Satellite Remote Sensing: Red-Green-Blue (RGB) & Fire Detection Products

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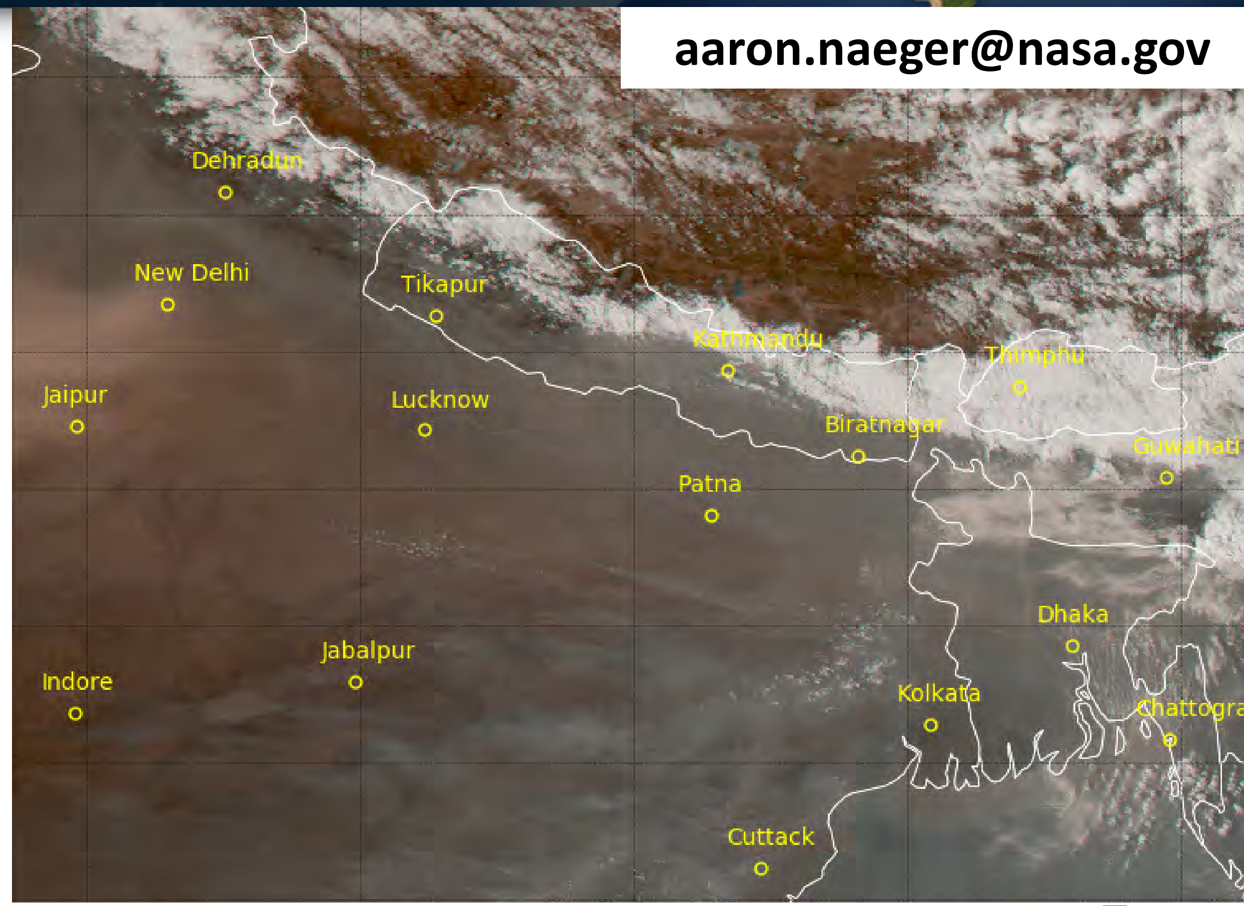
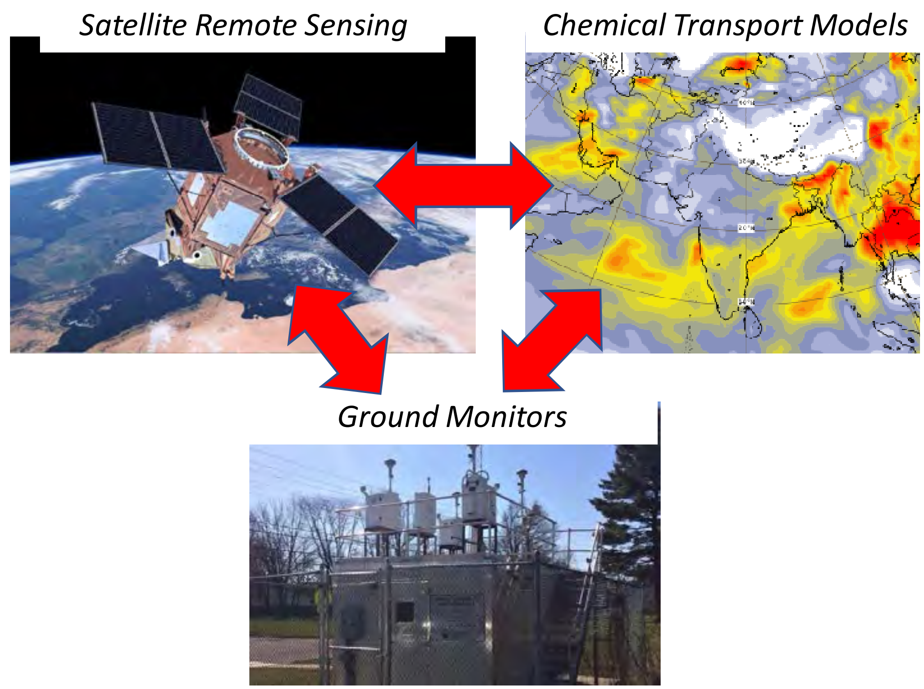


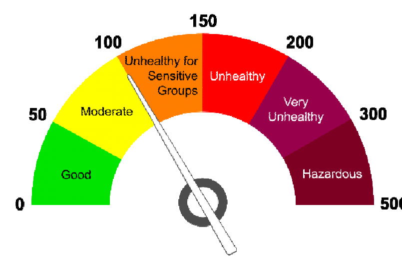
Project Overview

Air Quality Monitoring & Forecasting Tools

1. **New satellite GEO and LEO sensors** – high frequency observations for monitoring weather and air quality in the atmospheric column
2. **Ground-based monitors** – expanding network for measuring aerosols and trace gas concentrations at surface
3. **Chemical transport models** - air quality forecasting system for predicting air pollution and transport processes
4. **Lagrangian dispersion models** – efficient model for forecasting dust emissions, transport, and air quality impacts during dust storms



Suite of tools can deliver an advanced air quality monitoring & forecasting toolkit for providing accurate and timely alerts/warnings to the public



Project Objectives

1. Intelligently **fuse information** from state-of-the-art satellite sensors to develop comprehensive products **for advancing real-time air pollution & fog monitoring capabilities**
2. Design a **tailored chemical transport model framework for providing accurate AQ**, fog/smog, and temperature/stability **forecasts**
3. Build a **lagrangian dispersion model** informed by our tailored products **to aid in the rapid response to extreme AQ/disaster events**
4. **Implement the** satellite- and model-based **AQ products into applicable Decision Support Systems**, and develop customized end-user training

Overarching Project Goal:

Deliver an advanced air quality monitoring & forecasting toolkit for providing accurate and timely alerts/warnings to the public

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Key Products & Tools

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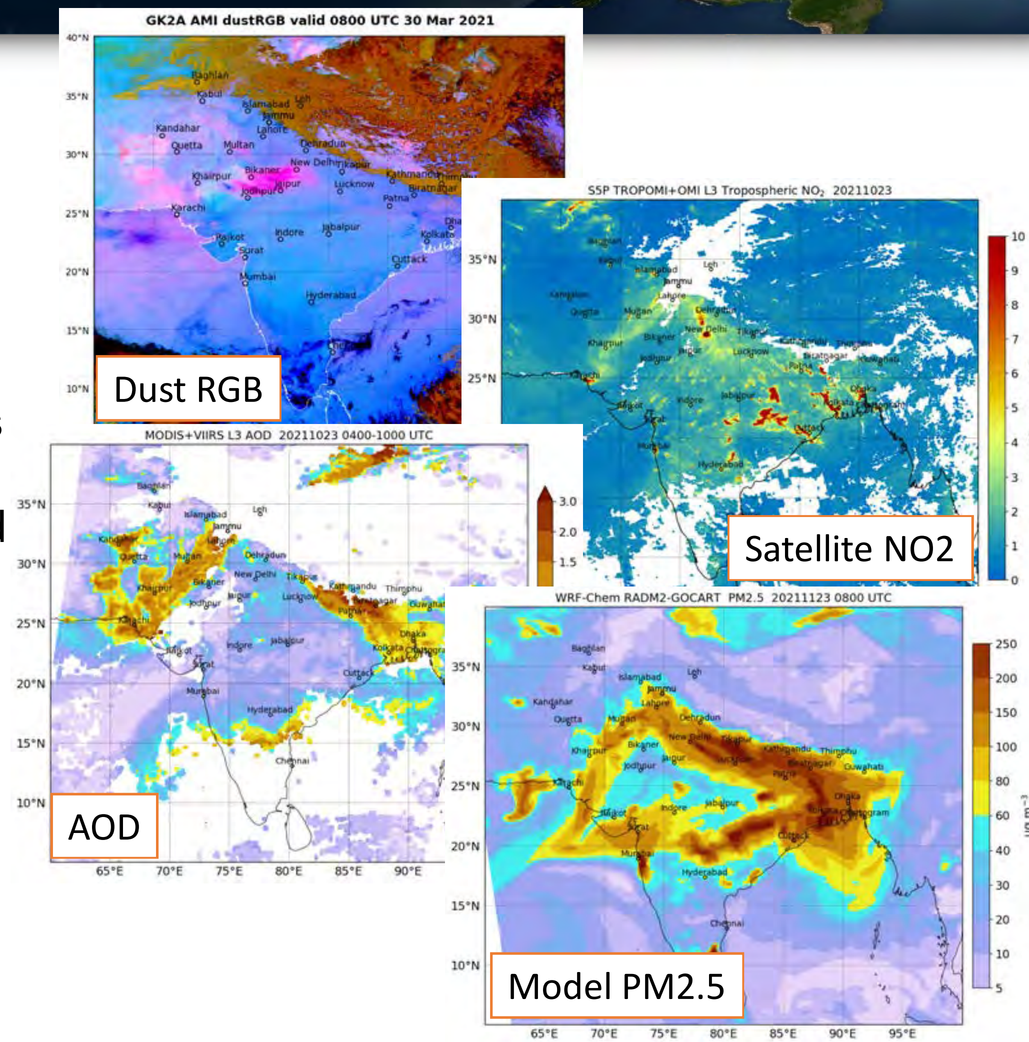
1. **Suite of Red-Green-Blue (RGB) products from the geostationary Advanced Meteorological Instrument (AMI) for monitoring diurnal evolution of dust, fires, smoke and fog**
2. High-level (L2+) trace gas and aerosol products developed from composite satellite and model data to track air pollution in the troposphere and surface layer
3. High-resolution chemical transport model for accurately predicting AQ in the HKH region and providing timely warnings to the public
4. Dispersion model designed for efficiently predicting dust pollution concentrations and enabling rapid response to dust storms



Introduction to Satellite Instruments & RGB Methods

GEO Channels for RGB Products

- RGB recipes are applied to GEO-KOMPSAT-2A (GK2A)/AMI for air quality related products
- AMI and Advanced Himawari Imager (AHI) have Visible Green channel at 0.51 micron
  - **Benefit**: No need to infer VIS-Green for affected RGBs, as in GOES ABI
- AMI does NOT have 2.3 micron SWIR
  - **Drawback**: Diminished ability to discriminate fire hot spot intensities and cloud particle size information

Channel No	Channel	AMI (µm) GK2A	ABI (µm) GOES-R	AHI (µm) Himawari
1	VIS (blue)	0.470	0.470	0.46
2	VIS (green)	0.511		0.51
3	VIS (red)	0.640	0.640	0.64
4	VNIR	0.865	0.865	0.86
5	SWIR	1.380	1.378	
6	SWIR	1.610	1.610	1.6
	(SWIR)		2.250	2.3
7	MWIR	3.830	3.90	3.9
8	MWIR (WV)	6.241	6.185	6.2
9	MWIR (WV)	6.952	6.95	7.0
10	MWIR (WV)	7.344	7.34	7.3
11	TIR	8.592	8.50	8.6
12	TIR	9.625	9.61	9.6
13	TIR	10.403	10.35	10.4
14	TIR	11.212	11.20	11.2
15	TIR	12.364	12.30	12.3

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LEO Channels for RGB Products

MODIS		VIIRS	
Band #	λ	λ	Band ID
1	620 - 670	600 - 680	I-1
2	841 - 876	845 - 885	I-2
3	459 - 479		
4	545 - 565		
5	1230 - 1250	1230 - 1250	M-8
6	1628 - 1652	1580 - 1670	M-10
		1580 - 1610	I-3
7	2105 - 2155	2225 – 2275	M-11
8	405 - 420	402-422	M-1
9	438 - 448	436-454	M-2
10	483 - 493	478-498	M-3
11	526 - 536		
12	546 - 556	545-565	M-4
13	662 - 672	662-682	M-5
14	673 - 683		
15	743 - 753	739-754	M-6
16	862 - 877	846-885	M-7
17	890 - 920		
18	931 - 941		
19	915 - 965		

MODIS		VIIRS	
Band #	λ	λ	Band ID
20	3.660 - 3.840	3.610 – 3.790	M-12
		3.550 – 3.930	I-4
21	3.929 - 3.989		
22	3.940 – 4.001		
23	4.020 - 4.080	3.973 – 4.128	M-13
24	4.433 – 4.498		
25	4.482 – 4.549		
26	1.360 - 1.390		M-9
27	6.535 - 6.895		
28	7.175 - 7.475		
29	8.400 - 8.700	8.400 – 8.700	M-14
30	9.580 - 9.880		
31	10.780 - 11.280	10.263 – 11.263	M-15
		10.050 - 12.400	I-5
32	11.770 - 12.270	11.538 – 12.488	M-16
33	13.185 - 13.485		
34	13.485 - 13.785		
35	13.785 - 14.085		
36	14.085 - 14.385		

General Formulae for RGB Products

$$Red = \left(\frac{R - R_{min}}{R_{max} - R_{min}}\right)^{1/\gamma}$$

$$Green = \left(\frac{G - G_{min}}{G_{max} - G_{min}}\right)^{1/\gamma}$$

$$Blue = \left(\frac{B - B_{min}}{B_{max} - B_{min}}\right)^{1/\gamma}$$

Where:

- *R, G,* or *B* is the present pixel value
- *min* and *max* are the calibrated thresholds applied to a given channel or channel difference
- *1/γ* is the calibrated power scale to affect the color stretching

RGB Product Methods

Satellite Product	*Red*	*Green*	*Blue*	*Gamma*	*Applications*
Dust RGB	$IR_{12.3} - IR_{10.5}$ (-6.7 to +2.6C)	$IR_{11.2} - IR_{8.7}$ (-0.5 to +20C)	$IR_{10.5}$ (-11.95 to +15.55C)	1.0 (RB) 2.5 (G)	**Dust plume monitoring**
Nighttime Microphysics	$IR_{12.3} - IR_{10.5}$ (-6.7 to +2.6C)	$IR_{10.5} - SW_{3.8}$ (-3.1 and +5.2C)	$IR_{10.5}$ (-29.55 to +19.45C)	1.0	**Fog, smog, and low-cloud detection**
Truecolor RGB	$VIS_{0.64}$ (0 to 1.0 refl)	$VIS_{0.51}$ (0 to 1.0 refl)	$VIS_{0.47}$ (0 to 1.0 refl)	2.2	**Land surface, clouds, and aerosols**
Natural Color Fire RGB	$SW_{3.8}$ (0 to 60C)	$VIS_{0.87}$ (0 to 1.0 refl)	$VIS_{0.64}$ (0 to 1.0 refl)	0.4 (R) 1.0 (GB)	**Fire hot spots [and smoke]**

Dust RGB Product

Dust RGB – Quick Brief

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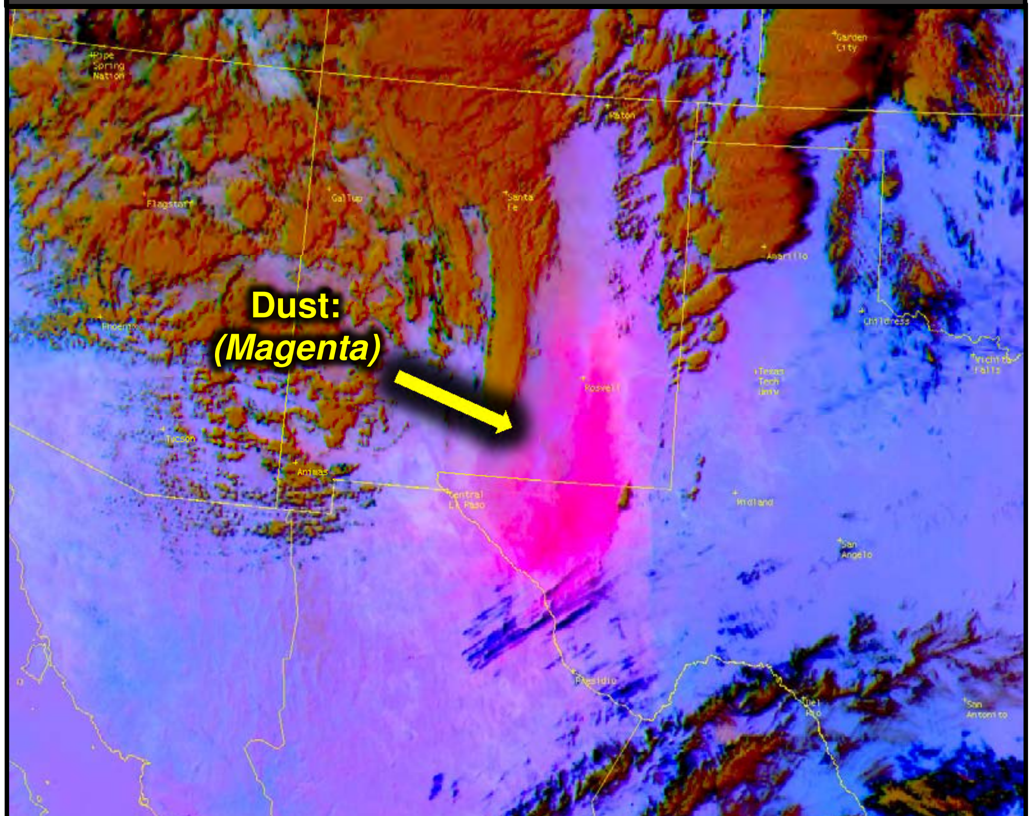
Dust RGB via GOES-16 over Southwest U.S.
at 2322 UTC 23 March 2017



