Operational Forecasting of Pollution for Improving Air Quality Alerts

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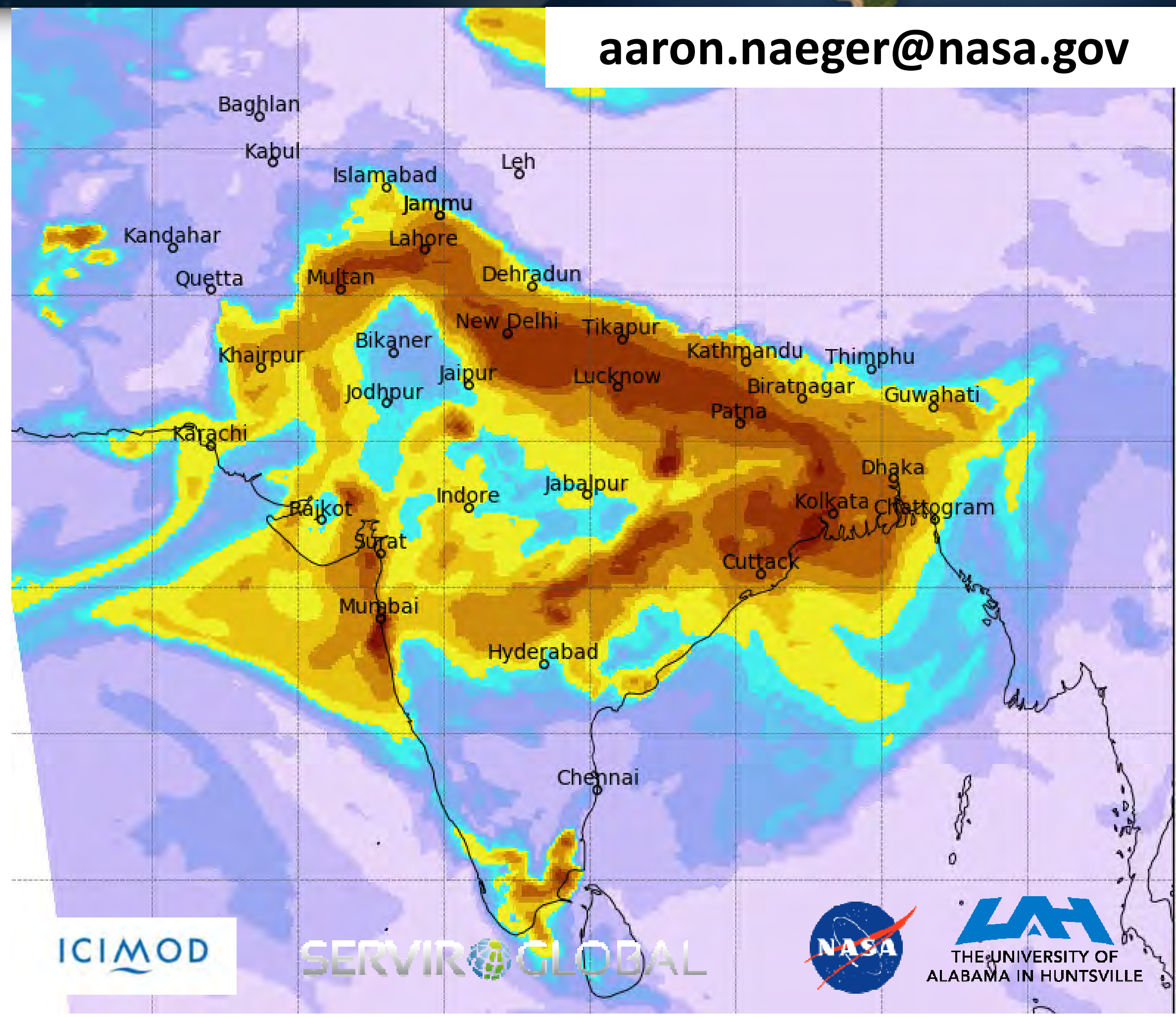

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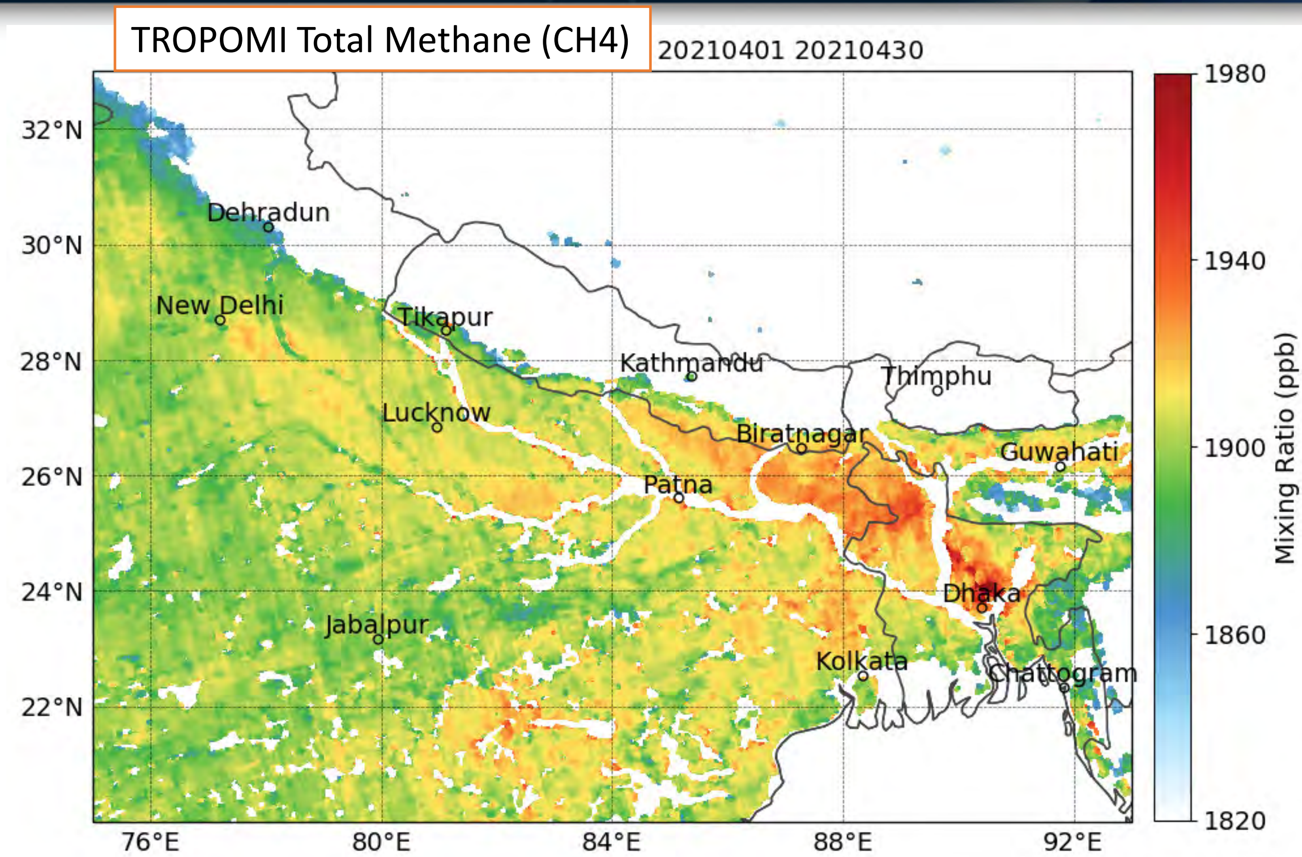

https://archive.dhakatribune.com/bangladesh/2021/04/29/dhaka-landfill-emits-4-tons-of-methane-per-hour

Project Objectives

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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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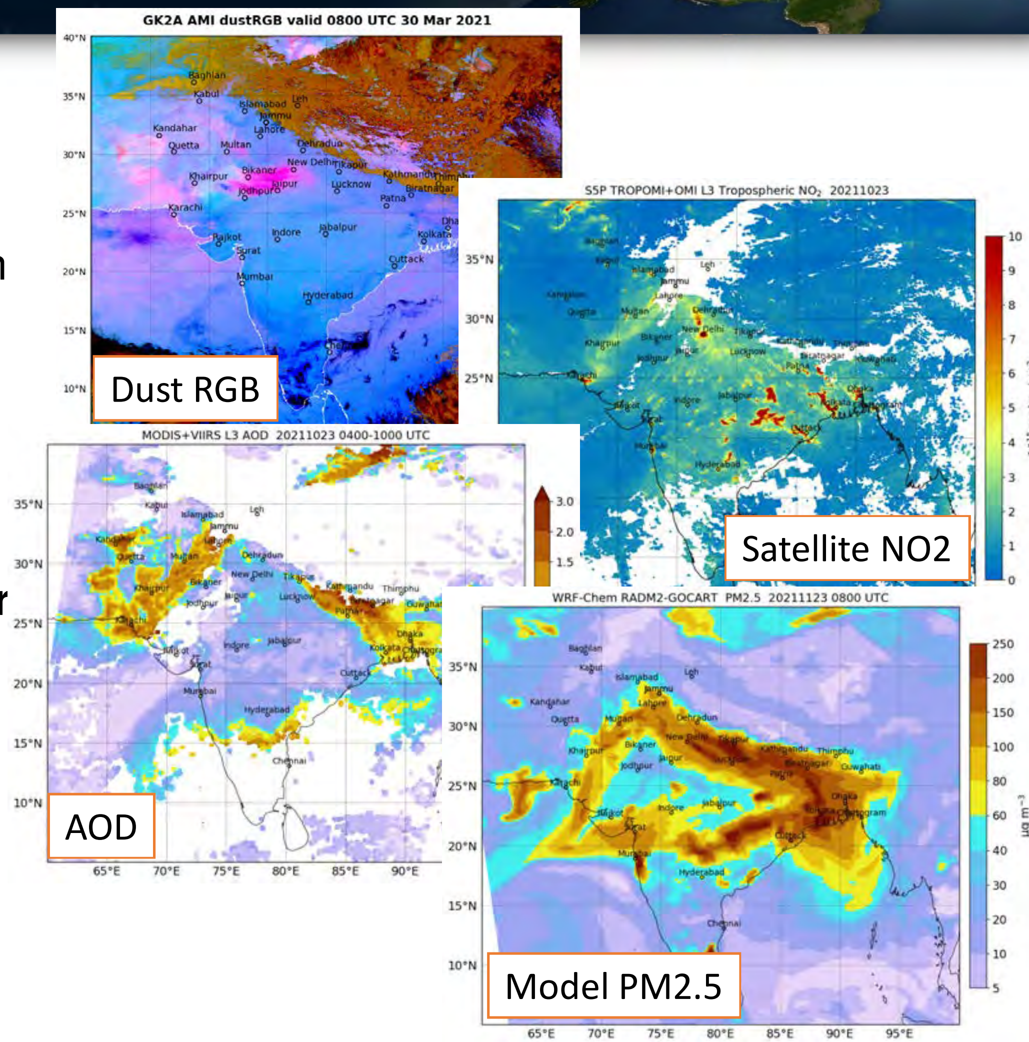
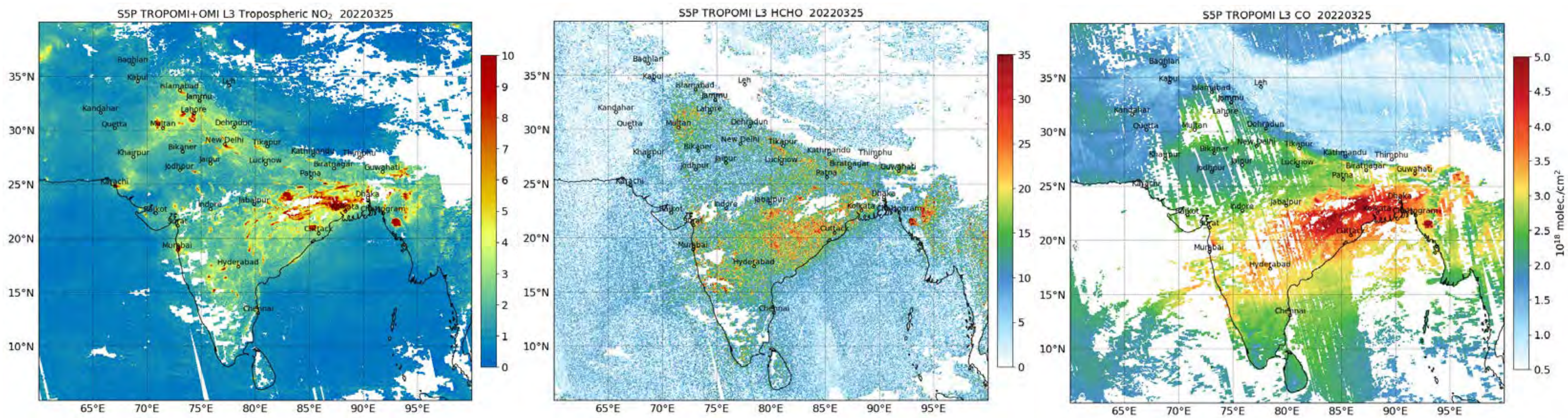
Key Products & Tools

