NASA Science Mission Directorate
Research Opportunities in Space and Earth Sciences
NNH19ZDA001N-ESROGSS
A.33 Earth Science Research from Operational Geostationary Satellite Systems
Abstracts of Selected Proposals

NASA's Science Mission Directorate, NASA Headquarters, Washington, DC and NOAA National Environmental Satellite, Data, and Information Service, Silver Spring, MD, have selected proposals for the Earth Science Research from Operational Geostationary Satellite Systems in support of the NASA Earth Science Division (ESD) and NOAA GOES-R Program. The solicitation seeks advanced research and practical applications using data derived from instruments aboard U.S. and international geostationary satellites including NOAA's Geostationary Operational Environmental Satellite R series (GOES-R) of satellites and international geostationary satellites, such as the Japan Meteorological Agency's Himawari and Korean GEO-KOMPSAT-2A satellite systems. The selected proposals achieve the goals through the generation of data products and/or the utilization of data products in scientific research and operational applications.

The research and development projects selected through this solicitation included tropospheric state and weather monitoring, convective storms, air quality, studies of aerosol characteristics, volcano monitoring and land surface vegetation characterization and phenology studies.

The NASA ESD has selected 9 out of a total of 83 proposals for the funding of $5.7M over three years. The NOAA GOES-R program has selected 18 out of 69 proposals received in response to this solicitation for the funding of $9.6M over three years. The combined total funding for these investigations, over a period of 3 years, is approximately $15 million.

Kristopher Bedka/Langley Research Center
Automated Detection and Analysis of Severe, Tropopause-Penetrating Convective Storm Patterns Using Remote Sensing Data Fusion and Deep Learning
19-ESROGSS-19-0088

Intense convective storms are sustained by strong updrafts that generate a variety of weather hazards including hail, tornadoes, damaging wind, aircraft turbulence, and icing, in addition to climate impacts via their injection of moisture, aerosols, and trace gasses into the upper troposphere and lower stratosphere (UTLS). Gravity wave breaking occurs atop storms with tropopause-penetrating updrafts in environments with sufficient wind shear, which causes cirrus cloud injection into the stratosphere above the tropospheric anvil cloud top. These above-anvil cirrus plumes (AACP) have been linked to the highest WV ever observed in the mid-latitude UTLS and are routinely found atop the most severe storms on all continents. An AACP is the strongest geostationary satellite-observed

indicator of a severe storm documented to date, and severe weather outbreaks can feature dozens of long-lived AACP-producing storms.

Tropopause-penetrating updrafts, often called “overshooting tops” (OTs), and AACPs exhibit unique patterns within the latest generation of geostationary (GEO) imagery being collected with higher spatio-temporal resolution than ever before. Rapidly rising air within OTs generates cold temperatures, texture in visible imagery, and high lightning flash rates that can be detected by the new GOES-16/17 Geostationary Lightning Mapper and other future GEO lightning imagers. AACPs are not rising and reside in the lower stratosphere, allowing them to adjust to an environment that can be 20 K warmer than the underlying anvil top, making AACPs evident to the human eye and detectable by pattern recognition algorithms.

Though previous efforts have been devoted to automated OT and AACP detection, new, open-source, neural network-based “deep learning” methods have recently emerged that are optimal for spatial pattern recognition. Such methods could significantly improve our ability to detect and analyze these important cloud-top patterns. Previous research has identified 10,000’s of storm cells with OTs and AACPs tracked using GEO and weather radar data over the U.S. We believe that deep learning methods, when trained with a large database of known OT and AACP events, offer the best possible opportunity to detect these patterns. Pixel-scale OT and AACP identifications are needed to identify processes that generate AACPs and to advance our knowledge of their frequency, geographic location, association with severe weather and aviation weather hazards, cloud height, and impact on UTLS composition.

The primary objective of this proposal is to use GEO satellite data, gridded weather radar volumes, model data, and human-based AACP identifications to detect and improve analyses of hazardous convection. This novel combination of GEO visible, IR, and lightning detection data processed within state-of-the-art deep learning methods will provide 1) the most comprehensive understanding of the strengths/limitations of deep learning for analysis and detection of hazardous convection, 2) open-source automated storm detection software that can be leveraged by the Earth Science research community and industry, and 3) new insights into the physical processes that lead to cloud top spatio-temporal evolution depicted by current and future GEO imagers. Remote sensing data fusion enabled by storm cell tracking and GOES stereoscopic analyses provides the opportunity to analyze cloud top height and microphysics in new ways to address uncertainties in how convective storm processes impact cloud-top appearance. In addition to addressing several NASA and science community research goals, a diverse set of international and industry partners seek to evaluate detection products in real time for operational forecasting and aviation industry applications, as well as to set requirements and become early adopters for the hazardous storm detection software.

Emily Berndt/Marshall Space Flight Center
Development of Limb-Corrected and Intercalibrated Multispectral Composites From the Constellation of Geostationary Satellites

19-ESROGSS-19-0034

NASA's MODIS instruments on the Terra and Aqua satellites have been providing imaging capabilities from polar orbit for the last 20 years allowing for twice daily sampling of mesoscale atmospheric features with multispectral or Red, Green, Blue (RGB) composite imagery. With the launch of the next generation of geostationary sensors the capability exists for expanded coverage of RGB imagery with the ability to track features over long distances and study the processes that contribute to the development of fast evolving features. However, the use of RGB imagery on a global basis is not without limitations due to the impact of limb-effects at high viewing angles and subtle spectral channel differences between satellites. Therefore, this proposal addresses an unmet need of the research community for access to science-quality, global RGB imagery to support research process studies through the creation and distribution of a standard suite of RGB products from all available geostationary satellites (GEOKOMPSAT-2A, Himawari-8, GOES-R Series, Meteosat Second and Third Generation).

This proposal responds to sub-element 2.2 NASA Earth Science Research as a Type 1 investigation to develop and refine geostationary limb-correction and intercalibration of short-wave, near-infrared, thermal infrared, and water vapor bands to develop a suite of high-quality RGB products including the Air Mass, Differential Water Vapor, Simple Water Vapor, Night-time Microphysics, and Dust RGB products. The objectives of this project are (1) to expand the limb correction and intercalibration algorithm (Elmer et al. 2019) to the entire geostationary constellation and (2) integrate the processing algorithms into the GeoNEX framework for near real-time product generation, archiving, and dissemination to the research community. The result will be new, science-quality RGB products with high temporal and spatial coverage to allow for new investigations of fast changing weather and hazards. These objectives will be accomplished by developing limb-correction coefficients and intercalibration following the methodology of Elmer et al. (2016, 2019) and Berndt et al. (2018a), improving the methodology and expanding it to additional geostationary sensors. The team will quantitatively validate the products by calculating and comparing the statistical moments to determine the effectiveness of the limb-correction and intercalibration. Also RGB colors will be quantitatively validated by calculating the Euclidean distance in RGB space and qualitatively comparing the corrected RGBs in regions where nadir of one sensor and the limb of another sensor overlap. Once validated, the suite of RGBs will be created for select case studies and then used to demonstrate the value of the corrected RGBs for process studies (e.g., cyclogenesis, hurricane development, dust storms, and development of fog). Throughout the project, the team will coordinate with collaborators at AMES Research Center to integrate the algorithms in the GeoNEX processing pipeline which will enhance the ability for distribution of archived and near real-time science quality RGB products to researchers. This research will advance NASA Earth science research and application programs through the use of U.S. and International geostationary satellite data to provide RGB products critical to improve the understanding of weather and climate process and for associated applications. Development of these capabilities and RGB products will enable researchers access to science-quality products to address science and applications

questions in the 2017 Decadal Survey Weather and Air Quality Panel related to observing large scale circulations and organization of convection (W-2a), formation of clouds and heavy precipitation (W-4), understanding cloud microphysical processes related to aerosols and precipitation (W-9), and the impact of clouds and radiative forcing on short-term predictability (W-10).

Galina Chirokova/Colorado State University
GeoRing-ProxyVisible Satellite Imagery: Turning Night into Day with Machine Learning
19-ESROGSS-19-0010

Key objectives: Visible satellite imagery is routinely and widely used by operational forecast centers for marine, tropical and extratropical cyclone analysis and forecasting [e.g., at National Hurricane Center (NHC), Central Pacific Hurricane Center (CPHC), Ocean Prediction Center (OPC), Weather Prediction Center (WPC), Joint Typhoon Warning Center (JTWC)]. To address the lack of nighttime visible imagery, which can significantly limit the amount of information available to forecasters for some applications, and the limitations of existing alternatives, CIRA developed GOES-16/-17 ProxyVisible imagery (available online on CIRA/RAMMB SLIDER), a nighttime proxy for visible imagery based on Advanced Baseline Imager (ABI) infrared (IR) data. ProxyVisible was provided to NHC as part of GOES-R Proving Ground (PG) since 2018, was extremely well received by NHC's Tropical Analysis and Forecast Branch (TAFB) and Hurricane Specialist Unit (HSU) forecasters, and by 2019 became part of the standard NHC operational suite. However, ProxyVisible primarily focused on displaying low-level oceanic clouds, and is limited to its initially-developed capabilities. NHC forecasters have requested additional features, including better representation of mid-level clouds and deep convection, differentiation between deep convection and cirrus, limb correction, separate over-the-land and over-the-ocean versions, multi-satellite composites (MSCs), optimized processing time, and a fast-loading quick-look version. To address user requests, we propose to develop a new geostationary satellite product, GeoRing-ProxyVisible (GR-PV) nighttime imagery. The GR-PV will build on the lessons learned from ProxyVisible, and in addition to showing low-level clouds, has a much broader goal of using IR channels to attempt to fully replicate visible imagery (ABI Ch02, 0.64 µm) at nighttime.

