Weekly Report

RAMMB / CIRA
Cooperative Research Program Division (CoRP)
STAR/NESDIS
National Oceanic and Atmospheric Administration (NOAA)

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Prepared by: RAMMB/CIRA contributors
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Products and Applications

NCODA Derived Ocean products on SLIDER. Galina Chirokova and Kevin Micke implemented on RAMMB-CIRA SLIDER, https://rammb-slider.cira.colostate.edu, updated and new NCODA derived ocean products in GOES projection. The four derived ocean products including sea surface temperature (SST), ocean depth-averaged temperature (Tdy), ocean heat content (OHC), and sea surface salinity (SSS) have been updated with the new color tables and contours to highlight regions where ocean conditions are favorable for tropical cyclone (TC) intensification. SST and OHC are commonly used to estimate ocean effect on TC intensity. Depth-averaged temperature has been shown to be a better metric of ocean-TC interaction compared to commonly used OHC; and SSS has been shown to be important for TC rapid intensification.

As part of the JTTI project, we are testing Tdy in the National Hurricane Center's (NHC) statistical-dynamical TC intensity forecast models as a replacement for OHC. The basin wide version of the ocean products will be provided to NHC and Joint Typhoon Center (JTWC) forecasters for situational awareness. The new color tables were selected to provide the best display of the individual products, and also to allow overlaying ocean products and ocean products and satellite imagery on SLIDER. In addition, the new product, "SST cooling" has been added. SST cooling is calculated as the difference between Tdy and SST and shows the regions where the ocean is susceptible to storm cooling. The updated NCODA products are available in real-time for the GOES-16 area. We also plan to implement these products for GOES-17 and Himawari. (POC: G. Chirokova, Galina.Chirokova@rams.colostate.edu. Funding: JTTI)

