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## Decision-making Activity

This project will address the decision-making activities/actions regarding air quality by the Mongolian National Agency for Meteorology and Environmental Monitoring (NAMEM) and the Mongolian National Broadcaster (MNB). This study will directly result in NAMEM developing an improved modeling and observation system based on NASA satellite and numerical model earth observations to forecast wintertime pollution episodes, to inform decisions made by NAMEM on air quality health warnings. This study will also directly impact the local population through improved forecasts and guidance related to health exposure.

The decision-making capabilities with respect to air quality guidance beyond current conditions is highly lacking in Mongolia. This study will also enable improvements in the available monitoring of pollutants and short and long-term (out to 7 days) forecasts of pollution episodes. This knowledge will enable NAMEM to make more scientifically-based and informed decisions to warn the public about health hazards associated with high pollution, and to recommend actions for various groups (e.g., for sensitive groups to limit outdoor activities during high pollution levels). Specifically, this study will improve the capabilities of NAMEM and MNB for environmental monitoring of pollution, forecasting of high pollution episodes and dissemination of air quality observations and forecasts. NAMEM is mandated to provide weather, climate, hydrology, and air quality forecasts in Mongolia. The goal of NAMEM is to “provide government organizations and the public with weather, climate and hydrological forecasts and warnings for the protection of human life and property from natural disasters and the enhancement of the national socioeconomic development of the country.”

***Air quality monitoring***: The basic infrastructure is currently insufficient to accurately measure and forecast the pollution concentrations in Ulaanbaatar, Mongolia. Currently, the government air pollution-monitoring network routinely monitors PM2.5 and PM10 at only four locations in Ulaanbaatar using Ambient Dust Monitor GRIMM 180 and TEOM [Allen, 2013]. These instruments are known to be highly inaccurate; hence there are large uncertainties associated with the quality of the monitoring data and very limited spatial coverage.

***Air quality spatial analyses and forecasts***: Currently, there are no government-mandated air quality forecasts produced in Mongolia, only current conditions are reported. Analyses of air quality across regions, such as the airnow maps in the United States, do not exist in Mongolia. Therefore, air quality forecasts with any level of skill beyond persistence will be helpful to the people of Mongolia. Earth observations (model, satellite data, etc) are not currently used for air quality but have high potential to aid in this poorly monitoring region.

***Media dissemination to public***: Current air quality conditions and basic weather forecasts are given to the public through the national state-run television channel MNB. Air quality Index values are used on websites that disseminate the questionable in situ observations (e.g., <http://aqicn.org/city/ulaanbaatar/mnb/>). This information is also shown on the state television. However, limited information to help the public *plan ahead* is currently provided. We will work with the media contacts who are committed to this study to ensure that the improved forecasts that will be provided by NAMEM will be properly communicated to the MNB for effective dissemination to the general populace. Given the complex terrain that traps pollutants similar to those observed in the Salt Lake City, Utah area, we expect an increase in air quality forecasts from the current “1-day” model to a 5-7 day skillful forecast to help people make decisions on when to use less polluting sources of heating and/or when to limit outdoor exposure to pollutants.

Statement from NAMEM:

“The need for improved air quality forecasting and spatial analysis of pollutant distributions during complex stable cool season boundary-layers is sorely needed in the Ulaanbaatar, Mongolia region during the frequent and extremely hazardous wintertime stable boundary-layer conditions. Our improved ability to provide extended pollution forecasts after implementation of the proposed study (5-7 day lead time) is something that would allow decision-managers from all facets of our society to make many proactive and regulatory decisions regarding air quality management in the region, whether to advise health-sensitive groups which days to stay indoors and to limit exposure, or when to ask industry and public to limit activity to reduce pollution emissions. Currently, we do not have the resources to provide accurate forecasts or analyses of pollution episodes across the region. We look forward to working with PI's Munkh Baasandorj and Erik Crosman to integrate years of forecasting and air pollution expertise from basins in Utah to our Mongolian Basins, and for training our many talented Mongolian scientists on using state-of-the art NASA earth system modeling and satellite retrievals as part of this project, to create a "mountain basin" particulate pollution forecast and analysis capability that will be among the best in the world.”

Statement for state television media Mongolian National Broadcaster (MNB):

“Air quality and public health are major concerns that have been growing each year in Mongolia over the past decade. The MNB is very excited to be able to work with PI's Munkh Baasandorj and Erik Crosman to educate our public through the major state television channel in Mongolia about current pollution conditions in the region and detailed forecasts to assist in decision-making. Episodes of poor air quality are interspersed with cleaner conditions in the complex mountain basin that encompasses our largest city, Ulaanbaatar. Currently, the public is not well-informed about when the air will clean out or when it will worsen from day to day. This collaborative work would allow the conversation about limiting wood burning on highly polluted days and other strategies for limiting both pollution emissions and human exposure to be taken to a new level, with potentially significant implications for the health and well-being of over a million Mongolians.”

## Earth Observations

This project will utilize both satellite and numerical weather prediction earth observational data to develop a state-of-the art air pollution forecasting and analyses capabilities to be run by Mongolian government agencies.

The major advantage of using NASA GEOS-5 NWP output for this project are stated on the NASA website <https://gmao.gsfc.nasa.gov/weather_prediction/> that NASA weather prediction “products emphasize the traditional aspects of weather analysis and forecasting, [while also having] having a broader scope that includes aerosols and trace gases.” To our knowledge, the NASA GEOS-5 suite of NWP has not been previously implemented to improve forecasting of wintertime stable layers in complex mountainous topography despite the ubiquity of stable boundary-layer in basins during wintertime across the world.

The vast array of NASA satellite data combined with data from other earth system satellites will enable improved analyses of air quality and meteorology in Mongolia. The following earth observations as listed below will be utilized to both improve real-time data for pollution monitoring and to developing forecasting capability for pollution episodes. The forecasting funnel will train forecasters to utilize NASA GEOS-5 FP numerical weather output data available online at <https://gmao.gsfc.nasa.gov/products/nwp/> The GEOS-5 FP (analyses and forecasts produced in real time, using the most recent validated GEOS system; <https://gmao.gsfc.nasa.gov/products/>) will be used heavily in the forecasting product development. The GEOS-5 aerosol 180 hr forecasts that give prognostic aerosol and aerosol layer model output will also be tested in depth and potentially utilized

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| While long-term forecasting will depend on GEOS NWP, short-term forecasting and analyses of spatial pollution patterns will utilize real-time analyses of conditions across the region and any noted trends in these observations along with short-term NWP guidance. Products that will be incorporated into the short-term forecasting include data from the near real-time (NRT) Land, Atmosphere Near real-time Capability for EOS (LANCE), as well as an array of NASA land surface, cloud, and aerosol products will be utilized both for short-term forecasting and also for analyses of current conditions for decision-making. NASA Earth Observations to be utilized are:   * NASA AIRS sounder to aid in diagnosing vertical temperature profiles across the region * NASA MODIS visible imagery to ascertain extent of snow cover across complex terrain areas and to determine if NWP snow cover is adequately initialized in NWP products * NASA MODIS visible imagery and cloud products to determine if models are adequately initializing clouds cover in NWP products * NASA MODIS land surface temperature (LST) to determine surface state and to determine if models are adequately initializing land surface * NASA MODIS aerosol optical depth and other air quality products to diagnose spatial gradients in pollution across the region not captured by limited surface observations * NASA AIRS CO (total column) and Sulfur Dioxide (SO2) (day and night) * NASA AURA OMI Aerosol Optical Depth, Absorbing Aerosol Optical Depth and Aerosol Index, Ozone |  |

**Technical/Scientific/Management**

# **Overview**

## Problem Statement

Wintertime air quality forecasts in complex mountainous terrain, such as observed in Ulaanbaatar, Mongolia, are notoriously hard to predict (Reeves et al. 2011; Lareau et al. 2013). Recent short-term research studies have illustrated the benefits of utilizing earth observations for forecasting of stable wintertime boundary-layers (e.g., Crosman and Horel, 2017; Foster et al. 2017), but a more thorough evaluation and implementation of a system for utilizing earth observations for supporting air quality analyses and forecasts in complex environments is needed. The capital city of Mongolia, Ulaanbaatar, located in a cold mountain valley, is home to ~1.4 million residents, and is the second most polluted city in the world for airborne particulate matter and the most polluted city in the world that is highly impacted by strong wintertime cold-air pools. The terrain, high latitude and snow cover result in air stagnation October-March, when particulate matter (PM2.5 and PM10) accumulate to dangerously high levels. Currently, the analysis and forecasting ability during pollution episodes in Mongolia is virtually nonexistent, limiting the ability of Mongolian government agencies to make decisions regarding warning or recommending actions related to the poor air. The World Bank states that “reducing air pollution in Ulaanbaatar will require sustained efforts” [World Bank 2010]. Recent efforts to replace wood stoves with more energy efficient boilers were implemented, with mixed results. However, no effort to improve air quality forecasts and associated decision-making processes for protection of human health have been proposed to our knowledge. This study proposes to focus on synthesizing NASA earth observations with the existing knowledge of cold-air pool evolution and forecasting to develop tools to improve mountain weather and air quality forecasting and associated decision-making activities of the National Agency for Meteorology and Environmental Monitoring (NAMEM) of Mongolia and the Mongolian National Broadcaster (MNB; the National Agency for Television and Radio). The proposed synthesis of extensive NASA earth observations with wintertime stable layer scientific, air quality, and forecasting expertise has never before been conducted and the suite of NASA earth observations utilized are expected to result in a state-of-the art "mountain basin" particulate pollution forecast and analysis capability that could subsequently become a model that could be implemented in various complex terrain environments worldwide.

