NASA Science Mission Directorate
Research Opportunities in Space and Earth Sciences –2022
NNH22ZDA001N-MEASURES
A.27 Making Earth System Data Records for Use in Research Environments

The National Aeronautics and Space Administration's Earth Science Division (ESD) develops unique capabilities in remote sensing to implement a broad suite of space-based Earth observations which, together with many other data, are utilized to advance knowledge of the integrated Earth system, the global atmosphere, oceans (including sea ice), land surfaces, ecosystems, and interactions between all elements, including the impacts of humans. Sustained, simultaneous observations of many geophysical parameters are needed to understand the complexity of the global Earth system. The quantitative determination of global trends in the Earth's atmosphere, ocean, cryosphere, biosphere, and land surface and interior depends significantly on the availability of multiinstrument/multiplatform data sets, provided at a range of spatial and temporal resolution, which extent to time periods of a decade or longer. The ability to enhance Earth system models and advance predictive capabilities relies on dynamically consistent global observational data sets.

The overall objective of Making Earth System Data Records for Use in Research Environments (MEaSUREs) solicitation is to provide an opportunity for the research community to participate in the development and generation of data products, which complement and augment the NASA produced and distributed Earth science data products available to the research community and other stakeholders. An Earth System Data Record (ESDR) is defined as a unified and coherent set of observations of a given parameter of the Earth system, designed to meet specific requirements in addressing science questions. These data records are valuable to understanding Earth System processes; are critical to assessing variability, long-term trends, and change in the Earth System; and provide input and validation means to modeling efforts. Emphasis is placed into linking together multiple satellites into a constellation, developing the means of utilizing a multitude of data sources to form coherent time series, and facilitating the use of extensive data in the development of comprehensive Earth system models.

NASA received a total of 69 proposals in response to this NRA and selected 25 for funding. The total funding to be provided for these investigations is approximately $12 million over 5 years. The investigations selected are listed below. The Principal Investigator, institution, and investigation title are provided:

Paulo Arevalo/Boston University
Continuation and Improvement of A Moderate Spatial Resolution Data Record of 21st Century Global Land Cover and Land Cover Change
22-MEASURE22-0034

Land cover maps are essential for characterizing the ecological state and biophysical properties of the Earth's land areas. Because land cover maps synthesize a rich array of information related to the ecological condition of land areas and their exploitation by humans, they are widely used for model-based investigations that require information related to land surface biophysical properties (e.g., terrestrial carbon models, water balance models, weather and climate models, etc.), and are core inputs to models used by natural resource scientists and land managers. As the global population has grown over the last several decades, rates of land cover change have increased, with concomitant impacts on ecosystem properties and services (e.g., biodiversity, water supply, carbon sequestration, loss and expansion of agricultural land, etc.). Hence, accurate information related to land cover and land cover change is essential for managing natural resources and for understanding the ecological and resource footprint of society.

Over the last 4 years, through our Phase I MEaSUREs project, we created a suite of data sets, algorithms, and cloud-based tools that map global land cover and land cover change at 30 m resolution from Landsat imagery for the period 2001-2020. Our Phase I effort is currently on track to complete all of the tasks outlined in our original proposal: (1) we compiled a large, high-quality, and global data set of training sites that are used to estimate classification models; (2) we created a cloud-based data processing and classification workflow to generate global maps at 30 m spatial resolution and annual time step; (3) we compiled a global sample of high-quality reference data that we are using to quantify error and uncertainty in our map products; and (4) we collaborated with the team at the Land Processes Distributed Active Archive Center (LP DAAC) to create a data record and associated documentation to support public distribution of the data product that we created. Our efforts in Phase I created the foundation for creating and distributing robust and repeatable global land cover, land use, and land cover change data sets with well characterized uncertainty. V1.0 of the data set is scheduled to be released by the LP DAAC in the fall of 2022.

Here we propose Phase II of this project with two main goals: (1) to expand production of the data set beyond the original period of 2001-2020; and (2) to implement a focused set of refinements that enhance the quality of the product for the user community. For objective (1) we propose to extend the data set to include 10 additional years (1997-2026). By doing so, the data record will be expanded to include 30 years when land cover change from both natural (e.g., fire) and anthropogenic (e.g., agriculture) causes have been geographically extensive and increasingly intense. For objective (2) we propose to implement three key improvements. First, we will implement a variety of algorithm adjustments to strategically increase the accuracy of land cover maps in specific cases where results from Phase I indicate room for improvement. Second, we will improve the accuracy with which our MEaSUREs product captures land cover change. Third, we will refine our algorithms to improve the quality of mapping results in regions and times where the Landsat record has lower density of observations because of cloud cover or where images were not acquired or not archived prior to the launch of Landsat 8 in 2013. At the end of Phase II, the data product developed through this project will provide a 30-year record of global land cover, land use, and land cover change at 30-m spatial resolution, along with valuable datasets (training and reference data) and tools for analyzing the Landsat archive that will have broad utility and value to the community.

Ali Behrangi/University of Arizona
Next-Generation Global Precipitation Data Record with Improved Accuracy, Consistency, Timeliness, and Resolution for Climate Change, Early Warning and Scientific Analyses
22-MEASURE22-0030

Over the past two decades, the current and past Global Precipitation Climatology Project (GPCP) precipitation products have been used in over 5000 scientific journal articles and have become a science community standard for global precipitation observations to study trends, changes, closure in water and energy cycles, and to evaluate reanalyses and climate models. GPCP has been used as an observational reference in major climate analysis and reports (e.g., IPCC and annual State of the Climate), and contributed to the internationally coordinated set of (mainly) satellite-based global products dealing with the Earth's water and energy cycles, under the auspices of the GEWEX of the WCRP, as well as NASA's NEWS project.

The objective of this proposal is to produce significantly improved next-generation GPCP products (GPCP V4) using new satellite and in situ data sources and techniques. We will enhance the long-term GPCP precipitation products by improving consistency (using sensors, algorithms, station archives, and estimates with consistent records), Spatio-temporal resolution (shifting from 0.5º to 0.1º lat/lon and adding a 3Hourly resolution product to the Daily and Monthly products), accuracy (guided by modern sensors, including TRMM, GPM, CloudSat and GRACE), and timeliness (using improved data streams to reduce the latency from 3 months to 2 weeks). Over land, a rapid degradation in the last decade of rain gauge support for the GPCP will be mitigated to maintain a consistent high-quality product. The projected time span will be 1983-near present for the Monthly product, similar to V3, with the Daily and the newly developed 3Hourly products also going back to 1983 (instead of 2000 for the V3 Monthly). Both Daily and 3Hourly products will have an additional high-quality (HQ) data field, available from June 2000, by direct use of IMERG for enhanced accuracy. The key difference with individual mission data sets is that all the GPCP products will be combined into an integrated and inter-consistent framework, for all overlapping time spans, to provide an analysis useful for various studies on magnitudes and variations from synoptic through inter-annual, inter-decadal, and trend time scales.

We will bring together the latest retrieval methods and utilize emerging capabilities and complementary data sets to: (1) combine precipitation data from NASA CloudSat, TRMM, and GPM to guide our development, (2) analyze snow accumulations through several methods [e.g., mass balance using NASA GRACE and GRACE-FO observations over snow and ice surfaces, NASA OIB (and similar) over Arctic sea ice, and CloudSat over land and ocean] to refine the products, (3) merge the Climate Hazards Center (CHC) gauge analysis with the Global Precipitation Climatology Centre (GPCC) analyses to build a more robust gauge analysis for GPCP, (4) utilize new methods for gauge undercatch corrections in light of independent snowfall accumulation assessments, (5) incorporate sub-monthly CHC gauge information as constraints to Daily and 3Hourly products, and (6) use the long-term, consistent AVHRR record with new training from advanced sensors to replace the old TOVS/AIRS precipitation estimates in the critical polar latitudes, where long-term high quality PMW precipitation estimates are lacking.

Connecting the new, short-term measurements (e.g., NASA TRMM, GPM, CloudSat, GRACE, and OIB) to the long-term GPCP analysis will amplify the impact of NASA's recent missions. This makes the effort timely and fundamental not only for the proposed work, but also for any future updates of GPCP or other precipitation products that use GPCP for bias adjustment.

The proposal team includes key GPCP developers as well as the developer of the new gauge analysis used in GPCP V4; all have proven records of high-quality product development and delivery to the public.

Yehuda Bock/University of California, San Diego
Geodesy-Based Enhanced Solid Earth Science ESDR System (ESESES) for Research and Discovery
22-MEASURE22-0037