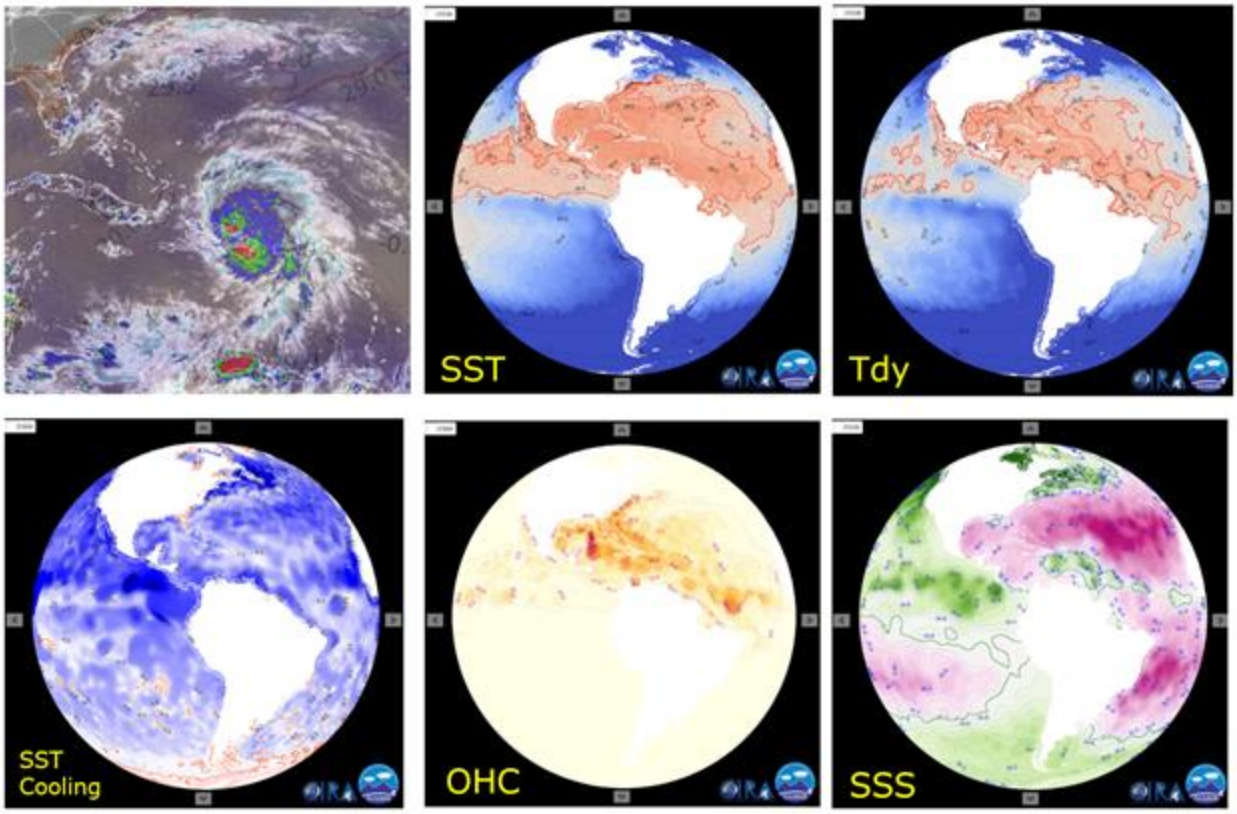
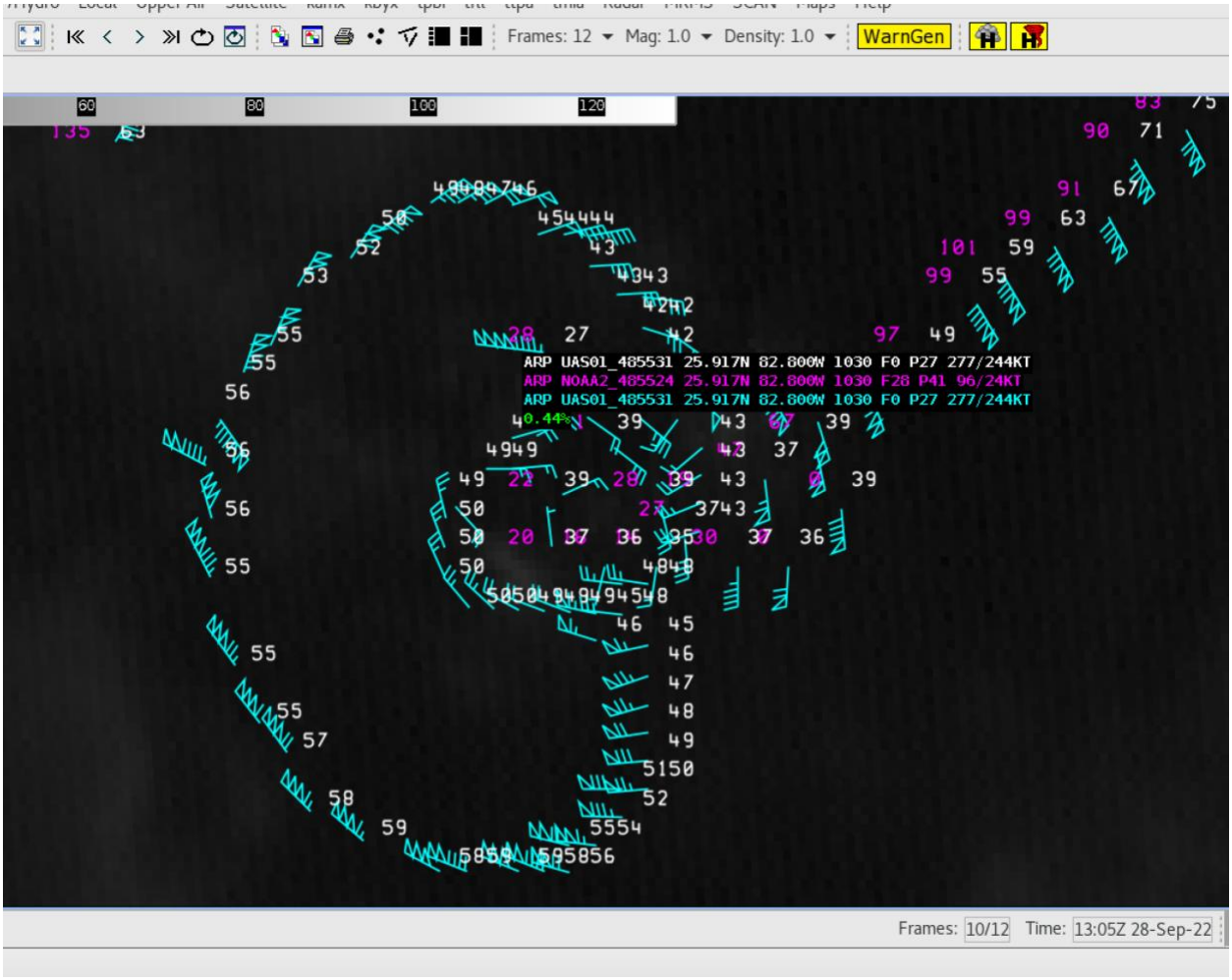


