2026 SWW Poster Abstracts - Wednesday, 29 April, 2026

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1. Introducing the TSIS-1 SIM MgII Index

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Funded by the Solar Irradiance Science Team's (SIST) CATNIP project, we present a new MgII Index derived from TSIS-1 SIM Solar Spectral Irradiance (SSI) measurements. The TSIS-1 SIM MgII index is produced not only on the standard L3 12-hour and 24-hour cadences, but also using the actual exposure times. Using the actual exposure times allows us to directly compare with other data products, such as Bremen, more precisely, as the MgII Index is known to vary considerably on shorter than daily timescales. Other MgII Indicies, such as GOES-R EUVS-C, are reported at much higher cadence (3 seconds), spectral resolution (0.0022 mm vs 0.16 nm for TSIS-1), and temporal completeness (coverage) than is possible with TSIS-1 SIM. However TSIS-1 SIM is very well calibrated, is traceable to NIST standards, and can be used to assist the calibration of other indices. Here we present the TSIS-1 SIM MgII index and demonstrate how it can be used to verify the degradation corrections that are being developed for GOES-R EUVS-C, and other instruments.

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2. Better real time neutral density specification and forecast

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Specification of neutral density for LEO satellite drag calculations has become a Space Weather top priority. Data Assimilation schemes using physics based background models have made significant progress and are now ready for operational use. We present results from over 5 years of neutral density assimilation using the Thermosphere Ionosphere Data Assimilation (TIDA) scheme assimilating CHAMP and GRACE neutral density measurements. As TIDA can now also assimilate ionosphere and plasmasphere measurements we show what improvements can be expected from the combined assimilation of neutral and plasma datasets. TIDA can be used to estimate the uncertainty and bias of any dataset, a critical feature as no uncertainties are specified and no biases are known for the assimilation measurements available today. Recognition of biases and identification of true uncertainties for real time applications is now our top priority.

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3. Bridging High-Fidelity Modeling and Operations with Reduced-Order Thermospheric Data Assimilation

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Accurate thermospheric mass density knowledge is critical for precise orbit determination, collision avoidance, and Space Situational Awareness/Space Domain Awareness (SSA/SDA). While physics-based General Circulation Models offer comprehensive atmospheric understanding, their computational demands preclude real-time use. Empirical models, though efficient, struggle to capture nonlinear thermospheric behavior, particularly during storm events. This work presents a data assimilation framework leveraging a reduced-order thermospheric model to bridge this gap toward operational SSA/SDA capability.
The framework centers on a reduced-order representation of thermospheric density dynamics derived from high-fidelity physics-based simulations, capturing dominant variability modes and their dependence on solar and geomagnetic drivers while enabling rapid propagation and real-time updating. Two reduced-order model classes are considered: a nonlinear sparse identification approach with control inputs (SINDyc) and a linear dynamic mode decomposition baseline (DMDc), both embedded within a Kalman filtering architecture for sequential density observation assimilation.
The framework is evaluated using in situ density measurements from CHAMP, GRACE/GRACE-FO, GOCE, and Swarm missions spanning diverse altitudes, local times, and geomagnetic conditions. Assimilation significantly improves density estimation accuracy over open-loop predictions, particularly during geomagnetically active periods. The nonlinear formulation consistently outperforms the linear baseline under limited observational coverage. A second evaluation phase incorporates the High Accuracy Satellite Drag Model (HASDM) and two-line element (TLE)-based orbital data, demonstrating compatibility with operational pipelines without proprietary inputs.
The framework delivers dynamically consistent density estimates, supports multi-satellite assimilation, and operates at computational costs suitable for real-time use. Future work includes heterogeneous measurement fusion and exploration of particle-based and generative modeling approaches, advancing reduced-order thermospheric data assimilation as an enabling technology for next-generation SSA/SDA systems.
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4. Uncertainty-Aware Spacecraft Guidance and Navigation Under Space Weather

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Thermospheric density is the dominant error source in low-Earth orbit prediction, yet density model uncertainties are seldom propagated through to the orbital quantities that drive operational decisions. Geomagnetic storms can enhance densities by factors of 2-5× within hours, and even during quiet times empirical models disagree by 20-40% but these uncertainties typically stop at the density level without reaching downstream orbital risk. The May 2024 G5 Gannon storm illustrates the consequence: KANOPUS-V 3 experienced 917 m of semi-major axis decay within days, exposing how quickly storm-driven density errors can cascade into collision avoidance challenges, premature reentry risk, and station-keeping violations.
We present a framework that bridges this gap by mapping any calibrated density uncertainty envelope into orbital impact. The approach propagates multiplicative density and ballistic coefficient uncertainties (??, ?B) through drag-specialized Gauss Variational Equations via an augmented state-covariance system, producing first-exit time distributions: the probability that along-track drift exceeds a prescribed tolerance as a function of time. This reframes the question from "how much will the orbit decay?" to "how much warning do I have?" a quantity directly relevant to maneuver planning. We demonstrate the framework on constellation station-keeping, where G5-level density uncertainty reduces median time-to-violation from days to hours.
The framework is density-model agnostic, currently baselined with NRLMSISE-2.0. Ongoing work will integrate the Reduced Order Probabilistic Emulator (ROPE), a data-driven thermospheric model developed at ASSIST Lab, West Virginia University that provides storm-resolved density distributions enabling a direct pipeline from calibrated space weather research to downstream orbital impact assessment.
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5. Improving Short-term Solar Proton Event Forecasting with Electron-Based Inputs and Transformer Architectures

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Solar Energetic Particle (SEP) events, specifically Solar Proton Events (SPEs), pose substantial radiation risks to spacecraft systems and human exploration missions. Relativistic electrons propagate more rapidly than protons and typically arrive at Earth earlier, making them a promising physical precursor for short-term SPE forecasting. In this study, we leverage high-energy electron flux measurements from ACE/EPAM and SOHO/EPHIN to predict SPE occurrences at Earth. As a baseline, we implement classical time-series classification approaches, including a Summary Classifier and the Sliding Window Multivariate Time Series (SlimTSF) classifier. The Summary Classifier extracts canonical global statistical features from the full time series, whereas SlimTSF applies hierarchical sliding windows to derive descriptive statistical features from multivariate time-series data. We generate predictions at 15-, 30-, and 60-minute forecast horizons prior to the ~S1-level SPE threshold, defined as ?10 MeV proton flux reaching ?10 pfu as measured by GOES. We benchmark this method against a Transformer-based model to evaluate whether multi-head self-attention mechanisms can more effectively capture long-range temporal dependencies inherent in heliospheric particle transport. Models are optimized for F1-score and further assessed using TSS and HSS to ensure operational relevance. Results thus far show that the EPHIN 1.08 MeV electron channel provides the strongest precursor signal across approaches. Our broader goal is to develop an efficient, short-term SPE forecasting tool to support future deep-space initiatives, including the Artemis missions.
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6. Physics-Informed ML Framework for Thermosphere Density Prediction

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Accurate thermospheric density prediction is critical for satellite drag estimation and space weather operations, yet existing approaches face a fundamental tension: data-driven models achieve good statistical performance but do not explicitly satisfy governing physical laws, while high-fidelity physics simulations remain computationally expensive for real-time use. This work presents a Physics-Informed Neural Network (PINN) framework that bridges this gap by constraining conventional ML architectures with the Walker diffusive equilibrium equations and the Bates temperature profile. Rather than predicting density directly, the network learns the exospheric temperature T_\infty and full altitude-dependent temperature profiles T(z) that render CHAMP satellite density observations physically self-consistent, enforcing barometric law and species-specific scale heights by construction. Trained on approximately 24 million CHAMP observations spanning 2002–2009, preliminary results show the physics-informed framework achieves a MAPE of 15.26% and R^2 of 0.8717, compared to 16.29% and 0.8692 for a purely data-driven baseline. This framework is hence designed to extend naturally to incorporate broader governing laws, including continuity and momentum equations from established physics-based models, with pathways to adapt these constraints across coordinate systems to capture Earth's geometric and geophysical structure better, therefore providing better confidence when extrapolating to unseen conditions. Operational trust in ML-based space weather tools remains a critical barrier to deployment. By constraining models to satisfy established governing laws and leveraging the network's nonlinear capacity to accommodate complexity beyond their scope, this framework advances toward solutions that are not only accurate but defensible, combining the interpretability of first-principles models with the efficiency of modern machine learning.