Methods proposed: To achieve this goal we will: 1) use Suomi National Polar-orbiting Partnership and NOAA-20 Visible Infrared Imaging Radiometer Suite (VIIRS) Day/Night Band (DNB) data for training; 2) use additional ABI channels, possibly including all channels available at night [Ch7 (3.9 µm), Ch8 (6.19 µm), Ch9 (6.95 µm), Ch10 (7.34 µm), Ch11 (8.5 µm,) Ch12 (9.61 µm), Ch13 (10.35 µm), Ch14 (11.2 µm), Ch15 (12.3 µm), Ch16 (13.3 µm)]; (3) use supervised machine learning (ML) methods, and select the best ML algorithm based on the balance between model accuracy and transparency; (4) perform post analysis of the selected ML model to identify the most important variables and understand the reasoning used by the ML algorithm, which will help users better understand and interpret the output. GR-PV will be developed for all

new generation operational geostationary satellites (e.g., NOAA GOES-16/17, Japan's Himawari-8/9, Korea's GEO-KOMPSAT-2A, and possibly EUMETSAT MTG), and as a MSC imagery from these satellites. In addition, GR-PV will be tested in existing daytime multi-spectral products [e.g. Day Cloud Convection RGB (0.64, 0.64, 10.35 µm)] as a replacement for Visible channel (ABI Ch02, 0.64 µm) to evaluate the possibility of developing nighttime versions. The project team will work closely with NHC forecasters and use feedback for product development. GR-PV will be made available in real-time for NHC's Advanced Weather Interactive Processing System (AWIPS2), and online for operational forecaster's evaluation and feedback.

Significance to the solicitation's objectives: This is a NOAA (Part 2.3) proposal Type 1 (Data Product Creation) that addresses data product creation from operational geostationary satellites for operational opportunities, is likely to lead to significant improvements in data products for weather forecast operations, is in direct response to the user request (NHC), and the project goals are consistent with NESDIS strategic Plan Goal of User-Inspired Science: develop and support algorithms to provide state-of-the art-science products to NWS.

Jaime Daniels/National Oceanic and Atmospheric Administration
New Fused GEO+LEO Multi-Satellite Product: Stereo-Winds from Collocated ABI and VIIRS Datasets
19-ESROGSS-19-0148

Satellite derived winds derived from Geostationary (GEO) and Low Earth Orbiting (LEO) satellites are a key component of the Global Observing System (GOS). These winds serve as key inputs to operational global and regional Numerical Weather Prediction (NWP) data assimilation systems and provide weather forecasters with situational awareness of the state of the atmosphere as they prepare their forecasts.
This proposed effort aims to develop the capability to derive 3D atmospheric motion winds ("3D" refers to the three-dimensional placement of wind in an atmospheric column) using stereoscopic views of ABI imagery from NOAA's GOES satellites (GOES-16 and GOES-17) and VIIRS imagery from NOAA and NASA's LEO satellites (NOAA-20 and Suomi-NPP). The ability to derive stereo winds is possible from these advanced imagers because they provide high quality imagery possessing high spatial and temporal resolution with very accurate and stable pointing accuracy.
Our ultimate objective is to develop this capability in a manner that easily facilitates its incorporation within NOAA/NESDIS' operational enterprise. This will be made possible by our deliberate approach to integrate the 3D-winds retrieval algorithm on top of NOAA's operational nested tracking algorithm used to derive winds from GOES-16, GOES-17, NOAA-20, and Suomi-NPP.
The GOES-VIIRS 3D wind datasets are expected to nicely compliment NOAA's operational GOES-16/17 ABI, NOAA-20 VIIRS, and Suomi-NPP VIIRS wind products. The ability to retrieve highly accurate cloud heights from stereography means satellite derived winds can be derived with highly accurate height assignment even in situations (ie., thin cirrus, elevated temperature inversions) that challenge traditional satellite winds

derived using cloud top heights derived from infrared measurements. This is crucial to their potential for improving their utilization in operational NWP forecast systems and for improving atmospheric wind analyses and the skill of global and regional forecasts.

Louis Giglio/University of Maryland, College Park
Development of a Next-Generation Science-Quality Geostationary Satellite Active Fire Product
19-ESROGSS-19-0114

Automated geostationary satellite active-fire detection algorithms were first developed in the late 1980s for the legacy GOES Visible Infrared Spin Scan Radiometer Atmospheric Sounder (VAS). That initial effort later evolved into the Wildfire Automated Biomass Burning Algorithm (WF-ABBA), which entered routine operations at NOAA in the early 2000s using subsequent GOES Imager data. Those geostationary data promised valuable diurnal cycle fire information to complement polar orbiting data from legacy NOAA Advanced Very High Resolution Radiometer and contemporaneous NASA Moderate Resolution Imaging Spectroradiometer (MODIS) global fire products, among others. Other initiatives followed using geostationary satellite data from EUMETSAT's Meteosat Second Generation (MSG). Despite their enormous potential, geostationary-based satellite fire products have remained largely underutilized over the years. Multiple factors have contributed to this underutilization, including the lack of well-established programs to support algorithm development and validation, the intrinsic quality limitations of previous generation geostationary sensor data sets (e.g., coarse spatial resolution and navigation errors, sub-optimal spectral/radiometric configuration leading to frequent fire-pixel saturation), and poor product documentation and/or access. Most importantly, existing algorithms are plagued by large commission and/or omission errors.

In this Type-1 NOAA proposal we aim to develop an optimized active fire detection algorithm for the new generation of geostationary satellites that entered operations with JAXA's Himawari-8 system in 2014, followed by the sister GOES-R series in 2016 and 2017, and soon expanded to the forthcoming Meteosat Third Generation (MTG) platform. Building on the experience gained during development and validation of the EOS MODIS and Joint Polar Satellite System Visible Infrared Imaging Radiometer Suite (VIIRS) fire products, we will seek a custom approach that fully exploits the advantage of the temporal and spatial information of the new data. Special attention will be devoted to minimizing false alarms, improving the detection envelope, optimizing processing to ensure near real-time data availability, and delivering sub-pixel fire characterization (fire radiative power) that is consistent with existing polar orbiting data sets. Focus will be given to the GOES-R series, although results are expected to be fully applicable to the Himawari and MTG satellites.

An essential element of the project will be validation of the new geostationary fire product. In this phase of the proposed effort, omission error (missed-fire) rates and commission error (false-alarm) rates will be rigorously quantified using an established methodology previously used to validate numerous active fire data sets, including

NASA's Terra MODIS active fire product, the Cooperative Institute for Meteorological Satellite Studies GOES Imager WF-ABBA fire product, and the current NOAA GOES-16/17 ABI Fire Detection and Characterization (FDC) product. Reference fire maps will be generated from Landsat-8 Operational Land Imager (OLI) data using an OLI-specific fire detection algorithm.

In addition to routine near real-time fire monitoring based on Level 2 (scan) data, satellite fire information also provides important input data to emissions modeling, land use/cover change mapping, and climate research. Typically, those applications have more strict requirements demanding higher level processing to reduce data uncertainty. Equally important, consistency among mainstream satellite fire data sets is key to support data interoperability with other systems. In response to these requirements, we will generate higher level data processing mimicking those of MODIS and VIIRS. Following product development and validation, we will lastly demonstrate and assess the strengths and weaknesses of the product for selected applications.

Bin Guan/University of California, Los Angeles
Lightning and Wind Structure of Atmospheric Rivers Affecting the Continental US Observed by GOES-16/17
19-ESROGSS-19-0095

The term "atmospheric river" (AR) was coined by Zhu and Newell (1998) to represent the relatively narrow filaments of horizontal water vapor transport that often occur within and across midlatitudes. ARs have long been recognized as the major precipitation deliverers, flood producers, and drought busters in the western US, and have been the focus of a rapidly increasing volume of studies in the recent few years. A key challenge facing these studies has been the lack of high-resolution observational data for better characterizing ARs and benchmarking model performance as they rapidly evolve over a life cycle of typically a few days (thus a complete AR life cycle cannot be adequately sampled by low Earth orbit satellites). The recently launched GOES-16 and 17 satellites provide opportunities for studying ARs affecting the US at spatiotemporal resolutions not available from previous generations of operational geostationary satellites nor from other observational platforms.

Taking advantage of these new data from GOES-16 and 17, a global AR tracking algorithm continually improving at UCLA/JPL, and existing and future AR dropsonde data collections by UCSD and its AR-focused regional modeling and data assimilation system, the proposed project aims to

1. Along the lines of our existing global and regional studies, continue our characterization of ARs over the eastern Pacific and across the Americas emphasizing on the continental US, with a (yet to be studied) focus on the influence of ARs on lightning activity. This objective will be obtained primarily using lightning observations from the two GLMs, in combination with longer term, but lower spatial or temporal resolution lightning observations from other platforms.

