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

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Project Overview
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
Key Products & Tools

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

### Table

<table>
<thead>
<tr>
<th>Channel No</th>
<th>Channel</th>
<th>AMI (µm)</th>
<th>ABI (µm)</th>
<th>AHI (µm)</th>
</tr>
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<tbody>
<tr>
<td>1</td>
<td>VIS (blue)</td>
<td>0.470</td>
<td>0.470</td>
<td>0.46</td>
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<td>SWIR</td>
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<td></td>
<td>(SWIR)</td>
<td></td>
<td>2.250</td>
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<td>7</td>
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<td>8</td>
<td>MWIR (WV)</td>
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<td>9</td>
<td>MWIR (WV)</td>
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<td>10</td>
<td>MWIR (WV)</td>
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<td>TIR</td>
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<td>14</td>
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<td>15</td>
<td>TIR</td>
<td>12.364</td>
<td>12.30</td>
<td>12.3</td>
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# LEO Channels for RGB Products

<table>
<thead>
<tr>
<th>MODIS</th>
<th>VIIRS</th>
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<tbody>
<tr>
<td><strong>Band #</strong></td>
<td><strong>λ</strong> (nm)</td>
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<tr>
<td>1</td>
<td>620 - 670</td>
</tr>
<tr>
<td>2</td>
<td>841 - 876</td>
</tr>
<tr>
<td>3</td>
<td>459 - 479</td>
</tr>
<tr>
<td>4</td>
<td>545 - 565</td>
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<td>5</td>
<td>1230 - 1250</td>
</tr>
<tr>
<td>6</td>
<td>1628 - 1652</td>
</tr>
<tr>
<td>7</td>
<td>2105 - 2155</td>
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<tr>
<td>8</td>
<td>405 - 420</td>
</tr>
<tr>
<td>9</td>
<td>438 - 448</td>
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<tr>
<td>10</td>
<td>483 - 493</td>
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<td>11</td>
<td>526 - 536</td>
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<td>12</td>
<td>546 - 556</td>
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<tr>
<td>13</td>
<td>662 - 672</td>
</tr>
<tr>
<td>14</td>
<td>673 - 683</td>
</tr>
<tr>
<td>15</td>
<td>743 - 753</td>
</tr>
<tr>
<td>16</td>
<td>862 - 877</td>
</tr>
<tr>
<td>17</td>
<td>890 - 920</td>
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<tr>
<td>18</td>
<td>931 - 941</td>
</tr>
<tr>
<td>19</td>
<td>915 - 965</td>
</tr>
</tbody>
</table>
General Formulae for RGB Products

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

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

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

Where:

- \( R, G, \text{ or } B \) is the present pixel value
- \( min \) and \( max \) are the calibrated thresholds applied to a given channel or channel difference
- \( 1/\gamma \) is the calibrated power scale to affect the color stretching
<table>
<thead>
<tr>
<th>Satellite Product</th>
<th>Red</th>
<th>Green</th>
<th>Blue</th>
<th>Gamma</th>
<th>Applications</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dust RGB</td>
<td>$\text{IR}<em>{12.3} - \text{IR}</em>{10.5}$ (-6.7 to +2.6C)</td>
<td>$\text{IR}<em>{11.2} - \text{IR}</em>{8.7}$ (-0.5 to +20C)</td>
<td>$\text{IR}_{10.5}$ (-11.95 to +15.55C)</td>
<td>1.0 (RB) 2.5 (G)</td>
<td>Dust plume monitoring</td>
</tr>
<tr>
<td>Nighttime Microphysics</td>
<td>$\text{IR}<em>{12.3} - \text{IR}</em>{10.5}$ (-6.7 to +2.6C)</td>
<td>$\text{IR}<em>{10.5} - \text{SW}</em>{3.8}$ (-3.1 and +5.2C)</td>
<td>$\text{IR}_{10.5}$ (-29.55 to +19.45C)</td>
<td>1.0</td>
<td>Fog, smog, and low-cloud detection</td>
</tr>
<tr>
<td>Truecolor RGB</td>
<td>$\text{VIS}_{0.64}$ (0 to 1.0 refl)</td>
<td>$\text{VIS}_{0.51}$ (0 to 1.0 refl)</td>
<td>$\text{VIS}_{0.47}$ (0 to 1.0 refl)</td>
<td>2.2</td>
<td>Land surface, clouds, and aerosols</td>
</tr>
<tr>
<td>Natural Color Fire RGB</td>
<td>$\text{SW}_{3.8}$ (0 to 60C)</td>
<td>$\text{VIS}_{0.87}$ (0 to 1.0 refl)</td>
<td>$\text{VIS}_{0.64}$ (0 to 1.0 refl)</td>
<td>0.4 (R) 1.0 (GB)</td>
<td>Fire hot spots [and smoke]</td>
</tr>
</tbody>
</table>
Dust RGB Product
Dust RGB – Quick Brief

**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
Dust RGB – Product Basics

Very small differences between ABI and AMI for these channels

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

- 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
Increased Lead Time & Awareness

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

**Kathmandu site**

**Episode #1**

29 Mar 30 Mar 31 Mar

**Episode #2**

GK2A AMI Dust RGB valid 0000 UTC 29 Mar 2021
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

CALIOP observes dust particles in this region of lighter magenta colors in Dust RGB
Strong increase in PM10 measured at surface monitor near Delhi

PM2.5 levels remain rather steady
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.
Substantial increases in PM10 during morning and afternoon

Bhopal, IN site

Increases in PM2.5 throughout the afternoon
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:

- 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.
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 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

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

- Improved awareness and lead time versus METARs
- More accurate depiction of fog vs band difference

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

- Shows spreading of fog outside of valleys
- VLIFR conditions

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:

- 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
- 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
Dull cyan features across North India and near Nepal border suggest extensive fog in region.

CALIOPI detects enhanced backscatter from feature in surface layer, indicative of fog.
- 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
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.
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
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.

<table>
<thead>
<tr>
<th>Warm Regime/Climate</th>
<th>Cold Regime/Climate</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Fog (thin to thick)</strong></td>
<td><strong>Fog (thin to thick)</strong></td>
</tr>
<tr>
<td>Gray to Dull Cyan</td>
<td>Gray to Yellow Green</td>
</tr>
<tr>
<td><strong>Low Clouds (thick)</strong></td>
<td><strong>Low Clouds (thick)</strong></td>
</tr>
<tr>
<td>Bright Cyan</td>
<td>Bright Yellow</td>
</tr>
</tbody>
</table>
Natural Color RGB
Natural Color Fire – Introduction

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
Challenge & Objective

- 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

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

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

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
AMI True Color RGB – Features & Use Case

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

![Hourly Fire Detections](image.png)
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