Investigation of African and Asian dust events using NOAA global forecasts

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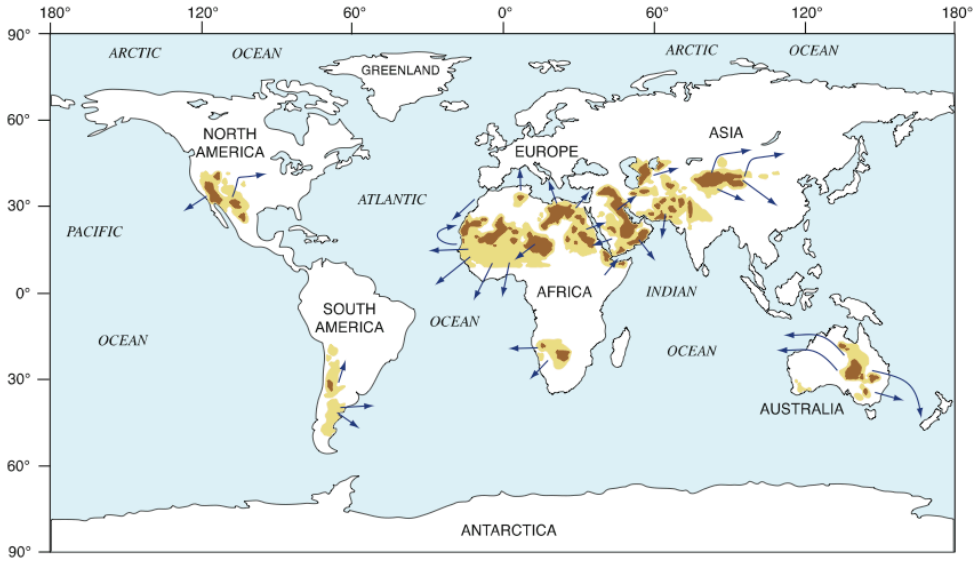
Outline

- Introduction
- Analyses of dust events
  - African (Saharan) dust event
  - Asian dust event
- Dynamic boundary conditions for regional AQ forecast
- Summary

Introduction

- For the continual U.S., the predominant long-range transport dusts were mainly from African and Asian region
- Since NOAA global forecasts (NGAC) provides routine global forecast of dust, the long-range transport of dust can be investigated

Global distribution of TOMS dust sources



(Prospero et al. 2002)

- The NGAC output can provide more realistic (dynamic) boundary conditions for regional air quality forecasts of aerosols, especially for the dust event prevailing season

Objective

- Understand the African and Asian dusts and their long-range transport
- Evaluate the influence of African and Asian dust events on the U.S.

Data sources

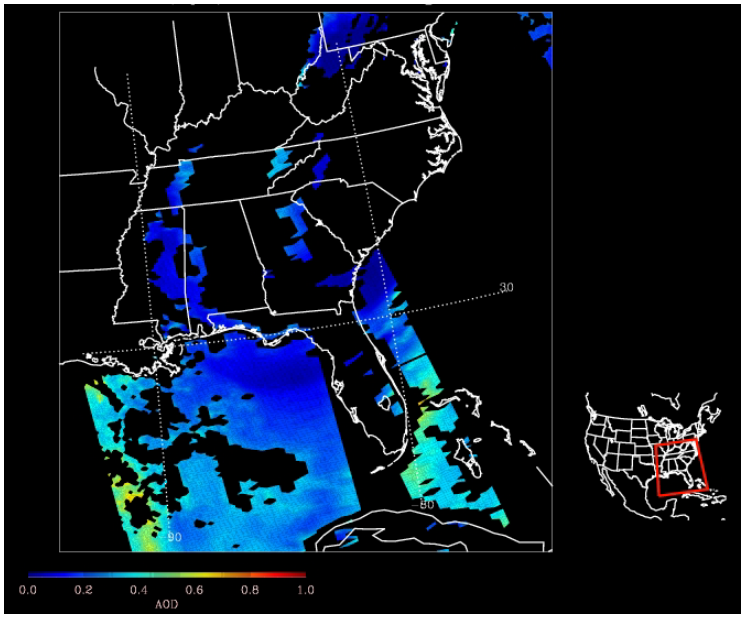
Data type	Data pool
In-situ observation	**AERONET** Level 1.5 from NASA GSFC
Satellite data	**VIIRS** from NOAA STAR (0.25°x0.25° gridded) **MODIS** Aqua from GES DISC (*Giovanni*) (1°×1° gridded)
Modeling data (1°×1°)	**NGAC** from NCEP (prod v1 and upcoming v2) **ICAP-MME** ensemble from US NRL (based on four comprehensive aerosol models, *ECMWF MACC, JMA MASINGAR, NASA GSFC/GMAO GEOS-5, FNMOC/NRL NAAPS, and three dust-only models, NOAA NGAC, Barcelona Supercomputing Centre NMMB/BSC-CTM and UKMO unified model*) **GEOS-5** form NASA GSFC

- The NGAC-simulated dust events will be evaluated with AOD observations from in-situ (AERONET) and satellite (VIIRS/MODIS) measurements, as well as AOD analysis from other centers (ICAP-MME, GEOS-5)
- Dust events are reported by forecast/observatory/AQ websites

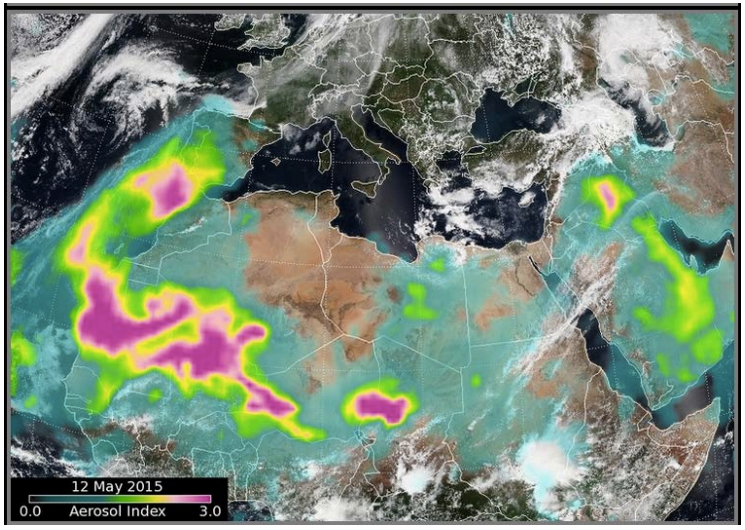
OMPS: Ozone Mapping & Profile Suite
EO: Earth Observatory
EUMS: European organization for the exploitation of Meteorological Satellites
BDFC: Barcelona dust forecast center
UMBC: UMBC smog blog

Saharan dust – May 10-14, 2015

MODIS AOD (Aqua), May 10



OMPS AI over VIIRS RGB, May 12



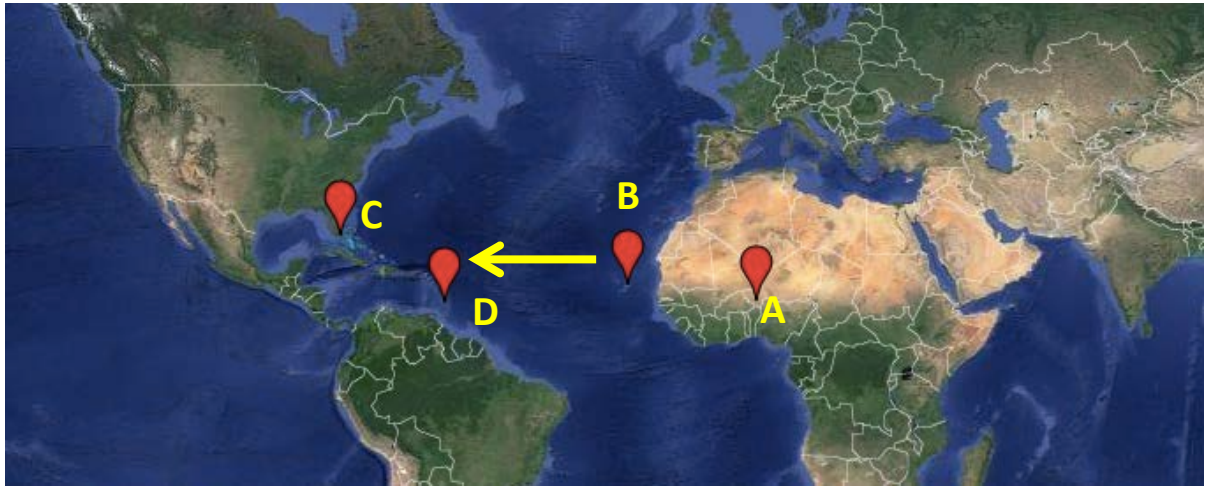
UMBC Smog Blog | May 10, 2015

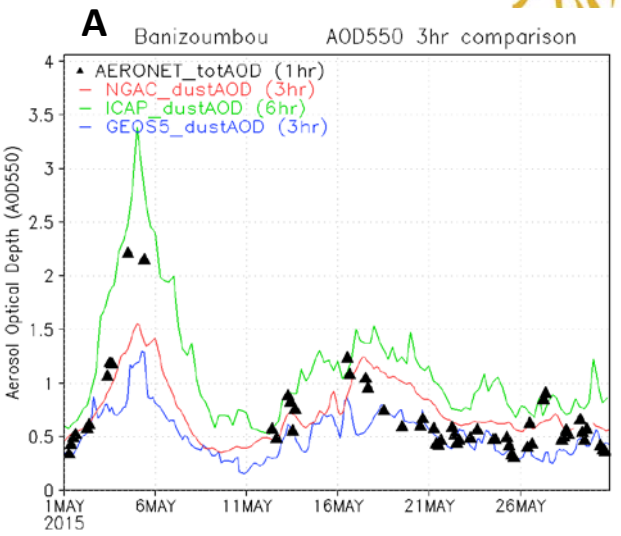
- The Saharan dust is seen stretching across the Caribbean Sea, northwestward into the Gulf of Mexico and over southern Florida
- The Saharan dust appears to also be mixing with a large area of smoke in the western Gulf of Mexico
- AOD retrievals over the Gulf and the southeastern U.S. shows AOD values ranging from 0.2-0.6 (top fig.)

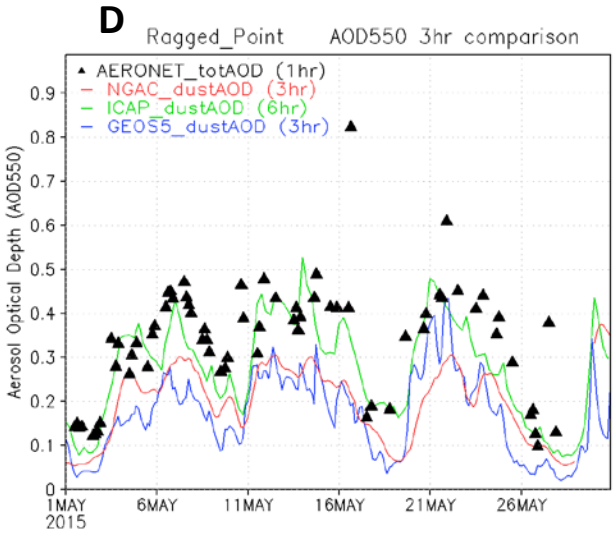
Ozone Mapping & Profile Suite | May 13, 2015

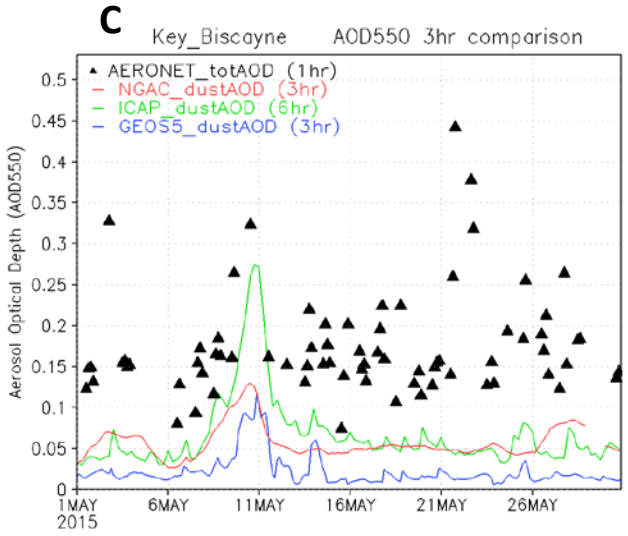
Over the last few days (May 10-12) a nice example of Saharan dust moving out to the Atlantic (bottom fig.)

