PHYSICAL SCIENCES LABORATORY

Physical Sciences Laboratory Publication Report

January through June 2025

48 articles, 1 report, 2 datasets

A list of PSL-affiliated articles, datasets, and reports with abstracts, plain language summaries, or significance statements. Some abstracts have been truncated for space. Listed alphabetically by lead author. PSL-affiliated authors at time of publication in **bold.**

January 2025

Bao, J.-W., E. D. Grell, S. A. Michelson and S.-Y. Hong: Diagnostic Investigation of Two EDMF Planetary Boundary Layer Schemes Used in the GFS Model. *Weather and Forecasting* (40), 93-103, https://doi.org/10.1175/WAF-D-23-0183.1.

> The behavior of two eddy-diffusivity mass-flux (EDMF) planetary boundary layer schemes used in versions 15 and 16 of NOAA's operational Global Forecast System (GFS) is examined in terms of local and nonlocal mixing processes in a one-dimensional (1D) model configuration. Diagnosis using process perturbation sensitivity experiments indicates that the nonlocal mixing represented by the mass-flux term is much more dominant in one scheme than the other. Quantitative aspects of the local eddy diffusivity are different between the two schemes, pointing to uncertainty in the physical partition of local and nonlocal mixing in the EDMF formulation. One of the two schemes is also shown to produce unphysical thermal and tracer tendencies due to the scheme's specific numerical treatment of moist nonlocal mixing. To resolve this problem, a physically and numerically consistent approach is proposed to calculate these tendencies.

Lee, J., A. H. Butler, **J. R. Albers**, Y. Wu and S. H. Lee: Impact of Sudden Stratospheric Warmings on Stratosphere-to-troposphere Transport of Ozone. *Geophys. Res. Lett.*, 52, e2024GL112588, https://doi.org/10.1029/2024GL112588.

> Sudden stratospheric warmings (SSWs) are extreme events which occur every few years in the Arctic stratosphere (the second layer of Earth's atmosphere). SSWs can have a significant impact on weather systems in the troposphere below, and can increase the surface weather predictability for the next several weeks to months. Within the stratosphere lies the ozone layer, and it has been shown that SSWs can affect the transport of ozone into the troposphere. The stratosphere-to-troposphere transport (STT) of ozone can be an important source of ozone near the surface. While ozone is beneficial in the stratosphere, it is harmful near the surface, and can lead to poor air quality, increased mortality and reduced plant production. However, little is known about where and when the impact of SSWs on the STT of ozone occurs. We find significant increases in lower tropospheric ozone both before and after the SSW onset in the extratropics, particularly over the Arctic, North America, and Europe. The influence of SSWs on lower tropospheric ozone concentration lasts up to 2–3 months after the SSW onset.

Oue, M., A. V. Ryzhkov, **S. Y. Matrosov,** P. Bukovčić and P. Kollias: Estimating ice water content for winter storms from millimeter-wavelength radar measurements using a synthesis of polarimetric and dual-frequency radar observations. , 42, 75-90, https://doi.org/10.1175/JTECH-D-23-0143.1.

> [...] Ice water content (IWC) estimation using millimeter-wavelength radar measurements has been challenging for decades, because of the complexity of snow particle properties and size, which can cause complex scattering at the shorter radar wavelengths. The suggested polarimetric techniques overcome this difficulty via utilizing specific differential phase KDP which is higher at millimeter wavelengths than at centimeter wavelengths. This study proposes new IWC relationships for Ka-band polarimetric radar measurements and evaluates them using a Ka-band Scanning Polarimetric Radar (KASPR) and a nearby NEXRAD (S-band) polarimetric radar for the U.S. northeast coast winter storms. The proposed techniques can be applied to other millimeter-wavelength radars and shed light on the millimeter-wavelength polarimetric radar IWC estimation.

February 2025

Agarwal, N., D. E. Amrhein and I. Grooms: Cross-attractor transforms: Improving forecasts by learning optimal maps between dynamical systems and imperfect models. , 52, e2024GL110472, https://doi.org/10.1029/2024GL110472.

> Modeling and forecasting natural systems, such as Earth's oceans and atmosphere, is difficult due to their inherent unpredictability, our incomplete understanding of their dynamics, and their vastness and complexity. One way to improve forecasts is by improving physical representations within numerical models. However, models will always have shortcomings. The alternative approach explored here is to maximize the utility of available imperfect or incomplete models by revising how the model is used and how its forecast is interpreted. Here, we employ machine learning to learn pre- and post-processing operators, called cross-attractor transforms (CATs), which reduce the overall forecast errors from imperfect models. We demonstrate the framework's efficacy by using a simplified dynamical model as an imperfect representation of a higher-dimensional chaotic dynamical system, analogous to using a simple pendulum to forecast the behavior of a double pendulum. In addition to improving forecasts, CATs offer insights into how the two systems evolve in time. The approach is generalizable across dynamical systems and disciplines.

Ahmad, S. V. Kumar, **C. Draper** and R. H. Reichle: Challenges in Unifying Physically Based and Machine Learning Simulations Through Differentiable Modeling: A Land Surface Case Study. *Geophys. Res. Lett.*, 52, e2024GL112893, https://doi.org/10.1029/2024GL112893.

> We test combining traditional land surface models and machine learning to better estimate soil moisture in the U.S. As an example, we use an approach proposed in the literature—differentiable parameter learning—to adapt the parameters of a land surface model to match satellite-observed soil moisture. We found that the approach learns content from external scaling factors more than the model's physical parameters. As a result, when parameters are transferred back to the physical model, the adjusted model cannot capture the full range of soil moisture in both wet and dry conditions. The proposed approach therefore cannot universally be applied to other problems.

Amaya, D. J., N. Maher, C. Deser, **M. G. Jacox**, **M. A. Alexander, M. Newman, J. Dias** and J. Lou: Linking projected changes in seasonal climate predictability and ENSO amplitude. *J. Climate*, 38, 675–688, https://doi.org/10.1175/JCLI-D-23-0648.1.

> Recent studies have shown that potential predictability and actual forecast skill have varied throughout the historical record, primarily due to natural decadal variability. In this study, we explore whether and how potential predictability is projected to change in the future as a distinct response to anthropogenic climate change. We estimate the potential predictability of El Niño–Southern Oscillation (ENSO) as well as global surface temperature, precipitation, and upper-atmospheric circulation anomalies from 1921 to 2100, within a perfect model framework, using five coupled model large ensembles. We find that historical and projected ENSO amplitude changes generate global-scale shifts in climate predictability via ENSO-driven changes in the signal-to-noise ratio of seasonal forecasts, with a 10% change in Niño-3.4 standard deviation leading to a 14% change in globally averaged forecast skill at 12-month lead. This relationship suggests that potential predictability changes across much of the globe in the coming decades could be linked to anthropogenic climate change of ENSO. However, since current models substantially disagree on the sign and intensity of projected ENSO change, the trajectory of future global predictability changes cannot yet be determined. This problem is demonstrated by widely varying predictability changes seen across the five large ensembles, with models exhibiting a robust increase, robust decrease, or no significant change in predictability, depending upon their respective projected ENSO amplitude trends. Our results highlight the need for climate model development aimed at better capturing past forced and unforced changes to ENSO variability, which is necessary (if not sufficient) to constrain projected changes to climate predictability worldwide.