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7. Thermospheric Neutral Species Reduced Order Probabilistic Emulator: Dimensionality Reduction

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With the increase in satellite density in low Earth orbit, drag modeling remains a key challenge for operators. While drag is affected by multiple factors, the most uncertain variable is the density of the upper atmosphere, given the system's solar-driven nature. This work focuses on improving thermospheric modeling capabilities by developing Reduced Order Probabilistic Emulators (ROPE) for the neutral species of the thermosphere. There are multiple benefits of developing models for neutral composition. First, modeling the neutral species and temperature allows for augmentation of sparse density data. Secondly, expanding to the higher parameter space is a step towards incorporating ionosphere-thermosphere coupling. Thirdly, the use of species opens the option to incorporate further physical processes into the network training or utilize the ROPE to drive physics-informed machine learning models. Finally, developing this type of ROPE allows for improved modeling of the drag coefficient, a key uncertainty in atmospheric drag. The dimensionality reduction component of this work is based on convolutional orthogonal autoencoders (COAE) and compresses TIE-GCM data for the neutral species and temperature on a 36 x 72 x 45 grid. This results in a spatial dimensionality of 116,640 and a total dimensionality of 583,200. To remain relevant for operational use cases, the full dimensionality is reduced with a 583,200:10 compression ratio. The models provide significant improvements in reconstruction abilities over classical PCA-based models at the same compression ratios, while outperforming PCA models with a three times reduction in compression ratio.

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8. ROPE: A Reduced-Order Probabilistic Emulator for Fast and Uncertainty-Aware Thermospheric Density Emulation

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In recent years, the interest of operators in sending satellites in the low Earth orbit atmosphere (LEO) has risen and LEO assets are expected to reach $1.8 trillion by 2035. Thus, real-time intelligent maneuvering has become of primary interest for stakeholders.
The largest source of uncertainty for operators in LEO is thermospheric density, which is deeply nonlinear due to the Sun's activity. To address this challenge, we have built a Reduced-Order Probabilistic Emulator (ROPE) framework, a data-driven complement to physics-based models like TIE-GCM and empirical models like NRL-MSIS-2.1. Physics based models, despite being of high fidelity, present large computational cost and challenging uncertainty quantification for operations. Empirical models, although computationally efficient, do not directly provide uncertainty quantification.

ROPE is a data-driven framework compressing global three-dimensional density fields into a compact latent representation using various encoding methods preserving essential structures and variability.
The first modeling strategy we use in latent space employs an autoregressive SINDyc, which explicitly identifies dynamics. Within this framework we observe a MAPE of about 6% for a 5-day dynamic forecast from 1996 to 2009.
To further enhance robustness and generalization, and to better capture geomagnetically active intervals, ROPE employs a neural-network-based meta-modeling framework reaching approximately 5% MAPE over the dataset. The resulting system delivers rapid, uncertainty-aware thermospheric density forecasts suitable for operational drag propagation and space traffic management pipelines.
Complementary to the data driven framework based on TIE-GCM, we leverage data assimilation to retrain using observationally informed latent states containing some physics that measurements incorporated.
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9. Classification of Suprathermal Electron Pitch-Angle Distributions: A Data-Driven Framework for Mapping Extreme Space Weather Hazards

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Suprathermal electron pitch-angle distributions (PADs) are instantaneous tracers of magnetic connectivity and heliospheric structure. However, traditional classification often relies on manual inspection or fixed heuristics that struggle to scale with large datasets. We present a fully data-driven, instrument-agnostic framework that employs an unsupervised K-Means architecture to discover a morphological "dictionary" of 32 PAD clusters from 20 years of ACE and STEREO observations.

Despite being physics-agnostic, the pipeline successfully recovers all canonical PAD shapes—including strahl, counterstreaming, and loss-cone types—while uniquely isolating rare morphologies such as pancake and butterfly distributions. Notably, our results reveal a striking co-occurrence of these rare PADs within the most extreme (G5-class) geomagnetic storms of the satellite era, including the 2003 "Halloween" events.

The framework utilizes a Random Forest classifier that generalizes across different instruments, facilitating real-time deployment for space weather monitoring. By identifying these morphologies as ICMEs propagate toward 1 AU, this work provides a scalable diagnostic for anticipating hazards in GEO. Future extensions could potentially apply this framework to near-lunar and Martian regimes to support deep-space exploration.

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10. WAM ROPE – Dimensionality Reduction using Dual Encoder Autoencoder

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Physics based models that produce atmospheric density data for drag modelling face challenges in operationalization due to large size and computational complexity. Our recent work enabled operationalization of TIEGCM data by using a deep learning based Reduced Order Probabilistic Emulator (ROPE) framework which encompasses dimensionality reduction, dynamic modelling in reduced state space, and uncertainty quantification using ensemble approaches. In applying the framework's first step of dimensionality reduction for WAM data, the autoencoder used for TIEGCM could not directly be adapted due to WAM data's complex nature and variability as it is coupled to the lower atmosphere. This paper introduces a new convolutional dual encoder autoencoder with customized data processing and loss function specifically designed to perform dimensionality reduction on WAM data and to capture the different data patterns at different altitudes. The model's Mean Absolute Percentage Error (MAPE) for higher altitudes is below 6%, and with the introduction of dual encoder and other customizations, the MAPE for lower altitudes came down from 14% to less than 8% without affecting the model's structure. The overall MAPE on the test set is 6.74%, capturing both mean and variability of the dataset well for above 120 km, and the mean of the dataset well for below 120 km. Although this MAPE is higher than that of TIEGCM, this model captures the complex patterns and variability in the WAM data well and is designed to perform well at all levels of geomagnetic activity, better than Principal Component Analysis.
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11. MAGNETOSPHERIC WAVE–PARTICLE INTERACTIONS DRIVING ELECTRON PRECIPITATION OVER THE SOUTH ATLANTIC MAGNETIC ANOMALY DURING AN ICME EVENT

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Over the South American Magnetic Anomaly (SAMA), energetic electrons and protons from the inner radiation belt can precipitate into the upper atmosphere as a result of wave-particle interactions, particularly during geomagnetically disturbed conditions. This process alters the composition of both the neutral and ionized atmosphere and can contribute to ozone depletion. To investigate this behavior, we conducted a case study considering a geomagnetic storm on 22 June 2015, which was driven by the impact of an interplanetary coronal mass ejection (ICME). Observations from the Van Allen Probes are used to analyze energetic particle fluxes and wave activity in the inner radiation belt. These measurements are combined with data from the Proba-V satellite as it crosses over SAMA region, considering the electrons with energies of 500–600 keV and protons in the range of 9.5–13 MeV. Preliminary results indicate that the geomagnetic storm not only enhances precipitation, but also expands the region of precipitation beyond SAMA to approach both auroral and equatorial latitudes across the Brazilian sector. The increased wave activity inside the plasmasphere during the event, including hiss and magnetosonic waves, appears to play an important role in scattering inner radiation belt particles, leading to the observed precipitation. Ongoing analysis focus on calculating the resonance conditions between the observed waves and the precipitated particles, as well as investigating the physical conditions responsible for the generation of hiss and magnetosonic waves.

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12. Ray-Tracing Analysis of Lightning-Generated Whistler-Mode Wave Propagation in Latitude-Limited Magnetospheric Ducts in the Earth's Inner Magnetosphere

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Radiation belt particles are a major component of space weather and can significantly impact satellites and space-based technologies. These electrons are strongly influenced by wave-particle interactions with whistler-mode waves, which regulate their acceleration, transport, and precipitation. Consequently, radiation belt diffusion processes depend critically on the spatial distribution and intensity of whistler-mode wave power in the magnetosphere. Lightning-generated whistler-mode waves are an important natural source of such waves and can propagate along geomagnetic field lines, interacting with radiation belt electrons during their propagation. This study investigates the propagation characteristics of lightning-generated whistler-mode waves in the inner magnetosphere in the presence of cold plasma density irregularities using a numerical ray-tracing model. The simulations incorporate a dipole geomagnetic field and magnetospheric ducts represented as latitude-limited Gaussian density enhancements centered near the magnetic equator with different latitudinal spans. The study focuses on latitudes of Palmer Station (??2.58) and Dunedin (??2.72) where extensive whistler observations datasets have been previously analyzed.
Backward ray tracing is used to determine the possible magnetospheric propagation paths of waves observed at the ground stations and to identify the conditions under which one-hop propagation and potential ground observation of lightning whistlers. The results indicate that both duct span and wave frequency influence successful ducted one hop propagation. Furthermore, the inferred source regions may extend to latitudes both

higher and lower than the magnetic conjugate points. These findings provide insight into how magnetospheric density structures control whistler-mode wave propagation and influence the distribution of wave power relevant to radiation belt dynamics.