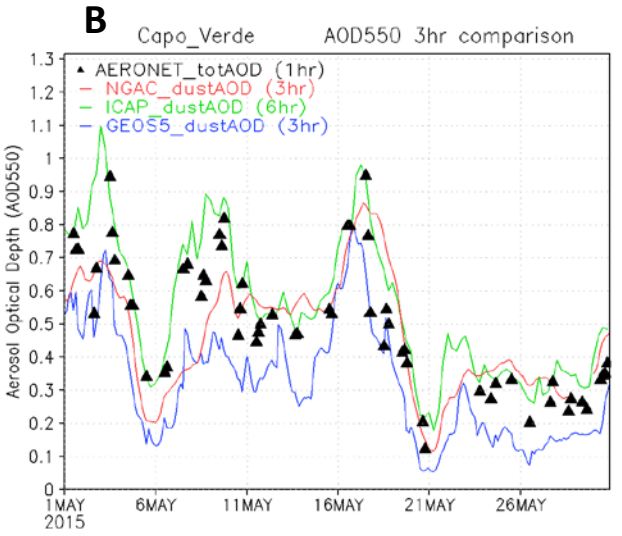
Comparison of AERONET vs. MOD





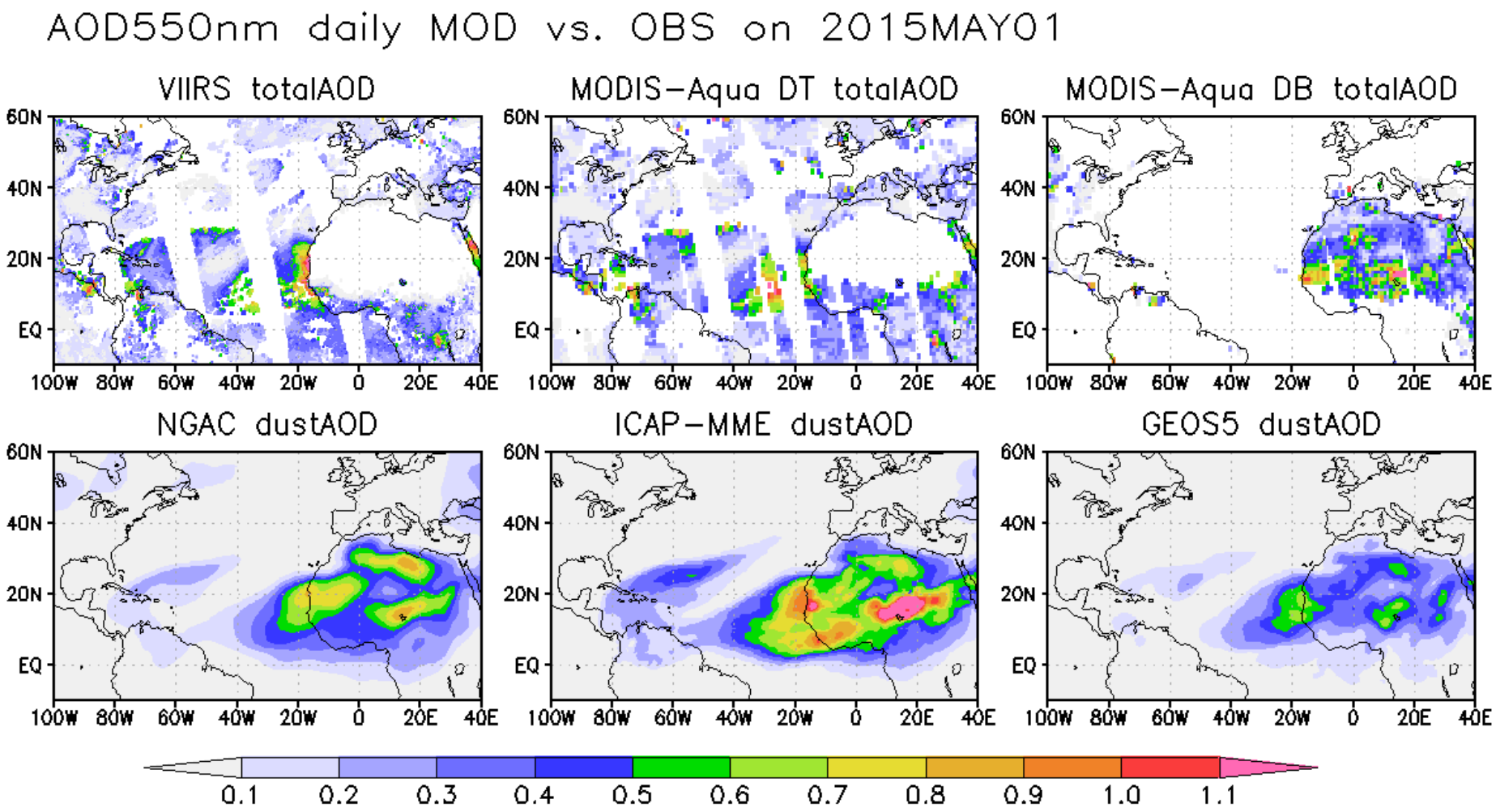






- The AERONET AOD were compared with NGAC, ICAP-MME and GEOS5 dust AOD near source region and the downwind region

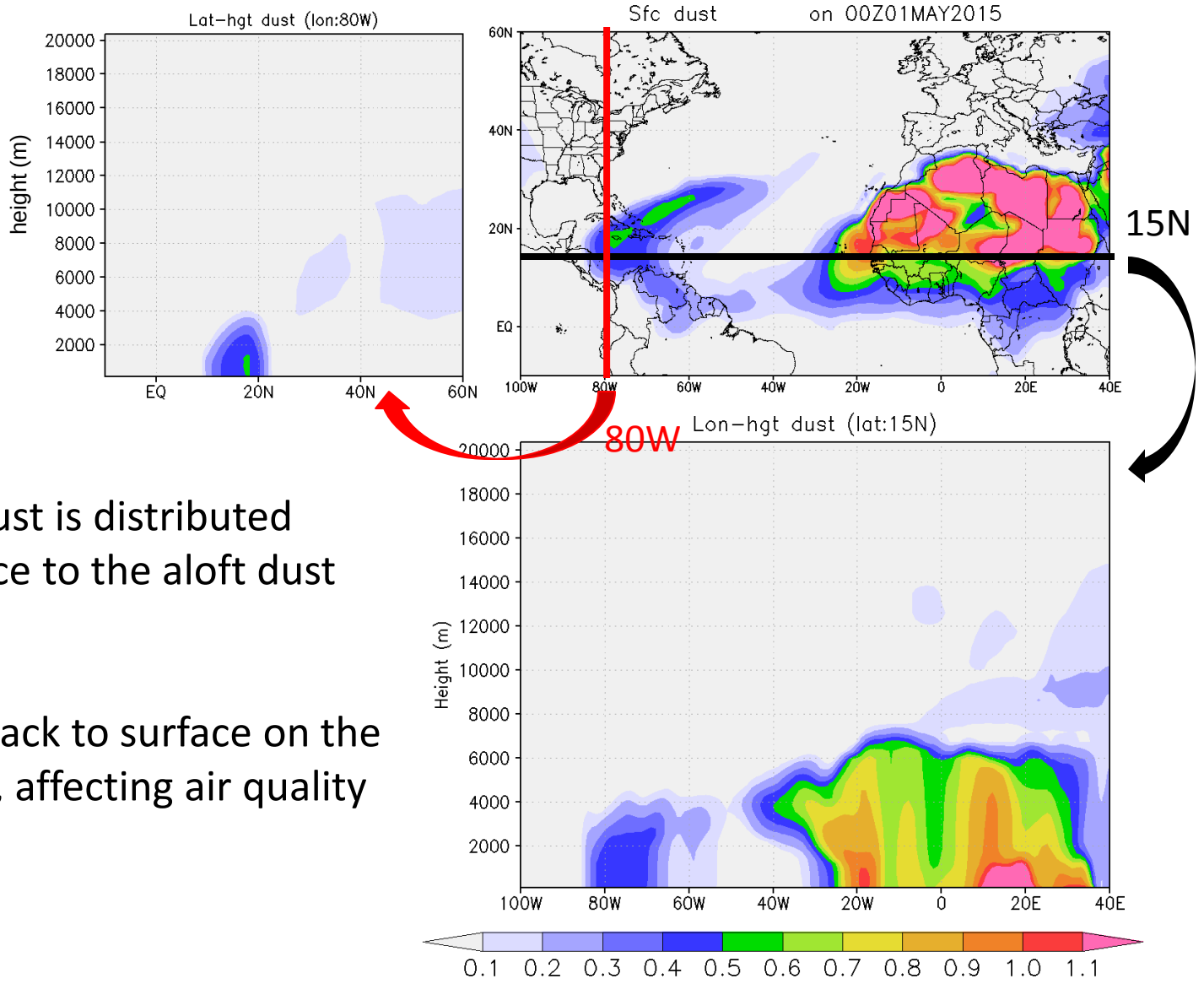
Daily total and dust AOD on May 1-15 2015 (dust event: May 10-14)



- The VIIRS and MODIS AOD were compared with NGAC, ICAP-MME and GEOS5 dust AOD across the Atlantic

NGAC **dust** cross section on May 1-15 2015 (dust event: May 10-14)

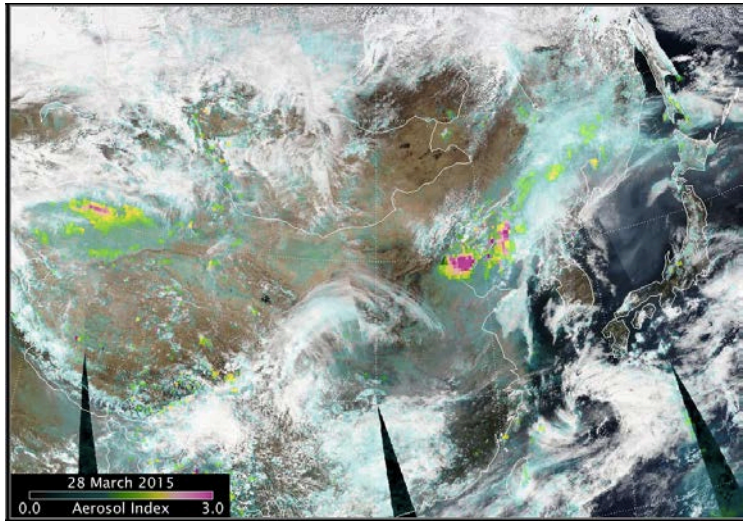
Cross-sections at 15N and 80W (unit: 10^{-7} kg/kg)

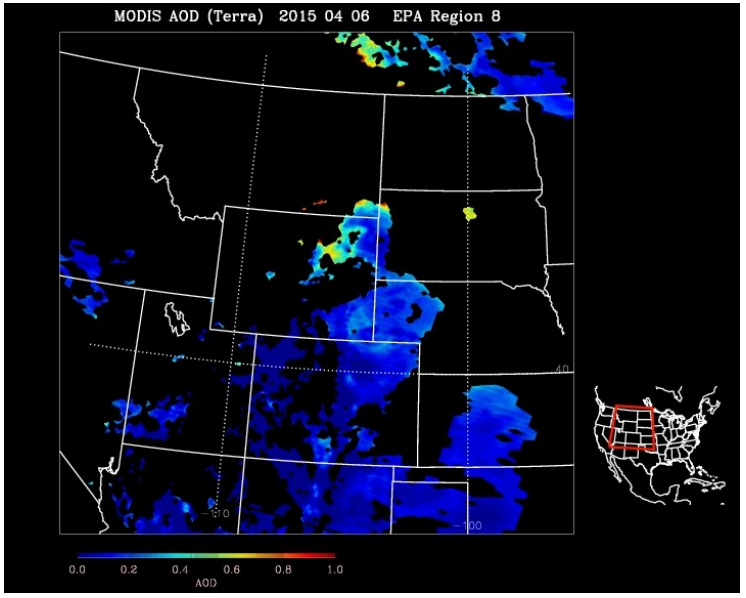


- The Saharan dust is distributed from the surface to the aloft dust layer
- Dust extends back to surface on the U.S. east coast, affecting air quality

