Overview of NOAA NWS Atmospheric Composition Modeling Capabilities and Plans

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Regional: Jianping Huang, Ho-Chun Huang (NCEP), Ivanka Stajner (NWS), Pius Lee, Youhua Tang (NOAA/ARL)

HYSPLIT Dispersion : Barbara Stunder, Glenn Rolph, Ariel Stein (NOAA/ARL)

Overview presented in 2016 ICAP WG meetings

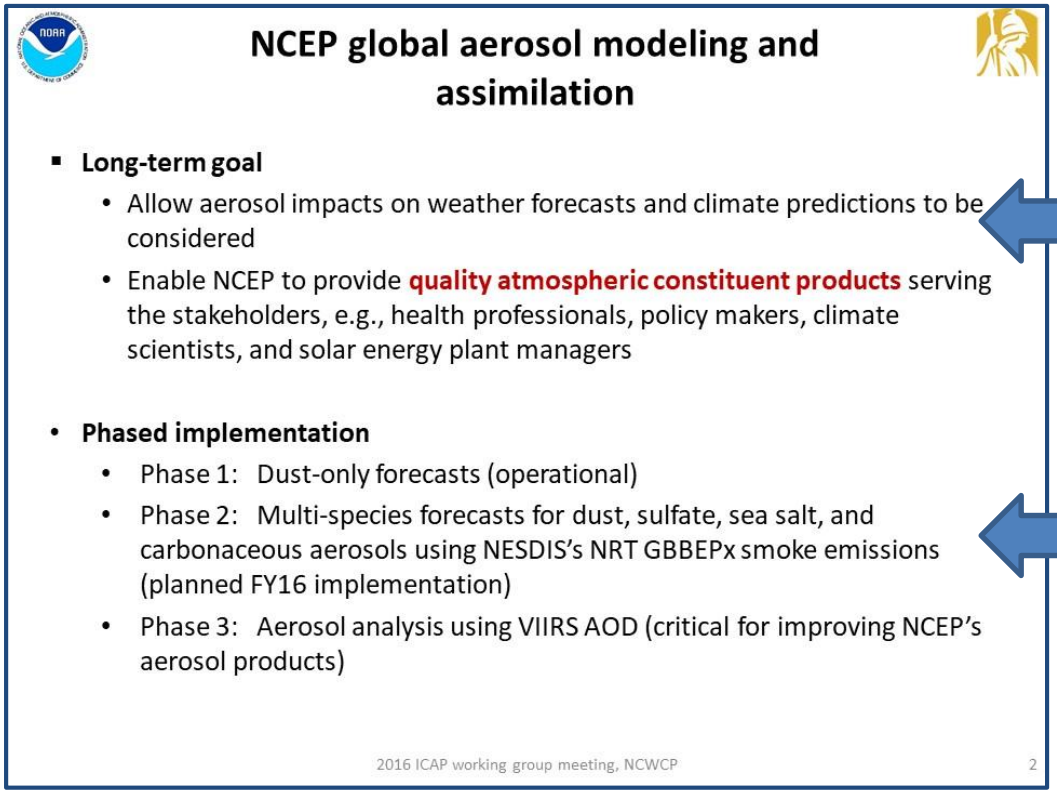
NCEP global aerosol modeling and assimilation

- **Long-term goal**
  - Allow aerosol impacts on weather forecasts and climate predictions to be considered
  - Enable NCEP to provide **quality atmospheric constituent products** serving the stakeholders, e.g., health professionals, policy makers, climate scientists, and solar energy plant managers

- **Phased implementation**
  - Phase 1: Dust-only forecasts (operational)
  - Phase 2: Multi-species forecasts for dust, sulfate, sea salt, and carbonaceous aerosols using NESDIS's NRT GBBEPx smoke emissions (planned FY16 implementation)
  - Phase 3: Aerosol analysis using VIIRS AOD (critical for improving NCEP's aerosol products)

2016 ICAP working group meeting, NCWCP 2

Overview presented in 2017 ICAP WG meetings



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The goals remain the same

- Phases 1 and 2 are implemented (dust-only NGACv1 and multi-species NGACv2)
- Phase 3: implementation is on hold while forecast model is transitioned to FV3GFS-based dynamic core
  - GFS physics except GFDL MP
  - FV3GFS 13 km : Feb. 2019

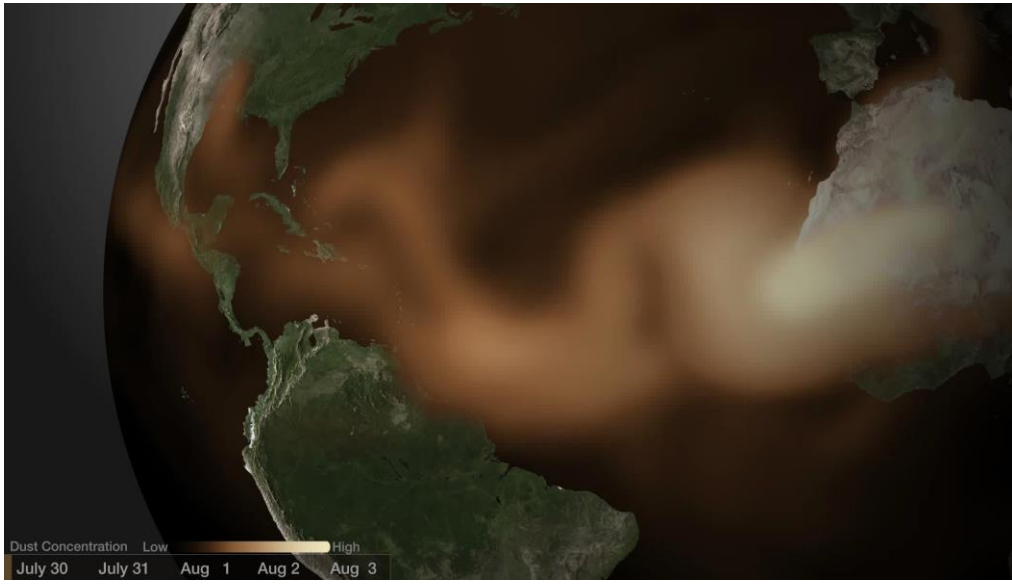
Development of aerosol modeling and data assimilation is presented by Mariusz Pagowski

