GOES-R Proving Ground/Risk Reduction Update: Tropical Cyclone Applications

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Tropical Cyclone Operations and Research Forum

75th IHC March 2021

With contributions from Monica Bozeman, Lee Byerle, Galina Chirokova, John Knaff, Alex Kowaleski, Dan Lindsey, Steve Miller, Debra Molenar, Kate Musgrave, Andrea Schumacher, Chris Slocum, Dakota Smith, Stephanie Stevenson,Chris Velden, Joe Zajic

Outline

- Overview of the GOES-R PGRR Program
- Quantitative ABI/GLM analysis/forecast algorithms
- Situational awareness products/training
- Cloud AWIPS for enhanced developer forecaster interactions
- A look ahead to GeoXO

GOES-R Proving Ground/Risk Reduction

- GOES-8 Launched in April 1994, Data available fall of 1994
  - Much higher IR spatial resolution, separate sounder, faster sampling
  - NWS was not ready for GOES-8 (AWIPS delayed, forecasters not fully training)
- GOES-8 lessons learned: GOES-R PG/RR program started a decade before launch
  - Training directly with NWS National Centers and WFOs using proxy data
  - Satellite liaisons assigned to OPC/WPC/SAB, SPC, AWC, NWS Training Center, OCONUS sites
    - Current Liaisons:
      - WPC/OPC: Javier Villegas Bravo
      - OPG: Connor Nelson
      - SPC/HWT: New hire
    - Current NHC/HRD product developers: Stephanie Stevenson → M. DeMaria, Andrea Schumacher, Debra Molenar
    - Liaison alumni: Michael Folmer, Chris Siewert, Israel Jirak, Bill Line, Jordan Gerth, Amada Terborg, Kaitland Rutt, Michael Bowland, Andrea Schumacher
  - Algorithm Working Group - Pre-launch product development
  - GOES-R Risk Reduction – Directed grants program for new applications

Quantitative Analysis/Forecast Algorithms

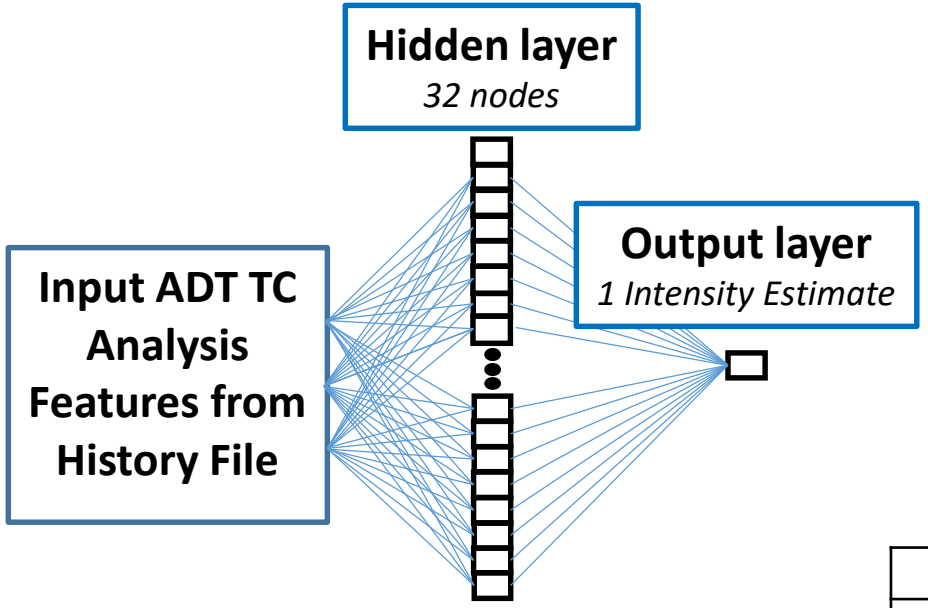
- Intensity estimation: AiDT
- Intensity Forecasting:
  - GLM: Lightning and rapid intensity change
  - Increased use of IR imagery for NHC intensity models
    - SHIPS, LGEM, SHIPS-RII
  - Global RI guidance (RIPA)
- Quantitative applications of Atmospheric Motion Vectors
  - Optical flow method for more accurate AMVs
  - AMVs for storm-centered vertical shear analysis

The Advanced (AI-infused) Dvorak Technique (AiDT)

Improving the ADT estimates of TC intensity using Machine Learning (ML)

Tim Olander, Chris Velden, Tony Wimmers

Motivation: Can we use ADT TC analysis information augmented with ML to improve ADT intensity estimates from Geo sats?



Model Development:

- Utilize ADT-V9.0 analyses for all global TCs from 2005-2016 for training the ML model
- 26 ADT analysis features are input into 1-layer ML model with 32 nodes
- Independent test/validation: 2017 TCs, verified vs. NHC/JTWC interp. Final Best Track max wind

Results:

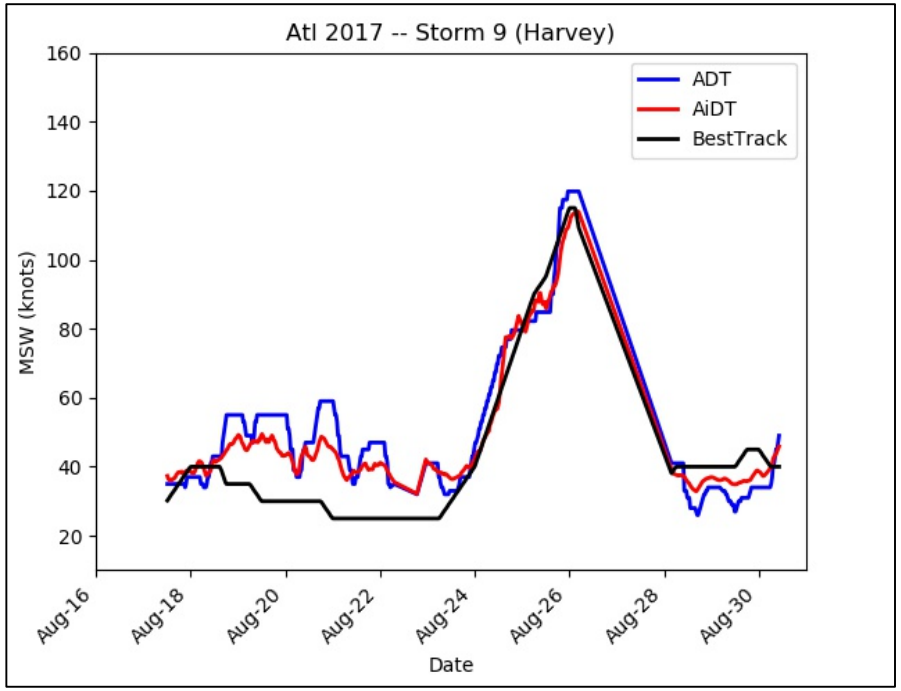
- ***AiDT notably improves ADT estimates, especially TS, H1, and H2 intensities***
- AiDT results competitive with more complex/time-consuming direct image analysis ML models; demonstrated to run in real time at 30 min. intervals