## Project Scope within NASA Health and Air Quality Applications Priority Topics

This project will be a novel application to incorporate NASA earth observations into a comprehensive air quality analysis and forecast tool within cold-season complex terrain environments, and to demonstrate qualitatively and quantitatively the practical uses and improvements gained through the use of these earth observations. This project directly addresses the global problem of wintertime air quality forecasting within topographically enclosed basins by addressing the problem in a city situated in the most highly polluted mountain basin in the world—Ulaanbaatar, Mongolia--and the decision-making agencies that are tasked with forecasting pollution for that region. As required (Section 3.3 of the NRA for NASA Health and Air Quality Applications), this study will involve substantial partnership with the two primary agencies that provide decision-making capabilities regarding air quality within Mongolia: The National Agency for Meteorology and Environmental Monitoring (NAMEM) of Mongolia and the Mongolian National Broadcaster (MNB; the National Agency for Television and Radio). This study will also include the assistance and expertise of collaborators from the USA Environmental Protection Agency, (EPA) to improve the quantitative metrics for measuring in situ particulate matter pollution. The decision-making activities conducted by the NAMEM and MNB that will be directly impacted include:

* Improving analyses and now-casting on the spatial and temporal variability of pollution to provide valuable data on where pollution levels are worse (or better) within the complex topography of the region;
* Improving air quality forecasts for up to 7 days in the future, allowing decision-managers to warn the public about dangerous health episodes in advance, rather than the current approach of reacting to conditions as they occur;
* Improving categorization and forecasts for pollution concentrations and corresponding health risk categorization (red, yellow, and green pollution days);
* Improving decision-making related to providing guidance on recommending wood-burning or industrial emission regulations to be implemented during the episodic pollution events.

All enhanced capabilities in this study will be developed in close partnership with these agencies to ensure a sustained, operational capability to enhance the air quality decision-making capabilities in Mongolia. A careful and extensive review of all recent projects conducted by the NASA Applied Sciences Health and Air Quality program <https://appliedsciences.nasa.gov/programs/health-air-quality-program> will be conducted at the onset of this study, to determine partners and possible uses of NASA earth system products that have already been developed that could potentially be transferred to this study.

## NASA Earth Observations and Study Application

As shown in Fig. 1, a wide array of NASA earth observations from satellite and numerical weather prediction directly observe key components of the meteorological ingredients that impact cold-air pool forecasts. The PI’s have extensive scientific background in studying the

meteorology and air chemistry of wintertime pollution episodes known scientifically as “cold-air pools” in northern Utah (e.g., Lareau et al. 2013; Crosman and Horel 2016, 2017; Baasandorj et al. 2017). It is well-established that the meteorology and chemistry of these episodes is impacted by many surface, boundary-layer, and tropospheric phenomena, including snow cover and albedo, cloud cover, terrain winds, and large-scale weather patterns. As shown in Fig. 1, a wide array of NASA earth observations from satellite and numerical weather prediction directly observe key components of the meteorological ingredients that impact cold-air pool forecasts. The NASA earth observations will be synthesized with current scientific knowledge obtained during field studies over the past decade to create a novel forecast and analysis system to be utilized as part of this study to enhance air quality decision-making in Mongolia. Utilizing NASA earth observations in both weather forecasting and air quality applications has been an area of major research in the last decade. However, as discussed by Duncan et al. (2014), greater incorporation of these data sets into decision-making agencies is needed, and in many smaller countries worldwide, largely unutilized. However, with the development of many global interfaces for viewing the data, such as the NASA Worldview and the numerous other online portals, the accessibility of these data sets is increasing. However, scientific training on how to incorporate these data sets into weather and air quality forecasting and decision-making is needed. This proposal seeks to address this problem in Mongolia, one of the most polluted places on earth in terms of particulate air pollution.

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| Figure 1. NASA Earth observations, derived products and models to be utilized in this study (denoted in colored text) and corresponding cold-air pool pollution forecasting applications (inner image) |

The following quote from Duncan et al. (2014) sums up the needs to utilize the earth observational data sets more for forecasting and decision support. “Satellite data of atmospheric pollutants are becoming more widely used in the decision-making and environmental management activities of public, private sector and non-profit organizations. They are employed for estimating emissions, tracking pollutant plumes, supporting air quality forecasting activities, providing evidence for “exceptional event” declarations, monitoring regional long-term trends, and evaluating air quality model output. However, many air quality managers are not taking full advantage of the data for these applications nor has the full potential of satellite data for air quality applications been realized. A key barrier is the inherent difficulties associated with accessing, processing, and properly interpreting observational data.”

## Innovative Uses of NASA Earth Observations for Decision-making

The proposed synthesis of extensive NASA earth observations with wintertime stable layer scientific, air quality, and forecasting expertise has never before been conducted and the suite of NASA earth observations utilized are expected to result in a novel "mountain basin" particulate pollution forecast and analysis capability. This step-by-step approach will be well-documented and disseminated publicly so that it is portable to other mountain valleys globally. It is known that a number of NASA aerosol and land surface products have problems over complex, snow-covered or arid terrain (e.g., Mongolia). The strengths and weaknesses of existing NASA earth observations for use in air quality monitoring and forecasting in complex terrain during wintertime pollution episodes will also be illuminated more rigorously than they have been to date through the rigorous evaluation of the NASA earth system products in this unique environment.

## II. Pollution and Current Air Quality Analysis and Forecast Capabilities in Ulaanbaatar, Mongolia: Background

The capital city of Mongolia, Ulaanbaatar, has a rapidly growing population currently estimated at over 1.4 million people. The Khentei Mountains surround the city, which is primarily situated in a highly density populated 4700 km2 area within the Tuul River Valley, which extends over ~150 km E-W and ~30 km N-S. The combination of surrounding high mountains, high latitude (47.9 °N) and high elevation (~1,350 m) of Ulaanbaatar result in prolonged periods of snow cover, stable temperature profiles, and high pollution episodes or wintertime cold-air pools during periods (Fig. 2) when a Mongolian/Siberian high pressure systems become established over the region (Batmunkh et al. 2013).

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| Figure 2. Top: Spatial modeling study showing variability in mean modelled PM2.5 in the Ulaanbaatar, Mongolia region from mobile transects during Feb 24-25 2010 (Allen et al., 2013 Figure 5) and bottom: Monthly average PM2.5 in the Ulaanbaatar, Mongolia region 2008-2011 (source: <http://urbanemissions.blogspot.com/2013/10/poisonous-air-in-ulaanbaatar-mongolia.html> |

The deep stable layers result in prolonged periods of very poor air quality from October to April of each year (Fig. 2b). While measurement accuracy is uncertain, wintertime average PM2.5 concentrations of 148 μg/m3 were reported to the World Health Organization (Allen et al. 2013). As discussed by Amarsaikhan et al. (2014):“air pollution in Ulaanbaatar city is a very serious problem and for its reduction, rapid and thorough measures should be taken.” Poor environmental management and behaviors result in serious exposure risk factors for Mongolians (Jadaamba et al. 2015) and motivate the importance of the goals of this study to enhance tools to allow Mongolians to make decisions that positively impact human health. While several field campaigns at better characterizing pollution in Ulaanbaatar have been conducted in the last decade (e.g, Allen et al. 2013), the analysis and forecast capabilities for decision-making on a routine basis are virtually non-existent. The basic infrastructure is also currently insufficient to accurately measure and forecast the pollution concentrations in Ulaanbaatar, Mongolia. Currently, the government air pollution-monitoring network routinely monitors PM2.5 and PM10 at only four locations in Ulaanbaatar using Ambient Dust Monitor GRIMM 180 and TEOM [Allen, 2013].