Our team at Scripps Institution of Oceanography and Jet Propulsion Laboratory has been a leader in the production of multi-level geodetic Earth system data records through a series of MEaSUREs projects. Our ESDRs fully archived at the CDDIS DAAC include a 30-year record of GNSS displacement time series from more than 3000 stations. They form the framework for derived higher-level displacement and strain rate grids, transients in the crustal deformation cycle, and natural and anthropogenic signals. Our ESDRs include high-rate seismogeodetic observations of early postseismic deformation, tropospheric delay for InSAR calibration and precipitable water vapor as harbingers of extreme weather events and climate change. We developed the interactive MGViz application and a rich MEaSUREs web site to improve accessibility and expand our user community through improved outreach, and instructional videos and a detailed and living on-line Algorithm Theoretical Basis Document (ATBD) for better documentation and instruction. One of the advantages of our ESDRs is that they have gone through a rigorous calibration and validation (Cal/Val) process, including independent processing by two distinct GNSS analysis packages in an effort to represent physical phenomena of interest with minimal artifacts. Our combination solutions have been demonstrated to improve precision, quality and robustness. Common-mode removal from Western U.S. stations is advantageous resulting in displacement rms values of about 0.7 mm in the horizontal and 2-3 mm in the vertical over 20- to 30-year data spans. By continuing and extending the current eight multi-decade ESDRs, our proposal is directly relevant to ESI's CORE" report and NASA's Earth Science Decadal Survey with specific focus on increasing the availability of high-quality data to better understand the nature of deformation associated with plate boundaries, and to the solid Earth response to climate-driven exchange of water among Earth systems. We will extend the multi-decade ESDRs another five years for a larger set of stations, the catalog and models of slow slip events (e.g., ETS) from Cascadia to other tectonically-active regions, in particular New Zealand, Central America and the Caribbean to better understand the crustal/earthquake deformation cycle and seismic hazards. Based on the directions of research in Earth Sciences and the needs of GNSS and InSAR practitioners, we propose the following four new higher-level ESDRs to: (1) Merge daily displacement time series with high-rate GNSS and seismogeodetic solutions, bracketing significant seismic, magmatic and transient events, for a better understanding of underlying physical processes. (2) Integrate GNSS and InSAR into bi-weekly displacement grids using our (5-minute) troposphere and displacement time series, building on operational procedures developed by us with experts at SIO and JPL, in anticipation of the scheduled NISAR mission. (3) Maintain an annotated data set of artifacts, transients and other phenomena developed as part of our ongoing Cal/Val. This is an important and unique training data for developing machine learning methods for improved data analysis, modeling and discovery. (4) Improve the precision and robustness of our displacement time series, in particular in the vertical direction, by creating time series that are corrected for surface loading mechanisms, including non-tidal atmospheric, ocean, and hydrological loading. All twelve ESDRs will be openly accessible through our CDDIS DAAC and SOPAC archives. We will continue to provide support to ongoing NASA Earth data system evolution by participating in Earth Science Data System Working Groups. The user community will be regularly engaged directly with the project, through public workshops and a community-based advisory board, reflective of the MEaSUREs call for applying ESD principles to community involvement. and seek community input and feedback to help guide and critique our work.

Larry Di Girolamo/University of Illinois at Urbana-Champaign
A New 22-Year Earth System Data Record of Cloud-Top Heights and High-Cloud Emissivities from Terra MODIS-MISR Fusion to Investigate the Climatology and Variability of Heights and Optical Properties of Two-Layered Cloud Systems
22-MEASURE22-0061

Clouds play a critical role in Earth's climate as a key component to the hydrological cycle and a key modulator of Earth's radiation budget. Climate model predictions of anthropogenic climate change includes changes to cloud properties, including rising high clouds and melting levels, narrowing of tropical ocean rainfall, lower amounts of mid-latitude low clouds, higher amounts of polar cloud, and a poleward shift in storm tracks. These changes could have a profound effect on, for example, fresh-water availability, food security, and human migration. Unfortunately, these predictions carry substantial uncertainty largely owing to the sub-grid parameterization of clouds in climate models and our incomplete understanding of cloud feedback and climate sensitivity. To make progress, accurate satellite Climate Data Records of cloud properties, including their diurnal to long-term variability, are essential to provide empirical constraints on sub-grid cloud parameterizations and climate predictions, and is one of the key objectives NASA's MEaSUREs solicitation.

Our longest (22-years) single-satellite cloud record that provides stable and multi-decadal observations (features of a desirable climate-quality record) comes from NASA's Terra mission. Cloud properties are derived separately from Terra's MODIS and MISR instruments. Recently, Mitra et al. (2021) provided extensive validation of cloud top heights (CTH) for these two datasets using the ISS-CATS lidar as a reference. Overall, they found that MISR CTH (retrieved through visible-band stereoscopy) offers high accuracy and precision, but often (~80% of the time) retrieves the height of low clouds when multi-layered clouds (most often thin cirrus over low clouds) are present. The uncertainty in the MISR low CTH is unaltered by the presence of the thin cirrus. They also showed that MODIS CTH (retrieved through IR techniques) is highly sensitive to the presence of single-layered cirrus, but can mischaracterize high, thin clouds as thicker mid-level clouds in multi-layered cloud scenes. Hence, the major weakness of each Terra sensor (missed high clouds for MISR and multi-layered clouds for MODIS) pose a significant observational challenge in estimating CTH and cloud optical property variability, especially for multi-layered clouds. Since multi-layered clouds form ~30% of global cloud cover (with 2-layered, thin cirrus over thick water or mixed-phase clouds dominating), they are climatically important.

We have recently developed and validated a physics-based MODIS+MISR fusion algorithm that leverages the strengths of each sensor to tackle the shortcomings of the other. This improvement reduces the MODIS CTH and effective emissivity bias in the retrievals of thin high clouds above thick low clouds by >75%, with a near-closure of the MODIS error budget. This leads to a reduction in error in modeled top-of-atmosphere longwave cloud radiative effects ranging between 5 to 45 W m-2, depending on the relative position and optical properties of the 2 cloud layers.

Here, we propose to operationalize this new algorithm to create a 22-year MODIS+MISR fusion Level 2 Earth System Data Record (ESDR) for CTH (including the heights of both layers in a two-layered system) and cloud optical properties (including thin cirrus emissivity). This ESDR will also package relevant reanalysis data for ease of scientific research. The ESDR includes full documentation, will be fully validated, and made publicly available through a NASA DAAC. In addition, product development and validation will be aided by addressing the following science questions: (1) What is the climatology and meteorological drivers of 2-layered cloud systems sampled from Terra's morning orbit? and (2) Are the modes of variability of vertically separated (high vs low) cloud amounts from observations similar to those from fully coupled climate models? We also propose to actively participate in Earth Science Data System Working Groups.

Ardeshir Ebtehaj/University of Minnesota
A Multi-Decadal sAtellitE Snowfall daTa RecOrd (MAESTRO)
22-MEASURE22-0015

In a warming world, terrestrial snowpack is shrinking, and glaciers are losing their mass worldwide. Over the Arctic, sea ice extent is declining and Greenland is melting with an unprecedented rate. Snowmelt in mountain regions contributes to water supplies for almost one-sixth of the world's population. Climate projections indicate that a population of 2 billion people could be exposed to a high risk of decreased snow meltwater supply in the next century. These global losses of ice and snowpack are exacerbated as more precipitation is likely to fall in the form of rainfall instead of snowfall. Satellite observations of hydrologic cycle play a key role in uncovering the underlying physical mechanisms controlling changes of cryosphere. However, a long-term and accurate satellite data record of snowfall does not exist. Snowfall is one of the least observed hydrologic variables, especially in remote and high-altitudes areas.

The launch of the Global Precipitation Measurement (GPM) core satellite in 2014 was the beginning of a new era in measuring mid-latitude snowfall from space. Passive microwave Bayesian retrieval algorithms, that learn from coincidences of the GPM Dual-frequency Precipitation Radar (DPR) and an international constellation of spaceborne radiometers, provide state-of-the-art estimates of rainfall and snowfall. However, available satellite snowfall data are highly uncertain (e.g., 80% underestimation) mainly because of two reasons. (i) Active DPR observations are only available within 65º S-N and are not sensitive to occurrence of shallow high-latitude snowfall events. (ii) Bayesian retrieval algorithms exhibit large uncertainties over frozen surfaces as snow-cover and snowfall scattering signals interfere and their results are not currently used in the Integrated Multi-satellitE Retrievals for GPM product.

Research suggests that the W-band CloudSat Profiling Radar (CPR) provides the most accurate active observations of snowfall with an almost global coverage. Recent research by the team has produced a dataset of CPR-GPM coincidences (2014-2016) and demonstrated that through modern Bayesian passive microwave algorithms, which are robust to changes of surface emissivity, we can retrieve global snowfall with an unprecedented accuracy beyond what is possible through only learning from DPR data.

The main goal is to provide the longest and the most accurate satellite record of global snowfall (1987-present). The objectives are as follows:

(1) Collect and publish coincidences of CPR and DPR snowfall retrievals (2006-2009) with passive microwave observations from a constellation of spaceborne radiometers including: SSM/I (1987-2021), TMI (1997-2015), AMSR-E (2002-2011), AMSR-2 (2012-present), SSMI/S (2003-2022), AMSU-A,B (1998-2013), MHS (2005-present), ATMS (2011-present), and GMI (2014-present).
(2) Extend and implement a mature Bayesian snowfall retrieval algorithm that learns from coincidences of both DPR and CPR with the constellation of radiometers to detect the occurrence and estimate the rate of global snowfall with an unprecedented accuracy.
(3) Develop and validate a variational data fusion framework that optimally integrates orbital snowfall retrievals into a cohesive gridded global data product with reduced uncertainty.
(4) Disseminate the developed algorithms and produced datasets through a project specific web server and archive them in NSIDC DAAC.

The outcomes will provide new opportunities to answer science questions such as: How do space-time trends in high-latitude snowfall affect worldwide water availability and food security? How are the observed spatiotemporal changes of global snowpack and glaciers related to snowfall -- especially in mountainous watersheds? Can we shrink the uncertainties in mass balance analysis of the Greenland ice sheet and the associated sea level rise? How does the sea-ice surface energy balance alter in response to changes of the Arctic snowfall?

John Forsythe/Colorado State University
A Multidecadal Global Water Vapor Dataset for Research on Processes, Trends and Extreme Events
22-MEASURE22-0006

Water vapor is Earth's most important greenhouse gas and fuels clouds and precipitation. Both total column and vertical profiles of water vapor are recognized as Essential Climate Variables. NASA has pioneered the construction of multisensor, global, multidecadal water vapor datasets for use in understanding the Earth system and as an independent comparison to reanalyses and climate models.

Members of our team constructed the original NASA Water Vapor dataset (NVAP; 1988-1999) and successor NVAP-MEaSUREs (1988-2009) datasets which have been delivered to hundreds of users worldwide via the NASA Langley Atmospheric Science Data center. Via fusion of passive microwave and infrared satellite retrievals from many overlapping spacecraft, both total column water vapor (TCVW) and layered water vapor were derived. A hallmark of the NVAP effort was independence of the water vapor retrievals from dynamical weather prediction models, allowing researchers to independently compare the results.