This talk will present ongoing unified modeling efforts at NOAA

Operational NEMS GFS Aerosol Component

Current State

- Real-time operational system
- The first global in-line aerosol forecast system at NCEP
- AGCM : NCEP's NEMS GFS
- Aerosol: NASA/GSFC's GOCART
- 120-hr dust-only forecast twice per day (00, 12Z), output every 3-hr
- ICs: Aerosols from previous day forecast and meteorology from operational GDAS
- Dust Implemented into NCEP Production Suite in Sept 2012.
- Full package implementation (dust, sea salt, sulfate, and carbonaceous aerosols, 19 species) in FY16



Courtesy Jun Wang, NCEP

Ongoing Activities

- Provide lateral boundary condition for downstream regional CMAQ model
- Improvement on anthropogenic components
- Aerosol analysis using VIIRS AOD (S. Lu, M. Pagowski)
- **Integrate aerosols into FV3GFS**
- Provide aerosol information for potential downstream users (e.g., NESDIS's SST retrievals, CPC-EPA UV index forecasts, Solar energy forecast)

NOAA Next Generation Global Prediction System (NGGPS)

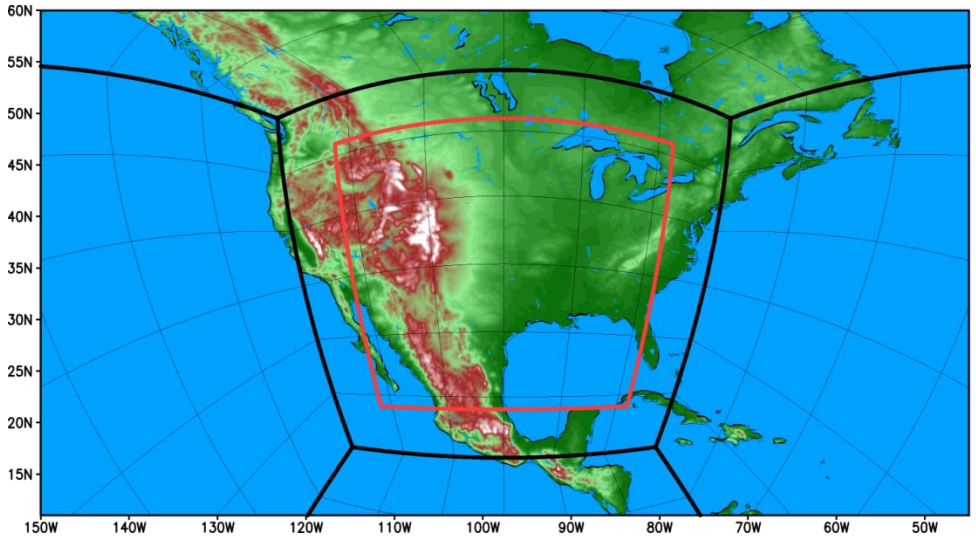
- NWS Research to Operations (R2O) initiative's:
  - upgrade the current operational Global Forecast System (GFS)
    - Unified Forecast System (UFS)
    - Fully coupled Next Generation Global Prediction System (NGGPS)
    - NEMS (NOAA Environmental Modeling System) infrastructure.
- FV3 dynamic core (NOAA/GFDL) Met Model
- Targeted implementation: Feb 2019

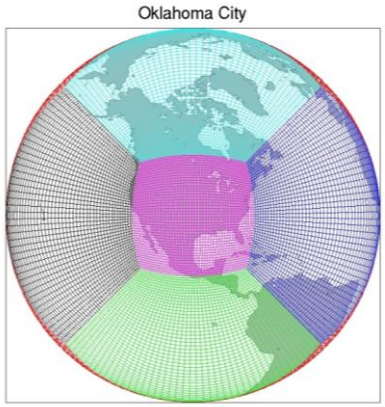
Thunderstorm-resolving resolution in a unified meso-global prediction system (FV3)

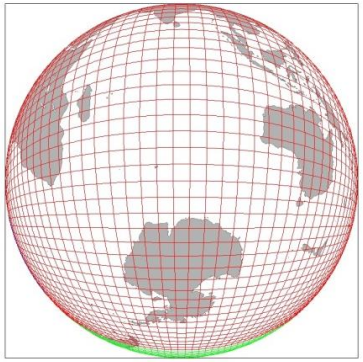
1) Grid stretching (smooth variation of grid spacing)

1) 2-way nesting (Harris and S.J. Lin 2014)
   FV3 is uniquely suitable for 2-way nesting, due to the application of two-time-level Finite-Volume transport scheme

2) Optimal combination of the “stretching” and “nesting”







FV3-GFS

→ FY19 Global : 13 km L64

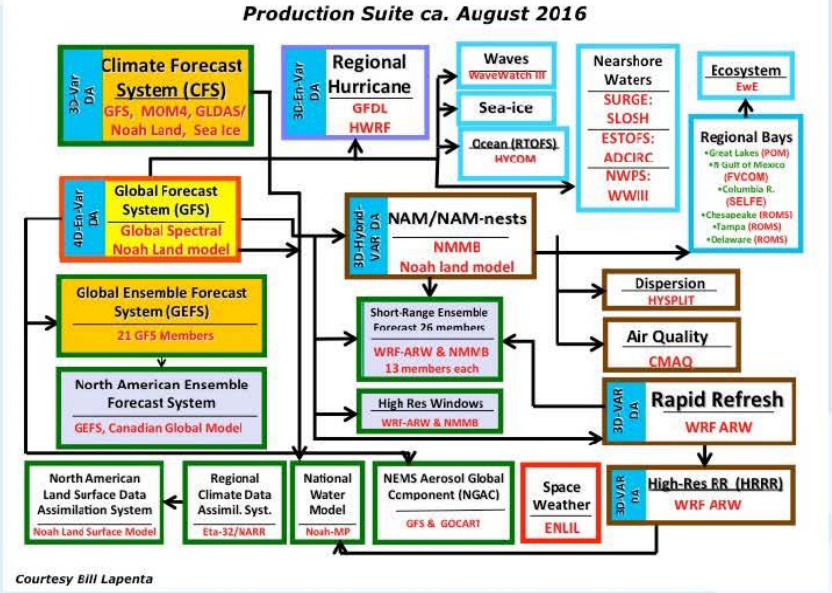
→ GFS physics + Aerosol aware GFDL microphysics/radiation option

