January 3, 2018

Dear Dr. Shepson,

Mountain research sites provide a unique window on atmospheric composition. These stations allow for continuous observations at high elevation, potentially in the free troposphere, where many important processes occur, and data are scarce. Observations on mountain-tops allow for studies on long-range transport of constituents, cloud and precipitation processes, and boundary layer ventilation. Receiving primarily long-range transported and well-mixed air, mountain sites are the best locations for studying long-term trends of climate-relevant gases and aerosols. Mountain stations provide an added vertical dimension to traditional sites without the expenses incurred by airborne sampling, while providing critical information for extreme episodes (e.g., biomass burning, radionuclide releases, erupting volcanoes, dust storms, stratospheric intrusions, etc.). Mountain research stations have also provided unique research training opportunities for numerous U.S. academic institutions.

At present, **the U.S. operates only a very few mountain sites for long-term observations of atmospheric composition.** As such, it is difficult to study important atmospheric phenomena that occur in mountainous environments. Thus, for some important atmospheric drivers, such as aerosols, ozone and other oxidants, or environmental toxins, we have only a weak understanding of key sources-sink relationships and long-term trends. Furthermore, most forests in the U.S. are in mountains and mountain forests are particularly sensitive to changing climate drivers. Assessing the national carbon balance, and contribution to carbon-climate feedbacks requires more direct measurements.

In the last decade, numerous reports, including three from the U.S. National Academies of Sciences (NAS), have advocated for long-term measurements at mountain sites. The 2010 NAS report[1] titled "America's Climate Choices: Panel on Advancing the Science of Climate Change" recommended the federal government to redouble efforts towards long-term, stable, and well calibrated observations. The report stressed that mountains are strong indicators of climate change. Also in 2010, the NAS report titled "Global Sources of Local Pollution"[2] stated that continuous aerosol measurements, including those made at strategically located mountaintop sites, can help identify sources, distinguishing between local and long-range transported pollutants. Most recently, a key recommendation of the 2017 NAS report[3] is that the "**National Science Foundation should take the lead in coordinating with other agencies to identify the scientific need for long-term measurements and to establish synergies with existing sites that could provide core support for long-term atmospheric chemistry measurements, including biosphere–atmosphere exchange of trace gases and aerosol particles".**

Given the national priority to better understand the global atmosphere, we believe the NSF "Mid-scale Research Infrastructure" could provide a critical boost to address this national need and opportunity. This NSF initiative could support infrastructure and initial operations for a network of mountain-based atmospheric observatories, dedicated to critical science questions that require long-term observations. As a starting point, we are calling this initiative the **U.S. Mountain Network for Atmospheric Composition (USMNAC)**.

The critical science needs are given below. Here we summarize six key science drivers and questions:

i. What are the sources and sinks of greenhouse gases in the U.S. and globally?
ii. What are the domestic and international sources of key global pollutants such as ozone, mercury, aerosols, and what are the implications of these pollutants?
iii. What determines the cloud nucleating properties and radiative effects of aerosols transported at higher elevations?
iv. What are the current fluxes of trace gases between the biosphere and the atmosphere and how will these change in the future?
v. What is the role of snow and ice in the climate system? How will mountain snowfall, along with aerosol deposition on snow/ice change in the future?
vi. What are the sources, sinks, and trends of reactive gases, and drivers in atmospheric oxidation chemistry and cycles?

As an appendix to this letter, we have compiled a list of current mountain observatories (Table 1), along with a possible list of key measurements and instrumentation. Based on the science drivers above, we have created two preliminary measurements lists. The first list (Table 2) includes continuous measurements that are needed at each mountain site, which can be supplemented by additional measurements (Table 3) for process studies. While neither of these three lists should be considered fully comprehensive or final, these serve as a starting point for future discussions on this initiative. Additionally, within the appendix, we have provided further detail on the science needs listed above, focusing on the role mountain stations will play to tackle these grand challenges.

