Post-Severe Thunderstorm Damage Assessment from March 2-3, 2020, Nashville, TN, Using Synthetic Aperture Radar Observations

Hannah G Pankratz [1], Alexander Melancon [2], Jordan R Bell [3], Andrew L Molthan [3]

1. NASA Postdoctoral Program, Oak Ridge Associated Universities/NASA Marshall Space Flight Center, Huntsville, Alabama, USA
2. Earth System Science Center, University of Alabama in Huntsville, Huntsville, Alabama, USA
3. Earth Science Branch, NASA Marshall Space Flight Center, Huntsville, Alabama, USA

Motivation and Objectives

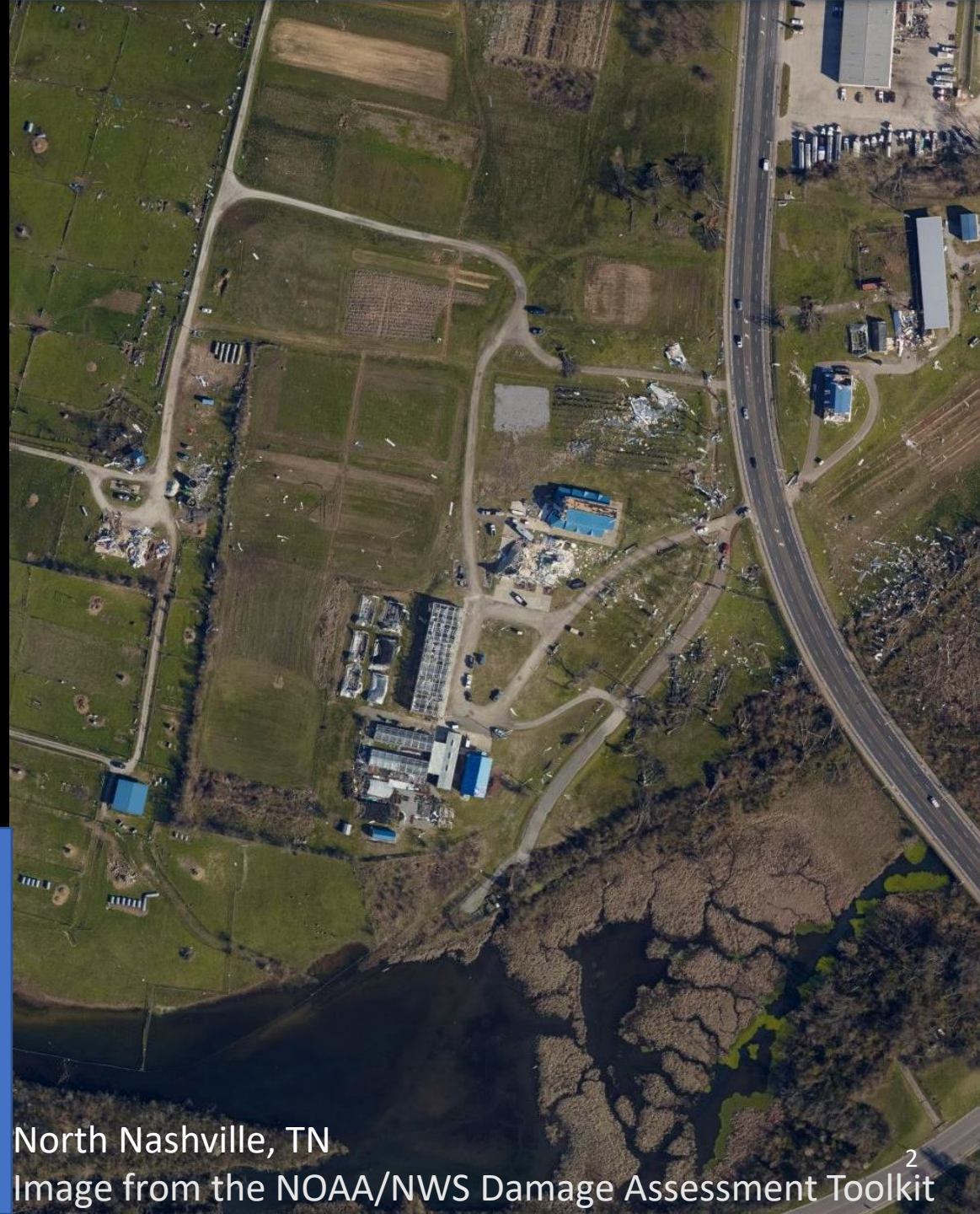
Motivation:

Severe thunderstorm events can be among some of the most destructive forces, comprised of tornadoes, hail, and strong winds that can cause widespread damage.

- The destruction caused by these events can cross several states, making damage estimates difficult, especially in heavily vegetated or rural areas.
- A rapid assessment of damage is crucial for supporting disaster response and recovery.

Objectives:

- Assess the ability of synthetic aperture radar (SAR) data to detect damaged areas after a severe thunderstorm.
- Evaluate the effectiveness of SAR data products (coherence and amplitude) to identify tornado tracks.



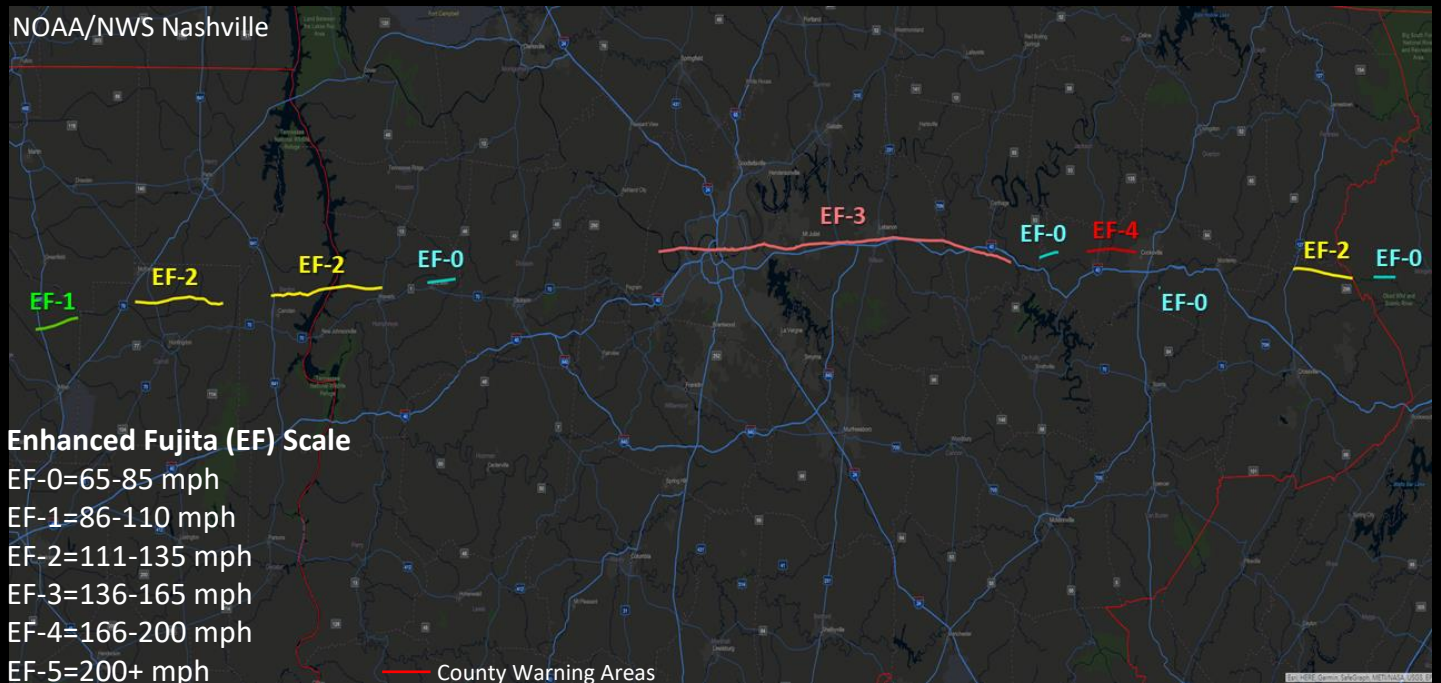
North Nashville, TN
Image from the NOAA/NWS Damage Assessment Toolkit

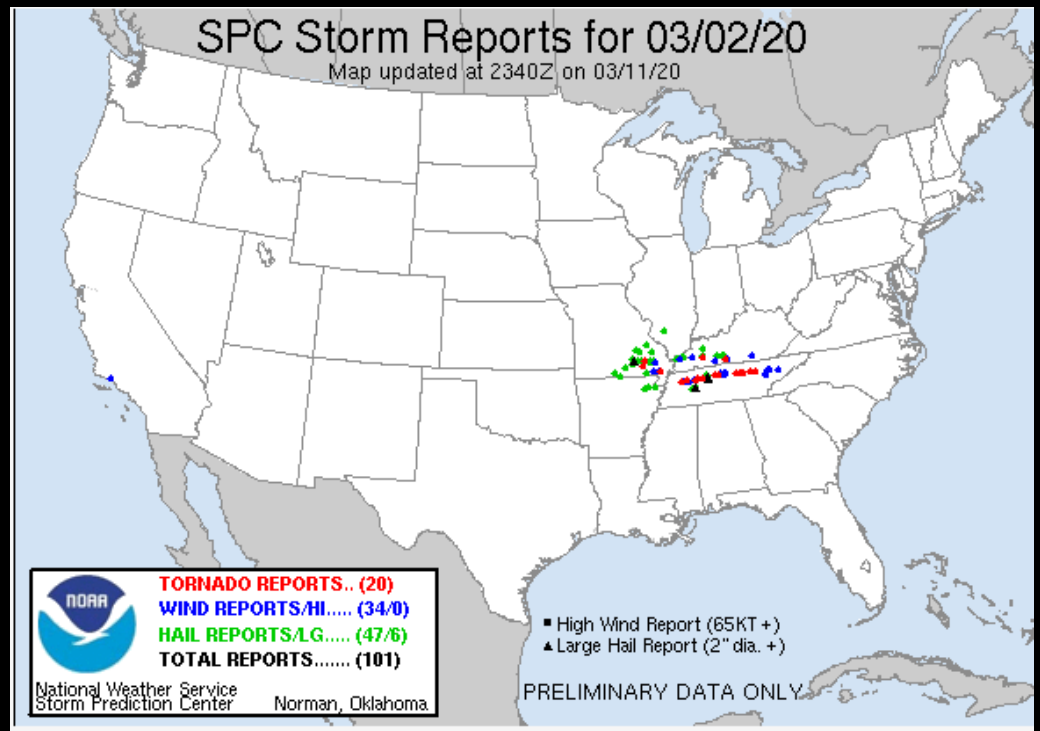
March 2-3, 2020 Tornado Outbreak

Late on March 2nd into the early morning hours on the 3rd, a supercell formed and tracked across Tennessee producing numerous tornadoes and large hail.

Ground surveys conducted by NOAA National Weather Service (NWS) meteorologists determined a total of 10 tornadoes touched down across Tennessee.