Dust RGB:

- ❑ Uses only IR window channels
- ❑ Adapted for GOES-16 and **AMI** *(originated by EUMETSAT)*

Issue:

- ❑ Detection and monitoring of blowing dust in data sparse regions, both day and night

Application Example:

- ❑ Blowing dust from 23 March 2017 in U.S. Southwest

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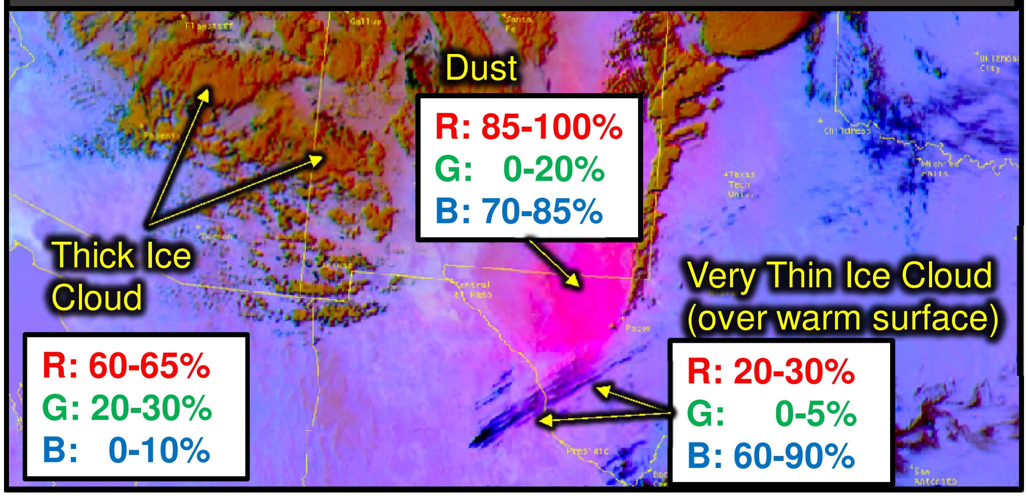
Dust RGB – Product Basics

Very small differences between ABI and AMI for these channels

Color	Band/Band Diff. (µm)	Physically relates to…	Small contribution to pixel indicates…	Large contribution to pixel indicates…
Red	12.3-10.3	Optical depth/cloud thickness	Thin clouds	**Thick clouds or dust**
Green	11.2-8.4	Particle phase	Ice and particles of uniform shape (dust)	**Water particles or thin cirrus over deserts**
Blue	10.3	Surface temperature	Cold surface	**Warm surface**

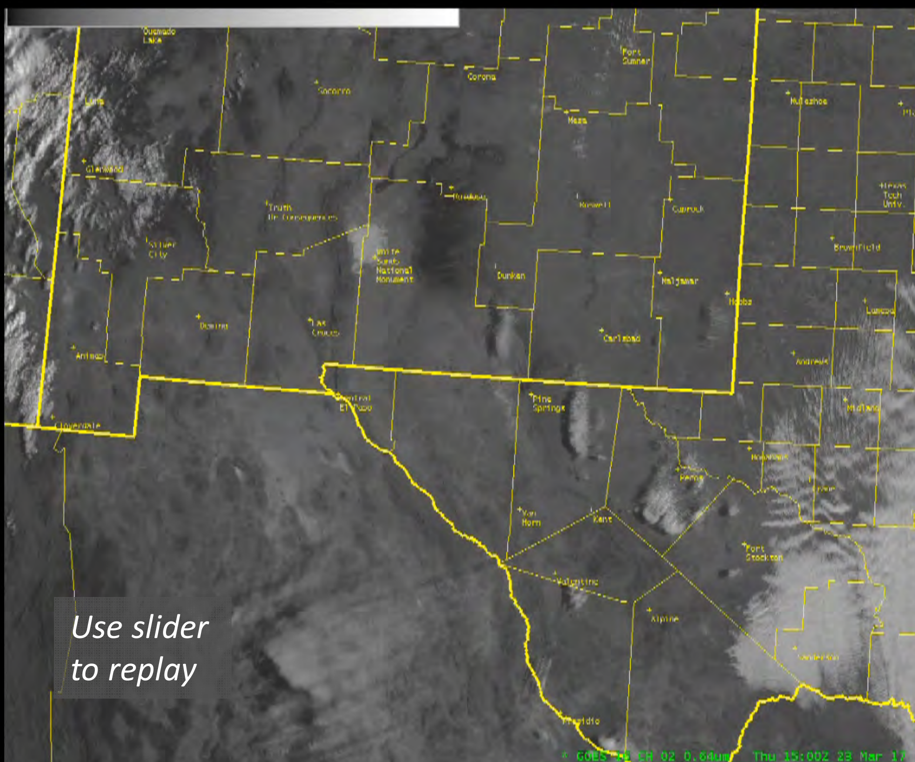
- ❑ 12.3 µm is semi-transparent to dust - > large red intensity compared to clouds
- ❑ "Warm" dust at low levels - > large blue intensity
- ❑ Dust plume resulting color: **magenta**
- ❑ Dust RGB valid day and night
- ❑ Note: shades of magenta relate to plume concentration, *not* physical thickness

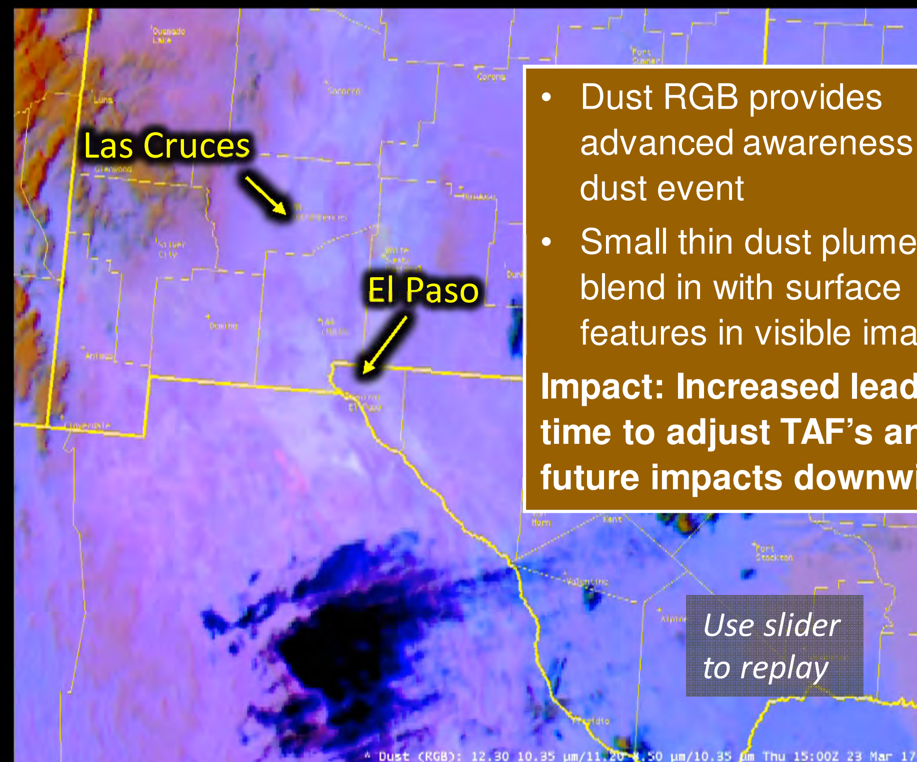
Dust RGB via GOES-16 centered on west Texas
at 0002 UTC 24 March 2017



Increased Lead Time & Awareness

GOES-16 Visible and Dust RGB Imagery from 1500-1842 UTC 23 March 2017 over Southern New Mexico, U.S





- Dust RGB provides advanced awareness of dust event
- Small thin dust plumes blend in with surface features in visible imagery

Impact: Increased lead time to adjust TAF's and future impacts downwind

Daytime Benefits: Extent and Analysis vs. Clouds

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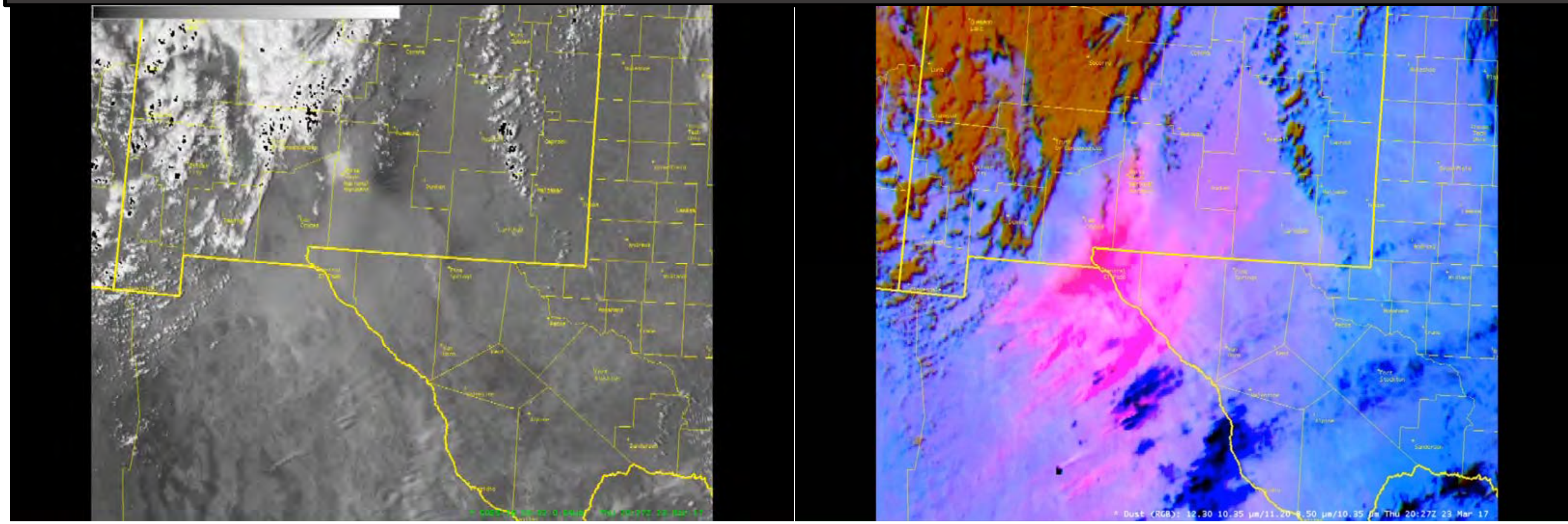
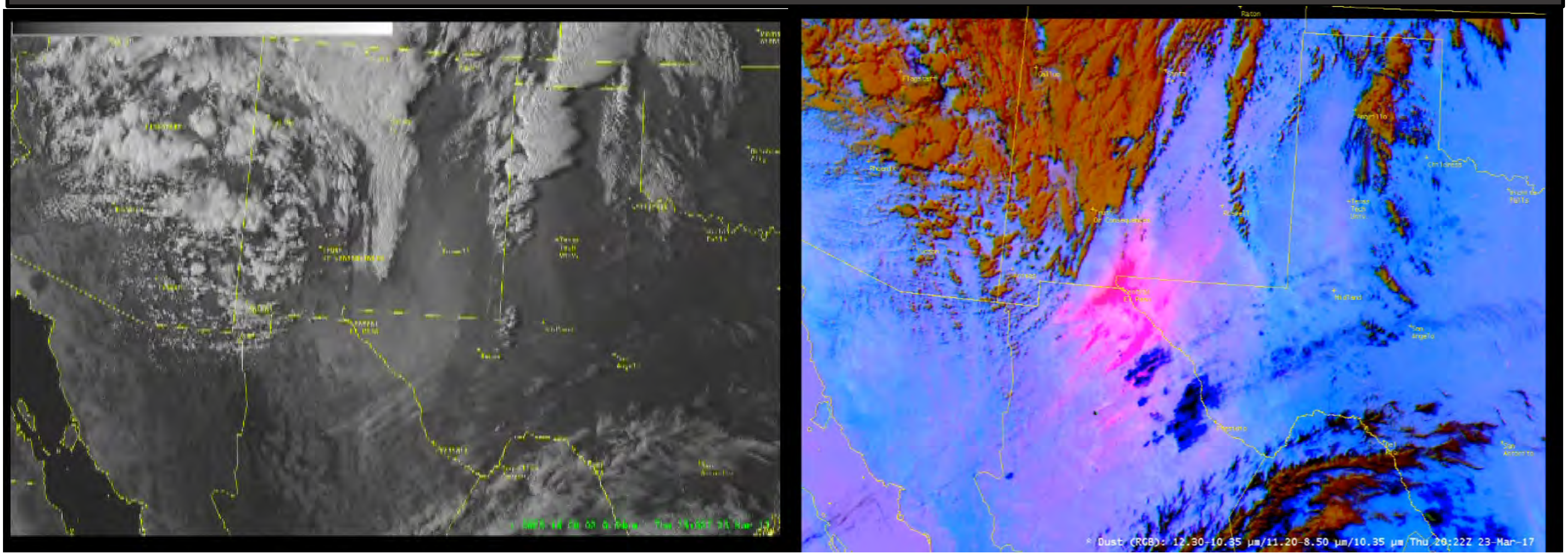
GOES-16 Visible and Dust RGB centered on southwest CONUS from 2027-2322 UTC 24 March 2017



- Dust RGB depicts the extent of the dust plume vs. clouds and surface features
- Visible imagery has similar coloring for both dust and underlying land surface

Nighttime Application: Detection & Monitoring

GOES-16 Visible Imagery and Dust RGB centered on southwest CONUS from 2302-0202 UTC, 23-24 March 2017



- Dust RGB continues to provide value at night when visible imagery is not valid.

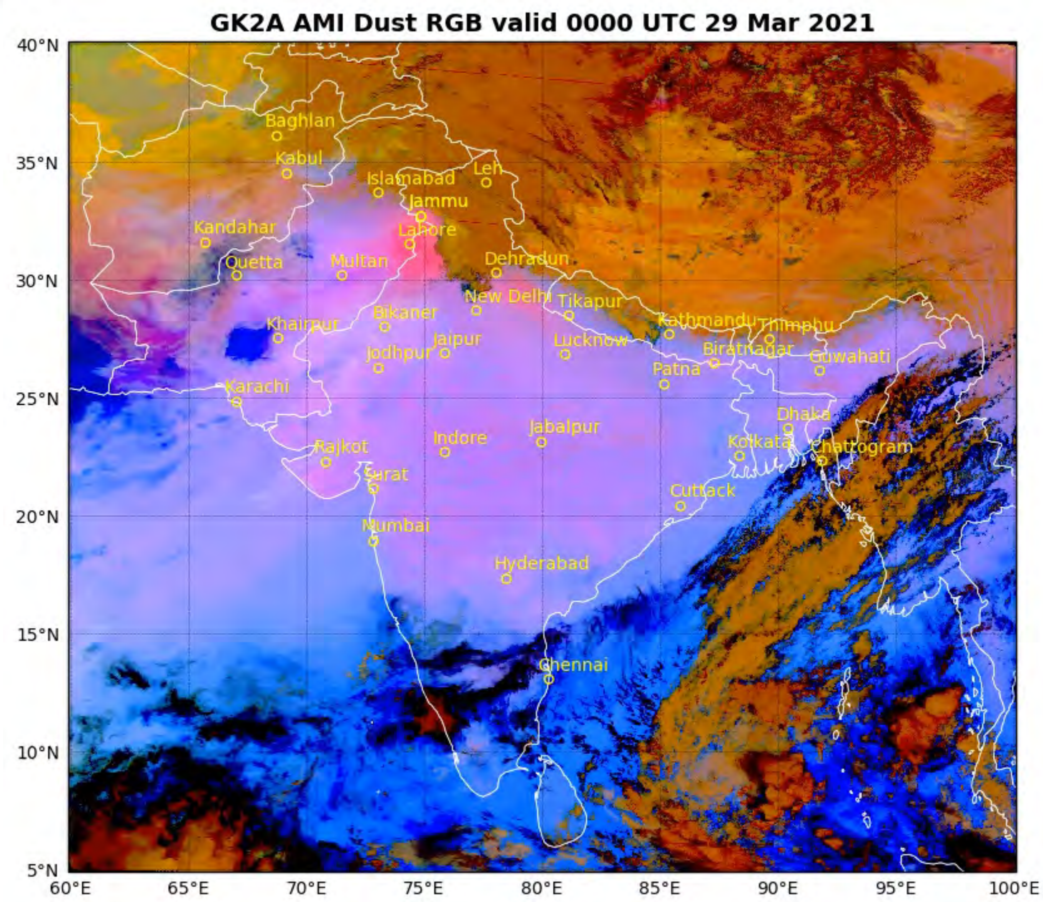
AMI Dust RGB – March 2021 Dust Event

AMI Dust RGB:

- RGB recipe applied to AMI with 2 km resolution for IR channels and 10-minute temporal frequency

Application Example:

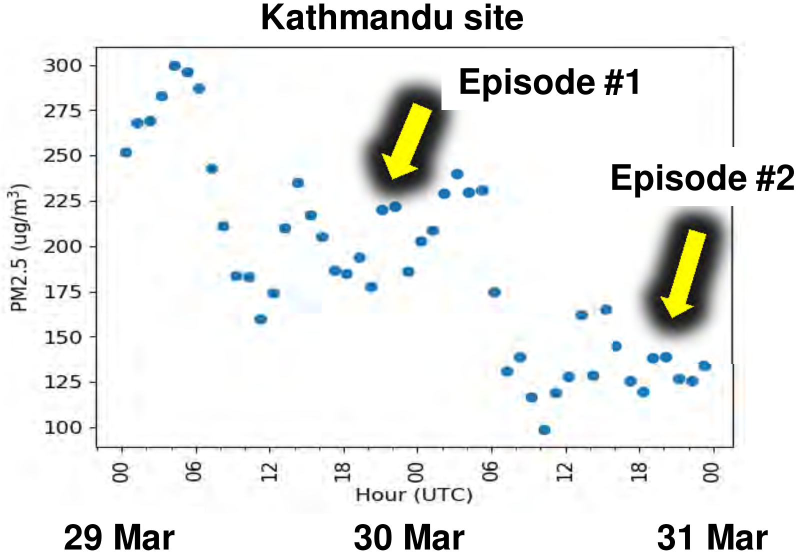
- Numerous areas of dust emissions occurred across region from 29 – 31 March 2021
- Large dust storm that initiated on 30 March near Pakistan-India border experienced rapid transport across India and into Nepal and Bangladesh
- AMI Dust RGB was capable of monitoring dust activity and transport across region during the day and night

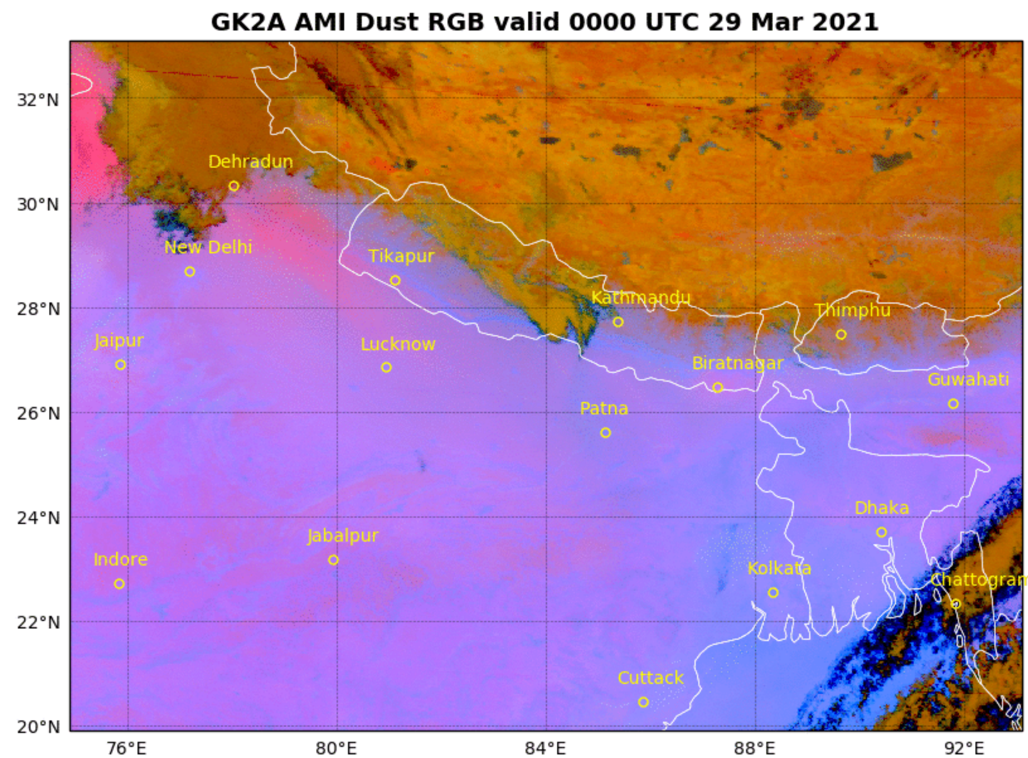


2 km resolution product at 10-minute frequency!

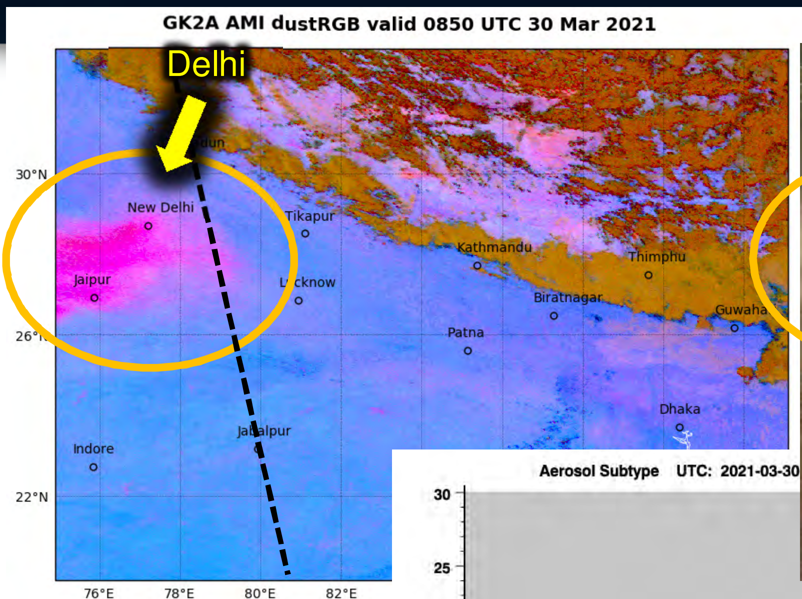
AMI Dust RGB – March 2021 Dust Event

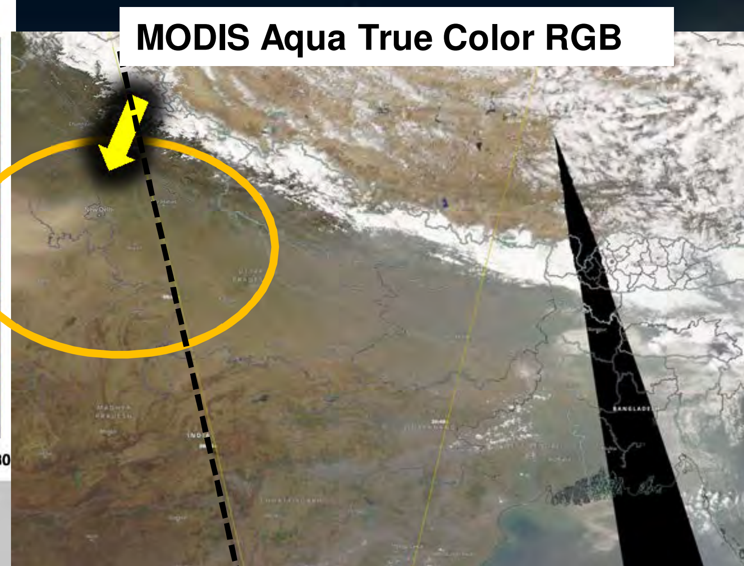
- Dust storm was transported to Nepal
- Dust likely contributed to increases PM2.5 concentrations at the U.S. Embassy site in Kathmandu from 30 – 31 March
- Smoke was major contributor to PM2.5, as highlighted by fire and smoke products in later slides

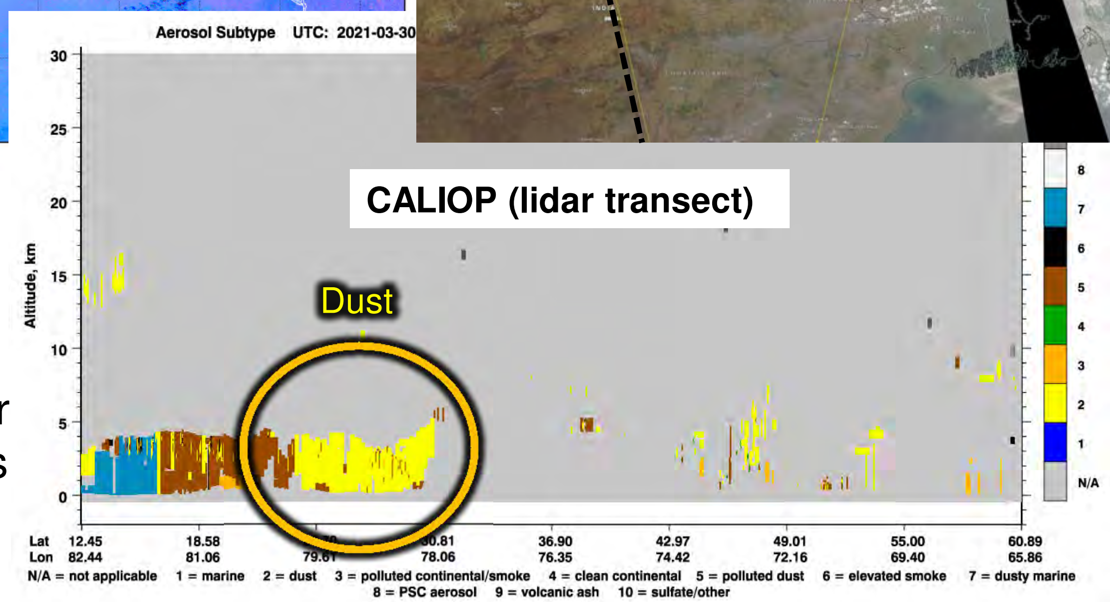




AMI Dust RGB – March 2021 Dust Event



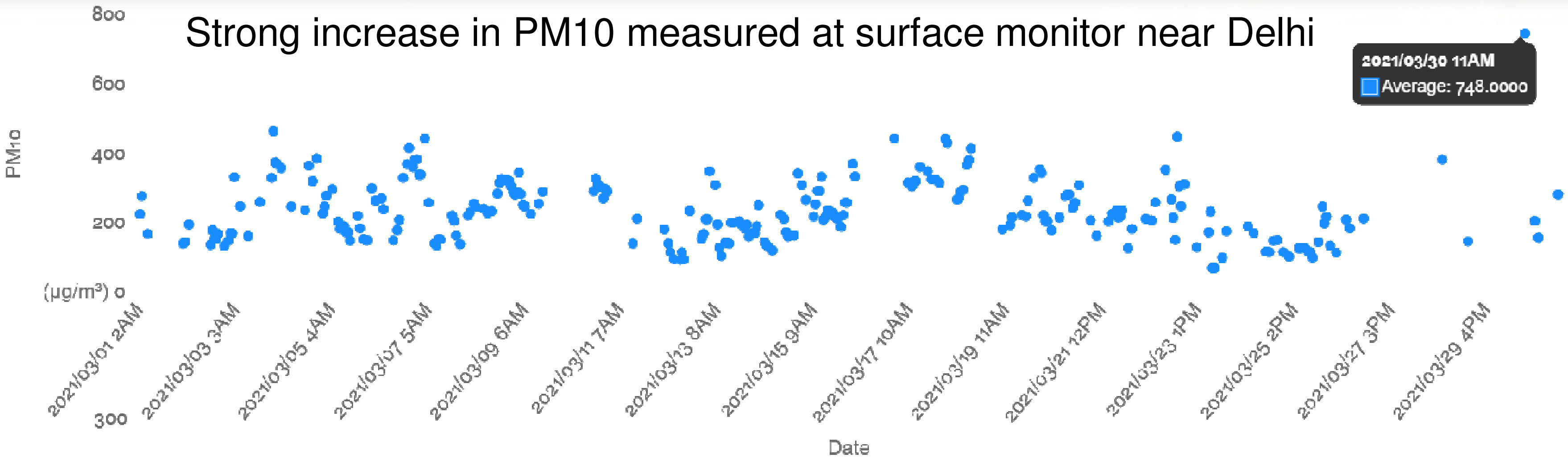


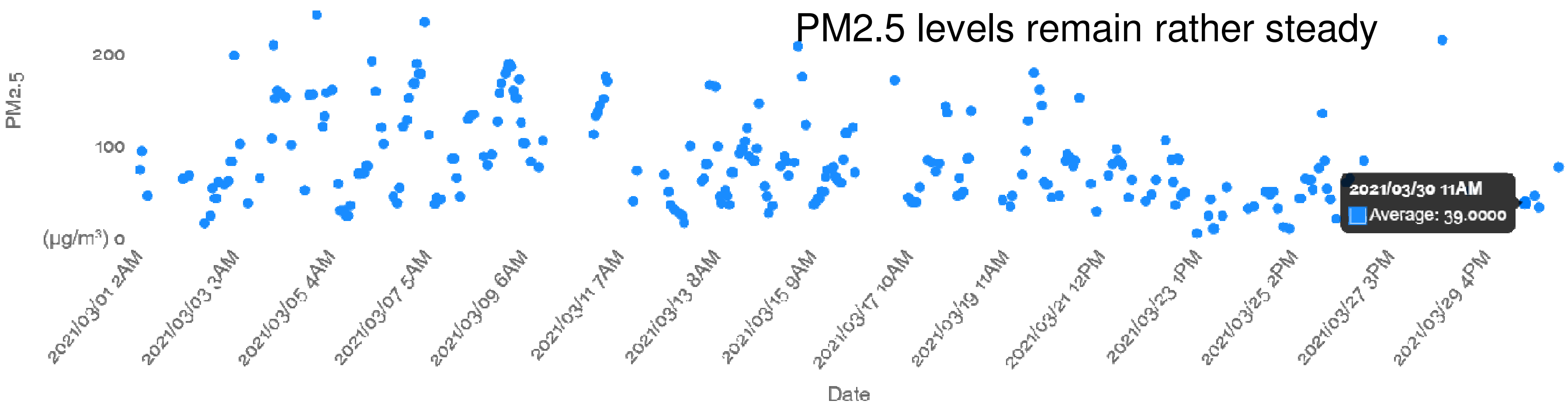


- ❑ CALIOP observes dust particles in this region of lighter magenta colors in Dust RGB

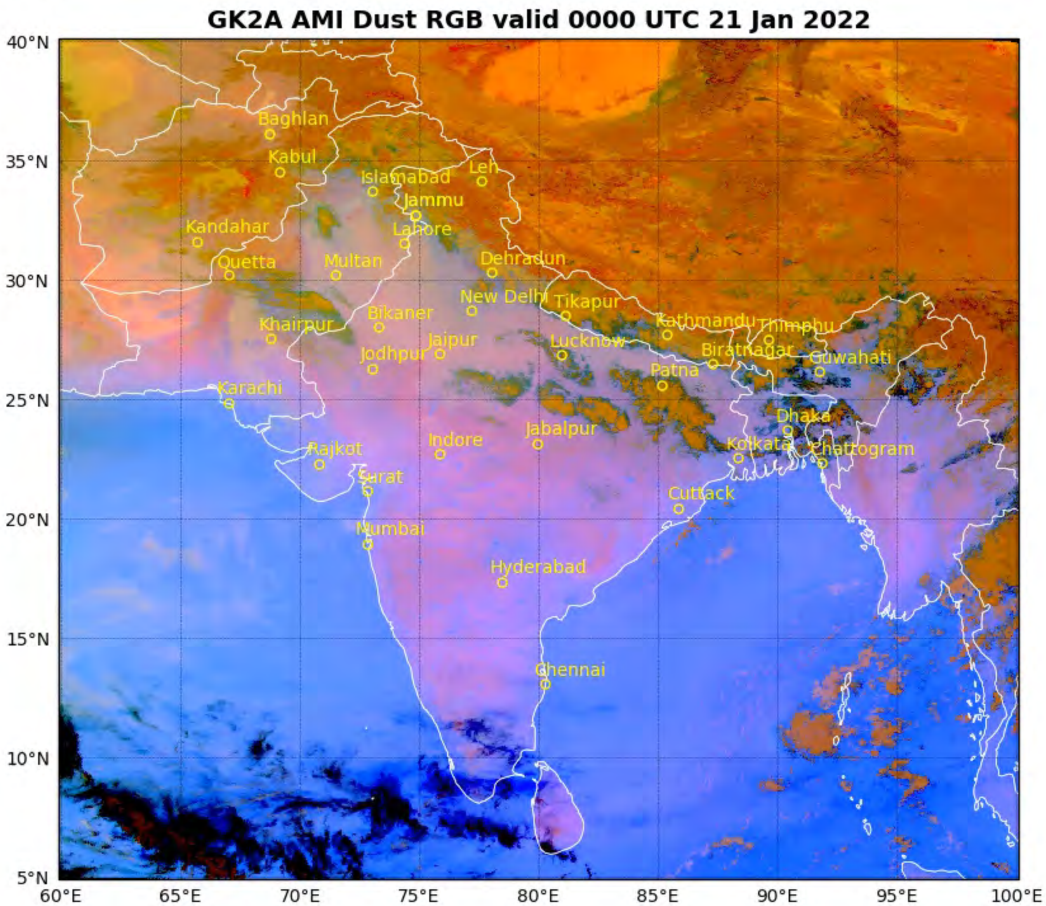
- ❑ True Color RGB imagery depicts dust in brownish tone (other pollutants in greyish tone)
- ❑ AMI Dust RGB clearly shows the dust storm in magenta (other pollutants not apparent)
- ❑ Magenta tones in Dust RGB are evident farther to the east compared to brownish tones in True Color RGB