Barrientos-Velasco, C., **C. J. Cox**, H. Deneke, J. B. Dodson, A. Hünerbein, **M. D. Shupe**, P. C. Taylor and A. Macke: Estimation of the radiation budget during MOSAiC based on ground-based and satellite remote sensing observations. *Atmos. Chem. Phys.*, 25, 3929-3960, https://doi.org/10.5194/acp-25-3929-2025

An accurate representation of the radiation budget is essential for investigating the impact of clouds on the climate system, especially in the Arctic, an environment highly sensitive to complex and rapid environmental changes. In this study, we analyse a unique dataset of observations from the central Arctic made during the MOSAiC (Multidisciplinary drifting Observatory for the Study of Arctic Climate) expedition in conjunction with state-of-the-art satellite products from CERES (Clouds and the Earth's Radiant Energy System) to investigate the radiative effect of clouds and radiative closure at the surface and the top of the atmosphere (TOA). We perform a series of radiative transfer simulations using derived cloud macro- and microphysical properties as inputs to the simulations for the entire MOSAiC period, comparing our results to collocated satellite products and ice-floe observations. The radiative closure biases were generally within the instrumental uncertainty, indicating that the simulations are sufficiently accurate to reproduce the radiation budget during MOSAiC. Comparisons of the simulated radiation budget relative to CERES show similar values in the terrestrial flux but relatively large differences in the solar flux, which are attributed to a lower surface albedo and a possible underestimation of atmospheric opacity by CERES. While the simulation results were consistent with the observations, more detailed analyses reveal an overestimation of simulated cloud opacity for cases involving geometrically thick ice clouds. In the annual mean, we found that, during the MOSAiC expedition, the presence of clouds leads to a loss of 5.2 $W\,m^{-2}$ of the atmosphere–surface system to space, while the surface gains 25.0 $W\,m^{-2}$ and the atmosphere is cooled by 30.2 $W\,m^{-2}$.

Barsugli, J. J., et al.: Climate Risk Reduction: Hazards and Processes for Operationalizing Climate Information into ASCE Standards and Manuals of Practice. ASCE-NOAA Summer Workshop Series, https://doi.org/10.25923/0d8c-dw27

In June 2024, the ASCE-NOAA Task Force held a two-day, invitation-only workshop focused on six climate-sensitive hazards of relevance to engineering practice and procedural discussions to accelerate the collaboration of engineering needs and Federal scientific data provision to address the increasing frequency and intensity of extreme weather and climate events. This workshop report is based on material presented in the plenary session and on the outcomes of structured discussions between climate scientists and engineers in breakout sessions during the workshop. Beyond documenting the workshop, the primary purpose of this report is to inform the ASCE-NOAA Task Force when planning its future activities. Additionally, as a public document, those developing climate services for the engineering sector may benefit from this synthesis of the workshop discussions.

Davis, J. R., J. Thomson, I. A. Houghton, **C. W. Fairall, B. J. Butterworth, E. J. Thompson, G. de Boer,** J. D. Doyle and J. R. Moskaitis: Ocean surface wave slopes and wind-wave alignment observed in Hurricane Idalia. *J. Geophys. Res. Oceans*, 130, e2024JC021814, https://doi.org//10.1029/2024JC021814.

Wave slope, or the ratio of a wave's height to its length, is explored in connection to wind and wave characteristics within Hurricane Idalia (2023). Slopes primarily depend on wind speed: waves steepen quickly in low-to-moderate wind conditions, but this rate of increase drops drastically at the high wind speeds found in hurricanes. At a given wind speed, buoy data from Hurricane Idalia reveal a dependence of slope on the relative alignment of the wind and wave directions. Slopes are elevated when the wind blows in the same direction the waves travel and are reduced when the wind blows roughly perpendicular to the waves. Wave slope, particularly of the shorter waves, is related to the roughness of the ocean surface, which is critical to modeling wind surface forcing (or “drag”) in hurricanes. Understanding variations in slope within hurricanes thus helps to inform the prediction models used for hurricane intensity and coastal flooding forecasts.

Dias, J., M. Gehne, G. N. Kiladis, Wolding and **A. Hoell**: Robust Multi-Decadal Variability of Madden-Julian Oscillation Amplitude in the 20th Century. *Geophys. Res. Lett.*, 52, e2024GL113303, https://doi.org/10.1029/2024GL113303.

The Madden-Julian Oscillation (MJO) is a prominent element of intraseasonal (30- to 90-day) variability in the tropical atmosphere that interacts with faster (weather) and slow (climate) atmospheric processes. The goal of this study is to assess our confidence in various aspects of observed MJO multi-decadal variability in light of the drastic changes in the global observing system over the last century. We find robust features, for example, an increase in MJO amplitude from the 1960s to 1990s and a decrease in amplitude thereafter to recent times. Those are in contrast to the larger MJO behavior uncertainties prior to 1960, where sparse and infrequent observations in the tropics limit our ability to clearly identify the MJO.

Frolov, S., K. Garett, I. Jankov, D. Kleist, J. Q. Stewart and J. T. Hoeve: Integration of emerging data-driven models into the NOAA research to operation pipeline for numerical weather prediction. *Bull. Amer. Meteor. Soc.*, 106, E430–E437, https://doi.org/10.1175/BAMS-D-24-0062.1.

To respond to the emergence of the data-driven models for numerical weather prediction, NOAA Research, NOAA's National Weather Service, and NOAA Cooperative Institutes convened a 2-day hybrid workshop in Boulder, Colorado. Participants discussed the following: Opportunities and barriers for incorporating emerging data-driven models into the NOAA research-to-operations pipeline; Pathways for connecting existing NOAA investments in basic research, Earth system observations, and traditional models with new opportunities in data-driven modeling; Partnerships needed within NOAA, private industry, and academia, and; Scope and focus of investment areas required to develop a viable research initiative in data-driven models at NOAA.

Heutte, B., H. Bergner, . . ., **M. D. Shupe**, et al.: Observation of high time-resolution and size-resolved aerosol chemical composition and microphysics in the central Arctic: Implications for climate-relevant particle properties.. *Atmos. Chem. Phys.*, 2207-2241, https://doi.org/10.5194/acp-25-2207-2025.

Aerosols play a critical role in the Arctic's radiative balance, influencing solar radiation and cloud formation. Limited observations in the central Arctic leave gaps in understanding aerosol dynamics year-round, affecting model predictions of climate-relevant aerosol properties. Here, we present the first annual high-time-resolution observations of submicron aerosol chemical composition in the central Arctic during the Arctic Ocean 2018 (AO2018) and the 2019–2020 Multidisciplinary drifting Observatory for the Study of Arctic Climate (MOSAiC) expeditions. Seasonal variations in the aerosol mass concentrations and chemical composition in the central Arctic were found to be driven by typical Arctic seasonal regimes and resemble those of pan-Arctic land-based stations. [...] While the analysis presented herein provides the current central Arctic aerosol baseline, which will serve to improve climate model predictions in the region, it also underscores the importance of integrating short-timescale processes, such as seasonal wind-driven aerosol sources from blowing snow and open leads/ocean in model simulations. This is particularly important, given the decline in mid-latitude anthropogenic emissions and the increase in local ones.

Jung, T., . .., **M. D. Shupe**, . .., T. Uttal, et al. (ONLINE): Year of Polar Prediction (YOPP): Achievements, impacts and lessons learnt. *Bull. Amer. Meteor. Soc.*, https://doi.org/10.1175/BAMS-D-23-0226.1.

The Year of Polar Prediction (YOPP), an international research initiative organized by the World Meteorological Organization's (WMO) World Weather Research Program from 2013–2022, aimed to markedly enhance environmental prediction capabilities in the polar regions and beyond, particularly in the context of a rapidly changing climate. YOPP achieved this through a concerted effort in observation, modeling, verification, user engagement, and educational activities. This article offers a comprehensive overview of YOPP's key outcomes and impacts, using a dual approach that merges qualitative success stories with quantitative metrics. Scientifically, the focus is on the role of polar observations in improving prediction accuracy, enhanced understanding of processes to support model development, advancements in forecast verification, particularly in sea ice prediction, an improved understanding of the interconnections between polar and mid-latitude regions, and effective user engagement. This paper also discusses how these scientific discoveries have been converted into practical applications, emphasizing the route from science to services. Additionally, it summarizes the education, communication, outreach, and coordination efforts employed to maximize YOPP's impact. Finally, the article provides a series of recommendations for future research, informed by the insights gained from YOPP's experiences and recent radical developments in technology.