Enhanced Fujita Scale	EF-0	EF-1	EF-2	EF-3	EF-4
Number	4	1	3	1	1



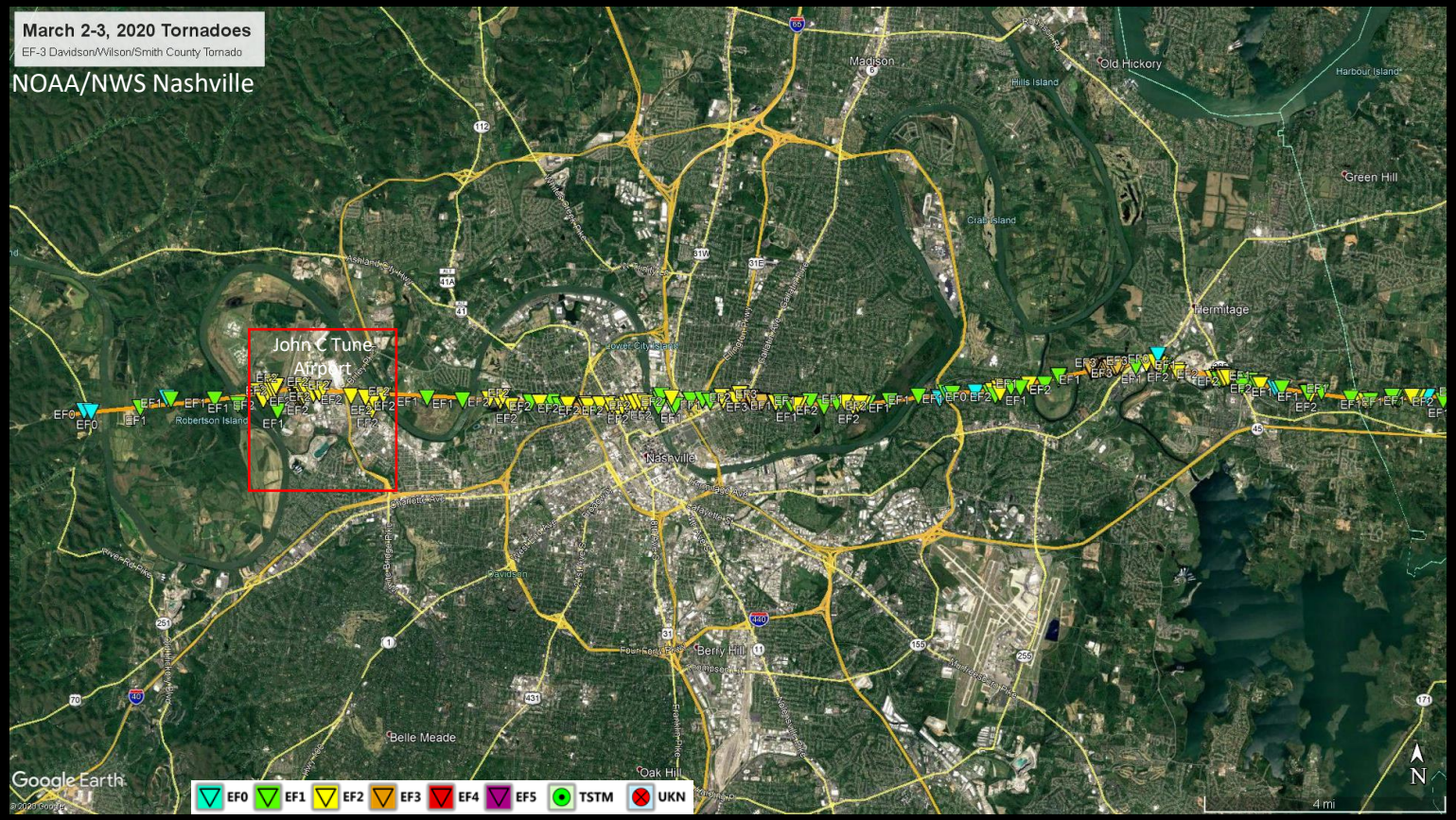


SPC Storm Reports for March 2-3, 2020

The EF-3 tornado was ~60 miles long and went through the Nashville metropolitan area, killing 5 people and causing hundreds of injuries.

- One of the longest known paths in the state of Tennessee.
- Over $90 million dollars of damage was reported from the John C. Tune Airport, located west of downtown Nashville.

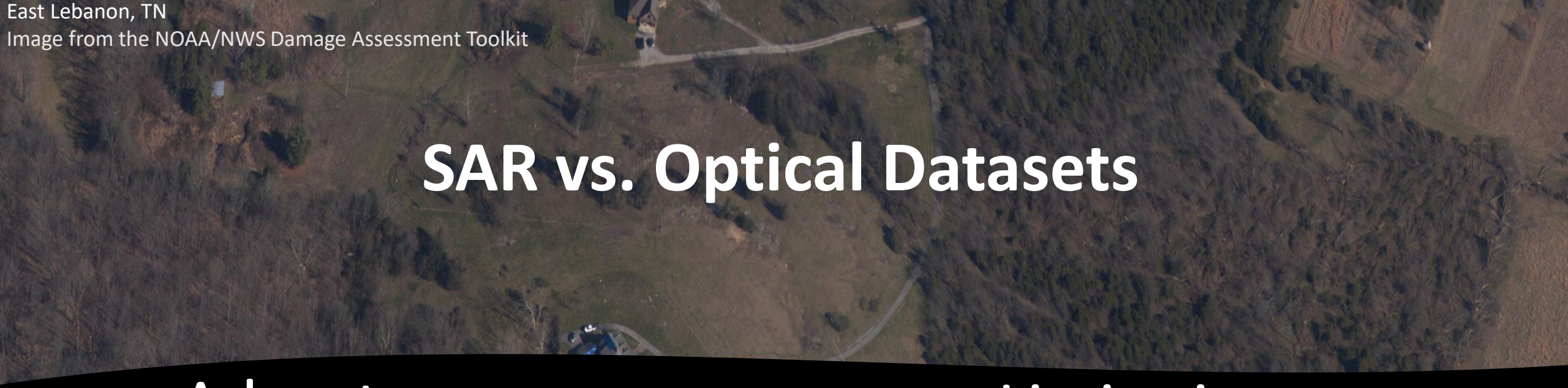
Davidson County Damage



EF Rating	Est. Peak Winds	Path Length	Max Width
EF-3	165 mph	60.13 miles	0.9 miles

John C Tune Airport, TN
Images from the NOAA/NWS Damage Assessment Toolkit

East Lebanon, TN
Image from the NOAA/NWS Damage Assessment Toolkit



SAR vs. Optical Datasets

Advantages

- Day and night collections as well as being mostly weather independent.
- Opportunity to explore different polarizations.
- Can provide a quick first look at the overall extent of damage, especially in rural/hard to reach areas before field surveys are conducted.
  - The large swath of Sentinel-1 is beneficial a first quick look of the damaged areas.
  - Higher resolution X-band SAR is beneficial for urban damage detection.

Limitations

- Coherence is sensitive to any “change” between the scenes.
- SAR products are seasonally dependent.
- Latency dependencies:
  - Sentinel-1’s 12-day repeat often misses the targeted event.
  - X-band sensors don’t have regular global acquisitions.
- X- and C-band SAR sensors are heavily impacted by dense vegetation, underestimating the extent of damage.

Data

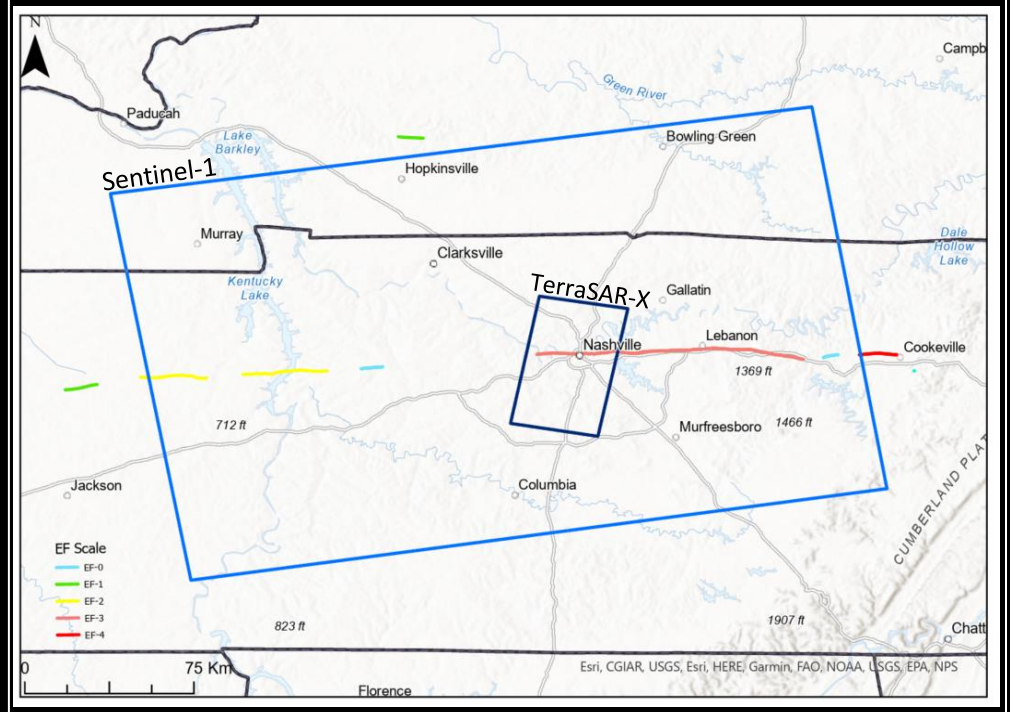
Ancillary

Identifying Events:

- NOAA/NWS severe thunderstorm and tornado Warnings
- Weather radar data and derived products
- State/County boundaries
- Hydrologic features

Validation:

- NOAA/NWS Damage Assessment Toolkit (DAT)
  - GIS platform that includes damage points, field photos, track polylines and polygons
- NOAA/National Centers for Environmental Information (NCEI) Storm Data
  - Official statistics from each tornado



The TerraSAR-X image only covered a portion of the EF-3 tornado and the Sentinel-1 covered 5 out of the 10 tornadoes.

Sentinel-1 Images were processed by the Alaska Satellite Facility (ASF) Vertex On-Demand services for the Sentinel-1 Images
https://hyp3-docs.asf.alaska.edu/

SAR

X-Band (~3 cm):

- Airbus's TerraSAR-X Satellite
  - Descending, co-polarized (HH) StripMap (SM) images were used.
  - Coherence Image:
    - Pre: 2/1/2020
    - Post: 3/16/2020

C-Band (~6 cm):

- European Space Agency's (ESA's) Sentinel-1 Satellite
  - Ascending co-polarized (VV) Interferometic Wide (IW) images were used.
  - Coherence Image:
    - Pre: 2/13/2020
    - Post: 3/8/2020

Radiometric Terrain Corrected (RTC) products were produced for both TerraSAR-X (HH) and Sentine-1 (VV and VH).