Using GOES-16 imagery

2017	Atlantic Basin *(n=5188)*		
Vmax (kt)	*Bias*	*MAE*	*RMSE*
ADT	-0.91	9.50	**12.33**
AiDT	0.33	6.59	**8.44**

Using GOES, Himawari, Meteosat imagery

2017	All Basins *(n=18672)*		
Vmax (kt)	*Bias*	*MAE*	*RMSE*
ADT	-0.13	8.50	**10.98**
AiDT	-0.35	6.03	**7.70**



GOES GLM: Lightning and TC intensity change

Project Objective Develop rapid intensification index (RII) that incorporates lightning predictors from GLM

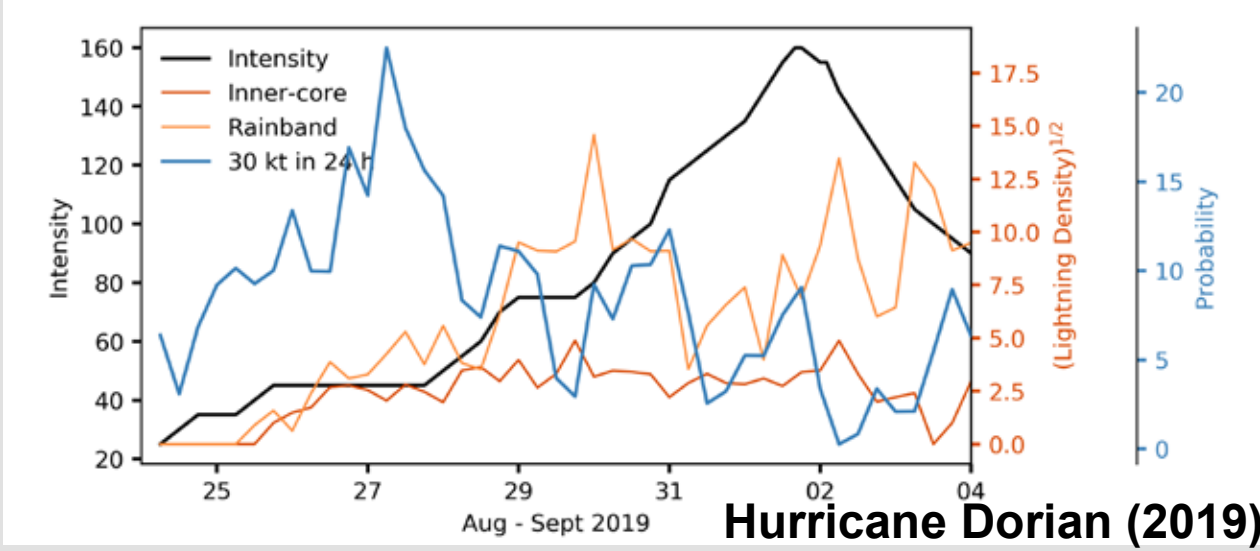
Methods

- Linear discriminate analysis (LDA)
- Regression of satellite-based GLM *(2017-present)* to ground-based WWLLN *(2005-present)* – longer historical lightning from ground-based networks needed for training

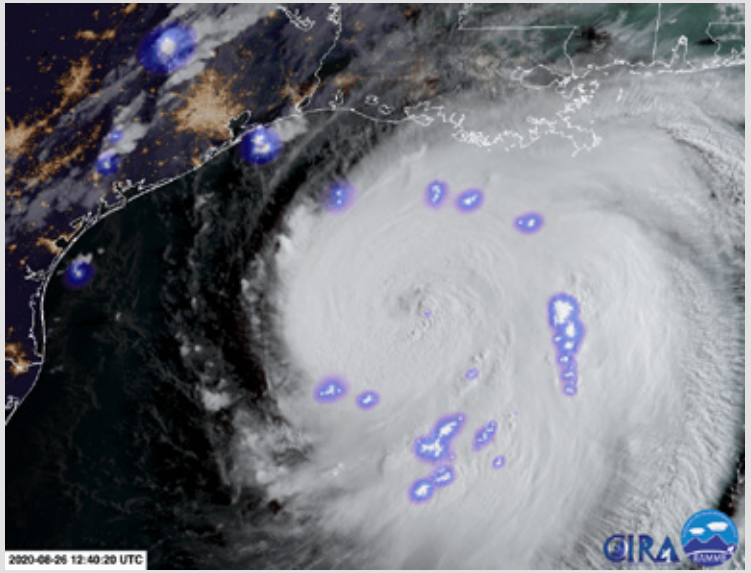
Status

- Real-time experimental version planned for 2021 hurricane season at NHC and CIRA
- Hollings Scholar will test additional lightning predictor configurations in summer 2021

Core Team Chris Slocum (NOAA/NESDIS), Stephanie Stevenson (NOAA/NHC), Kate Musgrave (CIRA/CSU)



Hurricane Dorian (2019)



Major Hurricane Laura (2020)

GOES GLM: Lightning and TC intensity change

Project Objective

- Extract TC structure from GOES GLM data and use its temporal variability to supplement TC intensity forecasts
- Develop a real-time tool for TC intensity change that uses GLM lightning

Methods

Machine learning (e.g., convolutional neural networks [CNNs])

Status

- Research phase, year 1 of funding
- 2023 season: real-time demo planned

Core Team

Stephanie Stevenson (NOAA/NHC), Kate Musgrave (CIRA/CSU), Kyle Hilburn (CIRA/CSU), Alex Kowaleski (CIRA/CSU)