Figure. Ocean displays for TC product suite on SLIDER. Upper left: Hurricane Fiona with IR imagery on the top of SST (red contours) and SST cooling (blue spots). This panel shows that Fiona is over high SST and also over the area where there is little potential for SST cooling, indicating that ocean conditions are favorable for intensification. Upper middle: SST; upper right: depth-averaged temperature (Tdy); lower left – SST cooling (Tdy minus SST); lower middle: OHC; and lower right - SSS.

Experimental small Uncrewed Aircraft System (sUAS) data displayed on the National Hurricane Center Cloud AWIPS during Hurricane Ian. CIRA staff coordinated with the NOAA Hurricane Research Division and National Hurricane Center (NHC) to display experimental sUAS flight level data on NHC's cloud AWIPS system from a mission into Hurricane Ian on September 28th. This was the inaugural mission of a new sUAS and the aircraft performed very well. CIRA's role was to assist with the real time data collection, testing decoders, troubleshooting data format issues and coordinating with NHC on the AWIPS data display. The figure below is a screen capture of the real time flight level data display on NHC's cloud AWIPS. The data is still undergoing evaluation, but has great potential for providing in situ wind observations at low levels not available from other sources, and for calibrating satellite wind estimation techniques. (POCs: Mark DeMaria, Mark.DeMaria@colostate.edu, Alan Brammer, Lixin Lu, Debra Molenar, Kate Musgrave, CIRA), (Funding: HFIP)



Caption: AWIPS display of sUAS flight level winds during Hurricane Ian on 28 September 2022. The new sUAS can fly lower than the NOAA and Air Force Hurricane Hunter aircraft to provide in situ data not previously available.

Awards and Recognition

CIRA's 2022 Research Initiative Awards: Congratulations to CIRA Employees Ryan Lagerquist, Yoo-Jeong Noh, John Haynes, and Curtis Seaman for winning CIRA's 2022 Research Initiative Awards. On 6 October 2022, the award winners gave seminars describing their award-winning research. Noh, Haynes, and Seaman talked about their research titled "Satellite-based 3D Cloud Data: Cloud Base Height Retrieval and User Engagement for Aviation Applications" and Lagerquist talked about "The right tool for the job: Augmenting traditional machine-learning tools for use in weather and climate applications". CIRA Director Steven Miller congratulated the winners. Former CIRA Director Tom Vonder Haar was in the audience. As the Founding Director of CIRA, he initiated this research award many years ago. (POC: R. Brummer, CIRA, Renate.Brummer@colostate.edu). Research Funding Source: NOAA/NESDIS and NSF.