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13. SkyCT -- Towards Global Monitroing of the D-region

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The D-region is the lowest and most anomalous region of the ionosphere, spanning the altitudes where the atmosphere quickly decays into a weakly ionized plasma. As such, the region is too low for in situ satellite monitoring, too high for balloons, and too sparse for conventional radar measurements. Previous studies (Richardson et al.) have used the Very Low Frequency (VLF) broadband impulsive emissions from lightning, known as sferics. to determine the average electron density of the D-region along the path from sferic to magnetic-field receiver. While these studies established and verified methods for converting noisy, scattered, and incoherent data into electron density estimates, the associated pipeline was not computationally capable of processing large volumes of data.
This software is scaling into an operational product, designed for scalability to global distances and engineered to support real-time processing, enabling continuous estimates of D-region electron densities. With this capability, we detect and present geophysical phenomena (such as solar flares and solar eclipses) in large datasets. We then explore how this capability could enable new operational and decision-making paradigms across multiple industry sectors.

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14. Retrieval of Planetary Waves and Tides in Earth’s Thermosphere using Solar Occultations: Assessing Visibility from Simulated Orbits for OWLS

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The OWLS instrument is a LASP-designed and built solar occultation instrument package that will resolve outstanding questions regarding the role of gravity waves in Earth’s thermosphere. Modelling groups have reached different conclusions on the degree of cooling induced by gravity wave dissipation in the thermosphere. OWLS will resolve this discrepancy by measuring gravity wave potential energy in the Mesosphere-Lower Thermosphere region and testing if this is correlated with an increase or decrease in thermospheric temperature. To better isolate the change in temperature associated with gravity wave activity, we must also measure and remove variability from planetary waves and tides that will be present in the dataset. Planetary waves and tides are perturbations in density and temperature acting on the background thermosphere. Solar asynchronous tides, to which solar occultations are sensitive, form a significant portion of thermospheric variability to which low Earth orbiting spacecraft are exposed. Characterizing these tides therefore becomes important beyond the specific science application of OWLS. Here, we present our work simulating planetary wave and tide parameter retrievals from the thermosphere, with the goal of assessing how orbit selection influences our ability to accurately retrieve the amplitude and phase of wave features. We consider a selection of Sun-synchronous orbits at different local times of the ascending node as the primary representatives of the OWLS orbit. We further augment our study to include the ISS orbit and select orbits of commercial constellations to provide insight into other possible deployments of solar occultation sensors.

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15. **Climatology of Orbital Propagation Error in LEO**
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Unprecedented congestion in LEO has driven surging demand for satellite conjunction assessment, leading to hundreds of thousands of collision avoidance maneuvers annually. Satellite operators must reliably predict trajectories more than 24 hours in advance to identify and mitigate potential conjunctions, but that capability is severely compromised during geomagnetic storms when trajectory predictions are especially poor.

Atmospheric drag is the primary source of propagation error for satellites in LEO. Errors in drag specification come from errors in the forecasts that drive the atmospheric models, errors in the atmospheric models themselves, or errors in the satellite ballistic coefficient. This work seeks to disambiguate the contributions from forecast and model errors in satellite propagation to better understand where new efforts from the space weather research community would provide the highest value for satellite operators.

This effort leverages ESA's Swarm satellite data over a solar cycle to assess forecast versus model error impacts on 3-day orbit predictions. A high-fidelity propagator runs three scenarios using (1) forecasted space weather drivers, (2) historical measured drivers, and (3) onboard accelerometer-derived neutral density, isolating errors from forecasts, models, and the propagator (and ballistic coefficient) respectively. Analysis across the solar cycle, particularly during geomagnetic storms, reveals that improving forecasts—not models—is the top priority for reducing orbit prediction errors when operators need accuracy most. This effort should help to better align the space weather research community with the rapidly evolving needs for ensuring space safety in the years ahead.
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16. **Development of a WACCM-X Interface for the JEDI Data Assimilation System**
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The Joint Effort for Data Assimilation Integration (JEDI) is a state-of-the-art unified data assimilation (DA) system developed by UCAR’s Joint Center for Satellite Data Assimilation (JCSDA), which is slated for operational implementation at many agencies and will also serve as a community system for research. To couple the NSF NCAR Whole Atmosphere Community Climate Model with thermosphere and ionosphere extension (WACCM-X) to the JEDI framework, the cam-jedi model interface is developed as the JEDI interface for the Community Atmosphere Model (CAM). The current implementation supports the CAM finite-volume (FV) dynamical core geometry and utilizes the ECMWF Atlas library to enable parallelized I/O and computational operations. This interface exchanges information through file-based data communication and defines the interaction between WACCM-X and the JEDI through a set of standardized model-specific classes. Currently, these classes include the Geometry, GeometryIterator, Fields, State, Increment, VariableChange key components, consistent with the modular class framework used by JEDI model interfaces. These classes together provide the foundation for representing model states within the JEDI. At present, radiosonde and ionosonde observations can be ingested through the HofX application to support observation operator evaluation. Ongoing development includes the ensemble HofX capability and the Model class, with the goal of implementing the

Local Ensemble Transform Kalman Filter (LETKF) DA algorithm. This work contributes to ongoing efforts to integrate WACCM-X with advanced DA systems and supports future ionospheric and thermospheric forecasting applications.

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17. DENTS, An Instrument Solution to Measure and Predict the 'Hail' of Space Weather: Debris and Meteoroid Impacts

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Spacecraft in Low Earth Orbit (LEO) are frequently struck by both natural meteoroids and human-created space debris. These objects strike at hypervelocity speeds (> 1 km/s) with the potential to degrade, damage, or destroy spacecraft systems. In a space weather context, these impactors are analogous to hail.

The threat of space debris impact is rising sharply as the pace of space launches continues to increase. Each launch generates new debris, and the probability of catastrophic collisions continues to climb. In this rapidly changing environment, there is a stark observational gap for small debris (< 3 mm) in LEO. Small debris cannot be efficiently detected from the ground, nor by current on-orbit optical systems. Most assets capable of in-situ small debris detection have been retired. At the same time, small debris orbital evolution is not well-constrained by modeling since, in addition to gravity and drag, electromagnetic and photon pressure forces can strongly influence small debris orbital dynamics.

This presentation describes an innovative instrument designed to quantify small debris and meteoroids: Debris and meteoroid ENvironmenT Sensor (DENTS). DENTS combines three well-established measurement techniques into a single coherent detector. DENTS characterizes the size and velocity distributions of small debris and meteoroids, while simultaneously measuring impact-caused changes to the environment around a spacecraft. DENTS is a modular instrument, capable of being deployed on platforms ranging from cubesats to the International Space Station.

This presentation describes DENTS instrument development and the utility of DENTS data for measuring and predicting debris and meteoroid impacts.

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18. Space Atlas - Driver-resolved attribution and forecasting of voxel-level thermospheric density, with per-edge uncertainty and learned time-lag

Heidi Bennett, Nervous Machine
Operational thermospheric models provide bulk density estimates but lack driver-resolved attribution and forward prediction of how perturbations propagate spatially and temporally. We present a causal discovery framework that decomposes density variations at the voxel level into individual drivers: solar EUV, geomagnetic activity, seasonal-latitudinal patterns, solar wind dynamic pressure, and Joule heating, while learning the time-

lag structure governing how each driver's influence persists across orbital shells. The learned lag structure enables forward prediction: given a driver impulse, the model forecasts how the resulting density perturbation evolves across voxels over hours to days, with certainty quantified per edge.

We validated across two data regimes to isolate the role of observation cadence. On NOAA/NCEI TLE debris catalog data (156 voxels, 726 validated causal edges), the pipeline achieved 16% MAPE for bulk density versus 85% for JB2008 under equivalent storm conditions. However, TLE cadence (~daily) proved insufficient to resolve temporal lag structure. Certainty dropped under tighter driver attribution requirements, confirming that daily observations cannot support per-driver causal decomposition or forward prediction.