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**



Recap from Yesterday

- ❑ Provided details on True Color RGB, Fire Detection, and Trace Gas Products



- ❑ Today will provide details on aerosol products, regional chemical transport model framework, and lagrangian dispersion forecasting of dust storms

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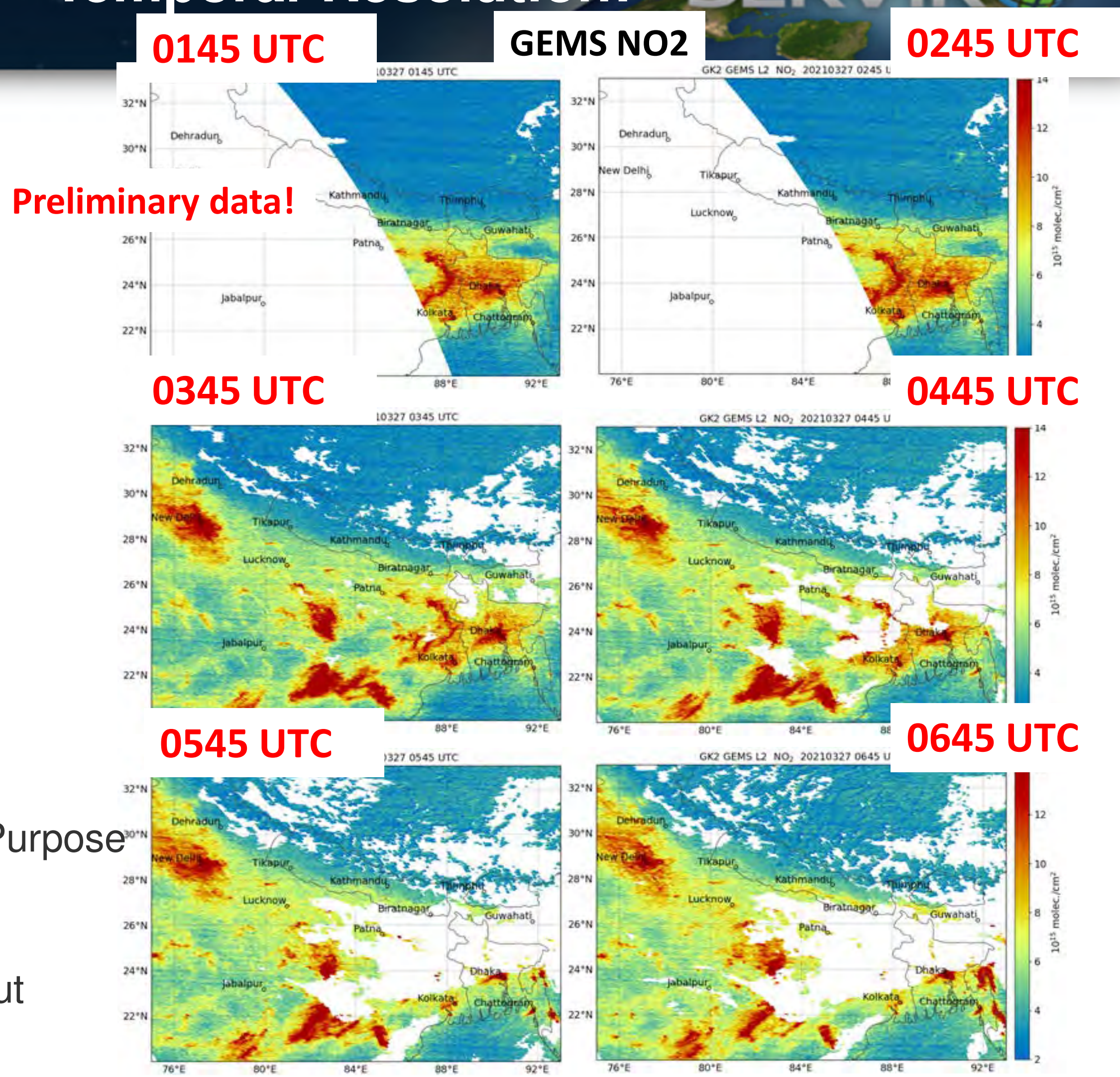
Satellite Trace Gas Measurements – Temporal Resolution!

Kim et al. (2020)

Product		Importance	Spatial resolution (km × km) at Seoul	SZA (°)
NO_2	TROP / STRAT	O_3/aerosol precursor	7 × 8 × 2 px	<70
SO_2		Aerosol precursor	7 × 8 × 4 px × 3 h	<50
		Volcano	7 × 8	
HCHO		VOC proxy	7 × 8 × 4 px	<50
CHOCHO			7 × 8 × 4 px	<50
O_3	TROP	Oxidant, pollutant	7 × 8	<70
	STRAT	Ozone layer		
	Total			
Aerosol	AOD	Air quality, climate	3.5 × 8	<70
	UVAI			
	SSA			
	AEH		7 × 8	



- ❑ Korean-led Geostationary Environment Monitoring Spectrometer (GEMS) was launched in Feb 2020
- ❑ GEMS is onboard the Geostationary Korea Multi-Purpose Satellite 2 (GEO-KOMPSAT-2) mission so nearly collocated in space with AMI
- ❑ GEMS has been making observations over Asia but publicly available data is not yet provided

Aerosol Retrievals and Products from AMI

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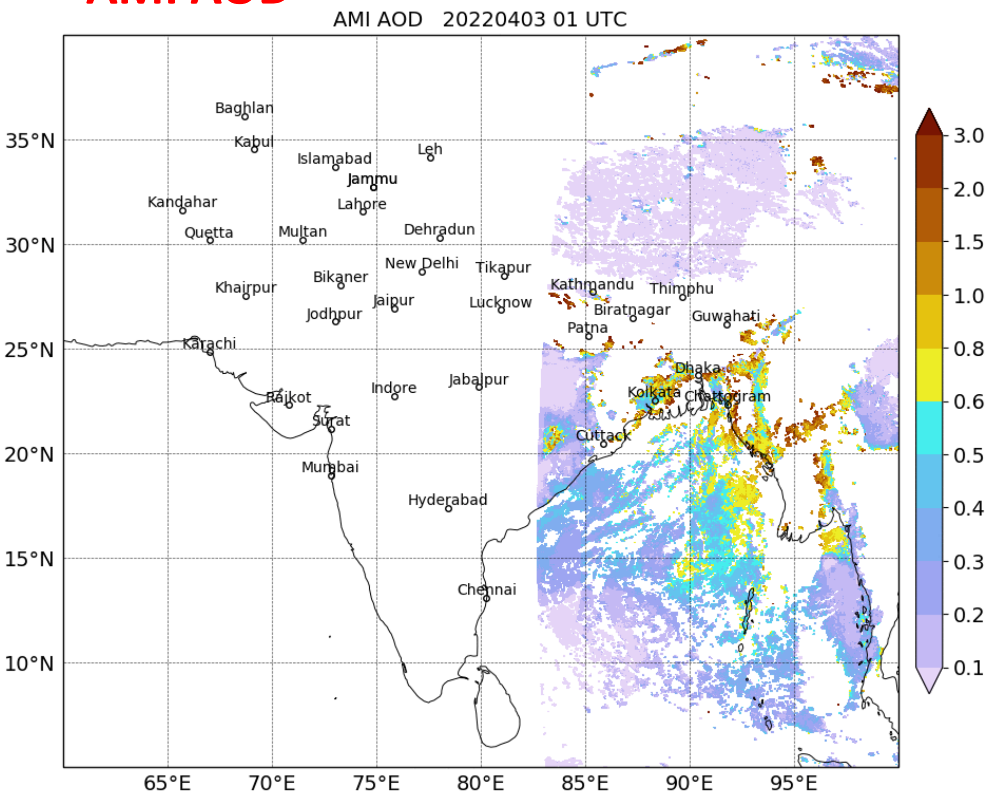
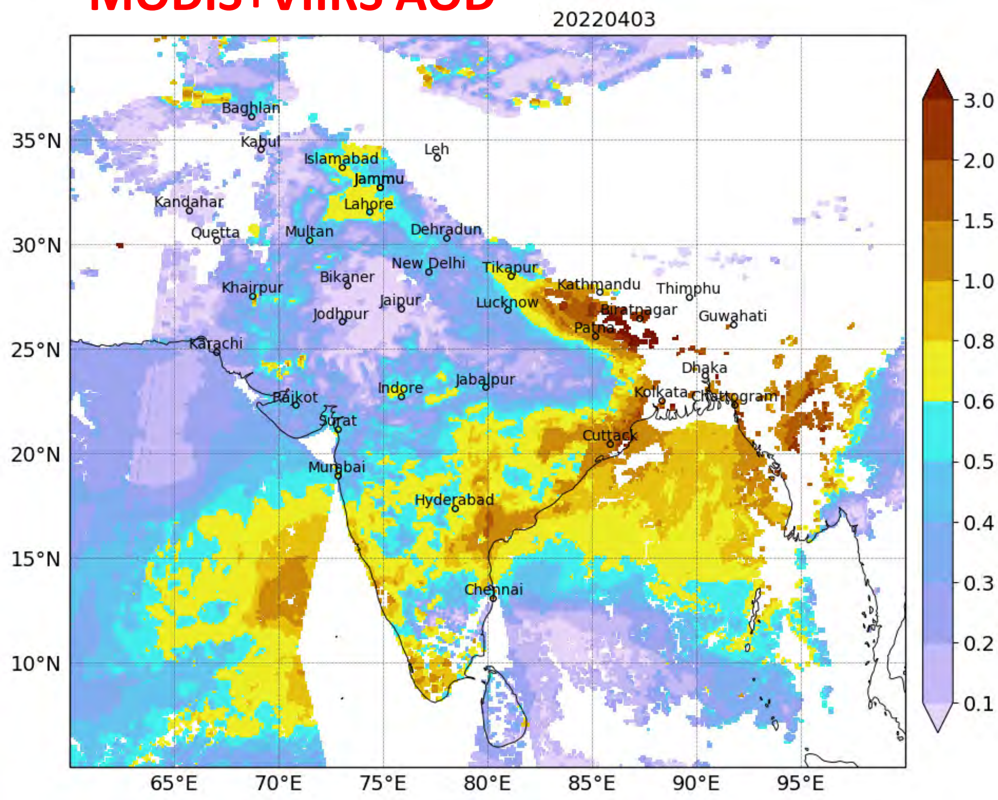
LEO vs GEO Aerosol Optical Depth (AOD)