Approach

Coherence

Identifying Events

- Ancillary Storm Data
- Coherence Image (nearest pre and post)
- Identity damage polygons
- Polygons are combined
- Polygons lengths are measured

Validation

- NOAA/NWS DAT
- NOAA/NCEI Storm Data

Amplitude

Identifying Events

- Ancillary Storm Data
- RTC Image (nearest post-event)
- Identity damage polygons (HH/VV/VH)
- Polygons are combined
- Polygons lengths are measured

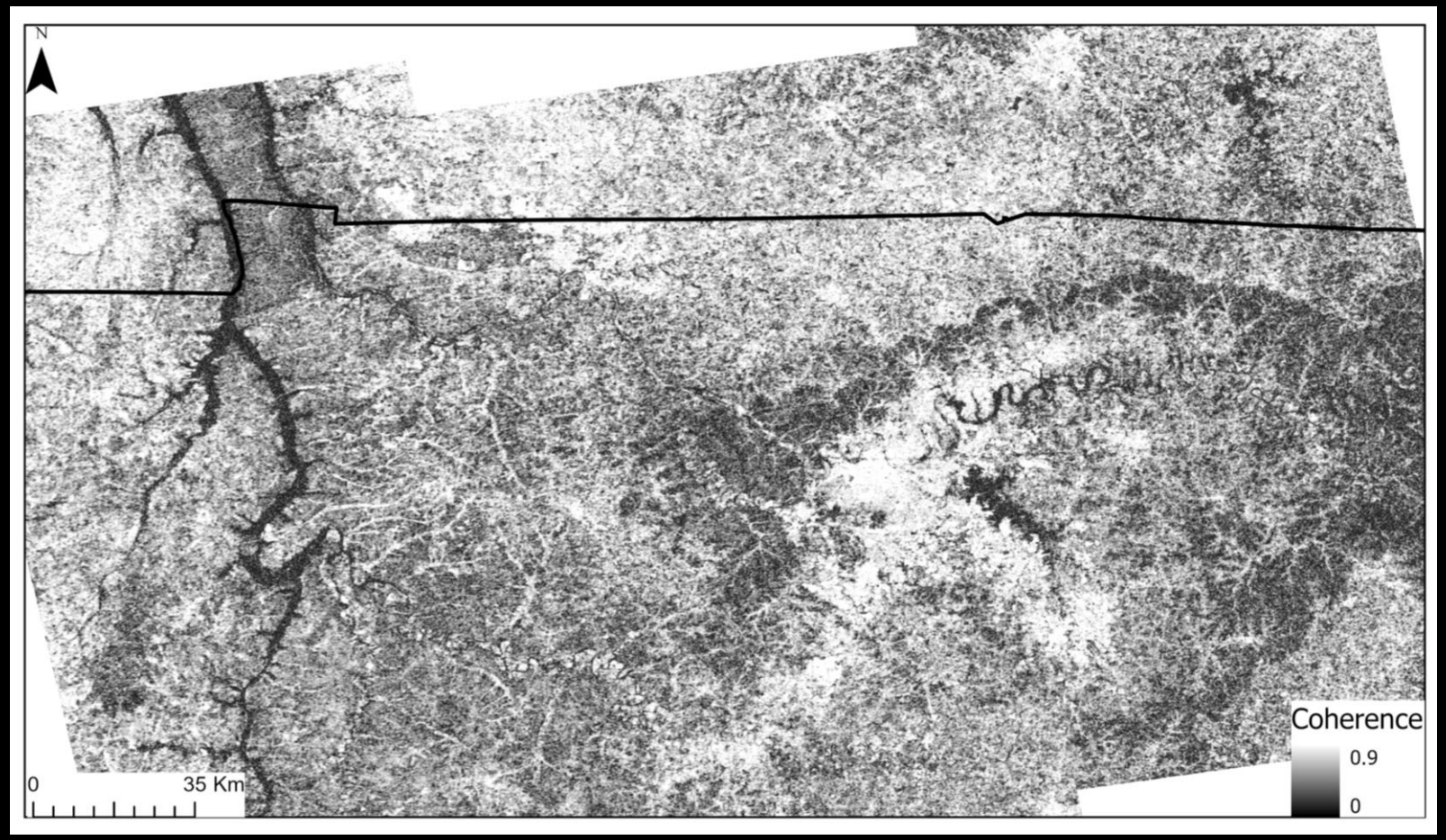
Validation

- NOAA/NWS DAT
- NOAA/NCEI Storm Data

For the first stage of the project only length was measured and compared to the official surveyed results.

Donelson Neighborhood, Nashville, TN
Image from the NOAA/NWS Damage Assessment Toolkit

Sentinel-1 Coherence



ASF DAAC 2023, contains modified Copernicus Sentinel data 2020, processed by ESA.

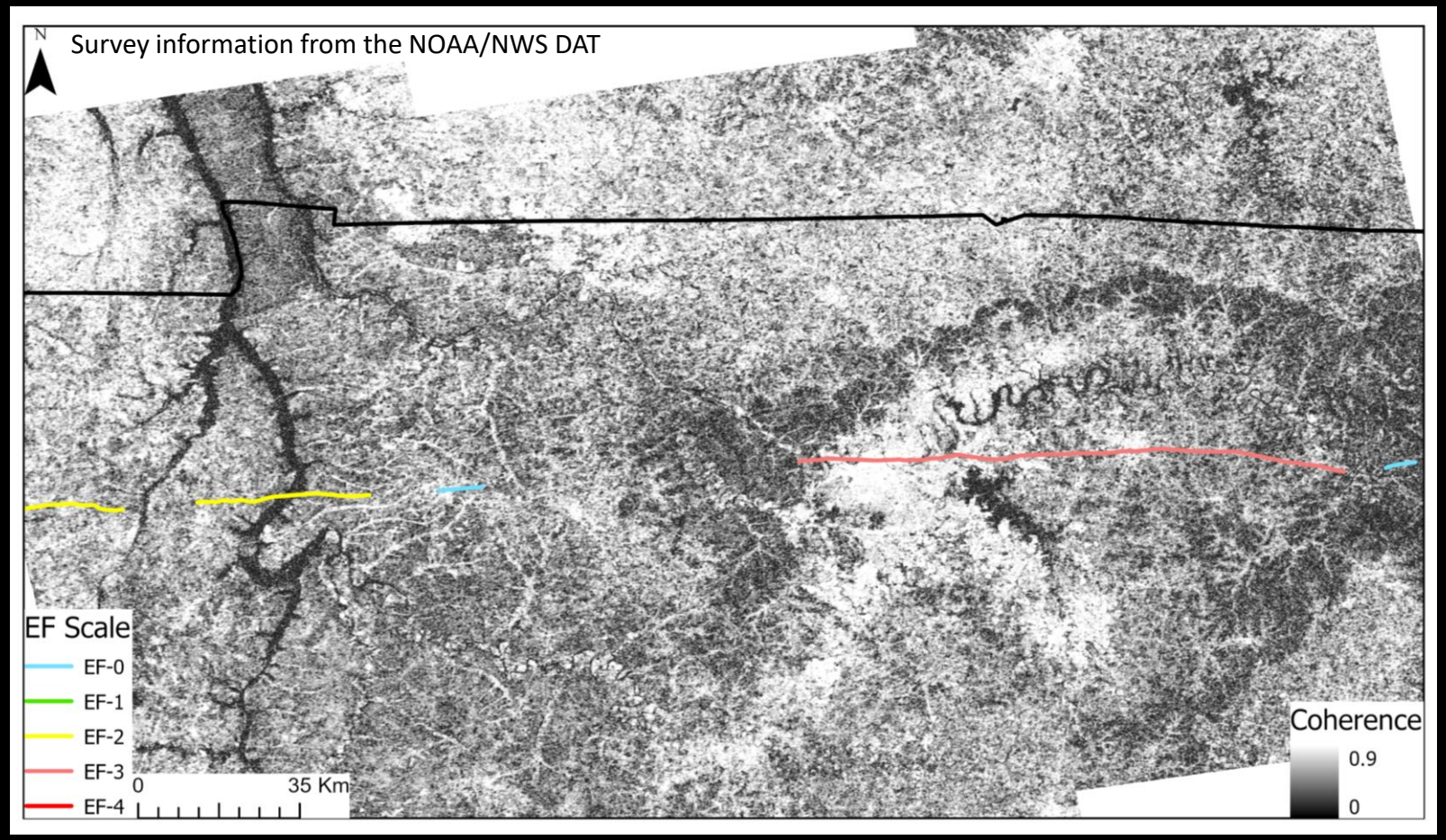
80 m Sentinel-1 Coherence Product

Pre: 13 February 2020 Post: 8 March 2020

Tennessee Outbreak
March 2-3, 2020

The storm was moving in an east-west direction through Middle Tennessee

Sentinel-1 Coherence



ASF DAAC 2023, contains modified Copernicus Sentinel data 2020, processed by ESA.

80 m Sentinel-1 Coherence Product

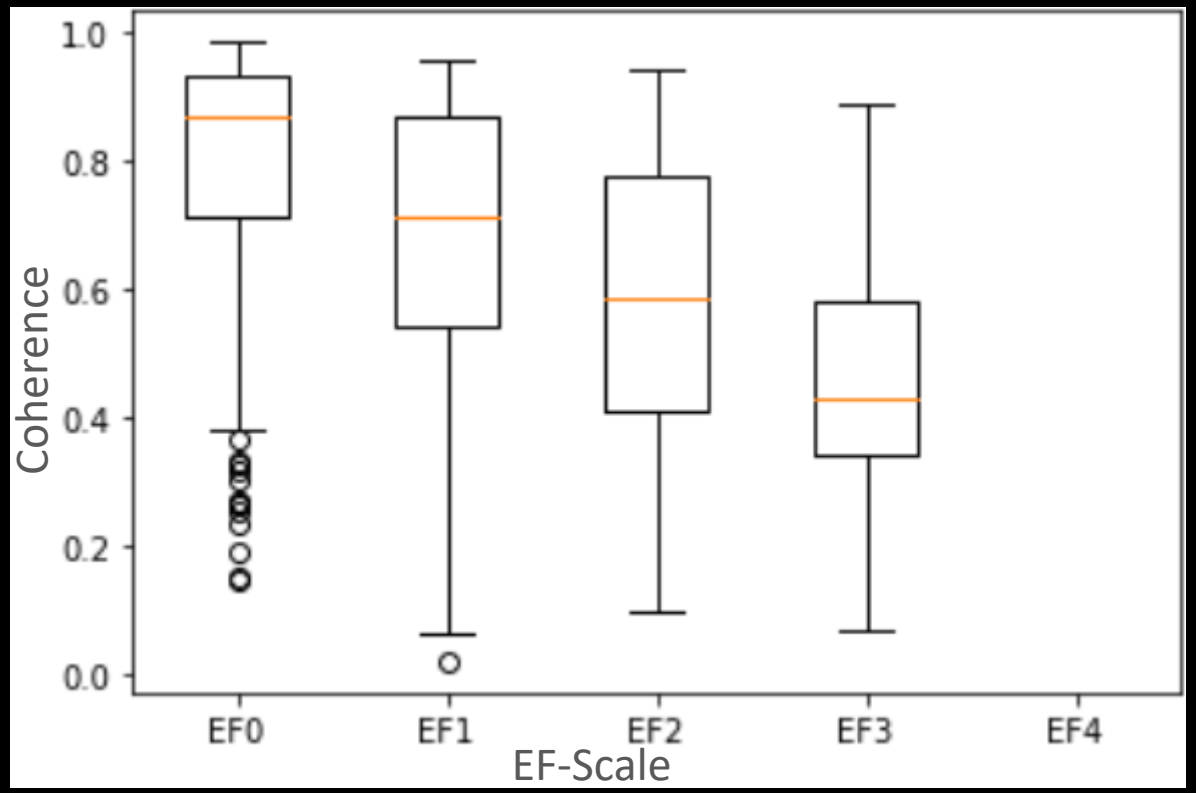
Pre: 13 February 2020 Post: 8 March 2020

EF Scale	Number in the Image
EF-0	2
EF-1	0
EF-2	2
EF-3	1
EF-4	0

EF Scale	Wind Speed
EF-0	65-85 mph
EF-1	86-110 mph
EF-2	111-135 mph
EF-3	136-165 mph
EF-4	166-200 mph

Coherence and EF Ratings

Sentinel-1 Coherence Image
Pre: 13 February 2020 Post: 8 March 2020



*This plot is only from track 19 which did not include an EF-4 tornado.