2. Make use of our global AR detection algorithm (Guan and Waliser, 2015; Guan et al., 2018) – developed to version 3 recently (Guan and Waliser, 2019) that enables spatiotemporal tracking of AR life cycles – to understand the temporal evolution of lightning activity over the AR life cycle, particularly the relationship between lightning, AR intensification/weakening, and presence/location of narrow cold-frontal rainbands.
3. Provide a (so far lacking) baseline characterization of the value of the GOES-16/17 sampling capabilities for monitoring ARs, particularly with respect to the vertical and horizontal structures of wind (alongside water vapor, an integral component of ARs) and variations over the AR life cycle. The uncertainty of AMVs and water vapor derived from the ABIs in representing ARs will be quantified by comparing with other reliable observations such as from AR Reconnaissance dropsondes.
4. Assess the potential value of the GOES-16/17 information on wind (and accompanying water vapor) for improving forecasting of ARs and their multi-scale features in a data assimilation context, focusing on evaluating how these new information may benefit assimilating small-scale features and how these benefits may project to better-quality forecast of AR precipitation and winds. This objective will be obtained by employing a regional model developed and used at UCSD and optimized for simulation of ARs and their fast-moving features and assimilation of both conventional and remotely-sensed data.

The proposed project is in response to Section 2.2 (NASA Earth Science Research) and Type 2 (Data Analysis) of the solicitation. Expected results from this project will provide an improved observational understanding of the processes during AR life cycles focusing on the interplay between lightning, water vapor and wind structure, and associated extreme precipitation, and a baseline evaluation of the utility of the GOES-16/17 information on winds and water vapor for monitoring and forecasting ARs in a data assimilation context, whereby providing a useful basis for the consideration of future NASA or NOAA geostationary missions and data products.

Andy Harris/University of Maryland, College Park
Use of Modern Geostationary Data to Improve a Global Diurnal Warming Model for Multi-Satellite Data Fusion
19-ESROGSS-19-0103

Optimal combination of sea surface temperature data from different satellite instruments requires accounting for the magnitude of the cycle at each observation time throughout the day. In this project, we propose to exploit the latest generation of high-quality geostationary SST observations in the development and validation of a new diurnal model that will be used for this purpose.

Parameterization of upper ocean warming is key to predicting both the vertical transport of heat and the details of air-sea heat exchange. Each of these processes contribute to uncertainties in the global heat budget which need to be narrowed in order to better quantify and model the transport and storage of heat in the climate system. The ocean gains most of its heat from incoming solar radiation, and the majority of that energy is

absorbed very close to the surface (about 25% within the top few cm). While significant effort has been expended on characterizing in-water absorption (e.g. due to chlorophyll), far less attention has been paid to the effect of the atmosphere on the spectrum of incoming radiation.

We have developed a new parameterization for insolation that accounts for certain atmospheric effects while retaining compatibility with in-water models for different water types. Initial tests using a 2nd-order turbulence closure scheme show that this new parameterization is able to largely resolve long-standing issues with estimating the correct magnitude of warming in different geographical locations.

We will refine our parameterization, including optimization of the banding and extension to account for other effects. To do this, we will use a combination of modeling, radiative transfer, satellite-observed sea surface temperatures, atmospheric information, and observations of upper ocean structure.

The new parameterization will allow us to go on and refine key turbulence mixing parameters in the model itself, particularly those that govern model response in the critical turbulence-to-laminar transition. Because of the interplay between insolation, which is the heat source term within the column, buoyancy production and turbulent eddy suppression, it is vital to establish the known physics first (i.e. radiative transfer of incoming solar energy) before attempting to modify these other parameters.

The development of these key model turbulence parameters requires comprehensive testing and validation. This proposal is a timely exploitation of high-quality SSTs observations from modern GOES-R type sensors. These observations will form the cornerstone of model development and verification on a near-global basis. The vast areal coverage and data volume cf. in situ observations is, of course, a huge benefit. Emerging technology on SST algorithm sensitivity will allow the correct diurnal excursion to be estimated (previously it was often simply assumed that the relationship was 1:1). Furthermore, the increase in degrees of freedom in the retrieval, due to more radiometric channels, inherently lead to improved sensitivity throughout the diurnal cycle cf. previous generation sensors.

The proposed work will immediately be exploited in an improved diurnal model as part of the aforementioned diurnally adjusted Geo-Polar Blended SST Analysis. Output from the model will be made available to the scientific community via the web, along with the validation datasets. Additionally, a long-term record of modeled diurnal warming will be produced and made available to the community. This dataset can, for example, be used in the correction for observation time-of-day for the historic satellite SST record, which is needed because early platforms suffered from orbital drift in their local crossing times.

Finally, there will be a contribution to fundamental scientific knowledge of upper ocean heating and vertical mixing, both via provision of the model code and publication of the new parameterizations and tunings developed during this project.

Kyle Hilburn/Colorado State University
Assimilating GOES-R Latent Heating in FV3 Using Machine Learning
19-ESROGSS-19-0011

Imagery from the GOES series has been a key element of U.S. operational weather forecasting for four decades. While GOES observations are used extensively by human forecasters for situational awareness, there has been limited usage of GOES imager data in numerical weather prediction (NWP), and operational data assimilation (DA) has ignored cloudy and precipitating pixels. The motivation of this project is to bring the benefits of GOES-R Series enhanced capabilities to improve convective-scale (CS) DA for improving CS forecasts.

The field is moving towards CS resolution over ever larger domains, and ground-based radar data are key for successful CS DA. Current operational techniques using radar data are initialization approaches, direct insertion and digital filter, and hybrid variational-ensemble assimilation is the next step. However, good coverage of radar data is mostly limited to flat, populated areas over land. Our recent research has demonstrated that the enhanced spatial, spectral, and temporal resolution of ABI combined with lightning information from GLM can be used in many cases to provide accurate estimates of cloud/precipitation latent heating comparable to the quality of radar data if state-of-the-art machine learning (ML) techniques are used. Through use of convolutional neural networks, we are able to learn the structures present in radar reflectivity profiles, relate them to the spatial and temporal variability in the satellite data, and thus reconstruct synthetic radar data from GOES-R series observations with an accuracy far above previous attempts to use the data.

In addition to using ML for pre-processing the satellite observations as described above, this project is also innovative in being the first time ML will be used for the nonlinear latent heating observation operator in the hybrid Gridpoint Statistical Interpolation (GSI) system. This approach will provide all elements of the Jacobian needed for GSI data assimilation and has the advantage of automatically maintaining the tangent linear and adjoint models through finite difference mathematics. Thus, the proposed project supports the transition in operational usage of latent heating information from initialization to hybrid variational-ensemble DA methods. We expect this will lead to improved usage of satellite and radar information in operational forecasts.

The first objective of this project is to produce a new latent heating product from GOES-R that serves as input to the DA. For the purpose of DA development, this could be run on an as-needed basis, however we believe the product will have value to forecasters, and so we are planning on running it in near-real-time and providing imagery via CIRA SLIDER website. We will also deliver documentation for this product, which will characterize the uncertainties needed for DA.

The second and the major objective of this project is to provide new capabilities to GSI for assimilation of the latent heating product discussed in the first objective. We plan to

first implement this in a 3DVar framework, and then extend it to 3DEnVar as resources allow. By focusing development efforts on the FV3 dynamical core, this project is supporting NOAA's development of the FV3-based forecasting system. We will initially implement this for the global FV3 system and extend it to the regional FV3 system when it is available. We expect the biggest advantage of assimilating GOES to be in the global model due to lack of global radar coverage. Since the AHI and AMI sensors are so similar to ABI, our technique can be applied to Himawari and GEO-KOMPSAT-2A to obtain coverage over the West Pacific, although uncertainties are somewhat larger when no lightning observations are available. We hope that by the end of the project, we will be on a pathway to implementing this in the Joint Effort for Data Assimilation Integration (JEDI) framework. The major deliverables will be new modules for GSI and supporting documentation.

Robert Holz/University of Wisconsin, Madison
Development of a NASA Cloud Product Suite for the Next Generation Geostationary Observations
19-ESROGSS-19-0052

We propose to continue the development of our NASA cloud continuity products, applying them to the next generation geostationary imagers that include GOES-16+ ABI, Japan's Himawari AHI, and South Korea's recently launched GEO-KOMPSAT-2A AMI. The goal of this effort is to develop a suite of geostationary cloud retrieval algorithms that provides algorithm continuity with NASA's LEO data record (MODIS, VIIRS) adding 10-minute temporal sam-pling that will enable new and important capabilities for the NASA Program of Record. Further-more, this work will leverage an independent but complementary proposal that is being submitted by Co-I Heidinger requesting NOAA support to develop new techniques that utilize the time-dependent information provided by the geostationary imagers to improve IR cloud products (in-cluding cloud-top properties). These proposed collaborative efforts continue our longstanding NASA/NOAA partnership that was instrumental in the development of the NASA EOS-SNPP imager cloud climate continuity products CLDMSK (cloud mask) and CLDPROP (cloud-top and optical properties). The CLDMSK and CLDPROP product algorithms share heritage with the NASA MODIS MOD35/MOD06 Collection 6 cloud mask and cloud optical property algo-rithms and the NOAA IR cloud-top property algorithms developed by Co-I Heidinger as part of the Clouds from AVHRR Extended (CLAVR-x) product. Both the MODIS and VIIRS CLDMSK and CLDPROP continuity products are processed at the University of Wisconsin NASA Atmosphere SIPS and are publicly archived and distributed by LAADS at NASA GSFC.
The proposed effort will focus on continued software and algorithm development to efficiently process the geostationary observations, and development of an evaluation infrastructure allowing direct inter-comparisons between the LEO and GEO observations that can then be used to investigate and further refine the algorithms. We expect to have a well-characterized geostationary cloud retrieval algorithm processed on a limited time interval of geostationary observations (GOES-16/-17, AHI, GEO-KOMPSAT-2A) that will be used to evaluate consistency with the same products from MODIS and VIIRS. In

parallel with heritage cloud detection and thermodynamic phase classification approaches, it is proposed that a recently developed Machine Learning cloud classification algorithm that makes use of spatial information be extended to include GEO temporal information.