AMI AOD



MODIS+VIIRS AOD



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LEO vs GEO Aerosol Retrievals

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- ❑ Aerosol Optical Depth (AOD) retrievals from GEO satellites (e.g., AMI) face unique challenges but also interesting opportunities compared to LEO satellites (e.g., MODIS)
- ❑ Challenges:
  - Account for the varying solar geometry throughout the day
  - Increasing pixel sizes moving towards edges of satellite Field of View
  - Less spectral bands compared to LEO for cloud clearing tests and AOD retrievals at standard wavelength of 550 nm
- ❑ Opportunities:
  - Fixed viewing geometry over same Field of View enables development of customized regional solutions for aerosol retrievals
  - Temporal information for high frequency AOD retrievals and unique cloud clearing tests

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

New Generation GEO satellites can be especially valuable over the HKH region where rapidly evolving emissions and transport processes govern air quality in the region

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AMI Aerosol Optical Depth (AOD) Algorithm

- Leveraged aerosol retrievals initially developed for past generation GEO satellite technology with only 5 spectral bands (GOES-15 over North America, MTSAT over Asia; Naeger et al., 2016)
  - Limited number of spectral bands leads to large uncertainties and errors in aerosol retrievals
- Major updates, refinements, and customizations implemented in AMI AOD retrieval algorithm over HKH region
- Major algorithm steps include:
  1. **Production of previous 30-day maps of minimum AOD**
  2. Calculating minimum top-of-atmosphere (TOA) reflectance of 0.51 µm AMI band for 30-day time period
  3. Use precalculated Lookup Table of TOA reflectance at 0.51 µm for finding reflectance values associated with solar & viewing geometry, minimum surface reflectance, **and AOD conditions (AOD Index values range from 0.03 to 0.7)**
  4. Calculate simulated TOA reflectance using **Aerosol Model Lookup Tables** based on reflectance values from (3), solar & viewing geometry, and range of AOD conditions (AOD Index values range from 0 to 4)
  5. Find minimum difference between observed and simulated TOA reflectance to arrive at AOD solution
  6. Perform **cloud clearing to remove cloud contaminated AOD** retrievals
  7. **Determine if dust aerosols are dominant feature through dust threshold tests** (use of 10.3 – 12.3 µm test to identify dust pixels and apply Dust Aerosol Model Lookup Table)

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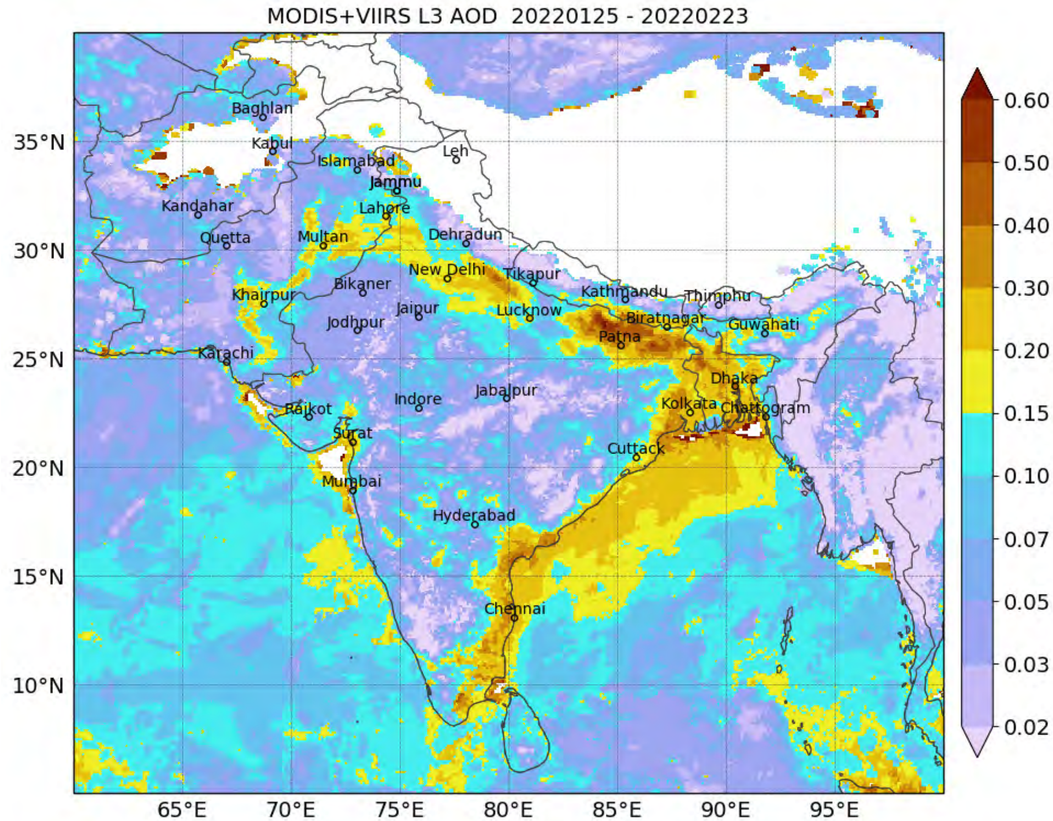
30-Day Minimum AOD maps

- Inclusion of 30-day minimum AOD maps is a critical customization to algorithm for HKH region
  - Assuming a low AOD background condition (~0.02 or 0.05) over a 30-day time period is not a valid approach over HKH (effectively operated over U.S. with GOES ABI)
  - Low AOD background assumption will lead to large underestimations in AOD
- 30-day minimum AOD approach uses MODIS and VIIRS AOD retrievals over previous 30-day period to account for varying AOD background in AMI AOD retrieval algorithm
  - Approach led to a significant improvement in AOD retrievals in region



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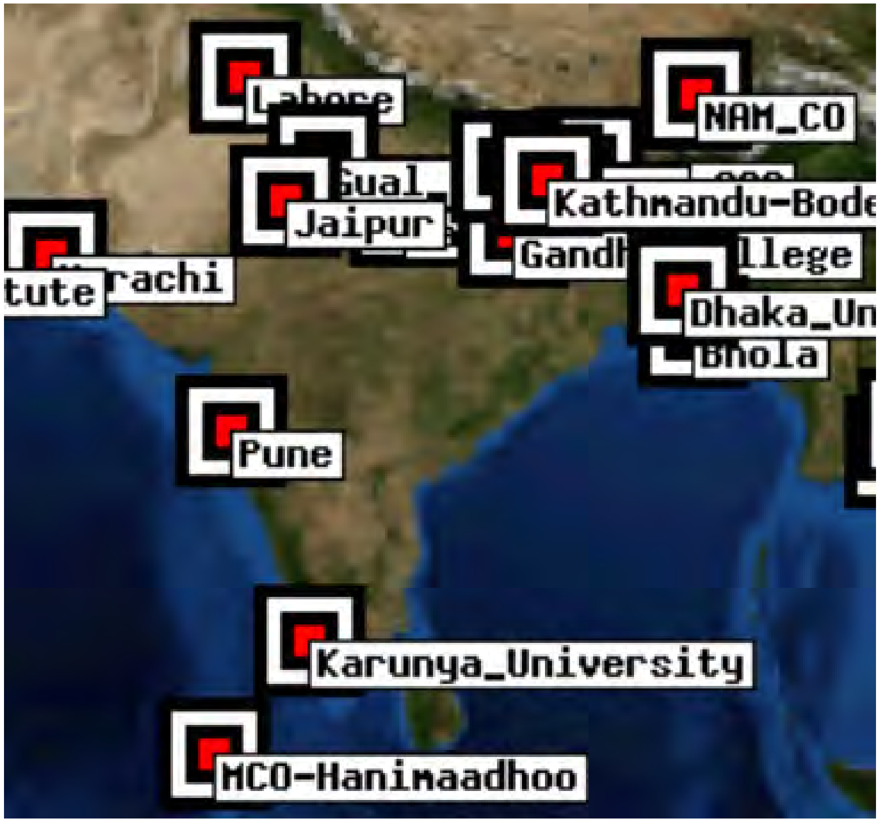
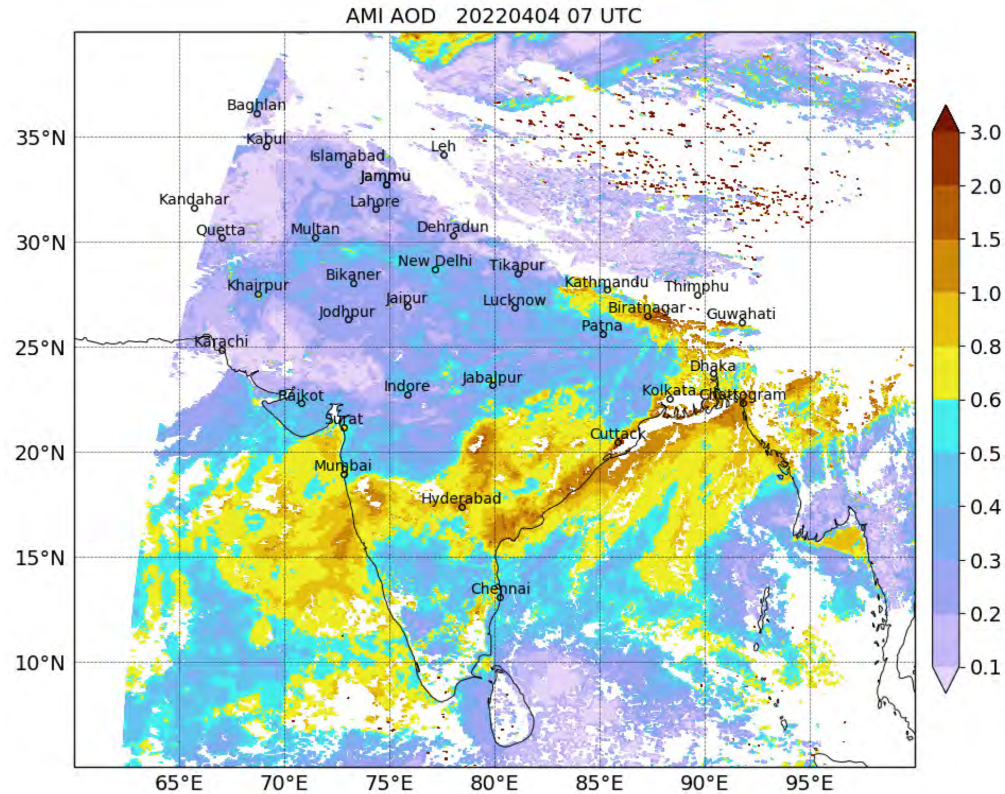
Aerosol Model Lookup Tables (LUT)