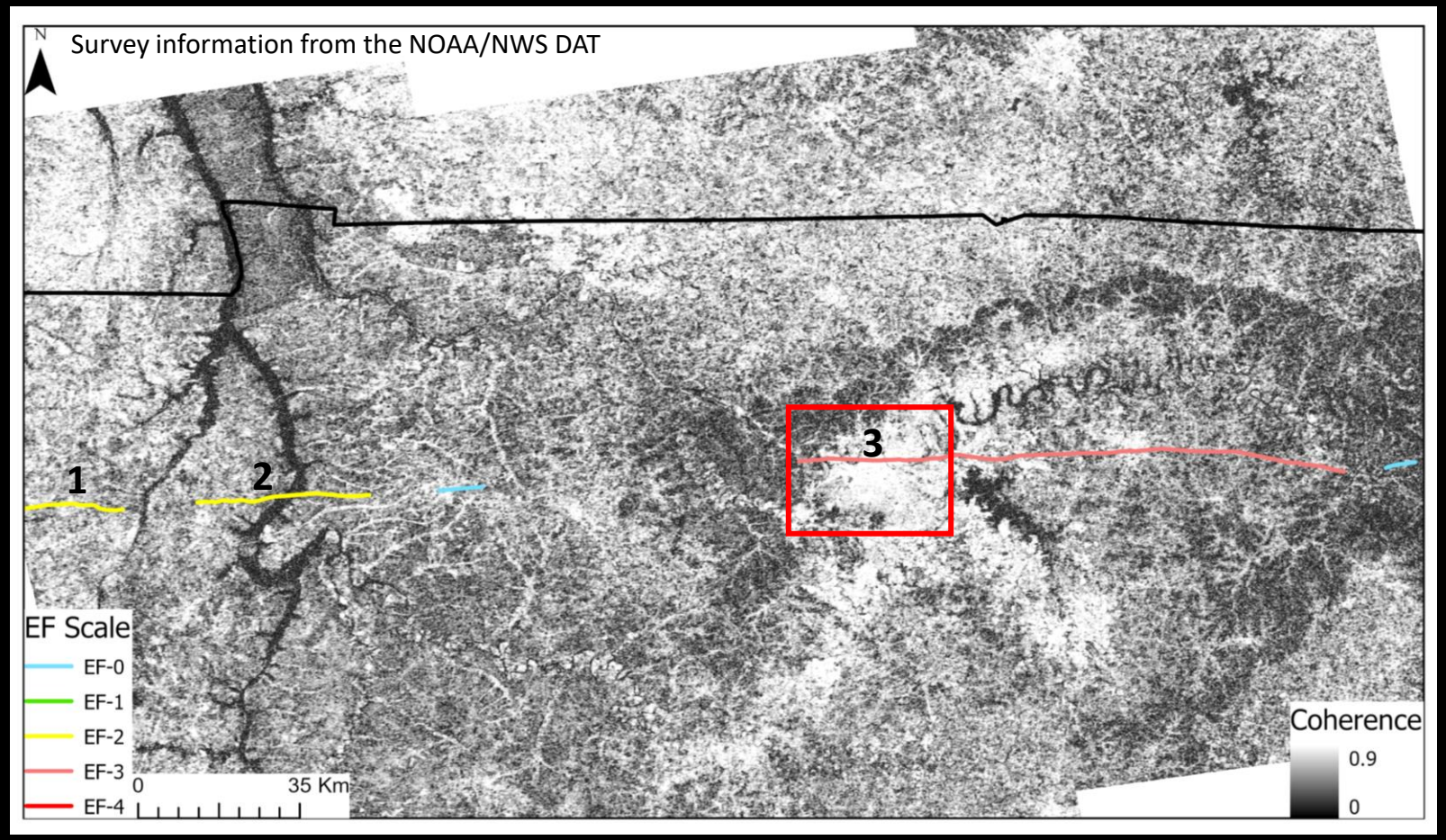
Comparing coherence-post values as a function of the EF-Scale.

All of the damage indictor points that overlapped with the Sentinel-1 coherence image were binned by their corresponding EF-Scale.

Lower EF-ratings was associated with a higher coherence value.

Higher EF ratings were associated with lower coherence values.

Sentinel-1 Coherence



ASF DAAC 2023, contains modified Copernicus Sentinel data 2020, processed by ESA.

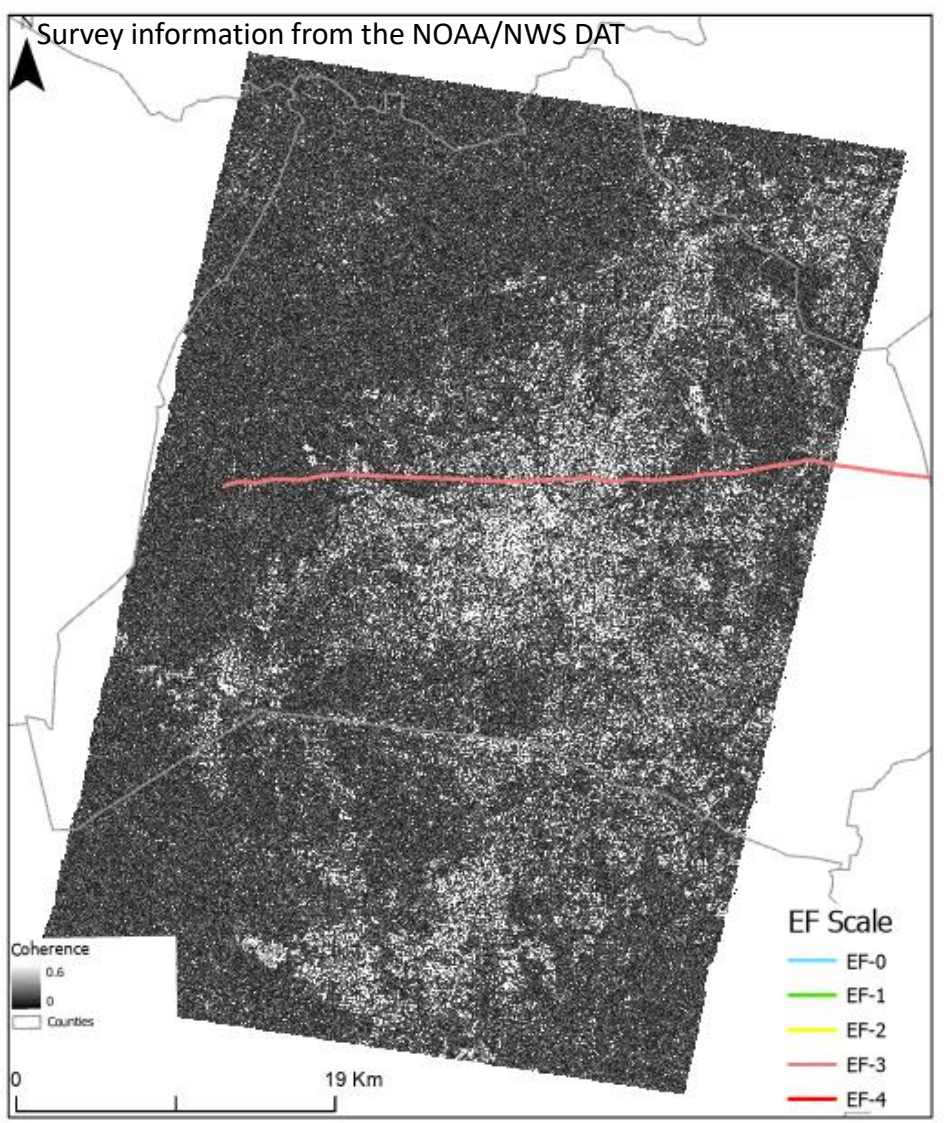
Portions of 3 out of the 5 tracks were identified.

- EF-2 and EF-3

ID	Sentine-1 Derived Length (miles)	NOAA/NWS Length (miles)	Percentage of the track covered by Sentinel-1
1	11.66	14.8	79%
2	20.73	18.72	*111%
3	49.78	60.13	83%

* Measuring a longer length in the SAR image was most likely caused by misidentifying low coherence as being associated with a track.

TerraSAR-X Nashville EF-3 Coherence



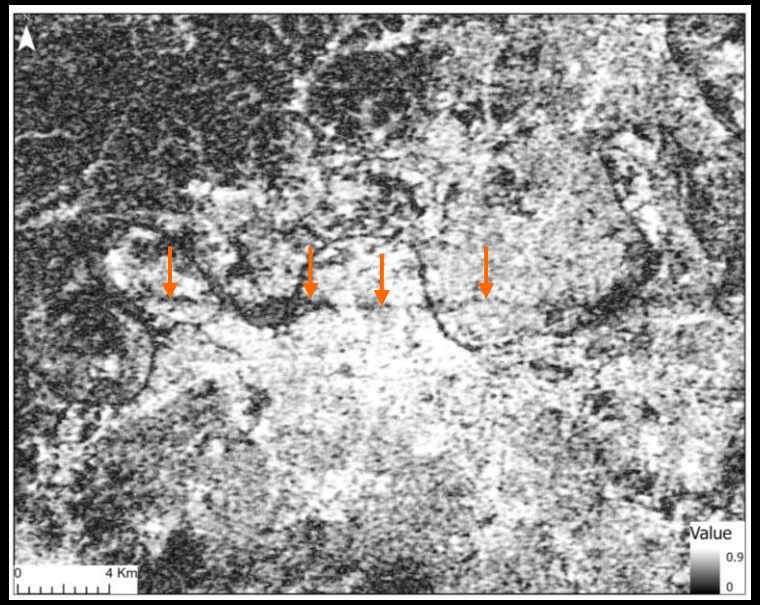
Only the EF-3 track overlapped with the TerraSAR-X image extent.