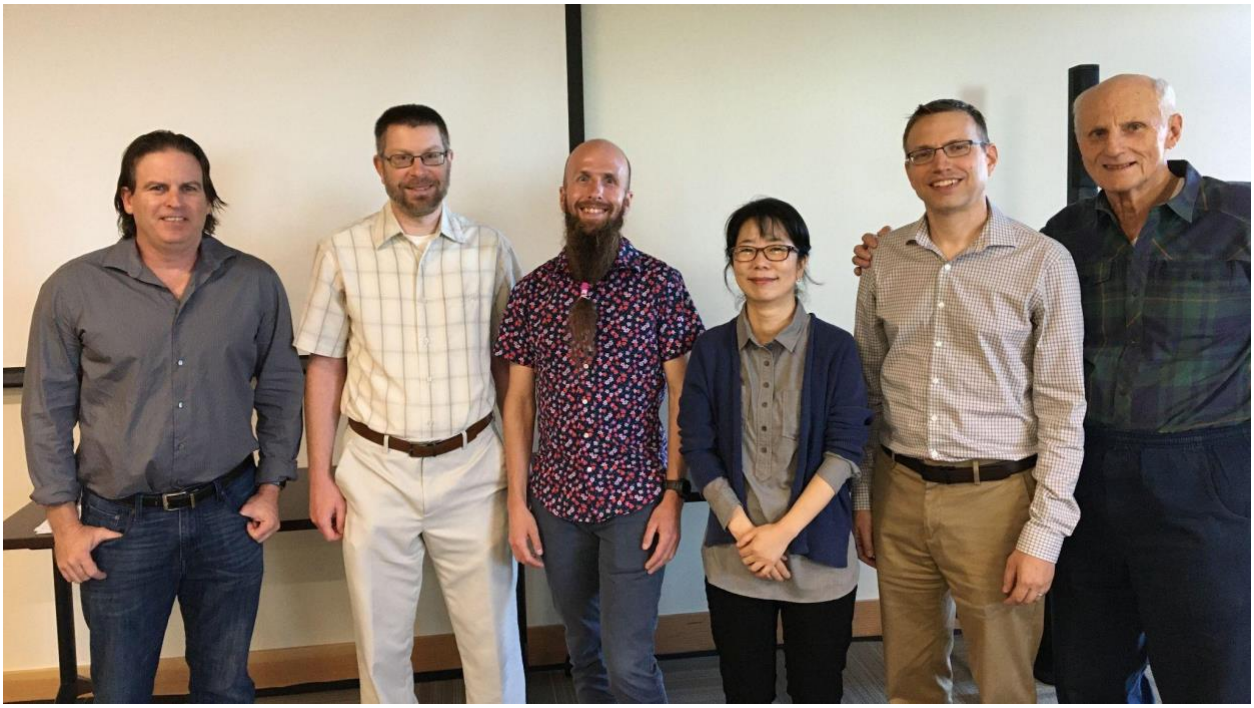


Figure: CIRA Research Initiative Award winners with CIRA Director Steven Miller and former CIRA Director Tom Vonder Haar. From left to right: Steven Miller, Curtis Seaman, Ryan Lagerquist, Yoo-Jeong Noh, John Haynes, Thomas Vonder Haar.

Publications (Citation: followed by a short **Summary:** (Why & so what)**, & detailed summary):**

Citation: Bringas, F., G. J. Goni, I-I Lin, and J. Knaff, 2021: Tropical cyclone heat potential [in "State of the Climate in 2021"]. Bull. Amer. Meteor. Soc., 8, s246–s248. https://doi.org/10.1175/BAMS-D-22-0069.1 **Summary:** This is an annual report, for calendar year 2021, of the state of tropical cyclone heat potential or oceanic heat content defined by the integration from the depth of the 26° isotherm to the ocean surface. This appears as part of *The State of Climate in 2021* published in the September issue of the *Bulletin of the American Meteorological Society*. (POC: John Knaff, John.Knaff@noaa.gov, (970) 279-1611, Funding: PRDA)