Smith, K. E., A. S. Gupta, **D. J. Amaya**, J. Benthuysen, M. Burrows, **A. Capotondi**, et al.: Baseline Matters: Challenges and implications of different marine heatwave baselines. *Progress in Oceanography*, 231, 103404, https://doi.org/10.1016/j.pocean.2024.103411.

Xenophyophores are an abundant component of the megafauna in parts of the equatorial and temperate North Pacific, but few records exist of these giant agglutinated foraminifera in northern North Pacific and adjacent waters. Here, we present a preliminary survey of xenophyophores from the bathyal Bering Sea (~3500 m depth) and at abyssal depths (4294–6555 m) adjacent to the Aleutian Trench, based on collected material, mainly fragments, and seafloor images. [...] Our results suggest that xenophyophores are as diverse in the northern North Pacific as they are elsewhere in the Pacific Ocean.

Smith, M. M., N. Fuchs, E. Salganik, D. K. Perovich, I. Raphael, M. Granskog, K. Schulz, **M. D. Shupe** and M. Webster: Formation and fate of freshwater on an ice floe in the Central Arctic. *The Cryosphere*, 19, 619-644, https://doi.org/10.5194/tc-19-619-2025.

The melt of snow and sea ice during the Arctic summer is a significant source of relatively fresh meltwater. The fate of this freshwater, whether in surface melt ponds or thin layers underneath the ice and in leads, impacts atmosphere–ice–ocean interactions and their subsequent coupled evolution. Here, we combine analyses of datasets from the Multidisciplinary drifting Observatory for the Study of Arctic Climate (MOSAiC) expedition (June–July 2020) for a process study on the formation and fate of sea ice freshwater on ice floes in the Central Arctic. Our freshwater budget analyses suggest that a relatively high fraction (58 %) is derived from surface melt. Additionally, the contribution from stored precipitation (snowmelt) outweighs by 5 times the input from in situ summer precipitation (rain). [...] Terms such as the annual sea ice freshwater production and meltwater storage in ponds could be used in future work as diagnostics for global climate and process models. For example, the range of values from the CESM2 climate model roughly encapsulate the observed total freshwater production, while storage in melt ponds is underestimated by about 50 %, suggesting pond drainage terms as a key process for investigation.

Thompson, A. J. , J. A. Hutchings and B. L. Konecky: The 1000-year context of extreme precipitation in the Central United States from a novel blend of observations and climate model simulations. *J. Climate*, 38, 1137-1154, https://doi.org/10.1175/JCLI-D-24-0098.1.

[...] We present a new method aimed at improving estimates of the magnitude and frequency of extreme precipitation. Our method lengthens the time coverage of precipitation data by combining weather station observations with climate model simulations spanning 850–2100 CE. We apply this methodology to a record-breaking rainfall event that occurred in July 2022 in the central United States. Our approach provides a more precise estimate of this event's frequency and demonstrates that the rainfall amount from this event is ~2–4 times more likely to occur in the future relative to the preceding millennium. Our findings can be used to better prepare society and infrastructure for the present and future risks posed by extreme precipitation.

Towler, E., D. Stovern, N. Acharya, M. Abel, W. R. Currier, J. Bellier, **R. Cifelli, K. M. Mahoney,** et al.: Implementing and evaluating National Water Model ensemble streamflow predictions using post-processed precipitation forecasts. *J. Hydrometeor.*, https://doi.org/10.1175/JHM-D-24-0111.1.

[...] The purpose of this study is to implement and evaluate the impact of statistically corrected ensemble weather predictions, with a focus on precipitation, on ensemble streamflow forecasts. Our results for a very wet year in California show improved performance in terms of both precipitation and streamflow, in particular reducing underestimation. This is important because advanced warning of potential heavy precipitation and streamflow is critical to improve society's readiness for adverse weather and water impacts.

Yang, C., . .., **D. J. Amaya**, . .., **L. C. Slivinski**, et al.: Gathering users and developers to shape together the next-generation ocean reanalyses. *Bull. Amer. Meteor. Soc.*, 106, E419–E429, https://doi.org/10.1175/BAMS-D-24-0034.1.

Ocean reanalyses are reconstructions of the past ocean state combining ocean numerical models and Earth observations through data assimilation techniques. As a result of their temporal and spatial consistency and continuity compared to Earth observations only and their high accuracy and quality compared to pure numerical model simulations, ocean reanalysis data are widely used in the scientific community (e.g., ocean and climate process studies) and private sectors (e.g., operational planning, shipping, and fisheries). For almost a decade, the Copernicus Marine Service has provided users with high-quality, regularly extended global and regional ocean reanalyses. The objective of this workshop was to gather the international community to 1) understand the users' needs for ocean reanalyses, 2) identify the strengths and weaknesses of current ocean reanalyses, 3) establish the way forward toward the next generation of ocean reanalyses by improving different aspects of these products to meet users' needs and science ambitions, and 4) improve collaborations within the community.

March 2025

Alexander, M. A., J. D. Scott, **M. G. Jacox, D. J. Amaya** and L. M. Wilczynski: Processes that influence bottom temperatures in the California Current System . *Journal of Geophysical Research: Oceans*, 130, e2024JC021886, https://doi.org/10.1029/2024JC021886.

> Temperature strongly influences marine organisms through their metabolism, growth and behavior, including species that live on or near the bottom, such as shellfish, crabs, and flounder. Although there have been many studies documenting sea surface temperature variability, much less is known about bottom water temperatures due to a lack of observations. Here, we use a recently developed reanalysis, which combines a wide array of observations with a computer model to obtain a fine-scale view of the coastal ocean. We examine processes that influence bottom water temperature along the West Coast of the contiguous United States and Baja California, where the ocean depth is less than 400 m. The temperature near the bottom and at the surface often vary together, especially during winter where the ocean is shallow when storms vertically mix the upper ocean. Deeper in the ocean, vertical movement of the thermocline, where the temperature decreases rapidly with depth, can also generate large bottom water temperature anomalies. Bottom water temperatures are more strongly affected by winds off the Pacific Northwest US coast and ocean processes initiated in the tropics further south. ENSO events have a strong influence on bottom water temperatures in addition to those at the surface.

Chen, T.-C., S. G. Penny, **T. A. Smith** and J. A. Platt: Machine Learned Empirical Numerical Integrator from Simulated Data . *Artificial Intelligence for the Earth Systems (AIES)*, https://doi.org/10.1175/AIES-D-23-0088.1.

> Recently, a number of state-of-the-art surrogate machine learning (ML) models have been designed for global weather and climate prediction, which have been trained using reanalysis data products. Reanalysis data products are constructed using numerical model simulations that combine numerical integration of partial differential equations and parameterization schemes. These products are typically only archived and made available using coarsened spatial and temporal resolutions. This study explores the impact of the numerical generation methods used to produce the training datasets and the temporal resolution of those datasets on machine learning surrogate models. Using the nonlinear vector autoregression (NVAR) machine as an explainable ML technique, simple dynamical systems are emulated with ML models trained on data produced by three classical numerical integration schemes. NVAR is validated as a skillful ML method, capable of producing accurate predictions and, more importantly, reconstructing both the underlying dynamics and the numerical integration scheme used to generate the training data. However, the machine fails to generalize predictions on unseen test data generated by different numerical integration schemes, despite the underlying dynamical system being the same. This result provides a word of caution for the growing field of machine learning emulation of weather and climate dynamics. Furthermore, we illustrate using NVAR that training on temporally coarsened data may increase the required complexity of ML models and potentially introduce new numerical challenges. Finally, we discover that empirical integration schemes with arbitrary time-stepping sizes can be constructed directly from the data, which implies a potential for the development of empirical numerical integration schemes.