TerraSAR-X Derived Length (miles)	NOAA/NWS Length (miles)	Percentage of the track covered by Sentinel-1
9.2	*18.24	50%

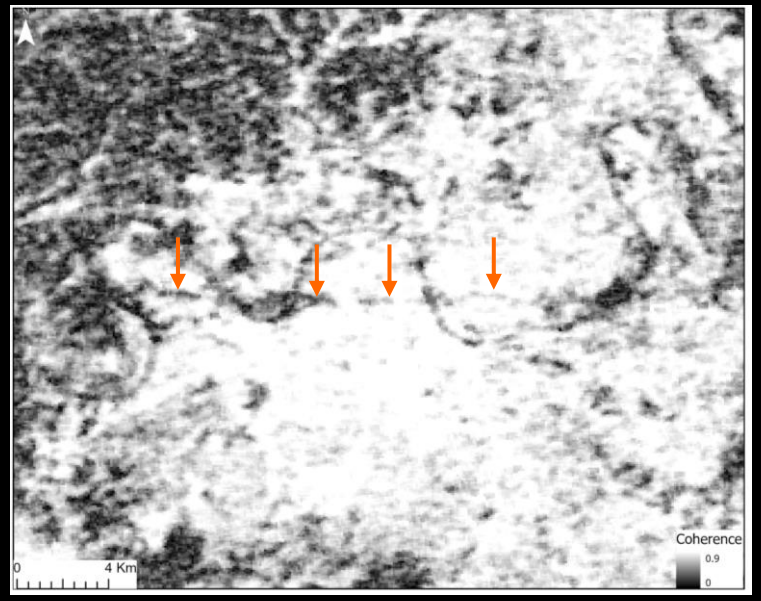
* Only 18.24 miles were covered with the image out of the entire length of 60.13 miles.

Nashville EF-3 Coherence Products

TerraSAR-X (3 m)
Descending
Pre: 1 February 2020
Post: 16 March 2020



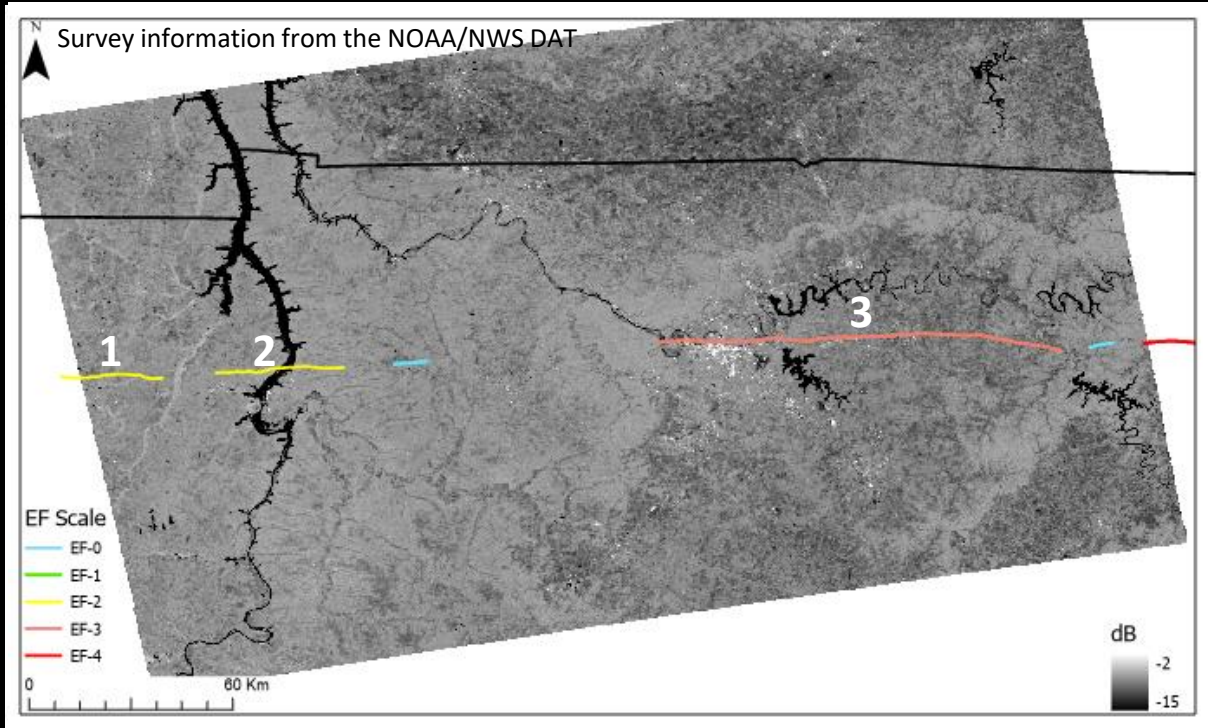
Sentinel-1 (40 m)
Ascending
Pre: 13 February 2020
Post: 8 March 2020



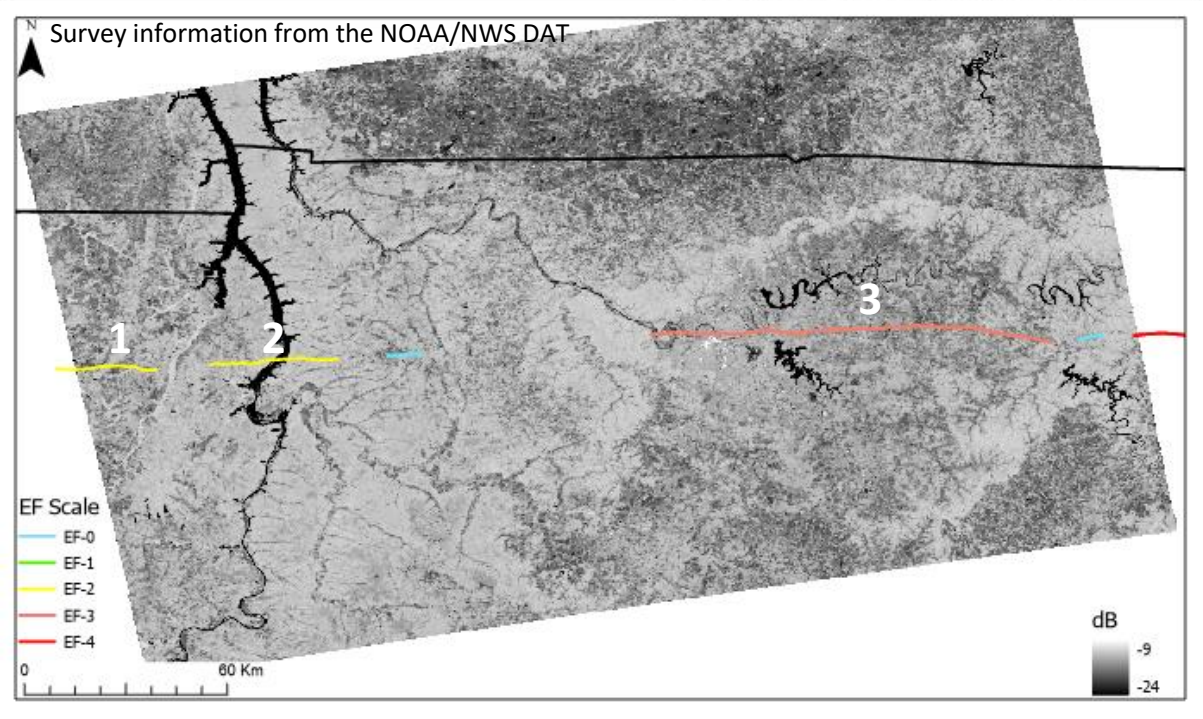
Sentinel-1 (80 m)
Ascending
Pre: 13 February 2020
Post: 8 March 2020

