# NASA Update

# GEOS-5 Model and Data Assimilation System: Aerosols and Clouds



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#### Outline

- Current NRT system
- Field campaigns
  - KORUS-AQ
- Ongoing work and future plans
  - AGCM and ADAS
  - New components
  - MAM7
- Chemistry and aerosol visualizations





#### Current NRT Configuration



## Current GEOS-5 NRT (forward processing) configuration



#### GMAO experimental forecasts





# Field campaigns

- VIRGAS: Volcano-plume Investigation Readiness and Gas-phase and Aerosol Sulfur
- 7-SEAS: The Seven SouthEast Asian Studies
- NAAMES: The North Atlantic Aerosols and Marine Ecosystems Study
- KORUS-AQ: International Cooperative Air Quality Field Study in Korea
- ORACLES: ObseRvations of Aerosols above CLouds and their intEractionS





Chemical weather maps of forecasted CO from fires in Africa and AOD in the ORACLE domain.

http://gmao.gsfc.nasa.gov/field\_campaigns/



# KORUS-AQ: 60-hr forecast for 25 May 2016

- Multi-model aerosol and weather forecasts • are used for flight planning
- Aerosol optical depth from four different modeling systems, including GEOS-5
- The 60-hr forecasts from all the models suggest an inflow of pollution from China over the Yellow Sea





24E 126E 128E 130E 132E 134E

30

NAAPS Total Optical Depth for 2016052208\_0 Sulfate: Orange/Red, Dust: Green/Yellow, Smo









72	
oke: B	Blue
13	35
2	47
	42
	37
	32
	27



### DC8 flight plan for 25 May



Data from this flight will help constrain the production mechanism of secondary organic aerosols, as well as dust emissions and settling velocities.

10 (km)



120



Flight plan for 25 May, 2016 aiming to capture both the pollution inflow from China and long-range transport of dust in the upper troposphere.



25.6
22.4
19.2
16
12.8
9.6
6.4
3.2
0

### 12-hr Forecast for 25 May 2016: Inflow Intensified







• The GEOS-5 12-hr forecast indicated an intensification of the pollution inflow from China compared to the 60-hr forecast.

Aerosol optical depth values above 1.0 were forecasted over the Yellow Sea, related to strong easterly wind flow.

## Comparison of DIAL-HSRL observations and GEOS-5: 25 May 2016



The high values of backscatter and low values of depolarization ratio below 2 km are an indication of small spherical particles originating from urban/industrial sources. Between 3-5 km, GEOS-5 indicates the presence of dust, although it underestimates the intensity.



GEOS-5 data assimilation results reproduced the general characteristics of the vertical column of the atmosphere.

#### Model and DAS updates



### GOCART updates

#### **Objectives:**

- Wet removal: address high BC concentrations and overestimated dust removal frequency
- Model that is stable across the 50km - 10km range of resolutions
- Add nitrate aerosol









AOT 1.43e-01 7.0e-01 4.4e-01 2.7e-01 1.7e-01 1.1e-01 6.6e-02 4.1e-02 2.6e-02 1.6e-02 1.0e-02 60°E 120°E 60°W 0° 180°



### GOCART updates

#### **Objectives:**

Wet removal: address high BC concentrations and overestimated dust removal frequency



- Model that is stable across  $\bullet$ the 50km - 10km range of resolutions
- Add nitrate aerosol





#### C720 (12.5km) AOD July 2008







### GOCART updates

#### **Objectives: Add Nitrate aerosols**

- Five new tracers (NH3, NH4, aerosol nitrate/NO3an: 0-0.5 um, 0.5-4um, 4-10um)
- Nitric acid is read from archived monthly output from a GMI chemistry run
- Uses RPMARES (SO4-NO3-NH4-H2O)

inputs: RH, T, SO4, NHO3, NH3, NH4, NO3an

outputs: HNO3, NH3, NH4, NO3an1

- Heterogeneous reactions on Dust and Sea salt particles inputs: RH, T, NHO3, Dust, Sea salt outputs: NO3an1, NO3an2, NO3an3
- Refractive indices of NH4NO3 from Lacis et al., (1997)





### New GEOS:CHEM components

- GEOSChem online version of the GEOS-Chem community model (3D atmospheric composition)
- **HEMCO** flexible grid independent emission component controlled by a configuration file:
  - ➡ MEGAN-v2.1
  - Impose weekly and hourly cycles on temporary coarse emissions
  - Overlay emissions from different datasets
- DNA a component that can be used to specify aerosol radiative properties from archived model output enabling model intercomparison or sensitivities studies





# The GEOS-5 Nature Run with full chemistry

**Objective: Provide realistic chemical state for OSSEs (geostationary atmospheric composition** satellites TEMPO, GEMS, SENTINEL-4)

- Atmospheric chemistry (run passively) is modeled • with the online GEOS-Chem component
- Aerosols are modeled with GOCART
- Replay meteorology from the MERRA2 dynamical • downscaling run
- Resolution: 12.5 km, 72 levels
- Period: July 2013 July 2014 (SEAC4RS, • DISCOVER-AQ)
- Output is being produced at 2880x1441 •