Clemens-Sewall, D., **C. J. Cox**, . . ., **P. O. G. Persson**, **M. D. Shup**e and M. Smith: Merged datasets for the Multidisciplinary drifting Observatory for the Study of Arctic Climate (MOSAiC) Central Observatory in the Arctic Ocean (2019-2020) version 2.. Arctic Data Center, Dataset, https://doi.org/10.18739/A2WD3Q35Z

> The Multidisciplinary drifting Observatory for the Study of Arctic Climate (MOSAiC) produced a wealth of observational data along the drift of the R/V Polarstern in the Arctic Ocean from October 2019 to September 2020. These data can further process-level understanding and improvements in models. However, the observational records contain temporal gaps and are provided in different formats. One goal of the MOSAiC Model Forcing Dataset Working Group is to provide consistently-formatted, gap-filled, merged datasets representing the conditions at the MOSAiC Central Observatory (the intensively studied region within a few km of R/V Polarstern) that are suitable for driving models on this spatial domain (e.g., single column models, large eddy simulations, etc). [...] This dataset contains version 2 of these merged datasets, and comprises the variables necessary to force a single column ice model. [...]

Hoell, A., M. L. Breeden, R. P. Worsnop and **R. Robinson** (ONLINE): An Unexpected Outcome Followed an Apparent Seasonal Forecast of Opportunity and Prolonged Drought in Southwest Asia. *Int. J. Climatol.*, e8851, https://doi.org/10.1002/joc.8851.

> Despite forecasts to the contrary, Southwest Asia precipitation was unexpectedly below normal in October–December 2023, which extended an ongoing three-year drought that was responsible for water shortages and acute food insecurity. Expectations for above-normal precipitation in this season were based on predictions made the prior September from initialized forecast systems, which indicated a greater than 60% chance of such an occurrence. Confident above-normal precipitation predictions, making October–December 2023 an apparent forecast of opportunity, were due to attendant El Niño and positive Indian Ocean Dipole (PIOD) events. An ensemble of model simulations during 1991–2020 indicates that the simultaneous behaviour of these two phenomena is related to the tropical forcing of the mid-latitude circulation over Asia resembling a Gill–Matsuno response over India and China, which is associated with precipitation-enhancing low pressure over Southwest Asia. The co-action of these two modes is related to greater chances of above-normal Southwest Asia precipitation than if El Niño were acting alone. Southwest Asia precipitation in October–December 2023 was 13 mm below average (15 percentile) and was principally caused by two periods of protracted dryness that each lasted up to 3 weeks. During 26 November to 14 December, high pressure moved slowly eastward across western Asia at the same time as a strong MJO event moved across the Indian Ocean in its Phases 4 and 5, which are related to below-average Southwest Asia precipitation. Cumulative regional precipitation while the MJO was in Phases 4 and 5 during this period was −6 mm, accounting for 46% of the seasonal precipitation deficit in the region. During 26 October to 19 November, high pressure persisted with very little eastward movement over Southwest Asia while the MJO was weak, which suggests that the precipitation deficit during this time was caused by internal atmospheric variability in the extratropics.

Jenny, A. M., R. A. Houze, Jr, P. LeMonde, **E. J. Thompson**, K. M. Nuñez Ocasio, C. Zhang and T. R. Nathan (ONLINE): Celebrating 50 years since GATE. *Bull. Amer. Meteor. Soc.*, https://doi.org/10.1175/BAMS-D-24-0063.1.

> The Global Atmospheric Research Program (GARP) Atlantic Tropical Experiment (GATE) took place from June to September 1974. It remains the largest field campaign in atmospheric science history. Its 50th anniversary was celebrated at the 104th AMS Annual Meeting in Baltimore on 1 February 2024. The celebration featured a series of events including town halls, sessions, and a luncheon. These events provided a platform for reflection and knowledge sharing among surviving participants and others and highlighted GATE's foundational role in advancing our understanding of tropical meteorology and oceanography. GATE was motivated by the need to address the challenge of global weather forecasting, and its science objectives remain relevant today. The campaign led to discoveries that continue to influence modern thinking about tropical meteorology and oceanography. It also impacted the design and goals of subsequent tropical field studies. This article briefly describes the 50th anniversary celebration, including some of the experiences of the participants, and summarizes seminal findings about tropical convection, the tropical atmospheric boundary layer over the ocean, easterly waves, oceanography, and air–sea interaction—fields where GATE's insights have guided subsequent research.

Kukal, M. and **M. T. Hobbins**: Thirstwaves: Prolonged Periods of Agricultural Exposure to Extreme Atmospheric Evaporative Demand for Water. *Earth*, 13, e2024EF004870, https://doi.org/10.1029/2024EF004870.

> The atmosphere is getting more demanding for water around the world, and this affects water use and farming outcomes. Previously, studies mainly looked at the overall atmospheric demand for water, but little is known about changes in occurrence of very high atmospheric demand for water over consecutive days. In this study, we introduce the idea of "thirstwaves," which are long periods of very high atmospheric demand for water. We looked at these thirstwaves that have occurred during 1981–2021 in the US and analyzed them for how intense and how frequent they were and how many days they lasted. We found that the worst thirstwaves happened in places that do not see the highest demand. Over time, all aspects of these thirstwaves have gotten worse. It has also become much less likely that a growing season will pass without any thirstwaves. These findings suggest that in addition to monitoring overall atmospheric demand for water, it's important to track, measure, and report thirstwaves to those managing agriculture and water resources.

Lisonbee, J., B. Parker, . . ., **M. T. Hobbins, A. Hoell,** . . . and **R. Pulwarty**: Prioritization of Research on Drought Assessment in a Changing Climate. *Earth*, 13, e2024EF005276, https://doi.org/10.1029/2024EF005276.

Drought is a period of abnormally dry weather that impacts water availability. Drought is commonly assessed to determine how abnormal it is, how severe its impacts are, or both. Climate change complicates traditional drought assessments. For example, some climates are becoming drier, making it more difficult to discern when a drought begins or ends. This paper highlights the challenges of assessing drought in a changing climate. It also identifies 10 key research priorities for advancing drought science and improving drought assessments in response to these challenges. These priorities include improving drought indicators to account for climate change; evaluating trends in drought impacts; acknowledging that the climate isn't changing in the same way or at the same rate everywhere, so drought assessments must address regional differences; determining how the underlying causes of drought are changing; exploring how changing precipitation characteristics, such as storm intensity and duration, impact drought; and better distinguishing drought in climates that are trending drier or wetter. We hope this work will improve drought assessments and will lead to better drought risk management, adaptation strategies, and planning.

Long, X., M. Newman, S.-I. Shin, et al.: Evaluating Current Statistical and Dynamical Forecasting Techniques for Seasonal Coastal Sea Level Prediction. *J. Climate*, 38, 1477–1503, https://doi.org/10.1175/JCLI-D-24-0214.1.

[...] Coastal floodings have occurred more frequently in the last few decades, and it is anticipated that the number of such hazardous events will increase. Therefore, accurate and reliable forecasting of coastal water level is becoming increasingly important. This study thoroughly evaluated some current forecast techniques for sea level at two pilot study locations on the U.S. Coast (Charleston, South Carolina, and San Diego, California) and found that those techniques are still not capable to produce usable forecasting of anomalous sea level 3 months in advance, due to model inadequacy. The current generation of forecasting models was not designed for coastal sea level prediction, and we propose a few potential improvements that can potentially advance our capability in coastal sea level and inundation forecasting in the near future.

Rudisill, W. , D. Feldman, **C. J. Cox**, L. Riihimaki and J. Sedlar: Seasonality and Albedo Dependence of Cloud Radiative Forcing in the Upper Colorado River Basin. *J. Geophys. Res. Atmos. 130*, e2024JD042366, https://doi.org/10.1029/2024JD042366.

The impact of clouds on the radiative energy at the Earth's surface in Upper Colorado River Basin is important, but their impact varies across seasons: clouds warm the surface in the winter and cool the surface in the summer. We show that the presence or absence of snow has a major impact on when and how clouds warm or cool the surface. Since less snow is predicted in the future, clouds will cool the surface more than they do now.

Sledd, A., M. D. Shupe, A. Solomon and **C. J. Cox**: Surface energy balance responses to radiative forcing in the Central Arctic from MOSAiC and models. *J. Geophys. Res. Atmos. 130*, e2024JD042578, https://doi.org/10.1029/2024JD042578.