Asian dust – Apr 1, 2015

OMPS AI over VIIRS RGB, Mar 29





MODIS AOD (Terra), Apr 6

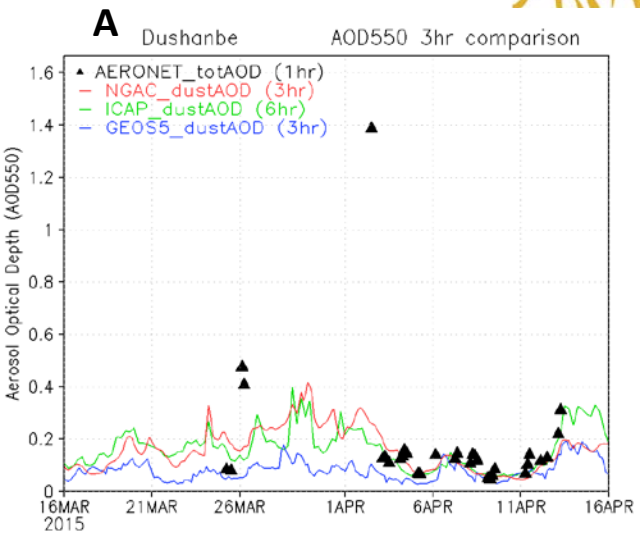
Earth Observatory | Ozone Mapping & Profile Suite | Apr 1, 2015

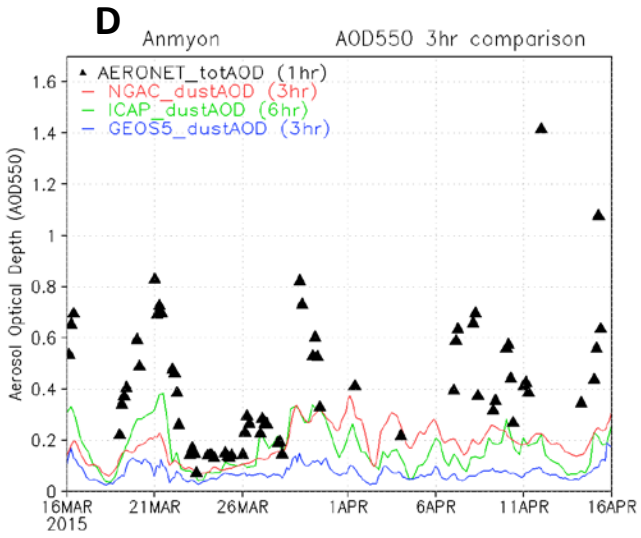
- Dust scattered between Taklamakan Desert and the east coast of China (left).
- A large and intense dust cloud can be seen just over and to the east of Beijing.
- Sometimes dust from these storms reaches North America and are detected all the way to the east coast.

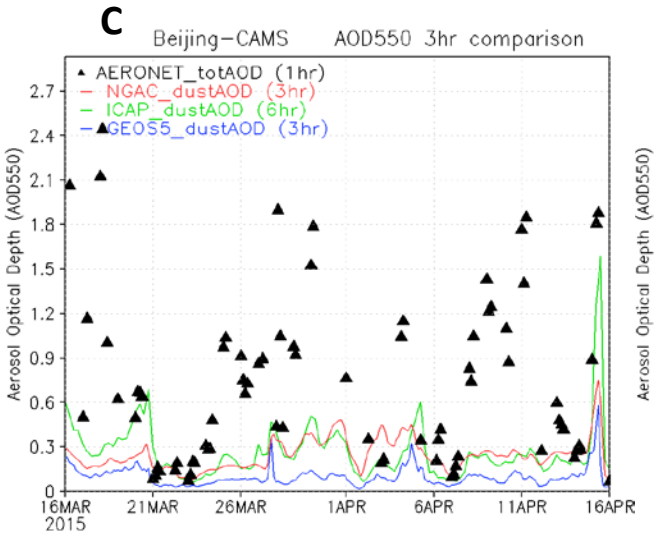
UMBC Smog Blog | Apr 6, 2015

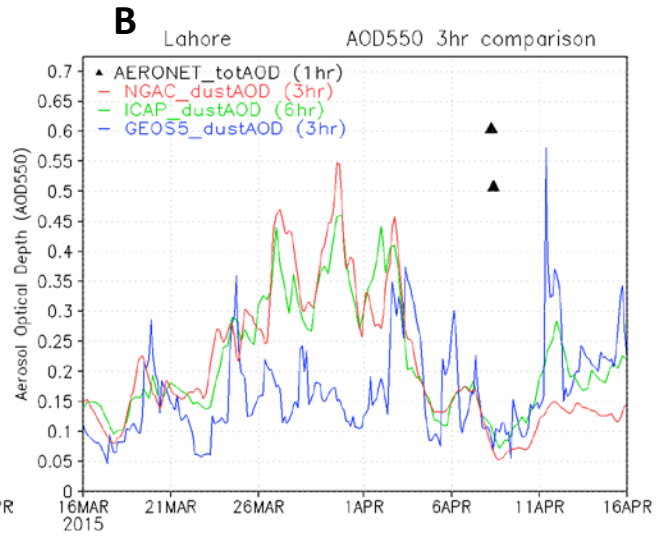
The MODIS Terra image (right) notes elevated AOD over northern Wyoming, crossing over into southern Canada over Quebec, Ontario, and Manitoba. The HMS Fire and Smoke text believes this to be an episode of elevated Asian dust.

Comparison of AERONET vs. MOD





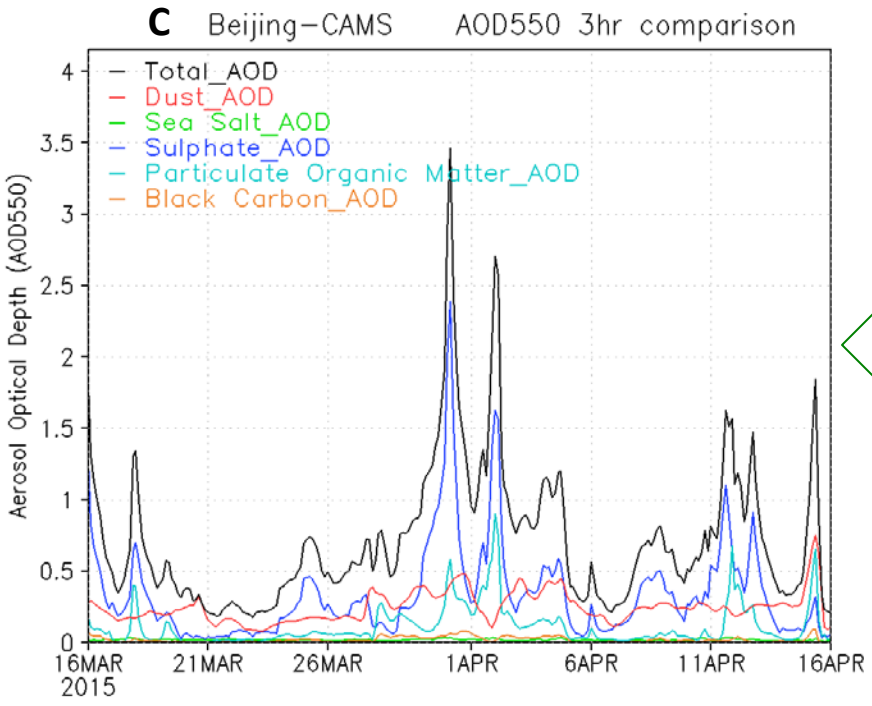


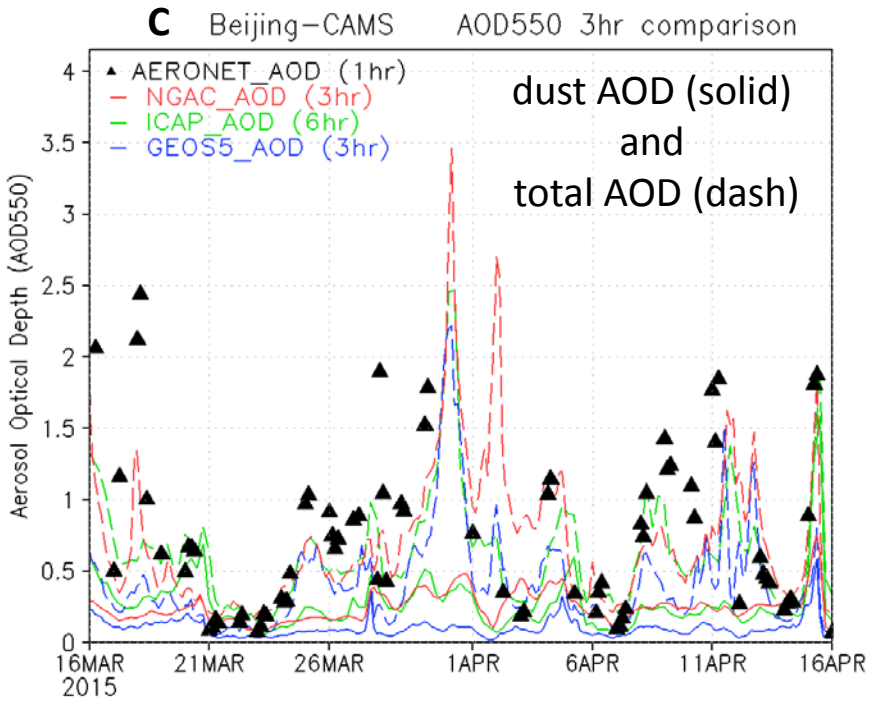


- The AERONET AOD were compared with NGAC, ICAP-MME and GEOS5 dust AOD near source region and the downwind region