Surface Monitors – March 2021 Dust Event

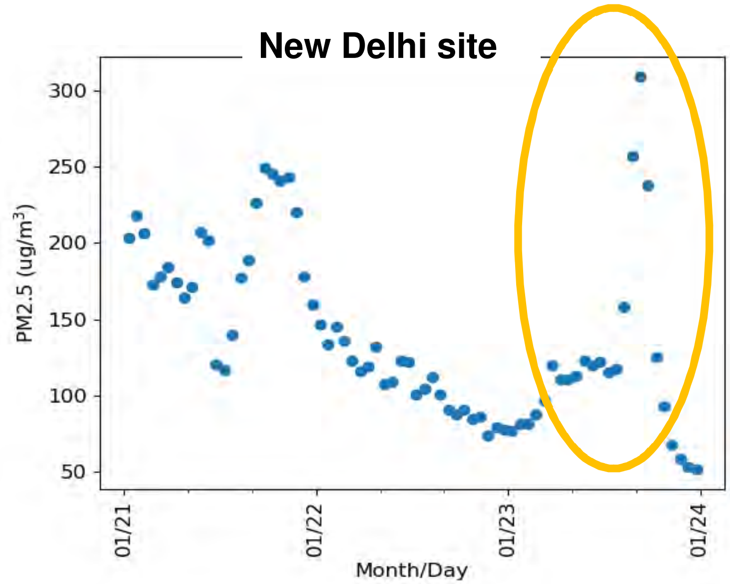




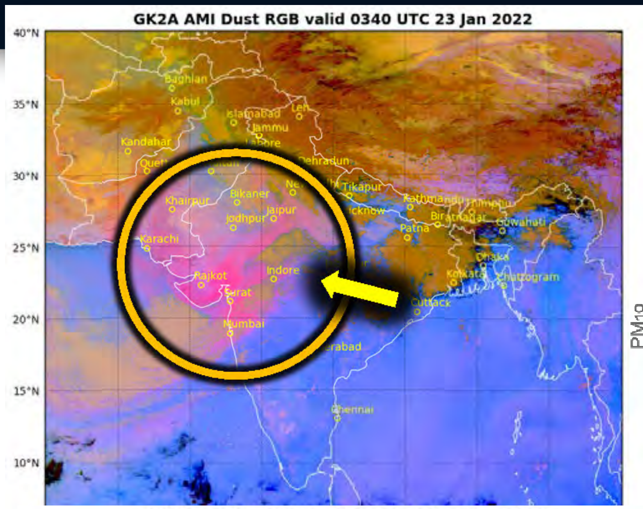
AMI Dust RGB – January 2022 Dust Event

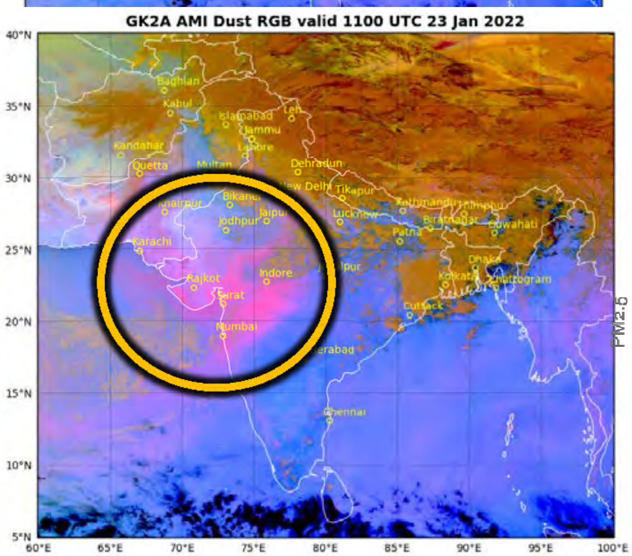


- Strong dust storm with origins from Pakistan Afghanistan, and Iran impacted large areas of India and parts of Nepal
- Surface monitors across New Delhi measured significant increases in PM2.5 during passage of dust storm over city

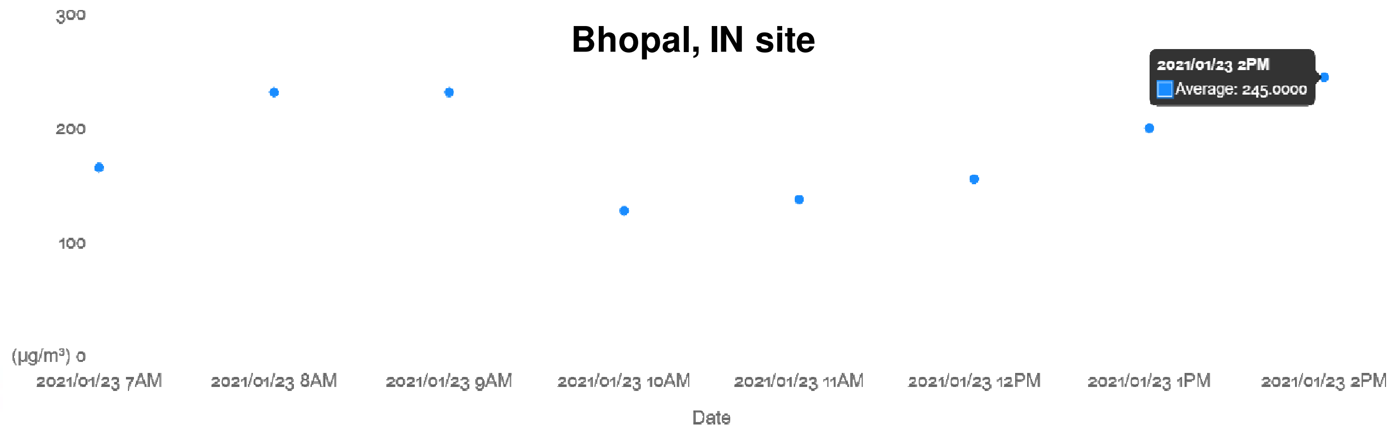


AMI Dust RGB – January 2022 Dust Event

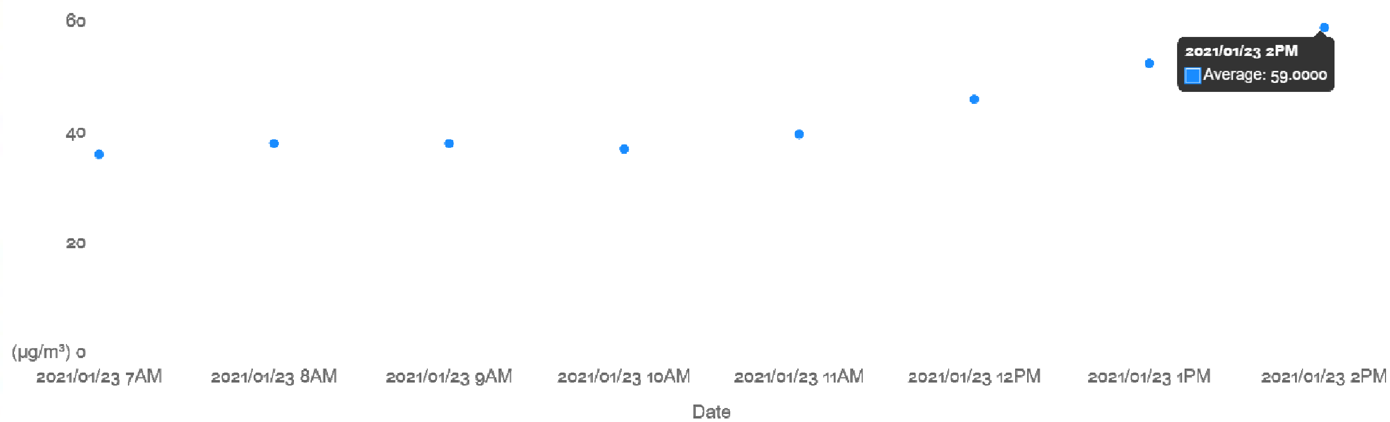




Substantial increases in PM10 during morning and afternoon



Increases in PM2.5 throughout the afternoon



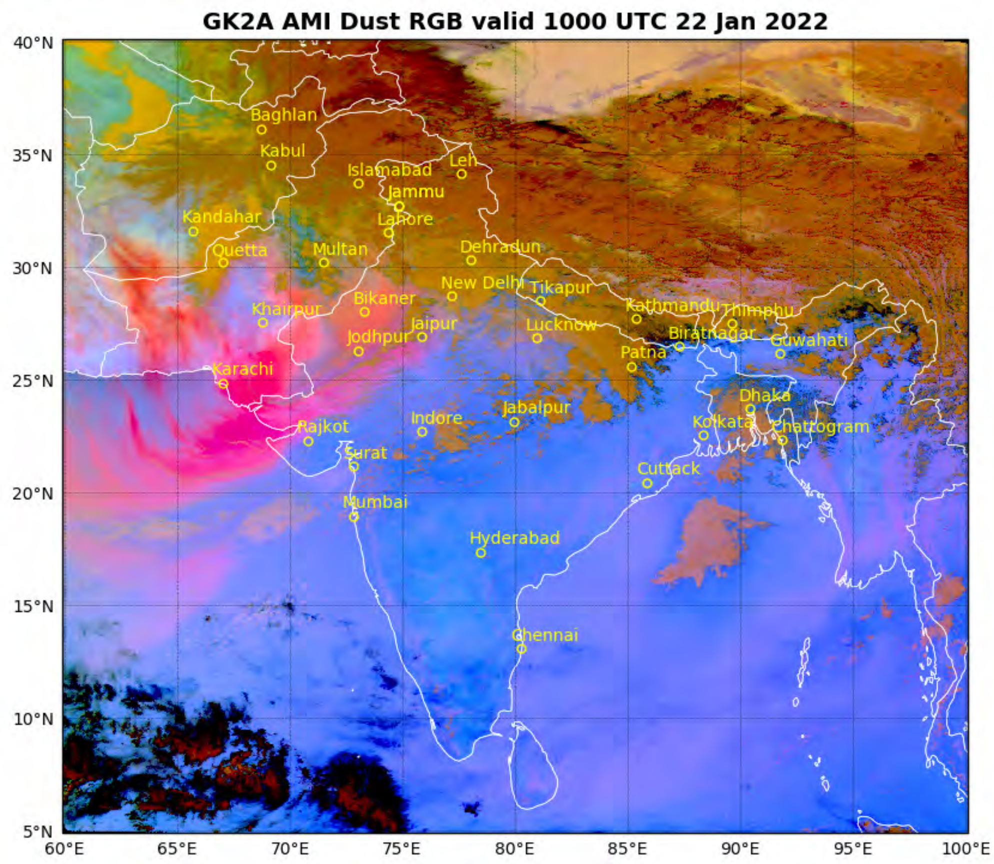
Dust RGB: Summary & Resources

Dust RGB Benefits

- ❑ Applies both day and night.
- ❑ Able to anticipate hazards to aviation and public
- ❑ Magenta coloring identifies and differentiates from surface and cloud features.
- ❑ Has greater contrast than visible and single-channel IR imagery
- ❑ Effective in identifying small-scale dust plumes and the extent of large events.

Additional Resources:

- Atmospheric Dust (COMET):
- Dust RGB for AMI (including Articulate Training and Quick Guide)



Break
Q & A

Nighttime Microphysics RGB

Nighttime Microphysics RGB – Quick Brief

Nighttime Microphysics RGB:

- ❑ Developed by EUMETSAT for SEVIRI
- ❑ Adapted to Himawari, GOES, **and most recently AMI**
- ❑ Provides cloud thickness, phase, and temperature in a combined product

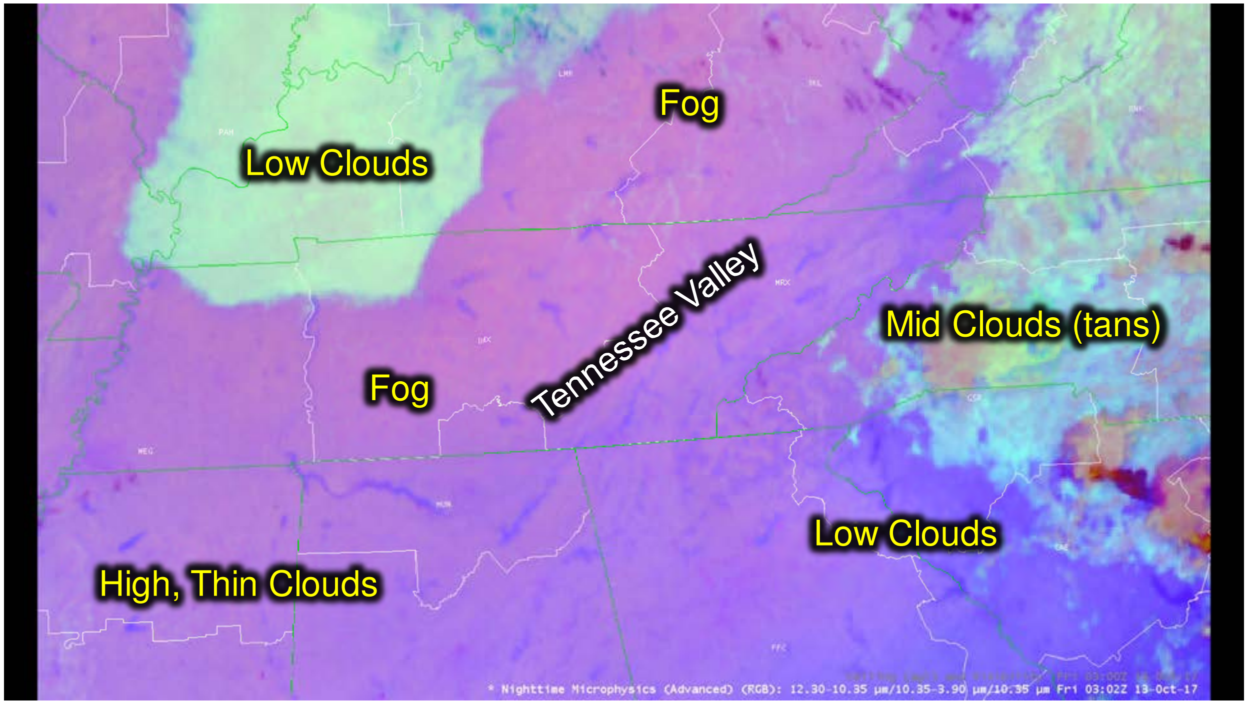
Issue:

- ❑ Diagnose fog vs. other cloud types and resulting decisions

Application Example:

- ❑ Fog in the Fall season across U.S.

NtMicro RGB via GOES-16 over southeastern North America, 06 to 12 UTC, 13 October 2017



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Challenge & Objective – Diagnosing Fog from Clouds

Forecasters familiar with “11-3.9 µm” to analyze low cloud and fog at night

- ❑ Applied in GOES-13/15 era to anticipate ceiling/visibility hazards
- ❑ 10.3 - 3.9 µm used for GOES 16/17
- ❑ Referred to as “Fog” product
- ❑ Limitation: Difficulty differentiating fog from low cloud

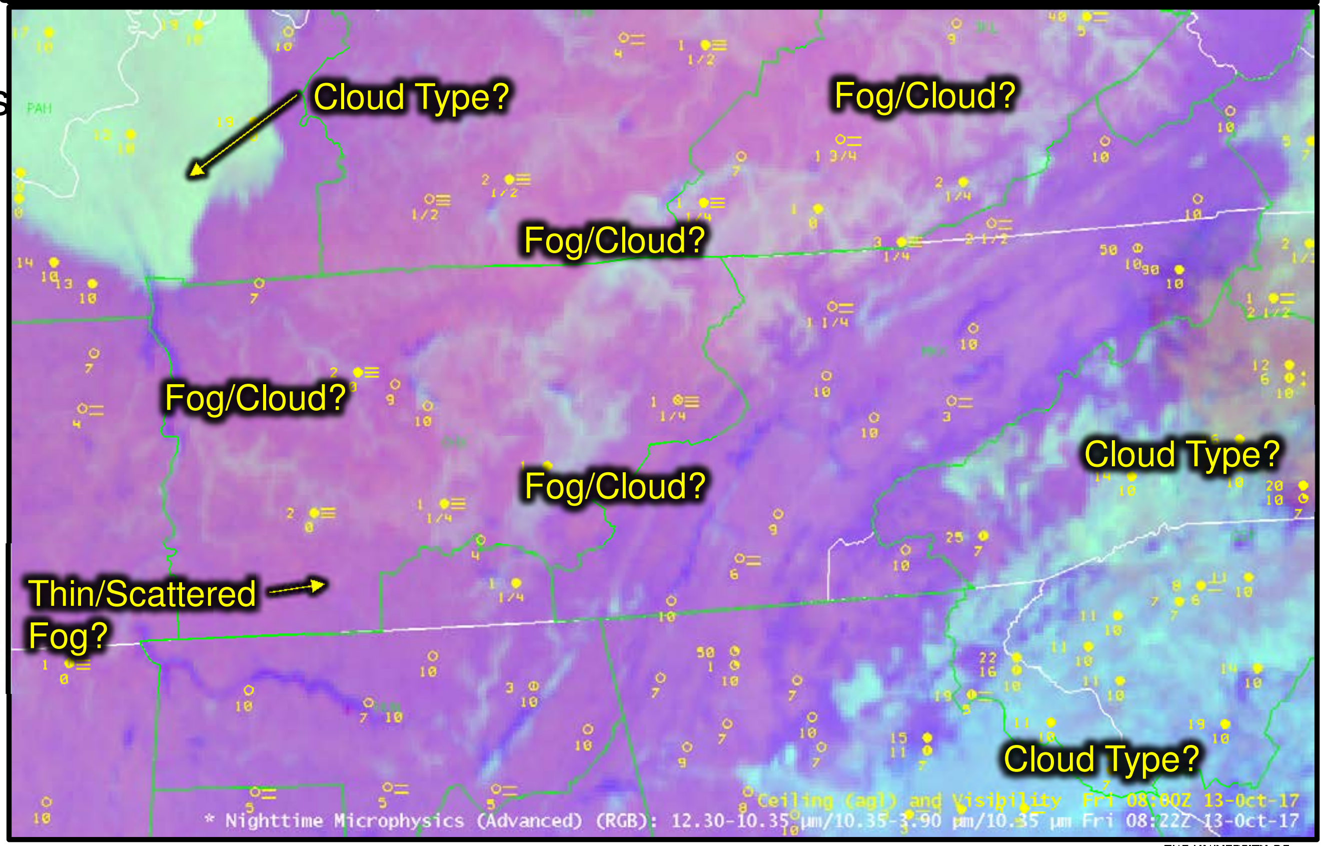
Forecast Challenge

- ❑ Diagnose fog from other clouds (i.e. low clouds & mid/high clouds)

