# NOAA ROSES Semi-Annual Report

**Reporting Period:** **September 2021 – February 2022 (FY21 / Year 2 – 1st half)**

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**Project Scientists:** Jason Apke, Matt Rogers, Galina Chirokova, Dakota Smith

**Project Title**: Advanced Concepts Enabling Situational and Hazards Awareness via Imagery (ACES-HAI)

## Executive Summary

Scientists at CIRA have pioneered the exploitation of the GOES-R series Advance Baseline Imager (ABI) for value-added imagery applications. From design of a 'missing' green band that enables true color imagery, to novel fire temperature products credited with saving lives, to fusion with the GOES Lightning Mapper (GLM) in ways that are now widely emulated, to advanced techniques in Dynamic Enhancement Background Reduction (*DEBRA*) for lofted dust, and the multi-dimensional blending technique that enables *GeoColor* imagery, CIRA's award-winning imagery that is used in circles of research, operational forecasting, and the news media. The objective of this project is to look for the vast array of additional and unexploited capabilities in the realm of imagery/product fusion. This project focuses on the development of novel and innovative approaches that tap into this potential, via a paradigm shift to the *GeoColor* application that pursues the following key, central objectives:

1) Signal encoding of lofted dust and a new short/mid-wave infrared ABI fire product
2) Propagating composite daytime snow cover information into the night
3) Integrating Proxy Vis to enable an advanced low-cloud description at night
4) Incorporating satellite-derived Level-2 products for imagery/product synergy
5) Enabling a 0.5 km, 1-min "mesobox-anywhere, on-demand" via spatial and temporal sharpening

## Special Achievements:

- **Special Achievement:** A paper written by S. Miller et al. with the title **"**A Physical Basis for the Overstatement of Low Clouds at Night by Conventional Satellite Infrared-Based Imaging Radiometer Bi-Spectral Techniques" was published in *Earth and Space Science.*
  **This paper was selected as an AGU Editor's Highlight.** (-> Publications)

- Work continued on the "DEBRA-like approach" to identify hot spots against a cloud-free background. (-> Milestone 1)

- New advancements were made with developing an algorithm for carrying daytime-observed snow fields into the night-side imagery as a layer of information in *GeoColor.* (-> Milestone 2)

- Successful development with solving two issues regarding the integration of Proxy Vis with *GeoColor* are summarized in below. (-> Milestone 3)

- Efforts to bring the Speed Sandwich Optical Flow product to SLIDER were completed this period. (-> Milestone 4)

- Work continued on bring “Mesobox-Anywhere” products to into SLIDER CONUS sectors by Jul 2022. (-> Milestone 5)

- Nine new **NOAA-NASA Earth from Orbit Animations** with CIRA GOES-R imagery were posted during this reporting period.

- **NY Times, Washington Post, CNN, The Guardian, BBC, CBC (New Zealand), ABC, Reuters,** and many other news organizations used CIRA’s GeoColor imagery loops in mid-January 2022 for their **news coverage of the volcanic Hunga Tonga - Hunga Ha’apai Eruption.**

- 4 February 2022**: CIRA’s Geostationary Lightning Mapper/GeoColor imagery used to display “megaflash” lightning records:** The World Meteorological Organization certified two “megaflash” lightning records. For the announcement, NESDIS communications requested an animation to include GeoColor and Global Lightning imagery. “

## Progress toward FY20 Milestones and Relevant Findings

**Significant Milestone Accomplishments during this reporting period are listed below:**

### 1) Cloud-free background for use in the fire detection algorithm

Research conducted by Curtis Seaman

Work continued on the “DEBRA-like approach” to identify hot spots against a cloud-free background. The goal is to develop a stable, cloud-free background surface in the shortwave and midwave IR bands to compare current observations against. During this period, we explored several options for the development of the cloud-free backgrounds.

As stated in the previous report, the original method attempted utilized the warmest longwave IR pixel for each image collected over a two-week period, and used this as a proxy for cloud-free conditions. This resulted in two primary issues: the warmest pixel over a given two-week period may already contain fires and, under certain conditions, boundary layer clouds/fog may have cloud top temperatures warmer than the surface and, hence, the resulting composite would not be cloud-free.

A long-used alternate approach is to take the darkest (or better, the second darkest) pixel from the red-wavelength visible band and assume these pixels are cloud-free. This has the benefit of removing nearly all clouds; however, this method often retrieves cloud shadows. In fact, it was found during this period that, even taking the fourth darkest pixel over a two-week period, the background would retain a few cloud shadows while also retaining a significant amount of cloud cover. The presence of cloud shadows would cause a significant amount of false alarms, as the difference in reflectance between a cloud-free (and cloud shadow-free!) current pixel compared against a background containing cloud shadows is similar to the reflectance increase caused by the fires themselves.

We also explored using ABI Bands 5 & 6 as the reference band, and taking the second darkest Band 5 (or Band 6) pixel and assuming these pixels are cloud-free with little success. Another compounding factor is the fact that Bands 5 & 6 are sensitive to soil moisture, and recent rains may cause a sudden decrease in surface reflectance between 10-20%. The alternative approach we have arrived at is what we are referring to as the “brightest of the darkest” approach. For images near solar noon each day, we identify the darkest pixel in each location for each image time over the prior two-week period. (For GOES-16, solar noon crosses the CONUS domain between 1600-2000 UTC.) Then, we identify the brightest pixel at each location for this collection of darkest pixel images over this ~4 hr period. To mitigate the effects of changing solar incidence angles throughout the year, ABI reflectance values are normalized by the cosine of the solar zenith angle first before the compositing. The resulting set of brightest pixels has minimized the amount of cloud cover (due to taking the darkest pixel at each image time) and minimized the amount of cloud shadows (by using only images near solar noon where cloud shadows are inherently minimized and by taking the brightest of these dark pixels). Initial evaluation of this approach shows that it works well for Band 5 (1.6 µm). However, this approach does not fully capture the variability of reflectance in Band 6 (2.25 µm), particularly near sunrise and sunset. It is possible that the apparent reflectance of Band 6 is influenced by changes in surface temperature (as it is closer to the mid-wave IR), or that there are bi-directional reflectance distribution function (BRDF) effects related to changes in the solar angle that are unaccounted for by this approach. We are currently investigating solutions for this issue.