Complex mountain meteorological flow regimes, including valley and slope flows have been modelled and observed to some extent in the greater Ulaanbaatar region, but their impact on spatial variations in local air quality have not been documented. While the wintertime cold-air pools have been extensively studied in the United States and Europe, they have not been studied in depth in Mongolia, and scientific forecasting and understanding by local forecasting agencies and decision-makers for these episodes remains understandably low. In this study we propose to develop a step-by-step approach to transfer forecasting and scientific expertise and take steps and with the assistance of our collaborators in the USA EPA to improve observations of particulate pollution, to aid Mongolia in helping take measures to improve forecasting, decision-making, and public exposure mitigation and emission reduction.

Improvements in routine analyses of current pollution episodes and forecasting the evolution of the wintertime stable boundary layer and resulting pollution concentrations are needed in basins worldwide. In the western United States, despite extensive research on cold-air pools, forecasts of cold-air pools remains a problem area both for numerical weather prediction and operational weather forecasters (Reeves et al. 2011; Lareau et al. 2013; Crosman and Horel 2017). Thus, the needs for a more rigorous forecast approach for these forecasts is a global problem that is not confined to Mongolia. Meteorological ingredients impacting cold-air pools and biases in difficult-to-model characteristics such as boundary-layer height, low clouds and fog, and snow cover must be identified in the numerical guidance in order to improve forecast guidance. As shown in Fig. 2, considerable spatial variability in pollution has been observed by mobile air quality observations (Allen et al., 2013), but the 4 observation stations in the region are inadequate to provide guidance on the spatial and temporal variability of pollutants across the region. PI Crosman has experience providing forecasts for several research studies on cold-air pools, including the 2010-2011 Persistent Cold-Air Pool Study (Lareau et al. 2013), 2015 Utah Wintertime Fine Particulate Study (Baasandoorj et al. 2017), and 2016 Utah Wintertime Fine Particlate Study (forecasts are archived here: <http://uwfps.blogspot.com/>). PI Baasandorj has extensive expertise on the chemistry and evolution of the pollution during these episodes and has coordinated several studies including The Salt Lake Valley PM2.5 Study 2015-16 and Utah Winter Fine Particulate Study (UWFPS). More information on the NOAA aircraft study can be found here: <https://www.esrl.noaa.gov/csd/groups/csd7/measurements/2017uwfps/>. Earth observations from NASA satellites and numerical weather prediction output has already been used to assist during these field campaign forecasts. However, this forecasting and chemistry expertise has not been effectively transferred to operational forecasters anywhere in the world, despite wintertime stable layers being a ubiquitous problem in many mountainous regions in the winter.

The Ulaanbaatar, Mongolia region is an ideal location to develop and implement an analysis and forecasting of complex terrain wintertime pollution due to the extremely high pollution concentrations (difficulties in observing aerosol by satellite over the snow-cover and arid landscape will likely be overcome by the extremely high levels of pollutants) and the potential to revolutionize air quality decision-making (which is largely absent) and consequently the quality of life and pollutant exposures for the 1.4 million people who live in the Ulaanbaatar, Mongolia metropolitan area.

We have been in contact with both the National Agency for Meteorology and Environmental Monitoring (NAMEM) of Mongolia and the Mongolian National Broadcaster (MNB; the National Agency for Television and Radio) and they are committed to work with us. Our commitment includes months of training, which is rarely conducted in scientific outreach activities. We believe the combination of training on the ground in Mongolia and their passion to improve the air quality decision-making capabilities will results in this project having a high probability of success.

**III. Methodology**

## Overview

We will develop a step-by-step implementation plan to integrate NASA Earth observations into an improved air quality analysis and forecast system in support of air quality related decision-making in Mongolia for this study (Fig. 3).

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| Figure 3. Flow chart illustrating the key infrastructure, air quality analysis and forecasting deliverables and decision-making pathways in this study. Please see the project management and schedule section for dates of deliverables and listing of corresponding NASA Application Readiness Level (ARL) for each component. |

Fig. 3 illustrates the key infrastructure, air quality analysis and forecasting deliverables and decision-making pathways. The end goal of the study is to synthesize NASA earth observations with knowledge of cold-air pool evolution and forecasting to develop tools to improve mountain weather and air quality forecasting and inform and develop new decision-making activities related to air quality and human health in Ulaanbaatar, Mongolia. The study consists of the following 8 task components that will be conducted in a step-by-step approach as discussed in more depth in the following subsections.

* Task 1: Testing and evaluating all available NASA earth system model and satellite observations for use in providing earth observations in support of air quality analyses and forecasts;
* Task 2: Synthesizing the NASA earth observations with recent advances in cold-air pool and stable boundary-layer research (observational and modeling);
* Task 3: Developing analyses of spatial patterns of pollution;
* Task 4: Developing effective “forecast funnel” conceptual models for both short-term and long-term (out to 7 days) forecasts for pollution episodes;
* Task 5: Evaluate/test the analysis and forecast systems;
* Task 6: Assist in developing capabilities for decision-making based on improved analysis and forecasting infrastructure;
* Task 7: Train Mongolian agencies;
* Task 8: Ensure maintenance and sustainability.

## Task 1: Testing and Evaluating NASA Earth Observations

A wide array of NASA earth observations will be used to develop the improved air quality analysis and forecast tools shown in Fig. 3. The NASA earth system observations and models that are currently planned to be utilized are listed in Table 1. Table 1 also summarize the aspects of cold-air pool forecasting or pollution analyses that each product will serve to diagnose, and the potential challenges associated with implementing each product into operational use. Additional NASA Earth observations that are not listed will likely be identified and utilized as this study evolves.

Table 1. NASA Earth observations to be utilized in this study, and their applications to improving cold-air pool pollution forecasts and spatial pollution analyses

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| **NASA Earth observation** | **Primary uses** | **Potential challenges** |
| GEOS-5 NWP weather model output | 2-7 days cold-air pool atmospheric forecasts | Weather forecast errors |
| GEOS-5 NWP prognostic aerosol and aerosol layer model output | Guidance for qualitative build-up of pollution in 2-7 day period | Weather forecast errors and relating aerosol to PM2.5 concentrations |
| NASA AIRS sounder | Guidance for short-term forecasts and analyses of vertical temperature profile, profiles of aerosol, CO, SO2 | Retrieval challenges over air and snow covered surfaces |
| NASA AURA OMI | Guidance for short-term air pollution (ozone, aerosol, | Retrieval challenges over air and snow covered surfaces |
| NASA MODIS aerosol | Aerosol optical depth and other air quality products to diagnose spatial gradients in pollution across the region not captured by limited surface observations | Retrieval challenges and relating aerosol to PM2.5 concentrations |
| NASA MODIS snow cover, visible clouds, land surface temperature | Detailed surface/cloud cover needed to determine model biases and current condition meteorology driving spatial variations in pollution | Weather forecast and analysis errors |

Each product will be subject to rigorous testing before being implemented into the forecast and analysis chain. Quantitative evaluation (i.e., comparing meteorological forecasts to weather station data, etc) will be conducted whenever possible. Through collaborator Russel Long from the USA EPA, we will attempt to calibrate the in situ PM2.5 and then relate them through best-available practices in the literature to the NASA satellite aerosol optical depth products. Fig. 4 shows an example of a NASA GEOS numerical model forecast product for the build-up of pollutants in various Asian basins that would be implemented in this study to help Mongolian forecasters.