Learning Objective

- ❑ Apply NtMicro RGB to diagnose fog *(or ‘false fog’ in other products)* to anticipate when a hazard forecast product may or may not be needed

Nighttime Microphysics RGB via GOES-R over Tennessee Valley
0822 UTC, 13 October 2017



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Nighttime Microphysics RGB – Product Details

Nighttime Microphysics RGB recipe:

Red: 12.3 – 10.3 µm
Green: 10.3 – 3.9 µm
Blue: 10.3 µm

Longwave/Shortwave difference (i.e. "Fog Product") still used in green color component

- ❑ Highlights water clouds, small drops

Additional channel difference and single channel used:

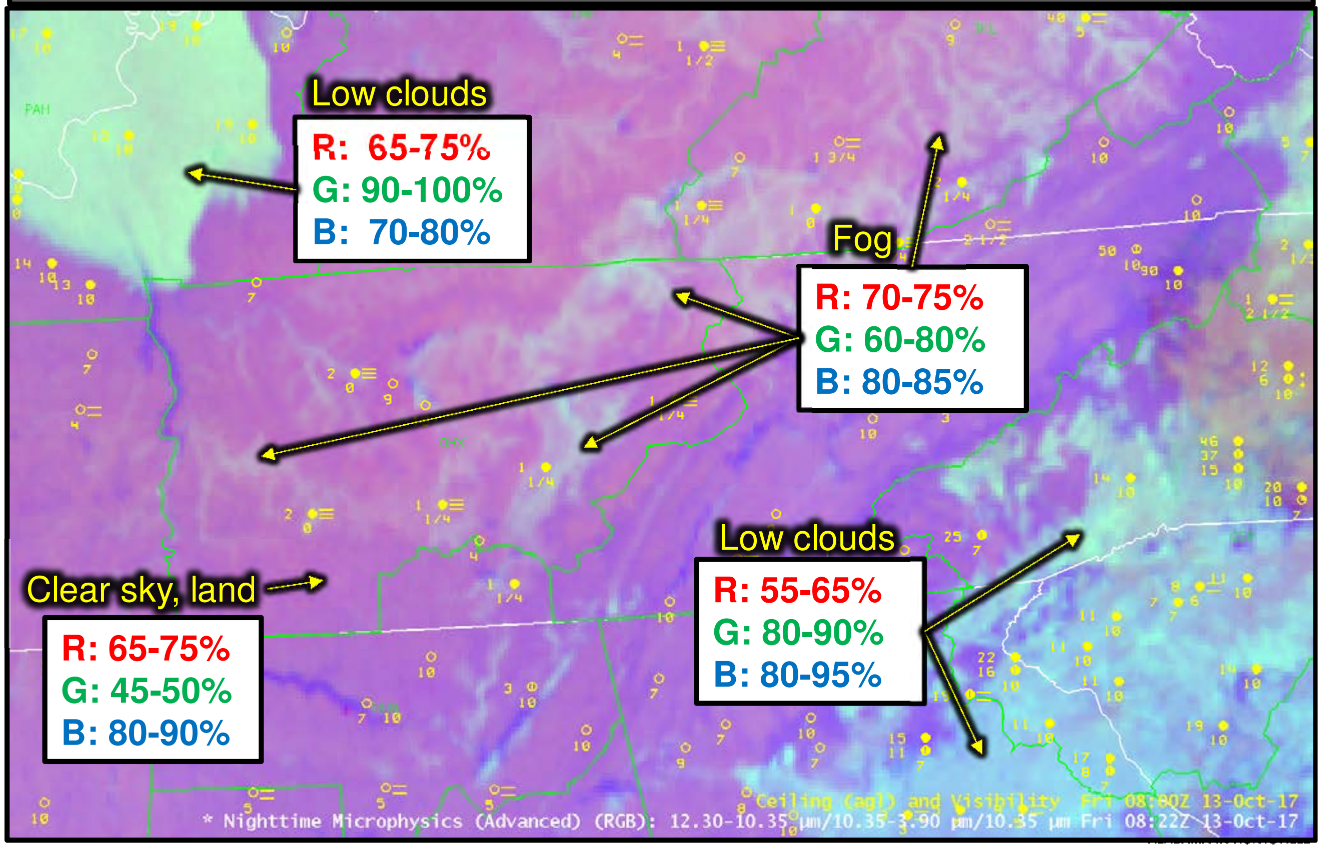
- ❑ 12.3-10.3 µm is proxy to thickness
- ❑ 10.3 µm cloud top thermal properties

Low Clouds: cyan to light green

Fog: dull cyan to gray

Clear sky, land: light purple to pink

Nighttime Microphysics RGB via GOES-R over Tennessee Valley, 0822 UTC, 13 October 2017



Impacts – Potential Increased Lead-time

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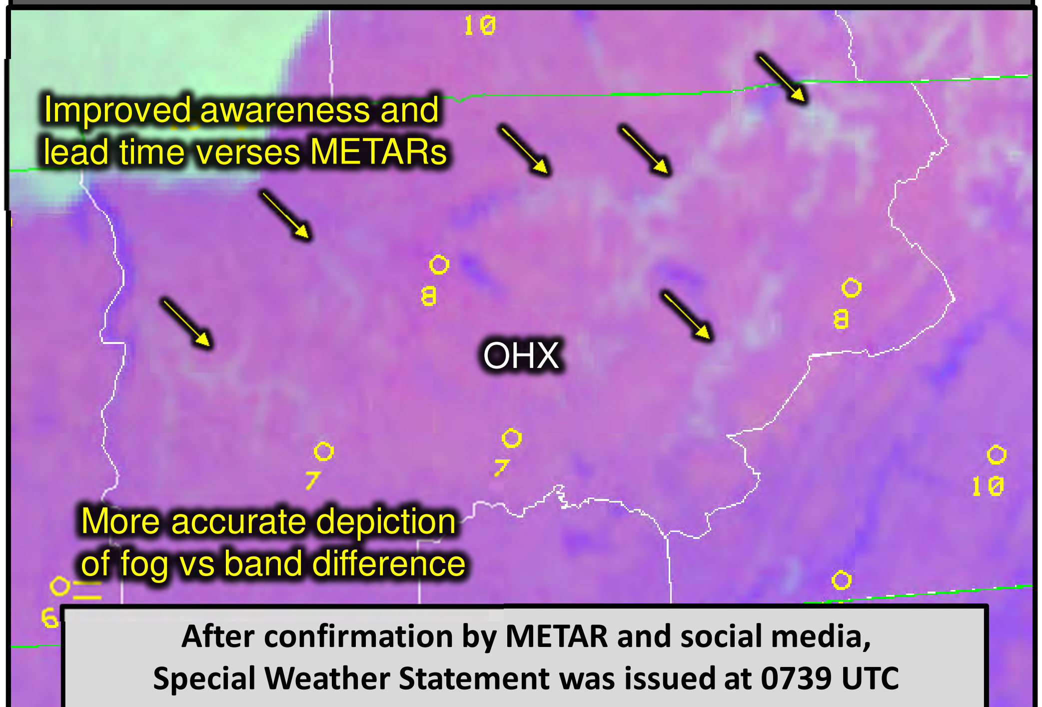
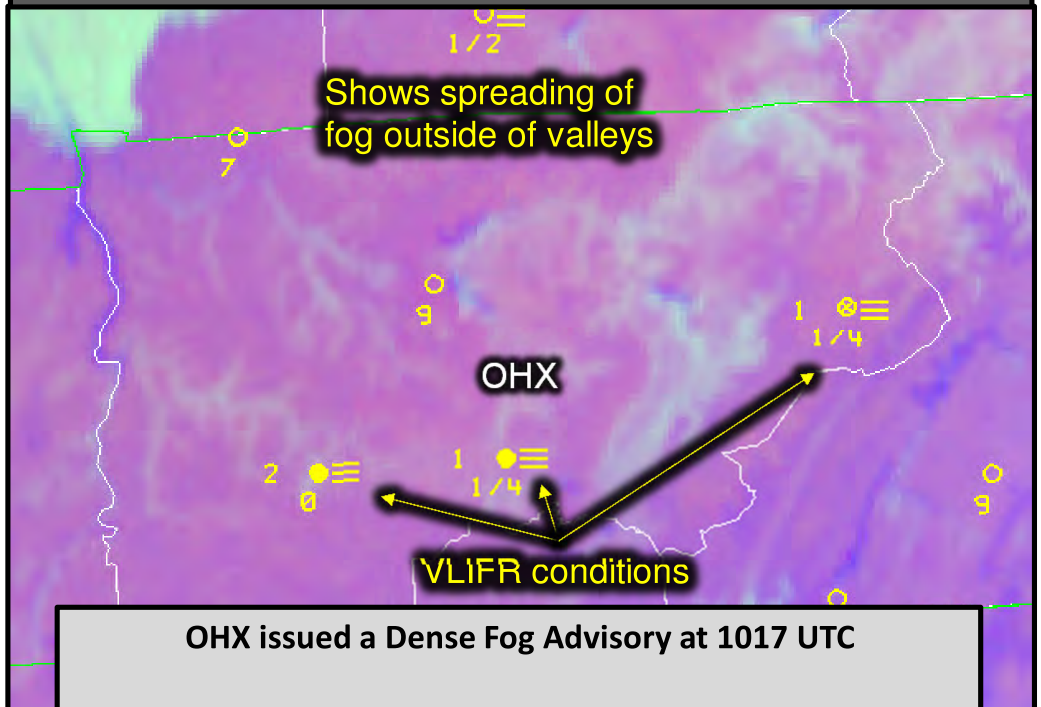
Nighttime Microphysics RGB via GOES-R, METAR Ceiling/Visibility at 0522 UTC, 13 October 2017



After confirmation by METAR and social media, Special Weather Statement was issued at 0739 UTC

NtMicro RGB allowed for a potential lead time increase of 1-2 hours given 0522 UTC image above

Nighttime Microphysics RGB via GOES-R, METAR Ceiling/Visibility at 0817 UTC, 13 October 2017



OHX issued a Dense Fog Advisory at 1017 UTC

METAR and RGB imagery at 1017 UTC remained similar to the 0817 UTC image above.
RGB may have allowed for additional lead time to advisory

AMI NtMicro RGB – January 2022 Low Clouds & Fog

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AMI NtMicro RGB:

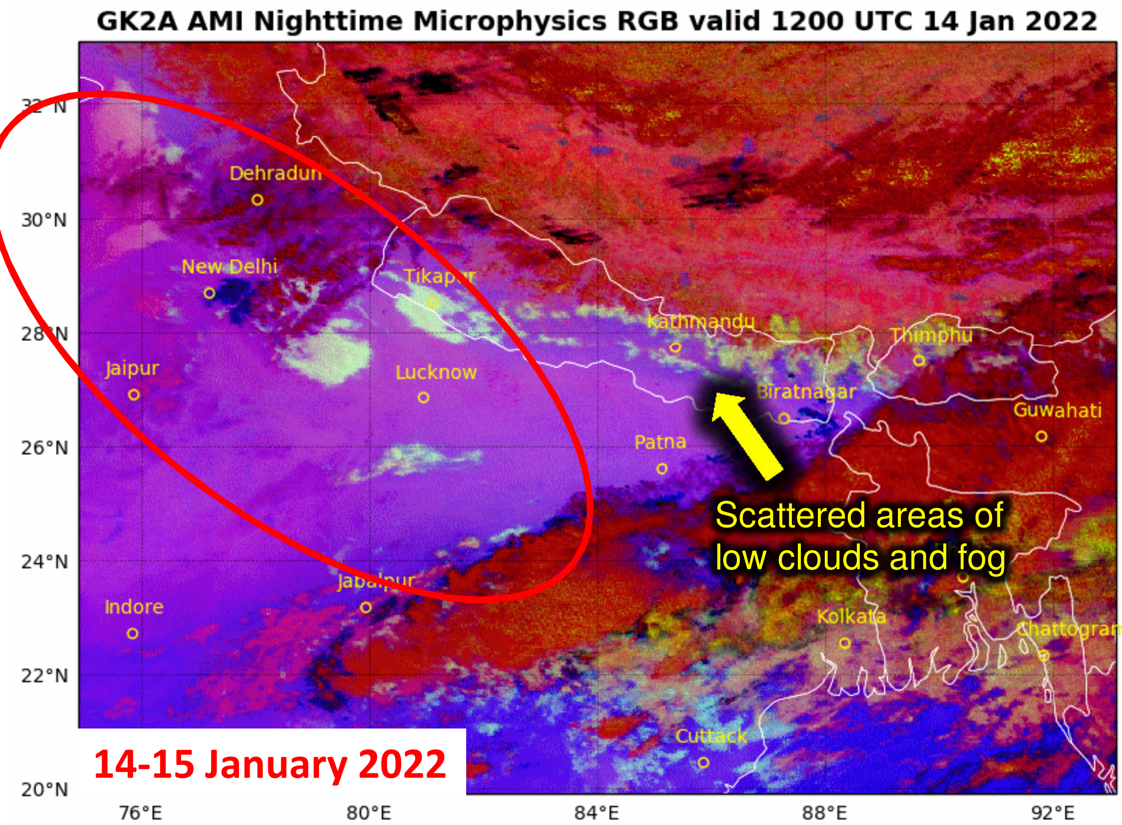
- RGB recipe applied to AMI with 2 km resolution for IR channels and 10-minute temporal frequency
- Low cloud and fog events frequently occur during the winter across HKH

Application Example:

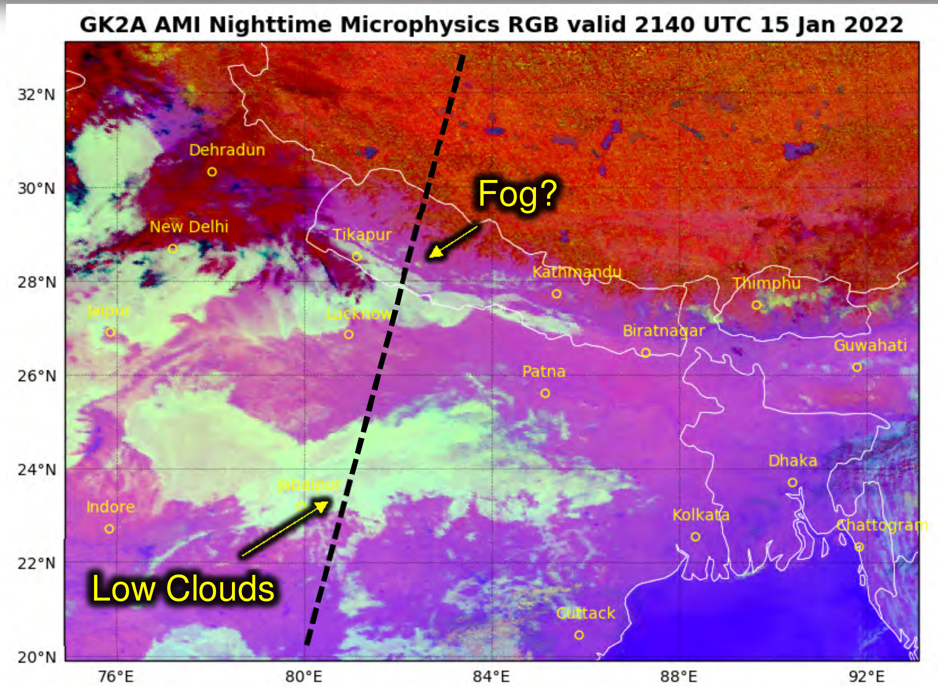
- Area of extensive low clouds and fog developed over North India during overnight from 14 – 15 January
- Scattered areas of low clouds and fog were present across Nepal