A comparison between the original "second darkest pixel" approach and the "brightest of the darkest" approach for ABI Band 5 may be done by downloading the following animations:
https://io.cira.colostate.edu/s/xiGaPpk5JjSDk37 (2nd Darkest Pixel)
https://io.cira.colostate.edu/s/2XjXPreg9DkCkxx (Brightest of the Darkest)

## 2) Carrying daytime-observed snow fields into the night-side imagery as a layer of information in *GeoColor*

Research conducted by Peter Marinescu and Steve Miller

The goal of this research is to develop a pseudo code for carrying daytime-observed snow fields into the night-side imagery as a layer of information in *GeoColor*.

The proposed approach for the snow layer algorithm is as follows:

- An array of same dimension as the ABI CONUS grid is initialized to floating point zero values. This array will accumulate detection "energy" for the mask → MASK_ACCUM
- Another array of same dimension is initialized to zero, to be used as a spatially-resolved counter → MASK_COUNT
- The binary cloud/snow enhancement (which demarcates snow as white and cloud as yellow) is run if the at-pixel solar zenith angle is below a critical threshold.
- Use the normalized-difference snow index (NDSI), normalized to NDSI_norm, as the energy term, summed up over the course of the mask compilation period.
- This NDSI is suppressed by an ABI 1.38 µm high cloud (e.g., cirrus or optically thick cloud), to reduce contributions to the energy term from large particle ice clouds.
- The number of times a pixel is incremented with NDSI_norm values, a counter is incremented.
- Upon completion of the mask window, MASK = MASK_ACCUM / MASK_COUNT (i.e., an average) for MASK_COUNT > threshold.

During this reporting period, we have continued to develop the snow layer, which is based on the accumulation of the normalized difference snow index (NDSI) during daytime period. More specifically, instead of weighting all the times of the accumulation equally, tests were completed where the more recent times had larger weightings, since they more accurately captured the current state of snow cover (**Fig. 2b**). Additionally, we also removed regions where clouds are detected in the weighting calculation. Therefore, in regions with transient clouds, the snow accumulation focuses on cloud-free time periods and reduces cloud impacts on the detection of snow-covered land regions (**Fig 2c**). Finally, additional case studies were identified to test these advancements in the snow layer algorithm.