Nashville EF-3 30 m Amplitude Products

VV



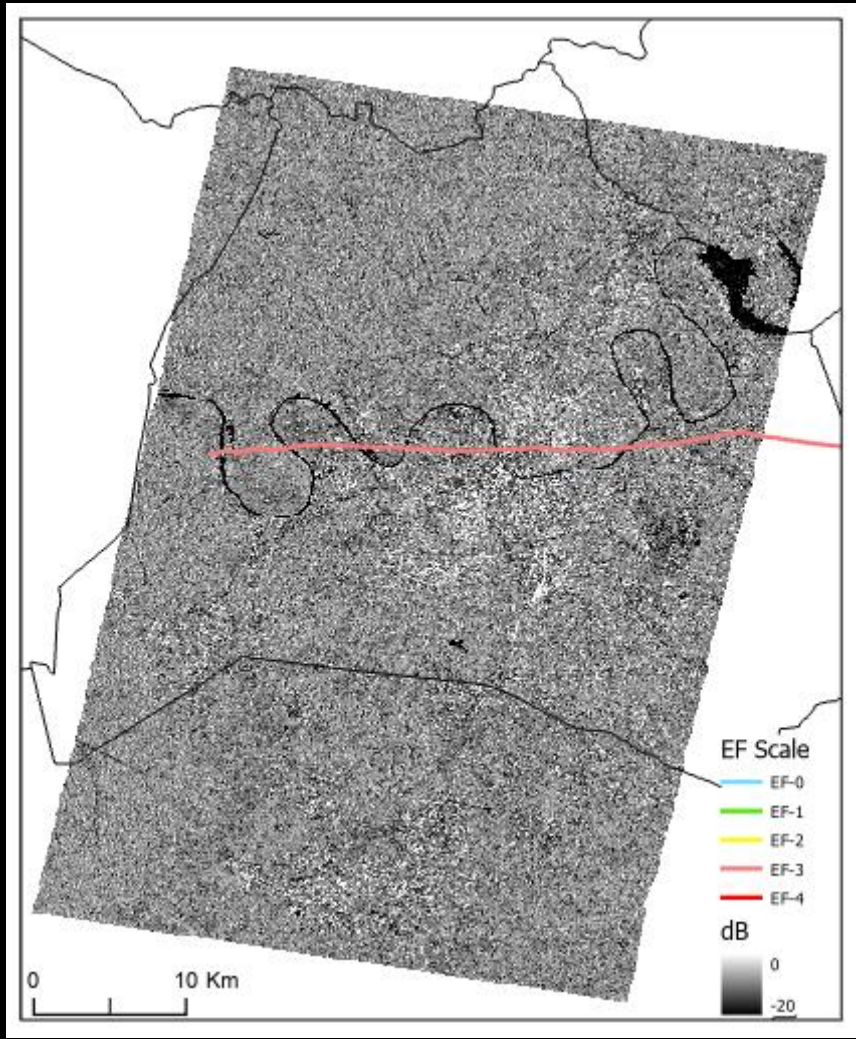
VH



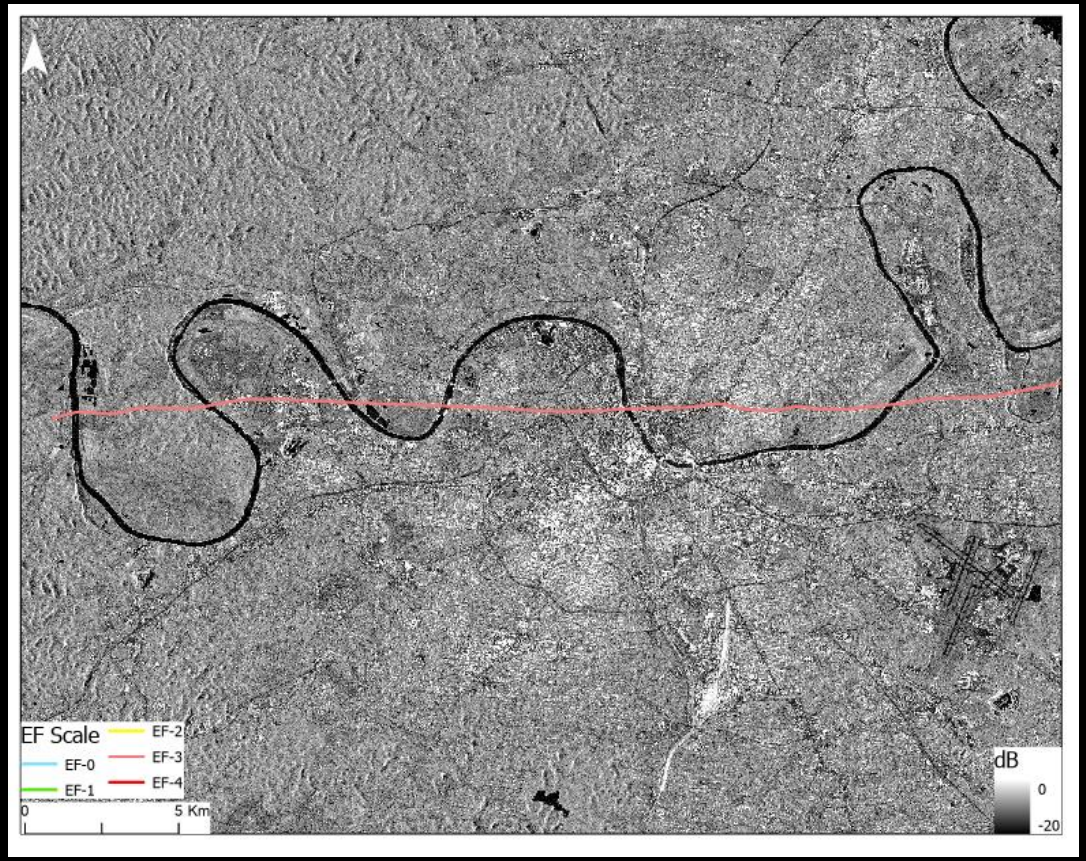
ID	Sentine-1 Derived Length (miles)	NOAA/NWS Length (miles)	Percentage of the track covered by Sentinel-1
1	3.45	14.8	23%
2	4.85	18.72	26%
3	11.6	60.13	19%

ID	Sentine-1 Derived Length (miles)	NOAA/NWS Length (miles)	Percentage of the track covered by Sentinel-1
1	N/A	14.8	N/A
2	N/A	18.72	N/A
3	10.26	60.13	17%

Nashville EF-3 TerraSAR-X Amplitude

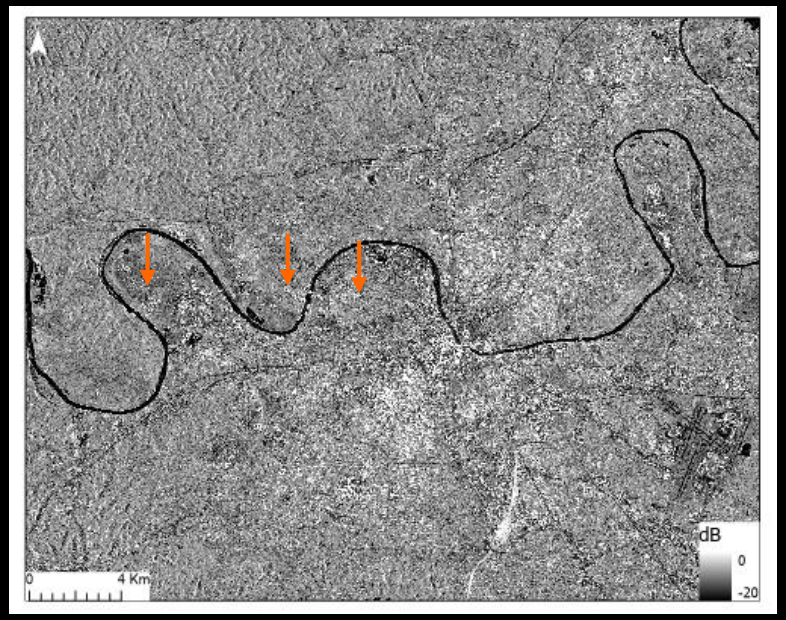


TerraSAR-X RTC HH
16 March 2020
Airbus Defense and Space GEO Inc U.S. 2020

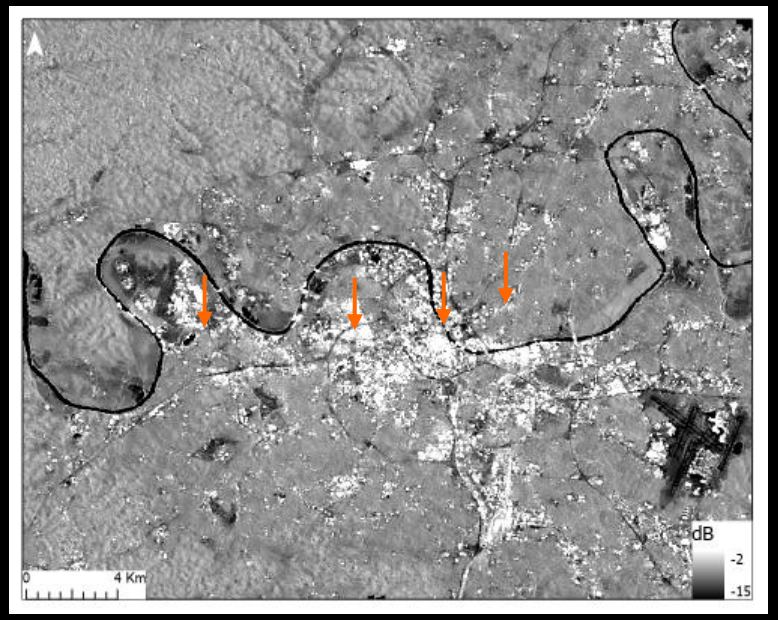


TerraSAR-X Derived Length (miles)	NOAA/NWS Length (miles)	Percentage of the track covered by Sentinel-1
5.24	*18.24	29%

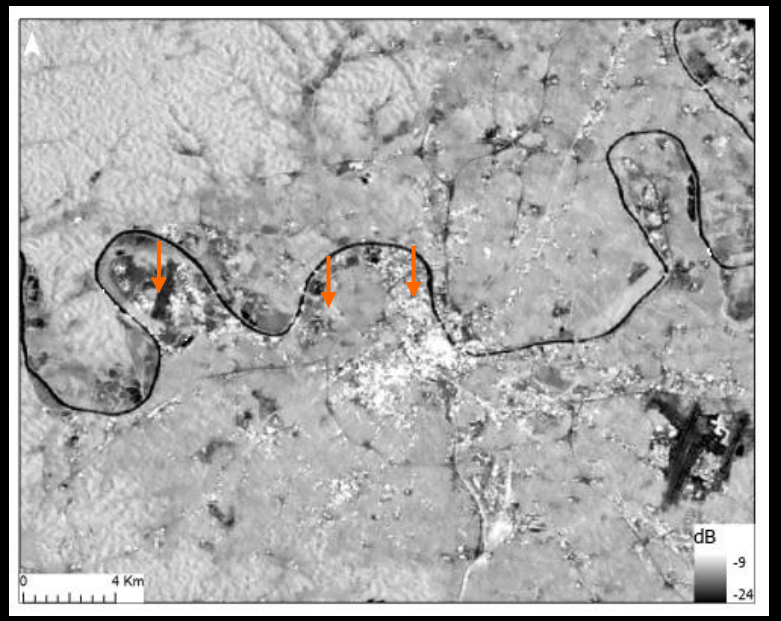
Nashville EF-3 Amplitude Products



TerraSAR-X (3 m)
Polarization: HH
16 March 2020



Sentinel-1 (30 m)
Polarization: VV
8 March 2020



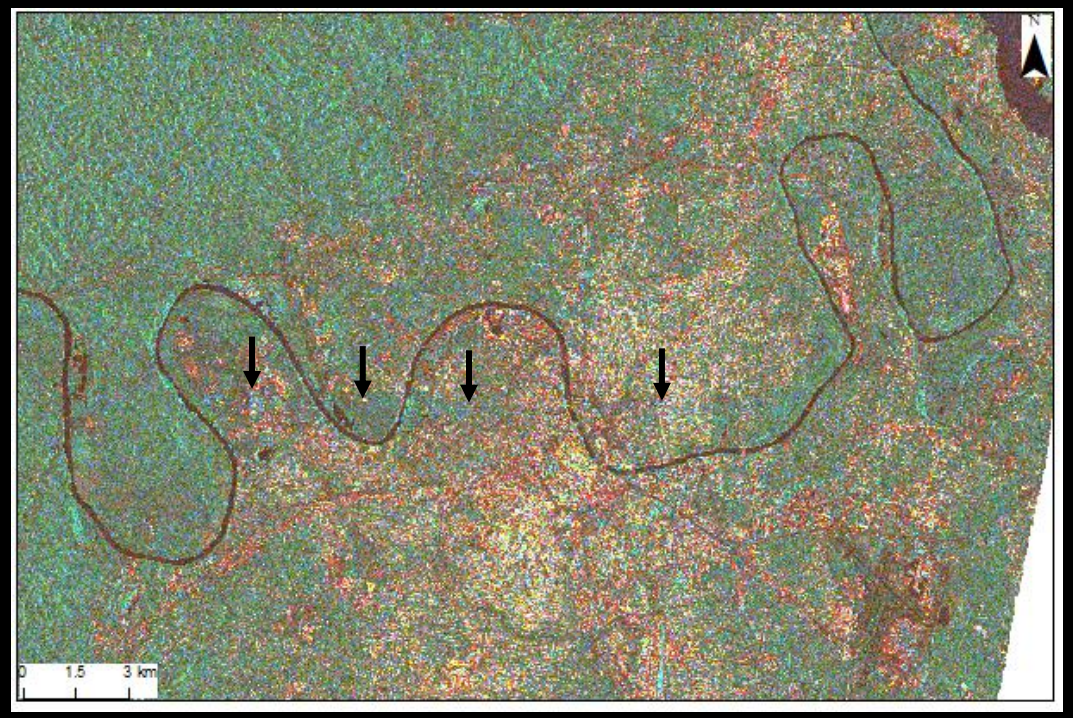
Sentinel-1 (30 m)
Polarization: VH
8 March 2020