Arctic sea ice grows or melts based on whether there is more energy going into it or leaving it. The amount of energy going into the sea ice depends on the atmosphere, and this energy exchange couples the surface below to the atmosphere above. Understanding this coupled relationship is important for accurate weather forecasts in the Arctic. We quantify how extra energy from the atmosphere, such as increased thermal heating from a cloud, is balanced at the surface using observations. During winter, additional energy from the atmosphere is balanced by the surface warming, sea ice growth decreasing, and mixing of the air above the surface. In summer additional energy causes the surface to melt or it moves deeper into the sea ice. Broadly, the different ways that energy is distributed depends on whether or not the sea ice is growing or melting. We use these relationships to test how well seven weather forecast models represent the balance of energy in winter. Most models disagree with the observations, either with how much additional energy is coming from the atmosphere or where the extra energy goes. Recognizing how models diverge from observations can help focus where the models need to be improved.

Slivinski, L. C., J. S. Whitaker, S. Frolov, T. A. Smith and **N. Agarwal**: Assimilating Observed Surface Pressure into ML Weather Prediction Models. *Geophys. Res. Lett.*, 52, e2024GL114396, https://doi.org/10.1029/2024GL114396.

> Recently, machine learning (ML) weather models have gained attention for providing forecasts that are as accurate as state-of-the-art physics-based models, but in a fraction of the time. However, these forecasts require an initial state, which currently comes from a process called “data assimilation” (DA) that combines information from physics-based models and observations. The DA process works because physics-based models can transfer information from scattered, incomplete observations to other locations and variables of interest. In this work, we tested whether ML models can effectively spread out information from sparse observations by assimilating real observations. Our results show that these models do not yet accurately capture the relationships between variables, suggesting that they lack certain key characteristics of physical weather models.

April 2025

Bengtsson, L., S. N. Tulich, J. Dias, B. Wolding, K. J. C. Hall**, M. Gehne, G. N. Kiladis and P. Pegion**: The Crucial Role of the Initial State in MJO prediction. *Geophys. Res. Lett.*, 52, e2025GL115833, https://doi.org/10.1029/2025GL115833.

> The Madden-Julian Oscillation (MJO) is a weather pattern in the tropics that affects rainfall, winds, and predictability on timescales of weeks. Forecasting the MJO is difficult because it depends on complex factors like the atmosphere's initial conditions and small-scale processes not fully captured by models. In this study, we used NOAA's Unified Forecast System to investigate how small differences in initial conditions impact MJO forecasts in the Indo-Pacific region. We compared forecasts that started with two different atmospheric data sets (reanalyses) and found that the strength of the MJO-related winds and circulation differed noticeably and lasted throughout a 15-day forecast. These differences were linked to variations in the atmosphere's initial stability: when the atmosphere was less stable at the start, stronger upward motion and winds developed during the forecast. Interestingly, an index based on convection showed less sensitivity to these initial conditions, meaning that differences in the MJO's wind patterns are not primarily caused by variations in tropical thunderstorms or heating. This highlights the importance of accurately representing atmospheric stability in the models starting conditions for better MJO predictions.

Cox, C. J., J. M. Intrieri, B. J. Butterworth, G. de Boer, M. R. Gallagher, J. Hamilton, E. Hulm, T. Meyers, S. M. Morris, **J. Osborn**, **P. O. G. Persson**, B. Schmatz and **M. D. Shupe**: Observations of surface energy fluxes and meteorology in the seasonally snow-covered high-elevation East River Watershed during SPLASH, 2021-2023. *Earth Sys. Sci. Data*, 17, 1481–1499, https://doi.org/10.5194/essd-17-1481-2025.

> From autumn 2021 through summer 2023, scientists from the National Oceanic and Atmospheric Administration (NOAA) and partners conducted the Study of Precipitation, the Lower Atmosphere, and Surface for Hydrometeorology (SPLASH) campaign in the East River watershed of Colorado. One objective of SPLASH was to observe the transfer of energy between the atmosphere and the surface, which was done at several locations. Two remote sites were chosen that did not have access to power utilities. These were along the valley floor near the East River in the vicinity of the unincorporated town of Gothic, Colorado. Energy balance measurements were made at these locations using autonomous, single-level flux towers referred to as atmospheric surface flux stations (ASFSs). The ASFSs were deployed on 28 September 2021 at the Kettle Ponds Annex site and on 12 October 2021 at the Avery Picnic site and operated until 19 July and 21 June 2023, respectively. Measurements included basic meteorology; upward and downward longwave and shortwave radiative fluxes and subsurface conductive flux, each at 1 min resolution; 3-D winds from a sonic anemometer and from an open-path gas analyzer, both at 20 Hz from which sensible, latent heat, and CO2 fluxes were derived; and profiles of soil properties in the upper 0.5 m (both sites) and temperature profiles through the snow (at Avery Picnic), each reported between 10 min and 6 h. The system uptime was 97 % (Kettle Ponds) and 90 % (Avery Picnic), and collectively 1184 d of data was obtained between the stations. The purpose of this article is to document the ASFS deployment at SPLASH, to document the data acquisition and post-processing of measurements, and to serve as a guide for interested users of the data sets […]

Dahlke, S., A. Rinke, **M. D. Shupe** and **C. J. Cox**: The two Arctic wintertime boundary layer states: Disentangling the role of cloud and wind regimes in reanalysis and observations during MOSAiC. *Atmospheric Science Letters*, 26, e1298, https://doi.org/10.1002/asl.1298.

The wintertime central Arctic atmosphere comprises a radiatively clear and a radiatively opaque state, which are linked to synoptic forcing and mixed-phase clouds. Weather and climate models often lack process representations surrounding these states, but prior work mostly treated the problem as an aggregate of synoptic conditions, resulting in partially overlapping biases. Here, we disaggregate the Arctic states and confront ERA5 reanalysis with observations from the MOSAiC campaign over the central Arctic sea ice during winter 2019/2020. Low-level winds and liquid water path (LWP) are combined to derive different synoptic classes. Results show that the clear state is primarily formed by weak/moderate winds and the absence of liquid-bearing clouds, while strong winds and enhanced LWP primarily form the radiatively opaque state. ERA5 struggles to reproduce these basic statistics, shows too weak sensitivity of thermal radiation to synoptic forcing, and overestimates thermal radiation for similar LWP amounts. The latter is caused by a warm bias, which has a pronounced inversion structure and is largest in clear and calm conditions. Under strong synoptic forcing, the warm bias is constant with height and discrepancies in mixed-phase cloud altitude appear. Separating synoptic conditions is regarded as useful for process-oriented evaluation of the Arctic troposphere in models.

Gichamo, T. Z., **C. Draper** and M. Barlage (ONLINE): Improving NOAA's Global NWP Snow Data Assimilation by Updating to an Ensemble Kalman Filter. *Journal of Hydrology*, 660, Part A, 133301, https://doi.org/10.1016/j.jhydrol.2025.133301.

In an earlier study, we implemented an Optimal Interpolation (OI) for snow data assimilation (DA) in NOAA's NWP system, the Global Forecast System (GFS). This snow depth OI, which is commonly used in NWP, significantly improved snowpack fields, resulting in improved short-range forecasts of near-surface temperature. Within the hydrology community, the Ensemble Kalman Filter (EnKF) is generally favored over simpler methods such as the OI, due largely to its more realistic representation of model errors. Here, we then compare the OI and EnKF assimilation of station snow depth, confirming that the EnKF significantly outperforms the OI. Compared to independent station snow depth observations, the Unbiased Root Mean Square Error (ubRMSE) of 210 mm for the Open Loop (OL) was reduced to 186 mm by the OI and to 161 mm by the EnKF; and the bias were reduced from 65 mm to 29 mm and −7 mm by the OI and the EnKF, respectively. The Normalized Information Contribution (NIC) in terms of RMSE from OI DA was close to 17 % compared to 33 % from EnKF. Snow covered area estimates were also improved by both methods, compared to the Interactive Multisensor Snow and Ice Mapping System (IMS) snow cover data. Model snow depth errors vary considerably in space and time, and investigation of these errors shows that the superior performance of the EnKF is consistent with its ensemble-based model error estimates better capturing this variability. These results suggest NOAA's GFS could benefit from adopting an EnKF snow DA.