N. Christina Hsu/Goddard Space Flight Center
Fusing GEO with LEO Satellite Observations to Infer the Diurnal Properties of Global Aerosol
19-ESROGSS-19-0032

Accurate determination of the global radiation budget is one of the key components for better understanding the complex nature of Earth's climate. Regional-to-global climate models play a great role in addressing this issue. Because of their important role in modifying the radiative energy balance, the characteristics of atmospheric aerosols, from sources to sinks, are essential components of these models. Many EOS-era instruments (e.g., SeaWiFS, MODIS, MISR) provide such data with a high degree of fidelity, and have been used (among other applications) to form consistent long-term aerosol data records for climate and air quality studies and to evaluate these models.

Despite these advances, satellite measurements have not yet been able to provide much information on the aerosol diurnal cycle on regional and global scales, because sensors with sufficient spectral measurement capabilities and calibration quality have been limited to Sun-synchronous low Earth orbit (LEO) satellites. However, with the successful launches of the geostationary (GEO) Himawari-8, GOES-16, GOES-17, and GEO-KOMPSAT-2A satellites, an unprecedented array of data taken with high temporal frequency and adequate spectral coverage for aerosol retrievals are becoming available for the first time over nearly three quarter of the world. Furthermore, with the upcoming EUMETSAT Meteosat Third Generation scheduled for launch in 2021, near-global coverage of measurements may be achieved from these similar GEO sensors. We therefore propose to expand the operational algorithms developed for MODIS and VIIRS to retrieve aerosol diurnal properties over both land and ocean using observations from the GEO constellation satellites. We will further synergize these new GEO products with LEO using consistent retrieval algorithms to help shed new light on diurnal variations of aerosol radiative energetics. Specifically, our proposed objectives are:

1) To improve understanding of the diurnal cycle of aerosol, particularly over regions with high spatial and temporal heterogeneity, by applying the operational MODIS/VIIRS Dark Target and Deep Blue algorithms to GEO data;
2) To advance the EOS-heritage aerosol algorithms in those components such as cloud screening and surface reflectance schemes by fully utilizing the GEO high temporal resolution, which is not available from sensors like MISR, SeaWiFS, MODIS or VIIRS;
3) To validate the GEO aerosol products against ground-based measurements and retrievals from AERONET and field campaigns over various atmospheric and surface conditions;

4) To enhance the temporal resolution of long-term LEO records by producing daily and monthly fused GEO/LEO aerosol products over land and ocean.

The overarching goal of this proposed research is to produce high quality consistent LEO/GEO aerosol products, which can be used to address important science questions related to the long-term and short-term aerosol variabilities for climate and air quality studies. By combining our existing expertise in developing the operational Dark Target and Deep Blue algorithms over the LEO imager spectral domain with the new temporal information from GEO constellation, the results of this work will significantly enhance both the spatial and temporal coverage of the existing aerosol datasets and help address the differences between the morning and afternoon satellites found in the LEO aerosol products.

James Jung/University of Wisconsin, Madison
Assimilation of Radiance Tendency of Water Vapor Bands From Geostationary Satellites Using FV3GFS
19-ESROGSS-19-0035

The objective of this project is to investigate a new approach for Assimilating Radiance Tendency (ART) water vapor (WV) observations. These observations are available from the advanced imagers onboard domestic and international Geostationary (GEO) satellites, such as Advanced Baseline Imager (ABI) on the GOES-R series, Advanced Himawari Imager (AHI) on Himiwari-8/9, and Advanced Meteorological Imager (AMI) on Geostationary - Korea Multi-Purpose Satellite-2 (GK-2). The advantage for using ART is that it does not require a bias correction, because the radiance tendencies from both observations and background can be considered bias free within a short period of time (i.e. 1 hour). The bias correction, used to remove biases between observations and background for traditional assimilation technique, may reduce or compromise the useful information in the observations. The proposed work will develop the technical methodology, test and assess the impact of ART from domestic and international GEO satellites on global weather forecast skill using a recent version of the FV3GFS that has a 4-D hybrid EnVar data assimilation system.

Pierre-Emmanuel Kirstetter/University of Oklahoma, Norman
Probabilistic Quantitative Precipitation Estimation with Geostationary Satellites
19-ESROGSS-19-0125

As highlighted by the 2017 Decadal Survey, progress in precipitation estimation is critical to advance weather and water budget studies and prediction of natural hazards caused by extreme rainfall events from local to global scales. The low latency and high space/time resolution from geostationary satellites (e.g. GOES-16/17, Himawari-8) are essential for monitoring and predicting precipitation processes occurring over short space and time scales and driving hydrometeorological hazards. An interdisciplinary challenge in remote sensing, meteorology and hydrology is the representation, use, and impact of

uncertainty. Hydrometeorological applications require more than just one deterministic precipitation ""best estimate"" to adequately cope with the intermittent, highly skewed distribution that characterizes precipitation. However, despite the indirect information provided by (near-)infrared passive radiances on surface precipitation rates, geostationary quantitative precipitation estimation (QPE) is currently deterministic. We propose to advance the interpretation of GOES-16/17 observations for hydrometeorological applications with the use of probability as an integral part of QPE.
The overarching goal of this research project is to leverage reliable ground-based radar Multi-Radar/Multi-Sensor (MRMS) quantitative precipitation applications to geostationary missions and synergize CONUS-wide GOES-16/17 precipitation enhancement. We will explore the use of GOES-16/17 ABI multiple spectral bands and high space/time resolution through spatial and temporal textures. Probability distributions of precipitation rates will be established using models quantifying the relation between ABI observations and the corresponding ""true"" precipitation from MRMS. This approach integrates sources of error in QPE and provides a framework to diagnose uncertainty when instruments sample precipitation scenes or processes that challenge the QPE algorithm assumptions. Probabilistic QPE (PQPE) mitigates systematic biases from deterministic retrievals and quantifies uncertainty for hydrologic applications and advances the monitoring of precipitation extremes with remote sensing. It provides the basis for multisensory integration across GOES-16, GOES-17, and MRMS through quantified uncertainties to optimally merge PQPEs. PQPEs can be more readily fused with MRMS ground radar products for seamless precipitation estimation over CONUS, specifically in the western United States where the vantage point of space can complement the degraded weather radar coverage of the NEXRAD network. It opens perspectives for improved estimation of precipitation at multiple scales, hydrological prediction, and risk monitoring. This work can be extended to Himawari-8/9 with the space-based Global Precipitation Measurement (GPM) radar. Tasks are:
1. Generate a vastly expanded GOES-16/17 - MRMS matchup product. MRMS spatial information is instrumental to bridge across space-based sensors with various resolutions and sampling. The use of the GPM radar will be explored to expand toward Himawari-8/9 and GEO-KOMPSAT-2A and prepare multi-satellite composite products.
2. Develop and validate probabilistic QPE for GOES-16/17 trained on MRMS. This task builds upon the matchup datasets from task 1 and the investigators' previous experience with GOES-16.
3. Merge GOES-16/17 and MRMS PQPEs.
Relevance and Broader Impact: The proposed research directly addresses the ESROGSS Research Announcement objective to "enhance the utilization of the GOES-R sensors" by integrating space-based GOES-16/17 geostationary observations and ground-based MRMS to advance our applications of precipitation. The proposed research leads to a synergistic effort from NASA, NOAA and universities toward improve multisensor estimation beneficial to the research communities and operations. This work will also aid in merging GEO-PQPE with other global products.

Janet Machol/University of Colorado, Boulder
Determination of Exospheric Neutral Hydrogen Density From GOES-R

19-ESROGSS-19-0080

This proposal will use measurements of the extreme ultraviolet from GOES-R satellites to determine daily neutral hydrogen (H) density distributions of the terrestrial upper atmosphere. Knowledge of the neutral H density distribution at the bottom edge of the exosphere (the exopause) is needed to set the upper boundary for the empirical MSISE model which provides the neutral temperature and densities in Earth's atmosphere from ground to thermospheric heights. MSISE is the international standard model used to estimate satellite drag for orbit calculations. Currently the error is approximately a factor of two in the upper boundary for MSISE, and so improved estimates would greatly help the satellite operator and atmospheric modeling communities.

The GOES-R satellites are in geostationary orbit. The GOES-R Extreme Ultraviolet and X-ray Irradiance Sensors (EXIS) measures solar emissions at multiple ultraviolet and X-ray wavelengths on a less than 1 minute cadence. Solar emissions at one of these wavelengths, 121.6 nm, known as Lyman alpha, come from hydrogen in the solar atmosphere. This 121.6 nm is scattered by the neutral H in the earth's upper atmosphere in the vast geocorona of hydrogen that surrounds the earth. GOES-R circles the earth at the geosynchronous altitude of 42,000 km. On the anti-solar side of the earth (i.e., during local night time), EXIS observes the sun through a significantly increased H column density and so the EXIS Lyman-alpha measurements have a nighttime dip due to scattering by the geocorona. The EXIS measurements can be used to determine the neutral density profile.

Two complementary techniques will be used to estimate the H neutral density. The first technique is a 2-D tomography method that has been used to estimate the neutral density components in the Martian atmosphere as measured by instruments aboard the MAVEN spacecraft. The second technique, which has had preliminary tests with Lyman alpha data from earlier GOES satellites, fits the scattering dip based on an assumed functional shape for the atmospheric neutral density distribution. This requires an estimate of the full solar signal, which can be obtained using a model based on other EXIS measurements (such as the Mg II index determined from measurements at 281 nm). Additional improvements by using both operating GOES-R satellites will be considered and the practicality the method will also be tested on the EUVS data from earlier GOES satellites.