Retraining the identical pipeline on GRACE-FO accelerometer-derived density (sub-minute cadence) recovered both attribution and prediction: all five drivers exceeded 0.91 certainty, 93% of edges surpassed Z=0.80, and the learned lag model produced validated multi-day forecasts using GRACE-FO as error signal. Condensed temporal sampling enabled the pipeline to learn how perturbations propagate, not merely where they are.

Live LEO GPS drag residuals already provide GRACE-FO-comparable cadence but remain unexploited for thermospheric characterization. Our framework can ingest these signals to deliver certainty-quantified, driver-resolved nowcasts and spatiotemporal perturbation forecasts without dedicated science missions. We present the causal graph structure, certainty evolution across regimes, and a prototype voxel-level forecasting pipeline.
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19. Spacecraft Environment Discharges in the Geostationary Environment: Radio Signatures and Relationship to Plasma Population and Geomagnetic Indices

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Charging by the plasma environment is a leading cause of detrimental impacts to spacecraft in geostationary orbit, including memory upsets, operational anomalies, and even loss of mission. Studies of spacecraft charging generally either compare >100 keV particle flux with anomaly occurrence rates as a proxy for internal charging or measure the spacecraft surface potential using plasma analyzers. Radio frequency (RF) signatures of onboard discharges may be a direct measure of the space environment’s charging effects on a spacecraft. These have not been measured in geostationary orbit since the Spacecraft Charging At High Altitudes (SCATHA) mission in 1979-1980. Determining the important plasma energy regimes associated with such discharges has therefore proved challenging, especially at energies <50 keV.

The Space Test Program-Satellite 6 (STPSat-6) presents a unique opportunity to examine the dependence of surface charging on the lower-energy portion of the geostationary plasma population. STPSat-6 carries two relevant instruments: the Radio Frequency Sensor (RFS), a VHF radio receiver; and the Z-Plasma Spectrometer (ZPS), a suite of electrostatic analyzers. In addition to lightning-generated emissions, RFS detects non-dispersed transients that we term spacecraft environment discharges (SEDs). The low energy instrument of ZPS measures both electron and ion flux in 72 channels between 2 eV/q and 50 keV/q.

We present an analysis of the occurrence rates of SEDs measured on STPSat-6 and compare these with electron and ion flux measured aboard the spacecraft, as well as geomagnetic indices. We additionally present case studies of SED occurrence during spacecraft eclipse and substorm injections.

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20. Multi-month Thermospheric Neutral Density Nowcast and Forecast Using Multiple Low-Earth Orbit Satellites Based on the Whole Atmosphere Model

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Whole Atmosphere Model (WAM) is operated by NOAA's Space Weather Prediction Center (SWPC) and simulates the whole atmosphere neutral compositions in real time, while WAM tended to have a positive bias compared to various observations. SpaceX Starlink constellation provides orbit-effective density measurements obtained by monitoring the dissipation of orbital energy. The multi-months density measurements were assimilated to WAM, using the Iterative Driver Estimation and Assimilation (IDEA) data assimilation technique. The study period, January–April 2023, covers four solar rotations, a severe G4 geomagnetic storm on 23 April, and several minor storms. Results show that the data assimilative WAM density (WAM-DA) effectively captured the Starlink orbit-averaged density during both quiet and storm time, with a root-mean-square error (RMSe) at 6.6%. In addition, a cross-comparison was conducted with the accelerometer estimates of neutral density from GRACE-FO. The good agreement (RMSe = 6.4%) between WAM-DA and GRACE-FO shows that the Starlink neutral density estimates can be used to improve the WAM neutral density outputs in the IDEA data assimilation scheme. A 2-day neutral density forecast has also been performed to evaluate the improvement in the forecast mode with the IDEA-estimated model heating. With the rapid growth in the number of spacecraft and debris objects in LEO (Low Earth Orbis), reducing neutral density uncertainty remains one of the most effective ways to improve orbit prediction and collision avoidance, and this study can be of benefit to improve thermospheric neutral density specification.

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21. HASDM-Sol: a Machine-learned Model of Thermospheric Density Trained on Two Solar Cycles

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This work introduces a prototype machine-learned thermospheric density model, HASDM-Sol, designed as a surrogate model for the High Accuracy Satellite Drag Model (HASDM). The model uses space weather indices that are available operationally in near real-time to derive input features, and was trained using a 25.5 year database of HASDM nowcast densities as the target variable.

Development of HASDM-Sol emphasizes parameter reduction of the HASDM density target data, which begins on a grid of time, altitude, local solar time and latitude ?H(t, h, LST, ?). This parameter reduction is carried out in two stages: firstly, a spherical harmonic (SH) expansion of log(?H(LST, ?) x10^12) is calculated to limited order, allowing the local solar time and latitude variation to be expressed along a single dimension of SH coefficients; secondly, the altitude and SH coefficient dimensions are flattened then compressed into a set of principal components inside the model training loop.

We demonstrate how the performance of HASDM-Sol varies over two solar cycles by re-training five versions of HASDM-Sol using the same parameters but different permutations of training data. This creates five year contiguous testing periods for each model, covering 2000-2005, 2005-2010, 2010-2015, 2015-2020 and 2020-

2025. Over each testing period, HASDM-Sol statistically outperforms the JB2008 empirical model, producing density estimates that more closely match HASDM.
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22. From Protons to Neutrons (and back again): Changepoint Detection, Spallation Modeling, and Spectral Inversion for SEP Events

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We present a three-part framework for extracting more information from Solar Energetic Particle (SEP) events and neutron observations. First, we develop an adaptive, stochastic fitting approach that continuously matches a double Band function to incoming Geostationary Operational Environmental Satellite (GOES) proton data, using a changepoint algorithm to identify SEP onset and cessation independently across multiple energy thresholds. Second, we combine these inferred proton inputs with physics simulations to estimate neutron production from both SEP-related processes and proton-on-satellite spallation, giving an estimate on total (environmental and spallation-induced) neutron signal. Finally, we introduce a new inverse model that uses Bayesian inference to estimate the incident proton spectrum with uncertainties directly from neutron count rates. This model is trained and evaluated using the past decade of SEP events observed by the GOES series, learning behavior across events by adaptively aligning them on the same time axis. Together, these methods allow for improved SEP fitting and spectrum reconstruction from neutron measurements, and will be used to obtain SEP characteristics from the satellite-based neutron instruments.

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23. CONTIGO: Building Open-Source Tools for Orbit-Derived Thermospheric Density Estimation and Improved Orbit Prediction

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The rapid proliferation of objects in Low Earth Orbit (LEO) has created an urgent need for improved orbit prediction and uncertainty quantification. The CONTIGO (Collaboration for Observational and Numerical Thermosphere with Integrated Geospace Orbits) project addresses this by building a flexible, open-source framework for thermospheric density determination and orbit propagation that bridges the gap between space

weather research and operations. During the first year of the CONTIGO project, we have developed critical foundations for (1) orbit-based density determination, (2) a prototype data assimilation framework, and (3) assessment of neutral density impacts on orbit determination/prediction using the General Mission Analysis Tool (GMAT). This work represents advancement toward providing open source, collaborative tools linking Heliophysics research to its orbital drag-related impacts. Here we show initial results from our first year and outline goals and areas of potential collaboration for the ongoing project.

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24. Diagnosing Upward Drifts in GOES Ring Current Proton Energies Caused by Radiation Damage

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Proton fluxes of 10's-to-100's of keV observed by solid state telescopes have been observed to decrease gradually with time. This decrease has been attributed to radiation damage by the protons being detected. As the resulting dead layer grows, protons deposit less energy in the active part of the detector, and higher energies are required to meet the detected energy thresholds. The channel effective energies drift upward, and thus the observed fluxes decrease. Past correction methods have used comparisons between recently-launched and older instruments, but observed differences can have more than one cause. Energy-dependent periodicities of drift echoes in geostationary orbit provide a measure of channel energies. We have developed an automatic method for detecting and characterizing drift echoes that can be applied to multiple years of satellite data and thereby track any change in channel energies. We identified drift echo candidates by applying CLEAN to high-pass-filtered flux time series in overlapping sliding windows sized to the expected proton and electron drift periods at geostationary orbit. Within each window, statistically significant oscillation frequencies were isolated iteratively using FFT peak detection, sinusoidal fitting and subtraction, and Monte Carlo testing relative to a residual-based lag-1 autoregressive red-noise model. Application of this method to over eight years of GOES-16 proton and electron fluxes confirms that proton channel energies increased with time while electron channel energies were stable. The collected drift echo detections have been used to study the behavior of drift echoes at all local times in response to solar wind drivers.