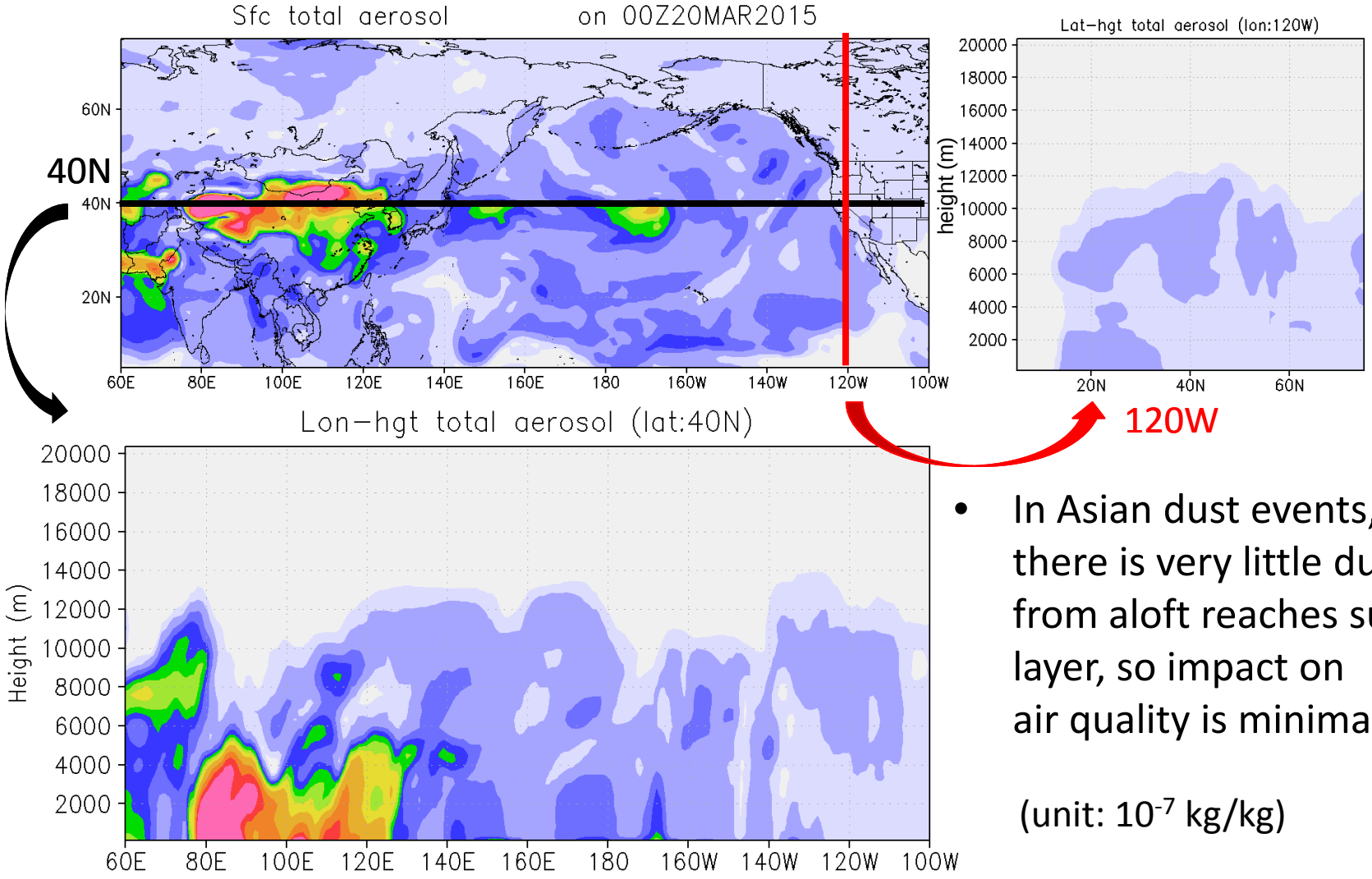
Dust AOD vs. Total AOD

- The Asian dust events are associated with more complicated composition of aerosol properties





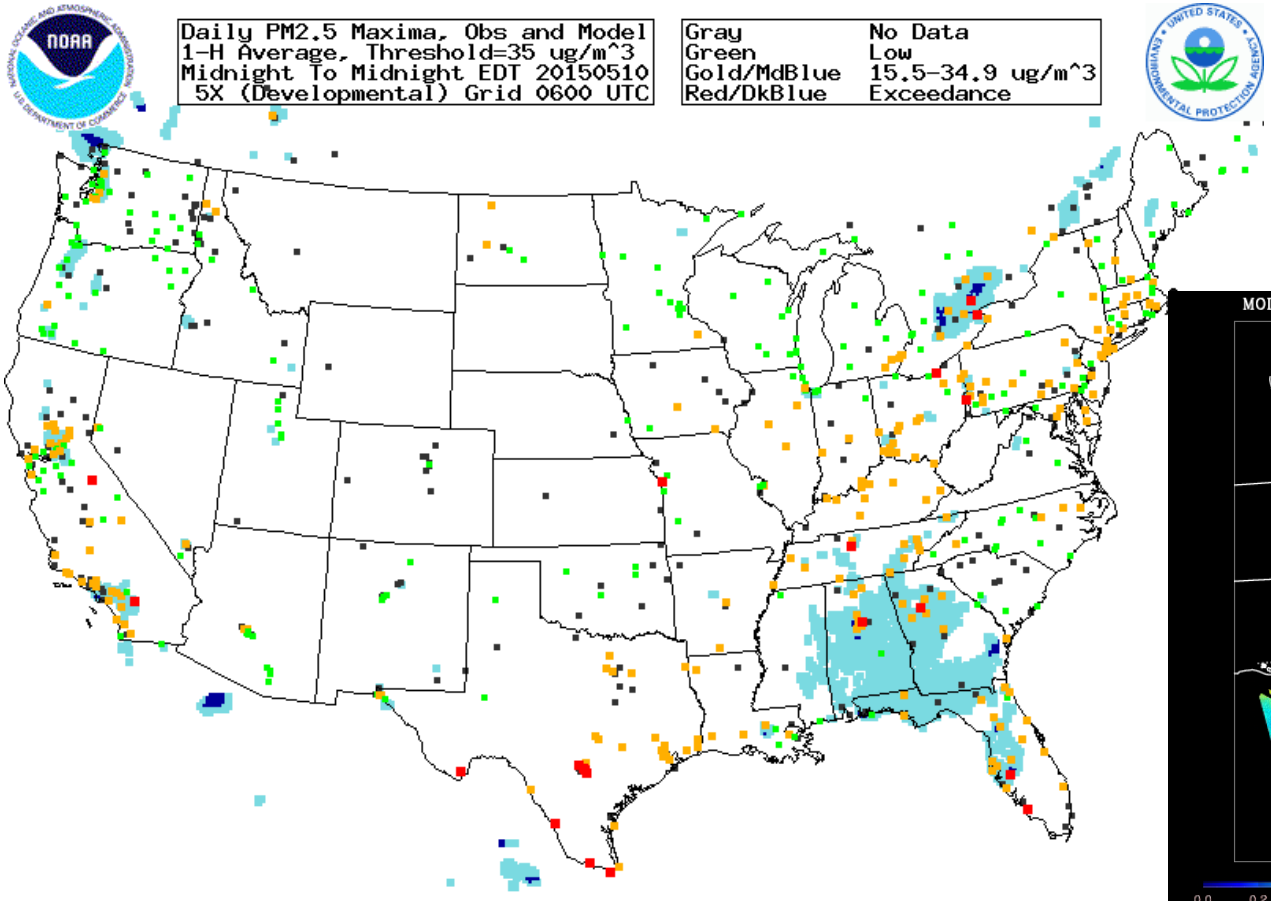
NGAC **total aerosol** cross section on Mar 20-Apr 7 2015 (dust event: Apr 1)



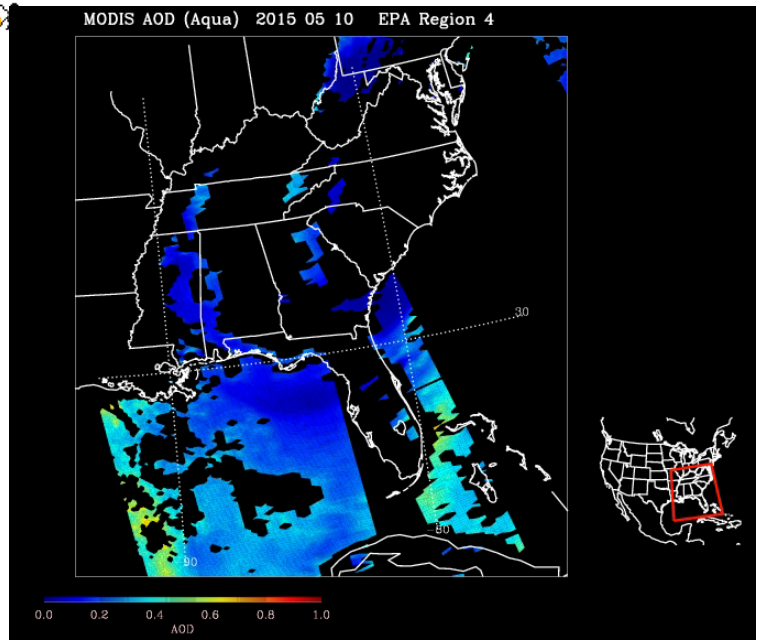
- In Asian dust events, there is very little dust from aloft reaches surface layer, so impact on air quality is minimal

(unit: 10^{-7} kg/kg)

AirNow and MODIS observations



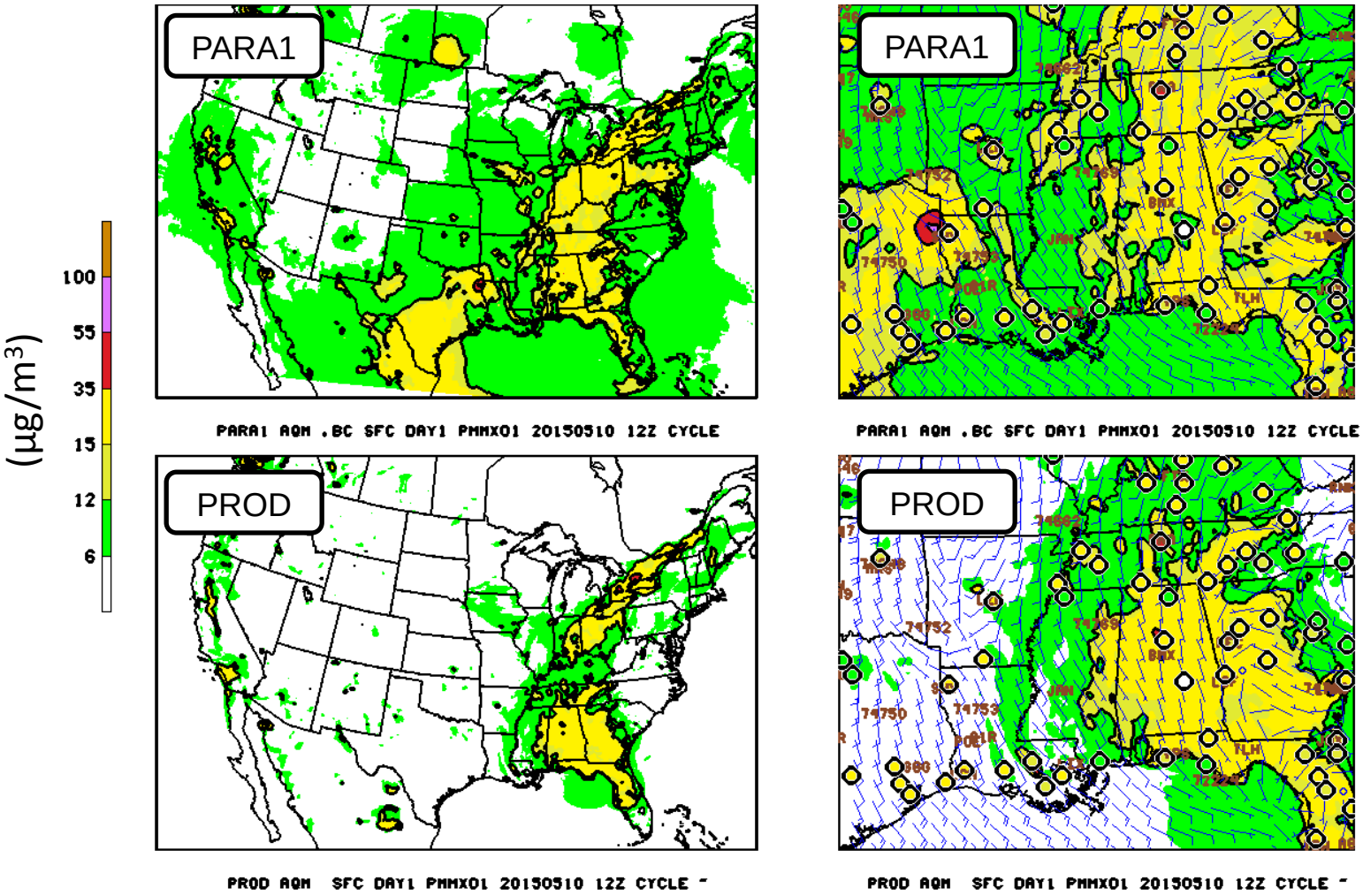
AirNow *(http://www.airnow.gov)*



UMBC smog blog *(http://alg.umbc.edu/usaq)*

The elevated daily $PM_{2.5}$ concentrations (> 35 µg/m^3) and AOD indicated the dust intrusion event associated with long-range Saharan dust transport

NAM-CMAQ $PM_{2.5}$ run



- NAM-CMAQ operation runs with static LBCs/22-layer (prod) and **dynamic LBCs from NGAC**/35-layer (para1)
- The CMAQ para1 shows better agreement with the observed $PM_{2.5}$ values

Summary

- In megacities, both local emissions and long-range transport pollutions affect local air quality
- For Saharan dust event:
  - At source region, NGAC dust AOD are comparable with OBS total AOD
  - Dust is distributed from the surface to the aloft dust layer. There is dust near the ground when the event reaches the east coast, affecting air quality
- For Asian dust event:
  - The Asian dust events are associated with more complicated composition of aerosol properties (i.e., air pollution)
  - There is very little dust below the dust layer when reaching west coast of U.S. and, thus, poses minimal impact on air quality
- Improvement of regional AQ forecasts with dynamic boundary conditions from NGAC can be demonstrated

Thanks.

