Black Colleges and Universities (HBCUs) into their research and development enterprise.**

***R6.2:** CSL leadership should work hard to create a strong culture of diversity and inclusion throughout the organization.*

Action: CSL is developing a Diversity, Equity, & Inclusion (DE&I) Implementation Plan to address how CSL will implement the strategic plans of DOC, NOAA, OAR, ESRL, and cooperative institute partners, e.g., CIRES. Currently, CSL is actively increasing the diversity of its leadership and staff, including having a working group on inclusive hiring practices. CSL is also increasing its interactions and collaborations with CSCs through the ESRL/CSC engagement series and engaging with other minority serving institutions/organizations. It would be beneficial for OAR to be the primary Line Office for a CSC. CSL has a grassroots Working group on Equity & Inclusion that is working directly with the Director's Office to create a strong culture of diversity and inclusion.

Start/Completion Dates: June 11th, 2021/June 30th, 2022

Plan: CSL is developing a DE&I Implementation Plan that will address the above recommendations and DE&I more broadly in CSL. The Implementation Plan will address how CSL can improve the diversity of its leadership and staff through recruitment and hiring processes, form relationships with HBCUs and other Minority Serving Institutions (MSIs), including tribal colleges, through engagement with the NOAA Cooperative Science Centers (CSCs) and other organizations, and cultivate a strong culture of diversity and inclusion in the lab through trainings, mentorship, and evaluating workplace climate and structures to better support a more diverse workforce. It is imperative the CSL DE&I Implementation Plan aligns with DOC, NOAA, and OAR DE&I strategic plans, which are currently being finalized. In addition, since over half of the CSL staff are CIRES employees, it is also imperative to work with the CIRES Diversity and Inclusion Program in developing the CSL DE&I Implementation Plan. The CSL DE&I Implementation Plan will also include input from our current Federal and CIRES staff, in particular from the CSL Working Group on Equity and Inclusion (WEI).

***R1.2:** The CSL Research Strategy which encourages a high level of integration between field campaigns, laboratory studies, modeling, and instrument development across all research foci leads to outstanding research and should be actively nurtured and maintained.*

Action: Agreed. CSL will continue to nurture its Research Strategy of integration between field campaigns, laboratory studies, modeling, and instrument development across air quality, climate, and the stratosphere research themes.

Start/Completion Dates: Ongoing

Plan: CSL's core scientific goal is to improve the understanding of air quality, climate, and the stratosphere. This goal feeds the CSL Strategy, allowing for discovery, new questions, and stakeholder needs to be addressed using state-of-the-art instrumentation and models, world-class laboratory studies, and unparalleled field campaigns. CSL will continue to nurture this strategy by encouraging and providing opportunities for the eight CSL Research Programs to collaborate on research related to air quality, climate, and the stratosphere.

***R1.3:** NOAA OAR should continue to entrust CSL leadership with the management of the Laboratory's research funds and scientific direction.*

Action: Agreed. CSL will continue to take actions that instill trust in OAR to allow the laboratory manage its funding and scientific direction.

Start/Completion Date: Ongoing

Plan: The evaluation and recommendations from the 2021 laboratory review indicate that CSL leadership has been highly successful in managing laboratory resources and in providing research and management guidance and direction. The research landscapes for CSL themes of air quality, climate and the stratosphere are constantly evolving in terms of total knowledge and new opportunities. CSL leadership is comprised of experts who have successfully identified opportunities in these landscapes for CSL scientists and support staff to contribute to advancing research knowledge and other products, and research to operations/applications. These contributions are well documented in the review materials. CSL leadership will continue to manage and direct CSL research and communicate with NOAA OAR leadership as appropriate.

Air Quality Recommendations

R2.1: CSL research could better integrate environmental justice in considering how to prioritize scientific topics.

Action: Consideration of environmental justice science will be integrated into field campaign planning, data analysis, and modeling at CSL.