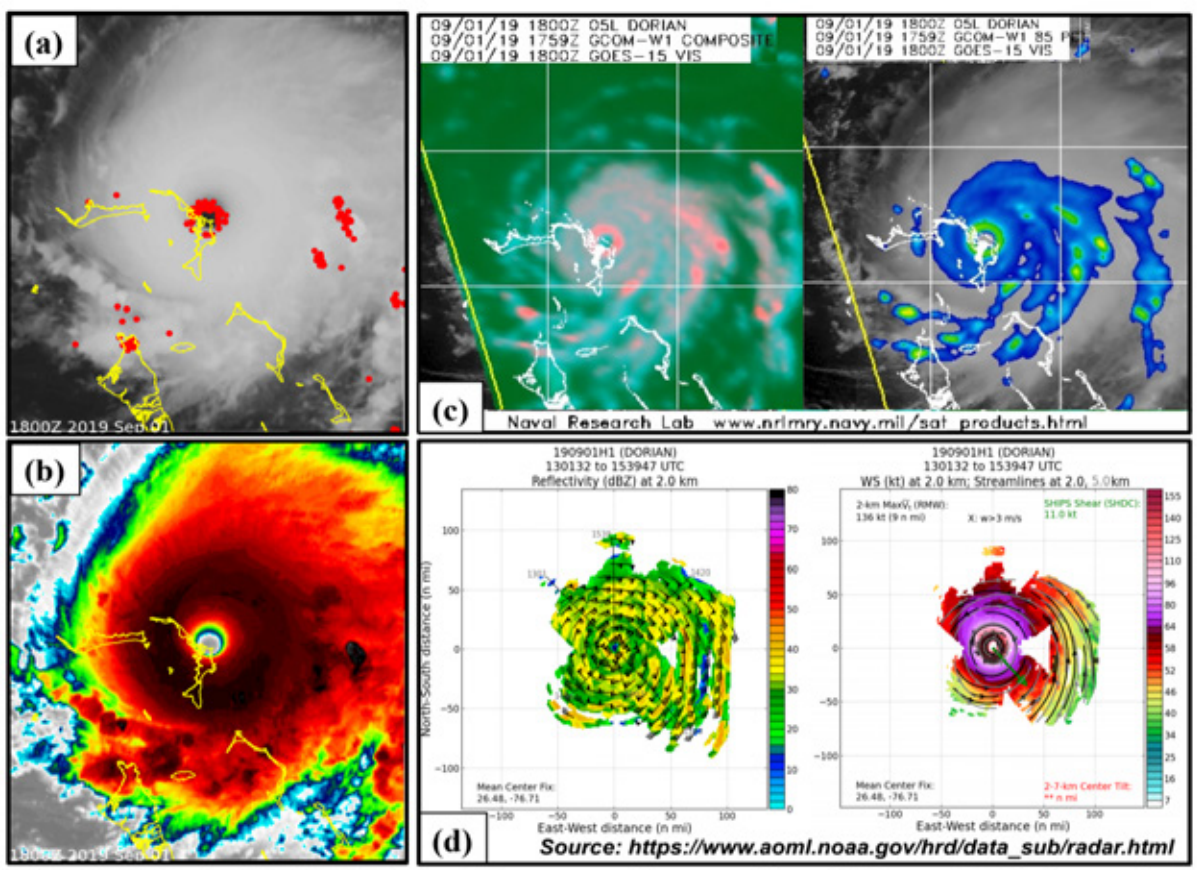
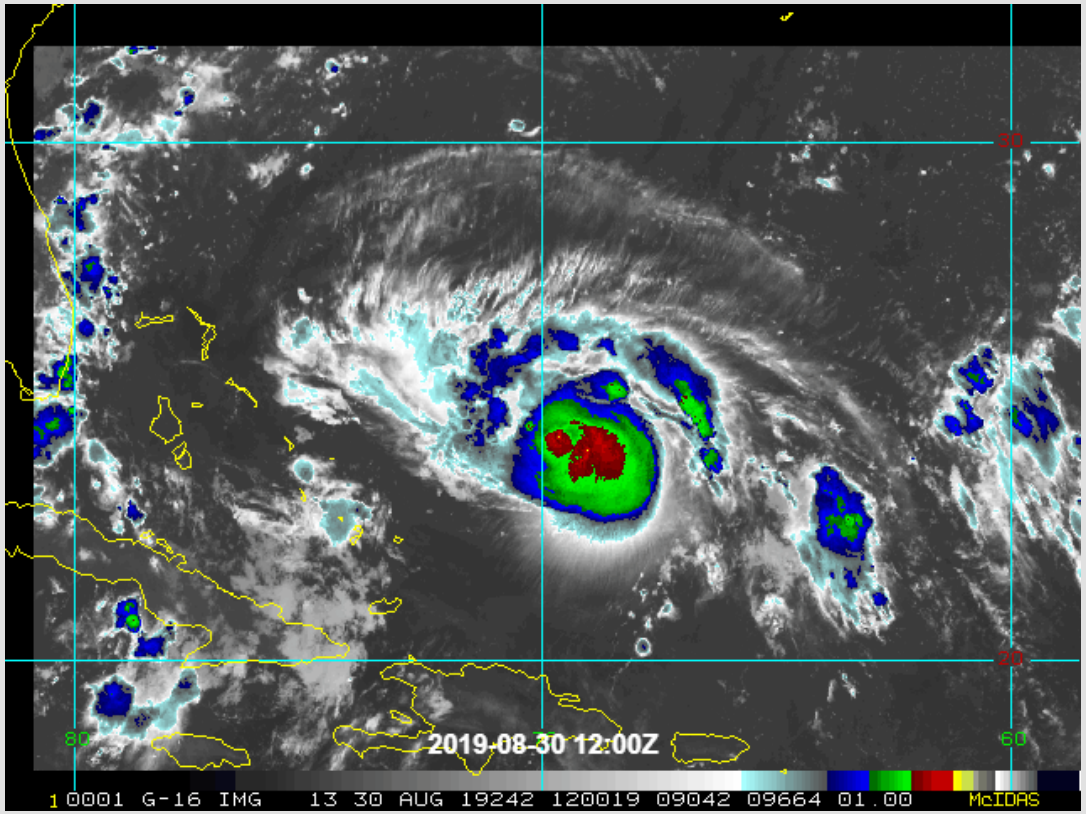


Figure 6. Sample GOES ABI 10.3μm IR imagery: (a) greyscale with 30-min GLM lightning flash centroids [red] and (b) color-enhanced, (c) AMSR-2 microwave imagery [left: Color 37-GHz, right: Polarization Correction Temperature (PCT) 85 GHz], and (d) NOAA TDR analyses [left: radar reflectivity composite, right: wind structure composite] from Hurricane Dorian at 1800 UTC 1 Sep 2019.

GOES-ABI: Increased use of IR data for NHC Statistical Intensity Models

- SHIPS/LGEM GOES-IR predictors
  - 50-200 km % area with brightness T < -20°C
  - 50-200 km brightness T std dev
- SHIPS-RII GOES IR predictor
  - 2nd Principal component of IR BT
- Increased use of temporal data
  - Objective eye detection algorithm and its time tendency
  - Complex principal component method in storm-centered r-θ coordinates
    - Detects amplitude and phase of propagating features
- Project team: M. DeMaria, S. Stevenson, J. Kaplan, J. Knaff



GOES-16 10.3-μm Imagery for Hurricane Dorian 30 Aug 2019 12-18 UTC

The Rapid Intensification Prediction Aid (RIPA)

Global tropical cyclone RI guidance

RIPA Provides (global):

1. Probabilistic forecasts for 10 RI thresholds
2. Deterministic forecasts for addition to intensity consensus aids

13 Predictors:

- Model forecasts (5) (shear, divergence, RH, temperature advection, eddy Fluxes)
- Ocean (2) (oceanic heat content, SST/potential intensity)
- GOES/GEO (4) (Convective vigor/organization, TC size, inner-core size)
- Current conditions (2) (intensity, 12-h intensity change)