Citation: Marinescu, P. J., L. Cucurull, K. Apodaca, L. Bucci, and I. Genkova, 2022: The characterization and impact of Aeolus wind profile observations in NOAA's regional tropical cyclone model (HWRF). Quarterly Journal of the Royal Meteorological Society, 1– 18. Available from: https://doi.org/10.1002/qj.4370. **Summary:** We assess the potential impact of assimilating horizontal wind profile data from the 2018 Aeolus satellite mission in NOAA's operational, tropical cyclone model (HWRF) using observation system experiments of 226 forecasts from 2019 hurricane season. The assimilation of Aeolus observations has the largest, positive impacts for tropical cyclones in the early-development stages and when reconnaissance flight data are not available for assimilation (see figure below). Reconnaissance flight data is typically only available for select, Atlantic-basin tropical cyclones. Assimilating Aeolus observations also results in larger

improvements on tropical cyclone wind structure in the upper troposphere and lower stratosphere, as opposed to near the surface, suggesting that traditionally-used, surface-based verification metrics can overlook the impact of some observation types. POC: Peter Marinescu, peter.marinescu@colostate.edu, Funding: NOAA OAR)

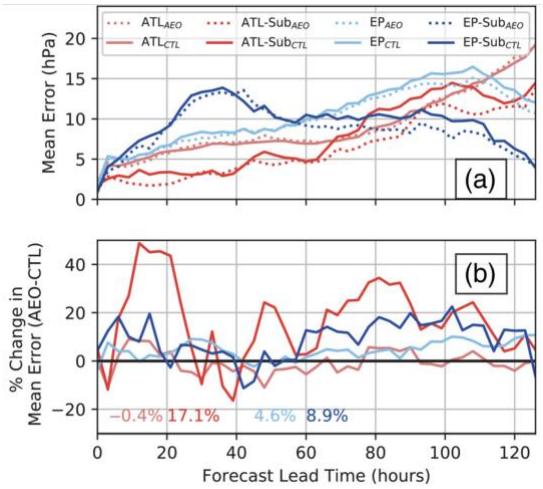


Figure: Comparison of minimum sea level pressure forecasts for the full Atlantic (ATL) and Eastern Pacific (EP) basin samples (light red and light blue) and subsets (Sub) of the full basin samples that only include forecasts with no reconnaissance flight data in the developing tropical storm stages (dark red and dark blue). Results shown as a function of forecast lead time. (a) MSLP errors; (b) percentage improvement in the Aeolus experiment (AEO) with respect to control (CTL), whereby the only difference between AEO and CTL is that AEO included the assimilation of Aeolus observations. Values shown in panel (b) represent the averages over all forecast lead times.

Citation: Lagerquist, R. and I. Ebert-Uphoff, 2022: Can we integrate spatial verification methods into neural-network loss functions for atmospheric science? *Artificial Intelligence for the Earth Systems*, pp. 1-51, early online release, Sept. 2022, https://doi.org/10.1175/AIES-D-22-0021.1.
Short summary: Neural networks in atmospheric science applications almost always use pixel-wise error functions as error metrics for optimization, although we would prefer to use metrics such as those used in spatial verification, since those are truly what we want to optimize. To achieve that goal this article explores different means to integrate spatial verification methods into neural network loss functions. **Detailed summary:** We develop spatially enhanced loss functions (SELF) and demonstrate their use for a real-world problem: predicting the occurrence of thunderstorms (henceforth, "convection") with neural networks (NNs). In each SELF we use either a neighbourhood filter or a spectral filter, employing Fourier or wavelet decomposition. We use these filters to spatially enhance common verification scores, such as the Brier score. We train each NN with a different SELF and compare their performance at many scales of convection, from discrete storm cells to tropical cyclones. Among our many findings are that (a) for a low (high) risk threshold, the ideal SELF focuses on small (large) scales; (b) models trained with a pixelwise loss function perform surprisingly well; (c) however, models trained with a spectral filter produce much better-calibrated probabilities than a pixelwise model. We provide a general guide to using SELFs, including technical challenges and the final Python code, as well as demonstrating their use for the convection problem. To our knowledge this is the most in-depth guide to SELFs in the geosciences. (POC: Ryan Lagerquist, Ryan.Lagerquist@colostate.edu, I. Ebert-Uphoff, iebert@colostate.edu, CIRA. Funding: NOAA-GSL, NSF, CIRA ML strategic funds.)