Start/Completion Dates: July 1st 2021/August 31st, 2023

Plan: The CSL research themes air quality and climate are particularly relevant to environmental justice since their impacts disproportionately disadvantage certain peoples' wellbeing and health. The incorporation of environmental justice as part of the CSL research portfolio must be carefully considered though. Environmental justice science aims to validate claims of environmental harm through data AND then productively engage with communities on their own terms to improve the environment for everyone. It is imperative that when CSL incorporates environmental justice into its research portfolio, it must have a plan developed in conjunction with social scientists, local/state/tribal agencies, and community members to achieve both aims of environmental justice science. CSL must not just show the disparities of how air quality and climate impact communities, but it must work with partners to empower those communities with data to engage in the decision-making process to have a healthy environment in which to live, learn, and work.

R2.2: CSL scientists should continue to play an active role in defining the components and preparing for NOAA's Geostationary and Extended Orbits (GEO-XO) satellite system.

Action: Agreed. CSL will continue its leadership role in informing the design of NOAA's next-generation geostationary satellite mission, GeoXO, by developing improved understanding and new applications of existing geostationary products.

Start/Completion Dates: Ongoing

Plan: In the next 5 years, CSL is planning a series of field experiments aimed at developing a better understanding of the utility and value of the TEMPO instrument and the application of TEMPO products to air quality prediction. Aircraft field work in AEROMMA (summer 2023) and in AQUARIUS (winter 2024/2025) will aim to quantify tropospheric profiles and columns of key trace gases and aerosols that impact urban and regional air quality across the continental US. CSL will compare these field measurements to TEMPO retrievals and other data sources (such as Pandora and TOLNET) and use TEMPO data in CSL's state-of-the-art regional air quality models. The result will be a quantitative assessment of the accuracy and variability of TEMPO trace gas and aerosol products and their value in NOAA's air quality forecasting. This work will inform the design and implementation of GeoXO's atmospheric composition instrument, ACX. CSL will also expand its involvement in GeoXO by making use of the current GOES-R Aerosol Baseline Imager (ABI) aerosol and fire radiative power measurements to analyze FIREX-AQ observations and to improve model treatments of wildfire smoke emissions, plume rise and chemistry. Lessons learned from analysis of ABI will be used to inform the design and implementation of GeoXO's imager, GXI.

R2.3: CSL modeling efforts should be expanded to include support for development of improved operational air quality predictions at national, global, and regional scales.

Action: CSL will continue to support development of NOAA operational air quality models at global and regional scales in particular through evaluation of model processes using aircraft data.

Start/Completion Dates: September 1, 2021/September 30th, 2023

Plan: CSL will continue to evaluate NOAA operational or planned to be operational global (e.g., FV3GFS-Aerosol component of GEFS*) and regional (e.g., RRFS-CMAQ**) air quality models against the ATom and FIREX-AQ aircraft campaigns in particular to diagnose problems, improve model process representations, and serve as a benchmark to evaluate model updates. Additionally, CSL in collaboration with other labs at NOAA and NCAR will develop a python model diagnostic tool called MELODIES-MONET to evaluate research, operational, and regulatory models against a variety of observations including surface, aircraft and satellite data all within a common framework. Through contributing to MELODIES-MONET development, CSL will not only provide evaluation plots for NOAA operational models, but a flexible and straightforward tool to do the evaluation, which will improve connections at NOAA between research and operations. Furthermore, CSL will collaborate with EPA to develop a new chemical mechanism called CRACMM, which will incorporate the latest advances in scientific research including accurate representation of multiphase chemistry and still be reduced enough to be considered for future use in operational and regulatory models. *GEFS = Global Ensemble Forecast System (GEFS); ** RRFS-CMAQ - Refresh Forecast System (RRFS) using the Community Multiscale Air Quality (CMAQ) chemistry

***R2.4:** Improve CSL's data management of air quality datasets by providing data in a timely manner and adopting open data policies.*