Input:

SHIPS Large Scale Diagnostics

Use:

Operational at JTWC (IO,WP, SH)

Testing at NHC (AL, EP)

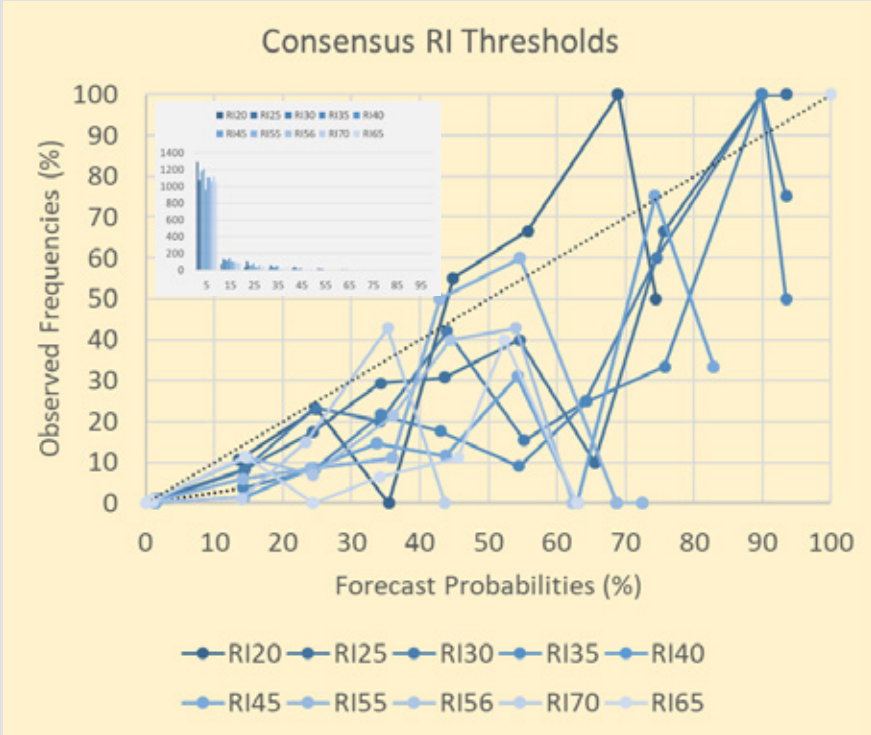
Performance:

JTWC loves their guidance!

RIPA was as good as DTOPS in the Atlantic (Matt O.)

Project Lead: J. Knaff NOAA/NESDIS

Atlantic/E. Pacific Preliminary Evaluation



Threshold	Climatology (%)	BSS (%)
RI20	6	24
RI25	12	21
RI30	8	18
RI35	5	7
RI40	3.5	-17
R45	6	4
RI55	5	7
RI56	6	6
RI70	3	1
RI65	8	-5

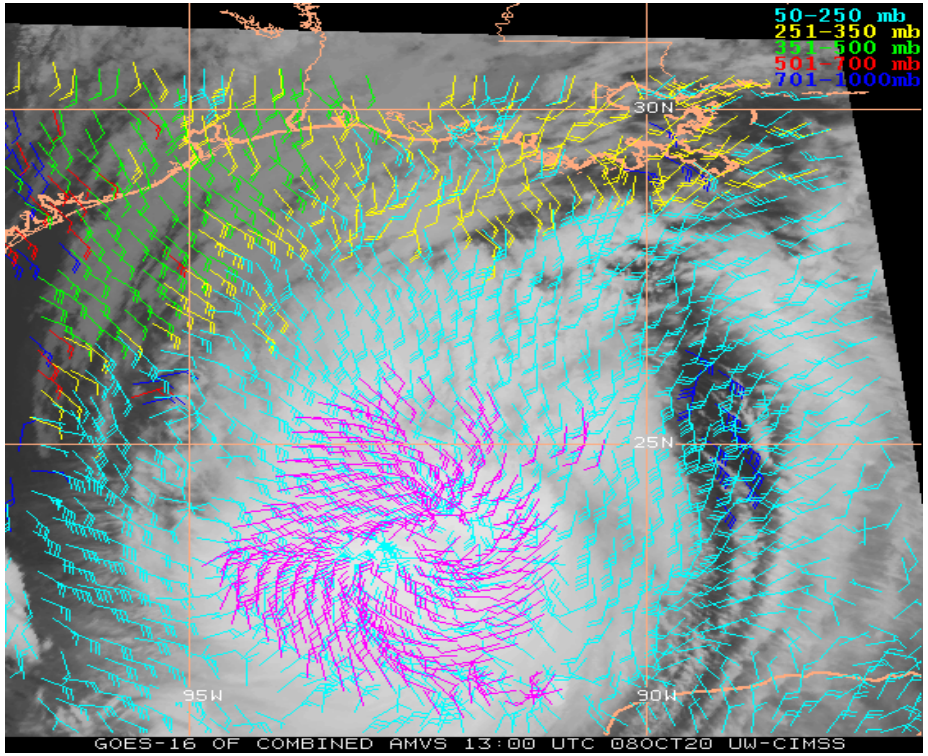
GOES/GEO provide real-time estimates of the **vigor** of deep convection, the **organization of deep convection**, and estimates of **storm and inner core size.**

Rapid intensity changes, especially in the next 36 hours, are more likely when there are wide-spread cold (<-50C) cloud tops that are symmetric about the center and storm have smaller sizes and cores.

GOES-R Risk Reduction and Proving Ground Project:
Development of TC Vortex-scale Atmospheric Motion Vector Fields and Assimilation into Hurricane Forecast Models

Project Goals: 1) Develop ultrahigh spatiotemporal atmospheric motion vector (AMV) datasets derived from the new-generation GOES-R series ABI 1-min. meso sector scans targeting tropical cyclones (TCs), optimize their assimilation into TC forecast models, and transition to operations.

2) Demonstrate novel Optical Flow tracking methodology for producing AMVs in the very cold/coherent clouds in the Central Dense Overcast region of TCs where conventional AMV techniques can struggle.