Questions and Comments?

Backup slides

Highlight dust events in 2015

Date	Event	Source/Reference
Feb 28, 2015	West Africa dust	EO
April 11, 2015	Mid Africa (Sahel) dust	EUMETSAT
April 20, 2015	Saharan dust (+smoke)	OMPS
May 10-14, 2015	West Africa dust (+smoke)	UMBC, OMPS
Jun 17, 2015	Saharan dust	UMBC, OMPS
Jun 21-26, 2015	Saharan dust	UMBC
Jul 1-2, 2015	Saharan dust	UMBC
Jul 7-10, 2015	Saharan dust	UMBC
Jul 13-14, 2015	Saharan dust	UMBC
Jul 20-23, 2015	Saharan dust	UMBC
Apr 1-6, 2015	Asian dust	EO, EUMETSAT, OMPS, UMBC
Apr 27, 2015	Asian dust	EUMETSAT

Only the dust events affecting U.S. are selected

OMPS: Ozone Mapping & Profile Suite

EO: Earth Observatory

EUMS: European organization for the exploitation of Meteorological Satellites

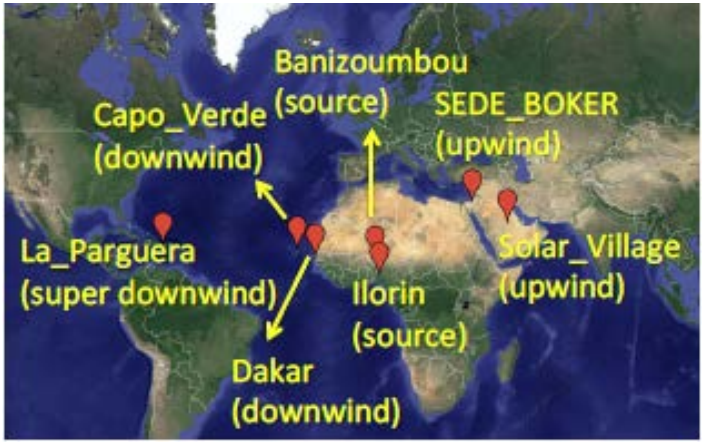
BDFC: Barcelona dust forecast center

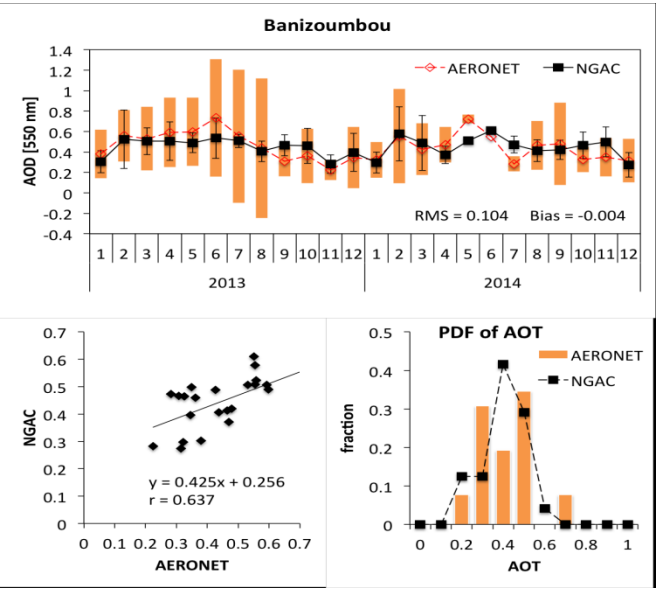
UMBC: UMBC smog blog

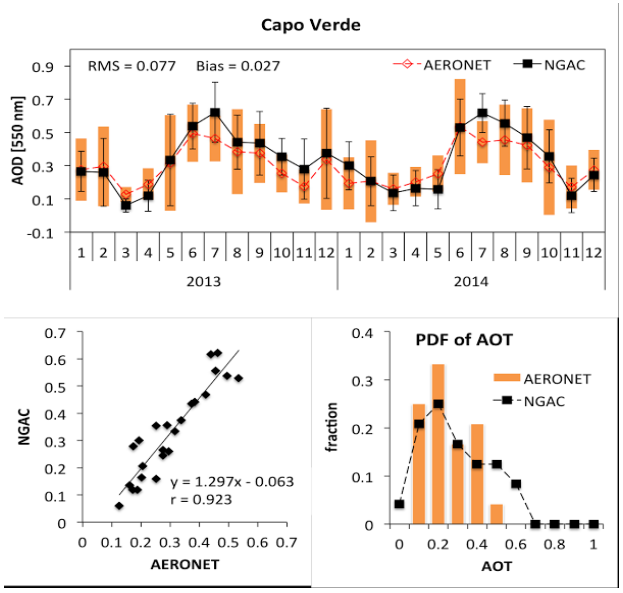
NGAC evaluation and verification

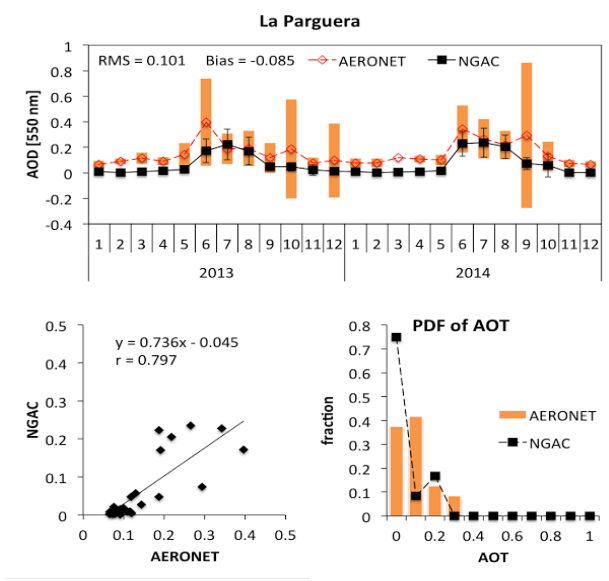
NGAC vs. AERONET (2013-2014)

Site	# of monthly mean compared	Correlation coefficient	Bias
SEDE_BOKER	24	0.78	-0.04
Solar_Village	15	0.83	-0.11
Banizoumbou	24	0.64	-0.00
Ilorin	16	0.56	-0.31
Capo_Verde	24	0.92	0.03
Dakar	24	0.91	0.02
La_Parguera	24	0.80	-0.08

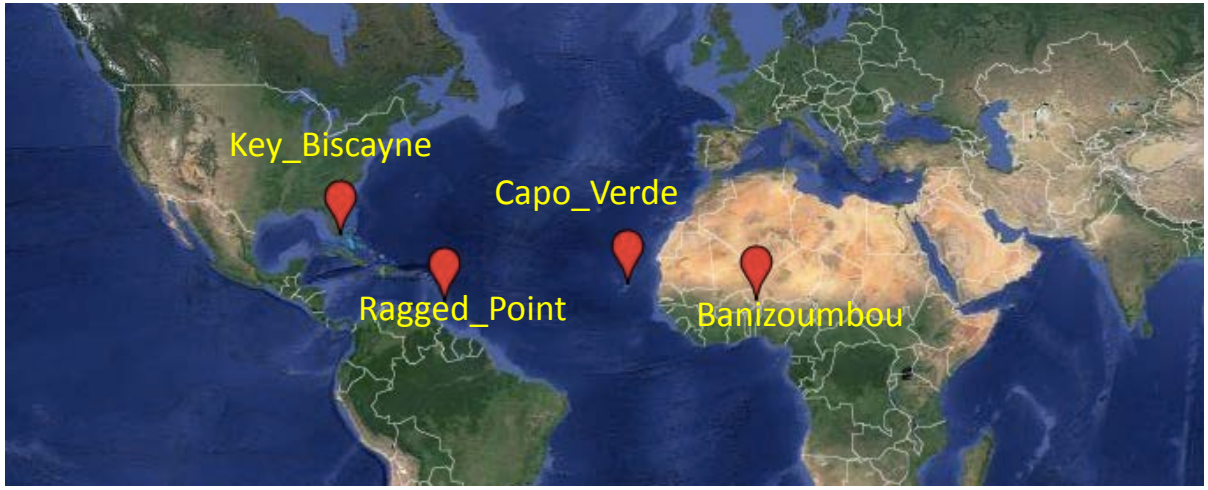


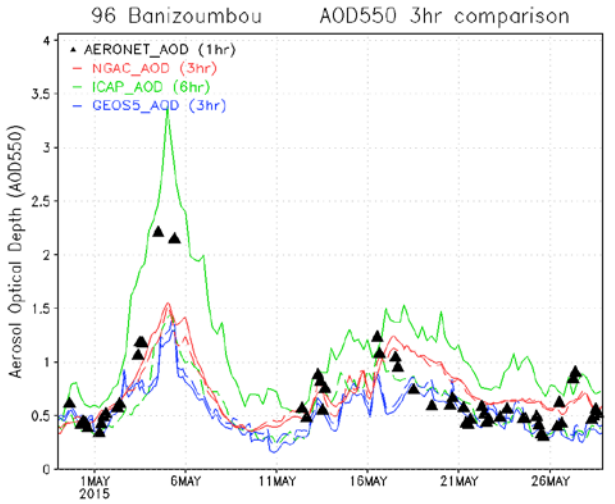


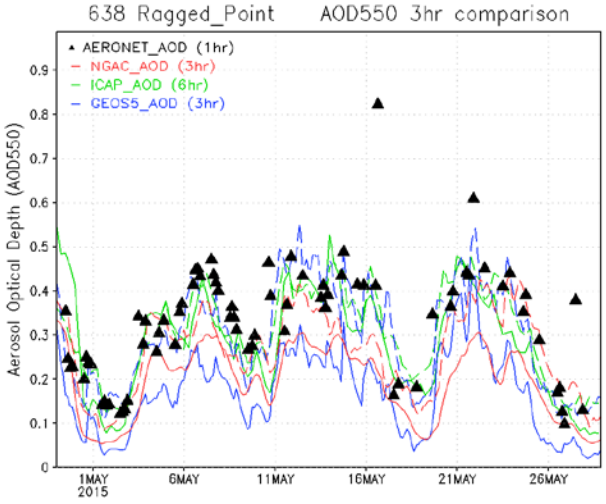


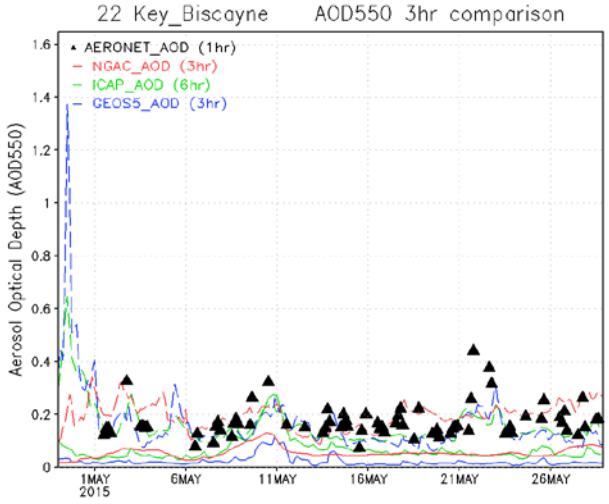


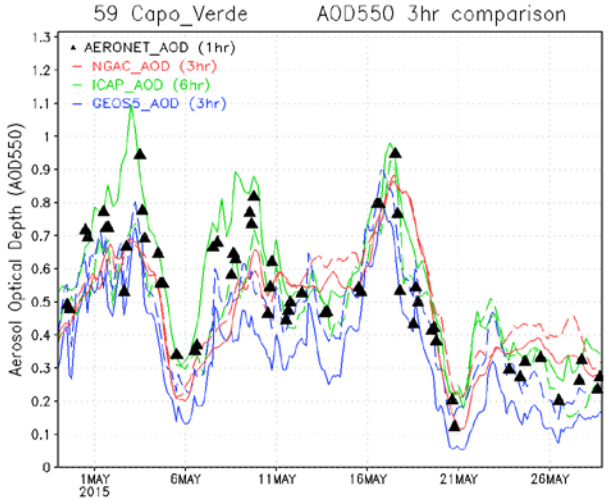
Total AOD Comparison of AERONET vs. MOD (dust event: May 10-14, 2015)