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| Figure 4. NASA GEOS-5 15-h forecast for aerosol optical depth showing polluted regions in China, Mongolia, and India on 11 November 2017 (top) and close-up image of Ulaanbaatar Mongolia region (bottom) distributed by the NASA Global Modeling and Assimilation Office (GMAO). Plotting obtained from <https://cds-cv.nccs.nasa.gov/GMAO-V/> |

## Task 2: Synthesizing NASA Earth Observations with Cold-air Pool Science

The wealth of knowledge obtained in the last decade regarding cold-air pool evolution and the many meteorological factors that impact forecasts of cold-air pools will be illuminated by applied use of an array of NASA earth observations (Fig. 1). Extensive research on the meteorology and air quality of cold-air pools resulting from high pressure systems over the Western US have been conducted over the past several decades. Several recent large field and modeling campaigns have resulted in improved meteorological forecasting and modeling capabilities for cold-air pools in the Salt Lake Valley, Utah (e.g., [Silcox et al., 2012](http://www.sciencedirect.com/science/article/pii/S0169809516303878#bb0250); [Whiteman et al., 2014](http://www.sciencedirect.com/science/article/pii/S0169809516303878#bb0295); [Lareau and Horel, 2015a](http://www.sciencedirect.com/science/article/pii/S0169809516303878#bb0155); [Lareau and Horel, 2015b](http://www.sciencedirect.com/science/article/pii/S0169809516303878#bb0160); [Crosman and Horel, 2016](http://www.sciencedirect.com/science/article/pii/S0169809516303878#bb0055); [Foster et al., 2017](http://www.sciencedirect.com/science/article/pii/S0169809516303878#bb0090), Crosman and Horel 2017), as well as better understanding of the coupling between the chemistry and meteorology within cold-air pools (Baasandorj et al. 2017). These studies have resulted in science that, when combined with NASA Earth Observations, will result in developing capabilities to:

* Improve lead-time and situational awareness for meteorological forecasters of PCAPS by incorporating forecast funnels of large scale high pressure regimes coupled with local surface state (snow cover, albedo, lake temperature, etc), terrain-driven flows, and other factors (such as low clouds);
* Improve numerical model predictive capabilities of cold-air pools;
* Increased scientific understanding of the lifecycle of cold-air pool.

The scientific understanding of how meteorological factors impact cold-air pool evolution and how the earth observations and models can be utilized to help quantify and predict those factors will be the focus of this task. PI Crosman and Baasandorj are both experts on cold-air pools, and Crosman has extensive experience providing forecasts for several research studies on cold-air pools, including the 2010-2011 Persistent Cold-Air Pool Study (Lareau et al. 2013), 2015 Utah Wintertime Fine Particulate Study (Baasandorj et al. 2017), and 2016 Utah Wintertime Fine Particulate Study (forecasts are archived here: <http://uwfps.blogspot.com/>). PI Baasandorj has extensive expertise on the chemistry and evolution of the pollution during these episodes. Earth observations from NASA satellites and numerical weather prediction output have already been used to assist during these field campaign forecasts. The NASA earth observations that we plan on utilizing and how these observations assist in improving analysis and forecasts are summarized in Table 1.

## Task 3: Developing Analyses of Spatial Patterns of Pollutants

As discussed previously, quantitatively determining PM2.5 from satellite aerosol optical depth is challenging, particularly over snow-covered arid terrain such as Mongolia. However, analysis of online NASA aerosol products (e.g., Fig. 5) shows that the extremely high pollution levels observed in the particular mountain valley result in more easily retrievable pollution observations than in other basins worldwide in the current suite of NASA aerosol retrieval products. On 20 October 2016 (Fig. 5), the PM2.5 concentrations observed by in situ observations ranged between 50 and 250 µg m-3. We are confident that the NASA aerosol products will result in useful spatial analyses of pollution gradients that are otherwise not observable due to a lack of in situ surface stations in the region. We will also attempt to calibrate the satellite aerosol observations to surface in situ PM2.5 and then relate them through best-available practices in the literature to the NASA satellite aerosol optical depth products. These products will be invaluable for providing spatial maps of where pollution exposure is worst for Mongolians. A few days of mobile observations around the Ulaanbaatar region confirms that significant spatial gradients in pollution exist (Allen et al. 2013), driven by the complex topography (Fig. 2). The improved spatial coverage will inform the air quality managers and public about the spatial distribution of the pollution at more local and regional levels, and will aid in tracking exceptional events like Asian dust storm or Siberian wild fire that often impact the region. In nearby China, studies have shown that spatial variations in PM2.5 can be effectively derived from MODIS satellite data (Zheng et al. 2016). However, many global PM2.5 satellite-derived climatologies do not capture the Ulaanbaatar, Mongolia region.

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| Figure 5. NASA MODIS aerosol optical depth retrievals for 30 October 2016 with MODIS true color imagery from NASA Worldview. The Ulaanbaatar, Mongolia urban area is circled in red. |

We will investigate utilizing existing algorithms relating to improved aerosol optical depth over snow-snow covered and urban regions (e.g., Gupta et al. 2016; Levy et al. 2016). The large signal in the PM2.5 over snow-covered Mongolia may help evaluate the utility of aerosol optical depth over snow-covered and urban areas.

## Task 4: Developing “Forecast Funnel” Conceptual Models

The results from Tasks 1-4 will be synthesized and a detailed document on the “forecast and analysis funnel” used for both training and sustainability (and portability) purposes will be used that outlines how forecasters and now-casters can best utilize the suite of earth observations to produce useful and skillful air quality forecasts and analyses. The analysis techniques will begin with model data at large spatial and temporal scales, and slowly “funnel” into increasingly smaller and more detailed scales. The high-resolution satellite products will be utilized both at the smaller scales for analysis (e.g., albedo and pollution variability) as well as for large-scale (e.g., weather systems). Please see the Project Management section for more details. The NASA Application Readiness Level (ARL) of the forecast tool will transition from each of the forecast funnel conceptual models as it develops from an ARL of 4 to 9 as the project matures.

## Task 5: System Evaluation

The process of developing a workable and sustainable analysis and forecast system to be utilized by NAMAM and MNB will require iteration with these agencies and their stakeholders to improve and develop the products. Consequently, the tools will evolve as a function of quantitative and qualitative evaluation of Tasks 1-4, as well as from feedback from NAMAM during and after the training workshops. Several qualitative and quantitative approaches will be used to determine the outcomes, results, and improvements to the air quality analysis forecasting capabilities and resultant decision-making processes employed by NAMEM, MNB, and end users (e.g., public, government). The forecast system components will be subject to rigorous testing before being implemented into the forecast and analysis chain. Quantitative evaluation (i.e., comparing meteorological forecasts to weather station data, etc) will be conducted whenever possible). Please see the Performance Measures section for more details.

## Task 6: Develop Decision-Making Capabilities

As discussed in the Project Management section, multi-week intensive air quality forecasting training sessions will be held at NAMEM each year of this study, imparting developed analysis and forecast capabilities and subsequent capabilities for decision-making. Please refer also to the separate Decision-making and Project Management sections for more details.

## Task 7: Train Mongolian Agencies

First, the PI’s will assess the technical levels of the staff to be trained and the resources available at the collaborating agencies and identify the needs of the trainees. Second, the PI will develop and conduct training workshops tailored to fit the group’s need to achieve tasks 3 – 5. The schedule of the training sessions is outlined in the Project Management section. The PIs will visit Mongolia at the outset of the project to better determine the user needs and any educational or other barriers that exists. Then, a 4-week intensive air quality forecasting training session held at NAMEM imparting developed analysis and forecast capabilities will be conducted in Spring 2019. The intensive training session will involve workshops on understanding and utilizing remote sensing and numerical model data, mountain meteorology, air quality, in addition to the primary training on using the developed forecast funnel approach. After feedback has been received and the “forecast and analysis funnel” has been improved, a second 4-week training workshop will be conducted at NAMEM in Spring 2020. A final 2-week workshop/training to facilitate long-term implementation and sustainability of the developed capabilities will be held in Spring 2021. Final documentation and websites will be developed and made publically available.

1. **Task 8: Ensure Maintenance and Sustainability**

A variety of planned activities will occur to enable the sustained use of the earth observations and the improved analysis and forecasting capabilities for use by NAMEM and MNB Please refer to the Transition and Sustainability Section for more information.

# **IV. Discussion of Project Application Readiness Level (ARL)**

The project will commence in year one with Application Readiness Level (ARL) in the developed discovery and feasibility (ARL 3-4) into integration and validation phase in the Mongolian Environment. All of the NASA earth observation products are used already widely in earth science applications. The discovery and feasibility portion will be with respect to determining shortcomings and limitation of these products in their usefulness in supporting the air quality analysis and forecast tools being developed. As the project continues, in year two the development, validation, and testing phase will be the focus (ARL 5-7). By the end of year three, the forecast products should be thoroughly tested and being transitioned to a sustainable product used in decision-making by NAMEM and also employed in daily television broadcasts by the MNB. Detailed ARL level classification of study deliverables are given in the Project Management section.

**VI. Project Challenges and Risks**

Any project that attempts to transition research and new applications of earth observations to operations and decision-making faces challenges. More information on the challenges to be overcome are listed in the Transition and Sustainability Section. In this study, we have identified three primary challenges:

* Language and science communication barriers in training Mongolian agencies;
* Challenges synthesizing multiple NASA products into a timely and effective analysis and forecast tool;
* Challenges in effectively communicating decision-making potential of the developed system to all stakeholders.