FY20 Regional: 3km nest or stand alone

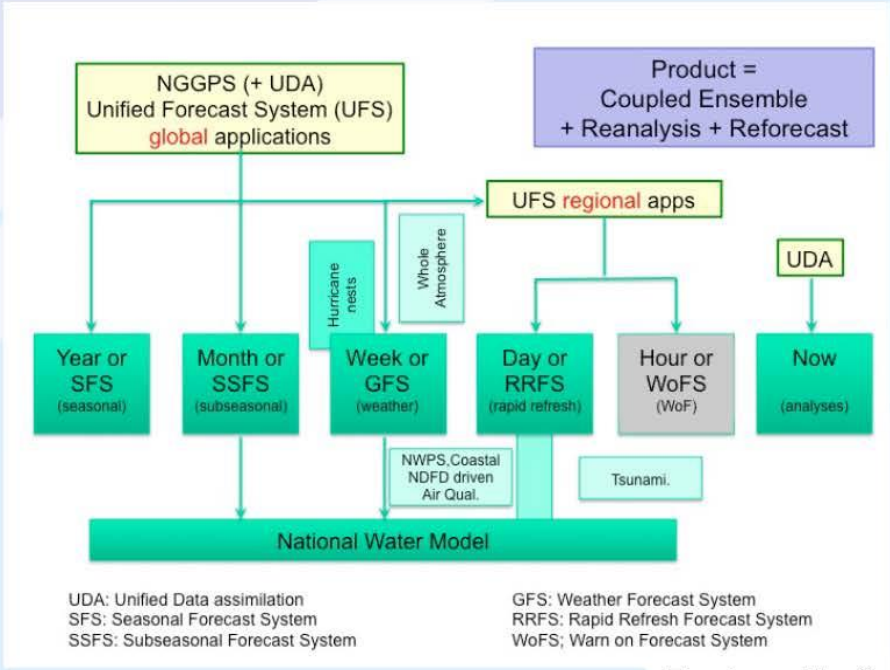
Roadmap: Big Picture

Moving from atmosphere focus to holistic environmental approach

Roadmap Fig. 1



… we will move to a product based system that covers all present elements of the productions suite in a more systematic and efficient way



Starting from the quilt of models and products created by the implementing solutions rather than addressing requirements ….

Roadmap Fig. 2

Presented by Timothy Schneider at NOAA testbeds & proving ground workshop, Apr 2018, Kansas City

Roadmap: 5 year "end state"

Focus on transition to Unified System

Roadmap Table 2

Element	Cadence	Range	Resol.*	Ens.	Update	RR
SFS	7 d	9-15 mo	50 km (g)	28	4 y	1979-present
SSFS	24 h	35-45 d	35 km (g)	31	2 y	20-25 y
GFS	6 h	7-10 d	13 km (g)	26	1 y	3 y
RRFS	1 h 6-12 h 6-12 h	18 h 30 h 60 h	3 km (r)	26	1 y	TBD
WoFS	5-15 min	2-4h	1 km (r)	26	1 y	TBD
Analyses						
Trad.	6-24 h	---	Var. (g)	---	6 mo	N/A
RUA	15 min	---	TBD (r)	---	6 mo	

SFS= Seasonal Forecast System
SSFS= Sub-Seasonal (Outlook) Forecast System
GFS= Global Forecast System
RRFS= Rapid Refresh Forecast System
WoFS = "Warn on Forecast" System
RUA = Rapidly Updating Analysis

(g) Global
(r) regional
Red: uncharted territory

Changing use of WCOSS
Needing ~ 37 PFlop machine

*Resolutions for atmosphere, other component models may have different resolutions

Presented by Timothy Schneider at NOAA testbeds & proving ground workshop, Apr 2018, Kansas City

Unified Forecast System – Definition

- Definition of the Unified Forecast System (UFS)
  - Review and contribute to definition at
    - https://tinyurl.com/ufs-def

- Simply put, the Unified Forecast System (UFS) is a **community-based, coupled comprehensive Earth Systems modeling system**. It is a research to operations framework that provides operational numerical guidance in support of NOAA's mission, and serves as a vehicle to support research and development in the community.

- The UFS numerical applications span local to global domains and predictive time scales from hours to one year.

Presented at UFS Steering Committee WG tele-con
Richard Rood and Hendrik Tolman (co-chairs)

NCEP Strategic Implementation Plan (SIP)

- Strategic Implementation Plan (SIP) for a Community-based Unified Modeling System has been developed
- The overall goal is to create a multi-year implementation plan to document the effort of the community participants that will work together to evolve the NGGPS UFS towards a n **unified Earth system modeling system for operations and research**, to the mutual benefit of both
- Working groups on system architecture, infrastructure, dynamics and nesting, model physics, data assimilation, convection-allowing models, marine models, land surface models, aerosols and atmospheric composition, ensembles, post-processing, and verification

https://www.weather.gov/sti/stimodeling_nggps_implementation

Transition Plan for Global FV3-Chem (FY2017-2020)

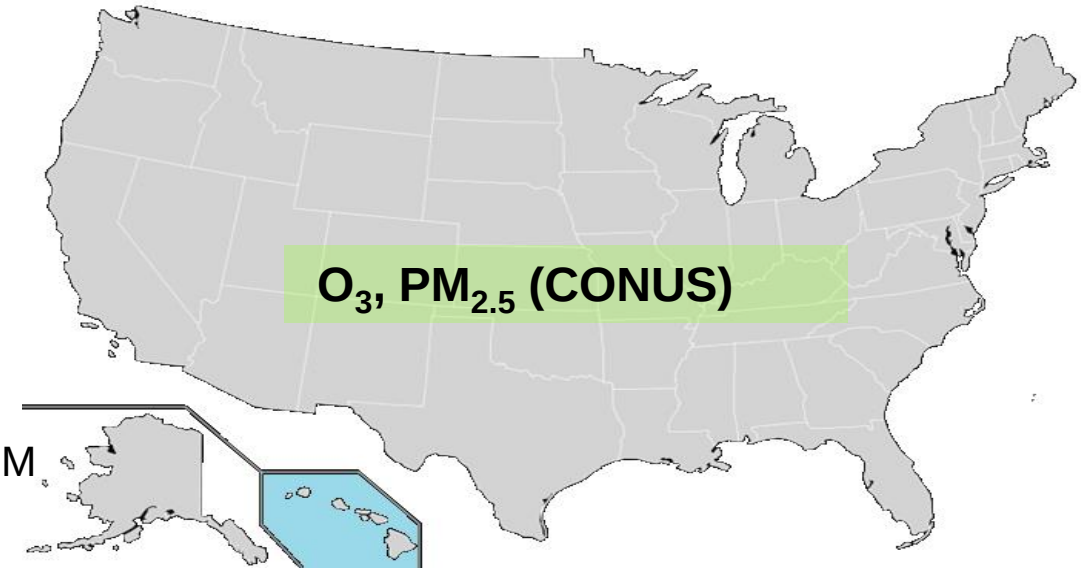
FV3Chem	FY17				FY18				FY19				FY20			
	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
FV3-Chem Development			Develop NEMS coupler and chem component and test C96 global FV3-Chem													
Glb FV3-Chem Configuration		Configure global FV3-Chem, resolution, coupling physics/dynamics, and increase horizontal resolution to C384L64														
FV3-Chem Data Assimilation development							Produce 1-year reanalysis with VIIRS AOD assimilation into GSI for FV3-Chem									
FV3-Chem Evaluation								Finalize FV3-Chem configuration* & perform 1 yr retros and real-time runs								
Glb FV3- Chem Implementation										Transition glb FV3-Chem into ops						
Reg FV3-Chem Configuration, Evaluation											Configure/Finalize Reg-Chem (CB-VI) w/ Reg-FV3, 2 month retros & real-time runs					
Advancement of FV3-Chem													DA for Global FV3-Chem, incl. nitrates, simple O3 chem			