Example: Hurricane Delta AMV fields produced at 15-min. intervals (OF vectors in magenta)

Stakeholders/ End Users: NHC, CPHC, JTWC TCFOs, NCEP/EMC/HRD TC models

Contributors:

CIMSS: Chris Velden, David Stettner, Steve Wanzong, Will Lewis

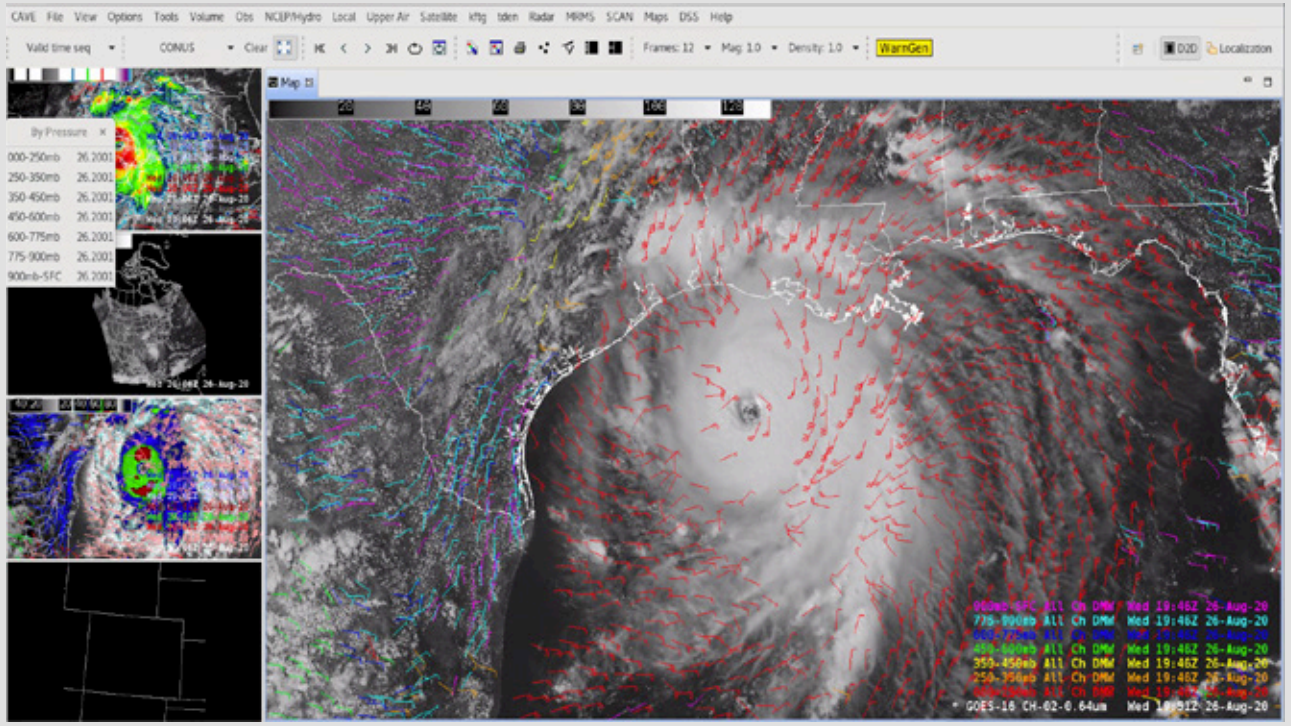
NOAA: Robert Rabin, Jaime Daniels, Jason Sippel

Project Progress:

- Proof of concept completed through case studies R&D
- Data assimilation activities underway with hurricane modeling partners (i.e. HWRF model)
- Data quality/validation studies ongoing (comparisons with high-level G-IV FL data/dropwinsondes)
- Successful completion of automated real-time demo with GOES-16 during full 2020 Atlantic TC season
- Plan to extend processing methodologies to GOES-17 and possibly Himawari-8/9
- Readying product for transition to NESDIS Enterprise system implementation and testing with STAR partners

GOES AMVs for Vertical Shear Diagnostics

- Use AMVs to diagnose vertical shear
  - Storm-relative framework
  - Compare with global model shear
  - Complements CIMSS shear products
- Automated tool with several specified averaging radii
- AWIPS application with user-specified input
- Project team: M. DeMaria, A. Schumacher, D. Molenar



AWIPS display of AMVs for Hurricane Laura

GOES Products for Situational Awareness/Training

- ABI/GLM Quick Guides
- ProxyVisible for nighttime TC analysis
- GeoColor for analysis/media briefings/outreach
- Synthetic microwave imagery from ABI
- GeoColor for media briefings/outreach

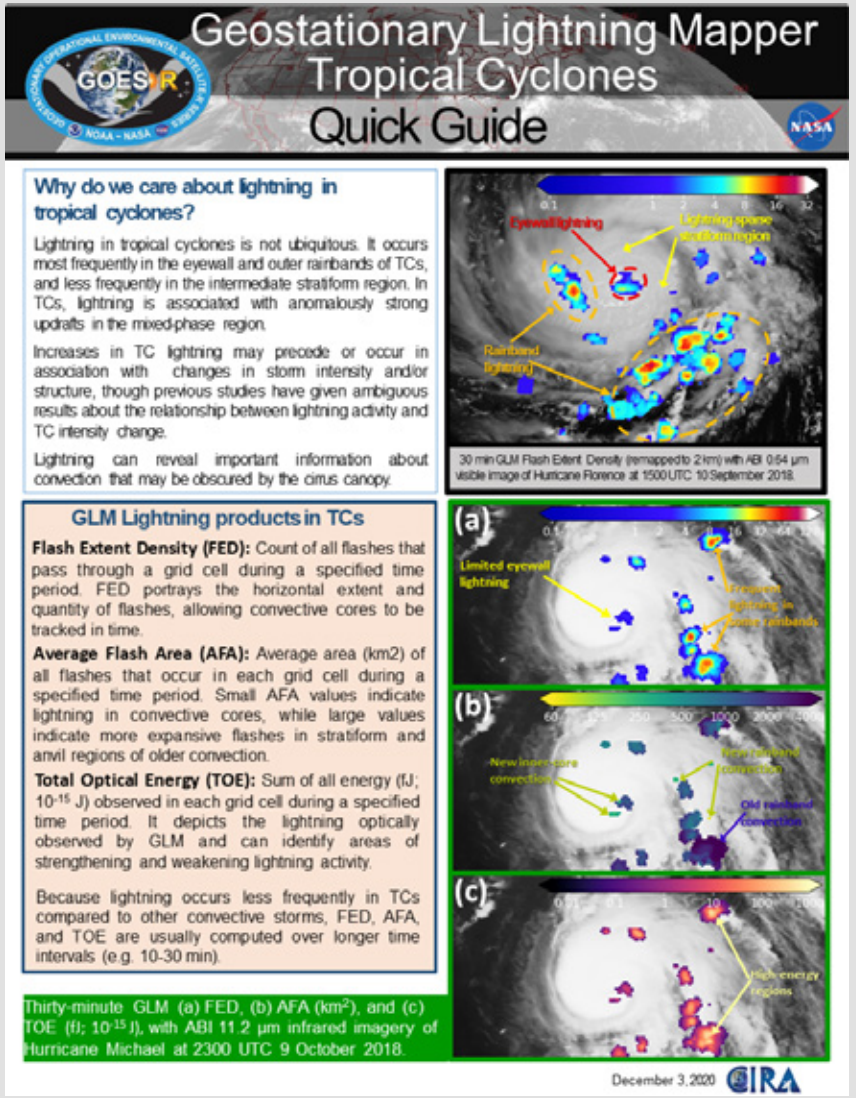
VISIT

- VISIT Home
- Training Sessions
- Training Calendar
- Blog Sites
- FDTD Satellite Applications Webinars
- VISIT Satellite Chat
- VISIT Satellite Help Desk
- The VISIT Program
- VISIT Contributors
- VISIT FAQ
- Links / Tutorials
- RAMSDIS Online
- Quick Reference

Quick Guides

Below is a list of Quick Guide reference documents for satellite imagery and products. SBN availability refers to availability in AWIPS via the Satellite Broadcast Network, products not on the SBN are generally still available in AWIPS via the LDM.