#### Coupled aerosol-clouds-radiation experiments with GEOS/MAM7

#### **Objective: Compare aerosols and** clouds from GEOS-5/MAM7 and **GEOS-5/GOCART runs**

- Aerosols are coupled with the radiation and with the 2-moment cloud microphysics.
- Strength of sea salt and dust emissions are tuned to match MERRA2 sea salt and dust aerosol optical thickness.
- Replaying MERRA2 meteorology of 2013. •



Monthly mean AOT 0.03

0.01

0.10

0.08

**401** 0.06 Monthly mean

0.02





#### Aerosol optical thickness











7.0e-01
4.4e-01
2.7e-01
1.7e-01
1.1e-01
6.6e-02
4.1e-02
2.6e-02
1.6e-02
1.0e-02



0.09
0.07
0.05
0.03
0.01
-0.01
-0.03
-0.05
-0.07
-0.09

#### Comparison with AERONET





## Clear-sky aerosol radiative forcing





- MAM7 aerosols have stronger than GOCART clearsky shortwave and longwave forcings at TOA with global net difference of about -0.8 Wm-2.
- MAM7 shortwave forcing at TOA is underestimated but agrees better with previously reported global estimates of -5±0.2 Wm-2 than the GOCART results.





#### Aerosol effects on clouds





1.0e+13

4.6e+12

2.2e+12

1.0e+12

4.6e+11

-2.2e+11

1.0e+11

4.6e+10

-2.2e+10

1.0e+10

100

90

80

60

50

40

- 30

![](_page_20_Figure_3.jpeg)

![](_page_20_Figure_4.jpeg)

![](_page_20_Figure_5.jpeg)

![](_page_20_Figure_6.jpeg)

![](_page_20_Picture_7.jpeg)

![](_page_20_Figure_8.jpeg)

![](_page_20_Figure_9.jpeg)

![](_page_20_Figure_10.jpeg)

#### NASA

#### Brighter clouds in the MAM7 simulation lead to bias of -4.5 W m-2 in the shortwave forcings at TOA.

![](_page_21_Figure_2.jpeg)

#### Cloud radiative forcings - comparison with CERES-EBAF climatology

![](_page_21_Picture_5.jpeg)

120
90
60
30
0
-30
-60
-90
-120

![](_page_21_Picture_7.jpeg)

-120
18
14
10
6
2
-2
-6
-10
-14
-18

### Planed upgrade to the GEOS NRT system

#### **3Q-2016**

- GEOS 4D-EnVar
- GCM: C720 L72 (**12.5 km**)
- ANA-EnVar:1152x721 L72 (**25 km**)
- 3D-EnKF: 32x576x361 L72 (**50 km**)
- 2D PSAS Aerosol Analysis  $\bullet$
- **FVCOR** updates  $\bullet$
- **Semi-Coupled Skin SST Analysis**
- GOCART  $\bullet$

![](_page_22_Picture_10.jpeg)

500 hPa Height Northern Hemisphere, Oct 2014 – Jan 2015

![](_page_22_Figure_12.jpeg)

The candidate NRT system has better forecast skill.

## Ongoing work and future plans

#### **NWP**

- 4D EnVar + 4D IAU
- GSI 'split' observer (multi-resolution, OMF on native grid, ...)
- Semi-coupled skin SST assimilation
- All-sky assimilation of MW radiances (imagers and sounders)
- Correlated observation error for hyperspectral IR  $\bullet$
- EnKF update for aerosol analysis (formerly PSAS)  $\bullet$
- EnKF update for skin SST analysis (formerly none)
- Aerosol effects on radiance assimilation (CRTM) lacksquare

![](_page_23_Picture_10.jpeg)

#### Mature

- **Trace gases** 
  - Generalized trace gas assimilation capability
  - STRATCHEM and GEOS-Chem for ozone assimilation

#### Land Surface

- Off-line EnKF (SMAP L4 soil • moisture, carbon fluxes)
- Inline EnKF weakly coupled to GEOS

![](_page_23_Picture_18.jpeg)

![](_page_23_Figure_19.jpeg)

### Aerosol analysis with EnKF update

- GMAO is transitioning to an EnKFulletbased aerosol assimilation to enable use of 3D lidar observations from CATS and CALIOP, in addition to current 2D AOD observations from MODIS, MISR, AERONET
- Framework development advanced  $\bullet$
- Assimilation of AOD in testing  $\bullet$

![](_page_24_Figure_4.jpeg)

![](_page_24_Picture_5.jpeg)

EnKF-based scheme recovers the AOD increments at similar locations, however the smaller AOD increments suggest insufficient ensemble spread.