The SIP plan

- Initial FV3GFS-Chem: 1) Couple with updated FV3GFS physics, dynamics; 2) Increase horizontal resolution to 35 km; and 3) Update GOCART to NASA 2018
- FV3GFS-Chem 35 km will be one member of Global Ensemble Forecast System (GEFS)
- **First Implementation: Fall, 2019**

Current Regional Model
NAM-CMAQ V5.0.2 Offline 12 km

- **CMAQ5.0.2** for **CONUS (Off-line)**
  - CB05 gas chemistry:
    - *Increased from 105 to 155 species*
    - Improved heterogeneous, aqueous, and winter-time reactions
  - From aero4 to aero6 chemistry:
    - Improved SOA and coarse mode PM
  - LBC: Static from GEOS-CHEM + Dynamic dust LBC from NGACV2



Wildfire Emission:

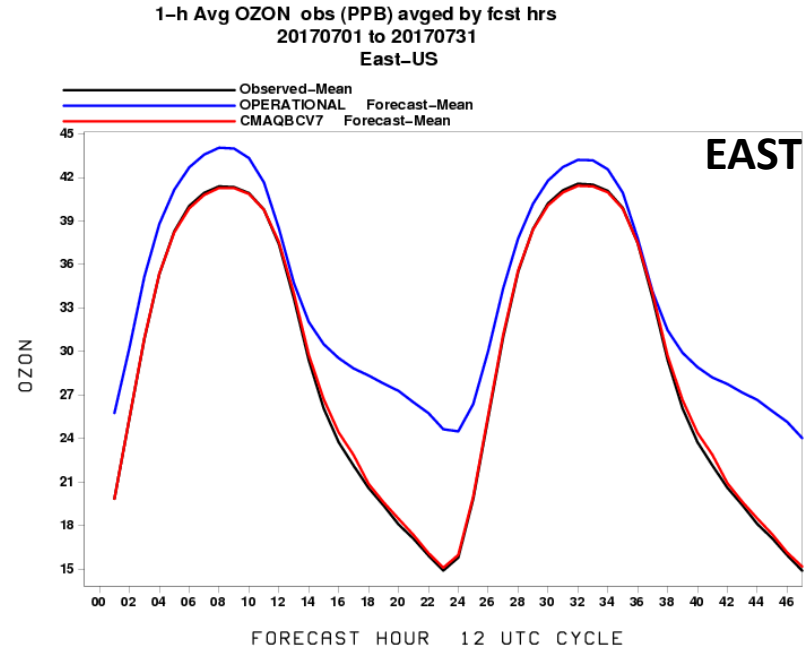
- Updated to latest Bluesky smoke emission system version 3.5.1 from US Forest Service
- Added a 24 h analysis PM cycle for consistent wild-fire smoke initialization with HMS fire info

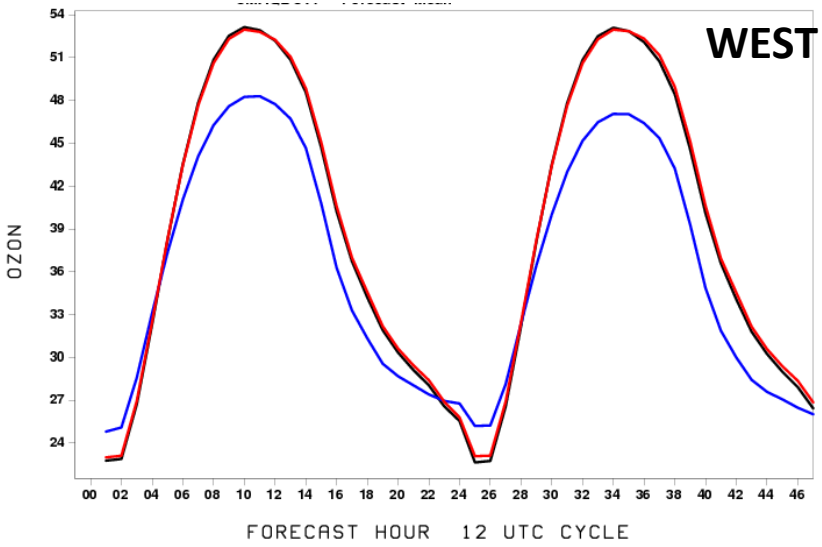
Bias Correction:

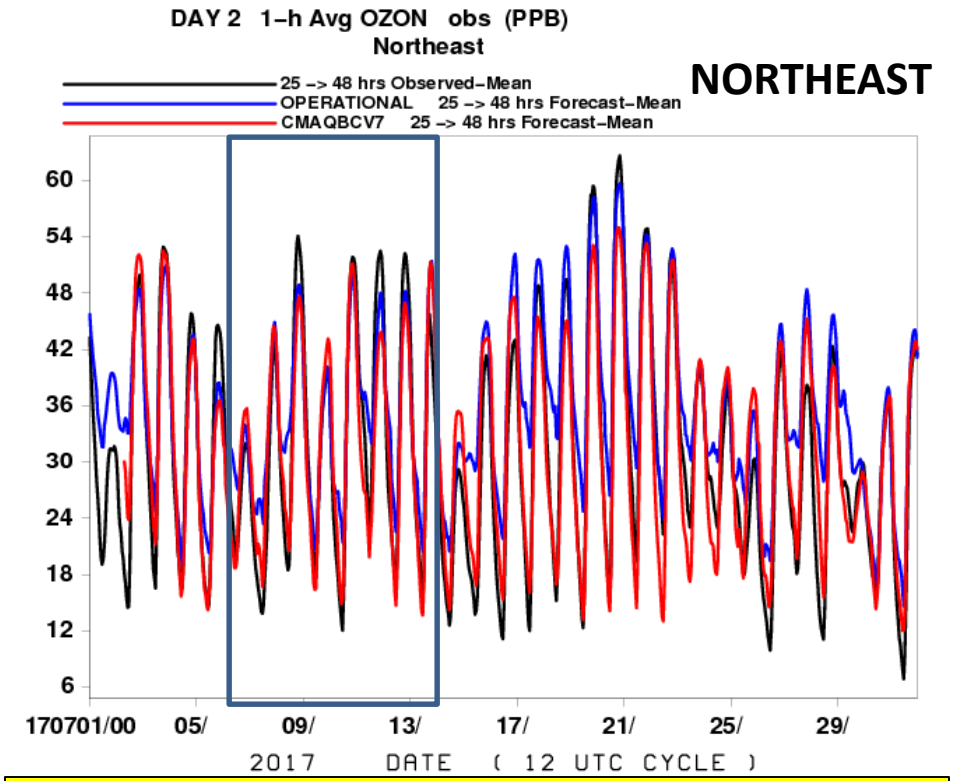
- Upgrade Bias correction to include temporal trends (Kalman Filter Analog technique, ESRL)
  - New output to NDGD & web svcs web site*: bias corrected hourly & daily 24 h avg PM2.5*