Harp, R. D. , et al.: Evaluation of the 2022 West Nile Virus Forecasting Challenge, United States.. *Parasites and Vectors*, 18, 152, https://doi.org/10.1186/s13071-025-06767-2.

West Nile virus (WNV) is the most common cause of mosquito-borne disease in the continental USA, with an average of ~1200 severe, neuroinvasive cases reported annually from 2005 to 2021 (range 386–2873). Despite this burden, efforts to forecast WNV disease to inform public health measures to reduce disease incidence have had limited success. Here, we analyze forecasts submitted to the 2022 WNV Forecasting Challenge, a follow-up to the 2020 WNV Forecasting Challenge. Forecasting teams submitted probabilistic forecasts of annual West Nile virus neuroinvasive disease (WNND) cases for each county in the continental USA for the 2022 WNV season. We assessed the skill of team-specific forecasts, baseline forecasts, and an ensemble created from team-specific forecasts. We then characterized the impact of model characteristics and county-specific contextual factors (e.g., population) on forecast skill. […] The relative success of the ensemble forecast, the best forecast for 2022, suggests potential gains in community ability to forecast WNV, an improvement from the 2020 Challenge. Similar to the previous challenge, however, our results indicate that skill was still limited with general underprediction despite a relative low incidence year. Potential opportunities for improvement include refining mechanistic approaches, integrating additional data sources, and considering different approaches for areas with and without previous cases.

Kiladis, G. N., J. R. Albers and **J. Dias** (ONLINE): Dependence of the Structure of Stratospheric Kelvin and mixed Rossby-gravity Waves on the Basic State Flow. *J. Atmos. Sci.*, https://doi.org/10.1175/JAS-D-24-0243.1.

We examine the structure, scales, and propagation of Kelvin and mixed Rossby-gravity (MRG) waves during extreme phases of the Quasi-Biennial Oscillation (QBO) at 50 hPa using ERA5 reanalysis data. During QBO easterly phases (QBOE), Kelvin wave activity tends to be concentrated over the Eastern Hemisphere, whereas circumglobal, pure zonal wavenumber one through three structures are dominant during the QBO westerly phase (QBOW). Kelvin waves during QBOE are also less equatorially trapped with much wider meridional structures, larger vertical wavelengths and larger upward group velocities than in QBOW. Linear theory provides a valuable guide for explaining at least the qualitative structure and basic state dependence of stratospheric Kelvin waves. In QBOW, MRG waves are characterized by the classical structures predicted by Matsuno (1966), but during QBOE they are highly altered, becoming dominated by low wavenumber, zonally standing structures, with their zonal group speeds approaching zero with respect to the surface. These previously undocumented features become dominant during QBOE flows stronger than -12 m s^{-1} , with purely downward phase propagation along with upward energy dispersion that is readily detectable even in raw data. Their spectral signal has significant power on the eastward inertio-gravity wave (EIG) region, but departs significantly from the classical MRG-EIG dispersion relationship. This behavior can be explained heuristically by consideration of scale dependent damping, such that waves of lower frequency, with smaller vertical wavelengths and upward group velocities, are selectively damped as their zonal phase speeds approach that of the background flow.

Naegele, S, **J. M. Wilczak,** S. J. Greybush, G. S. Young, M. Gervais and J. A. Lee: Analyzing Self-Organizing Maps of Modeled U.S. Coastal Wind Regimes with a Comparison to Observations. *Artificial Intelligence for the Earth Systems (AIES)*, 4, e240023, https://doi.org/10.1175/AIES-D-24-0023.1.

[...] Optimal wind energy utilization requires accurate wind forecasts, which in turn require an understanding of regional wind regimes. Our study used a machine learning method called a self-organizing map to identify the main types of weather regimes that affect offshore wind power for the northeastern U.S. coast: unidirectional flow, confluent/diffluent flow, and nearby pressure systems. In general, a unidirectional wind or a low pressure system north of the domain is a high-wind-speed regime beneficial for offshore wind energy, whereas confluence/diffluence zones or pressure systems within the domain are generally low-wind-speed regimes that are less beneficial for offshore wind energy. Future studies can apply this analysis for regime-based forecasting methods.

Toride, K. , M. Newman, A. Hoell, A. Capotondi, J. Schlör and **D. J. Amaya:** Using Deep Learning to Identify Initial Error Sensitivity of ENSO Forecasts. *Artificial Intelligence for the Earth Systems (AIES)*, 4, e240045, https://doi.org/10.1175/AIES-D-24-0045.1.

[...] This study demonstrates that combining deep learning and a simple analog forecasting method can yield skillful and interpretable El Niño–Southern Oscillation forecasts. A convolutional neural network is used to find critical areas for picking analog members. This is important because it is challenging to explain the decision-making processes of recent deep learning approaches. The developed approach can be applied to various climate predictions.

May 2025

Clark-Wolf, K. , . . ., **J. J. Barsugli**, et al.: Ecological scenarios: embracing ecological uncertainty in an era of global change. *Ecosphere*, 16, e70278, https://doi.org/10.1002/ecs2.70278.

Scenarios, or plausible characterizations of the future, can help natural resource stewards plan and act under uncertainty. Current methods for developing scenarios for climate change adaptation planning are often focused on exploring uncertainties in future climate, but new approaches are needed to better represent uncertainties in ecological responses. Scenarios that characterize how ecological changes may unfold in response to climate and describe divergent and surprising ecological outcomes can help natural resource stewards recognize signs of nascent ecological transformation and identify opportunities to intervene. Here, we offer principles and approaches for more fully integrating ecological uncertainties into the development of future scenarios. We provide examples of how specific qualitative and quantitative methods can be used to explore variation in ecological responses to a given climate future. We further highlight opportunities for ecological researchers to generate actionable projections that capture uncertainty in both climatic and ecological change in meaningful and manageable ways to support climate change adaptation decision making.

Currier, W. R., R. McCrary, **M. Abel**, T. Eidhammer, B. Kruyt, A. Smith, T. Enzminger, **K. M. Mahoney, R. Cifelli** and E. D. Gutmann: End-of-century changes in orographic precipitation with the Intermediate Complexity Atmospheric Research Model over the western United States. *J. Hydrometeor.*, 26, 577–595, https://doi.org/10.1175/JHM-D-24-0071.1.

> [...] A set of global climate model simulations was downscaled using an atmospheric model that contains key physical equations, referred to as Intermediate Complexity Atmospheric Research (ICAR). ICAR was used to examine projected changes in end-of-century cool-season precipitation over mountains in the western United States. Precipitation projections from ICAR were similar to projections that used statistical relationships to downscale climate projections. However, projections differed between ICAR and statistically downscaled datasets in whether they increased, decreased, or stayed the same in specific, hydrologically relevant regions such as the eastern Cascades and high elevation areas of the Upper Colorado River basin. These differences were attributed to the simulation of physical processes in ICAR. The results highlight the importance of kilometer-scale atmospheric processes in regional climate projections.

Grooms, I., **N. Agarwal,** G. Marques, **P. J. Pegion** and H. Yassin: The Stochastic GM+E closure: A framework for coupling stochastic backscatter with the Gent and McWilliams parameterization. *Journal of Advances in Modeling Earth Systems*, 17, e2024MS004560, https://doi.org/10.1029/2024MS004560.