***R5.2:** CSL should aspire to make their research enterprise more open by adopting Open Data and Open Source Software policies.*

Action: CSL will create a data management plan in accordance with NOAA Administrative Order (NAO) 212-15, Management of Environmental Data and Information

Start/Completion Dates: July 1st, 2021/September 30th, 2022

Plan: The CSL data management plan will be a combination of two major activities conducted in coordination, data management and data stewardship, which together will constitute a comprehensive end-to-end process including movement of data and information from the observing system sensors to the data user. This process includes the acquisition, quality control, metadata cataloging, validation, reprocessing, storage, retrieval, dissemination, and archival of data. CSL will create an overall data management plan with general guidelines for the storage and dissemination of the variety of datasets that are collected and analyzed, and specific plans for data that will be provided to the public. These data management plans will be stored in the local records management repository and also in the NOAA Data Management Plan repository. Hiring a full-time data manager would be instrumental in completing this task in a timely manner.

***R2.5:** Continue to develop and support a collection of state-of-the-science instrumentation to allow for both rapid and repeated deployment.*

Action: Agreed. Continue to develop and support a collection of state-of-the-science instrumentation to allow for both rapid and repeated deployment.

Start/Completion Dates: Ongoing

Plan: CSL develops new instruments to meet the changing needs in addressing important scientific questions related to air quality, climate, and the stratosphere. The CSL nature of collaboration allows for worldwide expertise in pursuing the most intuitive instrument designs that fall into the categories of innovation (new instrument concepts developed at CSL), evolution (continually improving existing instruments), and adaptation (enhancing the capability of commercially available instruments). CSL's approach to instrument development allows the laboratory to respond rapidly and repeatedly with state-of-the-science instrumentation to address stakeholder needs, new questions, and new discoveries.

***R2.6:** CSL should continue collaborations with scientists at academic institutions and other agencies to continue to maximize impact and catalyze research beyond NOAA.*

Action: Agreed. CSL will continue collaborations with scientists at academic institutions and other agencies.

Start/Completion Dates: Ongoing

Plan: CSL engages on a regular basis with scientists at academic institutions and other agencies. The engagements can range in scope from co-authoring publications to sharing data to hosting scientists at CSL to model evaluation to organizing large scale field campaigns. Collaborations are essential when conducting scientific research and this is recognized, valued, and supported at CSL.

***R2.7:** Seek strategic collaborations to implement the air quality health effect link early in the research value chain.*

Action: Strategic collaborations will be considered in order to incorporate air quality health effects in CSL research.

Start/Completion Dates: September 1st, 2021/August 31st, 2023

Plan: The research conducted by CSL on air quality has direct links to human and ecosystem (including agriculture) health. In fact, much of the research at CSL has informed policy decisions related to air quality over the past three decades. CSL could more effectively engage with the human and ecosystem health research community to develop its research goals and plans in a transdisciplinary manner. This requires seeking strategic collaborations with individual scientists that are able to and interested in engaging in transdisciplinary research on the human and ecosystem health impacts of air quality. CSL will continue to reach out to the human and ecosystem health community to establish relationships with scientists and co-develop research with them.

***R2.8:** Continue efforts to make efficient use of satellite products and prepare for full utilization through additional in-house expertise.*

***R3.4:** Given the importance of the TOAR effort, CSL should consider adding a new scientist with expertise in the retrieval of tropospheric ozone from satellite sensors.*

Action: Agreed. CSL will continue to evaluate the scientific expertise required in the laboratory to help develop and use satellite products efficiently and effectively to advance atmospheric chemistry and climate research as well as meet user needs.

Start/Completion Dates: Ongoing

Plan: CSL scientists currently use satellite products on a regular basis for database development, model evaluation, and measurement intercomparison activities. The development of new geostationary satellites with atmospheric composition instruments in the US, e.g., TEMPO and GeoXO, is revolutionizing how satellite products will be used for atmospheric chemistry and climate research. CSL will actively evaluate the expertise it has and needs to be a leader in the development, use, and evaluation of satellite products and will train/hire accordingly.