0.30 0.24 0.18 0.12 0.06 0.00 -0.06-0.12-0.18-0.24-0.30

# MERRA2: Documentation and Products

 Official data released via the NASA Goddard Earth Sciences (GES) Data Information Services Center (DISC):

http://disc.sci.gsfc.nasa.gov/daac-bin/ FTPSubset2.pl

http://disc.sci.gsfc.nasa.gov/uui/#/search/ %22MERRA-2%22

- Completed 1980 present, now running as a continuing climate analysis with 2 – 3 week latency
- NASA Tech Memos documenting the MERRA-2 meteorological and aerosol validation exercise will soon be available at: http://gmao.gsfc.nasa.gov/ pubs/tm/
- File specification: <u>http://gmao.gsfc.nasa.gov/pubs/</u> office\_notes/

![](_page_25_Picture_7.jpeg)

![](_page_25_Picture_8.jpeg)

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![](_page_26_Picture_7.jpeg)

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JOURNAL OF CLIMATE	
The MERRA-2 Aerosol Reanalysis, 1980 - onward	, Part 1: Data Assimilation
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C I ELVIN	JOURNAL OF CLIMATE
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ABSTRACT	
The Modern-Era Retrospective Analysis for Research and Application NASA's previous satellite era (1980-present) reanalysis system to inclu	ade
step towards a full Integrated Earth Systems Analysis, in addition to me	V. BUCHARD *
2 now includes assimilation of aerosol optical depth (AOD) from various g sensing platforms. Here, in the first of a pair of studies, we document the	the Research Association, Columbia, MD, USA
emisisons, and the quality control of ingested observations. We provide the analyzed AOD fields using independent observations from ground	e ini airc C. A. RANDLES <sup>†</sup>
Comparing to a control version of the same modeling system without assin proviments in AOD for MERRA-2. In our companion paper, we evaluate a	ssin Global Modeling and Assimilation Office, NASA Goddard Space Flight Center, Greenbelt, Maryland and GESTAR/Morean State University, Baltimore, MD, USA
aerosol properties not directly impacted by the AOD assimilation (e.g. portantly, while highlighting the skill of the MERRA-2 aerosol assimila	ae tion $A$ M DA SUVA A DARMENOV
caveats that must be considered when utilizing this new reanalysis production their interactions with weather and climate.	act f Global Modeling and Assimilation Office, NASA Goddard Space Flight Center, Greenbelt, Maryland
	P. R. COLARCO
<b>1. Introduction</b> The Modern Fra Retrospective Analysis for Research the MERRA-	Atmospheric Chemistry and Dynamics Lab, NASA Goddard Space Flight Center, Greenbelt, Maryland
and Applications, Version 2 (MERRA-2) is the new mod-	ME R. GOVINDARAJU
from the NASA Global Modeling and Assimilation Of-	Global Modeling and Assimilation Office, NASA Goddard Space Flight Center, Greenbelt, Maryland and Sciel Systems and Applications, Inc., Lanham, MD, USA
fice (GMAO) (Gelaro 2016). Following the success of the ing System, ve	R. FERRARE, J. HAIR, A. J. BEYERSDORF, L. D. ZIEMKA
et al. 2012, 20 tation of the h	14) ydro
<sup>†</sup> Corresponding author address: A. M. da Silva, NASA Goddard	) th silo
Space Flight Center, 8800 Greenbelt Road Code 610.1, Greenbelt, Maryland, 20771	can Climate and Radiation Laboratory, NASA Goddard Space Flight Center, Greenbelt, Maryland, USA and Earth S Science Interdisciplinary Center, University of Maryland, College Park, MD, USA
	ABSTRACT
	The Modern-Era Retrospective Analysis for Research and Applications, Version 2 (MERRA-2) is NASA's
	latest reanalysis for the satellite era (1980-present) using the Goddard Earth Observing System version 5 (GEOS-5) Earth system model. MERRA-2 provides several improvements over its predecessor (MERRA), including the inclusion of interacting correctly for the article period. In addition to example the inclusion of interacting correctly for the article period.
	Aerosol Optical Depth (AOD) from the Moderate Resolution Imaging Spectroradiometer (MODIS) on the Terra and Aqua satellites, it also includes the assimilation of bias-corrected AOD from Advanced Very High
	Resolution Spectroradiometer (AVHRR) instruments, Multi-angle Imaging SpectroRadiometer (MISR) AOD over bright surfaces, and ground-based Aerosol Robotic Network (AERONET) AOD. This paper is the second
	of a pair that summarizes our efforts to assess the quality of the MERRA-2 aerosol assimilation. In this study, we first follow previous work performed with version 1 of the MERRA Aerosol Reanalysis (MERRAero) us-
	ing independent observations. The evaluation of MERRA-2 Absorption Aerosol Optical Depth (AAOD) and ultra-violet Aerosol Index (UV-AI) against the Ozone Monitoring Instrument (OMI) observations show good
	ties. Next, we find that aerosol assimilation system improves the aerosol vertical structure when compared to estimates from the same version of the model without AOD assimilation. A similar conclusion is found for
	MERRA-2 aerosol surface fine particulate matter ( $PM_{2.5}$ ). However, deficiencies in the forward model such

![](_page_26_Picture_9.jpeg)

#### Visualizations