The NVAP data record currently ends in 2009, so this record is lacking the continued response of the hydrologic cycle to warming and extreme events. What is also lacking is full utilization of the NASA instruments on Terra, Aqua, SNPP and NOAA-20 which provide a record of TCWV and water vapor profiles in the 21st century. MODIS has the capability to retrieve TCWV over both land and ocean in clear skies, via a near-infrared reflected sunlight retrieval. AIRS and CrIS provide hyperspectral profiling ability in non-precipitating scenes with partial cloudiness.

A sampling gap due to clouds also exists in the satellite water vapor record for climate. The NASA Aqua spacecraft carries a microwave sounding instrument which failed a few months into in the mission in 2002. This reduced the capability of Aqua to retrieve water vapor profiles in cloudy atmospheres, which cover over 60% of Earth. Recent advances have created a quality-controlled, microwave sounding radiance record focused on sensors measuring radiance near the 183 GHz water vapor absorption line. It is now possible to add this missing water vapor profiling capability to the climate record. Two proven water vapor retrieval approaches will be applied to this record going back to the early 1990's. Retrievals from a non-Gaussian formulation which better captures extreme events will be added to the NVAP record. This system will run on the SSM/T-2 instrument from the Defense Meteorological Satellite Program, AMSU-A and -B data from the NOAA spacecraft and ATMS data from SNPP and JPSS-1 and -2. There is considerable overlap between these sensors allowing quantification of intersatellite biases.

Global and regional satellite water vapor trends, both at global and regional scales, will be derived. These will be supplemented with climate-quality radiosondes and surface GPS measurements as independent truth. The multidecadal time series of TCWV and layered water vapor from these satellite, model-independent sources will be compared to reanalyses products. Investigation of trends, biases and breakpoints in these records will be performed.

An international effort under the Global Energy and Water Exchanges (GEWEX) project, the Global Water Vapour Assessment (GVAP; http://gewex-vap.org/), brings scientists together to compare and evaluate these diverse representations of multidecadal global water vapor. We will participate in GVAP and share our multisensor record of water vapor with an international group of scientists. The multidecadal, satellite-only, water vapor records produced in this study will be entered into the Obs4MIPS archive for use by weather and climate researchers for a variety of trend, process and extreme event studies.

At project completion, a well-calibrated total and four-layer water vapor dataset spanning 1988   2026 will be available via the NASA Langley Atmospheric Science Data Center for use in research environments.

Alex Gardner/Jet Propulsion Laboratory
Next Generation - Inter-Mission Time Series of Land Ice Velocity and Elevation
22-MEASURE22-0023

The Next Generation - Inter-mission Time Series of Land Ice Velocity and Elevation (ITS-LIVE-NG) project has a singular mission; to accelerate ice sheet and glacier research by producing globally-comprehensive, high resolution, low latency, and temporally dense multi-sensor records of land ice and ice shelf change that are provided in a way that minimizes barriers between the data and the user.

The first incarnation of ITS_LIVE has put in place the first globally comprehensive record of ice flow, including all usable Landsat and Sentinel 1 and 2 data. ITS_LIVE has added depth and detail to the record of ice flow globally; it has worked to remove distinctions between satellite technologies, resulting in the most complete time series possible for all of the world's glaciers. This record of flow is complimented comprehensive , multi-mission records of ice sheet height change and ice shelf melt rates. The ITS_LIVE workflow is fully cloud-based, fully open source, and has an active development and user community. It has allowed us to add new data streams rapidly (Landsat 9 within a week of data availability in the cloud). The ITS_LIVE archive is fully public, discoverable, and web accessible from the time of product generation, allowing the lowest possible latency to the community. To this point it has both complemented other MEaSUREs ice flow products and extended them, either spatially, by sensor inclusion, or, for everywhere but Greenland, by developing publicly available dense time series for the first time.

This record opens a window on the prevalence and patterns of seasonal and shorter variations in ice flow speed and height - directly revealing the impact of basal hydrology and terminus change on valley glaciers and outlet systems; providing a first look at the extent and impact of basal sliding on total ice motion. This record is critical to following the future complex evolution of ice flow in temperate and tidewater glaciers responding to continued warming - directly contributing to NASA's efforts to understand present, and anticipate future, rates of sea level change.

In this proposal we of course continue the routine processing of Landsat 4, 5, 7, 8 and 9, Sentinel 2 (A, B and eventually C and successors), and Sentinel 1 (A, B if it comes back online, and successors) to ensure a timely monitoring of global ice flow is available to all and we will add to our surface elevation time series for the large ice sheets to ensure a consistent record across a complex suite of multiple new and past sensors. In addition, ITS_LIVE-NG will continue to evolve access to low-latency multi-sensor datasets by introducing a global ice front position dataset derived from Landsat 1,2,3,4,5,7,8,9+, Sentinel-2A/B+, Sentinel-1A/B+, ASTER, and RADARSAT imagery. We will also introduce Sentinel-3 into our height change product, and ASTER and RADARSAT into our L2 image pair velocity workflow. We will develop new tools for creating temporally and spatially continuous records height change and velocity.

Louis Giglio/University of Maryland
A Five-Decade Multi-Sensor Global Burned Area Data Record
22-MEASURE22-0064

A validated long-term, consistently processed, multi-decadal, record of global burned area (BA) is documented by the Committee on Earth Observation Satellites (CEOS) and the Global Climate Observing System (GCOS) as needed to support the information needs of the U.N. Framework Convention on Climate Change, and is an outstanding goal of the Global Observation of Forest Cover/Global Observation of Landcover Dynamics (GOFC/GOLD) Fire Implementation Team. There is considerable inter-annual variability in the distribution of fires, making long-term, consistent observation records a key requirement for analyzing the relationship between climate, fire regimes, and anthropogenic activity. Such a record is needed to document past fire activity, contextualize contemporary activity due to anthropogenic and climate change, and to understand the interplay between human activity and climate change on fire occurrence and behavior.

The only systematically generated global BA product was developed, and is maintained, by us under NASA funding using Moderate Resolution Imaging Spectroradiometer

(MODIS) data acquired since 2000. MODIS was designed with fire monitoring capabilities and has a heritage based on the Landsat and Advanced Very High Resolution Radiometer (AVHRR) sensors. Landsat provides the longest terrestrial satellite record, starting in 1972, but only with sparse global coverage, no dedicated fire monitoring capabilities, and a nominal 16-day repeat cycle. The AVHRR sensor series has been in operation from 1978 on the TIROS-N satellite, followed in 1981 on the NOAA Polar Orbiting Environmental Satellite series, and provide global daily coverage at coarse spatial resolution. Despite the obvious relevance of the AVHRR archive, the data are difficult to use for BA generation. Notably, the AVHRR sensors and their respective satellite platforms were not designed for fire monitoring and their use is confounded by factors including problematic and/or inconsistent visible-band calibration, variable and/or ill-behaved saturation of the mid-infrared band, poor navigation, and significant satellite orbit drift. Consequently, there is no definitively-processed global AVHRR BA data set, and the sole publicly available data set is inconsistent and the subject of scientific debate.

We will generate, quality assess, and validate, the first consistently processed, many-decade, multi-sensor global BA product. Specifically, a five-decade monthly 0.5° global BA Climate Data Record (CDR), with spatially explicit uncertainty characterization, will be generated for 1978 2020. This is an era, of changing fire regimes, when the human population has doubled and understanding humanity's role in modifying the environment and climate has evolved from research to widespread concern.

The BA CDR will be generated using gridded day and night active fire observations derived from 12 AVHRR sensors and calibrated with the NASA 500-m MODIS BA product. A targeted subset of the processing will be undertaken in the cloud using Amazon Web Services. The BA CDR will be quality assessed systematically following our NASA MODIS and VIIRS fire product QA approaches and validated, based on our previous BA product validation research, by comparison with Landsat-derived BA data sets. Science user community input will be sought by hosting workshops throughout the project under the auspices of the GOFC/GOLD Fire Implementation Team. The BA CDR will be made available via the NASA Land Processes DAAC with comprehensive documentation and a user guide.

The proposed long-term global BA record is directly responsive to the solicitation's requests to develop ESDRs/CDRs that are critical to assessing variability, long-term trends, and change in the Earth System; and provide input and validation means to modeling efforts" by linking together multiple satellites into a constellation" and utilizing a multitude of data sources to form coherent time series".

Simon Hook/Jet Propulsion Laboratory

A Unified and Coherent Land Surface Temperature and Emissivity (LST&E) Earth System Data Record (ESDR) for Earth Science

22-MEASURE22-0002

Land Surface Temperature and Emissivity (LST&E) data are critical variables for studying a variety of Earth surface processes and surface-atmosphere interactions such as evapotranspiration, surface energy balance and water vapor retrievals. LST&E have been identified as an important Earth System Data Record (ESDR) by NASA and many other international organizations including the Global Climate Observing System (GCOS), that has included LST as an Essential Climate Variable (ECV). Accurate knowledge of LST&E at moderate spatial and high temporal scales is a key requirement for many energy balance models to estimate important surface biophysical variables such as evapotranspiration and plant-available soil moisture. Currently LST&E products are produced using different retrieval methodologies, resulting in discontinuities in time-series, and no single satellite-sensor system exists that is capable of providing global LST&E products at both moderate spatial resolution and high temporal resolution. LST&E data products are currently created from sensors in low Earth orbit (LEO) such as the NASA Moderate Resolution Imaging Spectroradiometer (MODIS) instruments on the Terra and Aqua satellites, as well as from sensors in geostationary Earth orbit (GEO) such as the Geostationary Operational Environmental Satellites (GOES). Historically sensors in LEO orbits have provided global coverage at moderate spatial resolutions (~1km) but more limited temporal coverage (twice daily), while sensors in GEO orbits provide more frequent measurements (hourly) at lower spatial resolution (~3-4km) over a geographically restricted area.