> Models used to simulate global ocean currents often have horizontal resolutions that are too low to see ocean mesoscale eddies, which are to the ocean what weather systems are to the atmosphere. These ocean eddies jostle each other and the larger-scale currents in a chaotic manner, leading to variability on scales that could, in principle, be resolved by ocean models. But since the ocean models don't actually include the eddies themselves, the currents they resolve won't be jostled about realistically unless we enhance the models by adding a realistic description of the effects of the eddies that the models can't see. This paper develops such a description, called a stochastic parameterization. The eddies get their energy by taking some from the larger scales - the ones that the ocean model can resolve - and there is already a well-established representation of how the eddies remove energy from the large scales. The new stochastic parameterization developed here takes some of the energy that the eddies remove from the larger, resolved scales and recycles it back into the simulation in a random fashion that mimics the chaotic action of the unresolved eddies.

Gunnarson, J. L. , . . ., **D. J. Amaya**, et al. (ONLINE): Removing ENSO's influence from SST variability, with insights into the record-setting marine heatwaves of 2023-2024. *Bull. Amer. Meteor. Soc.*, https://doi.org/10.1175/BAMS-D-24-0023.1.

> The El Niño-Southern Oscillation (ENSO) is a dominant driver of seasonal-interannual climate variability and has been linked to record-setting extremes such as marine heatwaves (MHWs). However, quantifying the effects of ENSO on MHW characteristics remains a challenge due to data limitations. Here, we use an ensemble of tropical Pacific "Pacemaker" simulations with a fully-coupled Earth System Model as a testbed for assessing the skill of four empirical methods aimed at isolating ENSO's contribution to monthly SST anomalies including MHW extremes. We then apply the most skillful method to the observational record to determine ENSO's impact on the spatial coverage, intensity and duration of MHWs since 1960 (after removing the background warming trend). We find that the El Niño of 2023-2024 contributed to about half of the global coverage of record-setting MHWs, with the tropical Indian and tropical Atlantic Oceans being most clearly impacted. Our results shed light on the critical role ENSO plays in driving the most severe MHW conditions in the historical record.

Harris, A., **G. A. Wick** and S. Castro: The effect of water vapor and solar zenith angle on oceanic diurnal warming. *Geophys. Res. Lett.*, 52, e2024GL114394, https://doi.org/10.1029/2024GL114394.

> Reliable modeling of the oceanic diurnal warm layer is needed for improved understanding of several geophysical processes, and for analysis of satellite data. To date, obtaining consistent estimates of warming on a global basis has proved challenging. We show that careful accounting for spectral variations in incoming solar energy due to angle and water vapor produces significantly different patterns of warming when compared to a more typical static approach. Comparisons of modeled versus satellite-observed oceanic warming show that the new scheme provides more consistent warming estimates on the basin-scale.

Moore, B. J., **K. M. Mahoney** and **M. Abel** (ONLINE): Extreme wet spells in the Upper Colorado River Basin during the cool season. *J. Hydrometeor.*, https://doi.org/10.1175/JHM-D-24-0125.1.

Multiday periods of precipitation resulting in extreme accumulations can make substantial contributions to cool-season precipitation and snowfall in the Upper Colorado River Basin (UCRB) and, thereby, significantly impact regional water supply. This study conducts a climatological (1981–2023) investigation of these periods, termed extreme wet spells (EWSs), over the UCRB during the cool season (October–April). These spells tend to be long-lasting (> 5 days) and occur most frequently at high elevations in the basin. EWSs can account for appreciable portions (up to 20–30%) of seasonal precipitation and snowfall accumulations in the UCRB, with EWS-related precipitation explaining 65% of the interannual variance in the basin-integrated cool-season precipitation totals. Examination of relationships to four large-scale North Pacific-North America weather regimes reveals that EWSs predominantly occur in the two regimes characterized by an anomalous ridge upstream over the eastern Pacific. Composite analyses conditioned on regime type reveal four distinct synoptic-scale patterns associated with EWSs, each featuring an upper-level trough over the western U.S. In three of the regimes, this trough tends to be associated with anomalous water vapor transport within atmospheric rivers extending into the UCRB from the eastern Pacific. Compared with nonextreme wet spells, EWSs are characterized by more persistent synoptic-scale conditions and by a greater tendency to involve occurrence of multiple upper-level troughs and atmospheric rivers in rapid succession over the western U.S. The persistent conditions during EWSs are related to a tendency for these spells to involve atmospheric blocking.

Pantoya, A., S. R. Simonsen, E. Andrews, R. Burgener, **C. J. Cox**, G. de Boer, B. D. Thomas and N. Hiranuma (May 2025): Multi-seasonal measurements of the ground-level atmospheric ice-nucleating particle abundance on the North Slope of Alaska. *Aerosol Research* (3), 253-270, https://doi.org/10.5194/ar-3-253-2025

Atmospheric ice-nucleating particles (INPs) are an important subset of aerosol particles that are responsible for the heterogeneous formation of ice crystals. INPs modulate the arctic cloud phase (liquid vs. ice), resulting in implications for radiative feedbacks. The number of arctic INP studies investigating specific INP episodes or sources increased recently. However, existing studies are based on short-duration field data, and long-term datasets are lacking. Continuous, long-term measurements are key to determining the abundance and variability of ambient arctic INPs and constraining aerosol–cloud interactions, e.g., to verify and/or improve simulations of mixed-phase clouds. Here, we present a new long-duration INP dataset from the Arctic: 2 years of predominantly immersion-mode INP concentrations (nINP) measured continuously at the National Oceanic and Atmospheric Administration's Barrow Atmospheric Baseline Observatory (BRW) on the North Slope of Alaska. A portable ice nucleation experiment chamber (PINE-03), which simulates adiabatic expansion cooling, was used to directly measure the ground-level INP abundance with an approximately 12 min time resolution from October 2021 to December 2023. We document PINE-03 nINP measurements as well as estimated ice nucleation active surface site density (ns) over a wide range of heterogeneous freezing temperatures from −16 to −31 °C from which we introduce new season-specific parameterizations suitable for modeling mixed-phase clouds. Collocated aerosol and meteorological data were analyzed to assess the correlation between ambient nINP, air mass origin region, and meteorological variability. Our findings suggest (1) very high freezing efficiency of INPs across the measured temperatures (ns ≈ 2×108–1010 m−2 for −16 to −31 °C), which is a factor of 10–1000 times greater efficiency as compared to that found in the previous mid-latitude INP measurements in fall using the same instrument; (2) surprisingly high nINP (≥ 1 L−1 at −25 °C) for the examined temperatures throughout the year that were not measured by PINE-03 at other sites; and (3) high nINP in spring, possibly related to arctic haze episodes. Relatively low concentrations of aerosol surface area and contrasting high-INP concentrations at BRW relative to mid-latitude sites are the possible reasons for the observed high freezing efficiency.

Slinski, K., . .. and **A. Hoell** (ONLINE): In-Situ and Earth Observation Monitoring of Water Availability in West African Rangelands. *Frontiers in Water*, 7, https://doi.org/10.3389/frwa.2025.1320010.

> Rangeland ponds are vital to the livelihoods of pastoral and agropastoral communities in Africa, providing an important source of water for livestock. However, sparse instrumentation across much of Africa makes it extremely challenging to monitor surface water availability in these areas. Model estimates of surface water, for example as used by the Famine Early Warning Systems Network (FEWS NET) Water Point Viewer, are one of the few operational tools available to monitor surface water stress across pastoral areas of the Sahel and East Africa. Water availability data from these models are difficult to validate. New methods using satellite data to classify surface water provide an opportunity to assess the performance of these tools. This study compares water availability estimates derived from Landsat and Sentinel 1 satellite imagery to in situ observations and model simulations of water availability in 22 ephemeral ponds located in the Ferlo region of Senegal. The Active-Passive Water Classification (APWC) algorithm detected surface water at each location. Over 2022 and 2023, water was detected in pond locations annually at a frequency of 68.2% for all ponds and at frequency of 43.8% in ponds with a surface area less than 10,000 square meters (m 2). The APWC results outperform global and continental surface water datasets in the Ferlo region. Seasonal water availability was captured in twelve ponds over the 2022 and 2023 seasons. The twelve locations can function as sentinel ponds to monitor local water availability. Study results demonstrate the viability of satellite methods to assess water availability in the region as well as the challenges to using satellite-based methods to estimate water availability in small ponds.