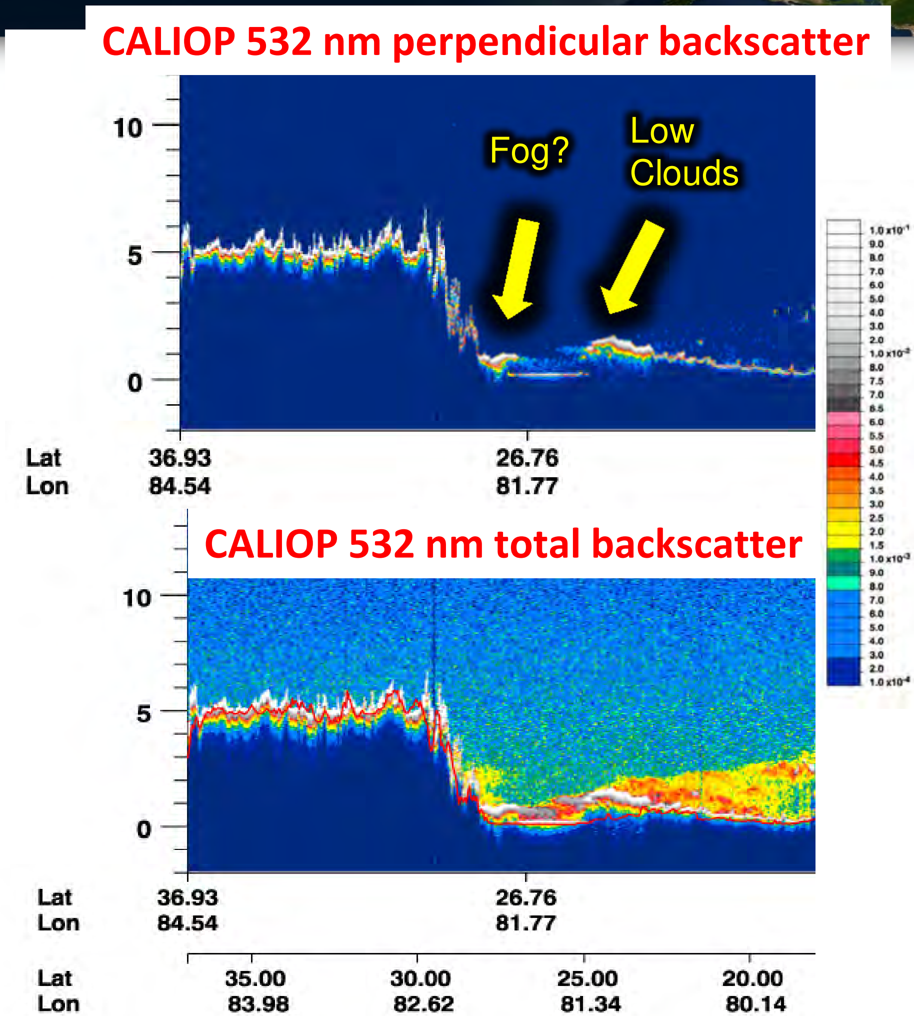
Limitation:

- Sunlight contamination of SW 3.8 µm channel limits its use to night only



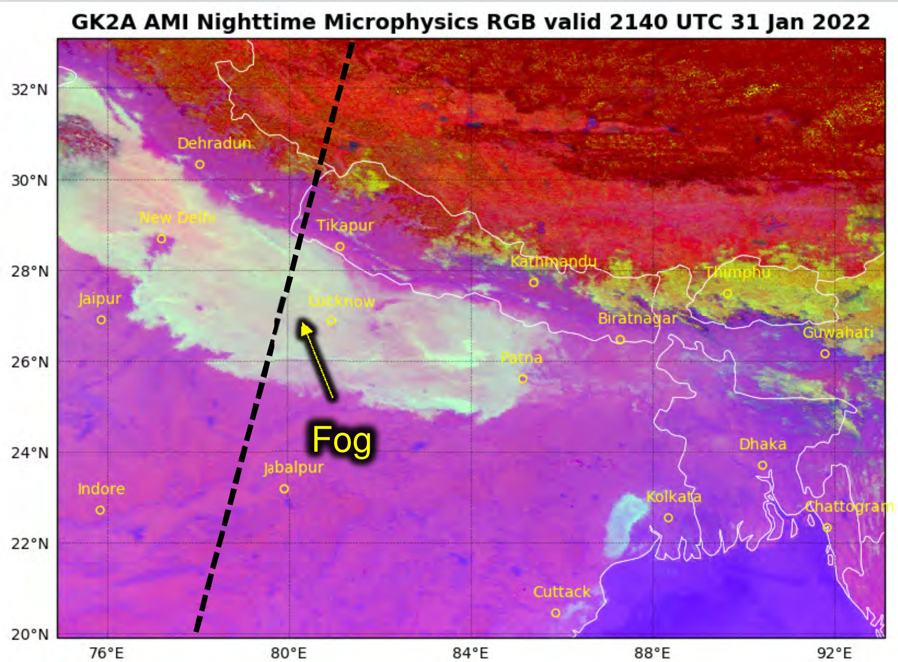
AMI NtMicro RGB – January 2022 Low Clouds & Fog

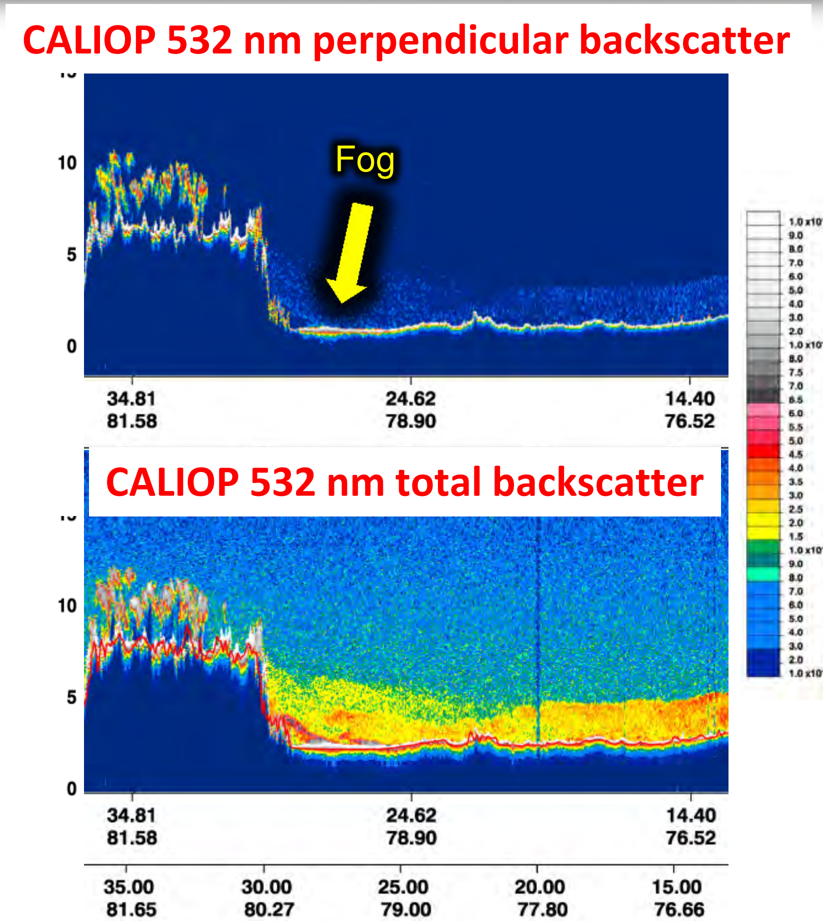




- ❑ Dull cyan features in Nepal suggest presence of fog in region
- ❑ CALIOP measurements indicate a transition from low clouds over North India to fog over Nepal

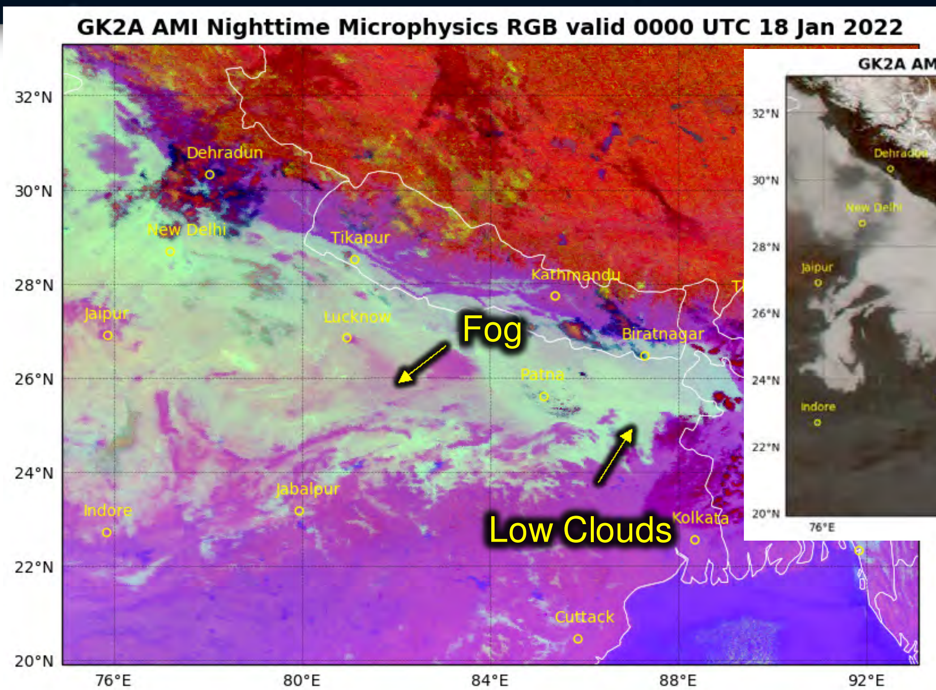
AMI NtMicro RGB – January 2022 Fog

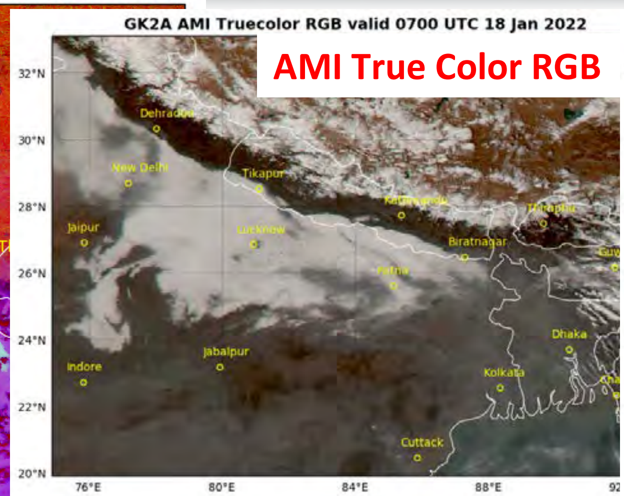


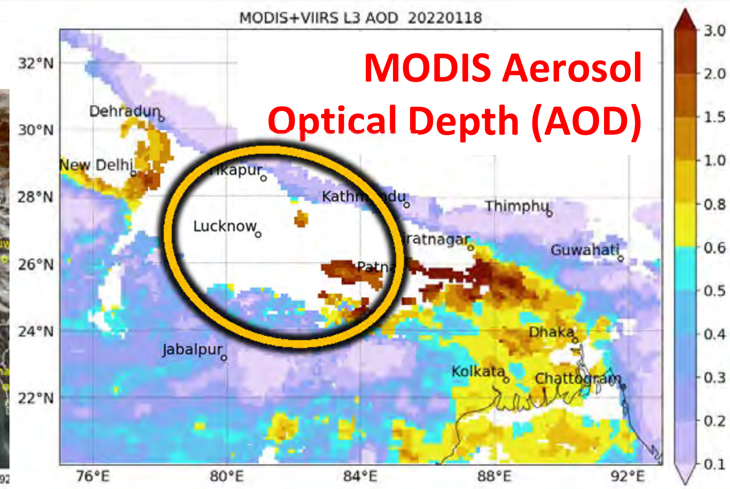


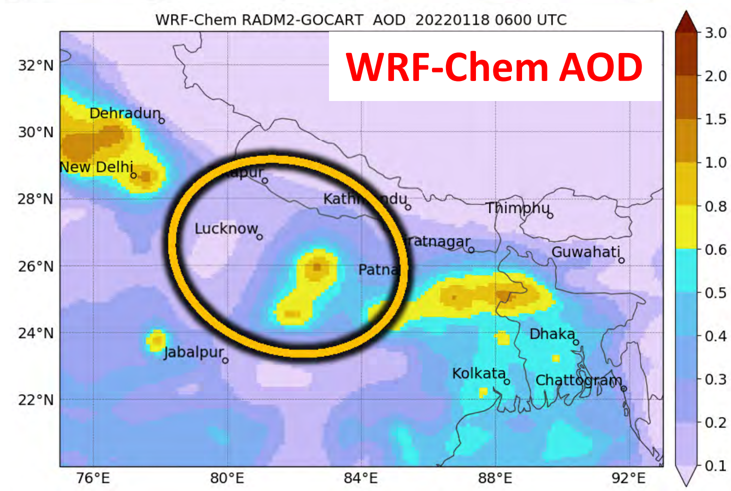
- ❑ Dull cyan features across North India and near Nepal border suggest extensive fog in region
- ❑ CALIOP detects enhanced backscatter from feature in surface layer, indicative of fog

AMI NtMicro RGB – Air Quality Related Applications



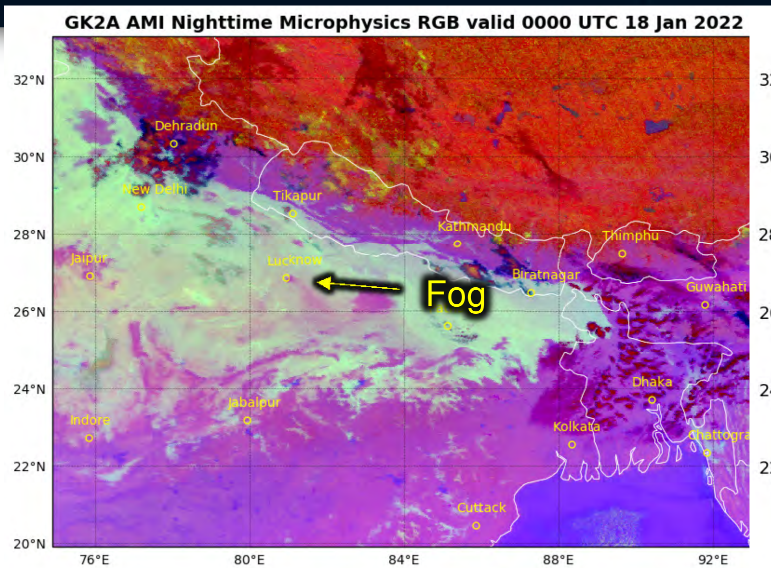


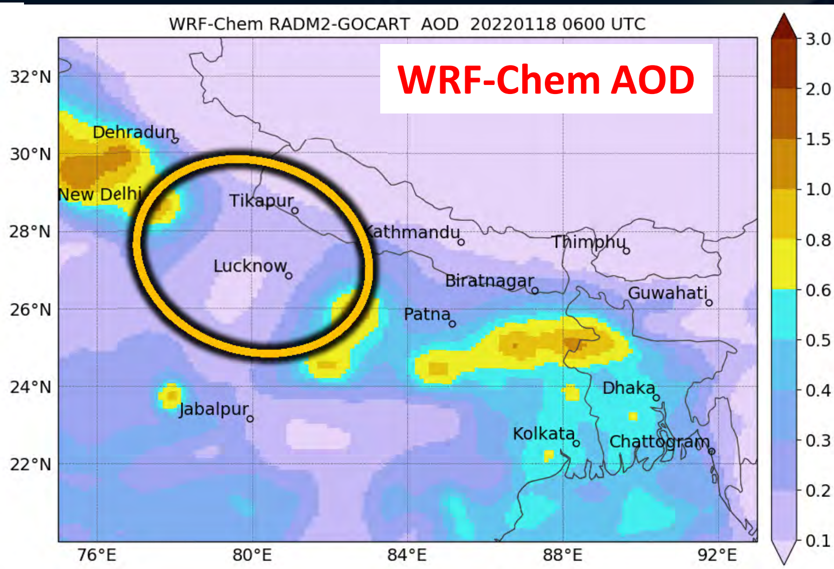


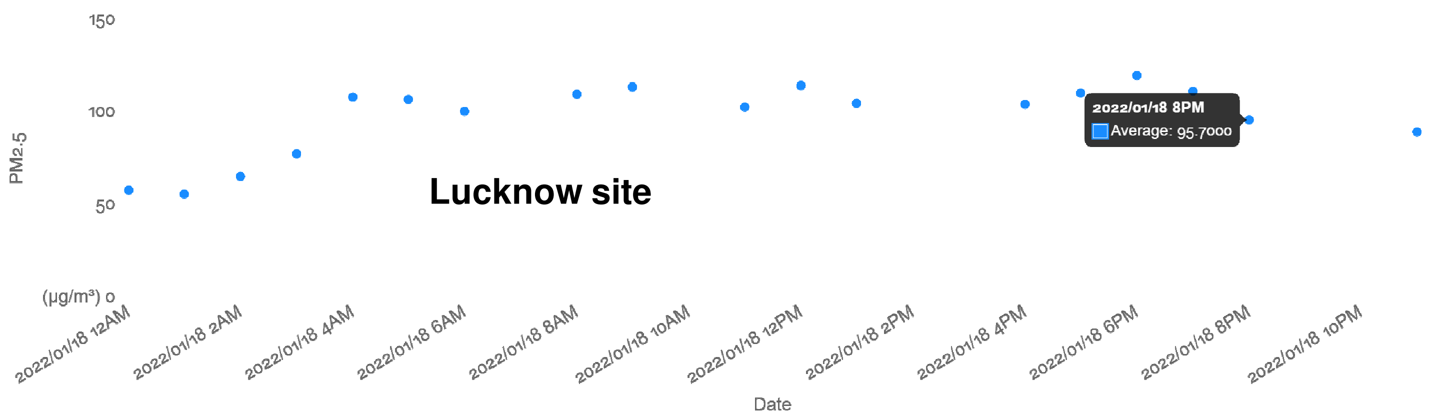


- NtMicro RGB can provide guidance on potential gaps in satellite aerosol and trace gas products
- These gaps can substantially reduce the positive impact of satellite data assimilation on air quality forecasts
- Low clouds / fog develop in stable environments, which can trap pollutants in the surface layer