- Used 6SV Radiative Transfer model to build precalculated LUT of simulated TOA reflectance values based on (1) continental-like and (2) dust aerosol models
- Continental-like aerosol model was customized for HKH by calculating using 10 years of AERONET ground-based data (gold standard aerosol data) in region
- Aerosol properties of size distribution and refractive indices from AERONET are applied to create continental-like aerosol model
- Apply standard Dust aerosol model in 6SV model since only minor differences were found between climatology dust and regional dust cases



Cloud Clearing Approach

- Uses spectral, spatial, and temporal threshold tests to effectively remove AOD retrievals with cloud contamination
  - Spectral tests consist of individual pixel-level band difference methods uses VIS to infrared bands on AMI
  - Spatial tests are applied over 3x3 or 5x5 pixel areas, suited for identifying areas of heterogeneous or scattered cloud cover that can impact AOD retrievals
  - Temporal tests can be effective at identifying potential cloud contamination of AOD from cloud edges
- Robust cloud clearing is important in AOD retrievals, especially when deriving value-added Level 4 PM products from the satellite AOD



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Dust Aerosol Model Application

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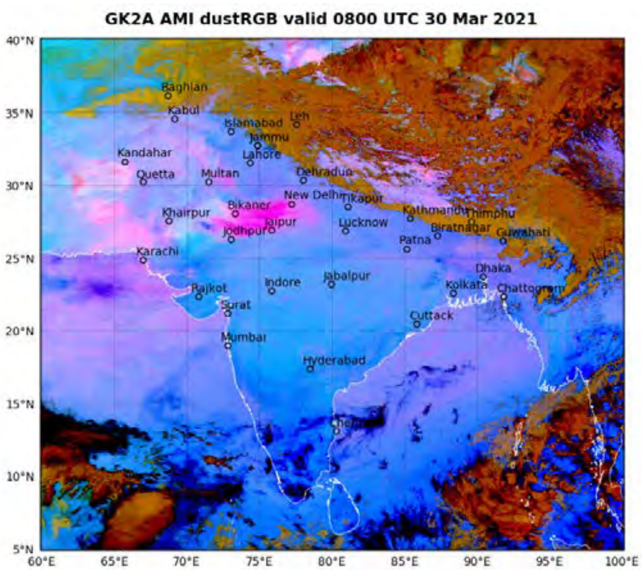
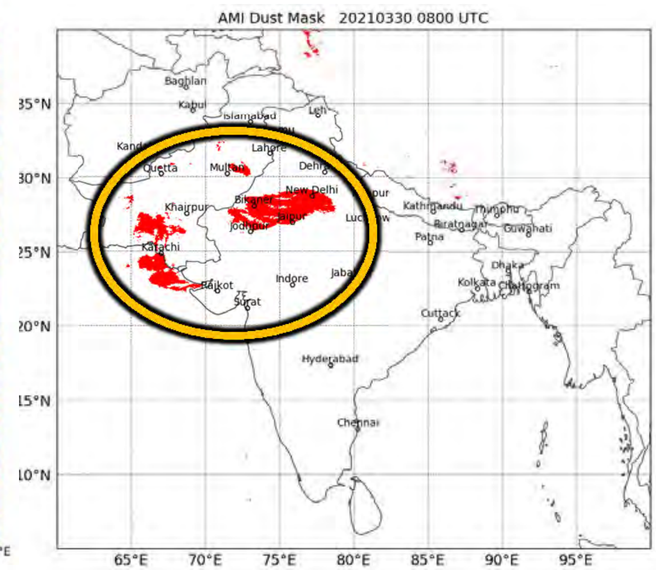
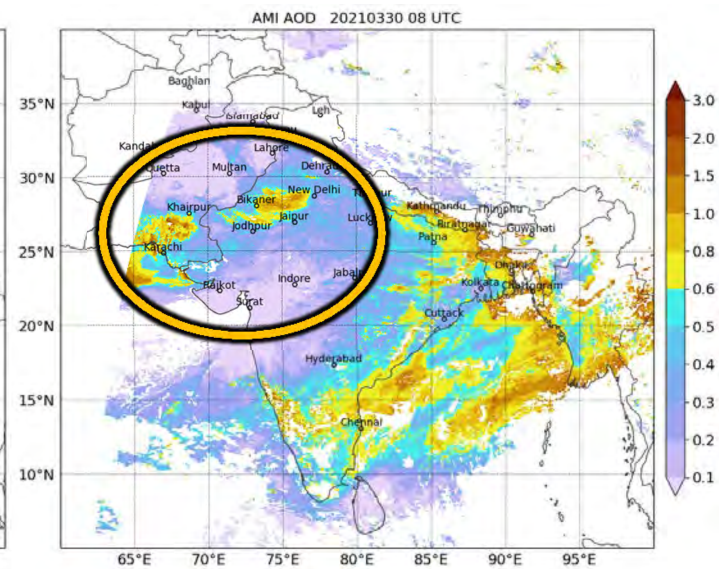
- Implement a second Aerosol Model (in addition to regional based continental-like aerosol model) to further improve AOD retrievals
- Apply a dust identification scheme that utilizes the 10.3 – 12.3 µm band differences to identify dust and retrieve AOD based on dust aerosol properties







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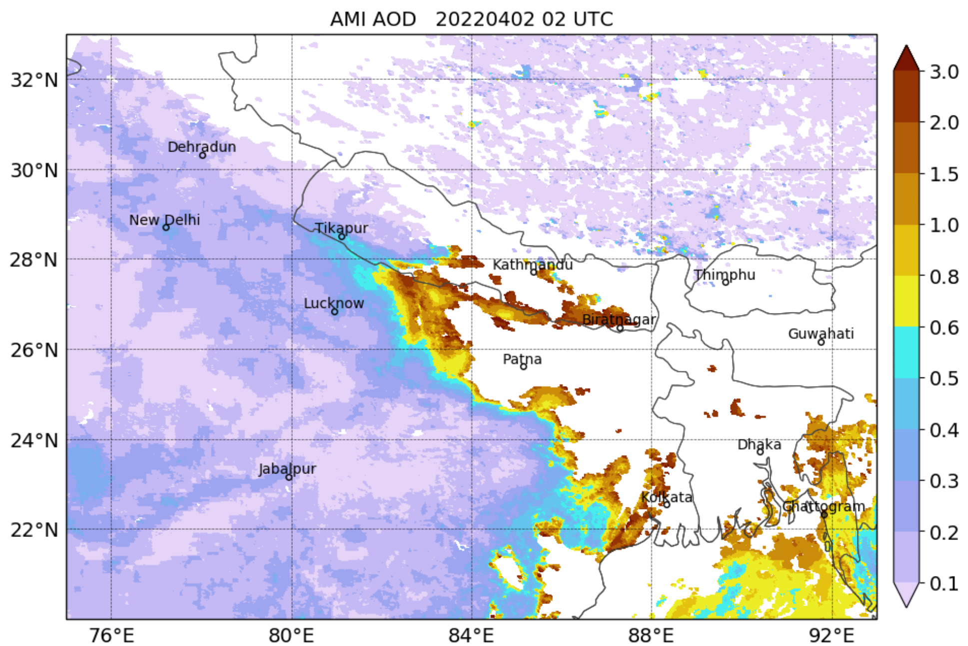
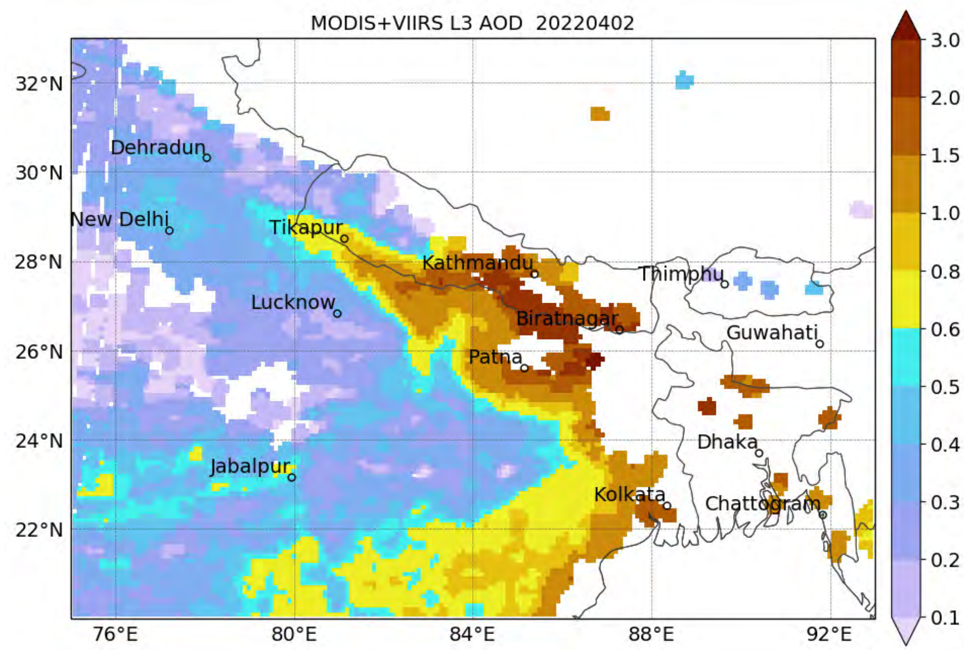
AMI AOD Use Case – 2 April 2022

