Interdisciplinary Workshop on Climate and Weather Extremes

May 16-18, 2023
Clemson University, Clemson, South Carolina, USA

School of MATHEMATICAL AND STATISTICAL SCIENCES Clemson University

National Science Foundation WHERE DISCOVERIES BEGIN

NISS National Institute of Statistical Sciences

Tuesday, 16 May 2023

8:00–8:30am	Check-In	Madren Hallway
8:30–8:45am	Introduction	BellSouth Auditorium
9:00am–12:00pm	Short Course I	*Toolkit for Extreme Climate Analysis (TECA)*, Instructor: Travis O'Brien, BellSouth Auditorium
12:00–1:30pm	Lunch	Madren Hallway
2:00–5:00pm	Short Course II	*Statistical Analysis of Weather and Climate Extremes*, Instrcutor: Eric Gilleland, BellSouth Auditorium
5:30–7:30pm	Welcome Reception	Madren Hallway

Wednesday, 17 May 2023

8:00–8:30am	Check-In	Madren Hallway
8:30–8:45am	Opening Remarks	BellSouth Auditorium
9:00–10:30am	**Talk Session I**	**Weather Extremes and Risk in a Changing Climate**
	Kenneth Kunkel	*Incorporating Future Climate Change into Rainfall Design Values?*
	Alexis Hoffman	*Climate Risk Analytics and Extremes: Applications in the Private Sector and Areas of Open Research*
	Ryan Sriver	*What are Relevant Climate Uncertainties for Local Impacts and Multi-sector Applications?*
10:30–10:45am	Break	Refreshments will be served

10:45am–12:15pm	**Talk Session II**	**Coastal Risk and Tropical Cyclones**
	Robert Lund	*Changes In North Atlantic Basin Tropical Cyclones*
	Williams Pringle	*U.S. Coastal Flood Hazard Modeling and Risk in a Changing Climate.*
	Thomas Wahl	*Bayesian Hierarchical Modelling for Extreme Sea Level Analysis*
12:15–1:45pm	Lunch	Madren Hallway
1:45–3:15pm	**Discussion Session**	
3:15–3:30pm	Break	Refreshments will be served
3:30–5:00pm	**Talk Session III**	**Multivariate and Compund Extremes**
	Dan Cooley	*Transformed-Linear Methods for Multivariate Extremes and Transformed-Linear Prediction*
	Mihai Anitescu	*Improving Power Grid Resiliency with Multivariate Extreme Modeling and Bi-objective Stochastic Integer Optimization*
	Ben Shaby	*Bayesian Model Averaging for Multivariate Extremes*
5:30–7:30pm	Poster session	Madren Hallway

Thursday, 18 May 2023

8:30–10:00am	**Talk Session IV**	**Big Data Hydrometeorological Extremes/ Detection and Attribution**
	Gabriele Villarini	*A Process-Driven Approach to Projecting Changes in Flooding Across the Contiguous United States*

	Emily Hector	*Distributed Inference for Spatial Extremes Modeling in High Dimensions*
	Michael Wehner	*Is Event Attribution Ready for Loss and Damage Claims?*
10:00–10:15am	Break	Refreshments will be served
10:15–11:45am	**Talk Session V**	**Detection and Attribution**
	Francis Zwiers	*Detection and Attribution of Human Influence on Extreme Precipitation Events*
	Samuel Baugh	*Bayesian Optimal Fingerprinting Methods for the Detection and Attribution of Climate Extremes*
	Richard Smith	*A Conditional Approach to Extreme Event Attribution*
11:45–12:45pm	Lunch	Madren Hallway
12:45–2:15pm	**Discuss Session**	
2:15–2:30pm	Break	Refreshments will be served
2:30am–4:00pm	**Session VI**	**Temperature Extremes**
	Likun Zhang	*Characterizing the Extremal Dependence in Spatial Analysis of 2021 Pacific Northwest Heatwave*
	Mitchell Krock	*Tail Dependence as a Measure of Teleconnected Warm and Cold Extremes of North American Wintertime Temperatures*
	Karen McKinnon	*Heat Extremes in a Warming World*
4:00-4:15pm	Closing remarks and adjourn	

Abstracts

Listed in order of the session schedule.