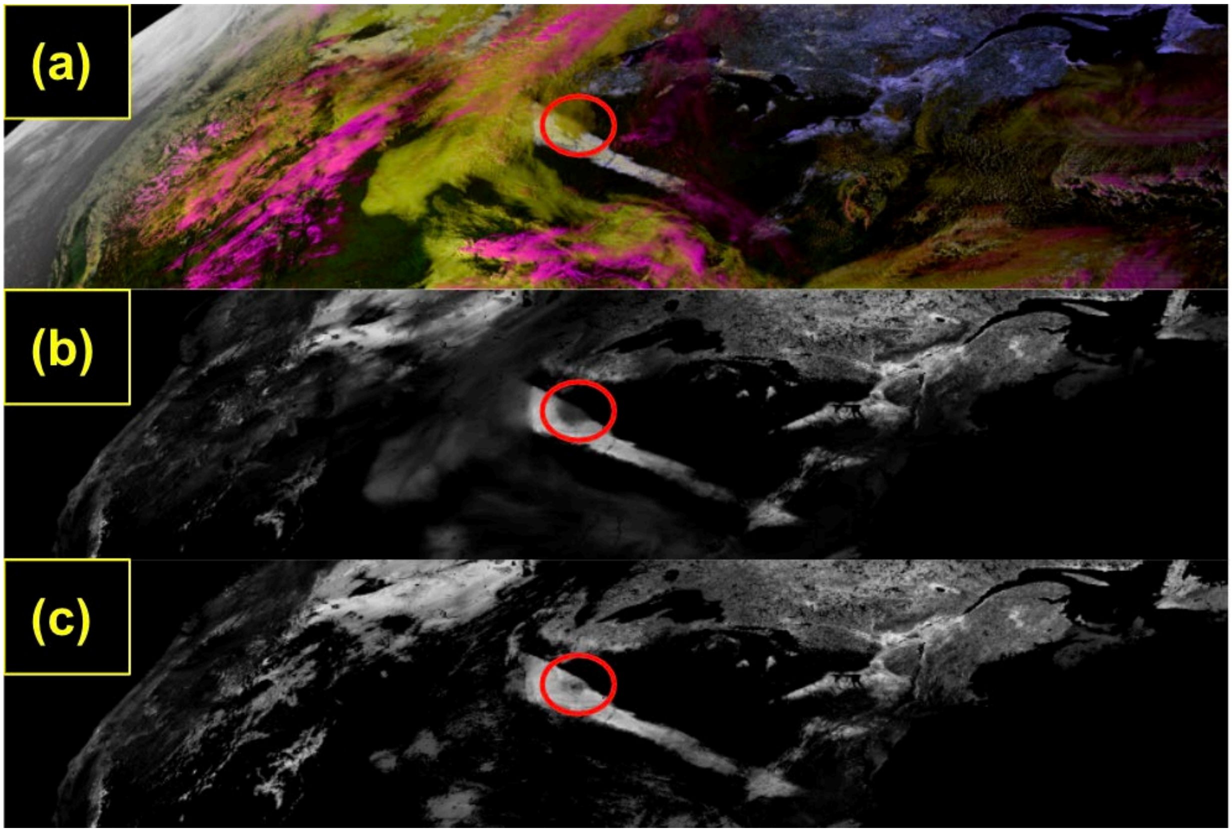



***Figure 2***. *Snow layer maps for March 25, 2018, 20:57 UTC. White and blue regions represent regions with snow cover. (a) represents an instantaneous snapshot of the NDSI snow mask (white, blue) and regions with low clouds (yellow) and high clouds (pink). (b) represents the NDSI-based snow mask, accumulated over a 6-hour period ending at 20:57UTC with the temporal weights linearly increasing from 15:00 to 20:57 UTC. (c) represent the same as (b), but with elimination of cloud regions in the accumulation of snow masks. The red circle marks one region that is improved by the algorithm adjustments described in the text.*

### 3) Integrating Proxy Vis with GeoColor to enable an advanced low-cloud description at night

Research conducted by Steve Miller (CSU/ATS and CIRA) and Galina Chirokova (CIRA)

Work continued on integrating Proxy Vis with *GeoColor* to enable an advanced low-cloud description at night.

Brief task summary:

- This research supports the continued advanced imagery processing techniques, building off the multidimensional blending.
- We develop satellite-based environmental analysis tools via multispectral, model-fusion and temporally-resolved techniques.
- We study cloud detection challenges in the marine boundary layer, and develop novel imagery applications for advanced analysis and situational awareness.

Significant progress was made in the development of a merged (single-code) GeoProxy product. The code merge involved isolating and extracting the most relevant ProxyVis component layer (i.e., the lowest-level component corresponding to low clouds which are often underrepresented or missed entirely in conventional nighttime GeoColor imagery) and converting the Python code to IDL (where the ‘sandbox’ development is occurring). A preliminary comparison to the un-merged code result (where ProxyVis was read in to GeoColor as an independently-produced file) confirmed the correct implementation of the embedded code.

We were successful with re-introducing the conventional nighttime low cloud at night as a layer placed *atop* the ProxyVis layer for GeoProxy and, in addition, we succeeded solving another issue related to the high cloud field being "too blue" compared to original GeoColor high-cloud field. We introduced a ProxyVis suppression factor which allows the high/cold clouds to regain their grayscale with the result that they appear like they currently do in conventional GeoColor. The result is a GeoProxy product with two-tone cloud layers (blue for low cloud, gray scale for high clouds) which can help forecasters analyze areas of low-level circulation vis-à-vis the upper layer cloud motion. The new code was tested on a data set previously used from 22-23 March 2021.

Most of this new GeoProxy work was conducted during March and April 2022. We will therefore provide a detailed report about these significant results in the next semi-annual report (covering our achievements during March – September 2022).

## 4) Incorporating satellite-derived Level-2 products for imagery/product synergy – using Dense Optical Flow

Research conducted by Jason Apke

Efforts to bring the Speed Sandwich product to SLIDER were completed this period. The Speed Sandwich has been produced in near real-time since November 2021 and can be viewed within the GOES mesosectors at https://rammb-slider2.cira.colostate.edu/ (**Fig. 4.1a**). The Speed Sandwich has also been improved significantly since the last report. It now includes a night-time version which blends 3.9 μm imagery with optical flow speed when the solar zenith angle exceeds 85°. Further, the daytime is now blended with a solar-zenith angle normalized reflectance, significantly highlighting important features like deep convection in a variety of lighting scenarios. Also, the original saturation floor has been increased such that all motions produce a color in the imagery to better highlight speeds of dim features such as dust and smoke. Finally, the product includes 5-min median smoothing, which was found to reduce distracting and inaccurate flickers caused by image navigation and registration jitters.

Viewing the Speed Sandwich in real-time with other CIRA-produced imagery and products highlights its value in operational forecasting. The speed sandwich is exceptional at isolating deep convection developing within strong wind speed shear, even within examples of low-topped supercells which do not produce obvious infrared signals (**Figs. 4.1b, c**).