As a practical matter, several signers of this letter have responded to the NSF “Dear Colleague Letter: Request for Information on Mid-scale Research Infrastructure.” We did this since it was not possible to include all of the important ideas under this initiative within the character limit restrictions of the submission. Thus, one group (D. Jaffe) has submitted science ideas on global pollutants, another group (E. Andrews) on atmospheric aerosols, a third group (J. Lin) on greenhouse gases, the fourth group (A. G. Hallar) on mountain snowfall, and a fifth group (S. Lance) on cloud chemistry. You should know that we are all enthusiastically supportive of the concept of USMNAC and will be happy to collaborate in future planning for this initiative.

In closing, we feel that the U.S. has under-invested in critical infrastructure in the Atmospheric Sciences. While the nation spends billions of dollars addressing problems from pollution and climate change, our investment in observations for understanding these problems is unfortunately lagging behind that of many other developed nations. Our proposed network of mountain observatories—USMNAC— will represent a paradigm shift in how U.S. infrastructure for observations in Atmospheric Sciences are operated, leading to major scientific discoveries of national importance, and engaging and energize a generation of students in the atmospheric and environmental sciences.

We look forward to further engaging with the NSF leadership on this important topic and very much appreciate your work and leadership for the Atmospheric Sciences.

Signed by:

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REFERENCES:

[1]National Research Council. "America’s Climate Choices: Panel on Advancing the Science of Climate Change”. 2010. *Adapting to the impacts of climate change*.

[2]National Research Council-Board on Atmospheric Sciences and Climate. Global Sources of Local Pollution: An Assessment of Long-Range Transport of Key Air Pollutants to and from the United States, 2010. Available at: http://books.nap.edu/catalog/12743.html

[3]National Academies of Sciences, Engineering, and Medicine. *The Future of Atmospheric Chemistry Research: Remembering Yesterday, Understanding Today, Anticipating Tomorrow*. National Academies Press, 2017.

APPENDIX:

One aspect which pertains to all six science drivers is that multiple mountaintop sites offer the ability to study airmass evolution of domestic emissions, as well as incoming transcontinental emissions. Additionally, atmospheric composition measurements at mountain sites are also critical for providing vertical evaluation of models and satellite-based retrievals of atmospheric constituents. These validations are critical and complicated over mountainous terrain.

Pertaining to science driver #1 (i) above, long-term monitoring of CO_2 and related tracers have been and continue to be vital for advancing our understanding of the fate of emitted CO_2 from anthropogenic sources and anticipating carbon-climate feedbacks that will have large impacts on future temperatures. There is a need to increase the density of these observations, recognizing that in many cases significant amounts of biomass are found in complex terrain, and that climate impacts are often more pronounced at high altitudes. Furthermore, satellite retrievals of CO_2 are also subject to larger errors in mountainous areas and hence the importance of the mountaintop sites.

Regarding science driver #2 (ii), one important example pertains to O_3, which has health and ecosystem impacts at levels relatively close to background concentrations. With a new lower O_3 standard, set in 2015, states and cities around the country must respond to demonstrate compliance by reducing emissions. But natural and global sources can elevate O_3 well above the standard. This has been most strongly demonstrated at sites like the NSF supported Mt. Bachelor Observatory (2.8 km asl, in Oregon). At present, it is not clear how or whether high elevation cities in the western U.S., such as Denver, will be able to meet the new standard, given our uncertainty in the sources of background O_3. While a few studies have demonstrated some success at modeling global O_3, there are large variations between models. A network of mountain observatories would provide substantial new information on O_3, as well as other key pollutants in the atmosphere.

Regarding science driver #3 (iii) above, it should be noted that currently, long-term aerosol number size distribution and cloud condensation nuclei measurements are significantly underrepresented within the U.S. This was noted clearly in the Asmi et al. (2013)[4] paper on aerosol decadal trends. No site in the U.S. exists with a continuous ten-year measurement of aerosol number size distribution, in stark contrast to the representation in Europe. Similarly, Schmale et al. (2017)[5] found only one long-term CCN data set in the US (in Barrow, AK) that was co-located with the measurements of size distribution and chemistry needed for evaluation of cloud processes. Schmale et al. (2017) further noted *"Collocated long-term observations of CCN activity, particle number size distribution and chemical composition are sparse", and stressed the need for this data at regionally-representative mountainous sites.*

The forest regions surrounding these mountaintop sites also allows for observations of local biomass smoke impacts as well as long-range transported smoke from wildland fires (pertaining to science drivers 2,3, 4, 5 and 6 above).