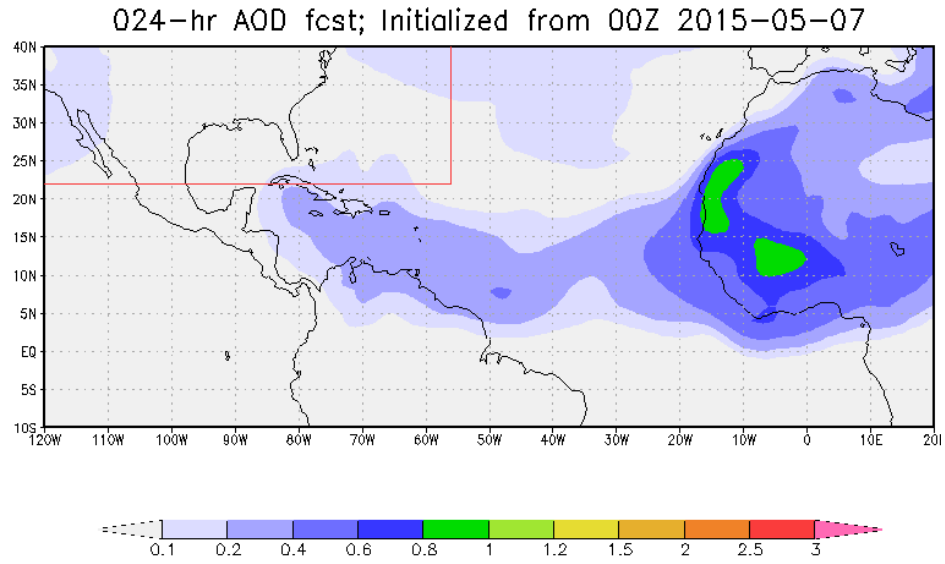




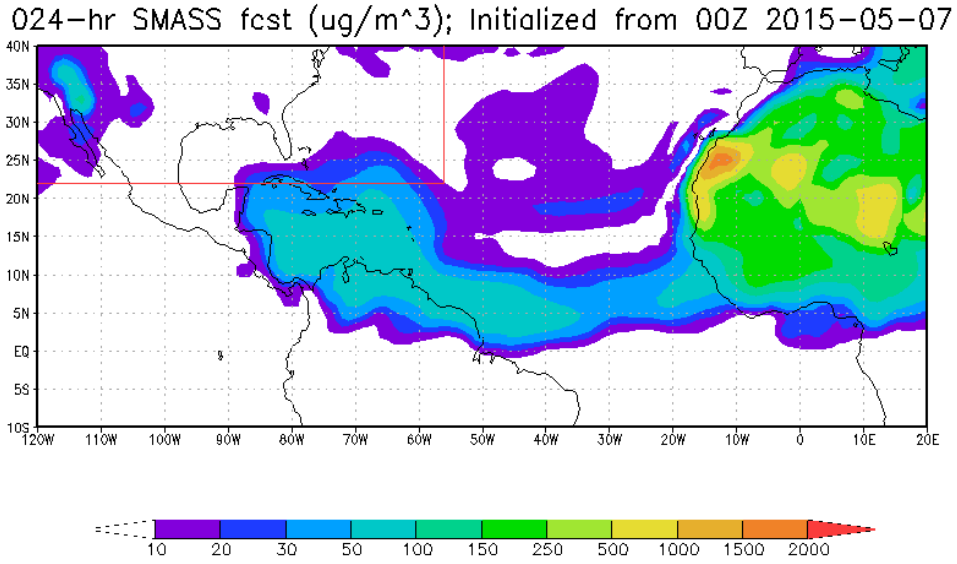
- The AERONET AOD were compared with NGAC, ICAP-MME and GEOS5 dust AOD near source region and the downwind region

Dynamic boundary conditions for regional AQ forecast

NGAC dust AOD

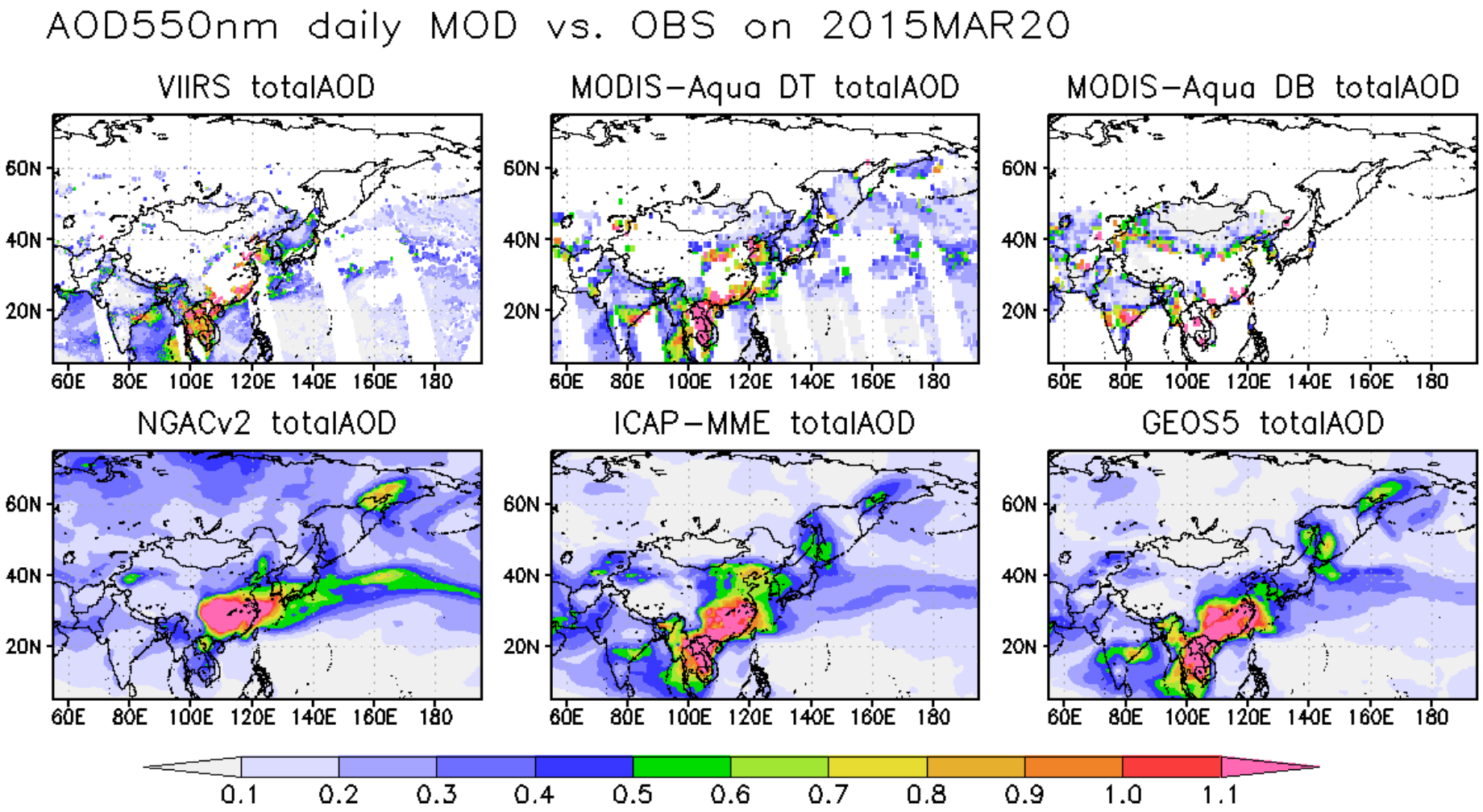


NGAC surface dust concentration



- 24, 48, 72-hr forecast of NGAC AOD and surface concentration (initialize from May 7)
- The NGAC results showed clear long-range dust transport reaching the continental US

Daily **total** ADO on Mar 20-Apr 7 2015 (dust event: Apr 1)



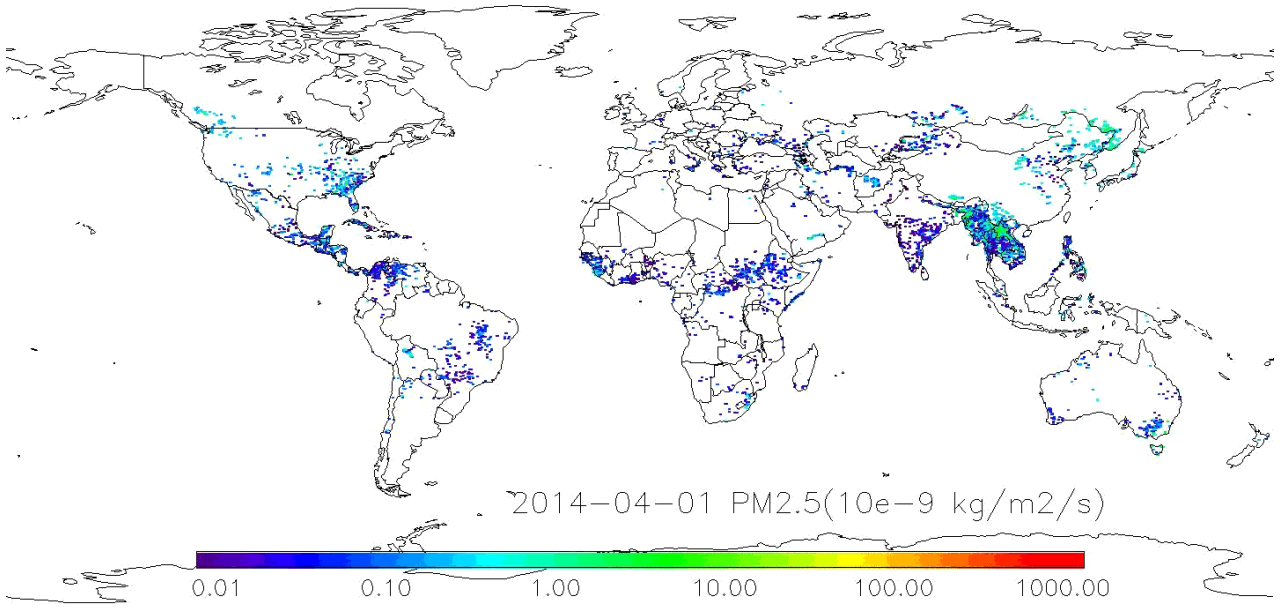
- The VIIRS and MODIS AOD were compared with NGAC, ICAP-MME and GEOS5 dust AOD across the Pacific

NGACv1 and NGACv2 (Q4FY15)