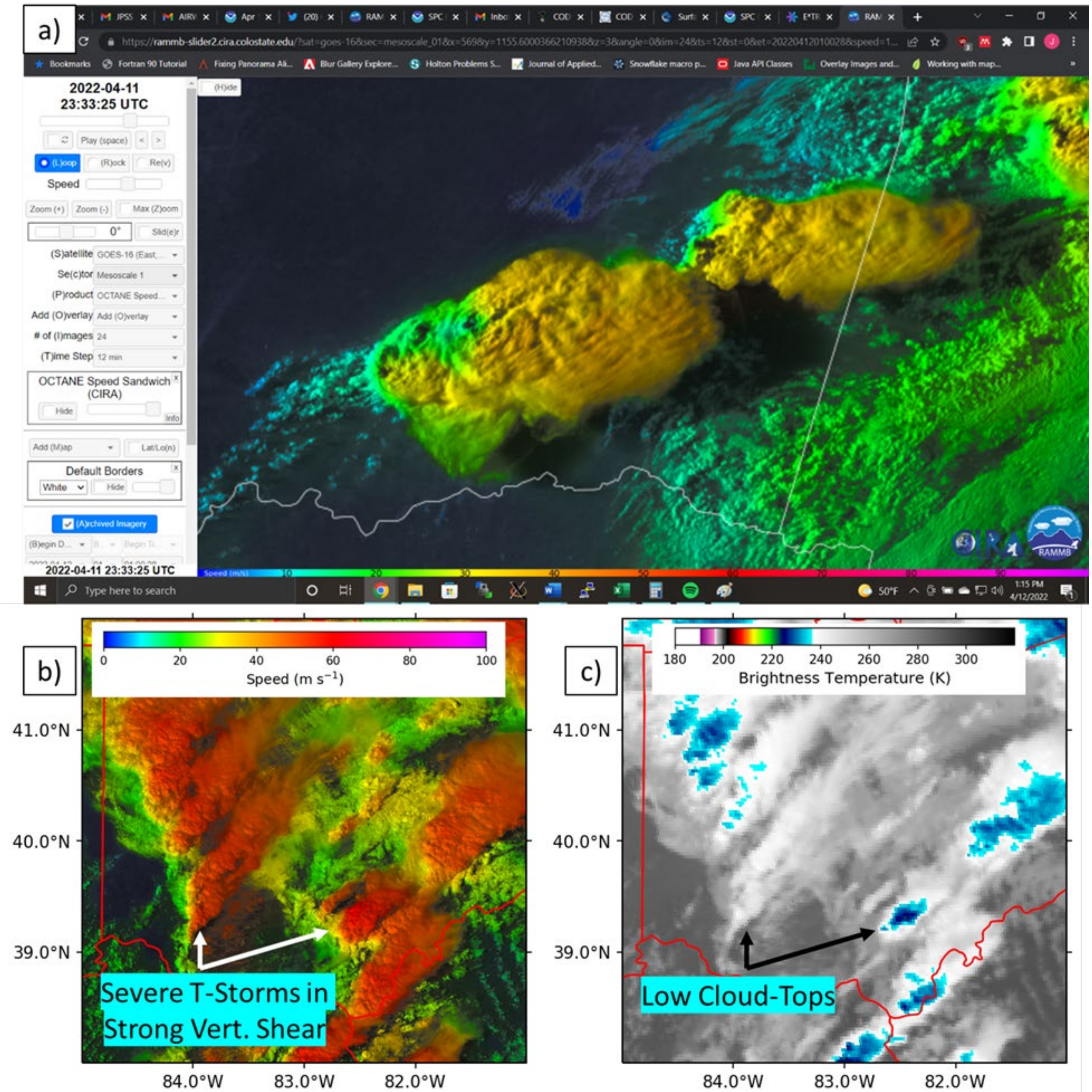



***Figure 4.1.*** *a) Speed Sandwich product demonstrated on the CIRA SLIDER System over a pair of supercells in OK, shown with b) The Speed Sandwich over central Ohio at 1941 UTC 23 Mar 2022 highlighting sheared low-topped severe weather-producing thunderstorms, and c) the GOES-16 10.3 µm band brightness temperature. Near-real time optical flow products can be accessed via the GOES-16 and -17 mesoscale sectors within https://rammb-slider2.cira.colostate.edu/.*

The speeds also can be blended with products like GeoColor on SLIDER (**Fig. 4.2a**), highlighting different cloud layers and motions in vertical shear. Further, speeds and their directions inferred from the texture can be used to infer heights of smoke plumes with proximity soundings which ordinarily produce very weak infrared signals (**Figs. 4.2b, c**). Work is underway to bring the cloud-top cooling blend up on SLIDER as well. These products were demonstrated at the AGU conference in Dec 2021, AMS conference in Jan 2022, and in an invited talk to the EUMETRAIN Winds Event Week group in March 2022.