The outcome of this proposal will be a validated method to estimate the exospheric neutral density distribution as well as a daily neutral density data product accessible from the NOAA NCEI GOES-R Space Weather data page. The code for this Level 2 product will be provided to the NOAA Space Weather Prediction Center (SWPC) so that they can produce a real-time data product for use with MSISE and other models. This product will documented in a journal article. GOES observations will be available for many years into the future and therefore will allow unprecedented continuous monitoring of H density in the geocorona for use in full atmospheric models. A long-term record of exospheric temperatures would be a valuable contribution to whole atmosphere and satellite drag models.

Steven Miller/Colorado State University
Advanced Concepts Enabling Situational and Hazards Awareness via Imagery
19-ESROGSS-19-0018

The GOES-R series Advance Baseline Imager (ABI) shifts the paradigm of geostationary imaging in all key aspects of resolution: spatial, spectral, temporal, and radiometric. These improvements translate to unprecedented visualization capabilities for the forecaster, and a new level of situational awareness for rapidly evolving atmospheric and surface natural hazards. The potential of the ABI in this regard extends far beyond the scope of the baseline products, consisting of single-band imagery for each of its 16 bands. In fact, these bands form the building blocks for a host of value-added imagery applications that incorporate physically-based enhancements of information and expedite forecaster analysis in a time-critical environment.

The Cooperative Institute for Research in the Atmosphere (CIRA) at Colorado State University has pioneered the exploitation of the ABI for such value-added imagery applications. From design of a 'missing' green band that enables true color imagery, to novel fire temperature products credited with saving lives, to fusion with the GOES Lightning Mapper (GLM) in ways that are now widely emulated, to advanced techniques in Dynamic Enhancement Background Reduction (DEBRA) and the multi-dimensional blending technique that enables GeoColor imagery (used regularly by researchers, operational users, and national and international news agencies), CIRA's award-winning imagery represents in many ways the face of the GOES-R program (https://www.goes-r.gov/featureStories/satelliteImageryRGBs.html).

Amazingly, despite all of these accomplishments, we have only scratched the surface of the ABI's capacity for advanced visualization! What lies beneath the surface is a vast array of additional and heretofore unexploited capabilities in the realm of imagery/product fusion. Here, we propose to develop novel and innovative approaches that tap into this potential, via a paradigm shift to the GeoColor application that pursues the following key, central objectives:

1. Signal encoding of lofted dust, snow, and a new short/mid-wave IR-based ABI fire product
2. Propagating composite daytime snow cover information into the night
3. Integrating ProxyVisible to enable an advanced low-cloud description at night
4. Incorporating satellite-derived Level-2 products for imagery/product synergy
5. A 0.5 km, 1 min "mesobox anywhere, on-demand" via spatial and temporal sharpening

The methods/techniques of this proposal leverage strong expertise in algorithm and visualization residing at CIRA. Environmental features, isolated via physically-based algorithms, serve as either normalized modulators to localized parts of GeoColor (signal imprinting), or as embedded layers of information can be combined within CIRA's generalized framework of multi-dimensional blending technique. Spatial sharpening of

day-side true color encodes red-band variance to the blue and synthetic green band, and temporal sharpening enlists optical flow to assign a dense vector field. The result is a new, information-rich display that can be customized and tailored to the needs of specific end-users.

We perceive that this research will advance, in a significant and paradigm-shifting way, the flagship imagery product of the GOES-R program—GeoColor. This NOAA-directed Type 1 proposal fits squarely within the NESDIS strategic plan to "Develop, support, or adapt algorithms to provide state-of-the-art science products." CIRA leverages well-established connections (in terms of both hardware/software tools/conduits and strong rapport with National Weather Service forecasters) to the operational forecaster via the NOAA Satellite Proving Ground. As such, product development occurs in a Research-to-Operations-to-Research (R2O2R) closed loop system—one that historically has proven highly effective in practice.

Michael Ramsey/University of Pittsburgh
Geostationary Analysis of Volcanic Activity: Improving the Near Real-Time Monitoring, Modeling, and Forecasting of Ash and SO2-Rich Plumes
19-ESROGSS-19-0107

This project is divided into three primary volcanological science tasks each centered around acquiring and modeling new thermal infrared (TIR) geostationary (GEO) observations from the Advanced Baseline Imager (ABI, GOES-16/17) and Advanced Himawari Imager (AHI, Himawari 8/9). The project will take advantage of the PI's pre-existing sensor web architecture that relies upon low-Earth orbit (LEO) sensors for volcanic detection and subsequent triggering of higher spatial resolution LEO data. Integrating GEO data into this system will provide information of the initial phases of the eruption for the first time. These data will also be made available for modeling of the heat flux and plume compositional characteristics. Volcanic eruptions producing high temperature lava at the surface will be modeled for the time average discharge rate (TADR) and total volume flux. This information, made available in near-real time on the web, is important for assessing the magnitude of the eruption, its intensity change with time, and potential hazards. For the more explosive eruptions, we will develop new data products for investigating the volcanic plume SO2 and ash compositions based on well-established principals of TIR spectral analysis. Specifically, we will generate maps of SO2 column density and the size distribution of volcanic ash particles in the proximal, or near-vent, portion of plumes, based on algorithms developed for TIR observations acquired by ASTER, MODIS, and VIIRS. Importantly, these new products will augment the current operational ABI products for volcanic ash and the near-vent particle size product will provide new input data for Volcanic Ash Transport and Dispersion (VATD) models.

Depending on the mode of observation, ABI acquires images of the Earth's hemisphere (Full Disk) at time scales between 5 and 15 minutes. The high frequency, or cadence, of the ABI observations is fundamental to the Science and Application Priorities identified

in the recent NAS Earth science decadal survey [National Academies Press, 2018]. These priorities include Science Question S-1: “How can large-scale geological hazards be accurately forecast?” with a Most Important Objective (S-1a) to measuring the pre-, syn-,.and post-eruption surface deformation of, and thermal, gas, and ash emissions from the Earth’s entire active land volcano inventory with a time scale of days to weeks. Similarly, Science Question S-2: “How do geological disasters impact the Earth system and society following an event?” includes a Very Important Objective (S-2b) to assess surface deformation, extent of surface change, and atmospheric contamination, and the composition and temperature of volcanic products following an eruption. Our new volcanic thermal and plume products will support the Designated Targeted Observable Surface Biology and Geology (SBG, TO-18), which was developed, in part, to address these Science Questions.

The spatial resolution of ABI and AHI is 2 km at nadir, but the spatial resolution will degrade for observations of volcanic plumes at high latitudes (≥ 50 degrees). We will also investigate the impact of this degraded spatial resolution on our volcanic products through comparison of corresponding products generated from AHI, MODIS, and VIIRS observations of the recent eruptions of Raikoke (June 2019) and Sheveluch (August 2019) volcanoes. To test the modeling, we will construct and evaluate the combined records of the data products from LEO sensors (MODIS, VIIRS, ASTER and ECOSTRESS). We anticipate that the data records will be complementary, with the continuous AHI observations and provide the temporal context for the punctuated LEO data at finer spatial resolutions (< 1 km).

Peter Romanov/City College of New York
Development and implementation of a Set of New Enhanced GOES-R ABI Snow Cover Products
19-ESROGSS-19-0102

Information on the snow cover properties constitutes one of the primary deliverables of the Advanced Baseline Imager (ABI) onboard GOES-16(R) and GOES-17(S). However one of the two snow products originally developed for ABI, the snow depth, has been excluded from the ABI Option-1 product list and thus is not being produced. The second product, the snow cover fraction has been generated since 2018, but has demonstrated an overall suboptimal performance with the retrieval accuracy below the requirements which made it unusable in any research or operational applications. As a result, ABI capabilities to provide information on the snow cover properties at high temporal resolution remain largely unused.

With this project we propose to develop and implement into operations a set of new GOES-R ABI snow retrieval algorithms and a corresponding set of improved snow cover products. The derived snow products will rely on the Enterprise snow retrieval algorithms and will provide high accuracy retrievals of the binary snow mask, the fractional snow cover, and of the snow depth at an hourly and daily time step at 2 km spatial resolution over the Western Hemisphere. The new snow products will be applied to ABI data from

both GOES-16 and GOES-17, and will be fully validated to demonstrate their compliance with the accuracy requirements. As a secondary goal we will develop a technique to derive spatially continuous (gap-free) snow products based on synergy of ABI observations with satellite observations in the microwave. This technique will be expanded to and tested with the data from other operational geostationary satellites including MSG, JMA Himawari and GEO-KOMPSAT-2.

As a result of the project execution the ABI mission objective with respect to the snow cover monitoring will be fully met and the user community will receive a new set of advanced operationally delivered products characterizing both intraday and daily changes of the snow pack properties over the Western Hemisphere and globally. The primary application of the new products is in the Interactive Multisensor Snow and Ice Mapping System (IMS) system operated at the National Ice Center (NIC), in numerical weather prediction models run by National Centers for Environmental Prediction (NCEP) of NOAA National Weather Service, at the National Operational Hydrological Remote Sensing Center (NOHSC) which needs information on the snow depth and snow extent to run the nation-wide modeling and data assimilation system (SNODAS) and at the NOAA NWS Office of Water Prediction engaged in the development and implementation of the National Water Model.