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25. A new space weather CubeSat for understanding solar soft X-ray emission: CubIXSS (the CubeSat Imaging X-ray Solar Spectrometer)

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and the CubIXSS Team

The CubeSat Imaging X-ray Solar Spectrometer (CubIXSS) is a 16U CubeSat funded under NASA's space weather initiative via H-FORT to measure soft X-ray spectral emission from the solar corona. CubIXSS uses two co-optimized, cross-calibrated instruments to fill a critical X-ray observational gap:
* MOXSI, a novel diffractive spectral imager using a pinhole camera and X-ray transmission diffraction grating for spectroscopy of flares and active regions over an unprecedented spectral range of 1 to >70 Å; and
* SASS, a suite of four spatially-integrated off-the-shelf spectrometers for high-cadence, high-sensitivity X-ray spectra of lines and continuum from 0.5 to >30 keV.

These instruments provide sensitive, precise measurements of abundances of key trace ion species, whose X-ray spectral signatures provide a unique diagnostic of the chromospheric or coronal origins of heated plasma across a broad temperature range from ~1 to >30 MK, thereby providing insight into links between plasma heating, particle acceleration, and magnetic reconnection. Concurrently, our database of high-cadence, high-resolution soft X-ray spectra across this unprecedented wavelength/energy range can serve as inputs to drive Earth ionosphere models.

CubIXSS is currently undergoing integration and test, and will launch into sun-synchronous polar orbit on Dec 2026 on USSF-178. We will launch together with SunCET, an H-FORT CubeSat using a novel wide-field EUV imager to study CME and solar wind acceleration through the inner and middle corona. In combination, CubIXSS and SunCET are a powerful space weather suite to understand the energetics of solar eruptions and the connections between coronal heating and solar wind formation and acceleration.

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26. Summary of the Office of Space Weather Observations (SWO) Space Weather Next GEO Analysis of Alternatives.

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The Office of Space Weather Observations (SWO) performed an Analysis of Alternatives (AoA) to define the scope of the Space Weather (SW) Next Geostationary (GEO) project. The SW GEO AoA assessed the cost, risk, and benefits of acquiring space weather observations from geostationary orbit. Expert teams conducted market research and trade studies, developing architecture and instrument catalogs to estimate the total cost for various mission alternatives and identify high-risk issues and technologies that may drive the schedule. The AoA considered the following observations or datasets: photospheric magnetograph, extreme ultraviolet (EUV) imagery, energetic particle flux, X-ray irradiance, EUV irradiance, magnetic field, and thermospheric far ultraviolet (FUV) measurements. A variety of mission concept alternatives were analyzed, including one concept with all observations and various missions with fewer observations. For each concept the ground system, communications, spacecraft requirements and launch vehicle requirements were updated and costs estimated. This allowed the team to identify key drivers of risk and cost. A final benefit/cost analysis demonstrated substantial benefits across all alternatives studied. Analyses of the initial AoA findings are ongoing.

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28. C-SWIM: A Coupled Space Weather Impact Model for Satellite Fleet Vulnerability and Economic Loss Under a 1-in-100-Year Solar Energetic Particle Event

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Modern economies depend critically on satellite infrastructure for navigation, communications, weather forecasting, and national security. This growing reliance exposes significant vulnerability to severe space weather, particularly to solar energetic particle (SEP) events, which can degrade or disable spacecraft electronics. However, the aggregate economic consequences of extreme SEP events have not been rigorously assessed. This study develops an integrated framework linking SEP hazard characterization, dynamic geomagnetic cutoff rigidity modeling, radiation dose transport, and fleet-wide failure probability estimation to macroeconomic impact analysis. Using extreme-value analysis of 50 years of proton flux observations, we derive 1-in-100-year event fluences and compute absorbed dose in silicon via spectral transport, combined with trapped-radiation baselines. Failure probability is estimated for ~12,000 US operational satellites using an established radiation-hardness assurance methodology by convolving the total-dose environment distribution with device failure threshold distributions under regime-dependent shielding and component assumptions. The assessment reveals that ~330 satellites (2.6%) are at critical risk of dose-induced failure, concentrated in high-altitude LEO and HEO orbits where trapped-proton-belt doses approach commercial component failure thresholds. Fewer than 700 satellites account for essentially all of the failure risk, while MEO and GEO satellites show effectively zero failure probability under assumed radiation-hardened designs, despite high particle access fractions. The expected capital loss, computed as replacement cost weighted by failure probability across the ~$312B fleet, totals ~$5.9B. Downstream economic impacts are assessed through three failure scenarios that progressively expand the set of failed satellites from critical-only (~330 satellites) to all with non-negligible risk (~5,000 satellites), yielding first-order daily economic impact estimates of $120M, $405M, and $1.66B, respectively, with Earth observation and military services most severely disrupted. This framework provides a first-order link between physical SEP hazards and economic consequences for satellite-dependent sectors.
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29. FAR ULTRAVIOLET SPECTRAL RESPONSE TO SOLAR FLARES: A comparative study of the 2003 and 2024 X3.9 flares

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Solar flares are powerful, sudden bursts of energy from the Sun than can disrupt the Earth’s space environment across many wavelengths, including the Far Ultraviolet (FUV). This research focuses on the X3.9-class solar flare that occurred on 3 November 2003, using high-resolution irradiance data from the SOLSTICE instrument onboard NASA’s SORCE satellite. During this flare, SOLSTICE operated in a Quick Scan mode, allowing the full FUV spectrum to be captured rapidly instead of relying on daily-averaged measurements. These

observations will also be compared with predictions from the FISM2 solar irradiance model to assess how well the model reproduces the flare's FUV response.
The main aim of this study is to understand how energy is distributed across the FUV during a flare, with particular focus on how much lies within and outside the Lyman-alpha line at 121.6 nm. To support this, a similar X3.9 flare from 10 May 2024 is used for comparison using GOES-R EUVS-B measurements in the 117–140.5 nm range. Emission within this wavelength range is integrated to examine how different spectral lines respond during a flare and to provide a consistent comparison with the SOLSTICE data.
This comparison helps place the 2003 flare in context and tests how well broadband instruments capture FUV variability. It also supports ongoing work to estimate how instruments such as GOES/EUVS-B and PROBA2/LYRA would interpret high-resolution spectra, and whether correction factors can be developed to improve their measurements.

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30. High Cadence Solar Spectral Irradiance Modeling

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High Cadence Solar Spectral Irradiance Modeling

Building on the empirical irradiance model of Coddington et al. (2025), we are investigating converting it from daily averages (i.e. climate) to 1-minute cadence (space weather). The essential inputs will be facular brightening from the Magnesium II index GOES-R/EXIS EUVS-C (McClintock et al. 2025), and a high cadence proxy for sunspot darkening. In this study, we are modeling the far ultraviolet spectrum which only depends on the facular brightening, so the sunspot darkening can be neglected.

Initial results show that during flare eruptions, the slope of the correlation between the FUV and MgII index changes from the daily-average slope.

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31. Continuous and clean space weather data from CPI

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This poster will discuss two incredibly valuable data streams currently being provided free-of-charge from Computational Physics, Inc. (CPI): magnetometer data from 13 instruments distributed across the continental US and neutral wind and temperature data from 4 Fabry-Perot Interfrometers (FPIs) from Maine to Brazil. Use cases and advances in data processing techniques will be shared for both data sets. The FPI data is a multi-decade record of neutral winds with unmatched precision and fidelity. These data have been used to develop the first-ever 3D climatalogical wind model for the thermosphere and are used by institutes worldwide. Assimilation into space weather forecasting has already demonstrated the importance of the magnetometer data, and CPI has been

developing algorithms to clean and fill the data in real-time, for improved operational capacity. CPI welcome conversation regarding future operational opportunities for this critical data.
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33. The Magnetospheric Auroral Asymmetry eXplorer: a Mission Concept for Improving Space Weather Monitoring and Forecasting

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The aurora is a critical value for monitoring and predicting space weather phenomena. Auroral activity tells us when space weather is active and dangerous; the lack of aurora is nature's "all clear" message. The location and intensity of the aurora mark regions of intense current flow, therefore indicating the threat of strong geomagnetically induced currents. The aurora is a major high latitude energy source for the ionosphere and neutral atmosphere. It is therefore a critical input for tracking and modeling ionospheric disturbances and neutral atmospheric drag. Despite being the lynchpin for space weather at Earth, there has not been a mission dedicated to viewing the whole aurora, either northern or southern, for over 20 years.