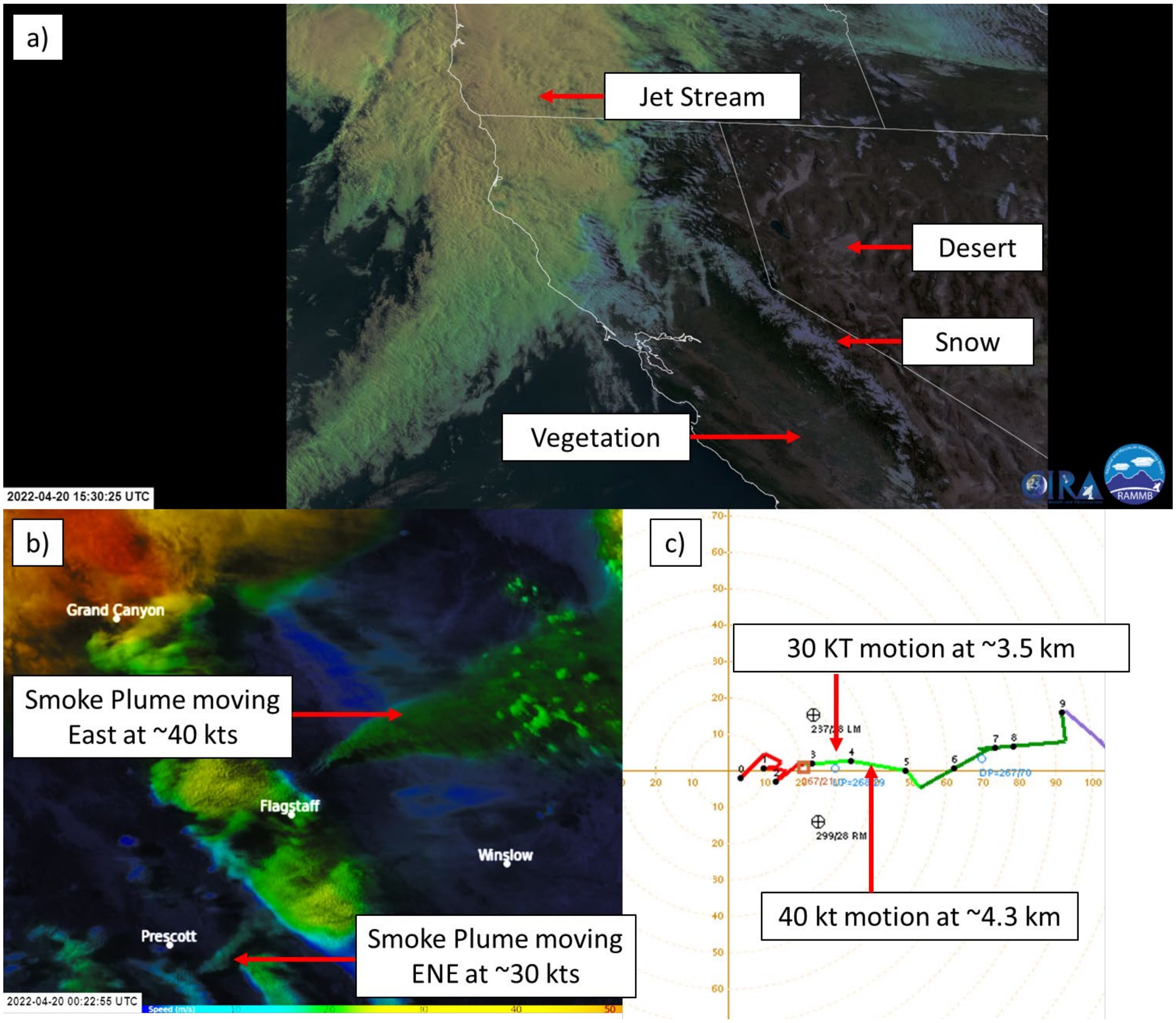



***Figure 4.2.*** *The a) GOES-17 GeoColor product blended with the Speed Sandwich over an atmospheric river event in northern CA on 20 Apr 2022, shown with b) the speed sandwich highlighting a pair of smoke plumes over central AZ on 20 Apr 2022, compared with c) the hodograph from a nearby rawinsonde launched in Tucson AZ at 0000 UTC. Annotations highlight how the speed sandwich can be used to infer smoke plume height where sufficient vertical shear exists, demonstrating that the northern most plume (the Tunnel Fire), associated with a larger fire run, is apparently higher in altitude than the southern fire (the Crooks Fire).*

**For relevant presentations see presentation section below**

## 5) Enabling a 0.5 km, 1-min "mesobox-anywhere, on-demand" via spatial and temporal sharpening

Research conducted by Jason Apke and Mathew Rogers

With the processing chain established for getting optical flow products displayed on SLIDER with the Speed Sandwich, work is currently underway to bring "Mesobox-Anywhere" products to the CONUS sectors by Jul 2022. This product will contain temporally interpolated GeoColor imagery from CONUS images blended with the mesosector 1-min imagery where they overlap. The blends will also be used for real-time validation, returning gradient-normalized mean squared error where mesosectors overlap with the CONUS interpolated products. The redesign was in response to a presentation by Chad Gravelle (Satellite Book Club, Oct. 2021) highlighting how forecasters who do not use mesosectors often do not realize the mesosector cover their CWA. Hence, a forecaster in need of 1-min updates could always use the Mesobox-Anywhere products and simplify their workflow. Demonstrations on released Mesobox-Anywhere products will be highlighted on subsequent reports, with plans to test several important 1-min RGBs in the future (e.g. Day-Cloud Phase Distinction and Fire Temperature). The work already achieved in temporally interpolated RGBs shown in the last report was demonstrated at the AGU conference in Dec 2021, AMS conference in Jan 2022, and in an invited talk to the EUMETRAIN Winds Event Week group in March 2022.

## ACES-HAI Product Dissemination:

- **GeoColor implementation at NESDIS**
  - GOES-16 and GOES-17 ABI GeoColor products are running in real-time at NESDIS
  - GOES-16 and GOES-17 ABI GeoColor imagery is available on the NESDIS GOES-East and on the NESDIS GOES-West Viewer websites:
    https://www.star.nesdis.noaa.gov/GOES/conus.php?sat=G16
    and
    https://www.star.nesdis.noaa.gov/GOES/conus.php?sat=G17

- **NOAA-NASA Earth from Orbit Animations**
  List of Earth from Orbit animations with CIRA GOES-R imagery
  https://www.nesdis.noaa.gov/real-time-imagery/imagery-collections/earth-orbit
  - 2 September 2021: **Hurricane Ida Causes Days of Destruction**
  - 16 September 2021: **Atlantic Hurricane Season Hits Its Peak**
  - 30 September 2021: **Hurricane Sam Powers Across the Atlantic**
  - 25 October 2021: **Atmospheric River Hits the West Coast**
  - 29 October 2021: **5 Haunting Sights from NOAA Satellites**
  - 2 December 2021: **The 2021 Atlantic Hurricane Season Comes to a Close**
  - 9 December 2021 : **Kona Low Slams Hawaii**
  - 13 January 2022: **Catching Bolides**
  - 26 January 2022: **The Hunga Tonga-Hunga Ha'apai Eruption, a Multi-Hazard Event**

- **GOES-16 and GOES-17 ABI GeoColor products are running at NWS WFOs** (through the AWIPS LDM) and are also being used by the **National Centers (OPC, WPC, SPC, AWC, NHC).**

- ACES-HAI baseline products, especially **GeoColor** imagery, are regularly being used by the **GOES-R Program Office**

## Additional Methods of Dissemination:

- **Training Sessions**
- Presentation at **scientific conferences** and **workshops (as listed below)**
- Posting on **twitter accounts** (especially on @CIRA_CSU, @NOAASatellites, @NWS)
- **Satellite blogs** using SLIDER imagery ( https://satelliteliaisonblog.com/ )
- **NOAA and CIRA Facebook pages** using SLIDER imagery (https://www.facebook.com/CIRACSU, https://www.facebook.com/NOAASatellites/ )
- Use of **SLIDER imagery / imagery loops** by **NOAA Management** (https://rammb-slider.cira.colostate.edu/)

- **Publications (as listed below)**

**CIRA/RAMMB Satellite Blogs:**

https://satelliteliaisonblog.com/
https://rammb2.cira.colostate.edu/research/goes-r/proving_ground/blog/

