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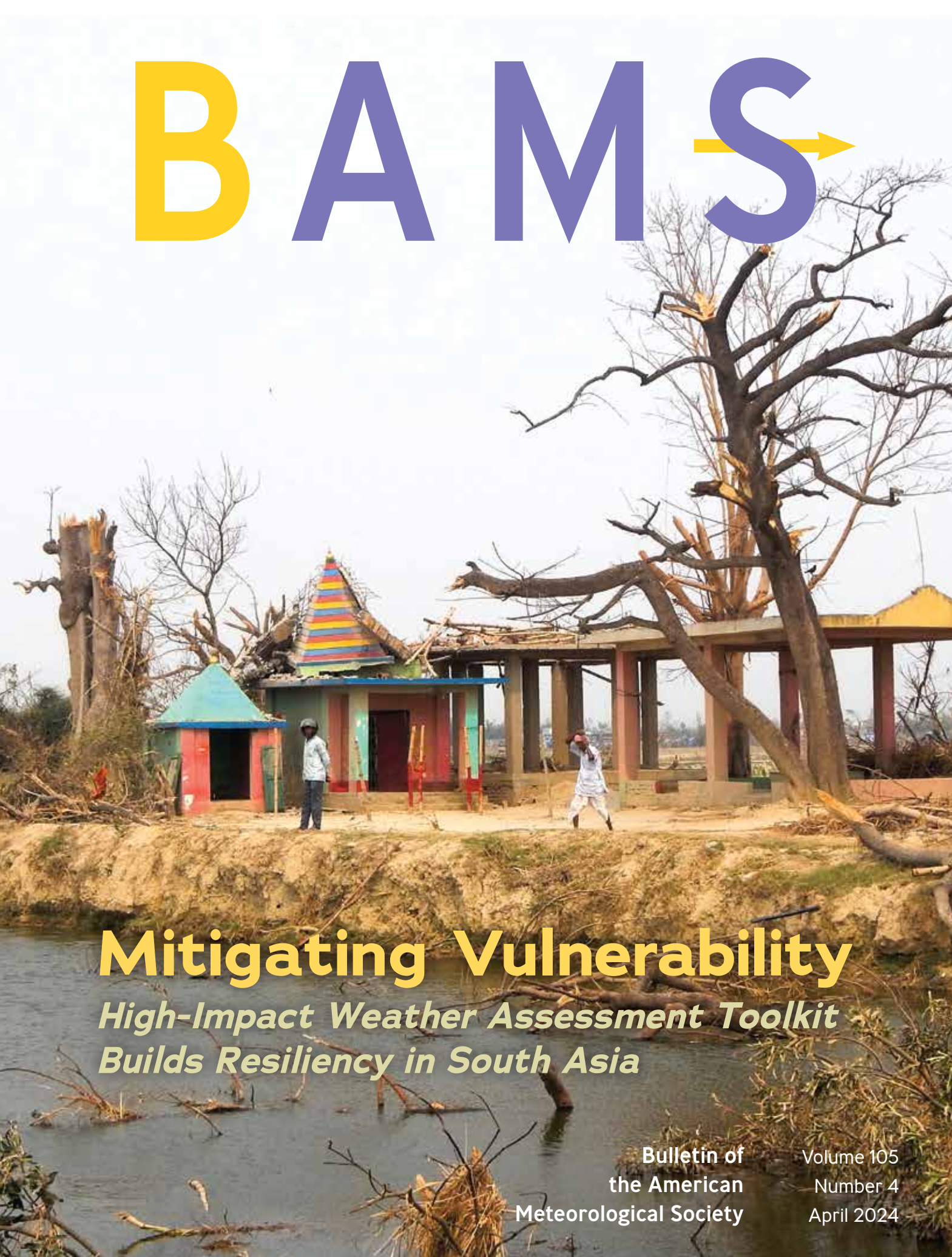