Airbus Defense and Space GEO Inc U.S. 2020

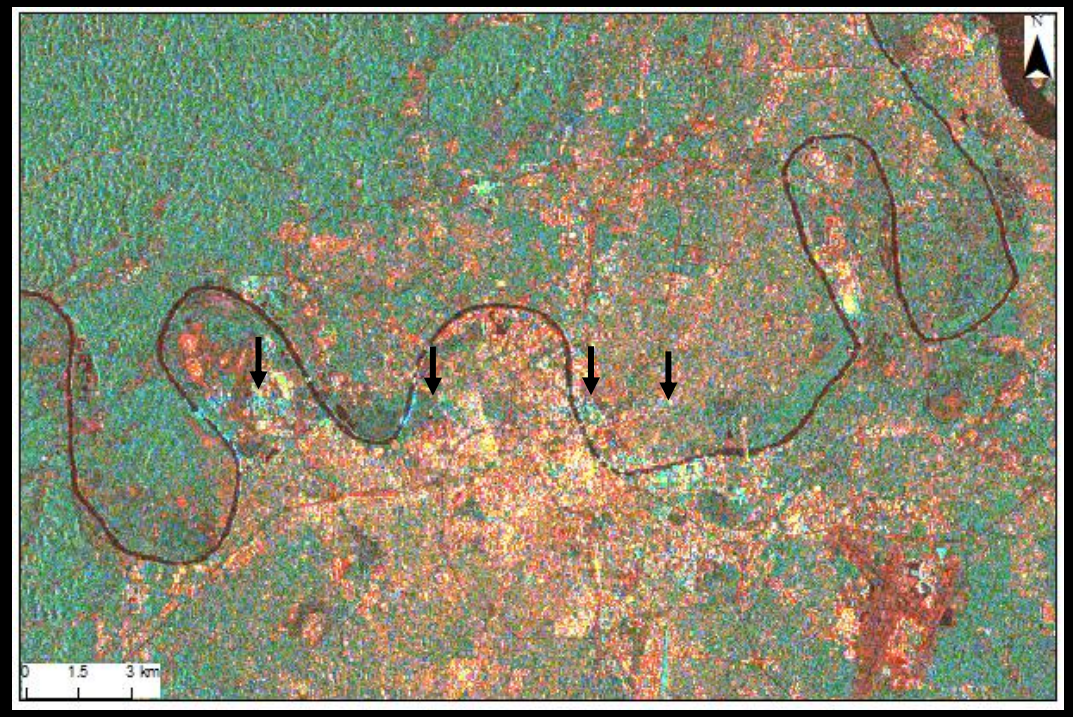
ASF DAAC 2023, contains modified Copernicus Sentinel data 2020, processed by ESA.

RGB Composite

TerraSAR-X
(Pre) 2/1/2020 & (Post) 3/16/2020

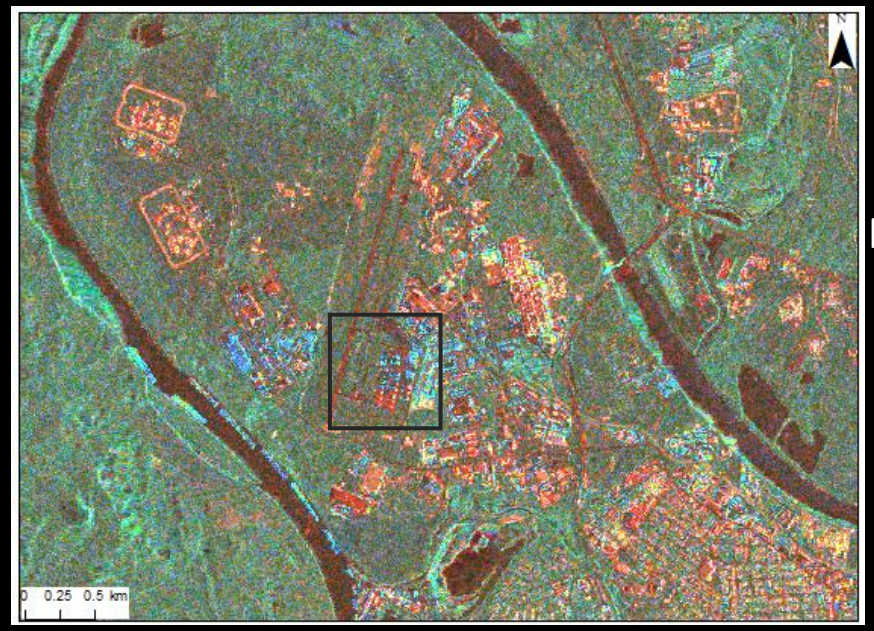


Sentinel-1
(Pre) 2/13/2020 & (Post) 3/8/2020

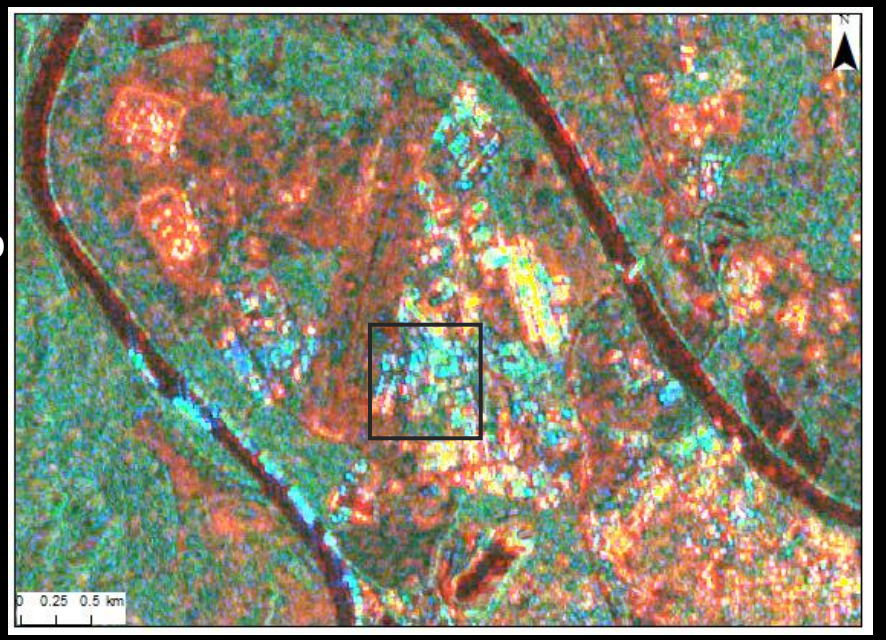


- The red channel (coherence): highlighting where the pre- and post-event scenes were similar.
- The green channel (average backscatter): normalizing the background, and highlighting areas dominated by vegetation.
- The blue channel (absolute value of the backscatter difference): resulting in areas of significant change having more blue contribution.

TerraSAR-X

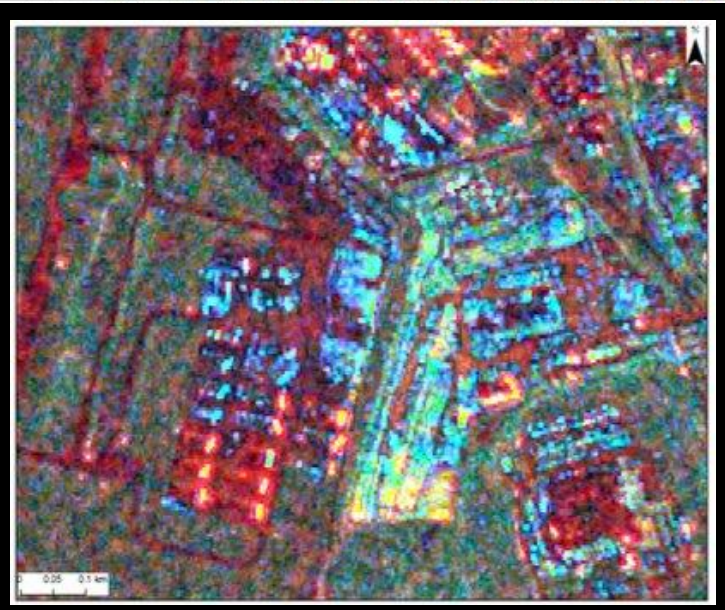


Sentinel-1



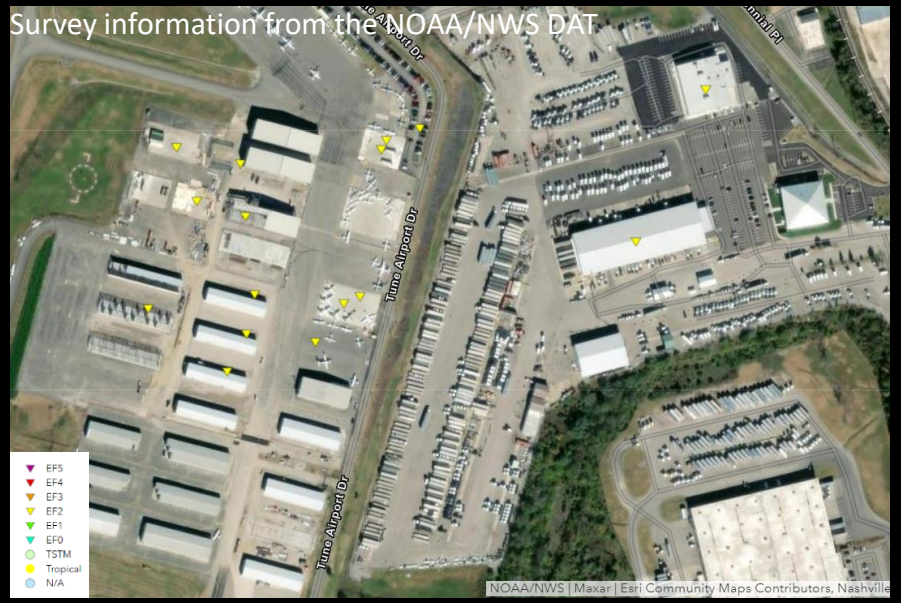
Nashville, Tennessee EF-3 Tornado
March 2-3, 2020
John C. Tune Airport Area

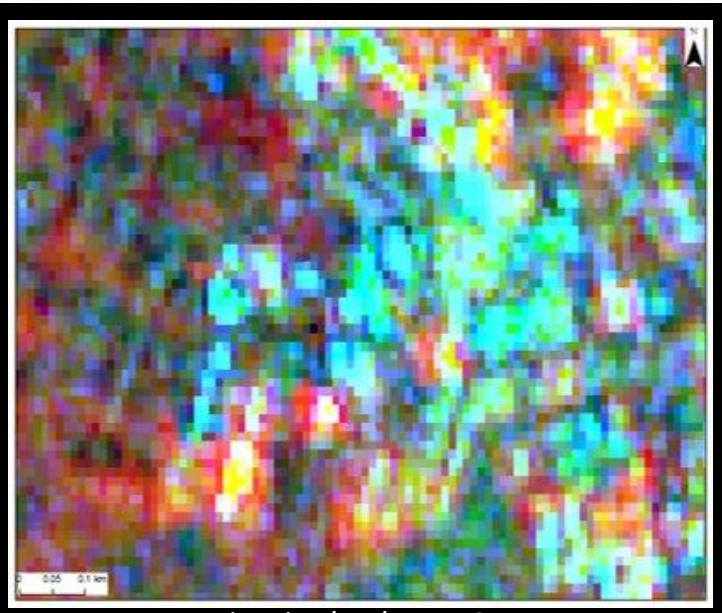
R: Coherence (phase)
G: Average backscatter (amplitude)
B: Absolute value of the Difference in backscatter (amplitude)



(Pre) 2/1/2020 &
(Post) 3/16/2020

Survey information from the NOAA/NWS DAT





(Pre) 2/13/2020 &
(Post) 3/8/2020

Preliminary Conclusions

- SAR amplitude and coherence products are proving beneficial in isolating damage caused by severe thunderstorm events (e.g., tornadoes and straight-line winds).
  - 3 (two EF-2's and the EF-3) out of the 5 tornadoes that covered the Nashville metropolitan area were able to be detected in the Sentinel-1 coherence image.
  - 2 (one EF-2 and the EF-3) out of the 5 tornadoes that covered the Nashville metropolitan area were able to be detected in the Sentinel-1 VV amplitude image.
- Lengths derived from the C-band Sentinel-1 data were very close to the official survey lengths.
  - Tracks were easier to identify in coherence than amplitude.
- Determining the length from the X-band TerraSAR-X data (amplitude and coherence) was very difficult.
  - X-band data did provide very beneficial in urban areas to detect damaged structures.
- Better detection for long track tornadoes and those with a higher EF rating (i.e., EF-2 or greater).
  - None of the EF-0 tornadoes were detected in the Sentinel-1 image in either the amplitude or coherence products.
  - Might improve with more X- and L- band coverage.
- Determining what situations using amplitude products is beneficial, either along with or in placement of coherence products.