## Relevant Publications:


Miller S. D., Y.-J. Noh, L. D. Grasso, C. J. Seaman, A. Ignatov, A. K. Heidinger, S.H. Nam, W. E. Line, and B. Petrenko, 2022: A Physical Basis for the Overstatement of Low Clouds at Night by Conventional Satellite Infrared-Based Imaging Radiometer Bi-Spectral Techniques. *Earth and Space Science.* **9** (2), e2021EA002137, https://doi.org/10.1029/2021EA002137
**Paper selected as an AGU Editor's Highlight:**
https://eos.org/editor-highlights/when-less-is-more-the-moon-sheds-light-on-clouds-at-night

Apke, J. M., and J. R. Mecikalski, 2021: On the Origin of Rotation Derived from Super Rapid Scan Satellite Imagery at the Cloud-Tops of Severe Deep Convection. *Mon. Weather Rev.*, **149**, 1827–1851, https://doi.org/10.1175/mwr-d-20-0209.1

Grasso, L. D., D. Bikos, J. Torres, J. F. Dostalek, T.-C. Wu, J. Forsythe, H. Q. Cronk, C. J. Seaman, S. D. Miller, E. Berndt, H. G. Weinman, and K. B. Kasper, 2021: Satellite Imagery and Products of the 16-17 February 2020 Saharan Air Layer Dust Event over the Eastern Atlantic: Impacts of Water Vapor on Dust Detection and Morphology. *Atmos. Meas. Tech.*, **14**, 1615–1634, 2021 https://doi.org/10.5194/amt-14-1615-2021

Miller, S. D., D. T. Lindsey, C. J. Seaman, and J. E. Solbrig, 2020: *GeoColor*: A Blending Technique for Satellite Imagery. *J. Atmos. Ocean. Tech.*, **37**(3), 429-448, https://doi.org/10.1175/JTECH-D-19-0134.1


## Presentations:

Lewis Grasso, Daniel Bikos, Jorel Torres, John F. Dostalek, Ting-Chi Wu, John Forsythe, Heather Q. Cronk, Curtis J. Seaman, Steven D. Miller, Emily Berndt, Harry G. Weinman, and Kennard B. Kasper, 2021: Satellite Imagery and Products of the 16-17 February 2020 Saharan Air Layer Dust Event over the Eastern Atlantic: Impacts of Water Vapor on Dust Detection and Morphology. EUMETSAT Meteorological Satellite Conference, Bucharest, Romania, 20-24 September 2021. Presentation type: Pre-recorded talk on youtube.

Lewis Grasso, Daniel Bikos, Jorel Torres, John F. Dostalek, Ting-Chi Wu, John Forsythe, Heather Q. Cronk, Curtis J. Seaman, Steven D. Miller, Emily Berndt, Harry G. Weinman, and Kennard B. Kasper, 2021: Satellite Imagery and Products of the 16-17 February 2020 Saharan Air Layer Dust Event over the Eastern Atlantic: Impacts of Water Vapor on Dust Detection and Morphology. ISDA 05 November 2021. Presentation type: Oral on Webex.

Miller, S. D. and S. van den Heever, 2021: CIRA and CSU – Selected Research Topics. *Visit of Dr. Matthew Hepburn to CSU/CIRA* (Dr. M. Hepburn: White House Office of Science and Technology, Director of COVID Vaccine Development, HHS-DOD Countermeasures Acceleration Group). 10 December 2021

Apke, Jason, S. Miller, M. Rogers, Y. Noh, K. Bedka, B. Line, Y. Lee, and K. Hilburn, 2021: Critical Research Pathways in Satellite-Based Dense Optical Flow Techniques for Atmospheric Science. Virtual Oral Presentation, *American Geophysical Union Conference 2021*, New Orleans, LA. https://agu.confex.com/agu/fm21/meetingapp.cgi/Paper/832956

Apke, Jason, S. Miller, M. Rogers, Y. Noh, K. Bedka, B. Line, Y. Lee, and K. Hilburn, 2022: New Techniques in Benchmarking and Quantifying Uncertainties of Dense Optical Flow Winds from Satellite Remote Sensing. Virtual Oral Presentation, *102nd American Meteorological Society Annual Meeting*, Houston, TX. Recorded Session: https://ams.confex.com/ams/102ANNUAL/meetingapp.cgi/Session/60244

Apke, Jason, S. Miller, B. Line, J. Forsythe, and K. Bedka, 2022: (*Invited*) Demonstrations in Satellite Product-Infused Dense Optical Flow Winds and Motions for Earth and Atmospheric Sciences. Virtual Oral Presentation. *EUMETRAIN Winds-Event Week.* Recorded Session: http://eumetrain.org/resources/wind_ew_2022_s8b.html

## Social Media:

Products developed under this ACES-HAI project are regularly being used by social media, twitter accounts, and by national and international news organizations.

**Some noteworthy examples are listed below:**

NWS offices around the world share GeoColor imagery loops:
https://twitter.com/NWSGray/status/1500095286999273476
https://twitter.com/NWSAnchorage/status/1503909410426408963
https://twitter.com/NWSPagoPago/status/1495219316521791489
https://twitter.com/NWSHonolulu/status/1502778540269477896

**23 March 2022**
**NOAA's Ocean Service** shared a GeoColor image to promote World Meteorological Day:
https://twitter.com/noaaocean/status/1506618526483853312

**NOAA's Ocean Service**
@noaaocean

Happy World Meteorological Day! We have several hands on activities for students who want to learn more about the weather!
🌀Follow That Hurricane: oceanservice.noaa.gov/education/acti...
🏗Build Your Own Weather Station: oceanservice.noaa.gov/education/acti...