We will employ all available resources to avoid being negatively impacted by these factors. Fortuitously, co-PI Baasandorj is Mongolian and a native speaker with excellent communication skills and knowledge of the background of Mongolian science education and background. By conducting multiple training workshops with ample time for feedback and product modification and improvements, we hope to overcome issues related to producing an effective and usable product both for the Mongolian agency partners and any end user decision-makers.

**Performance Measures**

Several qualitative and quantitative approaches will be used to determine the outcomes, results, and improvements to the air quality analysis forecasting capabilities and resultant decision-making processes employed by NAMEM, MNB, and end users (e.g., public, government).

NAMEM currently assesses their meteorological forecasts via standard statistic error metrics for forecasts at various lead times (e.g, bias, *RMSE* and various forecast hour lead times). It will be therefore fairly straightforward to extend these statistics to quantitatively assess the overall improvements in the meteorological forecasts. However, long-range air quality forecasts do not currently exist, and therefore no comparison metric will be possible. We will compare quantitative performance metrics of air quality forecasts with those shown from other locales globally, as well as qualitatively document the successes and failures of the new tools in the complex wintertime environment. We will also assess quantitatively and qualitatively as much as possible the usability, strengths, and weaknesses of all NASA earth observations (both from the GEOS-5 model and well as all of the various satellite-derived products). We will carefully document the improvements to all analysis and forecasting products and any new decision-making capabilities that are developed over the course of the 3-year study.

**Anticipated Results/Improvements**

This study is expected to result in sustained long-term improvements to the air quality monitoring and forecasting infrastructure in Mongolia. We expect the system developed in Mongolia to be portable and transferrable to other basins in the world who experience prolonged wintertime stable layers and attendant pollution. This study is also expected to revolutionize the ability of the key air quality and public communication agencies in Mongolia (NAMEM and MNNB) to make decisions related to air quality and public health. The forecast capabilities are currently very limited and no organized decision-making chain is currently in place with respect to warning the public about upcoming pollution episodes. This knowledge will enable NAMEM to make more scientifically-based and informed decisions to warn the public about health hazards associated with high pollution, and to recommend actions for various groups (e.g., for sensitive groups to limit outdoor activities during high pollution levels). Specifically, this study will improve the capabilities of NAMEM for environmental monitoring of pollution, forecasting of high pollution episodes and dissemination of air quality observations and forecasts on the primary National Mongolian state television channel. We expect the ability to provide useful decision-making information on pollution concentrations in the 2 to 7 day forecast period. This and new spatial analyses of pollution will allow for decision-making capabilities that have not been possible to be developed by NAMEM, including recommending limiting exposure during very polluted forecast time periods and providing recommendations on when to request wood burning or industrial activity bans.

**Transition and Sustainability Plan**

The specific end user organization that will be responsible for the operational, sustained deployment of the Earth-observing applications after the training and implementation of the improved air quality forecasts and spatial analyses of air quality in Mongolia facilitated by our team will be the National Agency for Meteorology and Environmental Monitoring (NAMEM) of Mongolia. NAMEM is the governing agency responsible for air quality management and related activities including air quality monitoring, reporting and assessment, emission inventory and standards, and development and proposal of new regulations. While the agency desires to improve the air quality forecasts and monitoring, infrastructure, expertise and training is currently lacking so that NAMEM is unable to provide the needed analyses and forecasts for cold-air pool episodes needed for improved decision-making.

NAMEM is enthusiastic about working with us during the 3-year study to implementing the proposed improvements and to develop the monitoring and forecasting programs that will aid in mapping the air quality across wider regions, issuing advance warning, and educating the public and formulating effective control strategies to reduce both emissions and exposure risks.

The Mongolian National Broadcaster (MNB), the primary state-run media in Mongolia has also agree to continue the dissemination of the improved air quality analyses and forecasts and associated public health air quality indexes (e.g., AQI index).

The following activities will occur to enable the sustained use of the earth observations and the improved analysis and forecasting capabilities for use by NAMEM and MNB:

* The PIs on this project will work closely with NAMEM to create infrastructure and train local expertise so that the new air quality instrumentation and earth system observational data utilized in the air quality forecasts and analyses remain part of the NAMEM organizational structure after the 3-year project ends. Given the high need for improved air quality in the region, we expect that once local stakeholders become accustomed to the improved products enabling decision-making based on air quality, those stakeholders will demand that this project continues, ensuring a successful continuation of this work.
* A primary challenge limiting the adoption of the improved forecast plans will be local expertise needing to be trained in using the array of NASA satellite and model earth observations required. Specifically to address this challenge, co-PI Erik Crosman and Munkh Baasandorj will spend 1 month in both year 1 and year 2 of this proposal to first evaluate the current training and education and technical needs of the NAMEM and MNB staff and then design and provide an extended training tailored to the determined needs. Each multi-week training session will begin with a 10-day intensive group training session for NAMEM air quality and meteorological forecasters. Then, private training, evaluation, and monitoring of each forecaster will be conducted for the next 2 weeks.
* The co-PI’s will also conduct quarterly evaluation of the NAMEM forecasts and provide feedback and reports to NAMEM on where weaknesses lie and where they need further training. In the final year of the project, co-PI efforts will focus on ascertaining that all infrastructure, training, and expertise is in place to ensure that the improved forecasts and associated decision-making infrastructure will be maintained after the end of the project. In the final year of the project there will also be a workshop specifically focused on long-term implementation and sustainability of the developed capabilities.

**Project Management & Schedule**

The project will be co-managed by Co-PI’s Crosman and Baasandorj. PI Crosman will be in charge of training and developing the earth observation system for analysis and forecasting of cool season pollution episodes. Co-PI Baasandorj will be in charge of assisting NAMEM and MNB in developing and improving decision-making pathways using the project results. Both Crosman and Baasandorj will assist overseeing the implementation and sustainability plan with NAMEM and state television media. A graduate student will assist in all aspects of the study and work toward a M.S. degree focused on the technical documentation of utilizing NASA earth observations for improved pollution forecasts. This study will require almost weekly communication, frequent emails and conference calls with Mongolian officials to be successful. A web page will be developed to track the progress of the study and to keep deliverables on track. Leadership at the MNB and NAMEM will be in close communication with the co-PIs Crosman and Baasandorj.

|  |  |  |  |
| --- | --- | --- | --- |
| **Project Milestone** | **NASA ARL Level** | **Description** | **Delivery Dates** |
| Initiate regular communication with NAMEM and MNB | **3** | Visit Mongolia for 1 week and determine needs and best strategies for pollution and analysis tools to be developed | Aug 2018 |
| NASA earth system products version 1 | **4** | Evaluate NASA earth system (models and satellite data) over Mongolia and begin assembling useful data) | Sept 2018 |
| Develop Forecast Funnel for NAMEM | **4** | Forecast funnel utilizing NASA earth observations (Satellite and Numerical Weather Prediction) developed for Mongolian climate | Feb 2019 |
| Training workshop #1 | **4** | 4 week intensive air quality forecasting training session held at NAMEM imparting developed analysis and forecast capabilities | Mar-Apr 2019 |
| Evaluation Period #1 | **5** | Improved air quality forecasting and decision-making evaluation period begins at NAMEM | November 2019 |
| NASA earth system products version 2 | **6** | Improved forecast funnel utilizing NASA earth observations (Satellite and Numerical Weather Prediction) based on correcting based on feedback and problems from NAMEM | Jan 2020 |
| Training workshop #2 | **6** | 4 week intensive air quality forecasting training session held at NAMEM imparting developed analysis and forecast capabilities | Mar-Apr 2020 |
| Evaluation Period #2 | **5** | Improved air quality forecasting and decision-making second evaluation period begins at NAMEM | November 2020 |
| Implementation | **8** | Improved air quality forecasting and decision-making procedure officially implemented by NAMEM (evaluation period ends) | November 2020 |
| Evaluation of decision-making | **7** | Evaluation of NAMEM improvements in forecasts supporting decision-making. Report and recommendations for sustainable implementation | Jan 2021 |
| Sustainability workshop | **9** | Final training session focused on long-term implementation and sustainability of developed capabilities. Final documentation and websites developed. | April 2021 |

|  |  |  |  |
| --- | --- | --- | --- |
| **Position Title, & Name** | **Time Charged to This Proposal** | **Time Not Charged to This Proposal** | **Total Time per Person per Year** |
| Co-PI, Erik Crosman | 6 months/year | N/A | 6 months/year |
| Co-PI, Munkh Baasandorj | 2 months/year | N/A | 2 months/year |
| Graduate Student #1 | 12 months/year | N/A | 12 months/year |

**Budget Justification – Year 1**

PERSONNEL

Co-PI – Erik Crosman: This position co-directs the overall project operation with a focus on developing tools and products from NASA earth observations. This position will also be involved in training NAMEM forecasters on utilizing the developed forecasting and analysis infrastructure effectively. During the first year the main focus of this position will be on developing and testing an effective analysis and forecasting framework utilizing NASA earth observation into an operationally accessible forecast and analysis product to aid air quality decision-making. Support of 6 months per year is requested for this position.