Stone, Z., . . ., **G. N. Kiladis**, et al. (ONLINE): The organization of tropical east Pacific convection (OTREC) field campaign - five years later. *Bull. Amer. Meteor. Soc.*, https://doi.org/10.1175/BAMS-D-24-0134.1.

> Studying convection, which is one of the least understood physical mechanisms in the tropical atmosphere, is very important for weather and climate predictions of extreme events such as storms, hurricanes, monsoons, floods and hail. Collecting more observations to do so is critical. It is also a challenge. The OTREC (Organization of Tropical East Pacific Convection) field project took place in the summer of 2019. More than thirty scientists and twenty students from the US, Costa Rica, Colombia, México and UK were involved in collecting observations over the ocean (East Pacific and Caribbean) and land (Costa Rica, Colombia). We used the NSF NCAR Gulfstream V airplane to fly at 13 kilometers altitude sampling the tropical atmosphere under diverse weather conditions. The plane was flown in a 'lawnmower' pattern and every 10 minutes deployed dropsondes that measured temperature, wind, humidity and pressure from flight level to the ocean. Similarly, over the land we launched radiosondes, leveraged existing radars and surface meteorological networks across the region, some with co-located Global Positioning System (GPS) receivers and rain sensors, and installed a new surface GPS meteorological network across Costa Rica, culminating in an impressive systematic data set that when assimilated into weather models immediately gave better forecasts. We are now closer than ever in understanding the environmental conditions necessary for convection as well as how convection influences extreme events. The OTREC data set continues to be studied by researchers all over the globe. This article aims to describe the lengthy process that precedes science breakthroughs.

Zhu, Y., W. Han, **M. A. Alexande**r, **S.-I. Shin**, C. Liu and Y. Lyu: Drivers of Low-frequency Variability of Ocean Heat Content on the U.S. Northeast Shelf. *J. Climate*, https://doi.org/0.1175/JCLI-D-24-0279.1.

> The drivers of low-frequency (i.e., interannual to multidecadal) variability and change in the ocean heat content (OHC) on the U.S. North East shelf (USNES) are investigated through heat budget analysis and Regional Ocean Modeling System experiments. Surface heat flux on the USNES has been responsible for warming since 1977, and it dominates the interannual-to-decadal OHC variability in the shallow shelf near the coast. In contrast, remote forcing from the open Atlantic has a weak impact on the warming trend due to contrasting effects from the northern and eastern parts of the Atlantic. Still, it plays a more significant role in interannual-to-decadal OHC variability in the deep shelf near the continental break. Both regional and remote forcings are important for the interannual-to-decadal variability of OHC integrated over the entire USNES. Regionally and remotely forced sea surface temperature (SST) anomalies alter surface heat flux over the USNES, inducing OHC variability. The remotely forced OHC anomalies result primarily from the advection of remotely forced temperature anomalies from the Scotian Shelf and along the shelf break by the currents driven by both regional and remote forcings. Furthermore, the interannual variability of shelfbreak jet significantly contributes to OHC advection through the northern boundary of the USNES. In contrast, the influence of the Gulf Stream on OHC advection across the USNES boundaries is relatively weak.

June 2025

Adler, B., V. Caicedo, **B. J. Butterworth, L. Bianco, C. J. Cox,** G. Boer, E. Gutmann, **J. M. Intrieri**, T. Meyers, J. Sedlar, D. D. Turner and **J. M. Wilczak**: The short life of upvalley wind in a high-altitude mountain valley in the Colorado Rocky Mountains. *JGR: Atmospheres*, 130, e2025JD043455, https://doi.org/10.1029/2025JD043455.

> The wind in mountain valleys typically follows a distinct diurnal cycle that is driven by heating and cooling of lower atmospheric layers with flow being directed up the valley during the day and down the valley during the night. In the high-altitude East River Valley in Colorado's Rocky Mountain, the upvalley (UV) flow stops early in midmorning on the majority of days when snow cover on the ground is low. This unexpected behavior can be explained by a coupling of the flow in the valley with the flow above the surrounding ridges when a deep well-mixed layer forms in the valley in the morning due to solar heating. Depending on the upper-level wind direction relative to the valley axis, upper-level flow is transported downwards and channeled along the valley in downvalley (DV) or UV direction. The frequency distribution of upper-level wind direction favors channeling in DV direction, which explains why days with short UV wind are more frequent. The valley wind patterns play an important role for the transport of water vapor and pollutants along the valley and above the ridges as well as for the formation of clouds.

Cox, C. J.: Aleutian Low-Beaufort Sea Anticyclone (ALBSA) index, 1940-2025. Arctic Data Center, Dataset, https://doi.org/10.18739/A2WP9T85G.

> The Aleutian Low-Beaufort Sea Anticyclone, or "ALBSA", is a daily, 4-point index combining two orthogonal 850 hPa (hectopascal) differences (one meridional, one zonal). Collectively, this captures the variability in the North Pacific/Pacific Arctic tropospheric circulation. The purpose is to track the juxtaposition of the Aleutian Low and Beaufort High pressure centers, specifically the strength/position of the former and the meridional dipole associated with the latter. The utility of the index is its sensitivity to advection events from the North Pacific into the Arctic and how the pattern of circulation steers that advection. It represents the variability of the NPI, and also includes information specific to the advection across Alaska and up through the Bering Strait, and the East Siberian/Chukchi/Beaufort Seas. To date, the index has been used to evaluate interannual variability in the timing of seasonal cryospheric transitions and ecosystem phenology of the North Pacific and Pacific Arctic, as well as subseasonal variability in Bering Sea ice expansion/retreat and aerosol transport events. The first data set in this series was calculated using the ECMWF Reanalysis v5 (ERA5) (see methods) for January 1940 through May 2025. We intend to update the series periodically, approximately annually in June because the index is most useful September through May, to append the most recent year.

Nakamura, H., . . ., **L. C. Slivinski**, et al. (ONLINE): Toward future reanalyses that meet evolving needs in science, public services, policy making and socio-economic activity. *Bull. Amer. Meteor. Soc.*, https://doi.org/10.1175/BAMS-D-25-0126.1.

> The Sixth World Climate Research Programme (WCRP) International Conference on Reanalysis (ICR6) took place in Tokyo from 28 October to 1 November 2024, and brought together reanalysis producers, observation data providers, numerical modelers and members of the user community to discuss progress, applications, challenges and future priorities in the field. The ultimate aim was to guide the development and use of reanalysis data in science, public services, policy making and socio-economic activity.

Stauffer, C. L., I. Tan and **S. Y. Matrosov**: Aerosol and meteorological influences on mixed-phase stratiform clouds at North Slope of Alaska. *Geophys. Res. Lett.*, 52, e2025GL114815, https://doi.org/10.1029/2025GL114815.

> Uncertainties in the estimated surface warming in response to climate change is largely due to uncertainties in Arctic clouds. Arctic clouds can be composed of both liquid and ice water, which change differently in response to climate change. Narrowing uncertainty in the response of changing Arctic clouds to surface warming requires a thorough understanding of the atmospheric properties that influence changes in the total amount of Arctic clouds present as well as the balance between the liquid and ice components of the clouds. As the surface warms, the melt season and anthropogenic activity change which alters the relative importance of different atmospheric properties. Increasing understanding of the basic influences of these properties becomes paramount in narrowing uncertainty in the Earth's response to climate change. This work blends different data sets related to Arctic cloud properties into one common data set with the specific purpose of analyzing the atmospheric characteristics that change these Arctic clouds. We find that a warmer and drier climate will cause a decrease in Arctic cloud amount and their associated water content. Aerosols, from both organic and anthropogenic sources, on the other hand, are essential in understanding the water phases individually, as they influence liquid and ice water differently.