Climate Recommendations

***R3.1:** Consider repeating the systematic sampling of the remote atmosphere similar to the recent ATom field campaign.*

Action: CSL will promote the scientific value of the ATom campaign to scientists and program managers to increase interest in conducting similar airborne campaigns in the future.

Start/Completion Dates: June 1st, 2021/December 31st, 2025

Plan: CSL has already begun discussions with partners considering potential future global-scale measurements over both continental and remote marine regions, likely coordinated with new satellite instruments such as TEMPO, PACE, GEMS, and, in the 2030's, GeoXO. As NOAA does not currently have an intercontinental-range research aircraft with the appropriate payload capability, coordination with NASA is essential. Preliminary discussions with other NOAA laboratories began in June 2021, and more focused discussion to design and identify resources for an ATom-like program will be ongoing in 2021 and 2022. Airborne sampling similar to ATom may be incorporated into projects envisioned for 2023-24 underneath geostationary satellites, but a dedicated project is likely only after 2024. One likely course action is to hold an informal virtual workshop in 2022 to 1) identify key scientific questions that can best be resolved by global-scale sampling; 2) specify required measurements, platform capabilities, and resources; 3) investigate locations/routes for sampling that best address (1) and that provide opportunities for new discoveries; and 4) develop funding partnerships that can share the considerable cost of an ATom-like project.

***R3.2:** CSL climate science should also consider focusing on solutions and reducing risk.*

Action: CSL conducts policy-relevant science that informs possible climate solutions and risk reduction.

Start/Completion Date: Ongoing

Plan: At NOAA we are enjoined to do science that is policy-relevant but not policy-prescriptive. Yet researching specific climate questions, such as fugitive emissions of methane from oil and gas fields, can often point to possible solutions. This panel recommendation specifically focused on the stratosphere. With the Earth Radiation Budget (ERB) project, CSL intends to significantly expand our research portfolio of stratospheric observations and modeling that will help show the background against which any stratospheric radiation management programs will be implemented. Understanding the existing stratosphere is essential to reducing the risk of any interventions.

***R3.3:** Continue to use the CLS LES ensemble simulations to develop low-order, simplified models.*

Action: Agreed. CSL will continue to use CLS LES ensemble simulations to develop low-order, simplified models.

Start/Completion Date: Ongoing

Plan: (i) CSL is expanding earlier emulator development towards studying stratocumulus evolution to include a diurnal cycle of evolution for Californian stratocumulus. Climatological input conditions based on ERA-5 have been identified and the LES model is being adapted for ingesting these conditions. Simulations will commence by September 1, 2021. Emulator codes are mature but will likely require modifications due to new external forcings; (ii) in collaboration with applied mathematicians at Scripps Oceanographic Institute (Prof. M. Morzfeld), CSL will continue our work using Markov Chain Monte Carlo methods to fit

LES output to a low-dimensional predator-prey (PP) model. Prior work identified optimal PP model parameters for a single case study. New work will expand to a broader range of conditions; (iii) CSL is further developing the PP model to include marine boundary layer processes at a range of temporal scales to explore the interplay between natural and anthropogenic forcings.

***R3.4:** Given the importance of the TOAR effort, CSL should consider adding a new scientist with expertise in the retrieval of tropospheric ozone from satellite sensors.*

Action: See R2.8

Stratosphere Responses

***R4.1:** Moving forward CSL should continue to focus on the impact of replacements for CFCs and observational strategies to continue ensuring a consistent long-term record of the evolution of stratospheric composition.*

Action: Agreed. CSL will continue laboratory studies to quantify the atmospheric chemistry and climate metrics of CFC replacements and improve stratospheric observational strategies and capabilities.