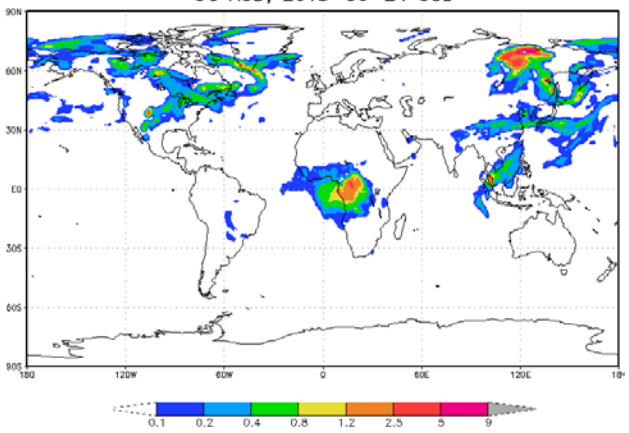
	NGACv1	NGACv2
Dust and Emission	GOCART emission (Paul Ginux) Annual global biomass emission (2010)	SS emission update (GOCART emission) **real-time biomass emission (GBBPEx)**
GFS-physics	Eulerian	semi-Lagrangian (trace not conserve)
convection	SAS (Simplified Arakawa-Schubert)	RAS (Relaxed Arakawa-Schubert scheme)
Aerosol	DU	**full aerosol (DU, SS, SU, BC, OC)**
Chem module	GOCART	updated GOCART

Q1FY16 upgrade: Multi-species forecast using near-real-time smoke emissions from satellites

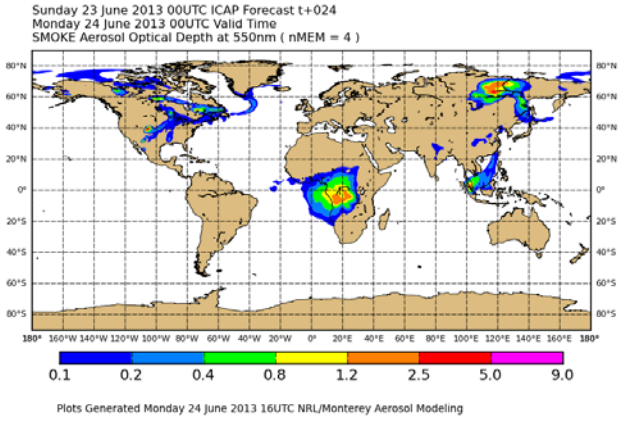
Temporal and spatial variation in smoke emissions from GBBEPx



NGAC Organic Carbon AOD

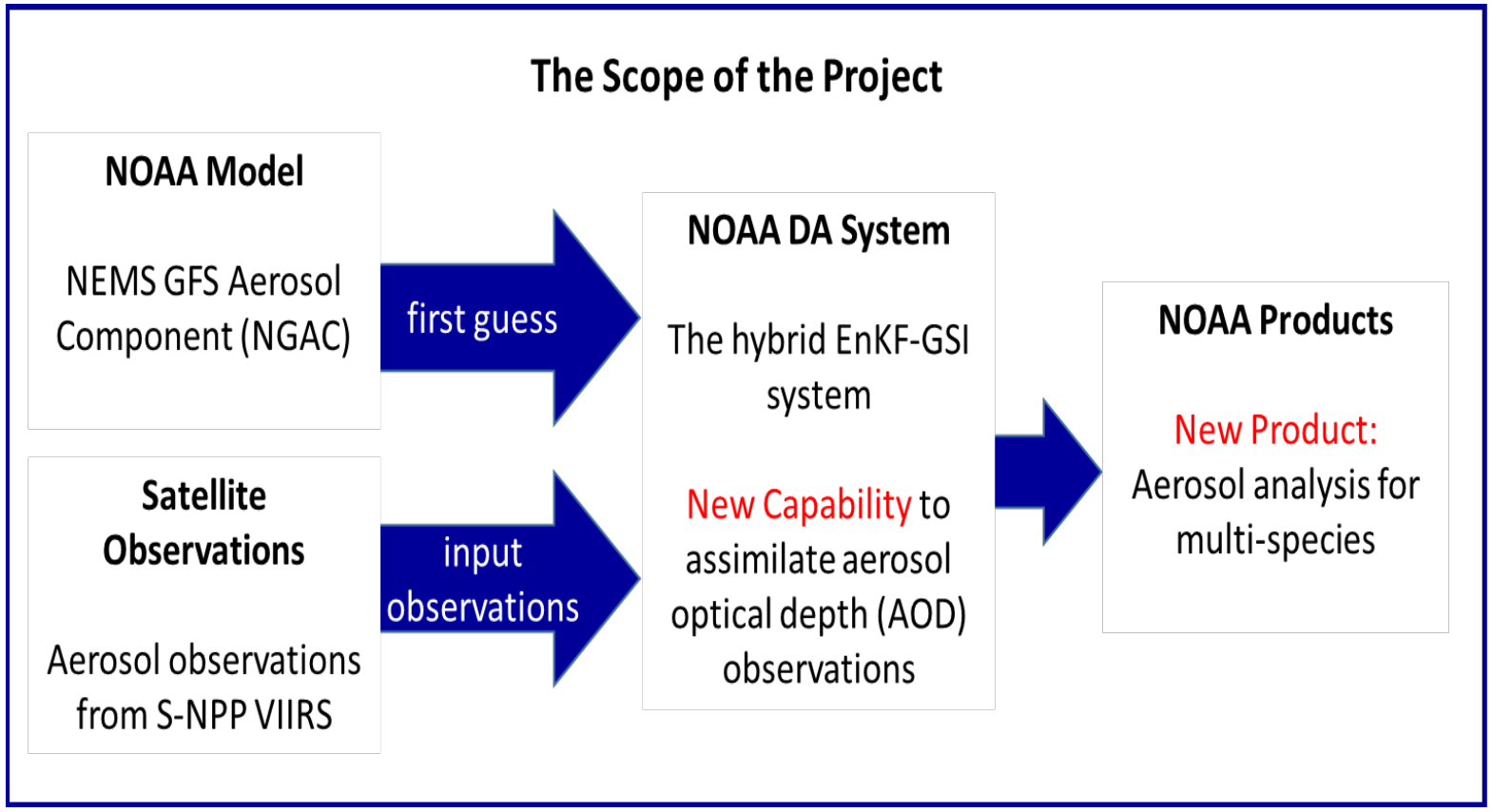


ICAP smoke AOD MME



GBBEPx: Global Biomass Burning Emissions Product-eXtended, blended from Geo (NESDIS's smoke products) and Polar (GSFC's smoke products)

FY17 Upgrade: Improving NCEP global aerosol forecasts using JPSS S-NPP VIIRS aerosol products



Aerosol Data Assimilation

- Values and benefits
  - Provide initialization for aerosol forecasts and thus improve aerosol forecast skills
  - Support NCEP's efforts to develop an unified global coupled data assimilation and modeling suite
- Observations: VIIRS AOD initially; extended to use multi-sensor/multi-platform aerosol observations

NGGPS Dust/Aerosol Development in Progress

Prognostic aerosols (GOCART) in candidate dynamic core

- Implementation and Testing of Regional and Global Dust Forecasting (Ginoux, GFDL)
- Using Advanced Photochemical and Aerosol Modules to Verify the Applicability of GOCART Aerosol Modules within Global Weather Prediction Models (Grell, ESRL)

Aerosols and weather/precipitation

- Investigation of Aerosol Effects on Weather Forecast using NCEP Global Forecast System (Lu, SUNYA)
- Evaluating the Impact of Cloud-Aerosol-Precipitation Interaction (CAPI) Schemes on Rainfall Forecast in the NGGPS (Li, U Md)

Upgraded to modal aerosol model

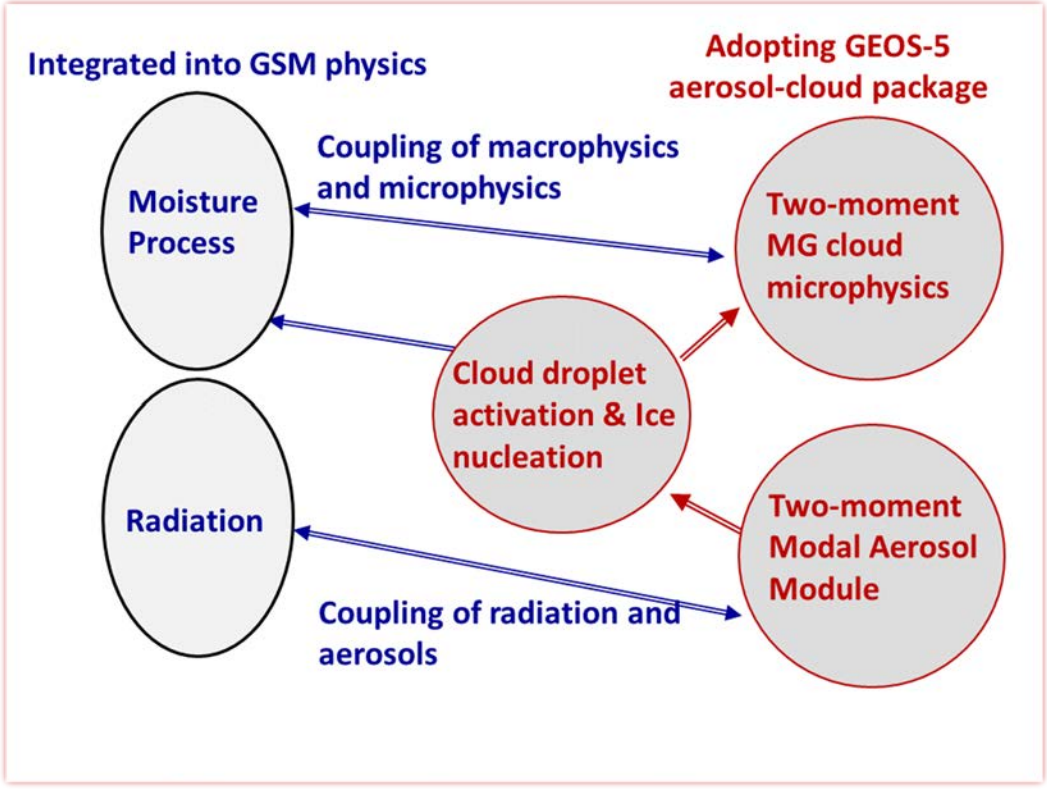
- Improving Cloud Microphysics and Their Interactions with Aerosols in the NCEP Global Models (Lu, SUNYA)

Improving Cloud Microphysics and Their Interactions with Aerosols in the NCEP Global Models

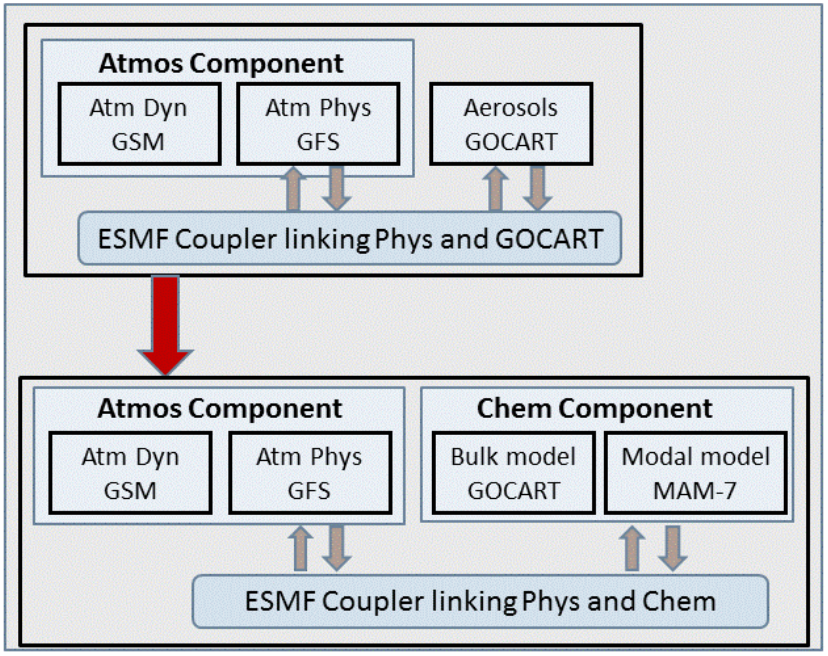
- Objective: Improve the representation of aerosol processes, cloud microphysics, and aerosol-cloud-radiation interaction in NCEP global models
- SUNYA-NCEP-GSFC collaborative efforts to upgrade NEMS physics suite by adapting GSFC's physically-based aerosol and cloud microphysics package (which in turn is based on NCAR CAM5)
- While this project is funded by MAPP-Climate Test Bed (CTB), the development work is closely aligned with the NGGPS's efforts to advance physical parameterization suite in NEMS