The project aims to significantly improve the current GOES-R ABI snow products and to develop new snow products that were originally included in the ABI Option-2 product list and is therefore directly responsive to the current solicitation. By developing the new advanced snow retrieval techniques based on Enterprise algorithms adopted to ABI the proposal addresses the NESDIS general objective to “Develop, support or adapt algorithms to provide state-of-the-art science products” and a specific objective to “Complete the transition to Enterprise algorithms” as formulated in the NESDIS Strategic Plan

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Martin Snow/University of Colorado, Boulder
GOES High Cadence Operational Total Irradiance (GHOTI)
19-ESROGSS-19-0075

GOES High cadence Operational Total Irradiance (GHOTI)
Extreme ultraviolet and X-ray Irradiance Sensors (EXIS) on the GOES-R series includes a quadrant diode that serves as the Solar Position Sensor (SPS). This diode has a broad wavelength response to the visible part of the spectrum. Total Solar Irradiance (TSI) instruments measure the integrated solar spectrum. Variation in the TSI is highly correlated to variations seen in the SPS on GOES-16 and GOES-17. Today, all but one TSI measurement is made from low Earth orbit, which results in time series with gaps due to eclipses from each instrument. The one exception is the TSI instrument on SOHO, launched almost 25 years ago, which may not have a stable calibration. All current TSI measurements are made at fairly low time cadence, often averaged over 400 seconds and then published on a 6 or 24 hours cadence. The SPS measurement can be used as a proxy to produce a TSI value every 3 seconds. We will use observations from the Spectral

Irradiance Monitor (SIM) on both SORCE and TSIS. The long-term calibration of this new dataset will use the daily measurements from TSI radiometers, since the SPS has no onboard calibration reference.

The new proxy for TSI that we create will be combined with the EXIS Channel-C Magnesium II index measurement to create a high cadence solar spectral irradiance (SSI) model using the well-established NRLSSI2 algorithm. The current NRLSSI2 depends on a daily measurement of sunspots, along with the daily Mg II observations from non-operational satellites. The GHOTI SSI can be generated at time cadences up to every 3 seconds. This will allow modeling of the atmospheric response to transient solar events such as flares that have previously been beyond any SSI measurement or model's capability.

Stephanie Stevenson/Colorado State University
Enhancing Forecast Applications of the GOES-R GLM in Tropical Cyclones Using Multi-Platform Data Fusion and AI to Assess Environment and Storm Structure
19-ESROGSS-19-0012

CIRA scientists are actively involved in lightning applications research and the continued development of the operational statistical-dynamical tropical cyclone (TC) models for NOAA's National Hurricane Center. Statistical intensity models, such as the Statistical Hurricane Intensity Prediction Scheme (SHIPS) and Rapid Intensification Index (RII), currently incorporate the symmetry and areal extent of cold cloud tops from geostationary longwave infrared imagery. The TC cirrus canopy, however, can obscure convection below the cloud tops. The Geostationary Lightning Mapper (GLM), one of the new instruments on the Geostationary Operational Environmental Satellite (GOES), provides an opportunity to observe convection below the cloud tops. Research with a ground-based lightning network showed improvements to the RII when simple lightning predictors were added (DeMaria et al. 2012), but recent research by Stevenson et al. (2018) found even stronger relationships to intensity change when TC structure is also considered. This work proposes to better understand the relationship between GLM lightning, TC structure, and intensity change to enhance and improve statistical intensity models.

The proposed work has four principal objectives: 1) normalize for external factors that may influence lightning density, 2) relate spatial lightning features to TC structure, and 3) relate spatial lightning features to TC intensity change, and 4) develop an automated real-time tool for TC intensity change using GLM lightning. Interpretation of GLM lightning flash rates over the oceans depends on the environment (e.g., aerosols, thermal oceanic conditions) and instrument limitations (e.g., diurnal detection variability, limb effects), thus it is critical to understand and normalize the lightning rates prior to accomplishing the other objectives.

Lightning can occur at all stages of a TC's lifecycle, and the lightning location and pattern can impact intensity change differently based on its relation to TC structure. The

proposed work will fuse commonly used in-situ and multi-satellite data (e.g., passive microwave imagery, aircraft flight-level and tail-Doppler radar data) to assess the links between spatial lightning features and TC structure, including its relation to the storm size, 3-D wind field, and eyewall(s). Spatial lightning feature changes, including connections to the diurnal cycle, will then be used to assess the temporal evolution of TC intensity. The proposal objectives aimed at linking lightning features to TC structure and intensity change will be completed using a combination of expert physics-based knowledge that is already understood and artificial intelligence, or machine learning-based techniques.

This proposal addresses the call for the development of applications to enhance the utilization of the new GOES-R GLM sensor through the fusion of data from multiple sources, and fills an unmet need for clarity on how operational forecasters can utilize lightning. The ultimate goal of the proposed work is to create the framework for a real-time application that uses GLM to predict TC intensity change. A proposal team with expertise on TC structure, satellite data, in-situ aircraft observations, statistical-dynamical models, and machine learning will help reach the proposed objectives.

Thomas Vandal/Ames Research Center
Quantifying Earth Process Dynamics with Optical Flow on GeostationarySatellite Imagery
19-ESROGSS-19-0123

Technological advancements in the recent generation of geostationary (GEO) satellites enable countless opportunities to extract valuable information using deep learning. For example, improvements in the GOES-16/17 Advanced Baseline Imager (ABI) provide access to improved spatial resolution at an unprecedented temporal frequency (eg. up to 1 minute), along with a more detailed spectral range. The enhanced data opens opportunities for methodological developments to better understand high-frequency earth processes. Although the developments outlined in this proposal have numerous applications, this proposal is focused on the production of Atmospheric Motion Vectors (AMV) and cloud height assignments, which are used for Numerical Weather Prediction (NWP) and data assimilation. By using video processing and computer vision techniques, AMV’s can be derived by quantifying motion from sequences of GEO images. Cloud heights assigned to AMVs with greater accuracy can also be found by using deep learning techniques. These two enhanced measurements are a vital part of improving downstream products.

In GEO images, optical flow, a computer vision algorithm to track the motion of objects in a sequence of images, can be used to produce frame by frame motion vectors for spectral channels of interest. While techniques do exist for extracting AMVs, the output produced often has poor accuracy and low yields leading to suboptimal model predictions. Preliminary work has shown that optical flow is an effective approach for temporal interpolation between GEO images as well as AMV estimation from physical model simulations. Similarly to the extraction of AMVs, there are existing methods to

assign cloud heights to AMVs. However, these cloud heights are affected by systematic model bias. To avoid this bias, radiances and atmosphere profiles can be directly mapped to cloud heights using neural networks.

The primary objectives of this proposal are to: develop probabilistic optical flow approaches that incorporate uncertainty quantification to GEO imagery; estimate AMVs by tracking clouds and water vapor; quantify AMV cloud heights using the CALIPSO low earth orbit satellite; evaluate AMVs with sparsely observed winds from LEO satellites; and test as part of data assimilation and NWP models. This is feasible via collaborations between the NASA Earth Exchange (NEX), the NASA Global Modeling and Assimilation Office (GMAO), and NOAA's Center for Satellite Applications and Research. Our team's expertise in machine learning, remote sensing, meteorology, data assimilation, and NWP will allow us to develop novel approaches, perform large scale data analysis, and evaluate with state-of-the-art systems.

The development of data analysis techniques using GEO satellites will target NASA's objectives to generate atmospheric wind data, improve weather forecasts, and quantify earth process dynamics. While the applications are numerous, we will focus on AMV estimation to improve the initialization of NWP and data assimilation models while producing a synthetic wind dataset. We will test our approaches by evaluating AMV estimates within the context of a full atmospheric data assimilation system.

Chris Velden/University of Wisconsin, Madison
Improved Monitoring of the Rapidly-Evolving Upper-Tropospheric Wind Fields Over the Core of Hurricanes from High Spatiotemporal Resolution Geostationary Satellite Observations
19-ESROGSS-19-0008

We propose to continue a research project supported by the NOAA/NESDIS GOES-R Risk Reduction program to utilize the rapid-scanning capabilities of the new generation of geostationary (GEO) satellite imagers for the derivation of high spatiotemporal atmospheric motion vectors (AMVs; tropospheric wind estimates) during targeted hurricane events. This effort aims to fill an important observational gap in hurricane analyses, as storm-scale dynamical information at the top of hurricane core and outflow regions is currently lacking and needed to intrinsically tie in convective processes with environmental interactions that can modulate intensity. The added data will not only improve our understanding of hurricane behavior (e.g. intensity and size fluctuations), but provide key vortex-scale information to rapidly-advancing hurricane data assimilation methodologies leading to improved numerical weather predictions. Specifically, we propose to: 1) Complete the refinement and testing of recently-developed processing strategies that have been optimized to extract maximum AMV information content in hurricane environments from GOES-16 meso-sector scans; 2) Tailor and test these strategies to operate with GOES-17 and Himawari-8/9; 3) With NWP collaborators, investigate approaches to more effectively assimilate the enhanced AMV data into operational hurricane prediction models (i.e. Hurricane WRF (HWRF)) to maximize the

information content getting into the initialized analyses and leading to improved forecasts; 4) Assist in the transition of this research to NESDIS and NCEP for operational testing and implementation in collaboration with STAR, JCSDA and EMC colleagues. These objectives will be accomplished by advancing the current NESDIS operational (enterprise) AMV algorithms and building on novel data processing approaches developed under GOES-R Risk Reduction support to enhance those strategies, by demonstrating the end-to-end capabilities via real-time testing, and by transitioning the methodologies to STAR (collaborative partner) for seasonal real-time operational testing (JCSDA). In tandem, the data treatment and assimilation strategies will be honed for maximum model analysis impact through close collaboration between the data providers and users (NOAA/HRD and NCEP/EMC). While a primary objective will be the application of the enhanced AMVs to support NWP models, NWS/National Hurricane Center forecasters should also benefit from the enhanced AMV datasets (viewed on AWIPS) in their analyses of rapidly-evolving storm conditions.
This work addresses the basic NOAA strategic goal of protecting lives and property from hazardous weather conditions such as hurricanes through the improvement of analyses and forecasts during these often catastrophic events. Furthermore, this proposal addresses the primary objective of the ROSES A.33 program element solicitation which is to utilize the new generation of operational geostationary satellite capabilities to advance and optimize tropospheric observing strategies, in this case specifically to extract dynamical information at the scales relevant to achieving better hurricane analyses and forecasts. While this proposed effort is listed as Type 2 (enhanced product applications) and will benefit many NOAA stakeholder applications, there is also an element of Type 1: the PI and associates hope to optimize and operationalize an AMV processing strategy that takes advantage of the new-generation imaging capabilities focused on the scales needed to positively impact hurricane analyses. Our plan is to exploit the amazing 1-minute imagery now routinely provided by the new advanced GEO Imagers and turn those spectacular displays of hurricanes into dynamical quantitative information towards improving the objective analyses and ultimately the forecasts with major benefits to society.