- Significant refinement was just implemented in AMI AOD algorithm last week, stricter solar and viewing zenith angle tests to remove anomalous AOD features
- Latest version of AMI algorithm shows realistic spatial patterns and evolution of AOD and close agreement to MODIS+VIIRS AOD for mid-day period





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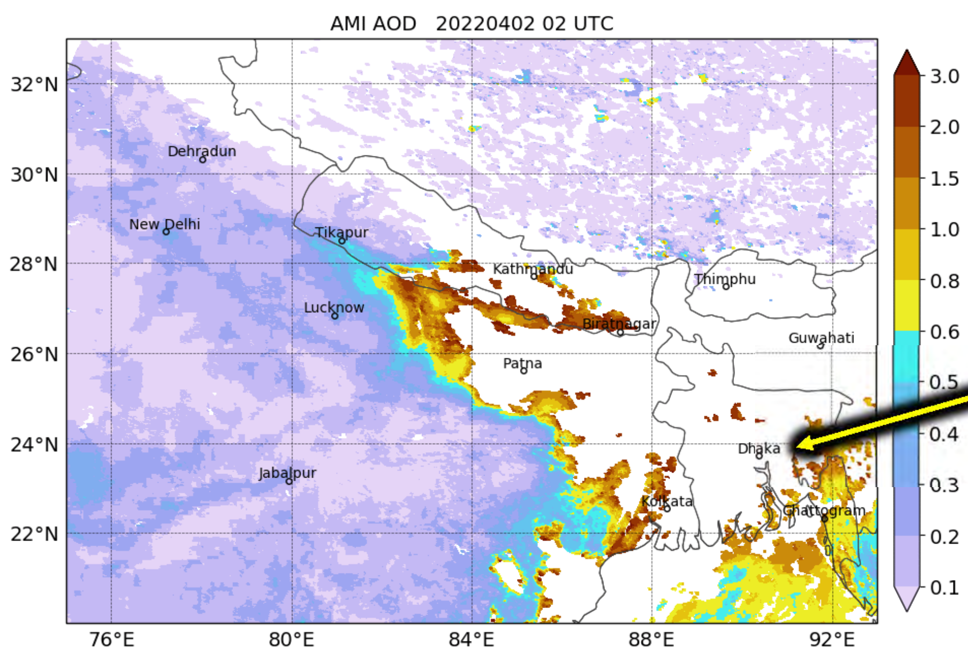
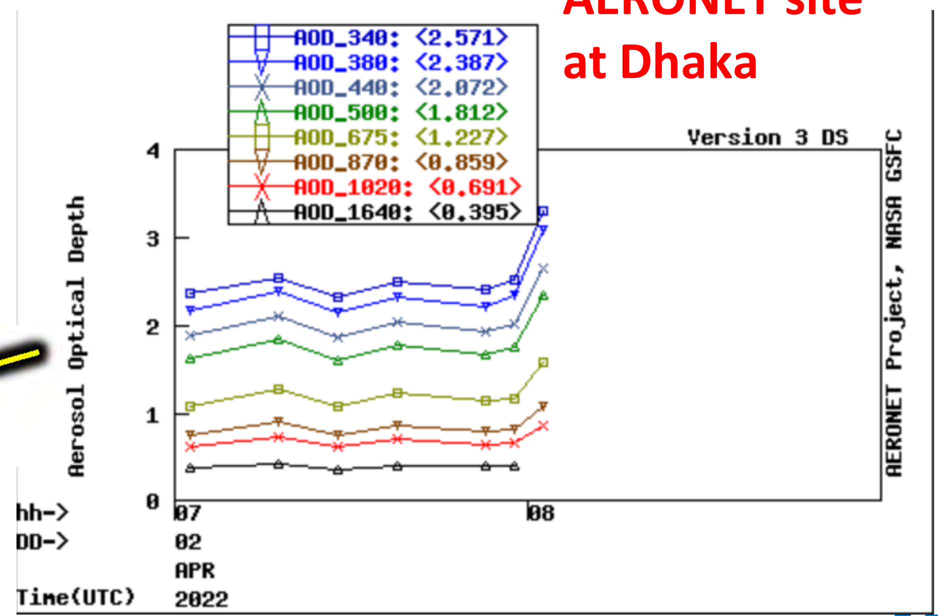
AMI AOD Use Case – 2 April 2022

- AMI AOD retrievals show values around 1.5 in the vicinity of the AERONET site at Dhaka, which shows good comparison to AERONET observations
- AERONET unable to retrieve valid AOD during morning hours due to cloud cover and AMI AOD retrievals are disregarded during this period due to cloud contamination issues

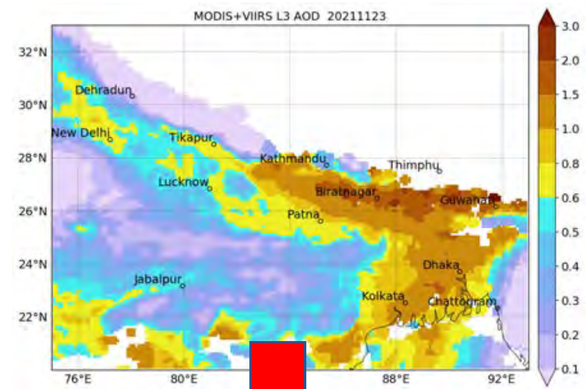


AERONET site at Dhaka

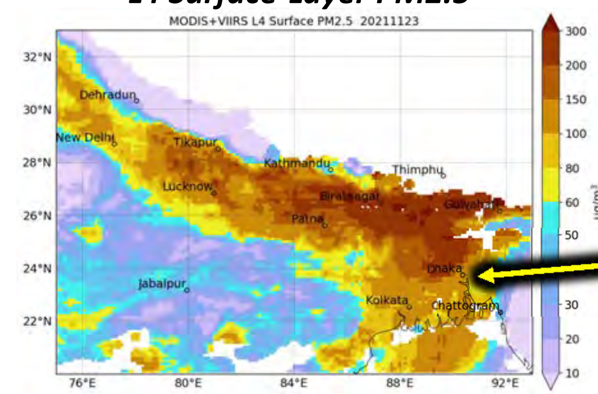


L3 AOD to L4 Surface-Layer PM2.5 Product

L3 MODIS+VIIRS AOD



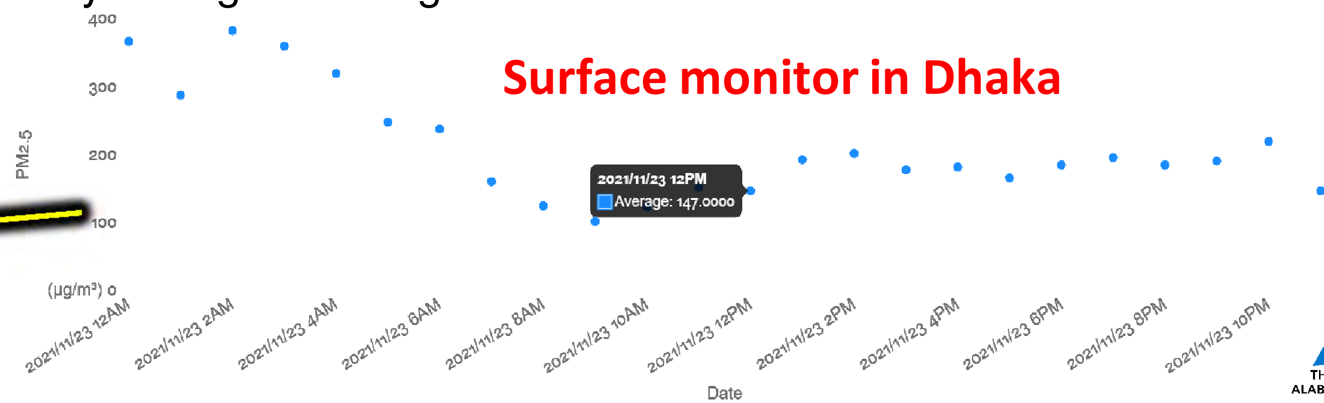
L4 Surface-Layer PM2.5



- L4 products fuse L3 AOD products and model data to estimate trace gas pollution at the surface where people live!
- The current L4 products are utilizing model profile information from the NASA Goddard GEOS Composition Forecasting System (GEOS-CF) at 0.25° grid spacing
- L4 products are produced once per day on regular 0.1° grid

Brief Method Description:

1. Model remapped to 0.1° grid
2. Calculate column AOD and surface-level PM2.5 concentrations from the model data
3. Multiply the observed AOD by the ratio of model surface PM2.5 and column AOD values
4. Produce surface-layer PM2.5 maps and data files



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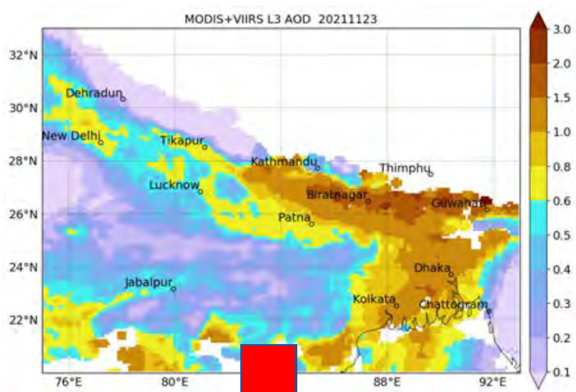
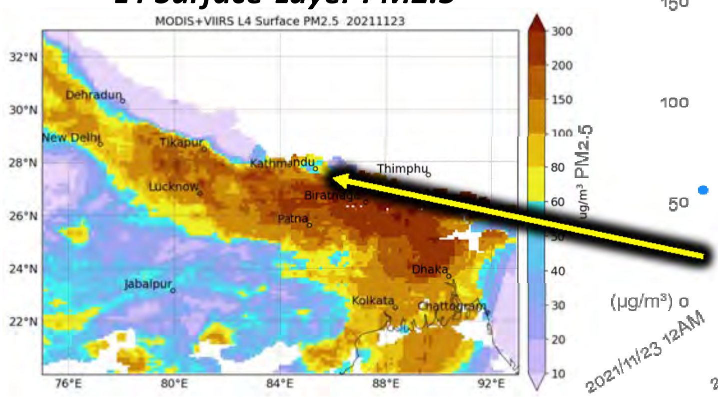
L3 AOD to L4 Surface-Layer PM2.5 Product