Ozone Errors: July 2017

Obs vs Raw vs Bias Corrected







East : Overprediction overall but underprediction for July 10-12 exceedences

West: Continued underprediction

<u>O3 BIAS CORRECTION</u>:

→ Diurnal performance good, overcorrects some events (July 10-12, 18-21)

Regional Atmospheric Composition Modeling Plan

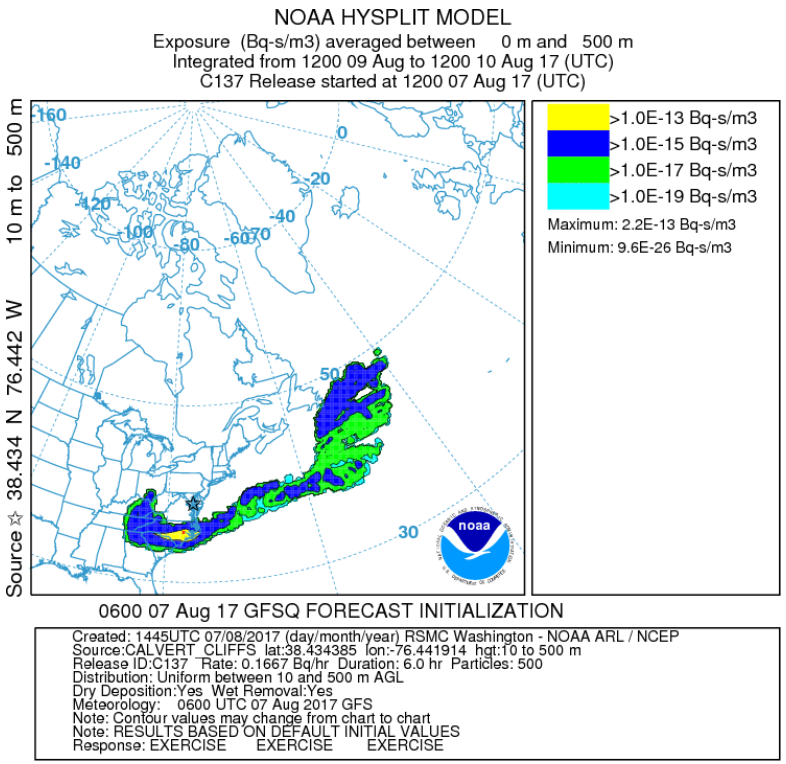
Implementation Plan for Regional AQ (FY2017-2020)

	FY17				FY18				FY19				FY20			
	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
U.S. NAM-CMAQ V5.1 DT&E			DT&E Regional NAM-CMAQ V5. updated emissions, EC/diurnal smoke, ozone bias correction, Implement													
Transition & Implement CMAQ V5.1/ update emissions									Emission update (NEI2014 mobile), CMAQ V5.2							
FV3-Chem Development			ESRL develop NEMS coupler and chem component													
FV3- Chem Regional configuration						Optimize emiss (CEDS)/regional chem config										
FV3-Chem Regional test							Test offline vs inline FV3-CMAQ for 1 summer and 1 winter month (V5.2/72h)									
Reg FV3-Chem Evaluation								Finalize FV3-Chem configuration* & perform retros and real-time runs								
Advancement of FV3-Chem													Further advancements of FV3-Chem and implementation of Regional FV3-Chem 10 km			

* Proposed changes for Reg FV3-chem(CB-VI): 1) Couple with advanced physics with reg. stand-alone FV3; 2) Test inline and offline approaches; 3) Update emissions to current year

HYSPLIT Semi-Lagrangian Dispersion Model on-demand

- Volcanic Ash, WMO/RSMC radiological particles
  - Monthly RSMC ex
  - WMO region IV (Americas)
  - GFS ¼ degree to 72 hrs
- Testing
  - FV3GFS 13 km
  - Transfer Coefficiants Matrix
  - VIIRS Ash DA



https://www.ready.noaa.gov/HYSPLIT.php

NGAC V2 Global Emissions: Target for FV3Chem

- NCEP uses GMAO's emissions data sets except for smoke emissions (GBBEPx)
- Dynamic sources (wind-speed dependent) are considered for DMS, dust, and sea salt
- Emissions for SO2 and carbonaceous aerosols are from anthropogenic and nature emission