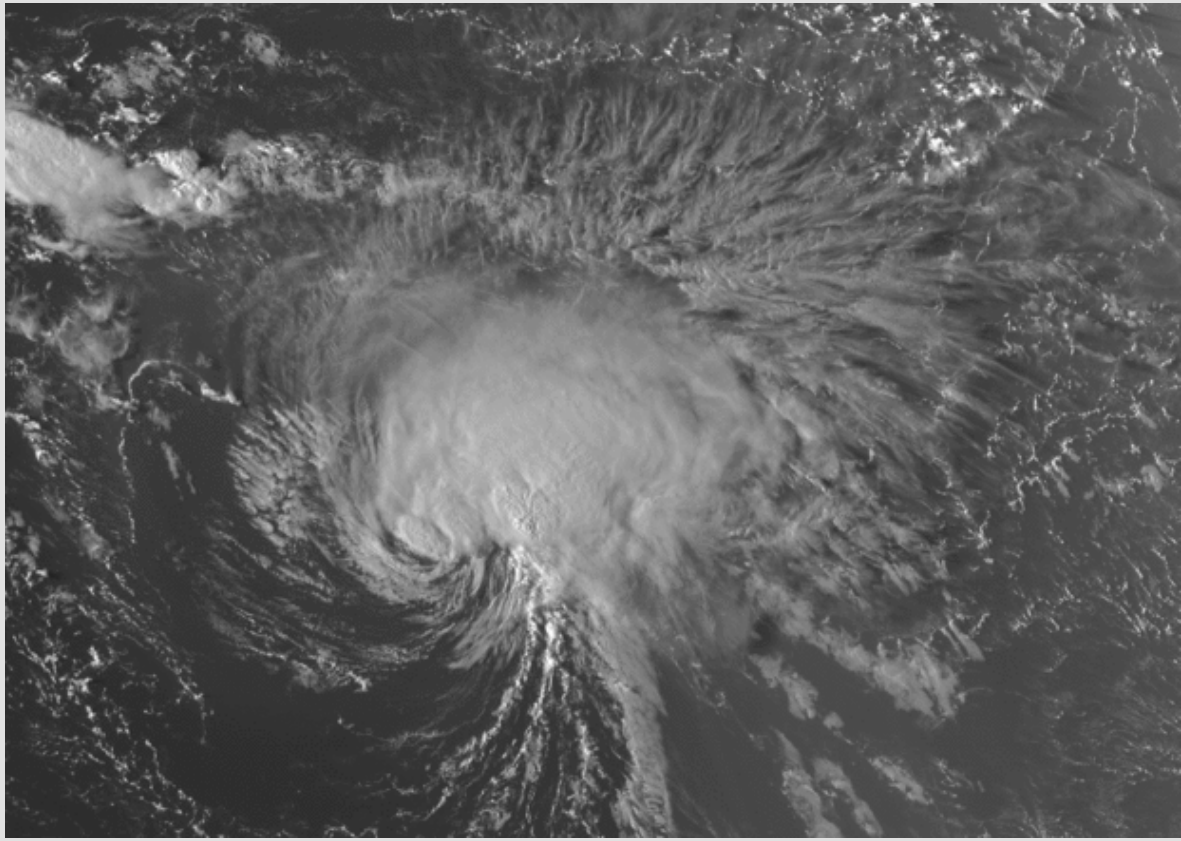
Product	Last Updated	SBN availability	Satellite	Category
DEBRA-Dust Product	2021-02-17	N	GOES-R Series	Product
Turbulence Probability Product	2020-12-03	Y	GOES-R Series	Product
GLM Minimum Flash Area (MFA)	2020-12-03	Y	GOES-R Series	GLM
GLM Full Disk Gridded Products	2020-12-03	Y	GOES-R Series	GLM
Fire / Hot Spot Characterization	2020-08-12	Y	GOES-R Series	Product
GOES-R IFR Probability	2020-08-07	N	GOES-R Series	Product
GOES-R Cloud Thickness	2020-08-07	N	GOES-R Series	Product
Legacy Vertical Profiles	2020-07-24	N	GOES-R Series	Product
GCOM AMSR2 Winds	2020-02-07	N	JPSS	Product
Jason Signficant Wave Height	2019-10-11	Y	JPSS	Product
Day Snow/Cloud Layers	2019-08-14	N	GOES-R Series	Product
Gridded NUCAPS	2019-08-02	N	JPSS	Product
SAR Winds	2019-04-15	N	JPSS	Product
VIIRS Active Fire	2019-02-08	N	JPSS	Product
Day Snow Fog	2020-06-11	Y	GOES-R Series	RGB
JPSS Snowfall Rate	2018-10-12	N	JPSS	Product
GCOM AMSR2 SST	2018-10-12	N	JPSS	Product
VIIRS Cloud Base Height	2018-10-05	N	JPSS	Product
VIIRS Ice Surface Temperature	2018-08-15	N	JPSS	Product
VIIRS Ice Concentration	2018-08-15	N	JPSS	Product
VIIRS Flood Extent	2018-08-07	N	JPSS	Product
GLM Average Flash Area and Total Optical Energy	2018-08-07	Y	GOES-R Series	GLM
GLM Data Quality	2018-08-07	Y	GOES-R Series	GLM



http://rammb.cira.colostate.edu/training/visit/quick_guides/

ProxyVisible Imagery

- Combines several IR channels to enhance cloud features at night
- Routinely used by NHC in operations
  - Also being provided to OPC/WPC
- Algorithm being improved
  - ML techniques
  - Tuning for specific conditions
  - Land vs ocean, low vs high latitude
  - Specialized version for ET transition
- Project lead: Galina Chirokova



ProxyVisible imagery for Hurricane Florence 7 Sept 2018

GeoColor Imagery

- Daytime visible color image
  - Estimates green from Vis, SW/IR channels
- 11-3.9 µm IR channel difference at night
- Static city lights image background at night
- Future plans
  - Creation in ISatSS
  - Replace night imagery with ProxyVisible
  - Add SST layer
- Project Team:
  - Steve Miller, Dakota Smith, NRL