Improving cloud microphysics and their interactions with aerosols in the NCEP global models (cont'd)

Primary outcome: NEMS physics suite improvement
Adapting physically-based aerosol and cloud microphysics package to improve aerosol-cloud-radiation interaction in NEMS physics



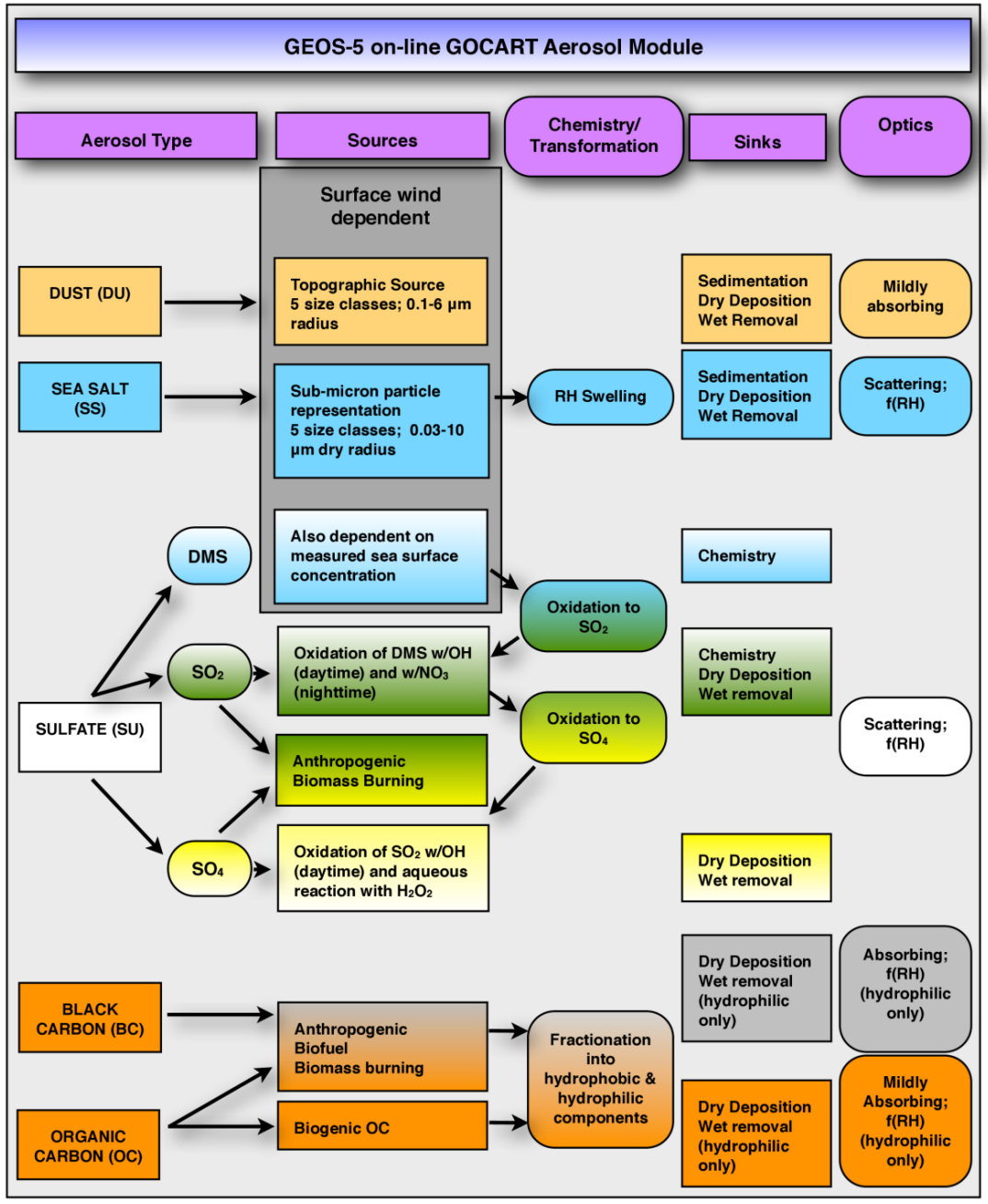
Secondary outcome: infrastructure upgrade
Introducing a generic chemistry component (containing GOCART and MAM) which can be easily extended to include GEOS-5 tropospheric and stratospheric chemistry)



NASA GOCART Module

In-line chemistry advantage

- Consistency: no spatial-temporal interpolation and same physics parameterization
- Efficiency: lower overall CPU costs and easier data management
- Interaction: Allows for feedback to
- meteorology



GOCART diagram provided by Peter Colarco (GSFC)

The Modal Aerosol Module (MAM)

- A **M**odal **A**erosol **M**odule (MAM, Liu et al., 2012) has been developed for the Community Atmosphere Model version 5 (CAM5), the atmospheric component of the Community Earth System Model version 1 (CESM1)
- MAM is capable of simulating the aerosol size distribution and both internal and external mixing between aerosol components, treating numerous complicated aerosol processes and aerosol physical, chemical and optical properties in a physically-based manner

Aerosol components

- Sulfate
- Black carbon (BC)
- Dust
- Sea salt
- Ammonium
- Primary organic
- Secondary organic

Aerosol modes

1. Aitken
2. Accumulation
3. Primary carbon
4. Fine sea-salt
5. Fine dust
6. Coarse sea salt
7. Coarse dust

Aerosol microphysics

- Nucleation (H_2SO_4-NH_3-H_2O and BL nucleation)
- Coagulation (intra- and intermodal of AIT, ACC, PCM)
- Condensation(H_2SO_4, NH_3 and SOA(g))
- Gas-aerosol exchange

Configuration of MAM7

Aitken	Accumulation	Fine Dust	Fine Sea Salt
number	number	number	number
sulfate	sulfate	dust	sea salt
ammonium	ammonium	sulfate	sulfate
secondary OM	secondary OM	ammonium	ammonium
sea salt	primary OM		
	BC		
	sea salt		

coagulation

condensation (H_2SO_4, NH_3, SOA)

Primary Carbon	Coarse Dust	Coarse Sea Salt
number	number	number
primary OM	dust	sea salt
BC	sulfate	sulfate
	ammonium	ammonium

Two attachment states:

*a) **interstitial** - suspended in air*

*b) **cloud-borne** - attached to / contained within cloud droplets (AP in convective cloud droplet are not treated explicitly)*

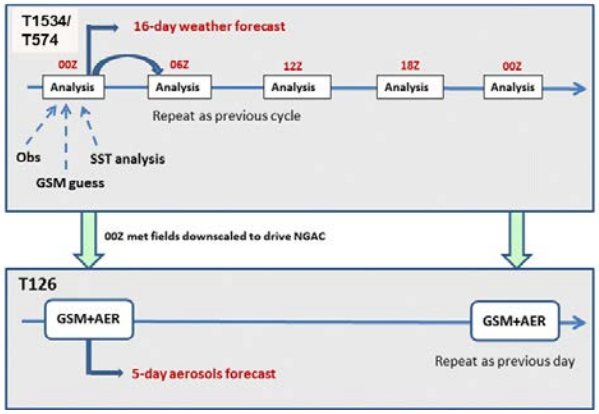
(Liu et al., 2012)

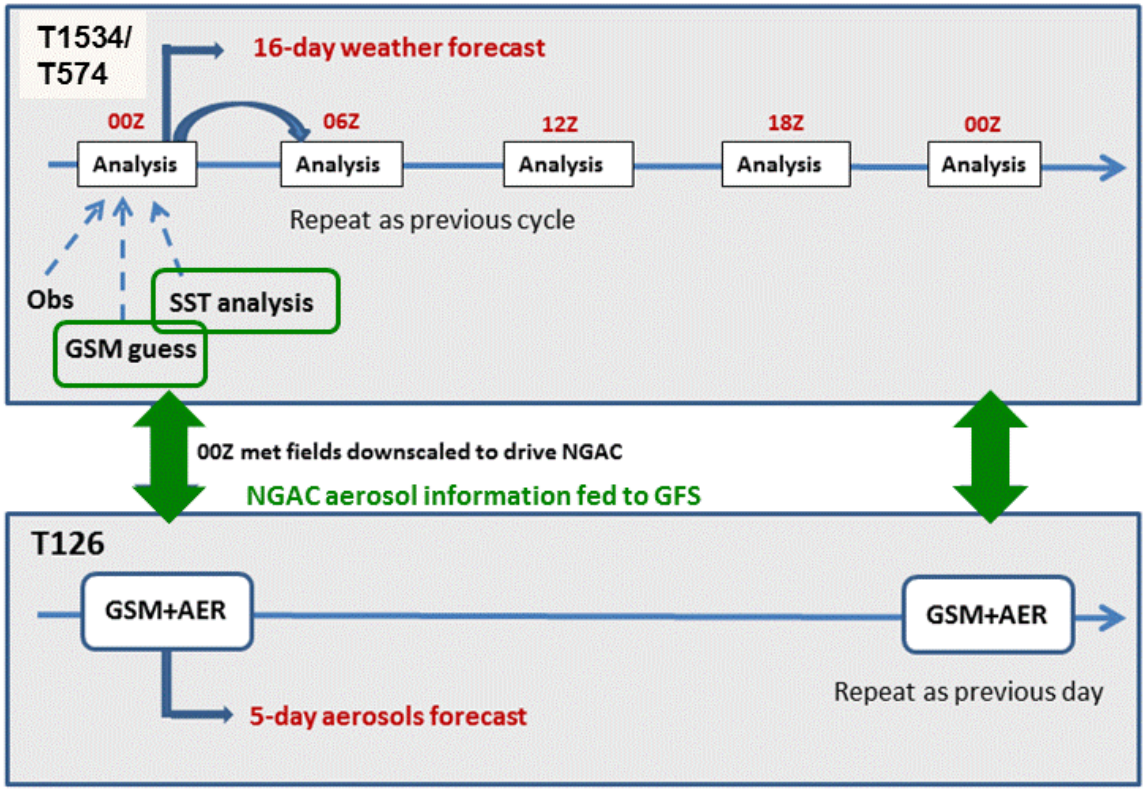
Investigation of Aerosol Effects on Weather Forecast using NCEP Global Forecast System

- Objective: Investigate how much complexity is needed to accurately represent the aerosol processes and effectively account for aerosol effects
- SUNYA-NCEP-STAR collaborative efforts, funded by NGGPS R2O, to explore the optimal (accurate and yet affordable) aerosol configuration in GFS parallel scripts (NCEP's full suite of scripts for the pre-implementation parallel runs)
- Tactical approach:
  - Producing an improved estimates of the temporal and spatial distributions of atmospheric aerosols
  - Using aerosol fields in conjunction with the forecast model (GSM), the analysis system (EnKF-GSI hybrid), and SST analysis (RTG_SST) to assess the atmospheric response to aerosols
  - Enhancing the parallel scripts through incorporation of flexible aerosol configuration

Dual resolution weather-aerosol system

Operational: One-way coupling





Proposed: Two-way loose coupling

Aerosol fields from low-resolution NGAC run are fed to high-resolution GFS run.
This allows aerosol radiative effects in GSM, physical retrievals in RTG_SST, and aerosol attenuation in EnKF-GSI hybrid to be determined from low-resolution NGAC simulations.
Use NGAC as the forward model in GDAS, which effectively fold the dual resolution system into a single fully-integrated system (tight coupling).


Great Basin
Turkestan
Gobi
Arabian
Sahara
Taklamakan
Chihuahuan
Indian
Sonoran
Iranian
Atacama
Namib
Kalahari
Great Australian
Patagonian
Desert (arid)
Steppe (semiarid)