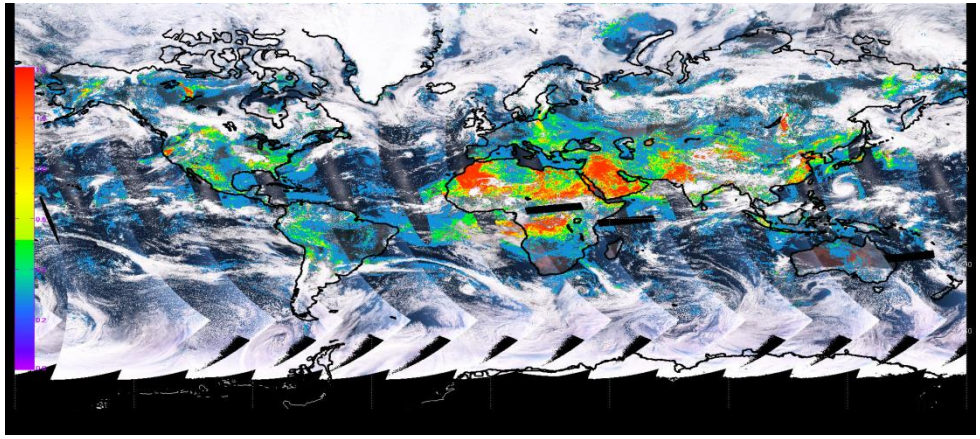
Aerosol type	Sources	Temporal Resolution
Dust	Wind-driven emissions with Ginoux et al. (2001) static topographic depression map	Model
Sea Salt	Wind-driven emissions	Model
Biogenic terpene	Guenther et al (1995)	Monthly-mean climo.
Di-Methyl Sulfide (DMS)	Lana et al. (2011)	Monthly-mean climo.
Biomass Burning (SO2, OC, BC)	**GBBEPx (Zhang et al., 2012)**	Daily
Anthropogenic SO2	EDGAR V4.2 (Duncan et al. 2003)	Monthly-varying
Anthropogenic SO4, POM and BC	AeroCom Phase II (HCA0 v1, Diehl et al. 2012)	Annually-varying
International Ships SO2	EDGAR V4.1 (European Commission, 2010)	Annually-varying

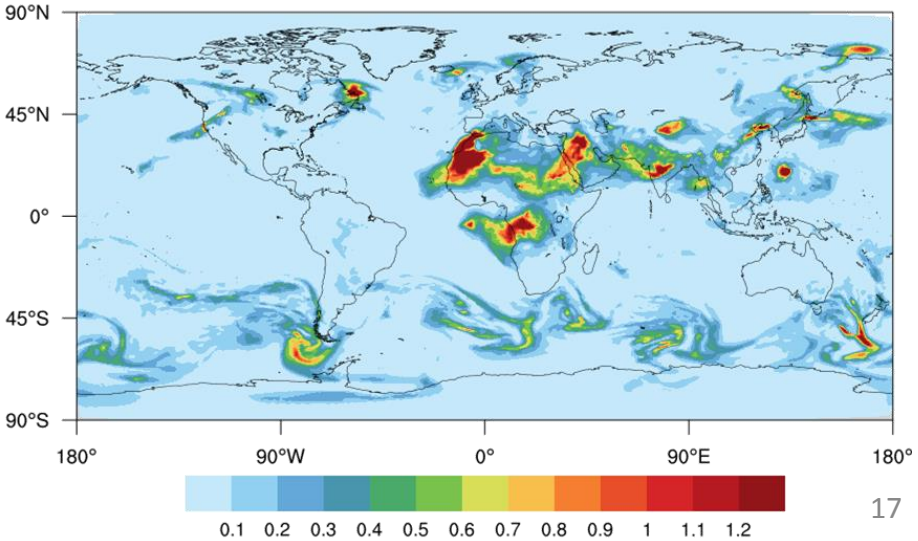
Towards replacing GFS based NGAC with NGGPS/FV3 based NGAC

Current work in progress at NOAA-ESRL/GSD & NWS/EMC

- Coupling FV3 with GOCART aerosol modules using National Unified Operational Prediction Capability (NUOPC)
- Hybrid data assimilation approach (GSI + EnKF) already exists for older inline version – movingdirectly to NUOPC version
  - AGU Poster: Assimilation of satellite AOD to improve aerosols forecasts with FV3-GOCART by **M. Pagowski,** A. daSilva, G. Grell, S. McKeen, and S. Kondragunta:
- Near future: Coupling EPA CMAQ modules(CB-VI, AERO-6 chemistry) using NUOPC

Example of FV3-GOCART runs before using NUOPC: Assimilation of Neural Net Retrieval observations with EnKF (bias corrected AOD derived from AVHRR and MODIS radiances)





FV3GFS-Chem Status

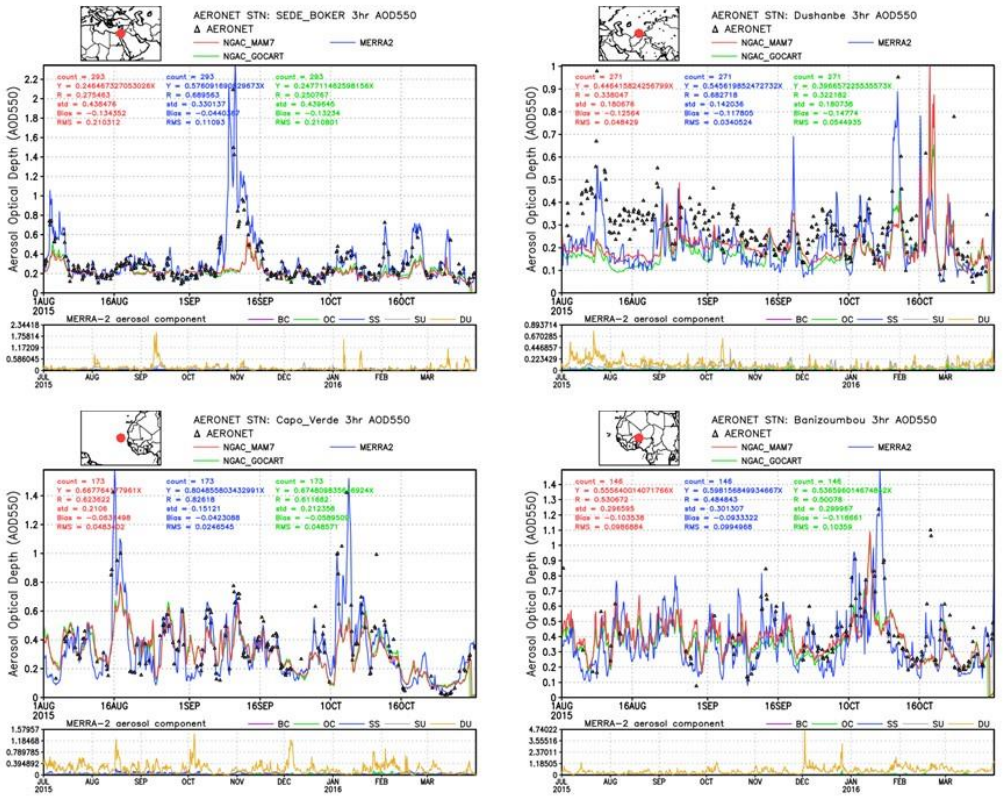
- ESRL's version of the NASA Goddard Chemistry Aerosol Radiation and Transport (GOCART old version) model implemented in WRF/FIM-Chem and FV3GFS-Chem
- Simple sulfur chemistry
- Hydrophobic and hydrophilic black and organic carbon
- 4-bin sea salt module (old version of GOCART)
- 5-bin dust modules (AFWA model)
- Dry and wet deposition
- Wildfires modeling using Fire Radiative Power (FRP) data from MODIS measurements, plume rise modeling with 1d clouds → Compare to NGAC operational NESDIS GBBEPx smoke emissions