Co-PI – Munkh Baasandorj: This position co-directs the overall project operation and is the primary liaison between this project and both the NAMEM and the state television. Dr. Baasandorj is a native of Ulaanbaatar and well-connected to state and academic air quality scientists in Mongolia. This position will focus on effectively training the local scientists to utilize the improved air quality forecast and analysis tools and products to enable enhanced decision-making within NAMAM. Support of 2 months per year is requested for this position.

Graduate Student #1: This position will involve a M.S. student who will be assisting with developing tools and products from NASA earth observations for use in air quality forecasts and analyses. The student will be 100% working on this project, providing remote technical and forecasting support to the Mongolian partner agencies during the 3-year project. The student will do a research project evaluating the changes in capabilities of Mongolian air quality forecasts. This will include interviewing both operational forecasters and public. Support of 12 months per year is requested for this position.

TRAVEL – DOMESTIC Total: $4,000

Domestic travel funds would support one project participant to participate in a satellite remote sensing NASA workshop (<https://arset.gsfc.nasa.gov/workshops>). While the upcoming ARSET tutorials have not been set, the plan would be to attend either an ARSET workshop on Satellite Remote Sensing of Air Quality, or Satellite Remote Sensing of Air Quality: Data, Tools, and Applications. Domestic travels funds would also support one of the project PIs to attend one NASA Applied Sciences Program workshop/conference (time/location TBD, participants teams can use Washington, DC as a domestic locations for budgetary purposes).

NASA ARSET Remote Sensing of Air Quality workshop, Host location and date TBD

NASA ARSET Remote Sensing of Air Quality workshop:

|  |  |  |
| --- | --- | --- |
|  | 1 trip x 1 person @ $750 airfare: | $750 |
|  | Ground transportation: | $65 |
|  | 6 nights hotel @ $140/night x 1 persons: | $840 |
|  | 5 days per diem @ $69/day x 1 persons: | $345 |
|  | Conference registration | $0 |
|  | Total | $2000 |

NASA Applied Sciences Program conference, Washington, DC date TBD:

NASA Applied Sciences Program conference:

|  |  |  |
| --- | --- | --- |
|  | 1 trip x 1 person @ $750 airfare: | $750 |
|  | Ground transportation: | $65 |
|  | 6 nights hotel @ $140/night x 1 persons: | $840 |
|  | 5 days per diem @ $69/day x 1 persons: | $345 |
|  | Conference registration | $0 |
|  | Total | $2000 |

TRAVEL – FOREIGN Total: $20,400

Foreign travel funds would support the two co-PI’s and the graduate student to travel to Mongolia for 4 weeks in early 2019 to conduct extensive training as discussed in depth in the proposal and hands-on mentoring using the developed improved air quality forecasting and analysis suite.

Intensive training and mentoring activities, 4 weeks at the Mongolian National Agency for Meteorology and Environmental Monitoring (NAMEM)

NAMEM intensive month-long (32 days) training and mentoring activities

|  |  |  |
| --- | --- | --- |
|  | 1 trip x 3 person @ $1673 airfare: | $5019 |
|  | Ground transportation: | $501 |
|  | 32 nights hotel @ $100/night x 3 persons: | $9600 |
|  | 32 days per diem @ $55/day x 3 persons: | $5280 |
|  | Total | $20400 |

SUPPLIES Total: $5000

Materials and supplies (peripheral computer hardware, backup tapes, material for NAMEM training sessions, etc.)

**Budget Justification – Year 2**

PERSONNEL

Co-PI – Erik Crosman: This position co-directs the overall project operation with a focus on developing tools and products from NASA earth observations. This position will also be involved in training NAMEM forecasters on utilizing the developed forecasting and analysis infrastructure effectively. During the first year the main focus of this position will be on developing and testing an effective analysis and forecasting framework utilizing NASA earth observation into an operationally accessible forecast and analysis product to aid air quality decision-making. Support of 6 months per year is requested for this position.

Co-PI – Munkh Baasandorj: This position co-directs the overall project operation and is the primary liaison between this project and both the Mongolian National Agency for Meteorology and Environmental Monitoring (NAMEM) and the state television. Dr. Baasandorj is a native of Ulaanbaatar and well-connected to state and academic air quality scientists in Mongolia. This position will focus on effectively training the local scientists to utilize the improved air quality forecast and analysis tools and products to enable enhanced decision-making within NAMAM. Support of 2 months per year is requested for this position.

Graduate Student #1: This position will involve a M.S. student who will be assisting with developing tools and products from NASA earth observations for use in air quality forecasts and analyses. The student will be 100% working on this project, providing remote technical and forecasting support to the Mongolian partner agencies during the 3-year project. The student will do a research project evaluating the changes in capabilities of Mongolian air quality forecasts. This will include interviewing both operational forecasters and public. Support of 12 months per year is requested for this position.

TRAVEL – DOMESTIC Total: $5,000

Travel funds include support for a graduate student to present this work at the AGU Fall 2019 conference on 9-13 December 2019 in San Francisco, CA. Domestic travels funds would also support one of the project PIs to attend one NASA Applied Sciences Program workshop/conference (time/location TBD, participants teams can use Washington, DC as a domestic locations for budgetary purposes).

AGU Fall 2019 meeting:

|  |  |  |
| --- | --- | --- |
|  | 1 trip x 1 person @ $550 airfare: | $550 |
|  | 5 days rental car: | $445 |
|  | 6 nights hotel at $160/night x 1 persons: | $960 |
|  | 5 days per diem at $69/day x 1 persons: | $345 |
|  | Conference registration: | $500 |
|  | Total: | $3000 |

NASA Applied Sciences Program conference, Washington, DC date TBD:

NASA Applied Sciences Program conference:

|  |  |  |
| --- | --- | --- |
|  | 1 trip x 1 person @ $750 airfare: | $750 |
|  | Ground transportation: | $65 |
|  | 6 nights hotel @ $140/night x 1 persons: | $840 |
|  | 5 days per diem @ $69/day x 1 persons: | $345 |
|  | Conference registration | $0 |
|  | Total | $2000 |

TRAVEL – FOREIGN Total: $20,400

Foreign travel funds would support the two co-PI’s and the graduate student to travel to Mongolia for the second 4 week extensive follow-on training and forecast implementation plan in early 2020.

Intensive training and mentoring activities, 4 weeks at the Mongolian National Agency for Meteorology and Environmental Monitoring (NAMEM)

NAMEM intensive month-long (32 days) training and mentoring activities:

|  |  |  |
| --- | --- | --- |
|  | 1 trip x 3 person @ $1673 airfare: | $5019 |
|  | Ground transportation: | $501 |
|  | 32 nights hotel @ $100/night x 3 persons: | $9600 |
|  | 32 days per diem @ $55/day x 3 persons: | $5280 |
|  | Total | $20400 |

SUPPLIES Total: $5000

Materials and supplies (peripheral computer hardware, backup tapes, material for NAMEM training sessions, etc.)

**Budget Justification – Year 3**

PERSONNEL

Co-PI – Erik Crosman: This position co-directs the overall project operation with a focus on developing tools and products from NASA earth observations. This position will also be involved in training NAMEM forecasters on utilizing the developed forecasting and analysis infrastructure effectively. During the first year the main focus of this position will be on developing and testing an effective analysis and forecasting framework utilizing NASA earth observation into an operationally accessible forecast and analysis product to aid air quality decision-making. Support of 6 months per year is requested for this position.

Co-PI – Munkh Baasandorj: This position co-directs the overall project operation and is the primary liaison between this project and both the Mongolian National Agency for Meteorology and Environmental Monitoring (NAMEM) and the state television. Dr. Baasandorj is a native of Ulaanbaatar and well-connected to state and academic air quality scientists in Mongolia. This position will focus on effectively training the local scientists to utilize the improved air quality forecast and analysis tools and products to enable enhanced decision-making within NAMAM. Support of 2 months per year is requested for this position.