Start/Completion Date: Ongoing

Plan: CSL will apply its expertise in laboratory studies to support stakeholder (industry, government agencies, and international assessments) needs in the evaluation of CFC replacement compounds and associated atmospheric degradation products. The development of in situ instrumentation within CSL to measure stratospheric composition is a major CSL priority. High-altitude flights for "SABRE" – Stratospheric Aerosol processes, Budget, and Radiative Effects are scheduled for FY22. These research flights will measure aerosols, ozone, and a suite of reactive species. This research will provide needed information on baseline stratospheric composition and inspire future missions to support an evaluation of a changing atmosphere.

***R4.2:** CSL should continue to expand the budget for POPS Balloon Baseline Stratospheric Aerosol Profiles (B2SAP) project, particularly with the new focus on climate intervention studies.*

Action: Agreed. CSL will continue and expand balloon borne measurements.

Start/Completion Dates: October 1st, 2020/September 30th 2025

Plan: CSL's balloon deployment program has the potential for exponential growth via expanded sampling in frequency, latitude, and longitude. Deployments from Quito, Ecuador and Hilo, HI are planned to occur in FY 22&23, with commensurate increases in package production and distribution. Additionally, balloon-compatible instruments of value to climate intervention science are being developed by CSL for co-flights as part of this program.

***R4.3:** CSL should leverage the potentially short-term ERB funding to support activities that will build strengths and skills in CSL that can be continued.*

Action: Agreed. CSL will leverage ERB funding to develop scientific capabilities (instrumentation, models, and expertise) that will enhance its boarder mission to advance scientific understanding of the chemical and physical processes that affect Earth's atmospheric composition and climate.

Start/Completion Date: March 6th, 2020/ongoing

Plan: Appropriated funds for FY2020 and FY2021 for NOAA to lead a multi-year research initiative to investigate natural and human activities that might alter the reflectivity of the stratosphere and the marine boundary layer, and the potential impact of those activities on the Earth System are being used by CSL to accelerate its strategy as outlined in the 2021-2026 CSL Strategic Plan. The development of instrumentation, models, and expertise to understand the Earth's radiation budget is occurring under the broader context of the CSL mission to advance scientific understanding of the chemical and physical process that affect Earth's atmospheric composition and climate. The acceleration of the CSL strategy ultimately better equips CSL to respond to additional emerging and evolving societal issues related to air quality, climate, and the stratosphere.

***R4.4:** The CSL chemistry-climate group, which has recently lost two modelers, should be a high priority for both the long-term retention of current modelling expertise and the potential location for a new hire.*

Action: Maintain staffing within the CSL Chemistry and Climate Processes program to support modeling studies related to stratospheric composition and stratosphere/troposphere interactions.

Start/Completion Date: July 1, 2021/November 30th,2021

Plan: In July 2021, the CSL chemistry-climate group hired one CIRES scientist to work on stratosphere/troposphere coupling/interactions; this will involve interpreting model output and eventually running climate models. An offer has been made for a second CIRES scientist to work on satellite data analysis and trajectory modeling to study the impact of intense convection on stratospheric composition, this individual should start in Fall 2021. Over the past 2 years, 2 mid-career scientists working on stratospheric composition and stratosphere/troposphere coupling were hired as federal employees. As younger scientists involved with modeling cycle through the program, we anticipate replacing them as funding allows.

Research Strategies Recommendations

R5.1: ***CSL should ensure stable base funding of its instrument engineering staff and plan ahead by developing viable succession plans for each staff member, because this team is critical to the continued success of CSL's integrated research strategy.***

Action: CSL's top-flight cadre of engineers and support scientists are critical to the laboratory's success, and CSL is currently developing plans to ensure continuity of this support.

Start/Completion Date: September 1st, 2021 / September 30th, 2023

Plan: CSL has ongoing needs for support in the areas of instrument design, software development, electronics, and data archiving and management. CSL has made recent hires in software development and instrument design within specific program areas and will train these support staff to serve the longer-term needs of the lab. CSL will identify opportunities for one or more new hires to specifically support the area of instrument design, for which there is a strong laboratory-wide need. CSL will continue strategic and targeted hiring to deepen support staff resources.