Currently GSD/EMC testing C96L65→ Goal: C384L65 35 km

Collaborative projects with FV3-chem

Project	Lead	Funding source	Delivery
Chem component using NUOPC cap	OAR/GSD	NGGPS	Oct 2017→Mar 2018
Test FV3GFS - GOCART w/ NUOPC cap	OAR/GSD	NGGPS	Dec 2017 → June 2018
Provide global CEDS anthropogenic emissions	OAR/CSD	NGGPS	July 2018
Verify FV3-GOCART w/ ATOM aircraft Data	OAR/CSD	NGGPS	Dec. 2018
Couple MAM-7 aerosols module	SUNY/Albany	CPO	FY19
Develop simple gas-phase chemistry	NESDIS/CIMMS	NGGPS	FY19
Develop improved dust module	OAR/ARL	JPSS	FY20
Implement CMAQ CB-VI/Aero-6 chemistry	OAR/GSD & EPA	USWRP	FY20

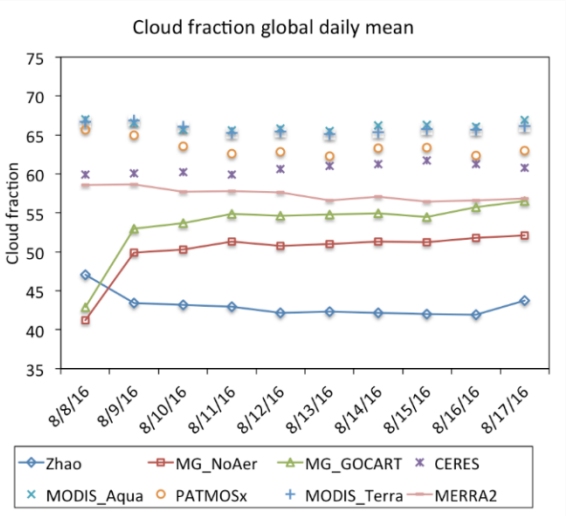
NGGPS Aerosol-cloud interaction



Time series of AOD at 550 nm from GOCART (green), MAM-7 (red), MERRA2 (blue), and AERONET observations (black) at 4 AERONET sites. The lower panel displays aerosol composition from MERRA2.

Global-mean cloud fraction from three model runs are compared with reanalysis and satellite-derived cloud products (right panel). Low biases in cloud fraction is improved as cloud microphysics is upgraded and cloud-aerosol interaction is accounted for.

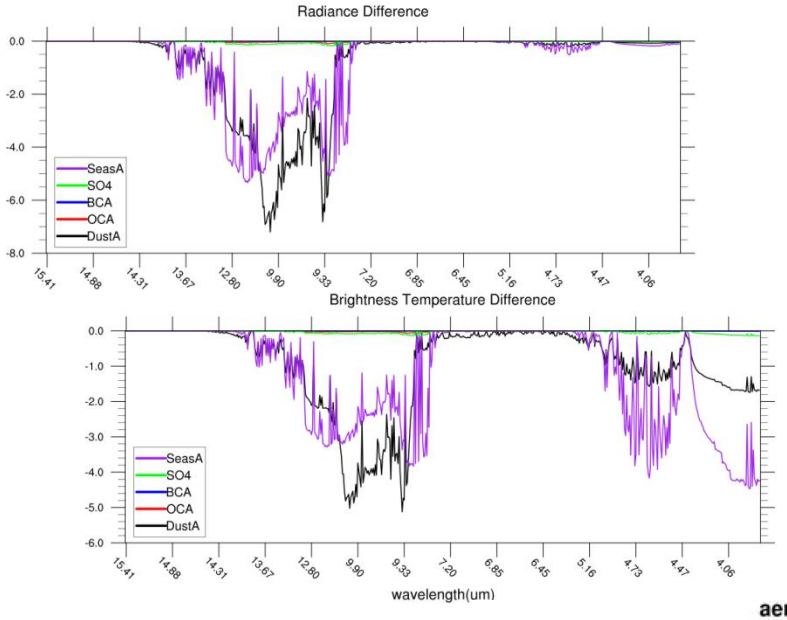
Modal Aerosol Model (MAM-7) is implemented and compared with GOCART (left panel). Both MAM-7 and GOCART capture Africa dust storms well but fail to capture mid-Sept dust outback in mid-East. For Asia, MAM-7 and GOCART simulated AOD is consistently lower than observations.



The MAPP/NGGPS joint project is led by S. Lu (SUNYA) in collaboration with NCEP (Y. Hou, S. Moorthi, F. Yang, J. Wang) and GSFC (A. da Silva, A. Darmenov, D. Barahona). This project aims to improve the representation of aerosol processes, cloud microphysics and aerosol-cloud-radiation interaction in NCEP global models. GSFC's physically-based aerosol and cloud microphysics package are implemented into NEMS (NOAA Environmental Modeling System) physics suite.

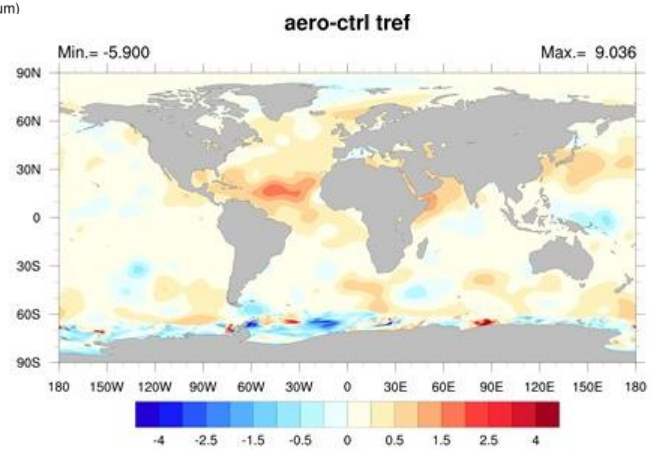
NGGPS Aerosols on satellite radiance

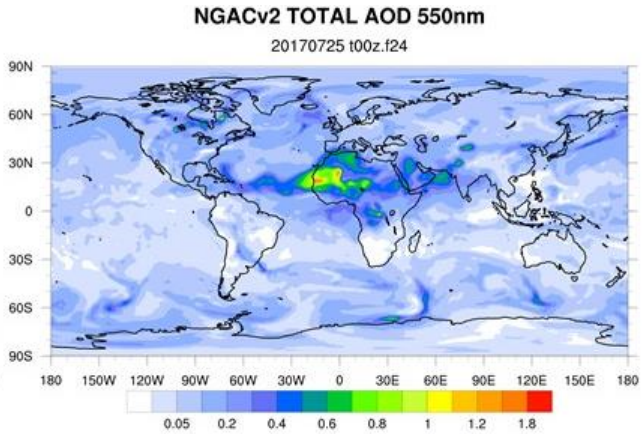
Differences (Aer-Ctr) for IASI/Metop-A



Results of CRTM (Community Radiative Transfer Model) experiments (left panel) show that dust and sea salt aerosols have significant impact on radiance and brightness temperature calculations at the longwave window channels.