L3 MODIS+VIIRS AOD

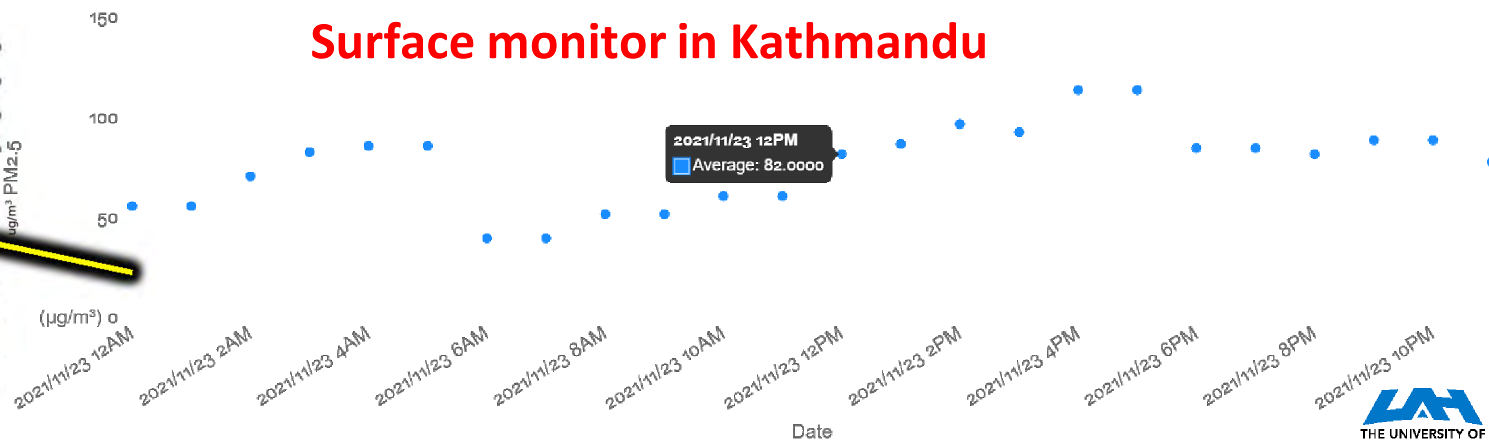


- ❑ By end of this month, we plan to have hourly surface PM2.5 product from AMI AOD retrievals and regional AQ model solution
- ❑ Conduct validation with surface monitors in region
- ❑ Implement any needed final updates to methods

L4 Surface-Layer PM2.5



Surface monitor in Kathmandu



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Discussion, Q&A
Break?

Regional Air Quality Forecasting Model

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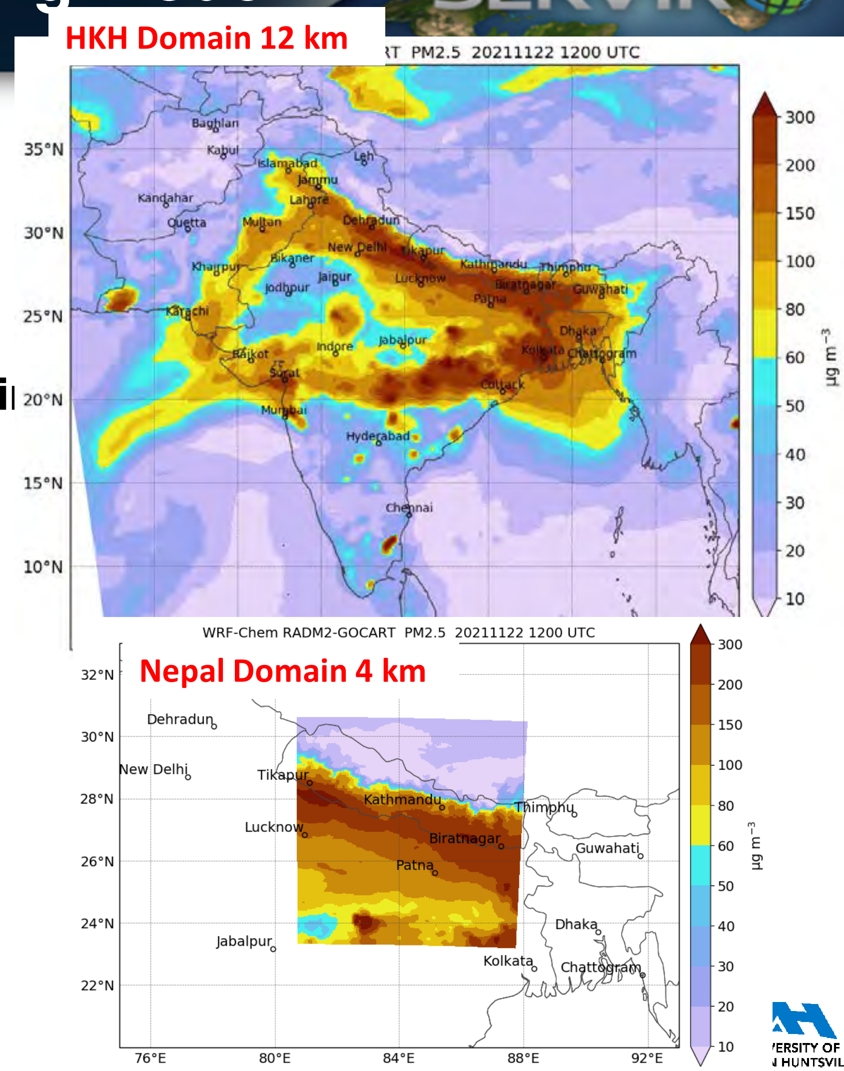
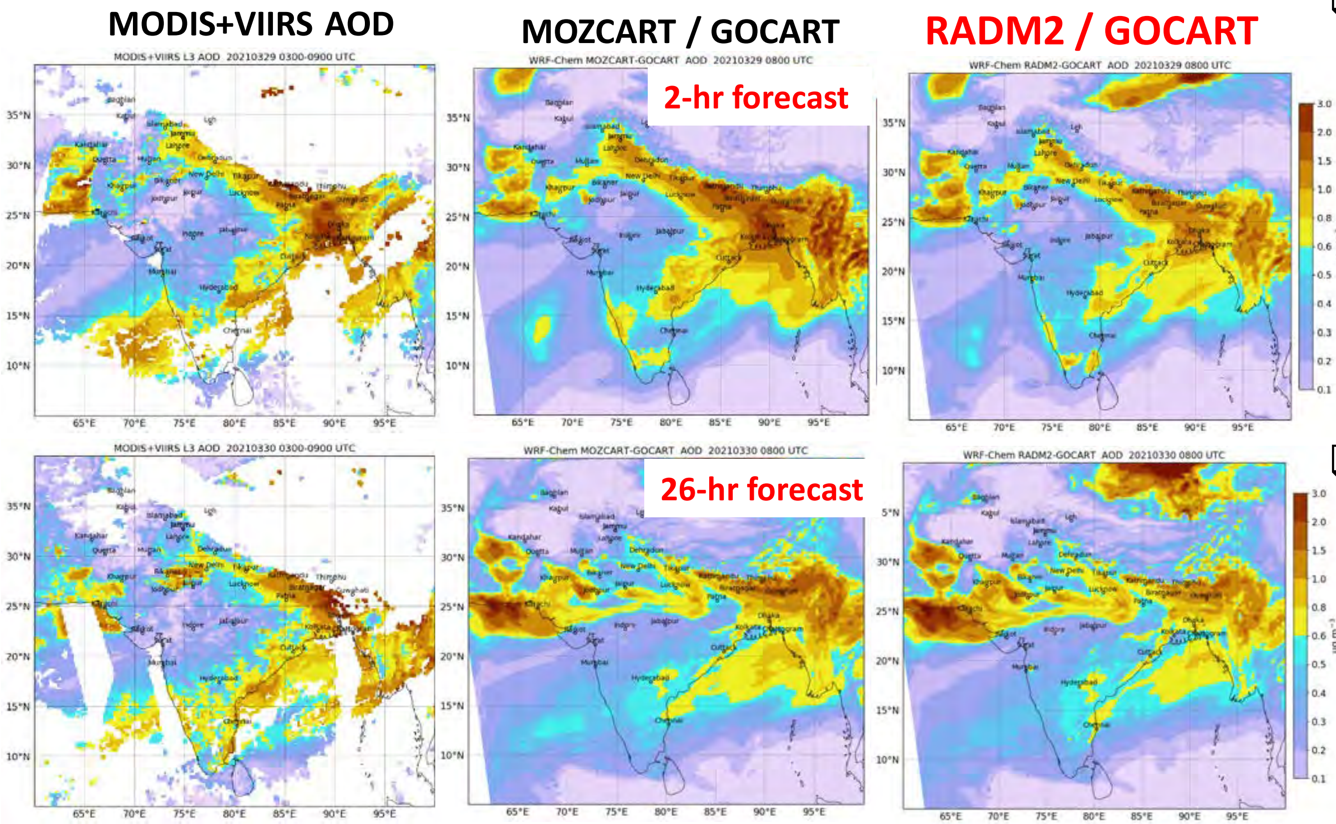
Operational Air Quality (AQ) Forecasting Model

Key Features:

- Tailored Weather Research and Forecast Model coupled with Chemistry (WRF-Chem) configuration over HKH
- 12 km grid over HKH region with **4 km grid centered over Kathmandu, Nepal to resolve fine gradients in ai pollutants**
- **Daily operational 48-hour forecasts** initialized at 06 UTC with model run time typically around 3 hours
- Global WACCM model for chemical initial & lateral boundary conditions and FINN fire emissions
- Chemical reactions including ozone chemistry predicted via RADM2 mechanism; GOCART for aerosols
- **3D variational data assimilation (3DVAR) of satellite AOD** during initialization time window from 03-09 UTC
- EDGAR-HTAP Version 2 for emission inventory