Graduate Student #1: This position will involve a M.S. student who will be assisting with developing tools and products from NASA earth observations for use in air quality forecasts and analyses. The student will be 100% working on this project, providing remote technical and forecasting support to the Mongolian partner agencies during the 3-year project. The student will do a research project evaluating the changes in capabilities of Mongolian air quality forecasts. This will include interviewing both operational forecasters and public. Support of 12 months per year is requested for this position.

TRAVEL – DOMESTIC Total: $5,000

Travel funds include support for one of the PI’s and a graduate student to present the outcomes of the first 2 years of training and working with NAMEM and how the decision-making process has been improved at the AGU Fall 2020 conference in December 2020 in San Francisco, CA. Domestic travels funds would also support one of the project PIs to attend one NASA Applied Sciences Program workshop/conference (time/location TBD, participants teams can use Washington, DC as a domestic locations for budgetary purposes).

AGU Fall 2020 meeting:

|  |  |  |  |
| --- | --- | --- | --- |
|  | 1 trip x 1 person @ $550 airfare: |  | $550 |
|  | 5 days rental car: |  | $445 |
|  | 6 nights hotel at $160/night x 1 persons: |  | $960 |
|  | 5 days per diem at $69/day x 1 persons: |  | $345 |
|  | Conference registration: |  | $500 |
|  | Total: |  | $3000 |

NASA Applied Sciences Program conference, Washington, DC date TBD:

NASA Applied Sciences Program conference:

|  |  |  |
| --- | --- | --- |
|  | 1 trip x 2 person @ $750 airfare: | $750 |
|  | Ground transportation: | $65 |
|  | 6 nights hotel @ $140/night x 2 persons: | $840 |
|  | 5 days per diem @ $69/day x 2 persons: | $345 |
|  | Conference registration | $0 |
|  | Total | $2000 |

TRAVEL – FOREIGN Total: $12,710

Foreign travel funds would support for the two co-PI’s and the graduate student to travel to Mongolia for two weeks for a project sustainability workshop in early 2021.

Intensive sustainability and mentoring activities, 2 weeks at the Mongolian National Agency for Meteorology and Environmental Monitoring (NAMEM):

NAMEM intensive two week (15 days) sustainability and mentoring activities

|  |  |  |
| --- | --- | --- |
|  | 1 trip x 3 person @ $1673 airfare: | $5019 |
|  | Ground transportation: | $251 |
|  | 16 nights hotel @ $100/night x 3 persons: | $4800 |
|  | 16 days per diem @ $55/day x 3 persons: | $2640 |
|  | Total | $12,710 |

SUPPLIES Total: $5000

Materials and supplies (peripheral computer hardware, backup tapes, material for NAMEM training sessions, etc.)

OTHER Total: $2,000

Publications: 1 paper in the Bulletin of the American Meteorological Society ($2000) and a short article to be submitted to EOS (free @ $0/paper)

**Erik T. Crosman**

Research Assistant Professor, Department of Atmospheric Science, University of Utah

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135 S 1460 East Rm 819 Salt Lake City, UT 84112-0110

EDUCATION

\* Ph.D. 2011, Atmospheric Sciences, University of Utah

\* M.S. 2005, Atmospheric Sciences, University of Utah

\* B.S. 2003, Earth Science in Meteorology, University of Northern Colorado

PROFESSIONAL EXPERIENCE

\*2015-present, Assistant Research Professor, University of Utah \*2011-2015, Postdoctoral Research Assistant, University of Utah \*2003-2011, Research Assistant, University of Utah

RELATED RESEARCH ACTIVITIES

# My research interests fall broadly is in four key areas: 1) Remote sensing of lakes, 2) thermally-driven flows with an emphasis on lake and sea-induced circulations, 3) numerical modeling, and 4) meteorological and air quality observations in complex mountainous terrain. I am currently working on evaluating daily lake temperature blended analyses from the NASA MUR product for the purpose of utilizing the data for input into regional and climate models. I am also working with the Utah Division of Air Quality to improve the meteorological simulations of winter stable layers for input into air quality models. Other active projects include understanding the impact of thermally-driven flows in the Salt Lake Valley on ozone and PM2.5 concentrations and transport, developing an observational platform to measure ozone and particulate sensors on light rail trains in an urban environment.

AWARDS

\* Edward Zipser Outstanding Graduate Student Award, University of Utah. 2011

\* Outstanding Service and Leadership Award for the Persistent Cold Air Pool Study (PCAPS). 2011

\* Best Student Oral Presentation award at the 14th Conference on Mountain Meteorology. 2010

\*NASA Earth Systems Science Fellowship Recipient. 2006-2009 \*2006-2009 College of Mines Outstanding Teaching Assistant Award, 2006

SELECTED PUBLICATIONS

Crosman, E., and coauthors, 2017: Satellite-derived lake surface water temperature: A review. In preparation, *Remote Sensing of Environment*.

Crosman, E., J. Vazquez-Cuervo, M. Chin, 2017: Evaluation of the Multi-Scale Ultra-High Resolution (MUR) analysis of lake surface temperature. Remote Sensing. 9(7), 723. doi:10.3390/rs9070723

Crosman, E., J. Horel, 2017: Large-eddy simulations of a Salt Lake Valley Cold-air Pool. *Atmospheric Research*. 193, 10-25.

Crosman, E. T., Jacques, A. A., & Horel, J. D., 2017: A novel approach for monitoring vertical profiles of boundary-layer pollutants: Utilizing routine news helicopter flights. Atmospheric Pollution Research. 8, 828-835.

Foster, C., E. Crosman, J. Horel, 2017: Simulations of a Cold-Air Pool in Utah’s Salt Lake Valley: Sensitivity to Land Use and Snow Cover. *Boundary Layer Meteorology*. 164, 63-87.

Blaylock, B., J. Horel, E. Crosman, 2016: Impact of Lake Breezes on Summer Ozone Concentrations in the Salt Lake Valley. *J. Appl. Meteor. Clim.* 56, 353-370.

Horel, J., E. Crosman, A. Jacques, B. Blaylock, S. Arens, A. Long, J. Sohl, R. Martin, 2016: Influence of the Great Salt Lake on summer air quality over nearby urban areas. *Atmospheric Science Letters*. 17, 480-486.

Jacques, A., J. Horel, E. Crosman, F. Vernon, J. Tytell, 2016: The Earthscope US Transportable Array 1 Hz Surface Pressure Dataset. *Geoscience Data Journal*, 3: 29–36.

Crosman, E., and J. Horel 2016: Winter lake breezes near the Great Salt Lake. *Boundary Layer Meteorology.* 159*,* 439–464.doi:10.1007/s10546-015-0117-6

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Neemann, E., E. Crosman, J. Horel, L. Avey, 2015: Simulations of a cold-air pool associated with elevated wintertime ozone in the Uintah Basin, Utah. *Atmos. Chem. Phys*., 15, 135-151.

Strong, C., A.K. Kochanski, E. Crosman, 2014: A Slab Model of the Great Salt Lake for Regional Climate Simulations. *J*. Adv. Model Earth Systems, 6, 602-615.

Grim, J.A., J.C. Knievel, E. Crosman, 2013: Techniques for Using MODIS Data to Remotely Sense Water Surface Temperatures. *Journal of Atmospheric and Oceanic Technology*, 30, 2434-2451.

Crosman, E.T., J.D. Horel, 2012: Idealized Large-Eddy Simulations of Sea and Lake Breeze: Sensitivity to Lake Diameter, Heat Flux, and Stability. *Boundary Layer Meteorology. 144, 309-328*.

Crosman, E.T., J.D. Horel, 2012: Sea and lake breezes: A review of numerical studies. *Boundary Layer Meteorology. 137, 1-29*.

Crosman, E.T., J.D. Horel, 2009. MODIS-derived Surface Temperature of the Great Salt Lake. *Remote Sensing of Environment. 113, 73-81*.

SELECTED EDUCATIONAL AND PROFESSIONAL ACTIVITIES IN PAST THREE YEARS

\* Supervising 1 Ph.D. student presently

\* On Supervisory committees of 4 student M.S. thesis and 1 student Ph.D. thesis

\* Co-Chair, 17th AMS Mountain Meteorology Conference, Burlington VT. 2016.