Session I: Weather Extremes and Risk in a Changing Climate

Kenneth Kunkel
Cooperative Institute for Satellite Earth System Studies, North Carolina State University

Incorporating Future Climate Change into Rainfall Design Values?

NOAA Atlas-14 (NA14) is the standard resource for rainfall design values in the U.S. It consists of a series of volumes by geographic region, developed over the past 20 years. Of central importance for this presentation, it assumes a stationary climate. Because of the high confidence that global warming will result in increases in heavy precipitation, NA14 is inadequate for the design of infrastructure with multi-decadal lifetimes. Indeed, since increases in extreme precipitation have already occurred due to recent global warming, it arguably is inadequate even for shorter-term timeframes. There are plans to develop a new atlas of rainfall design values, to be titled NOAA Atlas 15 (NA15). NA15 will incorporate non-stationarity and will be published as two Volumes. NA15 Volume 1 will provide updated estimates for the entire country using historical data and incorporating historical trends. NA15 Volume 2 will provide estimates for the entire country that incorporate future projections of extreme precipitation from climate models for various scenarios of future global warming. This talk will describe some of scientific and methodological challenges with regard to the development of Volume 2. A reasonable first-order approximation is the application of Clausius-Clapeyron scaling. But, some research suggests super-CC scaling for observed extremes. Furthermore, there is sparse information regarding future changes for hourly and sub-hourly durations. In the absence of such information, is it reasonable to assume that scaling for daily durations can be extended to shorter durations? Another challenge is the requirement to include very long average recurrence intervals (up to 1000 years). Is there any basis to expect that the future changes in the very rare events would be robustly different than shorter ARIs (20-100 yrs) that are likely to have a firmer support in existing datasets?

Alexis Hoffman
Jupiter Intelligence

Climate Risk Analytics and Extremes: Applications in the Private Sector and Areas of Open Research

Climate risk analytics is the quantification of climate risks due to hazards and how those risks are evolving as climate change progresses. In general, the public - and the consumers of climate risk products - are most concerned with extreme events. In this talk, we will walk through a few key pipelines to highlight a few of the challenges we face in applying extreme statistics at scale as well as a few of the open research questions we are trying to answer. If time allows, we can also touch on the applications of our physical climate risk products and discuss some of the challenges we face on the data science team.

Ryan Sriver
University of Ilinois at Urbana-Champaign

What are Relevant Climate Uncertainties for Local Impacts and Multi-sector Applications?

Managing the risks of a changing climate requires accurate, high-resolution climate projections as well as an understanding of the associated uncertainties. Here we analyze how various climate uncertainties can influence local climate impacts projections, utilizing recent statistically downscaled products based on CMIP5 and CMIP6 ensembles. Key sources of uncertainty include: anthropogenic forcing scenarios, internal variability, climate model structure, and downscaling and bias-correction methods. We highlight several examples related to extreme temperature and precipitation, and seasonal fire risk in the western US. Results have broad implications for local impacts assessments and multi-sector applications sensitive to climate and weather hazards.

Session II: Coastal Risk and Tropical Cyclones

Robert Lund
University of California - Santa Cruz

Changes In North Atlantic Basin Tropical Cyclones

This talk investigates changes in the North Atlantic Basin's tropical cyclone record from 1850-current. While most ocean basins in the world are not showing vast changes in tropical cyclone frequencies and/or individual storm strengths, the Atlantic Basin entered a period of very high storm activity circa 1995. Statistically, a multiple changepoint analysis of the Basin's record is conducted. This analysis is based on a penalized likelihood developed from minimum description length information theory principles and Poisson dynamics. Optimizing the penalized likelihood with a genetic algorithm yields estimates of the changepoint numbers and their location time(s). In addition to the 1995 change, some other interesting findings will be presented. Despite the recent increase in storms, we do not find any evidence that the individual storms are getting stronger.

Williams Pringle
Argonne National Laboratory

U.S. Coastal Flood Hazard Modeling and Risk in a Changing Climate

Coastal flood hazard on the Atlantic coast of the United States and projecting how it evolves due to climate change is tricky due the combined considerations of tropical and extratropical cyclone frequency and wind/rain intensity, sea-level rise, and random storm-tide phasing. I will present some of the work we have been doing on the coastal flood problem at Argonne and interesting future directions that we want to take.