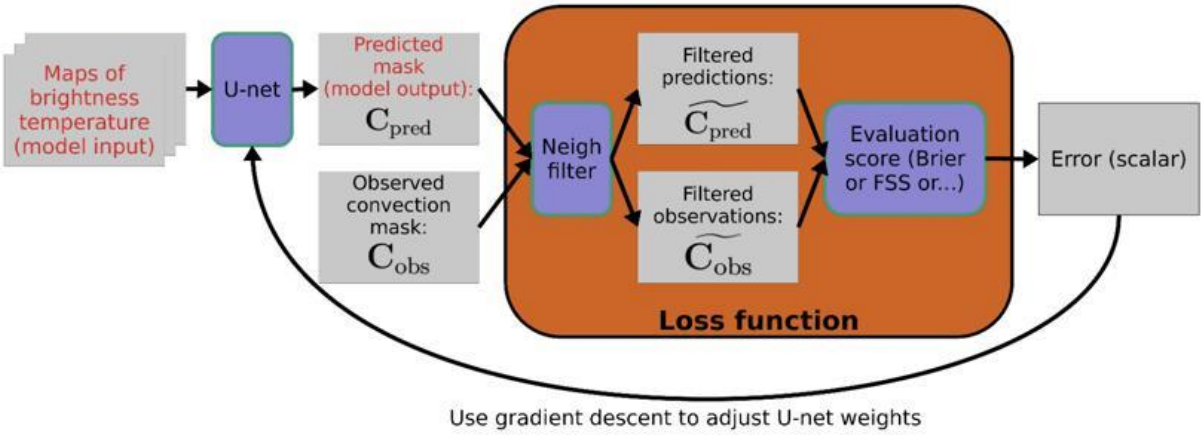


Figure 6 of Lagerquist and Ebert-Uphoff, 2022: Implementation of neighborhood filter inside a loss function.

Citation: Mamalakis, A., E. A. Barnes, and I. Ebert-Uphoff, 2022: Investigating the Fidelity of Explainable Artificial Intelligence Methods for Applications of Convolutional Neural Networks in Geoscience, *Artificial Intelligence for the Earth Systems*, vol 1, issue 4, Sept. 2022, https://doi.org/10.1175/AIES-D-22-0012.1,

Summary: This paper explores strengths and weaknesses of Explainable AI (XAI) methods for geoscience applications. We identify three desired properties of XAI methods that are particularly relevant to geoscience applications, and explore which of the dominant methods satisfy which ones of these properties. We then illustrate how these properties (or the lack thereof) translate into different results from these methods, and, finally, how to properly interpret results from the XAI methods taking their differences into account. The table below lists the XAI methods considered, along with which of three desired properties they satisfy. (POC: I. Ebert-Uphoff, iebert@colostate.edu, CIRA. Funding: NSF.)