We will continue and enhance an existing MEaSUREs LST&E project that began in 2014, for three different LST&E products:

1. A unified LEO-LST product, with a well characterized uncertainty, gridded at 0.25, 0.5, and 1° resolution optimized for the climate modeling community and generated by seamlessly merging the MODIS and VIIRS LST products starting in 2002 (Aqua) and 2011 (SNPP) respectively.
2. A unified GEO-LST product, generated by using data from the GOES 8 through 19 instruments, calibrated to create a consistent record of high temporal resolution (hourly) LST data.
3. A unified LEO-LSE (land surface emissivity) product (monthly, 0.05 degrees) obtained by merging the MODIS baseline-fit emissivity database (UW-Madison) and the ASTER GED v4 (JPL) and extending with the VIIRS emissivity, to create the most accurate emissivity dataset currently available for the radiative transfer and sounder retrieval community in terms of spectral and absolute magnitude in the 3.5-15 micrometer range.

This combination of products will provide unified records of moderate spatial resolution and high temporal resolution LST data, as well as a unified emissivity dataset spanning three decades. These multidecadal datasets will benefit all studies requiring consistent long-term LST&E measurements.

Joanna Joiner/Goddard Space Flight Center

FluxSat: Long-Term Earth Science Data Record (ESDR) for Terrestrial Gross Primary Production (GPP)
22-MEASURE22-0013

Gross primary production (GPP), the amount of carbon dioxide (CO2) assimilated by plants through photosynthesis, is one of the most variable and uncertain components of the global carbon cycle. Global GPP has been estimated with a number of process-based models, data-driven, and hybrid approaches. Dynamic global vegetation models (DGVMs), driven by observed environmental changes, are used for global carbon budget assessments and long-term (climate) prediction. Benchmarking these and other models globally with data-driven GPP estimates is critical for understanding the land sink and ensuring accurate forecasts of the carbon cycle. In addition, global data-driven GPP estimates are crucial for studies of inter-annual variability, including trends that are linked to mechanisms with large uncertainties, such as the indirect CO2 fertilization effect related to greening.

In response to a community need for a GPP data set that well captures spatio-temporal variability, we developed FluxSat, a data-driven approach that optimizes the use of satellite reflectance data from the NASA MODerate-resolution Imaging Spectroradiometer (MODIS) on the Terra and Aqua satellites, calibrated using ground-based eddy covariance (EC) data. Other available GPP products (e.g., FLUXCOM, MODIS MOD17, and the Vegetation Photosynthesis Model or VPM), have known deficiencies such as 1) too little interannual variability; 2) too low magnitude in the tropics; 3) inaccurate seasonal cycles; and 4) biases with respect to eddy covariance data.

We propose to enhance (spatially, higher resolution) and extend FluxSat (in time, with additional sensors) to create a high quality long term GPP Earth System Data Record (ESDR) for use in model benchmarking, carbon cycle modeling, and studies of trends and inter-annual variability. We will create a long-term GPP record using moderate spatial resolution sensors (of the order of a km) that spans a record of over 40 years. The MODIS sensors are set to be decomissioned at the end of 2023. The Visible Infrared Imaging Radiometer Suite (VIIRS) sensor is the MODIS follow-on for operations. It first flew on the Suomi National Polar-orbiting Partnership satellite (SNPP) satellite and now flies on the National Oceanic and Atmospheric Administration (NOAA) Joint Polar Satellite System (JPSS) series. The SNPP satellite could be decommissioned at around the same time as Aqua and Terra. That leaves the VIIRS sensors on the JPSS satellites as the primary sensor for the record going forward. For this proposal, we focus on the VIIRS on JPSS-1 (also known as NOAA-20) and JPSS-2 (launch date: 30 Sept. 2022); JPSS-3 is not scheduled for launch until no earlier than 2027 and is not a focus of this proposal. The Advanced Very High Resolution Radiometer (AVHRR, 1981), flying on operational weather satellites, provides observations for GPP estimates extending back in time.

Our team's objectives, responding to the creation of Earth System Data Records (ES-DRs), including Climate Data Records (CDRs)", in the 2022 ROSES A.27 call are to

1. Update and document the current MODIS FluxSat GPP (daily, 0.05æ and <0.5æ resolutions) products with latest available MODIS and EC data sets;
2. Extend FluxSat GPP record forward in time with VIIRS going forward;
3. Extend FluxSat GPP record backward in time using AVHRR;
4. Provide higher spatial resolution MODIS and VIIRS GPP(0.0083æ,<1km);
5. Thoroughly evaluate all FluxSat products with independent data;
6. Create a homogenized long-term GPP record spanning 40+ years;

Ian Joughin/University of Washington
Greenland Ice Mapping Project: The NISAR Era
22-MEASURE22-0003

Numerous studies have revealed rapid changes in ice discharge from Greenland, with many of the ice sheet's outlet glaciers accelerating dramatically over the last few decades. These observations are significant in that they show Greenland's mass balance can fluctuate rapidly and unpredictably. Despite the large magnitudes of these changes, we do not yet understand many of the underlying processes controlling fast flow well enough to determine their long-term impact on sea level. Observations made over the last two decades, including those from our prior projects, indicate less potential for run-away ice loss than was initially feared when the first observations of rapid change were made. Nonetheless, outlet glacier dynamics remain a wild card in the sea-level projections as noted in the last three Intergovernmental Panel on Climate Change (IPCC) assessments. Improving such predictions and gaining a firm understanding of the dynamics that drive mass balance requires annual to sub-annual observations of outlet glacier variability (velocity, elevation, and ice front position) to avoid aliasing of the rapidly varying signals. Furthermore, although glaciers can change far more rapidly (sub-annual scales) than expected, decadal-scale observations are still required to provide the knowledge needed for century-scale projection.

Our technology and workflow for measuring ice velocity in Greenland are mature as demonstrated through our ongoing and past Greenland Ice Mapping Projects (GrIMP). Through these projects, we have repeatedly measured ice velocity in Greenland, establishing a widely used record covering the period from 1985 to the present, which represents a nearly four-decade-long precursor leading up to the NASA ISRO Synthetic Aperture Radar (NISAR) era. With the next GrIMP, we will make a major leap forward in accuracy and coverage through the inclusion of NISAR data in our products. While Sentinel 1A/B data have greatly expanded the data available for Greenland since 2015, allowing us to significantly improve the spatio-temporal sampling of our products, the coverage is still limited. The next big increment in data volume will be in early 2024 when NISAR starts providing high-resolution, full ascending/descending coverage every 12 days suitable for both interferometry and speckle tracking. The ability to routinely use interferometric data from both ascending and descending data will allow us to improve accuracies over much of the ice sheet from a few m/yr to a few 10s of cm/yr. In addition, NISAR's L-band frequency will greatly improve interferometric correlation, providing much better performance, especially for the high-accumulation regions in the southeast that remain problematic with the Sentinel 1 C-band coverage. Since NISAR is a left-looking instrument to improve Antarctic coverage, it will miss the far northern parts of Greenland. Fortunately, this is the region that works the best with Sentenel 1 and our workflow can seamlessly blend data from Sentinel 1 and other sensors with NISAR to provide full Greenland coverage. As with our earlier project, GrIMP products will continue to incorporate Landsat and Sentinel 2 data. We will also continue producing regular SAR image mosaics and terminus positions for Greenland. Finally, we will continue to update the GrIMP DEM, including annual products that track regional change in fast-flowing regions.

Ryan Kramer/Goddard Space Flight Center
A Multi-Instrument Record of Radiative Forcing and Feedback Responses for Climate Monitoring and Global Change Studies
22-MEASURE22-0040

Changes in atmospheric composition, such as an increase in carbon dioxide, cause a radiative forcing   an initial perturbation to Earth's radiative energy balance. In response the surface temperature changes, inducing radiative feedbacks that further alter the initial radiative imbalance. This process is the fundamental control on the state of the climate. Consequently, diagnosing radiative forcings and feedbacks is a ubiquitous practice for improving our understanding of most climate processes and reducing uncertainty in climate projections. Despite this importance, no standard observational product of radiative forcing and feedbacks exists. This has hampered the scientific community, where researchers choose from a variety of data sources and methods for diagnosing these terms, leading to avoidable and unnecessary inconsistencies in the literature. We will address this shortcoming by using remote sensing observations from multiple NASA instruments to produce a climate data record of radiative forcing and feedback responses, resolved in space and time from 2002 to the present.

Using the popular radiative kernel technique and measurements from CERES, AIRS, CrIS, MODIS and VIIRS among other sources, we will deliver timeseries of:
(1) Broadband radiative forcing
(2) Broadband radiative feedbacks due to individual changes in temperature, water vapor, surface albedo and clouds.
(3) Spectrally-resolved longwave radiative forcing that can be used to isolate the radiative effects from changes in individual greenhouse gases.
(4) Spectrally-resolved longwave radiative feedbacks

We will produce these products for the top-of-atmosphere radiative balance and for the surface and atmospheric radiative budgets, allowing for the investigation of both climate sensitivity and hydrological sensitivity. The potential user base for these products is large and diverse. The scientific analysis community will use radiative forcing and feedback observations to improve process-level understanding of climate phenomena across disciplines, from land-atmosphere interactions to large-scale circulation changes to tropical cyclone development. Developers of both climate models and remote sensing retrieval algorithms will use these estimates to cross-check the quality of their products against expected radiative closure. With current and future satellite missions, NASA is heavily investing in measurements of the atmosphere's changing composition. To link these observations to the wider context of climate change, they must be accompanied by a measure of their radiative effects.

Importantly, radiative forcing is the most direct, unambiguous measure of the human impact on the climate. Therefore, our products will also have considerable appeal to the climate monitoring and climate policy communities. They can use our radiative forcing diagnosis to evaluate whether specific mitigation efforts are working as intended, using our spectrally-resolved radiative forcing to differentiate the climate effects of individual greenhouse gases. Such analysis will be increasingly important over the lifetime of this project, as governments, non-profits and the private sector attempt to meet their 2030 climate mitigation goals.