This poster introduces MAAX: the Magnetospheric Auroral Asymmetry eXplorer. MAAX is a mission concept that uses multiple spacecraft to completely view the entirety of both the northern and southern auroral ovals continuously. Observations would be made with a dual-wavelength ultraviolet imager aboard each spacecraft in order to specify the energy flux as well as the average energy, which informs researchers and models about the altitude of the energy deposition. This poster explores how the rich dataset MAAX provides could revolutionize existing auroral and space weather forecast models. We also illustrate the impact that a real-time data stream for MAAX would have on space weather operations, including forecasting and real-time monitoring.

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34. Solar Shenanigans: Space Weather Event Preparedness and Practice in Aotearoa New Zealand

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Michelle Bannister, Te Whare W?nanga o Waitaha University of Canterbury NZ

The Gannon storm of May 2024 significantly raised New Zealand's awareness of space weather risks, prompting focused consideration of our readiness and raising an important question: are we truly ready?

Led by the National Emergency Management Agency (NEMA), the New Zealand Government, space weather scientific community, and electricity industry united to rapidly improve our readiness in the following key directions:

1. Developed the National Space Weather Response Plan, which promotes effective emergency management and a coordinated response across NZ
2. Established a Space Weather Science Advisory Panel plus a response-focused sub-group. The wider panel contains representatives from NZ Science Agencies (Earth Sciences New Zealand), universities (notably the University of Otago) and impacted sector representatives. The sub-group is smaller, agile, contains deeper expertise, and is focused on delivering rapid scientific advice to NEMA and the electricity sector.
3. Conducted the two-day national Exercise Tahu-nui-?-rangi, which enacted a maximum credible space weather event to test the readiness of both the national plan and NZ, including NEMA, the Science Advisory Panel, and supporting agencies and sectors nationwide.

These steps form part of wider efforts to connect with domestic and international partners, raising the profile of space weather and building on the strong foundations of domestic science and research, notably the ongoing Solar Tsunamis research-to-operations programme.

Overall, New Zealand has made substantial progress — from novice to well?informed and increasingly resilient actor — by taking a domestically and internationally connected approach, focused on understanding and managing potential consequences.
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35. [State uncertainty quantification of forecast errors and horizontal winds in VLEO]

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Satellite operations in Very Low Earth Orbit (VLEO) present severe challenges, primarily driven by complex atmospheric dynamics and high sensitivity to space weather perturbations. This study characterizes predictive state uncertainty in VLEO by isolating the impacts of space weather forecasting errors, specifically deviations in the Ap geomagnetic index and F10.7 solar flux, alongside horizontal wind modeling and maneuver execution errors. A reference-based framework is employed across varying space weather conditions to isolate secular trajectory deviations driven by atmospheric forecast inaccuracies, contrasting propagation with and without horizontal wind models to quantify their contribution to positional uncertainty. To complement this environmental assessment, a mission operations analysis isolates maneuver execution errors via a targeted Monte Carlo campaign evaluating thrust magnitude, direction, duration, and start delay. Results demonstrate that in-track dispersion dominates state uncertainty, growing most rapidly at lower altitudes (~250 km) where sensitivity to drag and unmodeled winds is maximized. Forecasting errors in Ap and F10.7 during elevated geomagnetic activity act as primary catalysts for this growth. Concurrently, the operational analysis reveals burn duration drives in-track and radial errors, while thrust direction dictates cross-track deviations, combining for up to 8 km of in-track uncertainty over a 3-day horizon. Finally, conditional geostorm probability analysis contextualizes these deviations, distinguishing nominal uncertainty evolution from high-impact tail risks. These findings provide important insights to enhance VLEO operations, improve space traffic coordination, and inform resilient operational services.

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36. The need for real time radiation measurements at MEO.

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The Radiation Belt Forecasting Model and Framework (RBFMF) provides real-time forecasts and hindcasts of the radiation environment, which are used as inputs for the Satellite Charging Assessment Tool (Sat-CAT). Sat-Cat is used by satellite operators to model both long term and real-time effects of internal charging on satellite components.

We will present the validation results of the RBFMF, and will show how combining real-time electron flux observations with physics based modelling improves hindcasting capabilities at MEO and GEO of either method used alone. We will also highlight how new missions must consider data provision for real-time operational applications, and discuss the observational requirements and model development necessary for improved specification of the radiation environment through hindcasts and forecasts.

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37. The Role of International Partners in Ground Support for Space Weather Missions at L1

David Fritz, NESDIS/SWO - MITRE Corporation
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The National Oceanic and Atmospheric Administration (NOAA) continuously monitors solar activity from the Sun–Earth Lagrange Point 1 (L1) vantage point. A global network of ground stations ensures the high availability of L1 observations collected for space weather forecasters. In support of the Space Weather Follow On (SWFO) mission, NOAA's National Environmental Satellite, Data, and Information Service (NESDIS) developed the SWFO Antenna Network (SAN), a global ground station network which captures real-time observations from the Space weather Observations at L1 to Advance Readiness (SOLAR-1) observatory. SAN enables the integration of ground stations from international partners, continuing the Real-Time Solar Wind Network used for Deep Space Climate Observatory (DSCOVR). The Japan National Institute of Information and Communications Technology (NICT) provided the first international partner ground station to be integrated with SAN. The South Korea AeroSpace Administration (KASA) is preparing to provide the second partner ground station. Japan, South Korea and future partners will significantly increase the availability of observational data over the life of the SOLAR-1 mission. In preparation for future observatories, NESDIS will enhance the SAN to become a multi-mission Space Weather Antenna Network (SWAN) supporting the concurrent operation of multiple NOAA observatories at L1. NOAA is continuing to engage with international partners regarding the significant role they can play in supporting SOLAR-1 and future L1 missions. This poster outlines the SAN architecture, the role of international partners, the roadmap to the future SWAN, and the increasing need for high-availability collection of all L1 observations for space weather forecasting.

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38. Wave Synergy in Energetic Electron Precipitation: A Multi-Mission Study

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Energetic electron precipitation (EEP) plays a central role in radiation belt loss, magnetosphere-ionosphere coupling, and variable energy deposition into the upper atmosphere. Although individual wave modes, including electromagnetic ion cyclotron (EMIC), whistler-mode chorus, and electron cyclotron harmonic (ECH) waves, are each known to contribute to precipitation under specific conditions, their combined and potentially overlapping influences remain incompletely understood.

We present a multi-mission investigation of EEP associated with the joint effects of these wave populations using coordinated observations from THEMIS, ELFIN, and DMSP. THEMIS data are used to characterize wave activity and the surrounding magnetospheric environment, ELFIN provides low-altitude measurements of precipitating and trapped electron populations, and DMSP offers complementary particle observations that place precipitation signatures in a broader geophysical context.

The analysis focuses on identifying intervals in which multiple wave modes are present simultaneously or in close succession and on assessing their relative and combined contributions to electron precipitation across different energy ranges and spatial regions. By integrating measurements across missions, this study aims to better constrain the physical pathways through which wave-particle interactions produce EEP and to distinguish intervals dominated by a single mechanism from those involving coupled or sequential processes. The results will improve understanding of radiation belt dynamics and support ongoing efforts to better characterize and predict particle precipitation relevant to satellite environment specification, anomaly risk assessment, and future physics-informed forecasting applications.

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39. Modeling SEP Transport and Geomagnetic Cutoffs in Geospace from Magnetopause to LEO

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Solar energetic particles (SEPs) represent radiation hazards to spacecraft and human activities in space, with their penetration into near-Earth space controlled by the state of the geomagnetic field. This presentation describes new modeling capabilities for quantifying SEP transport in geospace, including particle energy spectra and geomagnetic cutoff rigidity, from the magnetopause to low-Earth orbit (LEO). The method applies Monte Carlo test-particle transport to trace the propagation of upstream SEP populations through the magnetosphere and to evaluate both the spatial variation of particle populations and the shielding provided by Earth's magnetic field.
The capability is being developed for community access through the NASA Community Coordinated Modeling Center (CCMC), where users will be able to define individual sampling points, virtual spacecraft trajectories and spherical shells for calculating particle fluxes, energy spectra, and cutoff rigidity throughout the region from the magnetopause to LEO. Planned outputs include global maps of cutoff rigidity as well as trajectory-based diagnostics that relate particle access at different geospace locations, supporting systematic analysis of regional variability in SEP penetration.
SEP transport is modeled using the geomagnetic field from both phenomenological and physics-based models,

enabling event-focused investigations as well as sensitivity studies. The presentation will include a case study illustrating the modeled transport behavior in geospace together with examples of the cutoff and spectral products that will be made available to CCMC users.