\*Faculty advisor, U. of Utah Student Chapter of the American Meteorological Society. 2016- \*Instructor, ATMOS 5050/6050: Atmospheric Instrumentation. 2014, 2016. \*Team Member, Cold Pool Modeling Working Group, Environmental Protection Agency (EPA). 2015- \*Team member, NASA Multi-sensor Improved Sea Surface Temperatures (MISST). 2011-

**Dr. Munkhbayar Baasandorj (Munkh)**

Research Assistant Professor ,University of Utah [m.baasandorj@utah.edu](mailto:m.baasandorj@utah.edu) Phone: 773-946-6959

**Education**

Ph.D., Environmental Science, School of Public and Environmental Affairs, Indiana University, specializing in atmospheric chemistry, 2003 – 2008

M.S., Environmental Science, Indiana University, Bloomington, IN, 2001 - 2003

B.S., Physics, Dokuz Eylul University, Izmir, Turkey, 1996 - 2000

**Professional Experience**

**Research Professor, 2016 – now**

University of Utah, Department of Atmospheric Sciences

**Environmental Scientist,** 2015 – 2017

Utah Division of Air Quality, Salt Lake City, Utah

**Consultant,** September – December 2014

Washington University in St. Louis, Department of Energy, Environmental, & Chemical Engineering, St. Louis, MO

**Postdoctoral Research Associate**, August 2012 –August 2014

University of Minnesota, Department of Soil, Water and Climate, St. Paul, MN

**Research Scientist**, February 2008 – June 2012

National Oceanic and Atmospheric Administration (NOAA), Chemical Sciences Division, Boulder, CO

**Associate Researcher**, June 2002 – January 2008

Indiana University, Bloomington, IN

**Field Campaigns**

* St. Louis Air Quality Regional Study (SLAQRS), St. Louis, MO 2013
* (PI) Salt Lake Valley Wintertime PM2.5 Study 2015
* (PI) West Valley High Time Resolution Air Toxics Campaign in Salt Lake City, UT 2015 – 2017
* (co-PI) Utah Winter Fine Particulate Study 2017 in UT

**Selected Publications**

**Baasandorj, M.**, S.W. Hoch, R. Bares, J.C. Lin, S.S. Brown, D.B. Millet, R. Martin, K. Kelly, K.J. Zarzana, C.D. Whiteman, W.P. Dubé, G. Tonneson, I.C. Jaramillo, and J. Sohl (2017), “[Coupling between chemical and meteorological processes under persistent cold-air pool conditions: Evolution of wintertime PM2.5 pollution events and N2O5 observations in Utah’s Salt Lake Valley](https://atmoschem.umn.edu/sites/atmoschem.umn.edu/files/baasandorj_2017.pdf)”, *Environ. Sci. Technol.*, doi:10.1021/acs.est.6b06603, 51, 2017

Zhu, L., D.J. Jacob, F.N. Keutsch, L.J. Mickley, R. Scheffe, M. Strum, G. González Abad, K. Chance, K. Yang, B. Rappenglück, D.B. Millet, **M. Baasandorj**, L. Jaeglé, and V. Shah, “[Formaldehyde (HCHO) as a Hazardous Air Pollutant: Mapping surface concentrations from satellite and inferring cancer risks in the United States](https://atmoschem.umn.edu/sites/atmoschem.umn.edu/files/zhu_2017.pdf)”, Env. Sci. Technol., 51, 2017

Millet, D.B., **M. Baasandorj**, L. Hu, D. Mitroo, J. Turner, and B.J. Williams, “Nighttime chemistry and morning isoprene drive daytime ozone downwind of a major deciduous forest”, *Environmental Science & Technology,* **50**, 4335 -4342, 2016

Millet, D.B., **M. Baasandorj**, D.K. Farmer, J.A. Thornton, K. Baumann, P. Brophy, S. Chaliyakunnel, J.A. de Gouw, M. Graus, L. Hu, A. Koss, B.H. Lee, F.D. Lopez-Hilfiker, J.A. Neuman, F. Paulot, J. Peischl, I.B. Pollack, T.B. Ryerson, C. Warneke, B.J. Williams, and J. Xu (2015), “A large and ubiquitous source of atmospheric formic acid”, *Atmos. Chem. Phys*., **15**, 6283-6304, 2015

**Baasandorj, M.**; Millet,, D.B.; Hu, L.; Mitroo, D.; Williams, B.J., “Measuring acetic and formic acid by proton transfer reaction-mass spectrometry: sensitivity, humidity dependence, and quantifying interferences”, *Atmospheric Measurement Techniques*, **8**, 1303–1321, 2015

**Baasandorj, M.;** Fleming, E.L.; Jackman, C.H.; Burkholder, J.B., “O(1D) Kinetics Study of Key Ozone Depleting Substances and Greenhouse Gases” *Journal of Physical Chemistry*, A, **117** (12), 2434-2445, 2013

**Baasandorj, M.**; Ravishankara, A.R.; Burkholder, J.B., “Atmospheric Chemistry of (*Z*)-CF3CH=CHCF3: OH Radical Reaction Rate Coefficient and Global Warming Potential” *Journal of Physical Chemistry*, A, **115** (38), 10539-10549, 2011

**Baasandorj, M.**; Feierabend, K.J.; Burkholder, J.B., “Rate coefficients and ClO Radical Yields in the Reaction of O(1D) with CClF2CCl2F, CCl3CF3, CClF2CClF2, and CCl2FCF3

” *International Journal of Chemical Kinetics*, **43** (8), 393-401, 2011

**Baasandorj, M.**; Papanastasiou, D.K.; Talukdar, R.K.; Hasson, A.S.; Burkholder, J.B., “(CH3)3COOH (t-Butyl Hydroperoxide): OH Reaction Rate Coefficients between 206 and 375 K and the OH Photolysis Quantum Yield at 248 nm. “ *Physical Chemistry Chemical Physics*, **12**, 12101-12111, 2010

1. **Current and Pending Support**

**Erik T. Crosman**

**Current Support**

**1) Title: UUNET DATA PURCHASE FOR NWS NATIONAL MESONET PROGRAM**

Supporting Agency: Synoptic Data Corporation

Total Award Period: 01/17/2017-01/16/2018

Total Award Amount: 33,600

Annual Man Months: 1

**2) Title: Assessment of HRRR Model Forecasts of Convective Outflows in the Fire Environment**

Supporting Agency: Department of Interior (Bureau of Land Management)

Total Award Period Covered: 08/01/2017-07/31/2019

Total Award Amount: $260,842

Annual Man Months: 3

**Pending Support:**

**1) Title: Utilizing Earth Observations to Improve Air Quality Monitoring and Forecasting in Ulaanbaatar, Mongolia**

Supporting Agency: NASA

Total Award Period Covered: 7/01/2018-6/30/2021

Total Award Amount: $593,371

Annual Man Months: 6

**2) Title: Improving Long-term Records of High-Resolution Satellite-derived Lake Surface Temperature for Global and Regional Climate Studies**

Supporting Agency: NOAA

Total Award Period Covered: 7/01/2018-6/30/2020

Total Award Amount: $268,424

Annual Man Months: 6

**Current and Pending Support: Dr. Munkhbayar Baasandorj**

**Current Support**

**1) Title: West Valley Air Toxics Study: 2015-2017**

Supporting Agency: EPA

Total Award Period: 11/01/2015-01/31/2018

Total Award Amount: 375,000

Annual Man Months: 12

**2) Title: UWFPS**

Supporting Agency: DAQ

Total Award Period: 06/01/2017-03/31/2018

Total Award Amount: 12,000

Annual Man Months: 1.5

**Pending Support:**

**1) Title: Utilizing Earth Observations to Improve Air Quality Monitoring and Forecasting in Ulaanbaatar, Mongolia**

Supporting Agency: NASA

Total Award Period Covered: 7/01/2018-6/30/2021

Total Award Amount: $593,371

Annual Man Months: 2

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Ulaanbaatar, Mongolia. Air Quality, Atmosphere and Health, 9, 137-150.

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in Ulaanbaatar city, Mongolia. J Geosci Environ Protect 2:123–128.

Baasandorj, M., S.W. Hoch, R. Bares, J.C. Lin, S.S. Brown, D.B. Millet, R. Martin, K. Kelly,

K.J. Zarzana, C.D. Whiteman, W.P. Dubé, G. Tonneson, I.C. Jaramillo, and J. Sohl

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pool conditions: Evolution of wintertime PM2.5 pollution events and N2O5 observations in

Utah’s Salt Lake Valley. *Environ. Sci. Technol.*, doi:10.1021/acs.est.6b06603, 51, 2017.

Batmunkh, T., Kim,Y.J., Jung, J.S., Park, K. and Tumendemberel, B. (2013) Chemical

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Ulaanbaatar, Mongolia. Journal of the Air & Waste Management Association, 63, 659-670

Crosman, E., and J. Horel 2016: Winter lake breezes near the Great Salt Lake. *Boundary Layer Meteorology.* 159*,* 439–464.doi:10.1007/s10546-015-0117-6

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