Thomas Wahl
University Of Central Florida

Bayesian Hierarchical Modelling for Extreme Sea Level Analysis

Obtaining robust and spatially continuous estimates of extreme sea level return periods along for coastal flood risk assessments and adaptation planning remains a challenge. This is compounded by the complexity of non-stationarity which can stem from changes in mean sea level but also changes in storminess, including changes in the magnitude, frequency, or tracks of tropical and extra-tropical storms causing coastal water levels to rise high above the predicted tide levels. A Bayesian Hierarchical Modelling (BHM) framework proposed by Calafat and Marcos (2020) was used to analyze changes in the storm surge climate across Europe, highlighting that annual maxima surges have increased in certain parts at a pace similar to relative mean sea level rise in the same locations. Leveraging a large ensemble (100 members) of climate simulations combined with data-driven storm surge modelling we quantified the anthropogenic contribution to the storm surge trends. While there is a detectable anthropogenic fingerprint the largest portion of the observed changes likely stems from natural variability exerting influences on extreme storm surge timeseries as long as 60 years or more. Recently, the same BHM was used to obtain spatially continuous return levels, with realistic uncertainty estimates, for the entire U.S. coastline, which can be compared to the results from a hydrodynamic model hindcast and regional frequency analysis which formed the basis for the extreme sea level assessment presented in a U.S. Interagency Task Force Report (Sweet et al., 2022).

Session III: Multivariate and Compund Extremes

Dan Cooley
Colorado State University

Transformed-Linear Methods for Multivariate Extremes and Transformed-Linear Prediction

In this talk, we will introduce transformed linear methods for extremes. By using the tail pairwise dependence matrix (TPDM) in place of the covariance matrix, and by employing transformed linear operations, extreme analogues can be developed for familiar linear statistical methods.
We will focus on performing transformed linear prediction for extremes. The transformed linear prediction equations are similar to the standard linear prediction equations, however uncertainty must be based on the polar geometry underlying regular variation. We will also present the idea of partial tail correlation, and show how it can be used to reduce complexity in a multivariate extremes model.

Mihai Anitescu
Argonne National Laboratory

Improving Power Grid Resiliency with Multivariate Extreme Modeling and Bi-objective Stochastic Integer Optimization

Designing a power grid that is both efficient on average and resilient to extreme weather events is a critical challenge. Multivariate extreme modelling is difficult, and traditional stochastic programming approaches to this are highly sensitive to sampling error due to the presence of low probability events with very high impacts. We present a multivariate extreme modeling approach based on a "bulk-and-tails" approach for the marginal distributions and a copula approach for the joint one integrated within a bi-objective modeling approach that addresses these issues and illustrate it in the context of capacity planning in the electric grid. In particular, our approach allows us to quantify the improvement in the statistical models in terms of the benefit for system resilience, a more impact-relevant metric.

Ben Shaby
Colorado State University

Bayesian Model Averaging for Multivariate Extremes

Model selection for multivariate extreme value analysis presents challenges because the necessarily tiny amount of data available in the far joint tail conveys little information to discriminate between often subtly different dependence models. Here, rather than trying to choose the best from a collection of candidate models, we use the entire library of models and combine the resultant predictions using Bayesian model averaging. We fit the individual models by exploiting the limit set representation of multivariate extremes, wherein observations are scaled to common light-tailed margins and transformed to pseudo-polar coordinates. The large radii are then approximately distributed as truncated gamma, where the scale parameter depends on the so-called gauge function associated with the multivariate model. After fitting all models by standard MCMC, we combine the resultant predictions using stacking weights, which are attractive in this context because they remain valid even when the true data-generating model is not contained in the library.

Session IV:Big Data Hydrometeorological Extremes / Detection and Attribution

Gabriele Villarini
University of Iowa

A Process-Driven Approach to Projecting Changes in Flooding Across the Contiguous United States

Floods affect many aspects of our lives, and our improved understanding of the processes driving the historical changes in this natural hazard can provide basic information to enhance our preparation and mitigation efforts. Here we analyze thousands of long-term streamgages across the contiguous United States and attribute the changes in flood extremes to precipitation and temperature. We then leverage these physical insights to assess the future changes in flooding using outputs from 28 global climate models and four Shared Socioeconomic Pathways part of the Coupled Model Intercomparison Project Phase 6. We find that contiguous United States is projected to experience an overall increase in extreme flooding, more marked for higher emission scenarios. There are also regional differences in the magnitude of these changes, with the Southeast (Great Plains of the North and Southwest) showing higher tendency towards increasing (decreasing) flooding. Moreover, even though trends may not be detected in the historical period, it should not be used as evidence for lack of trends in the future, highlighting the current needs for incorporating climate change in the future infrastructure designs and management of the water resources.