Pertaining to science driver #5 (v) above, snowfall can last many months, and is critical for maintaining water reservoirs that supply large urban areas; shifts in the types and amount of precipitation have serious repercussions for agricultural and domestic water availability, as well as for the winter recreational industry. Mountainous climate regimes are seeing a general shift towards precipitation types found in warmer climates such as wet snow and rain. Adequate long-term measurement capabilities do not currently exist to observe these transitions.

Based on these six science drivers, we have identified a group of high elevation locations (Table 1) possessing existing infrastructure and/or a history of previous measurements. These stations are currently managed by U.S. investigators, primarily from academic institutions. The locations represent different ecosystems and remote regions across the globe. The challenges listed above will be met both with existing and expanded instrumentation at these sites. A full list of instruments required and agreed upon is included as an appendix to this letter (Table 2). Many of these sites already have some subset of the instrumentation described below; however, to develop a cohesive/integrated picture, more overlap and consistency in instrumentation across sites are necessary. Long-term support is missing for most of these sites (exceptions are Mauna Loa, Summit, and South Pole).

Table 1. Proposed network of high elevation sites run by U.S. institutions

Mauna Loa, HI
Mount Bachelor, OR
Mount Lemmon, AZ
Hidden Peak, UT
Storm Peak Laboratory, CO
Niwot Ridge, CO
Elk Mountain Observatory, WY
Langmuir Lab, NM
Summit, Greenland
Pico del Este, PR
Appalachian State, NC
Mammoth, CA
Pinnacles, VA
Whiteface Mountain, NY
Mount Washington, NH
Pico Mt. Observatory, Azores
South Pole, Antarctica

Table 2: Possible instrumentation for all USMNAC observatories.

Measurement	**Science Driver**	**Examples of the types of instrumentation required**
Carbon Dioxide	#1: Carbon budget #4: Biosphere Flux	Cavity ring-down spectroscopy-based instruments (e.g., from Picarro & Los Gatos Research)
Methane	#1: Carbon budget #4: Biosphere Flux #6: Reactive Gases	Cavity ring-down spectroscopy-based instruments (e.g., from Picarro & Los Gatos Research) Gas Chromtography
Carbon Monoxide	#1: Carbon budget #6: Reactive Gases	TECO Model 48i CO analyzer
13C and 18O of CO_2	#1: Carbon budget #4: Biosphere Flux	Delta Ray™ Isotope Ratio Infrared Spectrometer (IRIS)
VOC measurements	#1: Carbon budget #4: Biosphere Flux #6: Reactive Gases	Whole air canister EPA TO-15 measurement; In-situ Gas Chromatography, whole air sample collection, PTR-MS
Snow Water Equivalent	#3: Aerosol Effect #5: Precipitation Changes	Multiple NOAH IV – ETI Precipitation Gauge
Snow Depth	#3: Aerosol Effect #5: Precipitation Changes	Multiple Sonic snow depth gauges
Snowflake Habit	#3: Aerosol Effect #5: Precipitation Changes	Multiangle Snowflake Camera
Aerosol Size Distributions from nano to coarse	#2: Long Range Transport #3: Aerosol Effect #4: Biosphere Flux	TSI Nano Scanning Mobility Particle Sizer (SMPS), TSI Standard SMPS, and TSI Aerodynamic Particle Size
Cloud Condensation Nuclei (CCN)	#3: Aerosol Effect	DMT Two Column CCN Counter
Aerosol Scattering	#2: Long Range Transport #3: Aerosol Effect	Ecotech Integrating Nephelometer
Aerosol Absorption	#2: Long Range Transport #3: Aerosol Effect	Brechtel Tri-color Absorption Photometer
Aerosol Concentration	#2: Long Range Transport #3: Aerosol Effect	TSI Condensation Particle Counter (both fine and ultrafine)
Aerosol Chemical Composition	#2: Long Range Transport #3: Aerosol Effect	Aerodyne Aerosol Chemical Speciation Monitor