AMI NtMicro RGB – Air Quality Related Applications







- PM2.5 measured at Lucknow, IN shows elevated pollution levels during low cloud / fog conditions, when valid satellite aerosol retrievals are unavailable
- Model severely underestimates AOD and, as a result, PM2.5 at Lucknow due to limited satellite AOD assimilation

Summary / Resources

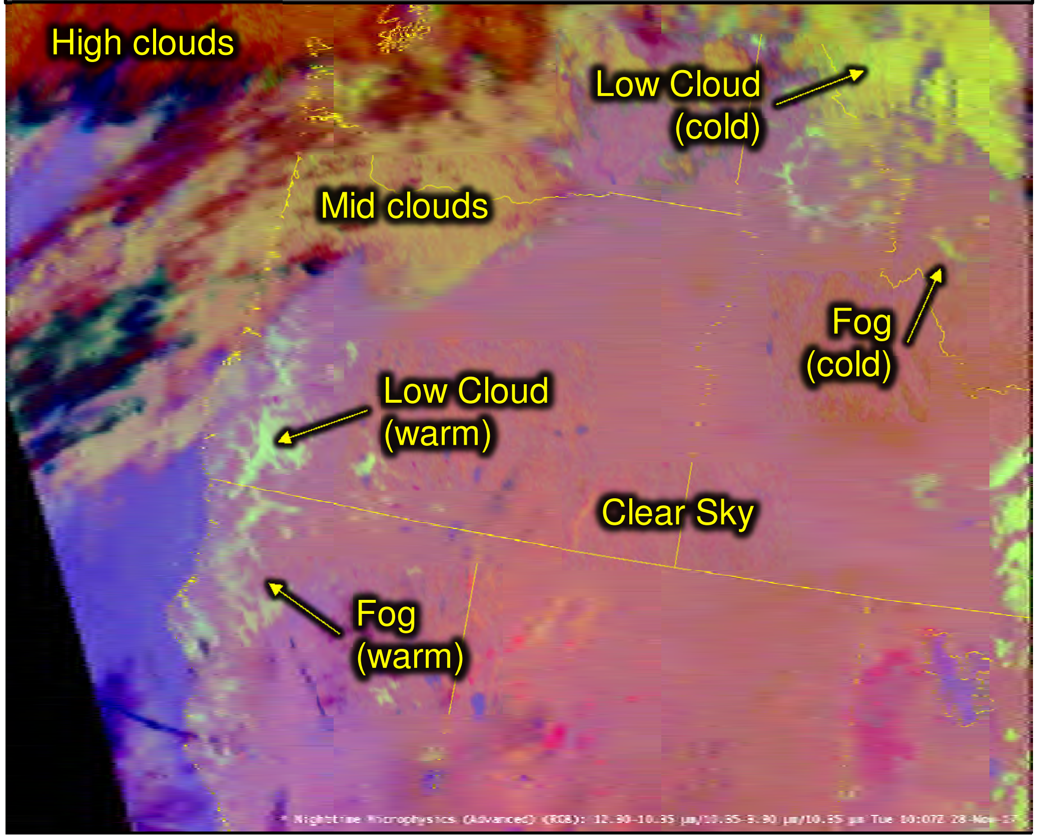
NtMicro RGB to analyze Fog vs Low Clouds / Clear Sky

Summary:
Learning Objective: Use NtMicro RGB to identify fog and anticipate hazards to aviation and public transit.

NtMicro provides:

- ❑ Early awareness of visibility issues related to fog
- ❑ Improved identification of cloud types and clear sky areas over the legacy “Fog” (10.3-3.9 µm) product
- ❑ **Awareness of possible gaps in satellite coverage of air pollutants and limitations in AOD assimilation**

Nighttime Microphysics RGB via GOES-R over northwest U.S.
1007 UTC, 28 November 2017



Summary / Resources

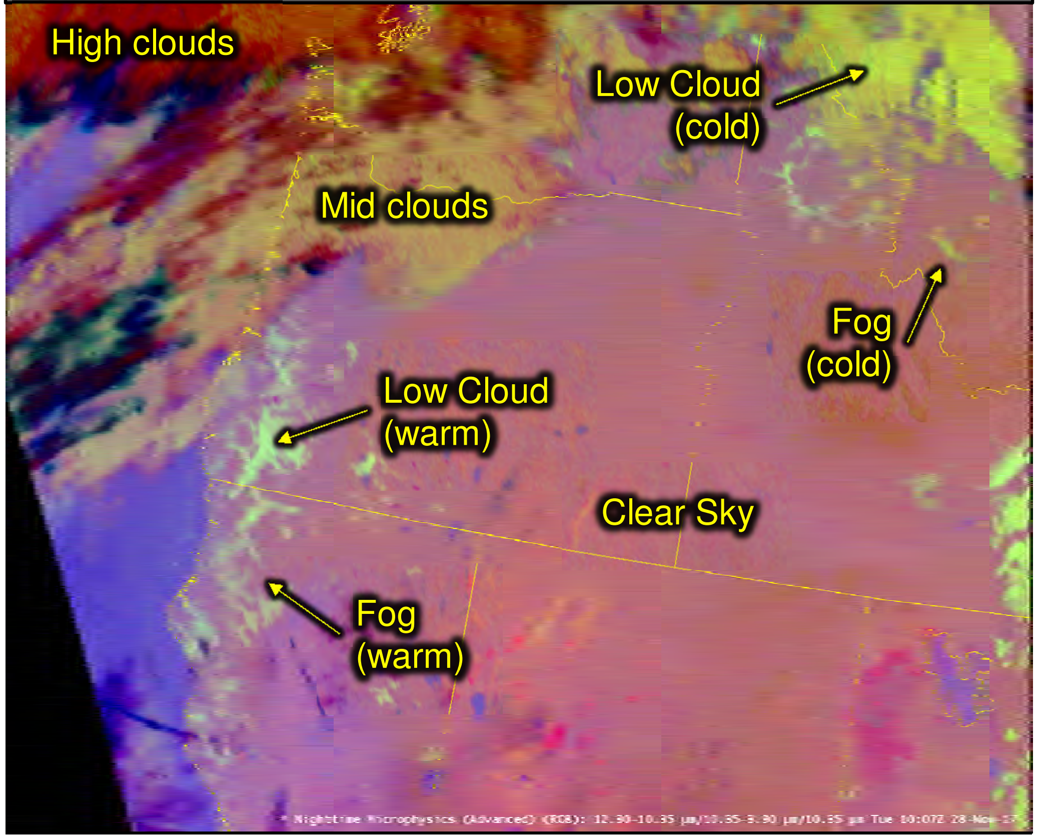
NtMicro RGB to analyze Fog vs Low Clouds / Clear Sky

Summary:
Learning Objective: Use NtMicro RGB to identify fog and anticipate hazards to aviation and public transit.

Warm Regime/Climate	
Fog *(thin to thick)*	Gray to Dull Cyan
Low Clouds *(thick)*	Bright Cyan

Cold Regime/Climate	
Fog *(thin to thick)*	Gray to Yellow-Green
Low Clouds *(thick)*	Bright Yellow

Nighttime Microphysics RGB via GOES-R over northwest U.S.
1007 UTC, 28 November 2017



Break
Q & A

Natural Color RGB

Natural Color Fire – Introduction

SERVIR

Day Land Cloud Fire RGB:

- Similar to Natural Color RGB (EUMETSAT)
- 1.6 μm band is replaced with 2.2 μm band from GOES to focus more on active fires and less on clouds
- **Note: No 2.2 μm band on AMI, so we apply 3.8 μm**

Issues:

- Typically, must use two products to view hot spots and smoke
  - Short-wave IR
  - Visible imagery
- 3.9 band saturates with all fires (from ‘warm’ to ‘very hot’)

Application Example:

- Analysis of hotspots and smoke in the Redwood Valley, Northern California

Natural Color Fire RGB via GOES 16 over Northern California from 1602-2057 UTC 09 October 2017

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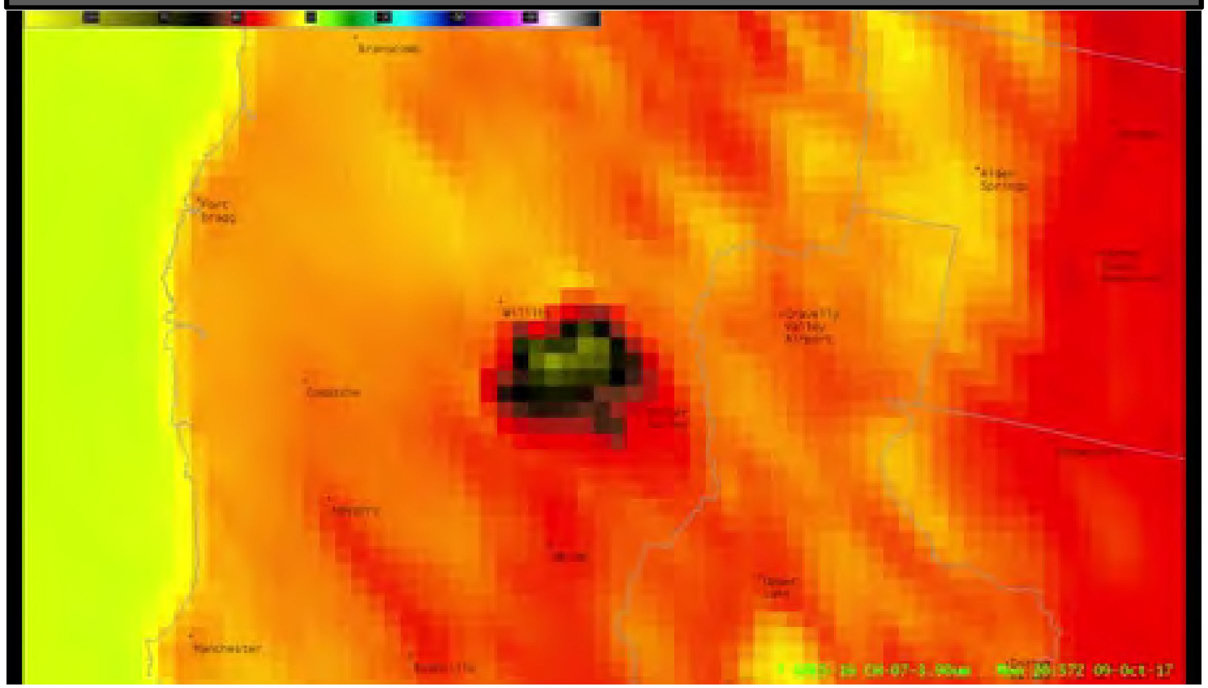
Challenge & Objective

3.9 µm channel via GOES 16 over Northern California
from 1602-2057 UTC 09 October 2017



- Fire hot spots detected using 3.9 µm channel
- Smoke is not easily detected using the 3.9 µm, and warm areas around the fire look similar to other land features
- Challenge: identify most active hot spot location

Analysis & Impact

via GOES-16 over Northern California
1757-2057 UTC 09 October 2017

In Natural Color Fire RGB loop…

- Hot spots appear in **red** pixels
- Smoke plumes appear in dark **cyan** to dark **blue**, like features in visible imagery

In 3.9 µm IR loop…

- Indicates a large burn area, but encompasses more than the red pixel of the Natural Color Fire RGB

In Visible loop…

- Can only see smoke plumes

In Natural Color RGB loop…

- Notably less red pixels appear to aid active fire analysis

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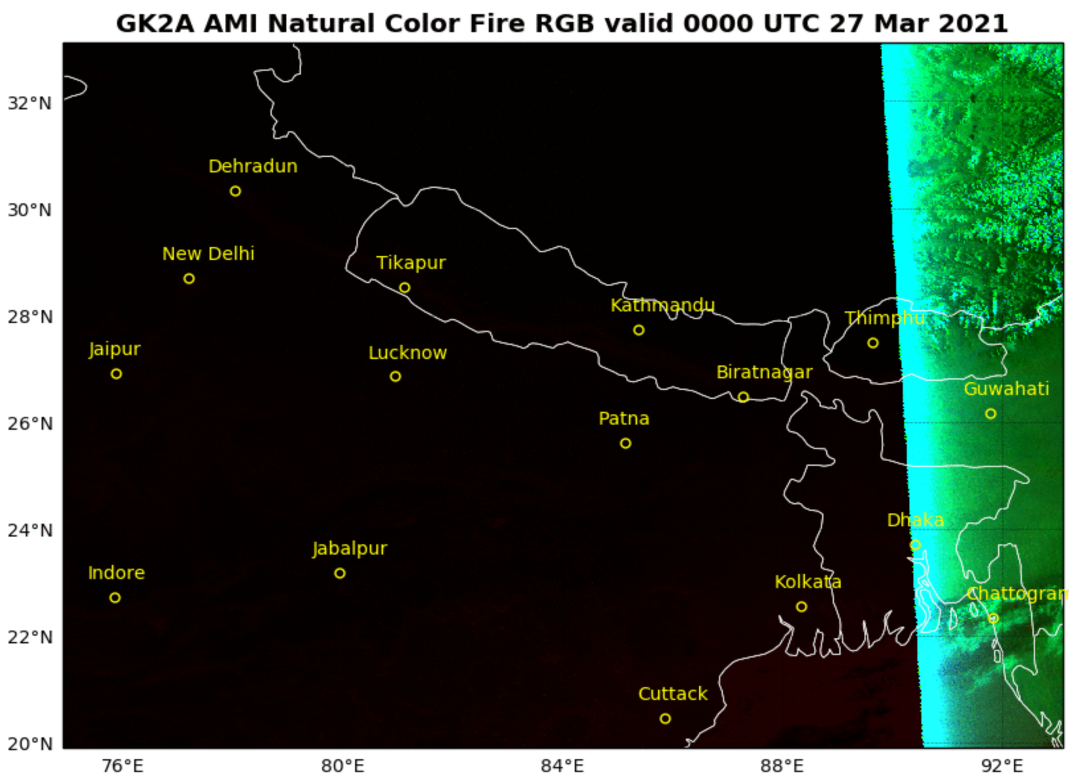
AMI Natural Color Fire RGB



Conclusions…

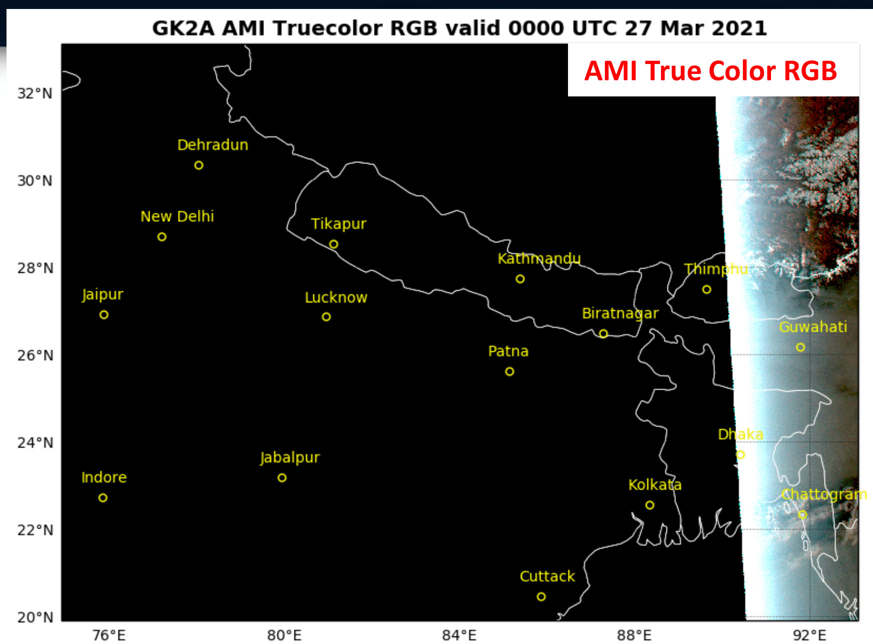
- Can monitor hot spots in wildfire areas
- RGB identifies areas of thick smoke, allowing the forecaster to monitor movement, like in visible
- <u>Use this RGB if desire to see hotspots from medium to large fires, smoke, and cloud cover within one product</u>

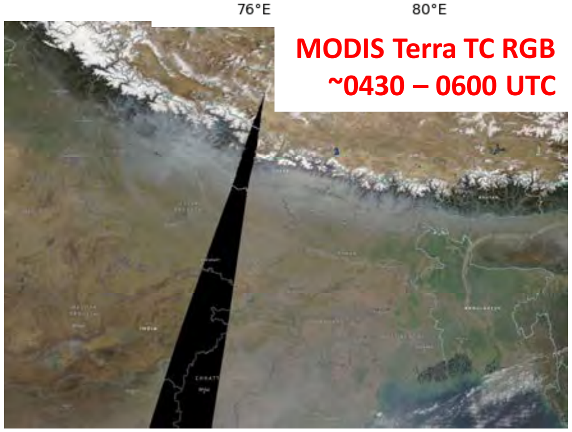
Keep in mind…

- Other fire products exist for use in analyzing fires
- Small fires and low-intensity fires, which are common across HKH, are less noticeable compared to just using 3.9 μm.
- Hot land surface over HKH leads to color contamination

True Color (TC) RGB & Fire Detections

True Color RGB - Introduction





- ❑ Uses the three visible channels of AMI to monitor aerosols, clouds, and vegetation
- ❑ Designed to imitate how the human eye would see the scene

Benefits:

- ❑ Easy to interpret
- ❑ Aerosols usually distinguishable from clouds
- ❑ Different aerosol types can have different color shades (i.e., ash, smoke, dust)
- ❑ Aids in fire detection and smoke monitoring