GeoColor loop for Hurricane Sally (2020)

AI Synthetic Passive Microwave from GOES-R

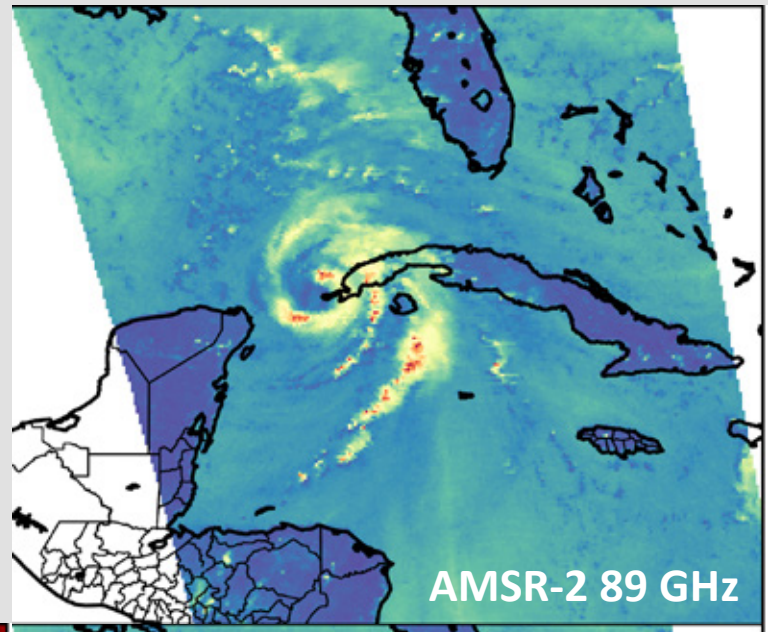
Operational Need:

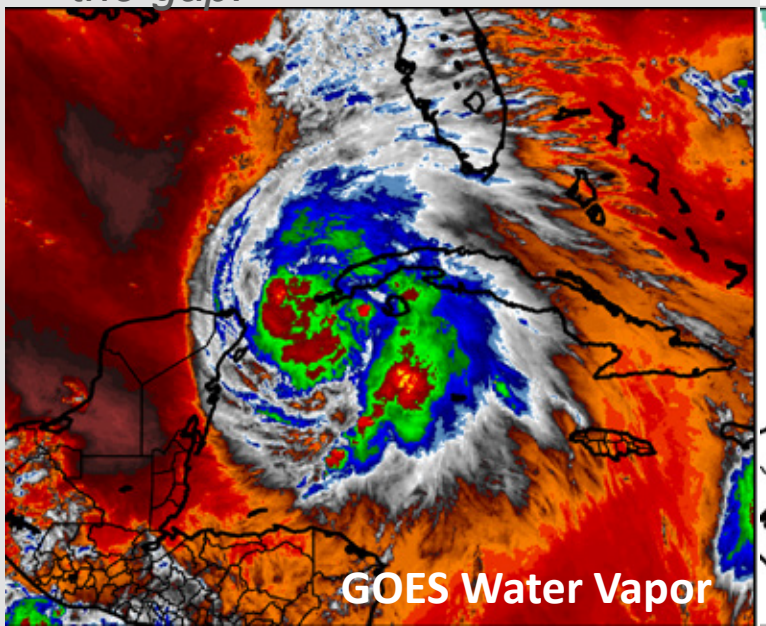
- Simulated microwave imagery with input from GOES Advanced Baseline Imager
- Routinely-available low- & mid-level information about convective structure in tropical cyclones

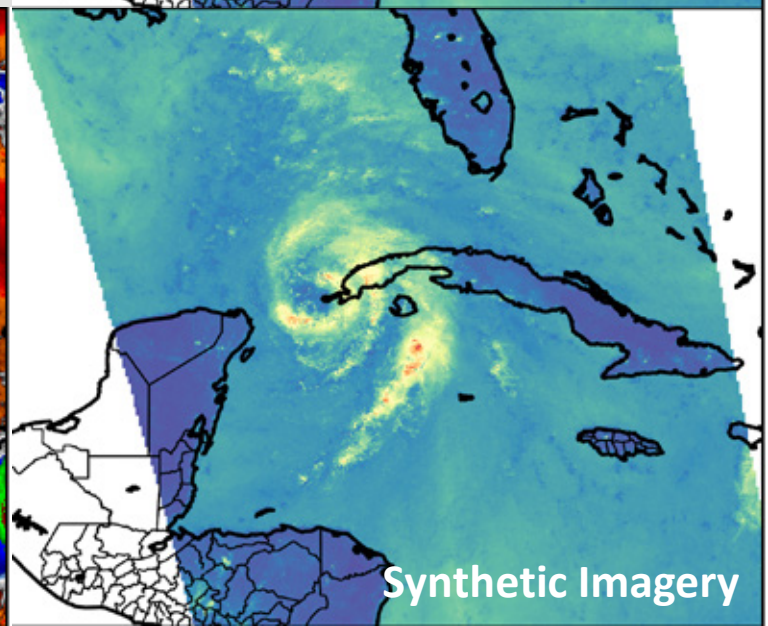
Setup:

- Input: GOES ABI imagery (12 of 16 channels)
- Validation: AMSR2 microwave channels
- Output: Synthetic microwave imagery
- Models:
  - Pixel based (traditional ML / Random Forest)
  - Deep learning (CNN/U-Net)

Example from Hurricane Michael (2018) off Cuba. From GOES-16 water vapor, the eye is obscured. In microwave imagery, clearly visible. Microwave from polar may not be available during critical forecasts. Synthetic microwave from GOES-16/-17 data can fill the gap.







AWIPS in the Cloud for Enhanced Forecaster-Developer Interactions

- NESDIS TOWR-S Developing Cloud AWIPS
- Viewed/ controlled jointly via internet by forecasters and development
- 30-day data archive
- Longer-term archive on request
- Can include NCEP or WFO domains
- cloudReach sessions with small groups of developers and forecasters
- POCs:

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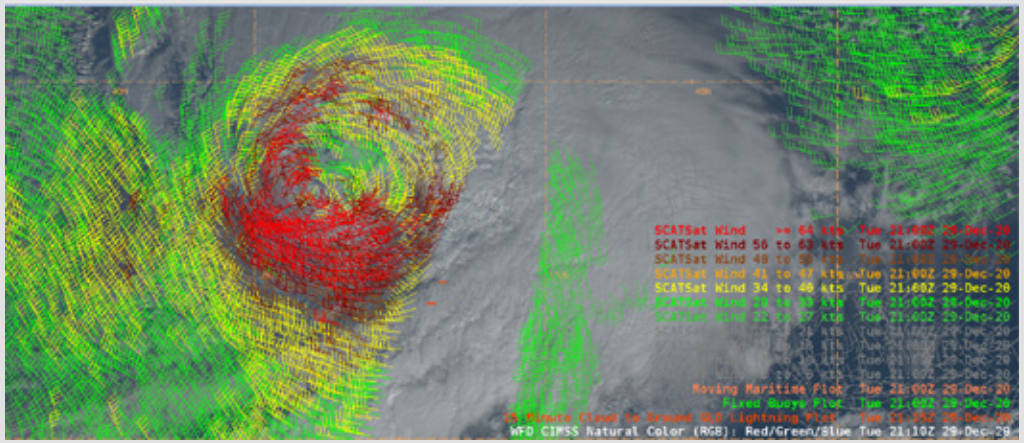
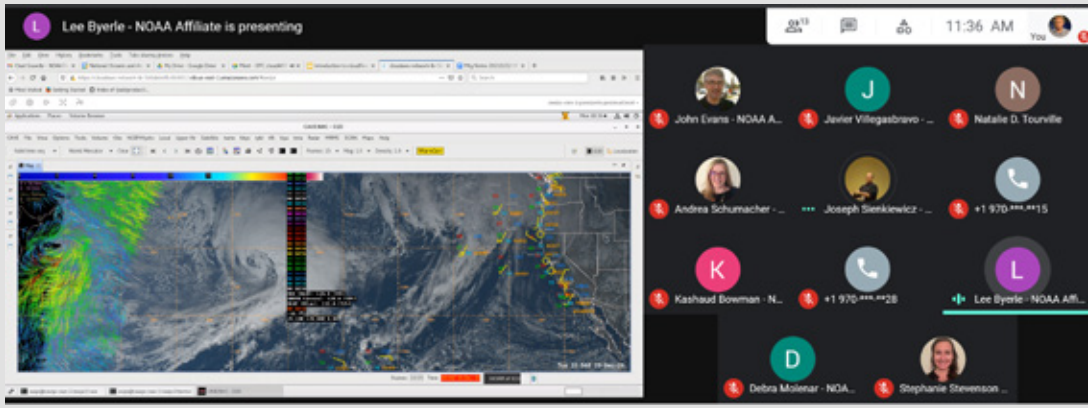
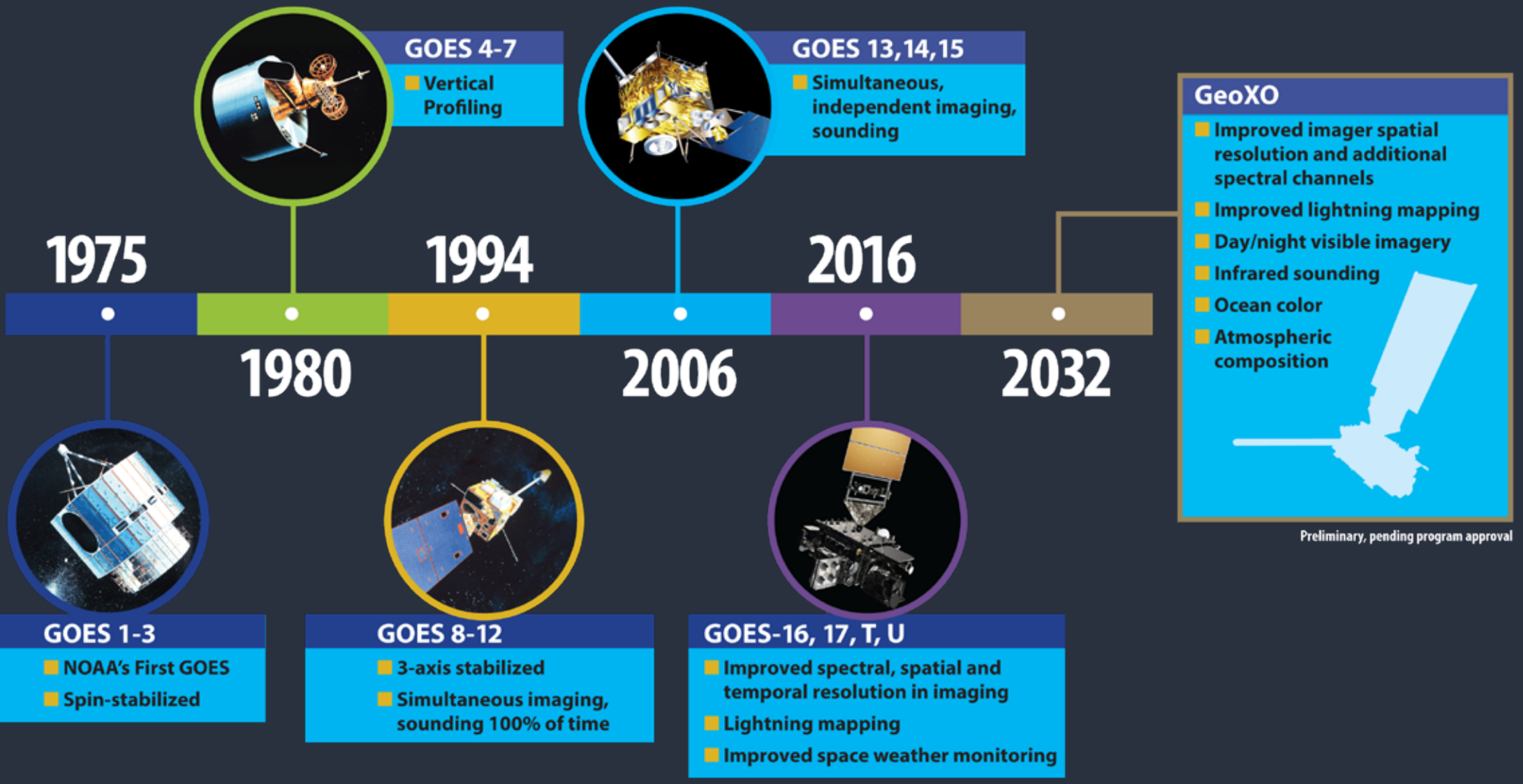
Kashad.Brown@noaa.gov





AWIPS Cloud Screen Captures from 2/22/21 Cloud Reach Session with TOWR-S, OPC, NHC

History of Geostationary Operational Environmental Satellites



Summary

- GOES-R Proving Ground for tropical cyclones transitioned from demonstration to product development emphasis
- Several applications under development for TC intensity analysis/forecasting
  - ADT with AI (AiDT)
  - New GLM and ABI input for NHC Guidance Suite
  - New AMV methods and shear diagnostics
- Machine-Learning for improved image combination products
  - ProxyVisible, synthetic microwave, GeoColor
- Product training activities continue
  - Quick Guides
- AWIPS in the Cloud will enhance forecaster-developer interactions
- Planning already underway for GeoXO (2032)