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40. Space Weather Roundtable asks "Can the US National Space Weather Enterprise Be More Effective?"

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Give us your ideas! The Space Weather Roundtable has held numerous meetings exploring the current state of the National Space Weather Enterprise. The Roundtable includes members from academia, government and commercial space weather service providers, and it is also attended ex-officio by representatives from NOAA, NSF, NASA and the DoD. In pursuit of its mandate from congress, the Roundtable has explored how the Nation might: (1) facilitate advances in space weather prediction and forecasting; (2) increase coordination of space weather research to operations and operations to research; and (3) improve preparedness for potential space weather phenomena.

The Roundtable is currently asking "Can the US National Space Weather Enterprise Be More Effective?", and we are looking for thoughts and opinions from the space weather community. Topics could include:
a) What does the future of the National Space Weather Enterprise look like?
b) What are the roles of NASA, NSF, NOAA and DoD in the future ‘National Space Weather Enterprise’?
c) What are the roles of commercial ‘Space weather service providers’
d) What is the role of Academia
e) The role of CCMC and Space Weather Testbed
f) The R2O2R program
g) Funding for Space Weather Research and technology development
h) Can we improve how space weather-related technology is transitioned to operational status?
i) How can the Space Weather community respond to evolution of the Space Industry?
j) Are there any User Needs that are not currently being met?
k) Any other ideas or topics for discussion?

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41. Developing and Validationg a Space Weather Concept Inventory (SWCI)

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Society’s increasing reliance on technology has highlighted the importance of promoting space weather literacy through educational research and outreach. Despite this need, space weather education lacks validated assessment tools capable of diagnosing misconceptions and measuring conceptual understanding across diverse audiences. This study describes the development and validation of the Space Weather Concept Inventory (SWCI), a 24-item diagnostic assessment designed to measure space weather literacy. Instrument development was guided by expert consultation and the identification of common misconceptions, followed by pilot testing and psychometric refinement. Participants were recruited through the Prolific research survey platform. A pilot sample of approximately 250 participants supported exploratory item analysis, followed by a larger validation sample of approximately 750 participants, with a final analytic sample of 719 respondents used for confirmatory evaluation. Analyses included classical test theory reliability, confirmatory factor analysis, Rasch modeling, and

regression analyses examining demographic and engagement predictors. Results indicate strong internal consistency (Cronbach's ? ? .88), stable measurement properties across a broad range of item difficulty, and a correlated two-factor structure consistent with interconnected domains of space weather understanding. Regression results indicate that engagement with space weather information and prior training were more strongly associated with performance than education level, occupation, age, or gender. These findings indicate that the SWCI provides a psychometrically grounded framework for diagnosing misconceptions and characterizing space weather understanding.
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42. Initial Survey Results on Aurora Chasers' Use of Space Weather Forecasts and Uncertainty Information

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Aurora chasers are a major public user group of space weather products and tools. Understanding how they use forecasts is important for public engagement, trust in science, and communicating the societal value of space weather research. We conducted a University of Minnesota IRB-approved online survey distributed through aurora-chasing communities and received 945 responses. Questions covered geography, chasing frequency, aurora science knowledge confidence, forecast resources used, confidence in local news coverage, and how forecast uncertainty affects chasing decisions.

This poster presents an initial analysis and highlights early results. Aurora science knowledge confidence increases with chasing activity level, and more frequent chasers report substantially higher confidence in aurora science and forecasting. Forecast uncertainty is also strongly tied to behavior. Casual and less-frequent chasers are much more affected by uncertainty, while frequent chasers are more likely to chase despite uncertain forecasts. These patterns indicate that uncertainty tolerance is a key part of aurora chase decision-making. In a forecast-format comparison, respondents strongly preferred the more detailed forecast with explicit uncertainty discussion over the simpler forecast. Views on local news station aurora coverage were mixed, which suggests another opportunity for improvement.

Although this sample is not representative of the general public, the method is effective, and the results are informative for improving space weather communication. Better-informed aurora users can become ambassadors for space weather and support citizen science and other scientist-public collaborations.

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43. Bridging Space Weather Operations and Local News

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“Will I see the aurora tonight?” Many broadcast meteorologists have found themselves answering this question from their viewers over the last couple of years. Several geomagnetic storms with aurora reported as far south as California and Florida increased public interest in space weather. Broadcast meteorologists became ad hoc interpreters of space weather for the public. Most meteorologists, however, have limited or no formal training in space weather, already handle time-consuming terrestrial weather forecasts, and face competition from other platforms communicating space weather to the public.
Space weather data and forecasts from operational centers come with some translational challenges and require adaptation for the general public. Broadcast coverage of space weather is currently limited. Forecasts of major geomagnetic storms or local reports of visible aurora are more likely to make the news. Geomagnetic storm forecasts may be presented with simplified explanations or graphics, often without real-time updates. Differences between predictions and actual observations may result in unmet expectations and questions about forecast reliability among the general public.
Space weather communication is evolving. Along with known challenges, there are opportunities for collaboration between broadcast meteorology and space weather professionals. Routine introduction of space weather topics beyond major events, conditional forecasts, and attention to local impacts can improve space weather literacy in the general public .
This poster examines current challenges and explores opportunities for collaboration between broadcast meteorologists and the operational space weather community to improve public understanding of space weather.

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44. Development of a stratospheric measurement platform for space weather

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The Aeronautical Regional Geospatial Observer System (ARGOS) is an uncrewed aerial platform designed for multiple applications. The vehicle is a solar-powered flying wing with a payload capacity of 10 kg and 20U. The prototype is being iteratively developed to operate continuously at 20 km for months. The current version demonstrates vertical takeoff and landing (VTOL) in our laboratory and low-altitude horizontal maneuvers in the desert. An early objective is to fly an Automated Radiation Measurements for Aerospace Safety (ARMAS) dosimeter above the aircraft corridor. The platform will provide data for multiple aviation applications by flying ARMAS dosimeters, dual-frequency Global Navigation Satellite System (GNSS) receivers to quantify signal degradation due to scintillation, three-axis magnetometers to map the geomagnetic field over the ocean, and environmental sensors to measure ionospheric and stratospheric conditions. We introduce a novel multi-sensor approach to control the flexible structure required for HALE performance. We present recent aerodynamic analyses and simulations as well as hardware-in-the-loop (HITL) and flight test results using this approach. We invite collaboration with researchers seeking new measurements at altitude.
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45. An Integrated Machine-Learning Framework for CME Time-of-Arrival and SEP Likelihood Forecasting

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We present, for the first time, an integrated space-weather forecasting approach that combines two machine-learning components for solar eruptive events. The first focuses on predicting the time of arrival (ToA) of coronal mass ejections (CMEs) at Earth. It is trained in a multivariate framework using CME parameters, including speed, angular width, and mass, together with ambient solar-wind conditions and in situ measurements from spacecraft for events observed both remotely and in situ. Preliminary tests on previously unseen events are encouraging, with a Mean Absolute Error (MAE) below 9 hours. In addition, more than half of the test events are predicted within 5 hours of the observed arrival time, indicating that the method has clear potential for operational CME arrival forecasting.
The second component estimates the likelihood of an associated solar energetic particle (SEP) event. In this case, logistic regression is used within a supervised machine-learning framework to distinguish between two classes: non-SEP events (0) and SEP events (1). The present implementation uses flare magnitude and near-Sun CME speed as the initial predictors, and is applied to separate non-SEP from SEP events for two energy thresholds, E>100 MeV and E>300 MeV.
We aim to connect CME arrival-time forecasting with an early radiation-hazard assessment in a single system that provides both timing and probabilistic information for space-weather applications. Bringing these two elements together in one end-to-end workflow opens a path toward future operational forecasting in near-Earth and inner-heliospheric environments.