Mitigating Vulnerability

High-Impact Weather Assessment Toolkit Builds Resiliency in South Asia

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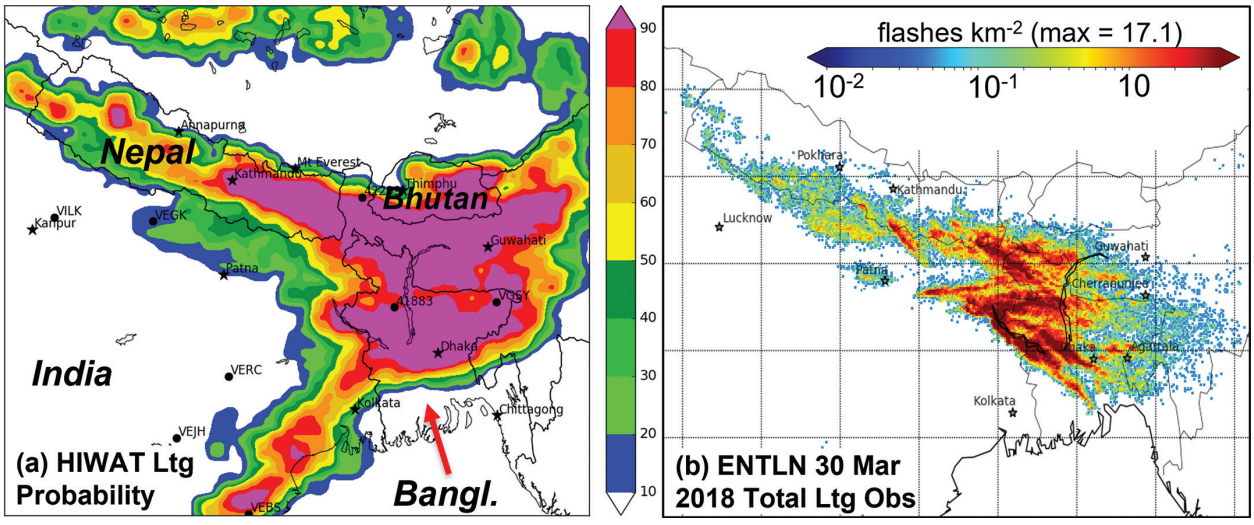
Southern Asia's Intense Thunderstorms

Building Up Resilient Forecasts in the Hindu Kush Himalaya Region

Key messages from "Building Thunderstorm Resilience in the Hindu Kush Himalaya Region through Probabilistic Forecasts and Satellite Observations," by **Jonathan L. Case** (ENSCO, Inc. and NASA Marshall Space Flight Center), **Patrick N. Gatlin**, **Jayanthi Srikishen**, **Bhupesh Adhikary**, **Md. Abdul Mannan**, and **Jordan R. Bell**. Published online in *BAMS*, May 2023. For the full, citable article, see https://doi.org/10.1175/BAMS-D-21-0260.1.

The Hindu Kush Himalaya (HKH) region of South Asia experiences some of the most intense thunderstorms on the planet and has historically been underserved by weather information needed to effectively communicate the hazards they pose. Recently, the High Impact Weather Assessment Toolkit (HIWAT) was designed through NASA's SERVIR program to help improve messaging of the impacts of extreme convectively driven weather events that plague the HKH region during the premonsoon and monsoon months. Our research documents a severe weather forecasting experiment that took place during 2018 and 2019, in which the Bangladesh and Nepal hydrometeorological agencies evaluated HIWAT's ensemble modeling system. The results indicate that a relatively simple configuration of a convection-allowing ensemble system enriches early warning services and enhances situational awareness of convective hazards in the HKH region.

During the experiment, the ensemble model was required to provide two days of real-time probabilistic forecast guidance on convective weather hazards. To accomplish this, a 13-node



(a) Day-1 summary of probability (%) of any lightning occurring within 20 km of a location during forecast hours 1–24, for the Weather Research and Forecasting (WRF) Model ensemble forecast initialized at 1800 UTC 29 March, 2018. (b) Total lightning flashes detected by the Earth Networks Total Lightning Network (ENTLN) during the same time frame of the ensemble probability map, spanning 1800 UTC 29 Mar–1800 UTC 30 Mar 2018. Reference cities/landmarks and sounding sites are denoted by stars and circles, respectively.

computing cluster was launched to run 12 configurations of the Weather Research and Forecasting (WRF) model, each including a convection-allowing nested domain with a different combination of initial conditions and physical parameterizations. Each ensemble member was initialized daily and produced outputs every hour through a 48-h integration time. The 12 simulations combine into various ensemble products that convey confidence in the predicted storm hazards, locations, and timing. They use proxy model fields associated with damaging thunderstorm hazards and set thresholds based on the impact potential. For example, the probability of 10-m wind speeds exceeding 40 kt was used since many shelters in the region cannot withstand such forces. Convective hazard proxies related to storm intensity, lightning activity, large hail, flash flood-producing rainfall, and tornadic activity are produced at each forecast hour. Daily situational awareness products are generated, akin to the Day-1 and Day-2 Convective Outlooks generated by NOAA's Storm Prediction Center for the United States.