7:07 AM · Mar 23, 2022 · Twitter Web App

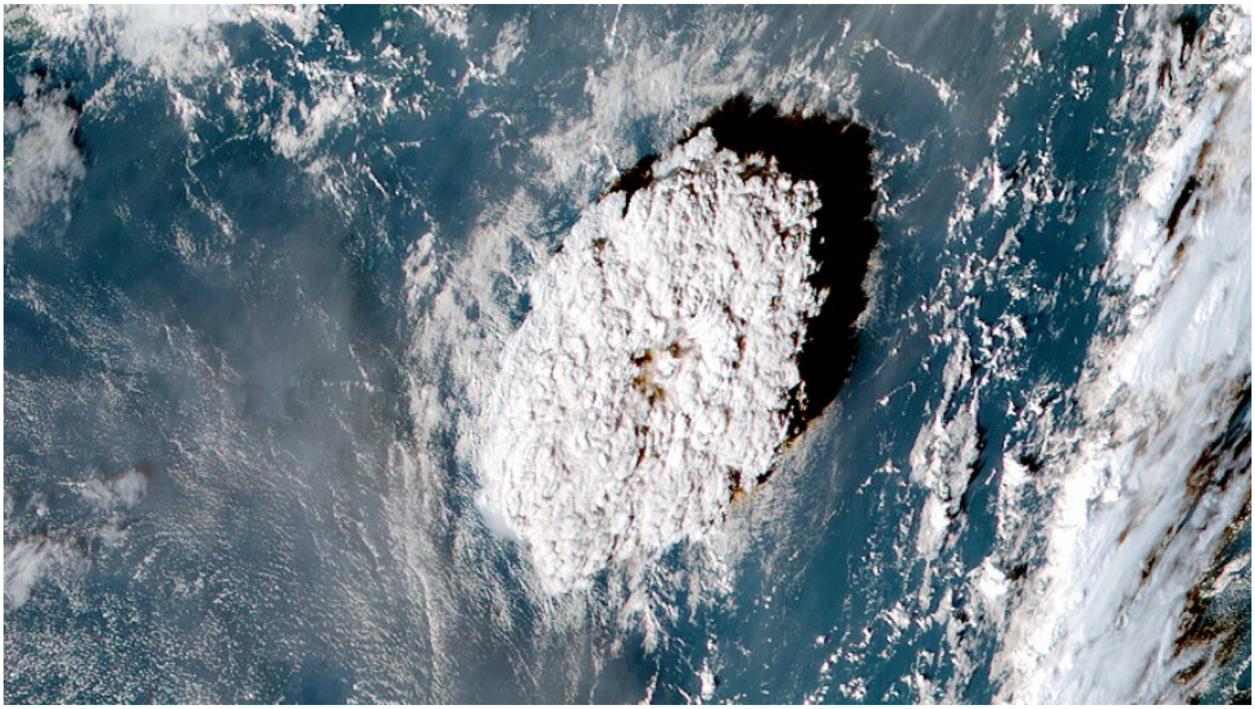
**69** Retweets **6** Quote Tweets **147** Likes

## <u>Noteworthy newspaper publication with GeoColor imagery:</u>

**15 January 2022:**

**News Coverage of Hunga Tonga - Hunga Ha’apai Eruption**

A volcano, named Hunga Tonga - Hunga Ha’apai, approximately 100 km northwest of Tonga’s capital of Nuku’alofa, violently erupted in mid-January. This eruption was observed by both Himawari-8 and GOES-17, and these images were published in numerous national and international news media outlets immediately. Imagery was used immediately after the eruption and in subsequent coverage of the aftermath.



**New York Times:**

Here's What Scientists Know About the Tonga Volcano Eruption; 01/19/22, https://www.nytimes.com/2022/01/19/climate/scientists-tonga-volcano-eruption-effects.html

**BBC News:**

Giant Tonga eruption caught on satellite images; 01/15/22, https://www.bbc.com/news/av/world-asia-60007163

Tonga volcano: Internet restored five weeks after eruption; 02/22/22, https://www.bbc.com/news/world-asia-60458303

**CBC News:** New Zealand's military sends flight to Tonga to assess volcano damage; 01/16/22, https://www.cbc.ca/news/world/tonga-volcano-eruption-tsunami-damage-1.6316914

**ABC News:**

Satellite pictures show huge Tonga volcano blast; 01/16/22, https://abcnews.go.com/International/video/satellite-pictures-show-huge-tonga-volcano-blast-82308226

Photos capture devastation from Tonga volcano eruption; 01/21/22, https://abcnews.go.com/International/photographic-timeline-tonga-volcano-eruption/story?id=82323579

Tonga volcano: Why was it so big, and are there others we need to watch out for?; 01/17/22, https://www.abc.net.au/news/science/2022-01-18/tonga-volcano-tsunami-hunga-eruptionwhy-so-big/100761750

**Nature:** Why the Tongan eruption will go down in the history of volcanology; 02/09/22, https://www.nature.com/articles/d41586-022-00394-y

**Scientific American:**

https://www.scientificamerican.com/article/tonga-volcano-eruption-created-puzzling-ripples-in-earths-atmosphere/

Starlink Offers Internet Access in Times of Crisis, but Is It Just a PR Stunt; 03/18/22, https://www.scientificamerican.com/article/starlink-offers-internet-access-in-times-of-crisis-but-is-it-just-a-pr-stunt/

**Washington Post:** Hunga Tonga volcano spewed ash 36 miles high, a world record; 03/05/22, https://www.washingtonpost.com/weather/2022/03/05/hunga-tonga-plume-mesosphere/

**Reuters:**

Explainer: Tonga's volcanic eruption may harm environment for years, scientists say; 01/18/22, https://www.reuters.com/business/environment/tongas-volcanic-eruption-may-harm-environment-years-scientists-say-2022-01-18/