Our products will be key tools for addressing multiple Science Questions from the 2017 Decadal Survey, including How can we & improve our ability to predict local and regional climate response to natural and anthropogenic forcings (C-2)?" and How do anthropogenic changes &modify the water and energy cycles at different spatial scales (H-2)?". Our products also respond to general calls for an advanced climate observing system with improved trend-detection capabilities, and specific recommendations for observations of radiative forcings and feedbacks as laid out in recent reports led by the Committee of Earth Observation Satellites (CEOS) and the Global Climate Observing System (GCOS) panel.

Nickolay Krotkov/Goddard Space Flight Center
Continuation of Multi-Decadal Global SO2 and NO2 Earth Science Data Records
22-MEASURE22-0049

Sulfur Dioxide (SO2) and Nitrogen Dioxide (NO2) are short-lived pollutant gases emitted from anthropogenic and natural sources. They have profound, long-term impacts on the Earth's atmospheric composition, air quality (precursors of ozone and aerosols), ecosystems (e.g., acid rain and eutrophication) and the climate and serve as proxies for activity patterns (e.g., COVID-19 effects). Long-term, coherent multi-satellite SO2 and NO2 Earth Science Data Records (ESDRs) are critical for detecting changes in atmospheric composition and for projecting future changes in air quality and climate. Building such records requires sustained effort to develop data from different instruments, old and new, by processing them in a consistent fashion.

Our team has unique multi-decadal experience producing and harmonizing SO2 and NO2 data from spaceborne instruments. Under the auspices of MEaSUREs-2012 (SO2) and MEaSUREs-2017 (NO2 - MINDS), we have released multiple ESDRs including our unique top down" SO2 emissions from volcanic and anthropogenic sources and NO2 column amounts. These ESDRs are produced with both current (OMI and TROPOMI) and legacy instruments that date back to the 1970s for SO2 (TOMS) and to the 1990s for

NO2 (GOME). They have been widely used by atmospheric and climate scientists, air quality managers, economists, and geologists. The science value of these ESDRs grows significantly with their length, and it is critical to update and extend them as data continue to be acquired by current instruments.

We propose to continue our coherent, long-term SO2 and NO2 ESDRs using current satellite instruments, including both Level 2/2G NO2 column amounts and value added (Level 4) satellite-based SO2 emission datasets that cover 17+ years for anthropogenic and volcanic degassing sources and 44+ years for explosive eruptions; and to supplement and enhance these ESDRs with improved error analysis.
Our specific objectives are to:
1. Continue producing and archiving climate quality NO2 ESDRs from current GOME-2 (morning orbit) and OMI/TROPOMI (afternoon orbit) instruments to extend the data records to over three decades (since 1995).
2. Extend and enhance our multi-satellite volcanic explosive SO2 emissions ESDR (MSVOLSO2L4, 1978-) by adding missing and new eruptions and by providing improved error analysis and height estimates.
3. Extend anthropogenic and volcanic degassing SO2 emissions ESDR (MSAQSO2L4, 2005-) by applying our top-down" emissions estimate algorithm to current instruments.
4. Engage the user community through participation in ESDSWGs (Earth Science Data System Working Groups), regular updates to our MEaSUREs websites, and established collaborations with the Environment and Climate Change Canada, universities, USGS volcano observatories and the atmospheric modeling community.

The proposed continuation and extension of our SO2 and NO2 ESDRs will yield an unprecedented long-term, top-down volcanic and pollution emissions database that will be of immense value to the broader climate modeling, air quality and Solid Earth Science communities. The NO2 and SO2 ESDR baselines established through our continuous MEaSUREs effort will also help us put in context and maximize science return from the atmospheric composition constellation of the geostationary satellites (Korean Geostationary Environment Monitoring Spectrometer (GEMS launched in 2020), NASA's Tropospheric Emissions: Monitoring of Pollution (TEMPO 2022), European Copernicus Sentinel 4 (2023)).

Sujay Kumar/Goddard Space Flight Center
Developing High-Resolution Multidecadal Satellite Remote Sensing-Based Snow Lifecycle Reanalysis Products Over the Northern Hemisphere
22-MEASURE22-0032

Objective: Though the importance of characterizing snow conditions on the land surface accurately is well-recognized, the spatiotemporal diversity of the snow formulation, accumulation and melt makes this a highly challenging problem. The currently available global and continental scale estimates of snow from models and remote sensing all have significant coverage and accuracy limitations. Most of these efforts are also focused on estimating snow mass or coverage only. A consistent set of products that map the lifecycle of snow is lacking in the community. In this proposal, we focus on addressing this significant gap to develop a first-of-its-kind, observation-driven record of snow lifecycle variable (snowfall, snow depth, snow water equivalent, and snowmelt) over the Northern Hemisphere at the topographic scales recommended by the NAS decadal survey for a time period of 2000-present.

Methodology: The proposed project will use a suite of well-established retrieval, physical, and data-driven models and assimilation approaches along with a comprehensive set of remote sensing data from passive microwave, active microwave, visible and infrared platforms. Established approaches such as the Goddard Profiling Algorithm (GPOF) will be optimized to develop accurate global retrievals of snowfall. Advanced machine learning models such as the Convolutional Neural Network (CNN) will be used to develop high quality snow depth retrievals. These products will be combined with sophisticated land surface and snow physics models with the NASA Land Information System (LIS). The modeling and assimilation of the snowfall and snow depth retrievals will not only extend the spatiotemporal coverage of these remote-sensing based products, but also will develop products such as snowmelt to provide a complete and consistent description of the snow lifecycle.

Anticipated benefits: The establishment of the snow lifecycle ESDR will provide a much needed benchmark of key snow variables that are important for answering critical questions about water cycle variability, availability, and hydrological extremes. In addition to these snow products, the project will also establish spatiotemporal quantification of snow mass retrieval sensitivities. We expect that these findings will help in further refining the choice of input channels for snow retrieval (e.g. choice of low frequency channels for better characterization of bare soil emissions, use of higher frequency channels for snow detection). The anticipated snow lifecycle ESDR will also serve as a reference against which both current and future model reanalysis and satellite retrievals can be evaluated. In this regard, the proposed work will enable direct contributions to the development of planned snow missions and field campaigns.

Felix Landerer/Jet Propulsion Laboratory
An ESDR of Surface Mass Change from a Hydro-Geodetic Sensor Combination
22-MEASURE22-0018

Mass redistributions within and between Earth's atmosphere, oceans, groundwater, and land ice are fundamental indicators of the large-scale dynamics of the planet. Over the last decades, an expanding network of observations and instruments, both on the ground and in orbit, has enabled researchers to 'follow the redistribution of water and ice' within the Earth system with unprecedented detail, providing an integrated global view of how Earth's water cycle and energy balance are evolving with important applications for everyday life such as drought assessments and flood potential.
We aim to produce a new Earth System Data Record (ESDR) of monthly global surface mass changes at a spatial resolution of up to 100 km by rigorously integrating GRACE

and GRACE-FO (G/GFO) intersatellite range-rate changes, satellite altimetry of surface elevation changes over ice sheets from ICESat /-2 and CryoSat-2, Global Navigation Satellite System (GNSS) observations of vertical displacements of solid Earth's surface, and (indirect) ocean mass change from steric-corrected sea surface height altimetry. The key innovation of our Mass Change ESDR is an order of magnitude increase in the spatial resolution of existing Mass Change climate data records from 100,000 km^2 (the native resolution of G/GFO) to 10,000 km^2. This will significantly broaden the scope of surface mass change science investigations and applications

A global integrated 1° mascon solution will be produced and made publicly available, enabling innovative process studies and applications for continental hydrology, surface mass balance of the ice sheets, and currents as well as sea level budgets, as well as providing better constraints to model these processes. Our ESDR covers the time period from 2002   2021, and will be updated with more recent data as it becomes available. We aim for our new G/GFO/GPS/altimetry global ESDR to become the new 'gold standard' hydro-geodetic ESDR against which geoscience and hydrology data are compared and form the basis for future mass-change data products.

Jaehwa Lee/Goddard Space Flight Center
Over Four Decades of Consistent Aerosol Data Records: Fusing AVHRR with EOS Sensors for Climate Studies
22-MEASURE22-0046

One of the key components of NASA's Earth Science Research Strategy to better understand the complex nature of Earth's climate is the determination of the global radiation balance, and how it is changing in response to natural and anthropogenic factors. Comprehensive regional-to-global climate models (R/GCMs) are playing an ever-greater role in addressing this issue. Because of their important radiative effects, understanding the characteristics of aerosols, especially near their sources and sinks, is of paramount importance in these R/GCMs. Since the late 1990s, many aerosol-capable instruments (e.g., SeaWiFS, MODIS, MISR, OMI, and VIIRS) have flown and provided such information with a high degree of fidelity. However, these time series (currently up to ~25 years) are not always of sufficient length to detect long-term trends in aerosol loading (in terms of aerosol optical depth, AOD). While offering limited information compared to these newer sensors, with an over-40-year combined data record, the series of AVHRRs provides an unprecedented opportunity to retroactively extend the time series.

Although the AVHRRs have previously been used to retrieve AOD over ocean, large-scale, long-term data sets over land have not yet been widely available to the scientific community. The AVHRRs present some challenges in terms of mechanical, optical, and radiometric factors. Mechanically, the overpass times of the satellites drifted in orbit, and only spatially subsampled measurements are available. Optically, the AVHRRs have (in most cases) only two solar bands, which means that the available information content for aerosol retrieval is lower than for newer sensors like MODIS. Radiometrically, these solar bands lack on-board calibration, making it difficult to accurately monitor the absolute calibration of the sensors and their degradation with time.