A major challenge in validating the HIWAT thunderstorm products is the lack of robust storm reporting in the HKH region. Hence, we relied on damage reports captured by local and regional media as well as collaborators in Nepal, Bangladesh, and India during the forecast experiment. Additionally, satellite-based observations of clouds, precipitation, and lightning were used to assess the forecast convective mode and storm intensity. Additionally, satellite-based land imagery before and after the forecast events helped to verify damage left by the severe weather events.

At least 35 severe weather events were reported across the eastern HKH region during March through May of 2018 and 2019. Only a few of these are highlighted in our study, including a hailstorm on 30 March 2018, that produced hailstones large enough to penetrate metal roofs across northern Bangladesh; a severe windstorm in mid-April 2018 that resulted in numerous fatalities and widespread damage across Kolkata, India, observed firsthand by several coauthors of this paper; and a well-documented but rare EF3-rated tornado in south-central Nepal on 31 March 2019, that left a damage scar along its path clearly visible in low-Earth orbit satellite imagery. In each of these severe thunderstorm events, the HIWAT ensemble's day-1 and day-2 outlooks and hourly hazard proxies correctly depicted the threat of large hail, damaging winds, frequent

lightning, and/or tornadic activity. Also, during the forecast experiment, a category 4 tropical cyclone (Fani) developed in the Bay of Bengal during early May 2019 and tracked inland across eastern India and Bangladesh. The HIWAT ensemble's 10-m wind speed products, which are primarily designed for thunderstorm forecasting, provided novel forecast information about the uncertainty in Cyclone Fani's track and accompanying wind threat as it was forecast to move across Bangladesh. The model correctly predicted the rapid weakening of the cyclone as it crossed Bangladesh.

A more quantitative evaluation of HIWAT's skill in forecasting precipitation and lightning during the 2018–19 experiment for each of the four eastern HKH countries was also conducted. The HIWAT precipitation forecasts exhibit significantly higher skill than NOAA's Global Ensemble Forecasting System, especially during the hours of peak convective activity. The HIWAT ensemble has higher skill predicting daily lightning activity in Bangladesh and India than in Nepal and Bhutan, albeit partially due to sparseness of the lightning sensors in the region during this experiment.

The essential pieces of implementing an ensemble modeling system in historically underserved regions are efficient yet affordable computational resources to provide timely forecast guidance and generating products that are easily digestible by the human-based forecast process. As a result, the Bangladesh Meteorological Department has recently installed the HIWAT ensemble forecasting system on their in-house computing cluster and incorporated the products into their storm warning services. Future verification studies of HIWAT are needed to further refine the critical thresholds used to produce the probability products. However, improvements will be modest until a more robust storm reporting system is in place over the HKH region.

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BAMS: What would you like readers to learn from this article?

Jonathan Case (ENSCO, Inc. and NASA Marshall Space Flight Center): *I would like to see readers be informed on the applicability of established convection-allowing ensemble modeling techniques to historically underserved regions of the world, so that these proven techniques can help increase societal awareness and minimize future casualties associated with severe weather hazards.*

BAMS: How did you become interested in the topic of this article?

JC: *At the time I was attending the University of Oklahoma, some of my colleagues (Daniel Bikos and Jonathan Finch) and I heard about the devastating Bangladesh tornado of 13 May 1996 that killed 600+ people and left thousands homeless. We began thinking about the meteorological and topographical setup of the south-central Asia region, and how it is ideally suited for extreme severe thunderstorms and tornadoes during the premonsoon season, particularly the month of April. That interest never waned over the years, as Finch conducted a comprehensive climatology of tornadoes in Bangladesh and published much of his work to the website, http://www.bangladeshtornadoes.org/. These efforts evolved into publishing our study on examining the near-storm environment associated with significant tornadoes (doi:10.1016/j.atmosres.2015.08.002). A chance to implement it arrived when several coauthors of our* BAMS *paper won a NASA SERVIR Applied Science Team award to establish the HIWAT capability for the SERVIR HKH region.*

BAMS: What surprised you the most about the work you document in this article?

JC: *While originally geared toward just severe thunderstorm hazards, we were pleasantly surprised at the applicability of the probability products to tropical cyclones in the HKH region, which can have enormous impacts there, especially in the low-elevation, densely populated country of Bangladesh.*

BAMS: What was the biggest challenge you encountered while doing this work?

JC: *The biggest challenge was to ensure that the ensemble products ran efficiently and reliably in real time, and that the products could effectively interface with the decision-support tools of the stakeholders. Forecasters in Nepal and Bangladesh came to depend on HIWAT products, which we had agreed to produce in real time for the experiment. So there was definitely pressure to ensure the products were created and delivered in a timely fashion so the forecasters would have them each morning to use in their daily forecasts.*