R5.2: CSL should aspire to make their research enterprise more open by adopting Open Data and Open Source Software policies.

Action: CSL is working on implementing Open Data and Open Software policies. Currently, it is difficult to obtain NOAA DOIs for datasets, but CSL is part of a NOAA working group to address this issue.

Start/Completion Date: October 1st, 2021/December 31st, 2023

Plan: CSL will expand the use of Github for software collaboration. CSL will expand datasets available in the public domain. Currently it is difficult to obtain NOAA DOIs for datasets and software products, but CSL is working with other NOAA research laboratories on the NOAA Environmental Data Management Council (EDMC) DOI reform working group to create a manageable and streamlined process for obtaining dataset DOIs.

R5.3: CSL should purposefully reach out to better incorporate Historically Black Colleges and Universities (HBCUs) into their research and development enterprise.

Action: See R1.1

R5.4: CSL should complement their laboratory studies with theoretical chemistry expertise through strategic collaborations and partnerships.

Action: CSL will continue to interpret complex chemical systems that are important to atmospheric chemistry and NOAA's research goals through the powerful combination of expert laboratory studies with theoretical chemical methods.

Start/Completion Date: January 1st, 2018/March 1st, 2026

Plan: Progress in the development of in-house theoretical capabilities has been enhanced in the past several years by leveraging NOAA's HPC facilities and through visiting scientist appointments, which will continue and be expanded in the future. CSL will focus on engaging inspired external theoretical experts to provide needed insights into chemical systems for which experimental measurements are currently not available, or possible.

R5.5: CSL should reinvest in and reestablish their heterogeneous chemistry expertise.

Action: The understanding of the chemical and physical processes that drive changes in atmospheric air quality, stratospheric ozone, and climate change will remain a CSL priority.

Start/Completion Date: January 1st, 2021/March 1st, 2026

Plan: There is a need within CSL for researchers to perform laboratory based heterogeneous chemistry experiments using, in particular, the high-resolution mass spectrometer instrumentation available within CSL and for the analysis of field data related to heterogeneous chemistry. Heterogeneous chemistry studies are underway in the laboratory to investigate heterogeneous optical and physical transformations of $CaCO_3$ particles, a candidate for use in climate intervention, upon exposure to chloride, nitrate, and sulfate. The solubility and aqueous phase processing of HPMTF and biomass burning products is also being investigated. In lieu of direct hires, CSL will work towards engaging inspired external scientists with expertise in heterogeneous processes in the research projects as necessary.

R5.6: CSL should continue to invest in the development of machine learning.

Action: Agreed. CSL has developed expertise in machine learning and will expand on these activities by applying them to a range of problems.

Start/Completion Dates: Ongoing

Plan: Machine learning (ML) is now an increasing part of activities in CSL and encompasses the following key themes: (i) physics parameterizations for large scale models, including cloud microphysics algorithms and surface radiation processes; (ii) identification of causal relationships between a set of inputs such as cloud field properties and outputs such as cloud fraction or cloud radiative effect in support of NOAA's Atmospheric Science for Renewable Energy (ASRE) surface solar radiation project; (iii) participation in 2 projects supported by FY19 Hurricane Supplemental Phase 2 (HSUP2) funding from Congress, CSL and CIRES are using observations from FIREX-AQ to evaluate ML enhancements to NOAA's next-generation high-resolution operational forecasts by the Rapid Refresh Forecast System (RRFS) combined with the Community Multiscale Air Quality (CMAQ) chemistry module. ML is being used by CSL/CIRES's HSUP2 partners to develop computationally efficient treatments for the diurnal cycle of wildfire emissions and plume rise and regional simulations of ozone and particulate matter in RRFS-CMAQ, while CSL is providing the observational testing and evaluation of these ML advancements; (iv) CSL is using large-eddy simulations combined with detailed chemistry treatments and ML to explore relationships between wildfire parameters and smoke plume rise and downwind chemistry. The eventual goal is to develop computationally efficient parameterizations that could be used in mesoscale air quality and smoke forecasting; (v) CSL is using artificial intelligence (AI) to improve skill in seasonal forecasts of the Southern Annular Mode (SAM), by utilizing the stratosphere as a source of long time-scale predictability; (vi) CSL plans to explore the potential for forecasting ozone air quality on subseasonal to seasonal (S2S) timescales. We will use persistent patterns of tropospheric and stratospheric large-scale circulation, and their remote teleconnections, as sources of predictability.