Our team has demonstrated expertise to meet all of these challenges. The Deep Blue aerosol algorithm family consists of mature, validated algorithms to retrieve AOD over both land and ocean, in cloud-/snow-/ice-free scenes, and has been applied successfully to the SeaWiFS, MODIS, and VIIRS instruments. These data products are heavily used for scientific analyses for applications, such as climate science and air quality, and are also being assimilated into forecast models by the US Navy and other national and international centers. We have previously dealt with issues of orbital drift, resampling, and calibration correction with these products, and our team includes NASA experts on AVHRR calibration to ensure data stability and smooth transitions between the series of sensors. We have created, validated, and published on new demonstration data sets using NOAA-11, 14, 16, and 18 AVHRRs to illustrate successful extension of our EOS-heritage algorithms to AVHRR spectral bands. These demonstration data sets have been used by external scientists, illustrating the demand for Deep Blue AVHRR aerosol data.

We propose to build on our previous work by extending the effort to complete AVHRR measurements, with better calibration corrections, from NOAA-7 (launched in 1981) onwards in order to create 40+ years of consistent aerosol records over both land and ocean. The data products will include AOD at 550 nm, the main reference wavelength used by the scientific community, as well as band 1 (near 630 nm). Radiometric cross-calibration of the AVHRRs to each other and then to the well-characterized MODIS Aqua will provide a stable fused time series. We will also validate the new data set against AERONET and other available data to assess long-term stability and consistency. By dramatically extending the global satellite aerosol record, this proposed work will provide critical pieces of the puzzle needed to form a consensus among the scientific community in determining the long-term role aerosols play in modifying the global radiative budget.

Dylan Millet/University of Minnesota
A Unified Decadal Data Record for Reactive Biosphere-Atmosphere Exchange
22-MEASURE22-0014

Isoprene and methanol are the two top volatile organic compounds (VOCs) emitted from the biosphere to the atmosphere, accounting for ~60% of the global biogenic VOC flux. Together with their oxidation product formaldehyde (HCHO), these compounds affect air quality and climate through their effects on the hydroxyl radical (OH), ozone, and aerosols.

Understanding the above effects is a critical science challenge that requires robust, unified, and self-consistent global data records. The CrIS and OMPS instruments onboard the SNPP and JPSS series of satellites offer an unprecedented combination in this regard, and one that can shed new light on biogenic emissions, atmospheric OH, ecosystem stress, variability, and trends. We propose to leverage this potential in generating a unified set of Earth System Data Records (ESDRs) for reactive biosphere-atmosphere exchange:

A) CrIS isoprene. We will generate daily L2G (L2 gridded) ESDRs for isoprene from the Cross-track Infrared Sounder (CrIS) throughout the SNPP, NOAA-20 (i.e. JPSS-1) and JPSS-2 records. Development of the corresponding SNPP and NOAA-20 products for methanol are being supported separately; work here will leverage that effort and extend it to JPSS-2.

B) OMPS HCHO. Our project also provides continuation for HCHO observations from the Ozone Mapping and Profiler Suite (OMPS) Nadir Mappers. Project activities will include maintaining this key L2 ESDR with ongoing retrieval improvements, calibration and validation activities, and extension from SNPP and NOAA-20 to JPSS-2.

C) Unified L3 gridded products. We will combine the above CrIS/OMPS isoprene, methanol, and HCHO datasets to create unified L3 gridded products for reactive biosphere-atmosphere exchange. Output will be generated as daily and monthly means, providing a rich, accessible new global tool for understanding ecosystem-atmosphere interactions.

D) L4 products for biogenic VOC emissions. Finally, we will apply the above data streams in an assimilation framework to generate and archive global L4 products for biogenic isoprene and methanol emissions. These observationally-constrained datasets will enable new research into biosphere-atmosphere exchange over seasonal to decadal timescales, and will also provide emission inputs for driving models over the 2012-present timeframe.

Relevant ancillary data will be included with all products, such as observation operators, cloud information, retrieval uncertainties, and data quality flags. Independent product evaluation will be performed as a core aspect of all tasks via comparison against in-situ observations and other satellite-derived datasets. In this way we will quantify uncertainties for each variable as a function of abundance and environmental conditions. ESDRs will provide comprehensive error statistics for each individual reported value.

We anticipate that the above products will find broad use for investigations of reactive biosphere-atmosphere exchange. Our work addresses core goals for this solicitation by providing higher-level data products driven by NASA's Earth Science goals" and through generation of data records for assessing variability and change in the Earth System, and as input/validation for modeling". The IPCC AR6 report specifically highlights biogenic VOCs and their temporal evolution as an important uncertainty in the context of short-lived climate forcers. Finally, our project addresses two of the foremost priorities identified in the National Academy of Sciences "Future of Atmospheric Chemistry Research" report: Quantifying emissions and deposition of gases and particles in a changing Earth system"; and Understanding the feedbacks between atmospheric chemistry and the biogeochemistry of natural and managed ecosystems".

Eric Rignot/University of California Irvine

Earth System Data Record of Ice Motion, Grounding Line, and Bed Topography in Antarctica from NISAR and Other sensors

22-MEASURE22-0044

The Antarctic Ice Sheet is contributing sooner and more significantly to sea level rise than anticipated. To understand these changes and project its contribution to sea level change in the coming decades, it is essential to obtain comprehensive, continuous observations of ice sheet and glacier dynamics, which is the dominant vector of rapid change. Our project addresses Antarctica and its 55-m sea level rise equivalent.

We will employ novel observations from the NASA/Indian Space Research Organization (ISRO) NISAR mission, an Earth System Observatory (ESO) mission to be launched in early 2024, and from the Agenzia Spaziale Italiana Cosmo Skymed Second Generation constellation launched in November 2021, along with several other sensors that include Synthetic-Aperture Radar (SAR) missions: 1) European Union Sentinel-1, 2) Canadian Space Agency RADARSAT-2 and RCM; and 3) Japanese ALOS PALSAR-2 and -4; and optical visible satellite imagers that include 4) the U.S.G.S/NASA Landsat-8 and 9, and 5) the European Union Sentinel-2.

We will produce new Earth Science Data Record (ESDR) of 1) monthly, ice-sheet wide, maps of ice motion using phase-only SAR data from NISAR augmented with CSK-2G and Sentinel-1 where available and needed; and complemented by speckle tracking-derived motion from multiple SAR/optical sensors where phase data is not available; 2) Annual maps of grounding zones based on a continuous mapping of grounding lines around the continent to delineate this critical ice-ocean boundary for mass balance assessments and numerical modeling of ice flow; 3) a new bed topography of Antarctica based on mass conservation method (a level-4 product) that extends over the majority of the Antarctic Ice Sheet for the first time and reduced the errors in bed elevation; and 4) Annual maps of ice front boundaries to track ice shelf advance and calving events;

These ESDRs will be unique (ice-sheet wide bed topography; grounding zones; phase-only motion), of higher quality (ice motion will be mapped with 10x more precision), lower latency (monthly instead of annual), and provided at 450-m posting instead of 1 km, to be improved to 150-m during the project. The ESDRs will be generated using an automated processing chain, that includes machine learning algorithms, extensively tested and vetted algorithms, that seamlessly ingests multi-sensor and multi-baseline data into ESDRs, and for which we have eliminated risks. The new bed topography, named BedMachine Antarctica, will cover a 10 x larger fraction of the continent using precision phase-derived velocity and a precise reconstruction of thickness based on mass conservation; it will be merged with the International Bathymetry Chart of the Southern Ocean (IBCSO).

The ESDRs will document ice sheet wide changes, thereby enabling a new generation of ice sheet models to assimilate a dense, comprehensive set of observations and reduce uncertainties of projections of sea level rise from Antarctica; and also to enable mass balance assessments for the community and IPCC reports.

These ESDRs will respond to critical needs from the ice sheet / ocean modeling community and the broad scientific community interested in understanding the evolution of ice sheets and their contribution to sea level. The ESDRs will improve the capabilities of numerical models to project the future contribution of ice sheets to sea level rise and inform the public and policy makers about the risks of rapid sea level change. Overall, the project will serve NASA's Earth science goal to study the evolution of the Earth's ice masses and their impact on sea level change.

Jackson Tan/Goddard Space Flight Center
Global High-Resolution Datasets of Convective or Stratiform Type for Precipitation
22-MEASURE22-0021

The goal of this proposal is to establish a robust framework to routinely produce convective or stratiform (C/S) probability estimates for precipitation at 0.1° every half-hour with global coverage beginning 1998, complementing the widely used Integrated Multi-satellitE Retrievals for GPM (IMERG) precipitation rate product from the Global Precipitation Measurement (GPM) mission. This C/S type separation is important to precipitation science due to their distinct particle size distributions, microphysical growth processes, dynamical environments, diabetic heating of the atmosphere, and representation in numerical models. Potential applications of such C/S type products include in-depth evaluation of satellite precipitation, calibration or adjustment of precipitation estimates, identification of extreme convective storms, global tracking of the C/S nature of precipitation systems, improved estimation of precipitation uncertainties, and evaluation and improvement of numerical models.

While C/S type estimates are provided by spaceborne radars on board the Tropical Rainfall Measuring Mission (TRMM) and GPM Core Observatory satellites, their very limited sampling severely handicaps the range of scientific studies and applications to which they can be applied. Fortunately, with recent advances in C/S type retrievals from low-Earth orbit passive microwave (PMW) and geostationary infrared (IR) observations, we can adopt a constellation strategy, leveraging on the IMERG legacy in merging precipitation retrievals from diverse sources, to create a high-resolution C/S type product with global coverage beginning 1998. This involves three Core Tasks: (i) extending the mature PMW-based C/S type algorithm to every sensor in the GPM constellation; (ii) refining the current IR-based C/S type algorithm; and (iii) identifying the optimal approach to merge the PMW- and IR-based C/S type estimates to obtain complete coverage at 0.1° every half-hour. This produces three Deliverables: a set of Level 2 PMW-based C/S probability products, a Level 3 IR-based C/S probability product, and a merged Level 3 PMW- and IR-based C/S probability product. Furthermore, there are two Additional Tasks that are logical extensions of the Core Tasks but have reduced chances of success: (iv) studying the feasibility of a single, unified C/S type retrieval scheme from collocated PMW and IR observations, and (v) exploring the potential of producing vertical profiles of latent heating at 0.1° every half-hour.