How big was the Tonga eruption?; 01/21/22, https://graphics.reuters.com/TONGA-VOLCANO/lgpdwjyqbvo/

Tsunami models underestimated shockwave from Tonga eruption; 01/28/22, https://www.reuters.com/world/asia-pacific/tsunami-models-underestimated-shockwave-tonga-eruption-2022-01-28/

**Independent:**

Huge Tonga volcano eruption that triggered tsunami capture on satellite; 01/17/22, https://www.independent.co.uk/tv/editors-picks/tonga-volcano-eruption-satellite-video-v8b0e220a

Tonga volcano eruption produced largest ash cloud ever recorded, NASA says; 02/17/22, https://www.independent.co.uk/space/tonga-eruption-largest-ash-cloud-ever-nasa-b2017678.html

**CNN:** Video shows underwater eruption a day before Tonga tsunami; 01/17/22, https://www.cnn.com/videos/world/2022/01/17/tonga-volcano-eruption-orig-tp-jc.cnn

**The Guardian:** Tonga's volcano eruption: in pictures; 01/18/22, https://www.theguardian.com/world/gallery/2022/jan/18/tongas-volcano-eruption-in-pictures

**USA Today:** Stunning satellite imagery shows underwater volcano eruption in Tonga; 01/15/22, https://www.usatoday.com/videos/news/2022/01/15/satellite-imagery-shows-underwater-volcano-eruption/6540016001/

**Mashable:**

Explosive NASA images show volcano's eruption reached incredible heights; 02/17/22, https://mashable.com/article/nasa-volcano-eruption-record-tonga

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**NOAA:** Ripple effect: What the Tonga eruption could mean for tsunami research; 02/03/22, https://www.noaa.gov/news/ripple-effect-what-tonga-eruption-could-mean-for-tsunami-research

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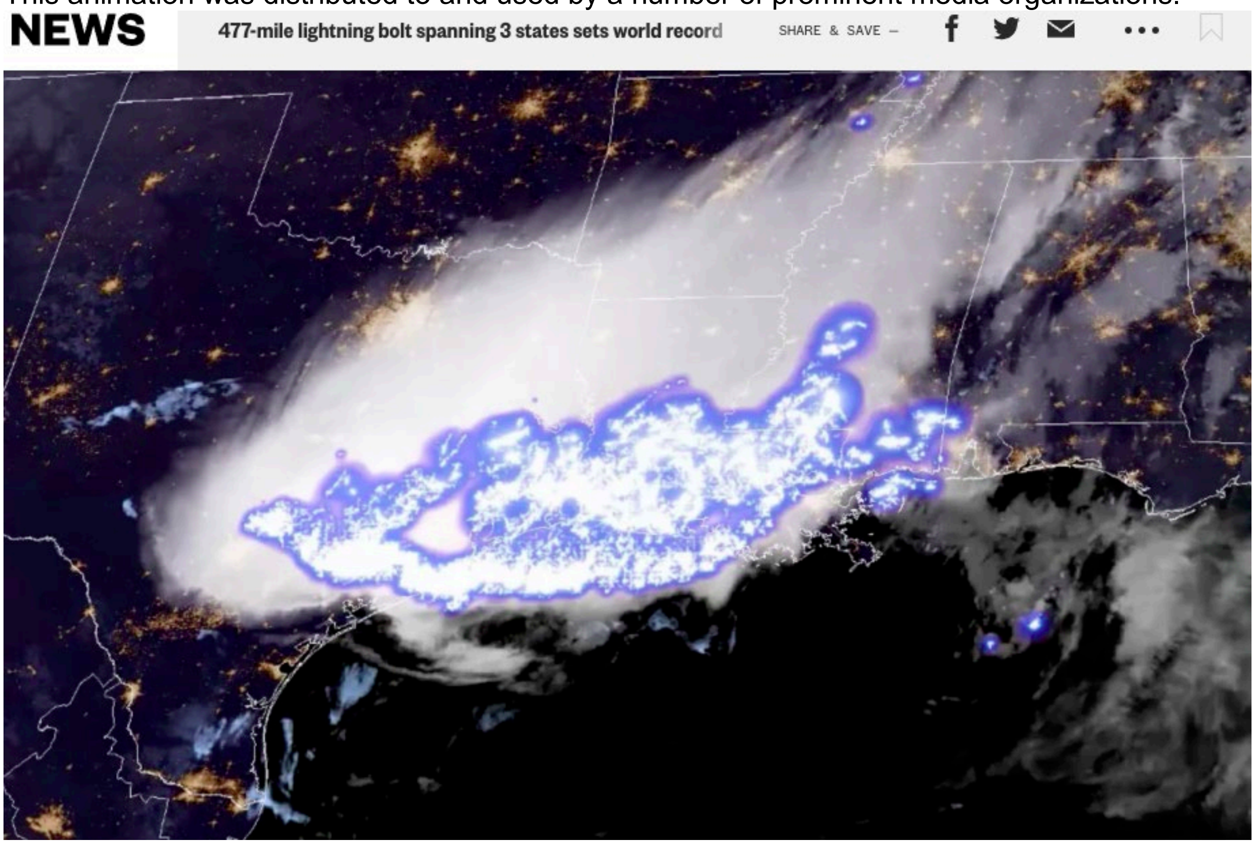
**04 February 2022:**

**Geostationary Lightning Mapper imagery used to display "megaflash" lightning records**

In early February, the World Meteorological Organization certified two "megaflash" lightning records. NESDIS communications requested an animation to include GeoColor and Global Lightning imagery. This animation was distributed to and used by a number of prominent media organizations.

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## Plans for Next Reporting Period

Work on all project milestones will continue during the next semi-annual period (March – September 2022).

============= End of Report ============