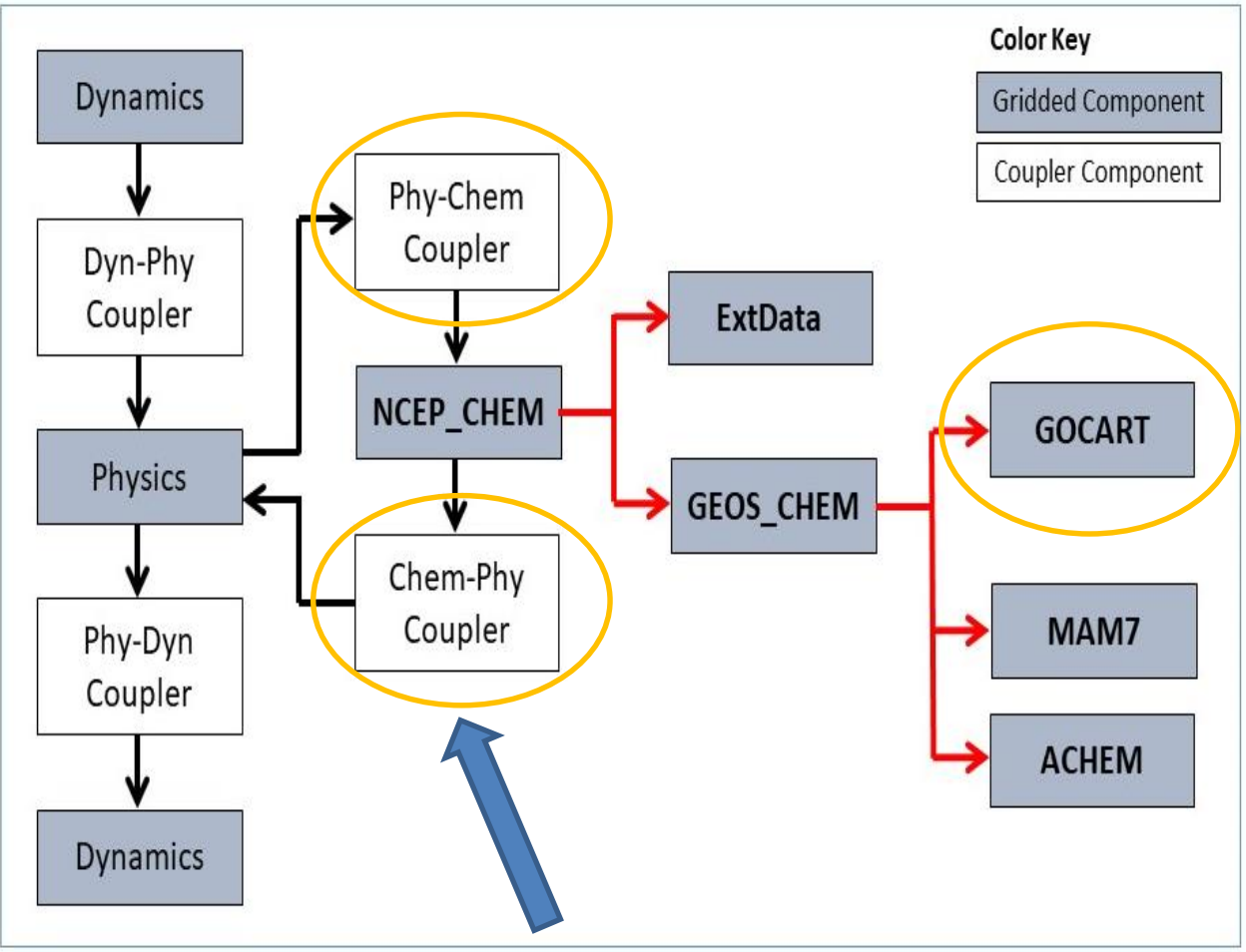
Fully-cycled GDAS (Global Data Assimilation System) experiments are conducted. The foundation temperature (T_f, the oceanic analysis variable determined by satellite radiance and in situ buys and ships observations) and AOD (aerosol optical depth) fed to GDAS are displayed below. Increased analysis surface temperature field is found over tropical Atlantic Ocean while decreased temperature field is found over Antarctic region.





The NGGPS R2O project is led by S. Lu (SUNYA) in collaboration with NCEP (R. Grumbine, A. Collard, J. Wang, P. Bhattacharjee, B. Katz) and STAR (Q. Liu). This project aims to investigate how much complexity is needed to accurately represent the aerosol processes and effectively account for aerosol effects. The impact of aerosols on radiance calculations and sea-surface-temperature (SST) analysis is investigated.

Implementation of MAM7 into NEMS GSM, funded by CPO MAPP-CTB program



NUOPC ESMF coupler: developed to couple FV3 with GOCART

- An ESMF component **FV3-Chem** is created to wrap around Chem and FV3 dynamics/physics
- **GOCART and (MAM7 is in GSM-NGAC)** are tested. Other chemistry modules are compiled as stub.

Courtesy Sarah Lu, SUNY-Albany

Aerosols & Atm. Comp. WG
Key issues to resolve

- Challenges:
  - Architecture for coupling of aerosols/composition and meteorology
  - Operational efficiency constraint vs complexity for research applications
- Science issues:
  - Consistent representation of atm. composition across scales (LBCs)
  - Various methods for representing aerosols (modal, sectional)
  - Evaluation protocols for adoption/support of new capabilities
  - Two-way coupling of aerosol, gaseous species with physics and meteorological data assimilation
  - Where to perform vertical mixing, deposition (physics/chem component)
- Barriers:
  - Inconsistent emissions databases
  - Limited resources for transition to operations, maintenance, support of multiple prediction options and maintenance of emissions databases

Presented at NOAA Community Modeling Workshop, Apr 2017, NCWCP