With extensive experience in conventional precipitation algorithms and an established record of applying machine learning techniques to precipitation, the proposal team is uniquely positioned to handle the tasks required in producing the Deliverables. The maturity of the algorithms and the baseline approaches, to which different members of the team have separately contributed, assure the success of the Deliverables from the Core Tasks. Such a global C/S type dataset can complement conventional satellite estimation of precipitation rate to enable the next-generation societal applications and scientific research.

Prasad Thenkabail/USGS Menlo Park
Global Food Security-Support Analysis Data (GFSAD) Products for an Evergreen Revolution in the Twenty-First Century: through High-Resolution (30m or better) Multiple Satellite Sensor Data, Machine Learning Algorithms, and Big-Data Analytics on the Cloud
22-MEASURE22-0001

Climate variability and ballooning populations are putting unprecedented pressure on agricultural croplands and their water use, which are vital for ensuring global food and water security in the twenty-first century. In addition, the COVID-19 pandemic, military conflicts, and changing diets have added to looming global food insecurity. Therefore, there is a critical need to produce consistent and accurate global cropland products at fine spatial resolution (e.g., farm-scale, 30m or better), which are generated consistently, accurately, and routinely (e.g., every year). In this regard, we produced the world's first Landsat-derived global cropland extent product @ 30m (GCEP30) (Thenkabail et al., 2021; download @ LP DAAC) funded by NASA MEaSUREs 2012.
The high impact of our previously-funded NASA GFSAD products such as Landsat 30m GCEP30, 1km cropland dominance, and 1km irrigated versus rainfed is demonstrated by the use of these data by 126 countries during 2018-2021 (97 countries in 2021 alone), continued average downloads every month by about 20 countries, publication of 11 key peer-reviewed articles which already have 1276 citations in a short time-period (2017-present), and use for a wide range of applications (see Section 2.0).
Therefore, the overarching goal of this continuity NASA MEaSUREs proposal is to develop a comprehensive global food security-support analysis data (GFSAD) project that will produce multiple cropland models, maps, and monitoring tools leading to a wide array of products using machine learning algorithms (MLAs), and satellite sensor big-data analytics through cloud-computing. In this new GFSAD project, we focus on producing four distinct Landsat-derived global cropland products for the years 2020 and 2025:

1. Global cropland Extent Product @ 30m (GCEP30) (LGCEP30-2020, LGCEP30-2025).
2. Global Rainfed and Irrigated Product @ 30m (LGRIP30-2020, LGRIP30-2025).
3. Global Cropping Intensity Product @ 30m (LGCIP30-2020 & LGRIP30-2025) &
4. Global Crop Type Product @ 30m for USA, Canada, and India (LGCTY30-2020USACAN, LGCTY30-2025USACAN; LGCTY30-2020India, LGCTY30-2025India).

The study will make use of Landsat 8, 9, and Sentinel-2A&2B surface reflectance products already available in the Google Earth Engine (GEE) cloud, and NASA's Harmonized Landsat Sentinel-2 (HLS) Landsat derived product (HLSL30) for 2013-present and Sentinel-2 derived product (HLSS30) for 2015-present, that together have sub-5-day global coverage at nominal 30m resolution. The four cropland products will be generated using 14 mature MLAs that the team has extensive experience with such as random forest, support vector machines, decision trees, and spectral matching techniques (e.g., Thenkabail et al., 2021, Oliphant et al., 2019, Teluguntla et al., 2018, 2015, Xiong et al., 2017a, Thenkabail et al., 2012, 2009, 2007, 2005) as outlined in the methods section, utilizing GEE.
All crop products will be evaluated for accuracies, errors, and uncertainties using various datasets such as 120,000 points in the global cropland reference dataset; cropland data from USDA CDL, Agri-Food Canada (AAFC) Canada, ground data for various countries through the CGIAR global network such as the ICRISAT, ICRAF, and IITA, country-wise irrigated and rainfed statistics of UN FAO through University of Goettingen (Dr. Stefan Siebert), an additional ~250,000 samples to be taken during the project period using our ground data Mobile App, country-wide reference maps, and sub-meter to 5m very-high-resolution-imagery (VHRI) from the National Geospatial-Intelligence Agency (NGA) available to USGS.

GFSAD will make significant contributions to the Earth System Data Records (ESDRs) including Climate Data Records (CDRs), the Group on Earth Observations Agriculture and Water Societal Beneficial Areas (GEO SBAs), and the GEO Global Agricultural Monitoring (GEOGLAM). All data will be released through NASA's LP DAAC like our earlier GFSAD releases.

Frank Wentz/Remote Sensing Systems
Extending the Air/Sea Essential Climate Variable Record with Observations from Two New Satellite Microwave Sensors: MWI and AMSR-3
22-MEASURE22-0007

One of the greatest consequences of our warming climate will likely be related to changes in the hydrologic cycle and general circulation. These changes will affect droughts, floods, and severe storms, all of which have enormous impacts on society. Of all spaceborne sensors, probably none provide a more complete and relevant array of essential climate variables for studying these hydrologic processes than microwave (MW) radiometers such as NASA's TMI/GMI, JAXA's AMSR-E/AMSR-2, and DOD's SSM/I, SSMIS, WindSat, and COWVR. Over the world's oceans, these satellite MW imagers make highly accurate measurements of (1) sea-surface temperature through-cloud (SST), (2) near-surface wind, (3) columnar atmospheric water vapor, (4) columnar cloud water, and (5) surface rain rate. All five parameters are classified as Essential Climate Variables (ECV) by the Global Observing System for Climate (GCOS). They provide essential information on the variability in the hydrologic cycle and general circulation. This set of satellite retrievals is called the Air-Sea Essential Climate Variables (AS-ECV). The AS-

ECV data record extends from 1987 to present, with the exception of the MW through-cloud SST record which starts in 1998.

To extend the AS-ECV record, two new MW imagers will soon be in operation: the Microwave Imager (MWI) on the Weather System Follow-on Microwave (WSF-M) satellite and JAXA's AMSR-3 on the GOSAT-GW satellite. The launch of MWI is scheduled for late 2023 and AMSR-3 is scheduled to launch in the April 2023 to March 2024 timeframe.

The objective of the proposed investigation is to merge the MWI and AMSR-3 observations into the existing AS-ECV data record, thereby extending the data record, possibly for another 15 years. The end result would be a 5-decade ESDR of air-sea interaction dynamics. To accomplish this, the existing data processing systems (DPS) for WindSat, GMI, and AMSR-2 need to be adapted to handle the new MWI and AMSR-3 observations. Then, after launch a precise inter-calibration of the new observations with the existing observations needs to be performed. This inter-calibration is a crucial part of the investigation to ensure consistency in the multi-decadal climate record. The foundation for the current AS-ECV data record is NASA's GMI sensor. GMI's on-board calibration system and its post-launch orbital maneuvers enabled an absolute calibration of the MW brightness temperatures. MWI has the same on-board calibration system as GMI, and it will provide the absolute calibration reference to tie together the next generation of satellite MW imagers (COWVR, AMSR-3, CIMR).

Over the course of this 5-year investigation, we will assess the long-term stability of MWI/AMSR-3 as well as the accuracy of the retrievals. Annual assessment reports will be prepared. These assessments will be based on comparisons with in-situ observations, numerical models, and independent satellite retrievals. The uncertainties in the AS-ECV retrievals will be characterized by assigning 1-sigma error bars to each retrieval.

To establish community involvement and critique for this project, a Science Advisory Panel (SAP) will be formed to review the product quality and acceptability of the MWI/AMSR-3 AS-ECV. In addition to the internal reviews, the SAP will organize an MWI/AMSR-3 Science Working Group (SWG). The SWG will bring together a larger group of scientists to evaluate the quality of the products and discuss how MWI and AMSR-3 are contributing to Earth science.

The MWI/AMSR-3 AS-ECV will be available in two forms: separate datasets for each sensor and a merged dataset which includes AS-ECVs from all available sensors. MWI/AMSR-3 calibrated brightness temperatures will also be provided. Furthermore, the developed software will be open-source and freely available, using resources such as the RSS website and GitHub.

Sun Wong/Jet Propulsion Laboratory
A Climate Data Record by Fusion of Multi-Platform Hyperspectral Atmospheric Sounders for Long-Term Polar Climate Studies

22-MEASURE22-0017

Polar regions in both hemispheres are responding rapidly to global warming because of the local large positive climate feedback to the enhanced radiative forcing, urging a thorough understanding of the complex feedback mechanisms. However, a data record that can capture a complete picture of the polar climate processes at all time scales is rarely available. We propose to fuse temperature and specific humidity profiles from currently operating polar-orbiting hyperspectral sounders, together with collocated longwave radiative fluxes and cloud properties, sea surface temperature, sea ice, ice mass, and reanalysis-based moisture transport data, to provide a long record covering multi-dimensional atmospheric and surface climate components for the study of climate changes and feedback in polar regions.

Polar regions have the largest temperature and sea-ice anomalies over the globe. Besides the surface albedo feedback, cloud and moisture variations provide longwave radiative feedbacks that couple with large-scale moisture transport and operate at faster timescales than a month. Current ground-based dataset (e.g., HadCRUT surface tempeature) has a low temporal resolution (e.g., monthly).   Research work in polar regions with high temporal resolution (e.g., daily) has depended upon reanalyses, which suffer from high uncertainties in cloud variables and, hence, hinder the analysis of longwave radiative feedback. Moreover, understanding the asymmetry in surface temperature response to global warming between the Arctic and the Antarctic calls for observation-based data records at least at daily temporal resolution, instead of at the commonly used monthly resolution, that also allow flexible incorporation of advanced analysis techniques beyond linear statistics.