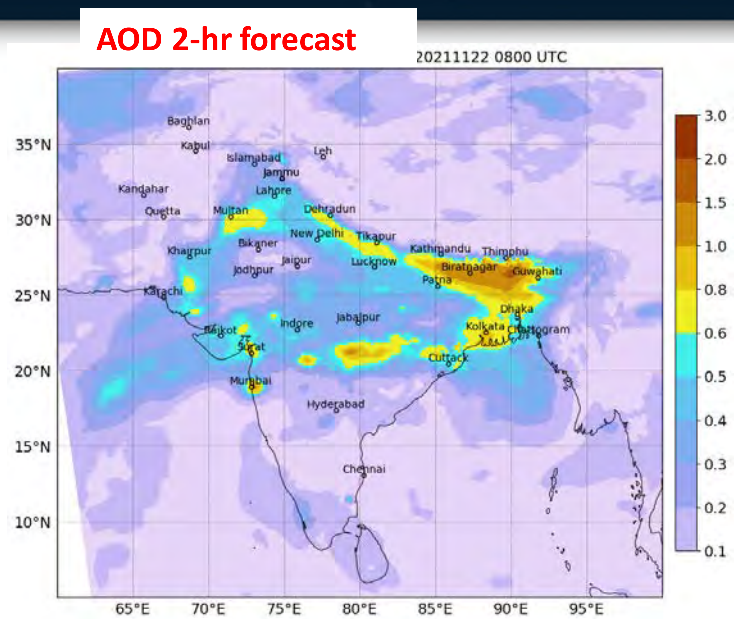


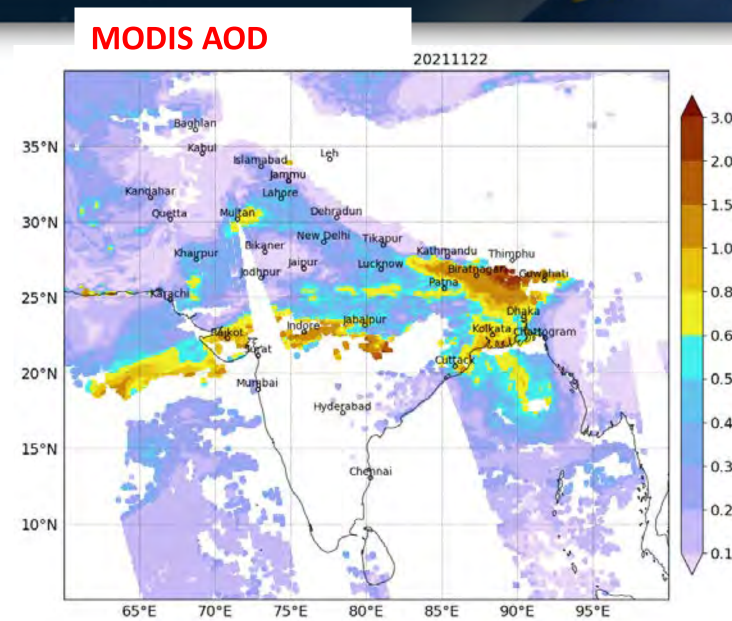
WRF-Chem AQ Model - Optimization



- Optimization of AQ model after numerous sensitivity simulations during 6+ month time period
  - Suite of different chemical mechanisms, cloud microphysics, domain sizes and locations, etc. were evaluated in terms of computational expense and forecast accuracy
- RADM2 / GOCART chemical mechanism and aerosol module was preferred choice
  - Differences in AQ forecasts between the more computational expensive MOZCART and less expensive RADM2 mechanisms diminished after performing AOD assimilation

Satellite AOD Assimilation





- ❑ Successfully operationalized GSI 3DVAR routine using MODIS AOD data
- ❑ Can also operate with VIIRS AOD, but data latency of 3+ hours limits any impact from VIIRS AOD in operations
- ❑ Updating code to assimilate AMI AOD, additional AOD information in mid-morning period should further improve forecasts

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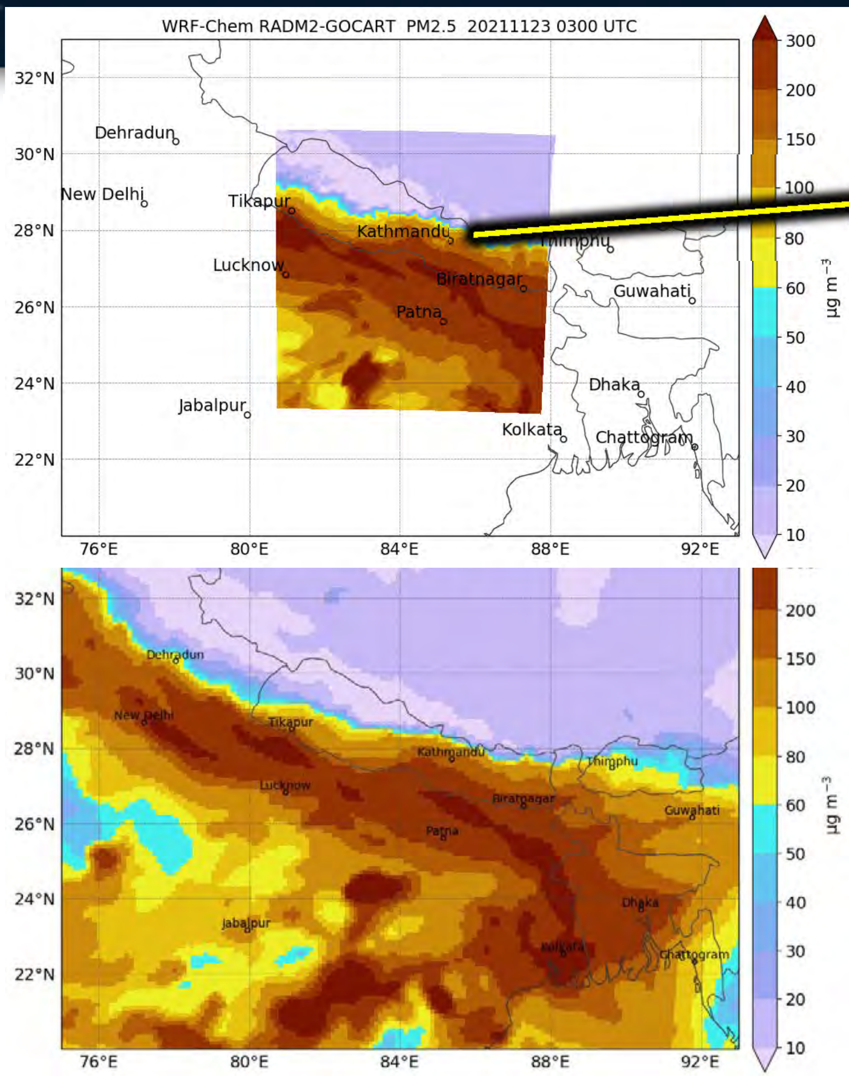
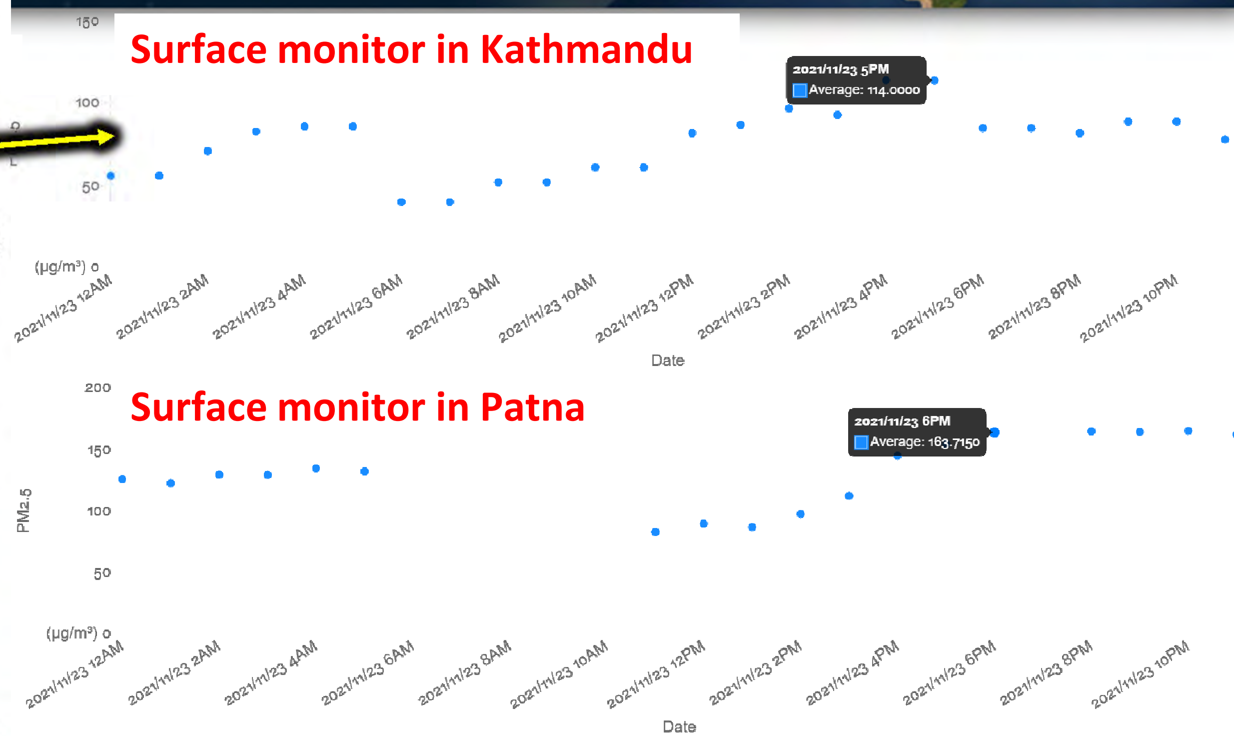
Operational Air Quality Forecasting Model





- 4 km model domain simulates fine scale structures in PM2.5, particularly in Kathmandu Valley
- Good agreement with surface monitors in Kathmandu and Patna