Leadership Recommendations

R6.1: More effective communication between CIRES and CSL leadership regarding career advancement opportunities.

Action: CSL will continue to work with CIRES to encourage science advisors and CIRES supervisors to make clear what success looks likes in the employee's position.

Start/Completion Dates: September 1, 2021/March 1st, 2026

Plan: CSL management must be measured here, as promotion and determination of success in CIRES is a CIRES administrative matter and Federal employees cannot interfere with that. Where allowable under the cooperative agreement, CSL management will work with the CSL CIRES lead to ensure that the Federal science advisors communicate with the CIRES supervisors and assist them in conveying expectations for success and requirements for advancement to more junior CIRES staff.

R6.2: CSL leadership should work hard to create a strong culture of diversity and inclusion throughout the organization.

Action: See R1.1

R6.3: *Ensure support for CSL scientists to take on leadership roles within future IPCC assessments.*

R6.4: *Continue to support and promote CSL scientists as leaders of activities within the World Climate Research Programme (WCRP).*

Action: The CSL Director will continue to support the involvement of CSL scientists in international assessments and organizations.

Start/Completion Date: September 1st 2021/March 1st, 2026

Plan: CSL is an international leader in atmospheric chemistry, composition, and climate due to its involvement and leadership in international assessments and organizations. The CSL Director's Office will continue to support and promote the involvement of its scientist to serve in leadership roles for international assessments such as the WMO/UNEP Scientific Assessment of Ozone Depletion and the IPCC. In addition, CSL will also encourage its scientists to serve the international community by serving in leadership roles for organizations such as the World Climate Research Programme (WCRP) Stratospheric-tropospheric Processes and their Role in Climate (SPARC), the Future Earth International Global Atmospheric Chemistry (IGAC) Project, and the World Meteorological Organizations (WMO) Global Atmosphere Watch (GAW) Programme.

Status/Notes: Dr. David Fahey is the co-chair of the Scientific Assessment Panel of the Montreal Protocol, which produces the WMO/UNEP Scientific Assessment of Ozone Depletion. Dr. Karen Rosenlof is on the WCRP-SPARC Steering Committee. Dr. Gregory Frost is on the IGAC Steering Committee. Dr. Owen Cooper is on the WMO GAW Scientific Advisory Group (SAG) for Reactive Gases.

R6.5: *CSL needs to continue its leadership and important role in the national discussion on research of climate interventions*.

Action: Agreed. The CSL Director and senior scientists will continue to seek opportunities to contribute to the national and international discussion of climate intervention research.

Start/Completion Date: Ongoing

Plan: CSL has a large and expanding role in climate intervention (CI) research due to its long-standing stratospheric research theme and more recently due to directed Congressional funding for the Earth's Radiation Budget program. In the past, this role has led to invitations to present CI research and concepts at high visibility national meetings, at internal NOAA and OAR meetings, in support of writing CI reports under the auspices of the National Academies of Sciences, Engineering, and Medicine, and in support of assessments prepared for the Parties to the Montreal Protocol on Substances that Deplete the Ozone Layer. CSL leadership will continue to seek out similar opportunities to contribute as the importance of the CI topic increases in our national discussion, including engaging critically in establishing a physical science roadmap that will lay out a list of checkpoints that must be met before implementation can be considered.