Emily Hector
North Carolina State University

Distributed Inference for Spatial Extremes Modeling in High Dimensions

Extreme environmental events frequently exhibit spatial and temporal dependence. These data are often modeled using max stable processes that are computationally prohibitive to fit for as few as a dozen observations. We propose a spatial partitioning approach based on local modeling of subsets of the spatial domain that delivers computationally and statistically efficient inference. The proposed distributed approach is extended to estimate spatially varying coefficient models to deliver computationally efficient modeling of spatial variation in marginal parameters. We illustrate the flexibility of our approach through simulations and the analysis of streamflow data from the U.S. Geological Survey.

Michael Wehner
Lawrence Berkeley National Laboratory

Is Event Attribution Ready for Loss and Damage Claims?

The recent establishment at the COP27 of a Loss and Damages fund for developing nations begs the question about how to make defensible claims against it if money is ever allocated for it. I will present an argument that certain techniques can provide defensible estimates of the damages caused by climate change for certain types of extreme weather impacts. The extension to climate change impacts experienced by developing nations present significant challenges. It is clear that scientists from those nations must provide their experience and insights into such damage estimates. This task is controversial from both scientific and political perspectives. I invite the attendees to express their opinions.

Session V: Detection and Attribution

Francis Zwiers
Pacific Climate Impacts Consortium

Detection and Attribution of Human Influence on Extreme Precipitation Events

The question of whether human influence on the climate system has affected the frequency and intensity of extreme events can be posed in different ways. This talk considers methods that are used to ask whether there is evidence in observations of precipitation extremes that human-induces changes that are expected to have happened over the industrial era have actually occurred. This question is addressed using so-called detection and attribution (D&A, or fingerprinting) methods that look for the presence of signals derived from historical climate change simulations in long-term observations. Studies using such techniques find essentially unequivocal evidence that humans have altered the frequency and intensity of temperature extremes and find increasingly stronger evidence that humans are also altering the frequency and intensity of extreme precipitation events. D&A techniques can be used in multiple ways. When expected historical change signals are obtained from a multi-model ensemble, the question focuses on whether those signals are present in observations. Results from such studies can be used in some types of extreme event attribution studies, and can also be used to constrain projections of future change. In addition, when expected historical change signals are obtained from individual climate models, D&A results can serve as an aid to model evaluation.

Samuel Baugh
Lawrence Berkeley National Laboratory

Bayesian Optimal Fingerprinting Methods for the Detection and Attribution of Climate Extremes

Optimal fingerprinting techniques facilitate detection and attribution by statistically comparing large-scale patterns of change, estimated from counterfactual simulations, to identify the causal impact of human influences on observed data. Although these methods have been effectively applied to various climate variables, their use in analyzing extremes is less common, as the focus typically lies on assessing the probability of discrete events. In this work, we explore the application of optimal fingerprinting techniques for analyzing changes in extreme probabilities at local spatial scales. By leveraging the extensive spatial structure inherent in the climate system this method achieves more accurate conclusions than when analyzing local areas independently. The hierarchical Bayesian structure of the model facilitates the natural incorporation of multiple sources of uncertainty, including observational error or sparsity, limited climate model runs, and climate model heterogeneity. Through true model validation studies, we demonstrate that the incorporation of these uncertainties generates more reliable credible intervals for detection and attribution parameters.