Elisabeth Weisz/University of Wisconsin, Madison
Realizing LEO Sounder Products at GEO Imager Spatial and Temporal Resolution
19-ESROGSS-19-0027

Synergistic use of high spatial and high temporal resolution GEO (geostationary orbit) imager data with high spectral resolution infrared LEO (low Earth orbit) sounder data provides advantages in various applications over the use of the individual datasets alone. Utilizing the imager’s radiometric information content we demonstrate the capability to transfer the sounder’s high spectral resolution individual radiances (or any spectral convolutions) as well as retrieval products (e.g., temperature and moisture layers, atmospheric stability, cloud and trace gas parameters) to the imager’s high spatial and temporal resolution.
We anticipate that the synergistic approach to the multitude of measurements from different instruments and platforms (through combining the advantages of each) has the

potential to significantly benefit weather fore- and nowcasting as well as environmental monitoring operations.

In this proposed work, we will develop and demonstrate nowcasting applications of the fusion process to connect LEO hyperspectral sounder products (e.g., the Cross-track Infrared Sounder or CrIS and the Infrared Atmospheric Sounding Interferometer or IASI) to time sequences of GEO imager radiances (e.g., the Advanced Baseline Imager or ABI and the Advanced Himawari Imager or AHI) to create a GEO sounder-like perspective of atmospheric changes in time. This work will provide an early look at nowcasting capabilities expected from GEO hyperspectral sounders.

In the GEO/LEO imager/sounder fusion approach high-spectral resolution sounder data (in terms of accurate high vertical resolution retrieval products) are transferred not only to high spatial resolution but to high temporal resolution as well. This means that the sounder's spatial detail is first enhanced and then conveyed to the GEO measurement times through investigating the changes in radiances measured with the ABI (or AHI) infrared bands.

Our team will:

- Refine and improve an innovative and practical method to construct polar hyperspectral sounder retrieval products from CrIS (and IASI) and also TROPOMI at imager spatial and temporal resolution by utilizing ABI (and AHI) radiance data
- Investigate a variety of fusion products, including moisture fields, cloud heights, severe weather indices and trace gas amounts (e.g., sulfur dioxide)
- Create time sequences of the fusion products and estimate uncertainties via comparisons with model fields, in-situ measurements and other satellite products
- Assess the potential use of the GEO/LEO fusion products in nowcasting applications (in collaboration with the National Weather Service)
- Work with the scientific community interested in improving atmospheric product generation and their applications by employing a fused product

This team of active investigators and collaborators has a long-term involvement with the production of operational atmospheric, surface, and cloud properties from broad-band and hyperspectral resolution polar-orbiting sensors, and comprehensive experience in the synergistic use of high spectral, spatial, and temporal resolution datasets. The investigators also have a long history of user engagement and documenting their work in peer-reviewed articles.

Anthony Wimmers/University of Wisconsin, Madison

Probabilistic nowcasting of Aviation Turbulence Using Deep Learning Applied to Advanced Geostationary Imagery

19-ESROGSS-19-0066

Here we propose to use deep learning (artificial intelligence) methods to produce nowcasts and short-term forecasts of aviation turbulence primarily from the GOES Advanced Baseline Imager and Lightning Mapper. These forecasts will serve the U.S. Aviation Weather Center, the Honolulu Forecast Office and the Alaska Aviation Weather Unit. We will work in partnership with these offices to distribute real-time products and work with their feedback. The main objective is to develop a mature nowcasting system

that demonstrates clear skill at identifying known turbulence hazards that are not captured well by numerical weather prediction (NWP) models. Other related objectives are to identify the sources of the deep learning algorithm's skill and to improve aviation forecasting techniques that combine satellite and NWP products.

To accomplish these objectives, we will develop a deep learning neural network algorithm that takes thorough advantage of relevant patterns in the multichannel imagery surrounding observed turbulence events, using GOES and Himawari-8 imagery collocated to years of available aircraft observations. The deep learning model can be trained to make direct predictions of the probability of significant turbulence, and then be implemented in the form of a complete two-dimensional probability map over the domain of the imagery. Further work will optimize the model for vertical resolution, turbulence severity, and mitigation on GOES-17 heat pipe failures. Another component of the project will model mountain wave turbulence events and use synthetic GOES ABI imagery to train a mountain wave turbulence deep learning module with a high density of samples. Aviation forecasters from three National Weather Service offices will provide regular evaluations of the derived products and develop best practices for using these together with existing NWP-based information.

This proposed work will develop new derived products from the current generation of GOES instruments, which takes full advantage of their spatial, temporal and spectral resolution and matches these to the vast potential of deep learning methods. The resulting methods to infer the present and near-future distribution of aircraft-scale atmospheric turbulence will provide a long sought-after capability of the U.S. forecasting offices to diagnose the potential for significant turbulence in terms of a simple probability. This fills a critical gap in the forecasting process due to the inadequacy of the present alternatives: incomplete real-time reports, oversmoothed numerical models and otherwise poorly quantified satellite imagery.

Xiaoxiong Xiong/Goddard Space Flight Center
Optimization of the G16/G17 ABI L1b Calibration Algorithm for Re-Processing through a New Geostationary Imaging Support Team (GIST)
19-ESROGSS-19-0117

The NOAA operational ABI L1b data product supports real-time weather and environmental satellite observations. Thus, the calibration is routinely updated to improve on its real-time products but not necessarily optimized for producing a consistent long-term Earth science data records. As a consequence, the long-term data records of the ABI instruments consist of numerous artifacts over time, some known radiometric and geometric calibration issues, and others yet to be explored in their long-term trends. These issues may include ground processing discrepancies, anomalies discovered on-orbit, radiometric calibration enhancements, geometric image navigation & registration (INR) enhancements, and systematic artifacts in the data. We propose a study to identify an improved radiometric and geometric calibration algorithm for G16 & G17 re-processing of ABI L1b data. This algorithm will aim to minimize these artifacts by first

identifying them through analysis of pre-launch data, nominal operational data, and special calibration collection data - then deriving appropriate corrections. This algorithm will be used to re-process a subset of ABI data to demonstrate its potential for establishing a consistent long-term Earth science data record. Cloud computing resources will be analyzed in terms of costs versus benefit for each level of processing to demonstrate a potential architecture. This effort provides an initial capability for the potential formation of a NASA Geostationary Imaging Support Team (GIST) that will ensure the Earth science quality of the ABI data records and potentially other Geostationary imagers.

Ping Yang/Texas A & M, College Station
Utilizing Geostationary Satellite Observations to Develop a Next Generation Ice Cloud Optical Property Model in Support of JCSDA Community Radiative Transfer Model (CRTM) and JPSS CAL/VAL
19-ESROGSS-19-0019

As a flagship effort of the multi-agency (NOAA, NASA, Navy and Air Force) Joint Center for Satellite Data Assimilation (JCSDA), the Community Radiative Transfer Model (CRTM) is a powerful and robust tool to facilitate the forward and adjoint radiative transfer simulations involved in satellite remote sensing programs and data assimilation efforts. To meet this objective, a state-of-the-art ice optical property model needs to be incorporated into the CRTM. Ice clouds are ubiquitous in the troposphere, covering approximately 30-40% of the tropics and 20-30% of the globe. These clouds play important roles in the radiative transfer process in the surface-atmosphere coupled system. It is well known that the “equivalent-sphere” model for ice clouds produces significant errors or even misleading results. Progress in the development of more realistic nonspherical ice crystal models has been steady but slow. The existing ice cloud optical property models still suffer various shortcomings. For example, some models lead to inconsistencies in applications in the solar and infrared spectral regimes, and some models lack microphysical consistency in comparison with in situ measurements. In response to this funding opportunity, we propose to develop a next-generation ice cloud optical property model for the CRTM, and such improved modeling capability will directly benefit the CAL/VAL efforts of the Joint Polar Satellite System (JPSS) mission in addition to data assimilation efforts.