A polar-orbiting instrument with wide scan-angles has many daily overpasses over polar regions. Fusing together samples collected from a constellation of infrared and microwave sounder suites is a key to construct datasets that suit the urgent needs of the polar climate science community. With multiple missions currently operating and planned to be launched in the future, a fused multi-decadal infrared plus microwave sounder data record (40+ years) will be attainable in the future. Applying uniform retrieval algorithms (SiFSAP and ClimFiSP) to radiance measurements from different polar-orbiting infrared plus microwave sounder suites will further avoid discrepancies among different algorithms, providing consistent datasets of atmospheric and surface properties at high spatial and temporal resolution. Together with innovative data fusion and uncertainty quantification techniques we will construct Polar Climate Data Records (PolarCDRs) at high spatial and temporal resolution that allow advanced statistical analyses for processes involving multi-dimensional components.

The proposed work will aim at achieving the following goals to provide Polar Climate Data Records (PolarCDRs):

"	(Goal-1) Construct and deliver long-term (2004 onward) consistent data records of vertical profiles of temperature and specific humidity, cloud property histograms, longwave radiative fluxes, cloud effective radii, and surface temperature over both polar regions (50° latitude poleward), with high spatial and temporal resolution by fusing

uniform retrievals from multi-polar orbiting infrared and microwave sounders on equal-area hexagons.
"	(Goal-2) Provide comprehensive uncertainty quantification for each fused profile of temperature and specific humidity.
"	(Goal-3) Provide collocated auxiliary datasets of sea surface temperature, sea ice concentrations, continental ice mass, as well as reanalysis winds and moisture transport diagnostics that are useful in process studies and climate feedback analyses, including climate model evaluation.

Hongbin Yu/Goddard Space Flight Center
Development of a Comprehensive and Augmented Multi-Decadal Remote-Sensing Observations of Dust (CAMRO-Dust) Data Record for Earth Science Research and Applications
22-MEASURE22-0033

Desert dust is abundant and recognized as an integral component of the Earth system that influences weather and climate via a suite of complex interactions with the energy, water, and carbon cycles. Dust storms cause detrimental losses of human life and economic activities through degrading air quality, spreading diseases, disrupting transportation, and reducing efficiency of solar power generation. There has been growing attention in the past decades to advancing the research of dust cycle   a chain of processes involving emissions, transport, transformation, and deposition, and its tight coupling with other bio-geo-chemical components of the Earth system and human dimension. However, many knowledge gaps remain.

Dust varies greatly across a wide range of temporal and spatial scales, resulting from a combination of sporadic nature of dust events, large variability of transport and removal processes, and the tight and complex coupling of dust with other components of the Earth system. Although data assimilation has been widely used in the satellite era to impose strong constraint on aerosol optical depth (AOD), dust is at most weakly constrained due to large uncertainty in model simulations of aerosol components and vertical distribution. Dust deposition from the reanalysis would suffer from a mass imbalance issue. It is thus critical to develop a comprehensive, remote-sensing observations based, and self-consistent global dust data record over multi-decadal time scales.

Built upon the team's extensive experience in satellite remote sensing, machine learning (ML), aerosol modeling, and integrated data analysis, we propose to create a Comprehensive and Augmented Multi-decadal Remote-sensing Observations of Dust (CAMRO-Dust) data record by integrating multiple satellites and developing novel approaches. Satellite sensors include MODIS, VIIRS, and CALIOP. Specifically, we will perform the following major tasks towards the creation of dynamically consistent data sets of dust:
1)	Improving and enhancing aerosol retrievals in both the mid-visible and thermal infrared wavelengths over global oceans from MODIS and VIIRS through implementing a ML-based dust detection algorithm and accounting for dust non-sphericity.

2) Deriving global dust optical depth (DOD) from MODIS and VIIRS retrievals by separating dust from other components based on size and absorption of dust particles.
3) Producing global 3-D distributions of fine and coarse dust extinction based on CALIOP observations of aerosol backscatter and depolarization ratio.
4) Estimating dust deposition fluxes into oceans by using the 3-D dust distributions from satellites.
5) Developing and validating a dust PM2.5 data record for accurately assessing the health impacts of dust.

With these concerted efforts we will develop a comprehensive, coherent, and multi-decadal data record of global dust for broad earth science research and applications. We will analyze and address data error and uncertainties. This unique dataset will be hosted at and distributed by one of NASA Distributed Active Archive Centers (DAACs) designated by the program management to the research community and other stakeholders, along with data readers and adequate documentation of retrieval methods, data production, and product quality. The so-produced dynamically consistent data record of dust can be used to advance the observational understandings of the interannual variability and trend of dust over recent decades, dust direct radiative effects on both solar and terrestrial radiation, air quality and health impacts of dust, and dust fertilizing effect on oceanic ecosystems. The comprehensive dust data set can also be used to systematically evaluate global and regional air quality, climate, and earth system models and effectively guide the reduction of modeling uncertainties.

Tianle Yuan/Goddard Space Flight Center
Making a Long-Term Data Record of Opportunistic Experiments for Studying Aerosol-Cloud Interactions
22-MEASURE22-0036

Objective: To produce a long-term data record of opportunistic experiments for studying aerosol-cloud interactions (ACIs) using both low Earth orbiting and geostationary satellite data. Opportunistic experiments include ship-tracks over the ocean, pollution tracks over land, and volcano tracks over both land and ocean. They can serve as laboratory experiments to study ACIs whose radiative forcing remains one of the key uncertainties in our understanding of drivers of climate change and a priority for the decadal survey and upcoming missions.

The unique elements of the data record include:
1. A long-term data record of ship-tracks and opportunistic experiments within low clouds over both land and ocean;
2. A comprehensive validation procedure to quality assure the detected opportunistic experiments;
3. A 7-year geostationary data record that characterize the temporal evolution of such experiments;
4. An auxiliary dataset containing collocated variables that characterize the environmental conditions and cloud properties;

5. A suite of software tools that enable analyzing ACIs within these experiments at scale.

Motivation: Understanding ACIs and reducing the uncertainty of aerosol indirect forcing are key priorities identified in the 2017 decadal survey (e.g., Applications Objective C-2h and C-2a) and will be major goals for the upcoming Atmosphere Observing System mission. The aerosol indirect forcing also represents the highest uncertainty in our understanding of climate forcing. A major difficulty for understanding ACIs is the complexity of cloud responses to aerosols under different environmental conditions and the entanglement of the influences of meteorology and aerosols using observations. Opportunistic experiments of ACIs provide laboratory-like settings to study ACIs where the influences of meteorology and aerosols can be separated. They can occur under various conditions and thus offer the opportunity to study the influences of environmental conditions on ACIs. Furthermore, the effects of ACIs on clouds can have strong temporal variations. We believe a comprehensive long-term observational record of such experiments is invaluable for advancing our knowledge of ACIs and reducing the uncertainty in aerosol indirect forcing. Such a record must contain both snapshot observations and temporal coverage.

Methodology: The project builds upon existing technologies developed by our group. We use an ensemble of deep neural network models to detect such experiments within raw satellite data at pixel-level without relying on cloud retrievals. We treat each experiment as an object and collect associated auxiliary dataset to characterize the environmental and cloud conditions for cloud both inside the tracks and in the background. We will develop a comprehensive validation plan to characterize the error statistics of detected experiment objects. Finally, to enable its utility and wide application, we will also build a set of foundational software tools that help data users to analyze detected experiments to study ACIs.

The data records will provide the community with a powerful tool to advance our state of knowledge of aerosol-cloud interactions, which will help to reduce the uncertainty of aerosol indirect forcing, the leading source of uncertainty in our estimate of climate forcings.

Howard Zebker/Stanford University
Deformation Time Series of Volcanic Regions from Space-Geodetic InSAR and GNSS Observations
22-MEASURE22-0012

Surface crustal deformation measurements are key constraints to the evolution of volcanic hazards, yet the available data are sparse and require sophisticated processing for the modeling of subsurface processes -- distinguishing among models of event triggering requires very accurate recording of deformation data. These data are in principle presented by a combination of GNSS and interferometric synthetic aperture radar (InSAR) data, and by InSAR alone in uninstrumented areas. Data are routinely acquired today by the ESA Sentinel-1 satellites, and in two years will be joined by the

NASA NISAR mission. The space agency projects running these missions typically support data acquisition and generation of lower-level data products, but many scientists and engineers who would like to apply these data to their work are not specialized in the processing and analysis of radar deformation data. In contrast, GNSS data are routinely reduced and available for much of the world, albeit at sparse spatial sampling at best, or no availability at worst. Here we propose to generate deformation time series at m-scale posting for much of the volcanically active parts of the globe, and serve these though a friendly interface that delivers map or point data. We have developed algorithms and code for reducing InSAR data to geocoded single-look-complex products, creating families of radar interferograms, applying phase unwrapping, and compensating these for time-varying atmospheric artifacts before using small baseline subset (SBAS) methods to create time series. Here we build on existing implementations of these codes and upscale the implementation through cloud platforms to store the time series data in a format that can be conveniently retrieved by any user. In our current implementation, we can retrieve GNSS stations within the InSAR scenes and present these simultaneously with the InSAR data. If no GNSS sites exist, or are time sporadic, only the InSAR data are reported. GNSS fusion is aided by processing all spaceborne radar data in geocoded coordinates, eliminating the costly steps of image registration and co-location. This work will enhance NASA's ability to use existing spaceborne geodetic data readily and accurately, and in particular will be applicable to data and products created by the upcoming NISAR mission.