Richard Smith
University of North Carolina

A Conditional Approach to Extreme Event Attribution

The frequency and intensity of extreme weather events is widely believed to be increasing as a result of human-induced climate change, but quantifying these changes is hard. This research aims to answer three questions, (a) characterizing the probability of an extreme event, (b) how global climate change has affected that probability (the attribution question), (c) how such probabilities will change in the future under various emission scenarios. I use only public data sources: daily temperature and precipitation data from weather stations, regional means from gridded data products, and climate models from CMIP6. I use extreme value theory to analyze how extremes at individual stations and spatially depend on regional climate averages, and develop a Bayesian hierarchical approach to link regional climate averages to climate models. The entire analysis is Bayesian, thus allowing realistic projections of uncertainty as well as estimates of extreme event probabilities. The approach is illustrated using data from three extreme weather events: the British/French heatwave of July 2022, the Northwest USA/Canada heatwave of 2021, and extreme rainfall events in 2017 from Hurricane Harvey. Comparisons are made with other approaches, in particular those from the World Weather Attribution group (https://www.worldweatherattribution.org). This is ongoing work: updated results and datasets are at http://rls.sites.oasis.unc.edu/ClimExt/intro.html.

Session VI: Temperature Extremes

Likun Zhang
University of Missouri

Characterizing the Extremal Dependence in Spatial Analysis of 2021 Pacific Northwest Heatwave

In late June, 2021, a devastating heatwave affected the US Pacific Northwest and western Canada, breaking numerous all-time temperature records by large margins and directly causing hundreds of fatalities. This unprecedented event was unforeseeable even after accounting for anthropogenic climate change, making it impossible to explain its abnormality or quantify the probability of a similar event in the future. Furthermore, the observed 2021 daily maximum temperature across much of the Pacific Northwest exceeded upper bound estimates obtained from single-station temperature records, meaning that the event could not have been predicted under standard univariate extreme value analysis assumptions. In this work, we utilize a flexible spatial extremes model that considers all stations across the Pacific Northwest domain and accounts for the fact that many stations simultaneously experience extreme temperatures. Our analysis incorporates the effects of anthropogenic forcing and natural climate variability in order to better characterize time-varying changes in the distribution of daily temperature extremes. We show that greenhouse gas forcing, drought conditions and large-scale atmospheric modes of variability all have significant impact on summertime maximum temperatures in this region. Nonetheless, while our model represents a significant improvement over corresponding single-station analysis, we are unable to fully anticipate the observed 2021 high temperatures even after properly accounting for extremal dependence, reiterating the uniqueness and unpredictability of the 2021 heatwave in the Pacific Northwest.

Mitchell Krock
Argonne National Laboratory

Tail Dependence as a Measure of Teleconnected Warm and Cold Extremes of North American Wintertime Temperatures

Current models for spatial extremes are concerned with the joint upper (or lower) tail of the distribution at two or more locations. Such models cannot account for teleconnection patterns of two-meter surface air temperature (T2m) in North America, where very low temperatures in the contiguous United States (CONUS) may coincide with very high temperatures in Alaska in the wintertime. This dependence between warm and cold extremes motivates the need for a model with opposite-tail dependence in spatial extremes. This work develops a statistical modeling framework which has flexible behavior in all four pairings of high and low extremes at pairs of locations. In particular, we use a mixture of rotations of common Archimedean copulas to capture various combinations of four-corner tail dependence. We study teleconnected T2m extremes using ERA5 reanalysis of daily average two-meter temperature during the boreal winter. The estimated mixture model quantifies the strength of opposite-tail dependence between warm temperatures in Alaska and cold temperatures in the midlatitudes of North America, as well as the

reverse pattern. These dependence patterns are shown to correspond to blocked and zonal patterns of mid-tropospheric flow. This analysis extends the classical notion of correlation-based teleconnections to considering dependence in higher quantiles.

Karen McKinnon

University of California, Los Angeles

Heat Extremes in a Warming World

The largest negative impacts of climate change typically manifest in response to extreme events. However, the inherently rare nature of extremes raises a number of challenges in their study, including a potentially large role of natural variability and the quantification of the probability of never-before-seen events. Here, we first explore the extent to which observed changes in extreme summertime temperatures in the Northern Hemisphere can be explained by a "shift" in the distribution without changes in shape using quantile regression to allow for non-normality. The vast majority of the observed behavior is explained by the "shift" mode, and climate model ensembles suggest that many of the shape changes are due to sampling of internal variability. We then test this understanding for the recent record-smashing 2021 Pacific Northwest heatwave. Similar to the hemispheric-wide results, there was not evidence in advance of 2021 of significant greater warming of the upper tail compared to the mean, and a comparison to a range of analogs in a climate model large ensemble indicates that the 2021 Pacific Northwest heatwave can occur without the tails shifting more than the mean, although its probability is astonishingly small. Importantly, we find many cases in the climate model where traditional extreme value analysis based on fitting Generalized Extreme Value distributions would fail to predict events as large as simulated.