Limitations:

- ❑ Only valid during the daytime
- ❑ The Green band for AMI (0.51 μm) is slightly shifted compared to the Chlorophyll-A visible reflectance peak
  - Differences in vegetation color less apparent for AMI than MODIS / VIIRS

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AMI True Color RGB – Features & Use Case

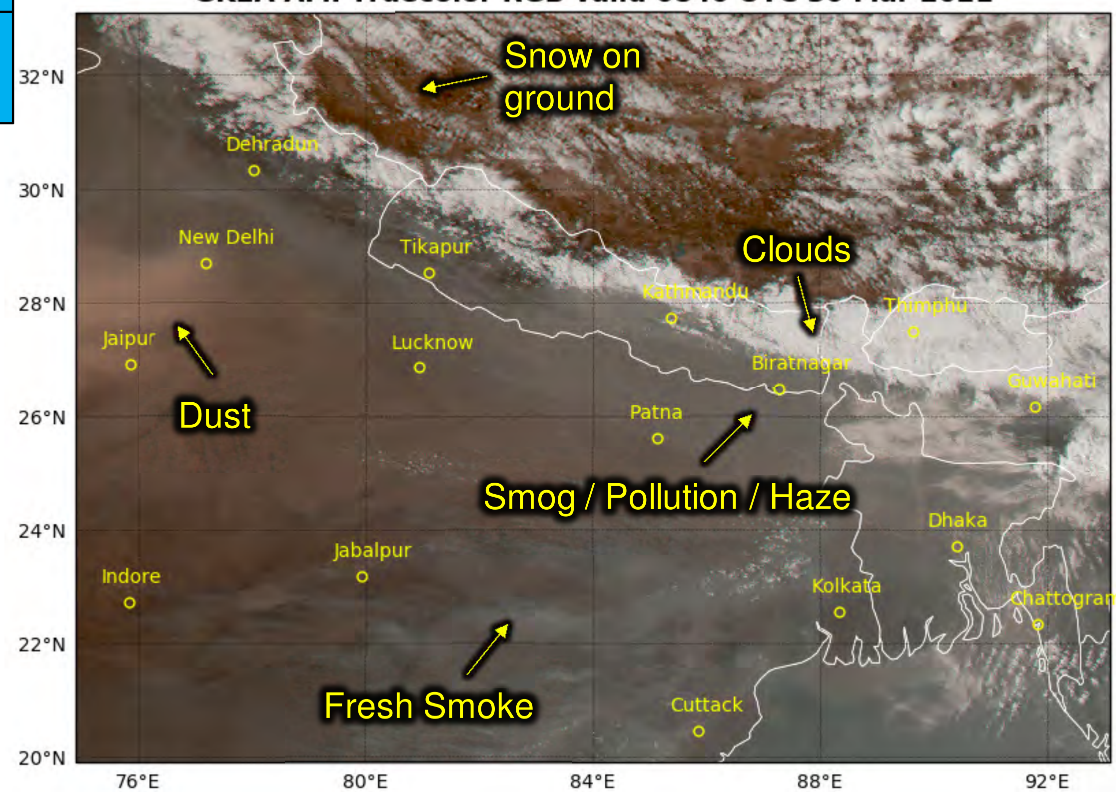
Red	*Green*	*Blue*
$VIS_{0.64}$ (0 to 1.0 refl)	$VIS_{0.51}$ (0 to 1.0 refl)	$VIS_{0.47}$ (0 to 1.0 refl)

- TC RGB tracks dust and smoke pollution on 30 March 2021
- Dust appears in a brownish tone
- Smog and haze appear grey
- Fresh smoke can appear grey with some bluish tone
- Clouds and snow on ground appear white
- "Dirty clouds" can be apparent in HKH region

Different shades of aerosols in TC RGB can be difficult to discern in HKH due to the complex pollutant mixtures that often impact the region.

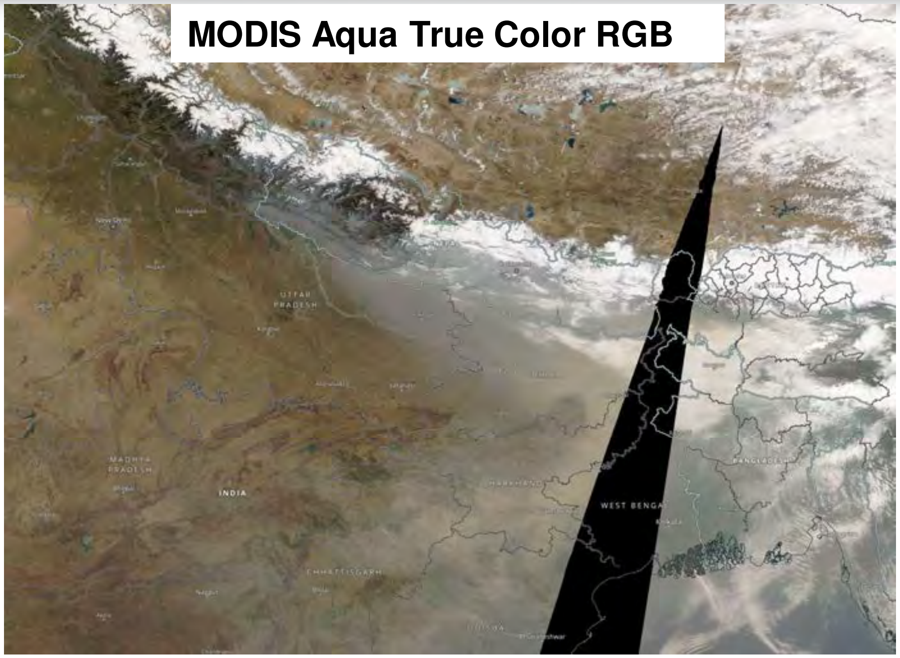
Using other RGBs can help!

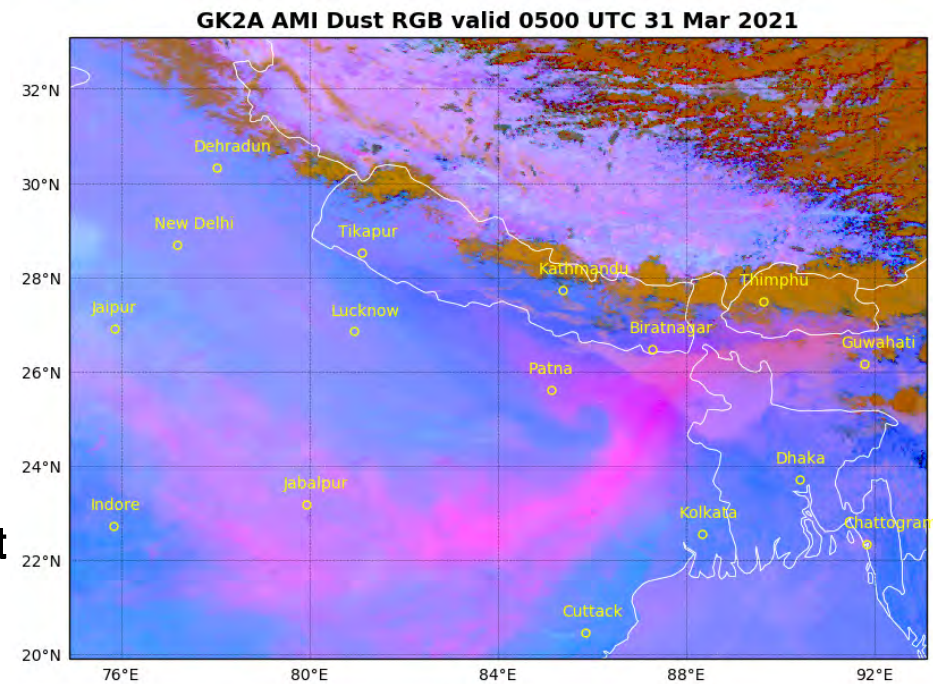
GK2A AMI Truecolor RGB valid 0840 UTC 30 Mar 2021



True Color RGB – 31 March 2022

MODIS Aqua True Color RGB





Combining information from RGB product suite can help better understand evolution of different pollutants in the atmosphere

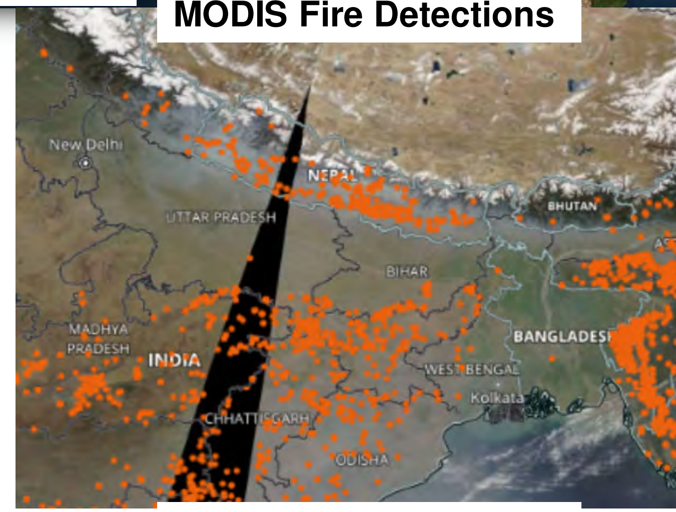
Fire Detection – Introduction

SERVIR

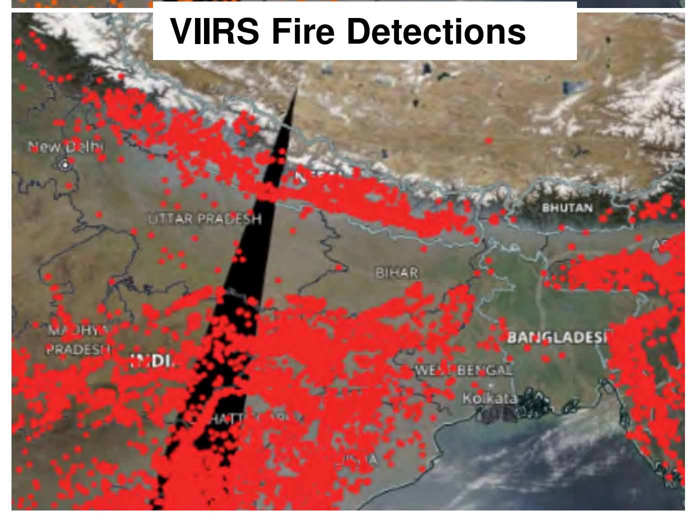
- MODIS and VIIRS have high spatial resolution (1 km for MODIS, 375 m for VIIRS) for detecting small scale fires, but lack the temporal resolution for monitoring fires throughout the day
- AMI has sufficiently high temporal resolution (10 minutes) for daytime monitoring of fires, but can often miss small fires due to its coarser spatial resolution (> 4 km over HKH)
- A range of different fire detection methods have been implemented using various satellite sensors (e.g., MODIS, VIIRS, GOES, AHI) with a common theme being the application of the SW 3.9 µm band
- Stringent threshold tests relying on the 3.9 µm band (e.g., > 60 K) alone have been implemented for GOES, but these simple methods are only applicable to high-intensity wildfire events
- We develop a more intensive methodology for AMI fire detection using a series of band threshold tests along with auxiliary data to detect smaller scale, lower intensity fires

27 March 2021

MODIS Fire Detections

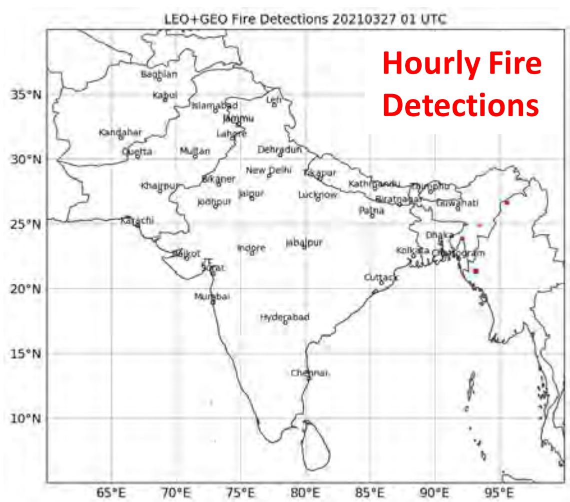


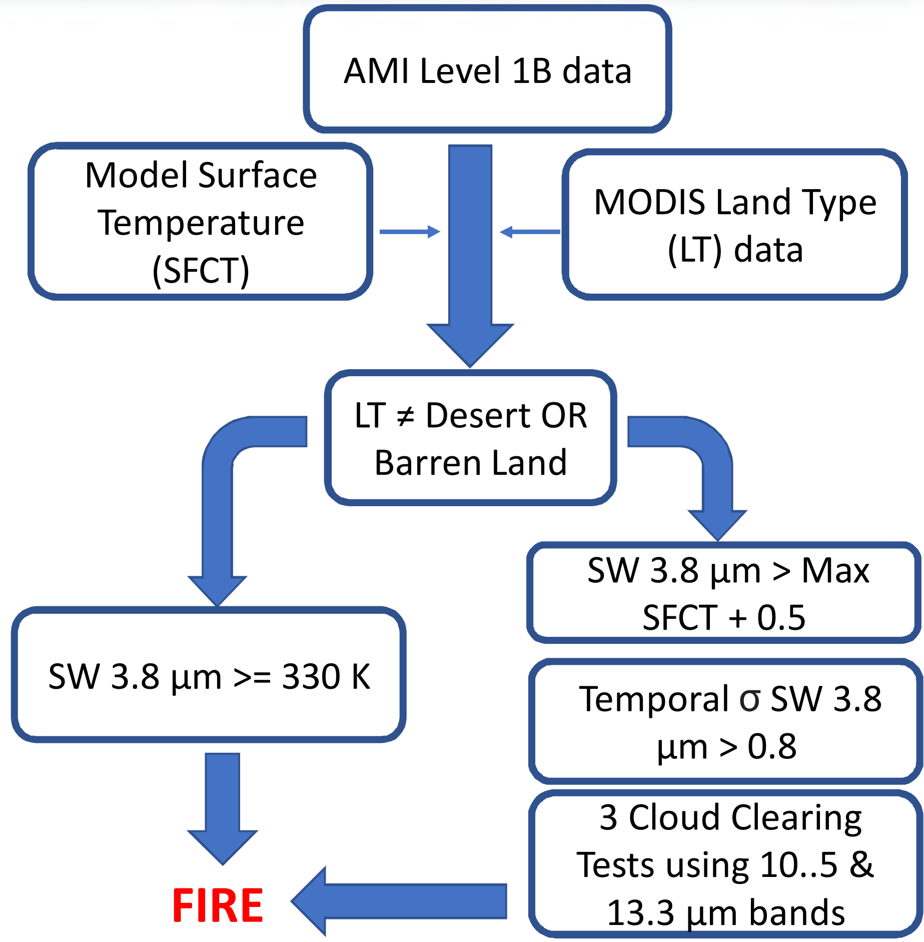
VIIRS Fire Detections



AMI Fire Detection – Methods

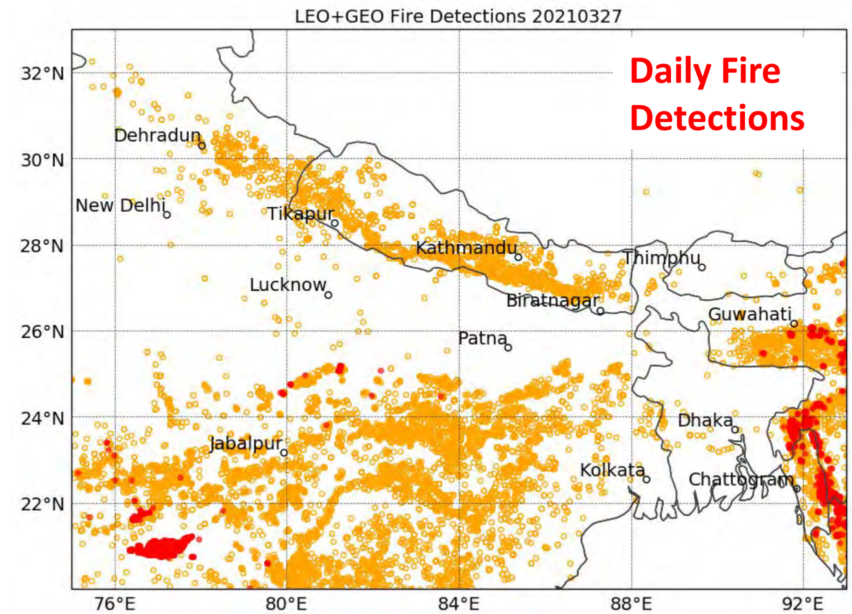
- ❑ AMI fire detection method is applied every 10 minutes!
- ❑ Hourly fire detection maps are a composite of the 10-minute AMI detections and MODIS fire detections in the 1-hour time window
- ❑ Daily fire detection maps are a composite of all AMI, MODIS, and VIIRS fires throughout the daytime
  - VIIRS is likely to have minor impact on fire detection map due to 3-hour latency





AMI Fire Detection – Results and Validation

- ❑ Algorithm was first tested in Spring 2021
- ❑ Initial validation efforts highlighted the good performance of the product
  - ▪ AMI detected numerous fire hot spots in the morning prior to MODIS and VIIRS observations
- ❑ As expected, MODIS and VIIRS detect many more fires compared to AMI due to higher spatial resolution
- ❑ Daily composite map of MODIS, VIIRS, and AMI fire detections show full extent of fires in region
- ❑ Additional validation efforts have commenced this spring to ensure methods are applicable across multiple seasons and years



AMI can provide valuable information on evolution of fires and smoke over HKH

Discussion, Q&A

Show recent RGB and Fire Products on project page