Donelson Neighborhood, Nashville, TN
Image from the NOAA/NWS Damage Assessment Toolkit

Future Work

- Measuring tornado tracks (length and width) from several outbreaks during different seasons and over a variety of different land covers across the Southeast using both amplitude and coherence products.
  - Final preparations for a manuscript on this to be submitted very early in 2024.

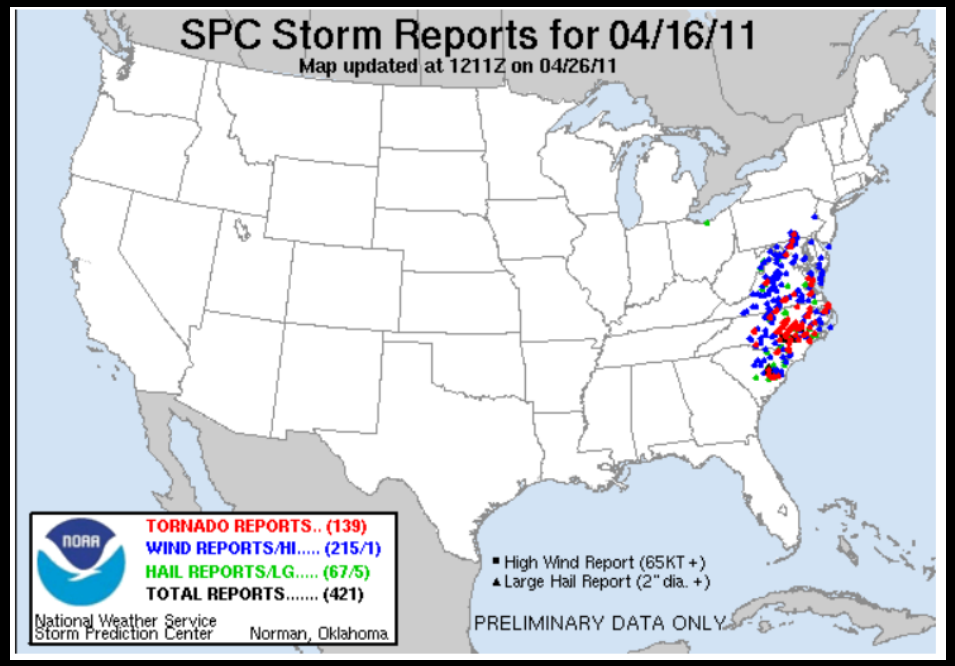
- Explore in greater detail the impact of using different polarizations to identify damage over different land cover types.

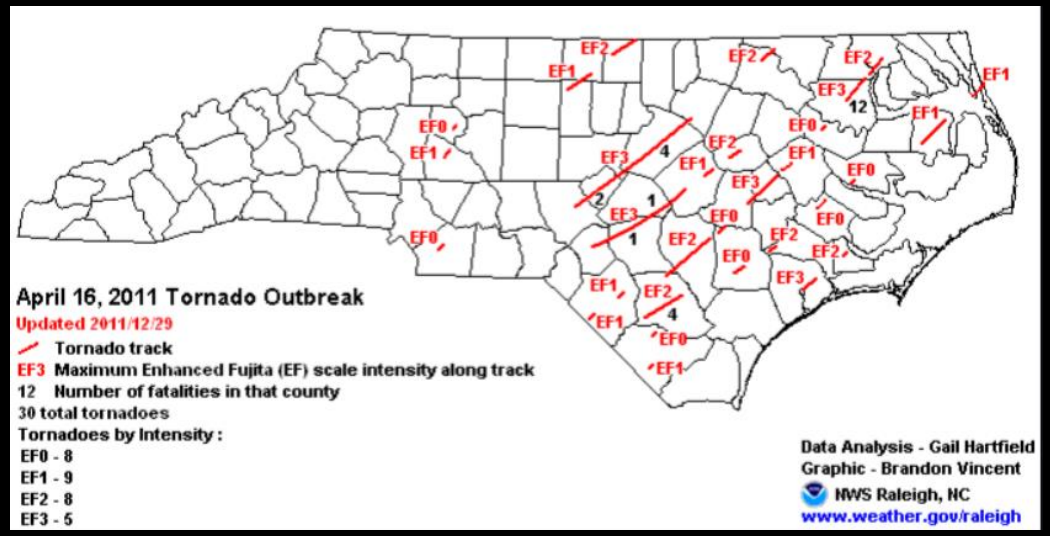
- The ultimate goal is to create a product that will isolate potential tracks using a semi-automated approach to provide a quick overall extent of the impacted area.

- The upcoming L-band (~24 cm) NISAR mission will provide more accurate estimates of damage especially in heavily vegetated areas, expanding the applications of SAR to assist in damage assessment caused by severe thunderstorms.

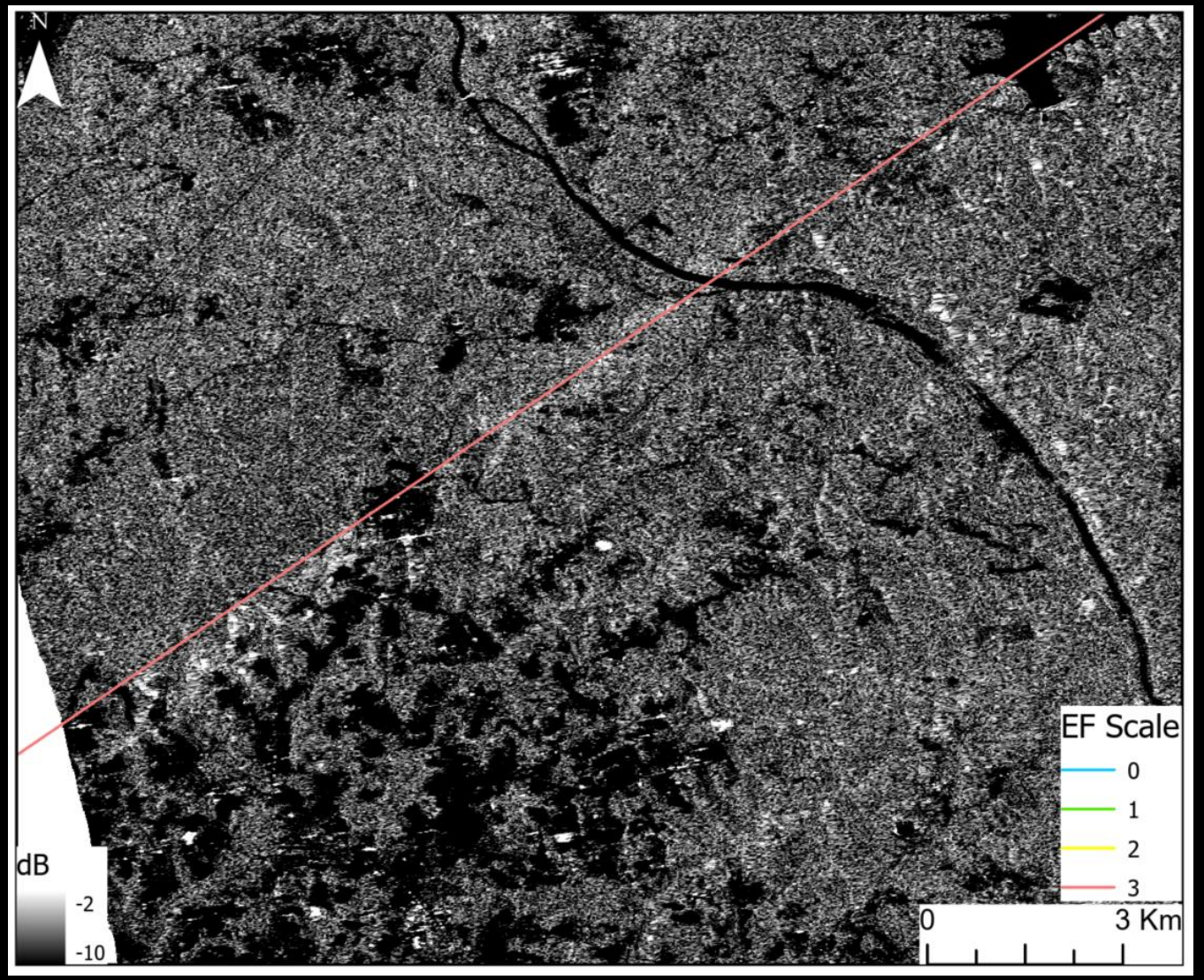
East Nashville, TN
Image from the NOAA/NWS Damage Assessment Toolkit

April 16th, 2011 Tornado Outbreak



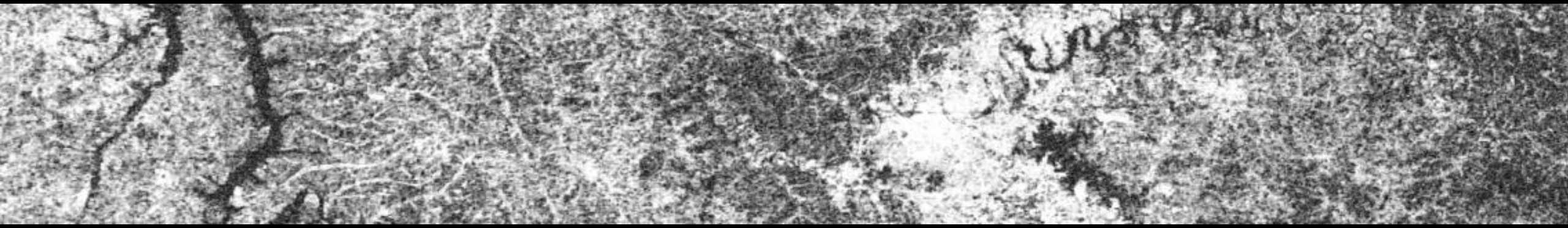


JAXA's ALOS PALSAR L-Band (~24 cm)
Polarimetric mode (VV), high-resolution RTC ~12.5 m



Dataset: ASF DAAC 2023, ALOS PALSAR_Radiometric_Terrain_Corrected_High_Res; Includes Material © JAXA/METI 2011.
Accessed through https://asf.alaska.edu 27 November 2023.

Thank You!



Acknowledgment

TerraSAR-X data was provided through the NASA Commercial SmallSat Data Acquisition Program.

Contact Information:

hannah.g.pankratz@nasa.gov