XAI method	Brief summary of the method	Desired property for CNN applications as explored in this study			Extra comments/insights
		Disentangles the sign of relevance	Insensitive to gradient shattering	Not ignorant to zero input	
Gradient (Simonyan et al. 2014)	Calculates the first partial derivative of the model output with respect to the input (sensitivity)	✓	×	✓	Estimates the sensitivity of the output to the input, which is not the same as the attribution; see appendix C
Smooth Gradient (Smilkov et al. 2017)	Calculates the average gradient across many perturbed inputs (sensitivity)	✓	×	✓	
Input*Gradient (Shrikumar et al. 2017)	Multiplies the input with the gradient (attribution)	✓	×	×	
Integrated Gradients (Sundararajan et al. 2017)	Multiplies the average gradient along the straight line between the input point and a reference point with the corresponding distance between the two points (attribution)	✓	×	✓	
$LRP_{\alpha 1 \beta 0}$ (Bach et al. 2015)	Layerwise backpropagation of each neuron's relevance based on the $\alpha 1 \beta 0$ rule (attribution)	×	✓	×	Considers only positive preactivations
LRP_{z} (Bach et al. 2015)	Layerwise backpropagation of each neuron's relevance based on the z rule (attribution)	✓	×	×	Equivalent to Input*Gradient for networks using ReLU activations
LRP_{comp} (Kohlbrenner et al. 2020)	Layerwise backpropagation of each neuron's relevance by combining the $\alpha 1 \beta 0$ rule and the z rule (attribution)	✓	✓	×	Combines the strengths of LRP_{z} and $LRP_{\alpha 1 \beta 0}$
$LRP_{comp/flat}$ (Kohlbrenner et al. 2020)	Layerwise backpropagation of each neuron's relevance by combining the $\alpha 1 \beta 0$ rule, the z rule, and the flat rule (attribution)	✓	✓	✓	Provides a coarser picture of attribution; not suitable if local accuracy is necessary
Deep Taylor (Montavon et al. 2017)	Applies Taylor decomposition of the relevance function for each neuron recursively (attribution)	×	✓	×	Equivalent to $LRP_{\alpha 1 \beta 0}$ for networks using ReLU activations; not defined for negative predictions
PatternNet (Kindermans et al. 2018)	Calculates the signal in the input for each neuron recursively (signal)	×	✓	✓	Estimates the signal (not the same as the attribution)
PatternAttribution (Kindermans et al. 2018)	Calculates the attribution in the direction of the signal for each neuron recursively (attribution)	×	✓	✓	
Deep SHAP (Lundberg and Lee 2017)	Approximates Shapley values for each neuron recursively (attribution)	✓	×	✓	Based on well-founded theory; computationally expensive

Table 1 from Mamalakis et al. 2022: Summary of XAI methods considered in this study, including practical strengths (check marks) and weaknesses (crosses) of each method.

Blog Posts and Social Media

Travel, Workshops, Conferences, and Meeting Reports

Training and Education activities

New COMET Banded Snowfall Training Module Features JPSS and LEO products: The COMET training module "Satellite Applications for Winter Weather: Mesoscale Banded Snowfall" has been published at https://www.meted.ucar.edu/education_training/lesson/10139. Intense banded snowfall that occurred over the Central Plains on 15-16 April 2020 is examined from the perspective of how forecasters can use traditional upper air, GOES and numerical models in conjunction with the more recently developed Advected Layer Precipitable Water (ALPW) and Snowfall Rate (SFR) products. ALPW and SFR are derived from passive microwave measurements on Low Earth Orbiting (LEO) satellites. The ALPW product played a key role in identifying and tracking patterns in the moisture field, indicating where the moisture source regions were and how they were moving over time. CIRA Research Associate Sheldon Kusselson assisted with the

analysis. The training is also available at the Commerce Learning Center. (POC: John Forsythe, John.Forsythe@colostate.edu, (970) 491-8589, Funding: JPSS PGRR)

Figure. Home page of the new COMET training module on forecasting mesoscale banded snowfall, showing GOES, radar and ALPW snapshots.

JPSS Webinar with Weather Forecast Office (WFO): J. Torres (CIRA) presented a ***'JPSS Product Applications for NWS Users'*** webinar on 6 October 2022; WFO San Francisco / Monterey, CA attended the webinar. The presentation and discussion covered the following topics: a JPSS overview, highlighted a variety of JPSS applications, showed users how JPSS complements geostationary data, provided how users can access data online and in AWIPS-II, satellite training materials and resources available for NWS users, user feedback on datasets and what to expect from JPSS-2 (i.e., NOAA-21).
(POC: Jorel Torres, Jorel.Torres@colostate.edu, (970) 491-8366, Funding: JPSS)

Future Meetings and Events (dates, meeting/event, location, staff involved)

Investigation of Convective Updrafts (INCUS) Science Team Meeting, 11-13 October 2022, Fort Collins, CO, John Knaff

Other