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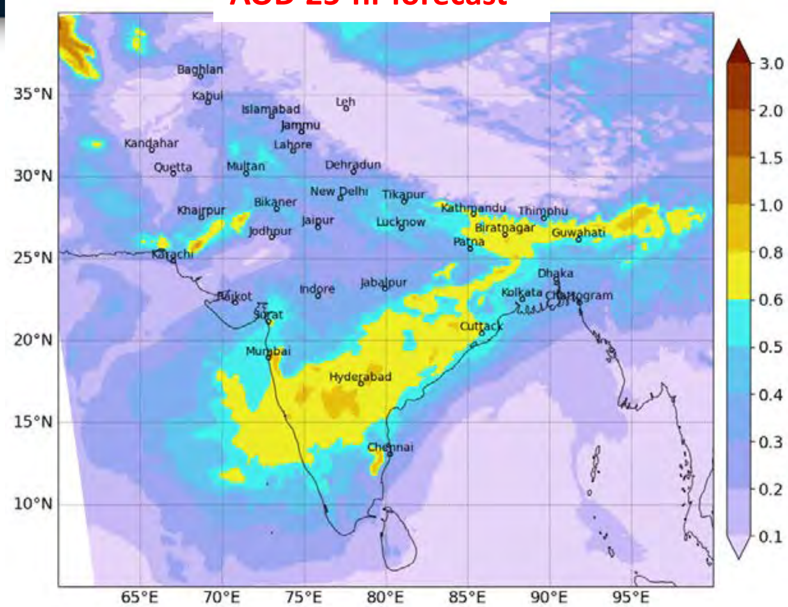
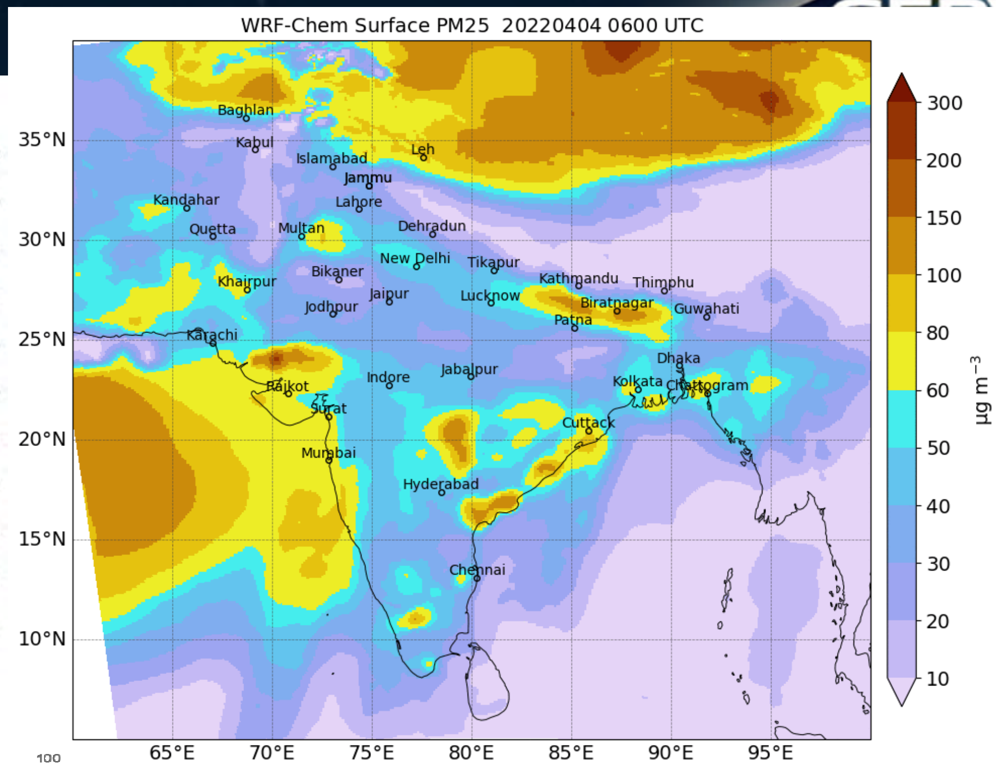
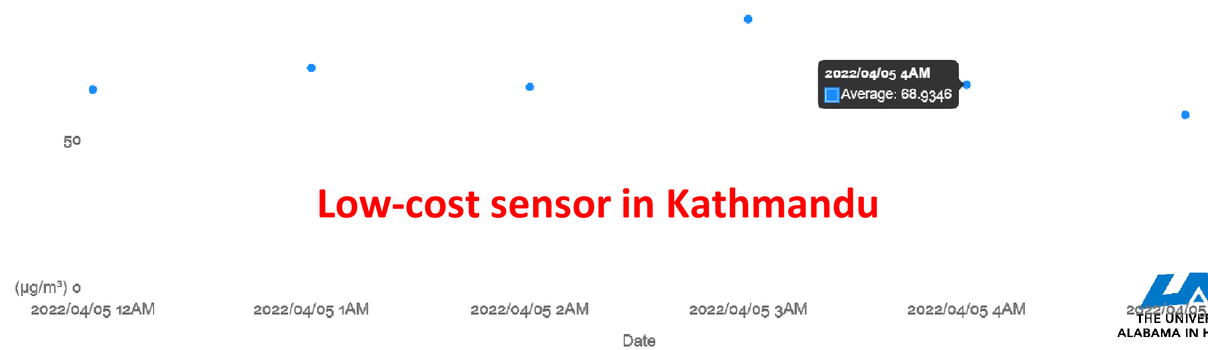
Yesterday's Forecast

AOD 25-hr forecast







Low-cost sensor in Kathmandu

- ❑ Model forecast AOD shows reasonable agreement to AMI AOD
- ❑ PM2.5 forecast shows an increase in PM2.5 during overnight on 5 April that follows trend in estimated PM2.5 from low-cost sensor

Dust Dispersion Forecasting

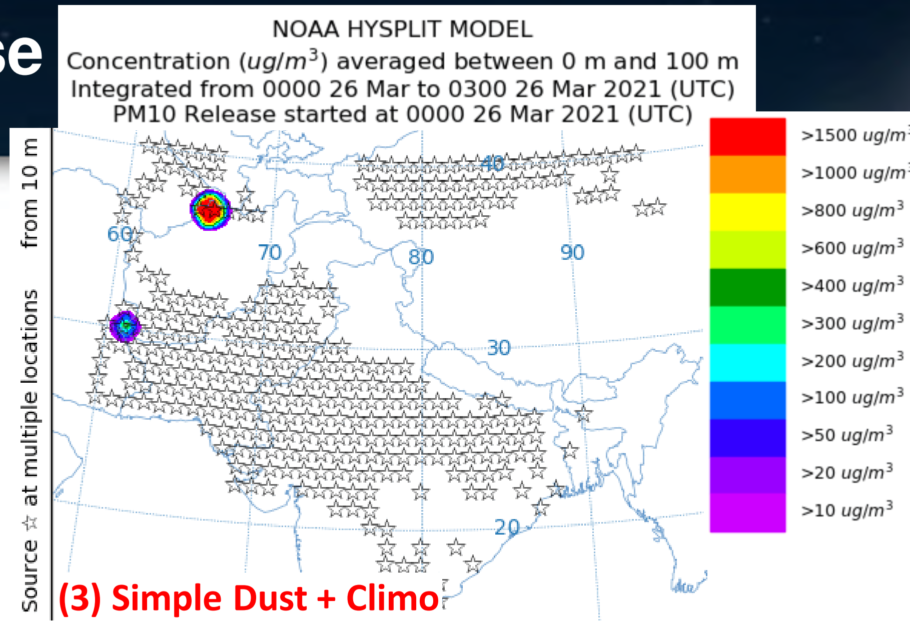
HYSPLIT dust dispersion forecasting

- Developed an efficient forecasting tool for dust storms using the HYSPLIT dispersion forecasting system
- Three methods to simulate dust dispersion in HYSPLIT
  1. Simple dust algorithm: $Q = 0.01\ U_*^4\ A$ (hard-wired threshold friction velocity, U_*, of 28 cm s^{-1} at prescribed desert land-use points, with emission area A)
  2. Spatiotemporally-varying U_{*t} and emission factor: $Q = K\ A\ (U_* - U_{*t})$
     - K A is the product of soil-dust density K and emission area A
     - Monthly climatology database of U_{*t} and K A based on MODIS AOD data (Draxler et al. 2010)
  3. Apply monthly climatology emission locations to simple dust algorithm

- Six-day simulations spanning 0000 UTC 26 March to 0000 UTC 1 April 2021
- Evaluation period identified method (3) as top performing configuration for region
- **HYSPLIT system has been operationalized, ready for dust season!**

HYSPLIT Use Case

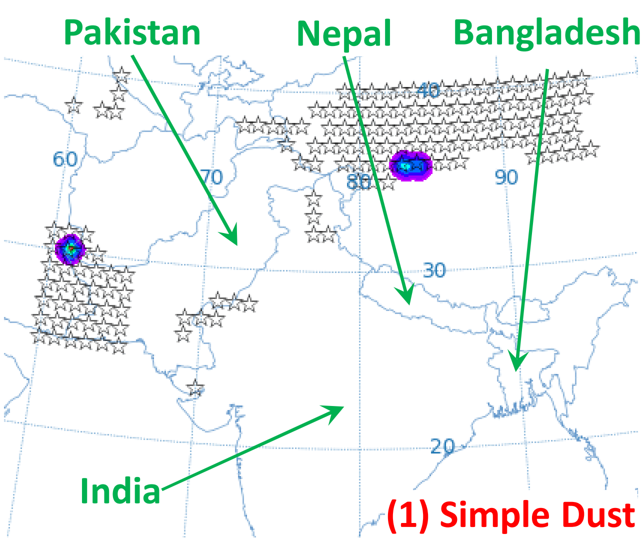
March 2021 Dust: HYSPLIT Sensitivity Simulations



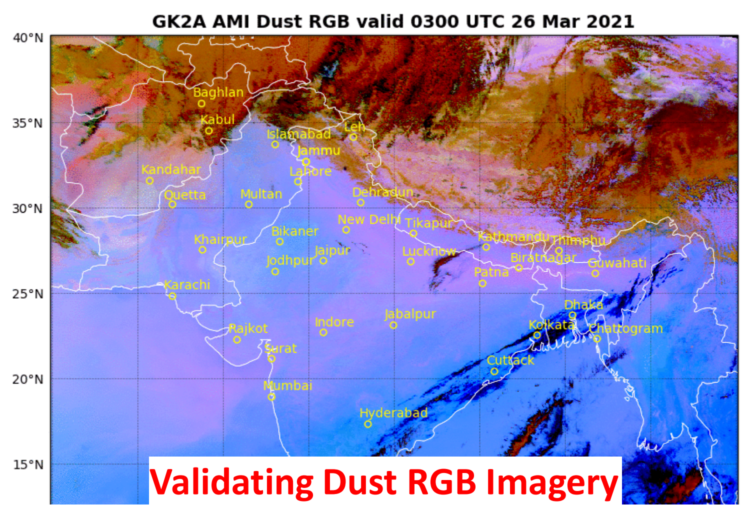
(3) Simple Dust + Climo

Some Take-Aways:

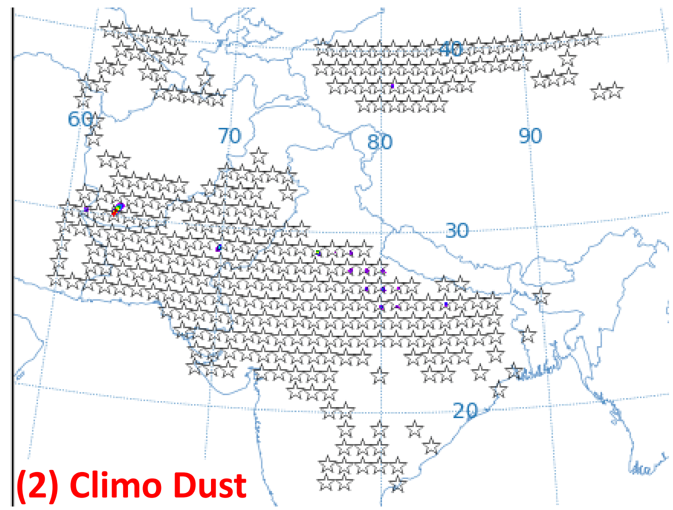
- Simple dust run (1) has far fewer emission locations than March monthly climo (2)
- Despite many more emission points, climo run (2) produces lowest overall concentrations
- Combo of climo points and simple dust algorithm (3; top) generated best overall pattern of high concentrations.



(1) Simple Dust



Validating Dust RGB Imagery


(2) Climo Dust

Discussion

NASA Worldview

https://worldview.earthdata.nasa.gov/

Products over HKH

https://weather.msfc.nasa.gov/sport/servir/