We will use observations made by the Advanced Baseline Imager (ABI) instruments aboard GOES 16 and GOES 17 to infer the radiative and microphysical properties of ice clouds (specifically, optical thickness and the effective particle size). Both the solar bi-spectral technique (i.e., the Nakajima-King method) and the infrared split window technique will be used with daytime ABI observations while only the infrared technique will be used for nighttime retrievals. Furthermore, we will collocate the aforesaid retrievals with CALIOP (Cloud-Aerosol Lidar with Orthogonal Polarization)/CALIPSO (Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observations) retrievals. In the proposed retrievals, an ice cloud optical property model must be used. We will test various ice cloud models and select the optimal model based on the spectral consistency

between solar- and IR-band based retrievals as well as the consistency between passive (ABI based) and active (CALIOP based) retrievals. After an optimal ice cloud model is identified, we will implement it in CRTM. Specifically, the implementation will be conducted for the channels of the Cross-track infrared Sounder (CrIS) and Visible Infrared Imaging Radiometer Suite (VIIRS) on JPSS. This effort will support the JPSS CAL/VAL effort. We call special attention to the ice cloud optical property datasets generated through the proposed project, which can be directly used to generate the forward look-up tables involved in JPSS-based cloud property retrievals that are consistent with the improved CRTM so data assimilation using CRTM and JPSS cloud products will be inherently self-consistent.

This is a NOAA type-2 proposal aiming at the CAL/VAL and data assimilation communities that critically need a state-of-the-art observational-based ice cloud optical property model in the CRTM. Our research team has extensive experience with CRTM and long-term collaborations with the JCSDA CRTM team, especially with the non-cost collaborators Mr. Kevin Garrett (NOAA), Drs. Benjamin Johnson and Patrick Stegmann (JCSDA). Leveraged on the strong and productive collaborations among team members, we believe that the proposed work can significantly enhance the CRTM capability in spite of a modest level of funding requested.

Xiwu Zhan/National Oceanic and Atmospheric Administration
Enhancing Evapotranspiration and Evaporative Stress Index Data Products from GOES-16/17 Advance Baseline Imagers for NOAA NWP, NWM and Drought Monitoring Operations
19-ESROGSS-19-0128

Evapotranspiration (ET) is a major component of the global and regional water cycle. Accurate estimation of ET is needed for numerical weather and water prediction models. Negative anomalies in ET are an indicator of drought occurrence. An operational GOES ET and Drought (GET-D) product system has been developed by NESDIS of NOAA for numerical weather prediction (NWP) and water model validation, data assimilation and for drought monitoring. The GET-D system was generating ET and Evaporative Stress Index (ESI) maps at 4-8km spatial resolution using thermal infrared (TIR) observations from the Imagers on GOES-13 and GOES-15 satellites before the primary operational GOES satellites transitioned to GOES-16 and GOES-17 with the Advanced Baseline Imagers (ABI). Preliminary tests have proved that the GET-D system can be upgraded and made operational with the new ABI observations. Several scientific advances to the Atmosphere-Land Exchange Inversion (ALEXI) model, which is the core of the GET-D system, have been made in the past years, for example, using Ka-band AMSR2 observations on cloudy days when the GOES TIR observations are not available. This proposed project will upgrade the GET-D software package with the recent improvements to the ALEXI model and the ABI observations. With the upgraded GET-D we will seamlessly generate ET products using observations from GOES-16 and GOES-17 ABI at high special resolution of up to 2 km. We will comprehensively validate the ET retrievals using ground ET measurements, build a long-term time series for an ET

climatology data set, and generate an ABI-based ESI data product for drought monitoring with the ET climatology. Application potentials of the ABI-based ET and ESI in NOAA-NCEP NWP models, National Water Model of National Water Center, and the US Drought Monitor of the National Integrated Drought Information System will be evaluated. Operational pathway of the upgraded GET-D at NESDIS STAR, OSPO, or the Cloud will be identified.

Daile Zhang/University of Maryland, College Park
Downscaling of GLM Lightning Observations Using ISS-LIS Data
19-ESROGSS-19-0119

The Geostationary Lightning Mappers (GLMs) onboard the GOES-R series (currently GOES-East and GOES-West) satellites observe optical signatures of lightning from geostationary orbit. Compared to 4x4 km for the previous Lightning Imaging Sensor (LIS) on the Tropical Rainfall Measuring Mission (TRMM) satellite and 2x2 km for cloud imagers like Advanced Baseline Imager (ABI), the relatively coarse spatial resolution of GLM, 8×8 km2 at nadir and 14×14 km2 at the edges of the field-of-view, limits the instrument's ability to precisely measure the illuminated cloud-top area for lightning flashes and sub-flash processes. This limitation is especially important during severe storms with high flash rates and correspondingly low flash sizes. It has been shown that storms with large numbers of small sources cause a reduced detection efficiency of GLM which impacts operational use of GLM data for severe storm forecasting and nowcasting. The second LIS, which is on the International Space Station (ISS), has 4 times the spatial resolution (4×4 km2 in the center) of GLM. The ISS-LIS under-flys the GLM domain 16 times per day and provides directly comparable observations (e.g. event, group, and flash), making it an ideal reference sensor for inter-comparison studies with the GLM measurements.
The goal of this study is to develop a technique to increase the precision of GLM observations by integrating the ISS-LIS data. It will help the forecasters/nowcasters to better characterize the light that makes it out of the cloud in those highly convective storms. We will compare the GLM data products to equivalent ISS-LIS products during simultaneous storm observations to build probabilistic correlations between event, group, and flash level characteristics including optical energy, area, and temporal evolution. Then a machine learning model that considers instrument sensitivity will be developed. This study will also leverage the historical TRMM-LIS database and high-altitude (20 km) aircraft measurements from the Fly's Eye GLM Simulator (FEGS). Based on the model and parameter distribution characteristics, we will create a downscaling technique for GLM data products. This technique will enable the integration of GLM and ISS-LIS data, or observations from any future Low Earth Orbit (LEO) lightning imagers, to enhance the precision of GLM measurements for operational and scientific applications. The techniques developed in this proposal will also improve the spatial resolution of the GLM products in the overlapping region between GOES-East and GOES-West (e.g. contiguous U.S.). Preliminary results have shown that there is a difference in the gridded (level-3) data products between the two GLM sensors. By leveraging the different footprint shapes and sizes from various measurements, we will be able to construct level-

3 products that are more consistent, robust, and accurate than the current products, which are used in the forecast officers and have been given positive feedback. This will facilitate operational use of the GLM data, especially for severe storm nowcasting and lightning-caused fire monitoring, as well as public safety and decision making.

Xiaoyang Zhang/South Dakota State University
Development of Near Real-Time Land Surface Phenology Product by Fusing Geostationary Satellite and VIIRS Observations in Support of Agriculture and Land Management
19-ESROGSS-19-0140

This proposal responds to ROSES2019 A.33 Earth Science Research from Operational Geostationary Satellite Systems (NASA Earth Science Research), focusing on the development of high-spatial-and-temporal environmental data products from geostationary satellite data. Specifically, we propose to develop and implement an operational Near Real-Time (NRT) Land Surface Phenology (LSP) product in support of agriculture and land management. The NRT-LSP product has the capability of providing near real-time monitoring and short-term prediction of vegetation phenology development. In this proposal, near real-time monitoring is referred to as the detection of phenological events that have occurred prior to the latest available satellite observation, and short-term prediction as the estimation of phenological events that will occur within 10 days after the most recent observation. The NRT-LSP product will be produced at 500 m resolution for North and South America, and updated biweekly (once every two weeks) with a latency of less than one week.
LSP reflects an interaction between plant's life-cycle events and environmental variables and is one of the simplest and most effective indicators of environmental change. Documenting LSP change supports efforts to reconstruct the historical environmental data record and to make predictions about biological responses to future environmental scenarios. During the past several decades, various LSP products have been produced from polar-orbiting satellite datasets such as AVHRR, MODIS, and VIIRS. However, those LSP products are updated only annually, and with a latency of more than a year. Because of frequent cloud contaminations, it is infeasible to utilize these data to detect LSP in near real time, or to predict short-term phenological development at regional or global scales. Existing historical LSP data have been invaluable for retrospective analyses, but an NRT-LSP product would have even greater scientific, cultural, and economic significance. An NRT-LSP product would be particularly important in assisting farmers and agricultural agencies for identifying the optimum timing of cultivation practices, monitoring crop growth, and estimating crop yield; foresters and land managers for detecting disturbances related to forest pests, disease outbreaks, and species invasion; weather modelers for estimating surface energy balance in weather prediction models; and tourists for seeing spring wildflowers and fall foliage colors. Indeed, there is an urgent and substantial need to produce an NRT-LSP product.
The high frequency of diurnal observations from geostationary satellites (GOES-16/17, Himawari-8/9, GEO-KOMPSAT-2A, and the upcoming EUMETSAT Meteosat Third Generation) maximizes the number of cloud-free views for creating a daily cloud-free

trajectory of vegetation greenness. This offers a unique opportunity to generate an NRT-LSP product for quantifying phenological timing of key growth transitions and phenological greenness of vegetation growth conditions. Thus, the purpose of this proposal is to operationally produce an NRT-LSP product at 500 m spatial resolution, with a biweekly update over the ABI full disk (North and South America). The specific goals of this proposal are:

- Establish climatological greenness trajectories from historical MODIS satellite data
- Calculate daily angularly-corrected vegetation greenness from diurnal ABI observations
- Generate synthetic time series of daily vegetation greenness by fusing ABI and VIIRS data to improve spatiotemporal resolution
- Simulate potential trajectories of LSP development from timely available ABI-VIIRS synthetic time series and MODIS climatological greenness trajectories
- Develop models for detecting phenometrics in near real time and 10 days ahead
- Validate NRT-LSP phenometrics using in situ and Phenocam observations

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