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46. The CDM (Compact Doppler Magnetograph) for Future Space Weather and Deep Space Missions
Don Hassler, SwRI
The Compact Doppler Magnetograph (CDM) is a space-qualified, miniaturized Doppler magnetograph, designed to provide photospheric line-of-sight magnetic field and Doppler velocity measurements of the solar surface. CDM is derived from the proven GONG (Global Oscillations Network Group) instrument design (Harvey et al., 1988, 1996), with a space qualified prototype tailored to the requirements of deep space and space weather missions (Hassler et al., 2020). CDM has roughly 1/3 the mass of current state-of-the-art Doppler magnetographs (e.g., SOHO/MDI, SDO/HMI, SolO/PHI), with greatly increased sensitivity to the magnetic field (B) and Doppler velocity (v). Future solar polar missions and the next generation of space weather observing systems will require taking new observations from vantage points far outside of both the ecliptic plane and the Sun-Earth line. Observing platforms from these vantage points will have significant Size, Weight and Power (SWaP) limitations, requiring miniaturized instruments tailored for their mission. Ideally, a common set of instruments could be deployed on modest sized spacecraft to remote destinations in the solar system (e.g., Solar Polar orbit, Sun-Earth L4/L5) to improve upon and ultimately provide reliable and continuous coverage over the entire solar sphere. In this regard, CDM is unique since it is the only instrument at TRL 6 that has the combination of low SWaP (Size, Weight & Power) requirements, and ability to meet the measurement requirements of a wide range of future/anticipated, resource constrained, deep space and space weather missions.

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47. Physics-Aware AI for Operational GNSS Resilience Under Space Weather Disturbance
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Space weather disturbances can significantly degrade Global Navigation Satellite System (GNSS) performance through ionospheric irregularities, scintillation, and rapid variations in total electron content, yet many existing scientific products remain difficult to translate into mission-relevant operational risk. We present an initial physics-aware AI/ML framework designed to convert ionospheric disturbance indicators into actionable GNSS resilience metrics for applications including precision agriculture, aviation, maritime navigation, and other position, navigation, and timing (PNT)-dependent systems.

The prototype combines physically interpretable inputs, including vertical TEC, TEC gradients, and scintillation-related parameters, with machine-learning models that estimate the likelihood and severity of GNSS degradation. Initial development uses a 12-month synthetic dataset to establish a transparent minimum viable framework and compare baseline methods, including logistic regression and random forest, with planned testing and refinement using observational data from Solar Cycle 25, including disturbed intervals, to evaluate model performance under real operational space weather conditions.

The framework is intended to move beyond black-box prediction by preserving the connection between geophysical drivers and operational outcomes. We describe the model architecture, feature engineering, and initial validation strategy, together with a roadmap toward multi-receiver spatial analysis, independent validation, and integration with real-time data streams. This work aims to help bridge the gap between ionospheric science and operational decision support by developing mission-specific risk products for end users affected by space weather impacts on satellite navigation.

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48. Solar Wind Measurements from an L1 Swarm: Enabling Space Weather Cal/Val and New Research

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The recently launched IMAP and SOLAR-1 (formerly: SWFO-L1) satellites are now at the Sun-Earth Lagrange 1 (L1) point having joined four earlier missions: ACE, Aditya-L1, DSCOVR, and Wind. Measuring the solar wind's plasma variables, its higher-energy particle populations, and the IMF from a 'swarm' of six platforms is unprecedented. The temporal overlap of the missions will last only a few months, but it will give us a more complete view of structures ranging from CMEs to switchbacks, waves, and turbulence. Understanding and modeling the spatiotemporal complexity of the upstream solar wind is expected to have benefits for optimizing the drivers of geospace models. Geoeffective structures (e.g. shocks) have direct impacts on space weather events on Earth (e.g., dB/dt variability which drives disturbances of the electric power grid). Partly due to these considerations, the mission lives of legacy spacecraft were recently extended to the end of 2026 to facilitate basic analysis such as Cal/Val of corresponding datasets as well as innovative research. Recently, detailed comparisons of magnetic-field data were made using IMAP and SOLAR-1 (with a proximity of <1 R_E during the transfer orbit to L1) and other satellites. Similar comparisons are planned for other measurements. To systematize the approach, mission and instrument PIs are working to specify datasets with optimal reference frames, resolutions, and formats before sharing the data with the community. The presentation will summarize these developments.

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49. Space Weather Follow On (SWFO) Products, Archive, and Dissemination at NOAA

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The Space Weather Follow-On (SWFO) project consists of an operational space weather station at the Lagrange L1 point (SWFO-L1 satellite) between Earth and the Sun and NOAA’s first operational (Compact) Coronagraph (CCOR-1) hosted on the GOES-19 spacecraft. SWFO-L1 provides a full complement of solar wind in-situ measurements through the SupraThermal Ion Sensor (STIS), Solar Wind Plasma Sensor (SWiPS), and Magnetometer (MAG) and a second remote sensing coronograph (CCOR-2). Since being declared operational, SWFO-L1 has been renamed Space Weather Observations at L1 to Advance Readiness, or SOLAR-1. The Space Weather Prediction Center (SWPC, part of NOAA’s National Weather Service) will provide real-time operational products and the National Center for Environmental Information (NCEI, part of NOAA’s National Environmental Satellite, Data, and Information Service) will provide retrospective products. We describe here the products, archive, and dissemination for the SWFO observations.

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50. Distributed Sensor Array for Mid-Latitude Ionospheric Characterization

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Geomagnetic and ionospheric disturbances can significantly impact both commercial and military communication systems. These disturbances can be detected and characterized using a distributed network of GNSS receivers, magnetometers, radios, seismometers, accelerometers, and electrometers. The mid-latitude regions are studied far less than the polar and equatorial regions. At the United States Military Academy (USMA) in West Point, NY, a distributed network of GNSS receivers and magnetometers is currently being emplaced in a 3 x 3 km area of the West Point Military Reservation to survey mid-latitude ionospheric and geomagnetic disturbances. Data from the CASES GPS receivers provides insight into total electron content (TEC) variation, amplitude scintillation, and phase scintillation. Two of the three planned CASES receivers have been emplaced and are operational. Ground-based magnetometers will provide data on ground-induced currents, field-aligned currents, and local magnetic disturbances. Ground-based magnetometer stations are currently in the late prototype phase and are pending deployment. Data collected from this network will be used to characterize

the structures and causal pathways of regional ionospheric and geomagnetic disturbances. This data will be used to inform future analysis of expected geomagnetic and solar events recorded from the distributed array system. This poster also presents the theoretically expected magnetometer and GNSS responses to representative space-weather drivers to support future event attribution and analysis. This project aims to use a novel methodology to document the mid-latitudes with a low-cost instrumentation network and a distributed laboratory for future space weather operations at USMA, providing valuable ionosphere data.
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51. Relationship between Pulsations and GICs during the April 2023 Geomagnetic Storm
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Our research focuses on the characteristics of geomagnetic pulsations and their association with geomagnetically induced currents (GICs) during the April 2023 geomagnetic storm using ground-based magnetometers. Geomagnetic storms, substorms, and ultra-low frequency (ULF) waves can drive GICs. Distinct ULF waves have been associated with the foreshock, substorm onset, solar wind pressure pulses, Kelvin-Helmholtz instability and more. The extent to which different magnetic pulsations and broadband ULF signatures influence GIC generation differently remains insufficiently understood. We aim to contribute to the understanding of causes for different magnetic pulsations and their unique relationships to GICs during geomagnetic activity.

Using OMNI, SuperMAG indices, and ground magnetometer data from the CARISMA and the UAF arrays, we examine the cause-effect relationships of geomagnetic pulsations during the April 2023 storm. Power spectra are generated for each station at any time when a power threshold is exceeded. We compare the resulting pulsation spikes to GIC responses, solar wind conditions, and geomagnetic activity indicators. Key findings include:

1. Some pulsations are associated with a strong GIC response but no obvious geomagnetic activity or solar wind changes, potentially indicating localized ULF wave-driven GICs.

2. Solar wind conditions and substorm activity excite pulsations in a broad frequency range; this suggests that using a specific type of pulsation as an indicator of substorm onset during storm time might not be accurate.

3. Peak pulsation power can occur simultaneously at different stations, but power distribution is strongly dependent on magnetic local time.
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