	#4: Biosphere Flux	
Aerosol Optical Depth	#3: Aerosol Effect #4: Long Range Transport	Sunphotometer
Aerosol Vertical Profile	#2: Long Range Transport #3: Aerosol Effect #4: Biosphere Flux	Micro-pulsed lidar
Ozone	#2: Long Range Transport #4: Biosphere Flux #6: Reactive Gases	Thermoscientific 49i
Nitrogen oxides	#2: Long Range Transport #3: Aerosol Effect #4: Biosphere flux #6: Reactive Gases	Thermoscientific 42i-TL
Sulfur dioxide	#3: Aerosol Effect #4: Long Range Transport	Thermoscientific 43i
Meteorology (including temperature, pressure, wind speed and direction, and relative humidity)	Needed for all Science Drivers	Multiple meteorological stations at strategic locations across each mountain.
Boundary layer dynamics in mountainous region	Needed for All Science Drivers	Wind Profilers, radiosondes

Additionally, we have included a request for a suite of instrumentation to study cloud microphysics which are not designed for long-term remote monitoring (i.e., they require the presence of personnel). Mountain research stations provide a platform to perform in-cloud studies, over extended time duration, without requiring the use of an airplane. Many of these sites allow for studies of mixed phase clouds, including compositions studies of ice and cloud nucleating particles. In comparison to warm clouds, less is known about aerosol effects and feedback mechanisms associated with mixed-phase clouds. Understanding the impact of mixed-phase clouds on atmospheric radiation and generation of precipitation is complex and this lack of knowledge is limiting our ability to describe clouds in global climate models, as emphasized in the Fifth Assessment Report[6]. Thus, we propose to establish several mobile packages of these instruments (Table 3) that can be moved from site to site for intensive campaigns. Each of these instruments is now commercially available and has been tested at a mountain-top facility.

Table 3: Potential intensive campaign instrumentation package

Measurement	**Science Driver**	**Instrumentation Required**
Cloud droplet size distribution	#5 Precipitation Changes #3: Aerosol Effect	DMT SPP-100
Cloud crystal size distribution	#5 Precipitation Changes #3: Aerosol Effect	DMT Cloud Imaging Probe and DMT Precipitation Imaging Probe

Insitu - Ice nuclei concentration	#5 Precipitation Changes #3: Aerosol Effect	DMT SPIN or Handix Scientific Continuous Flow Diffusion Chamber
Off-line Ice nuclei concentration	#5 Precipitation Changes #3: Aerosol Effect	Filter collection for drop freeze assay
Cloud chemistry	#5 Precipitation Changes #3: Aerosol Effect	
Water Vapor Isotope	#5 Precipitation Changes #3: Aerosol Effect	Cavity ring-down spectroscopy-based instruments (e.g., from Picarro & Los Gatos Research)
Ability to separate cloud drops from aerosol particles for further analysis	#5 Precipitation Changes #3: Aerosol Effect	Brechtel Counterflow Virtual Impactor

REFERENCES FOR APPENDIX

[4] Asmi, Ari, et al. "Aerosol decadal trends–Part 2: In-situ aerosol particle number concentrations at GAW and ACTRIS stations." *Atmospheric Chemistry and Physics* 13.2 (2013): 895-916.

[5] Schmale, J. and Coauthors, 2017: What do we learn from long-term cloud condensation nuclei number concentration, particle number size distribution, and chemical composition measurements at regionally representative observatories? Collocated observations of cloud condensation nuclei, particle size distributions, and chemical composition, Atmos. Chem. Phys. Disc., https://doi.org/10.5194/acp-2017-798.

[6] IPCC, 2014: Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, R.K. Pachauri and L.A. Meyer (eds.)]. IPCC, Geneva, Switzerland, 151 pp.