Posters

- David Lafferty, Department of Atmospheric Sciences, University of Illinois, “Downscaling and bias-correction contribute considerable uncertainty to local climate projections in CMIP6 ”
- Trung Nguyen-Quang, Department of Atmospheric Sciences, “Future intensity-duration-frequency curves of extreme precipitation in the Midwest United States”
- Kenneth Kunkel, Cooperative Institute for Satellite Earth System Studies, North Carolina State University, “How Well Do CMIP6 Models Simulate Heavy Multi-Day Precipitation Events?”
- Reetam Majumder, Department of Statistics, North Carolina State University, “A Deep Learning Synthetic Likelihood Approximation of a Non-stationary Spatial Model for Extreme Streamflow Forecasting”
- John O’Brien, National Center for Atmospheric Research & Lawrence Berkeley National Laboratory, “Title: Quantifying and Understanding Forced Changes to Unforced Modes of Atmospheric Circulation Variability over the North Pacific in a Coupled Model Large Ensemble ”
- Jahangir Ali, Department of Geosciences University of Arkansas, “Temperature forecasts for the continental United States: a deep learning approach using multidimensional features ”
- Pravin Maduwantha, Department of Civil Environmental and Construction Engineering & national center for integrated coastal research, University of Central Florida , “A multivariate statistical framework to derive boundary conditions for compound flood modelling in Gloucester City, NJ ”
- Ariadna Martin, Department of Civil Environmental and Construction Engineering & national center for integrated coastal research, University of Central Florida, “Temporal Clustering of Storm Surges”
- Muyang Shi, Department of Statistics, Colorado State University, “Gaussian Process Emulator for a Flexible Spatial Extreme Value Model”
- Troy Wixson, Department of Statistics, Colorado State University, “Attribution of Seasonal Wildfire Risk to Changes in Climate”
- Elizabeth Lawler, Department of Statistics, Colorado State University, “Anthropogenic and Meteorological Effects on the Occurrence and Size of Moderate and Extreme Wildfires”
- Shalini Mahanthege, Department of Statistics, University of Missouri, “Flexible modeling of multivariate extremes with Bayesian networks”
- Remy MacDonald, Department of Statistics, George Mason University, “Flexible Basis Representations for Modeling High-Dimensional Hierarchical Spatial Data”
- Mohammad Rubaiat Islam, Department of Earth and Atmospheric Sciences, Indiana University Bloomington, “Analyzing the effect of tropical cyclones on atmospheric river statistics and dynamics ”
- Joshua North, Climate and Ecosystem Sciences Division, Lawrence Berkeley, “A flexible class of priors for conducting posterior inference on structured orthonormal matrices”

- Yichan Li, Department of Geosciences, University of Arkansas, “Observational Uncertainty for Global Drought-Pluvial Sequential Events”
- Eva Murphy, School of Mathematical and Statistical Sciences, “Modeling Extreme Wind Speeds by Direction: A Conditional Approach”
- Jiyun Huang, School of Mathematical and Statistical Sciences, “Estimating Precipitation Intensity–Duration–Frequency (IDF) Curves using Large Initial Condition Ensembles”
- Sweta Rai, Department of Applied Mathematics and Statistics, Colorado School of Mines, “Fast parameter estimation of GEV distribution using neural networks”
- Geeta Nain, Department of Earth, Atmospheric, and Planetary Sciences, Purude & Environmental Science Division, Argonne National Laboratory, “Direct flow approach for synthetic tropical cyclone tracks ”
- Jin Hyung Lee, Department of Statistics, George Mason University, “Scalable Variational Method for Hierarchical Spatial Models”
- Kwesi Quagraine, Department of Earth and Atmospheric Science, Indiana University, Bloomington, “Intercomparison Of Atmospheric River Detectors To Analyse Differences In Meteorological Phenomena”
- John Landy, School of Marine and Atmospheric Sciences, Stony Brook University, “Quantifying extreme precipitation associated with atmospheric fronts ”
- Adam Diaz, University of California, San Francisco Brain Health Registry, “The Diablo Winds of Northern California: Exploring the Past and Future of an important Atmospheric Driver of Wildfires”

Organizing Committee

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