Development of an operational global aerosol forecast system and its use as boundary conditions for the National Air Quality Forecast System

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NOAA/NWS/NCEP/EMC
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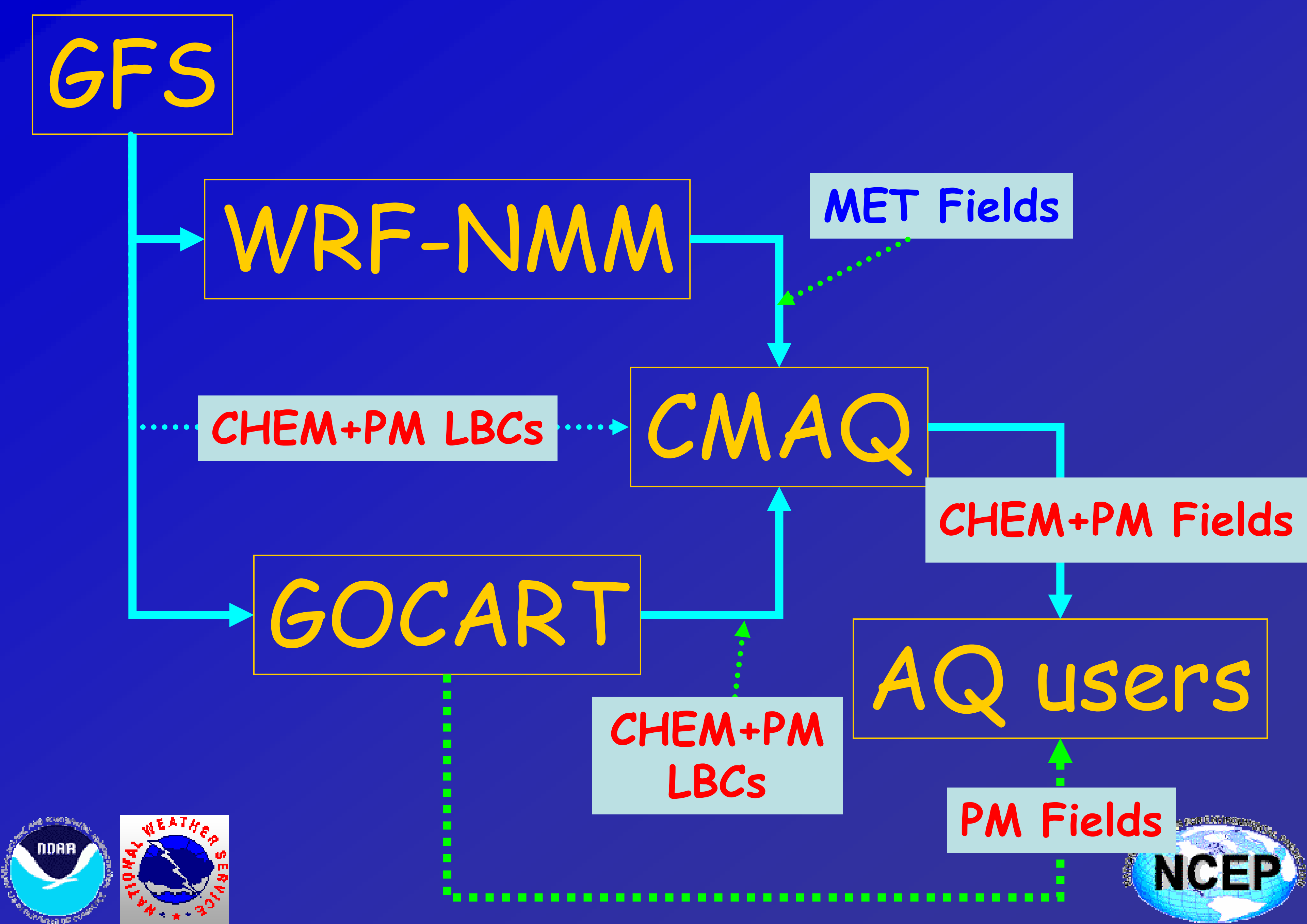
Outline

- Quick overview of the NCEP global dust and aerosol model (GFS-GOCART) development
- Experiment using the NCEP AQF System and GFS-GOCART dust simulations
- Future development

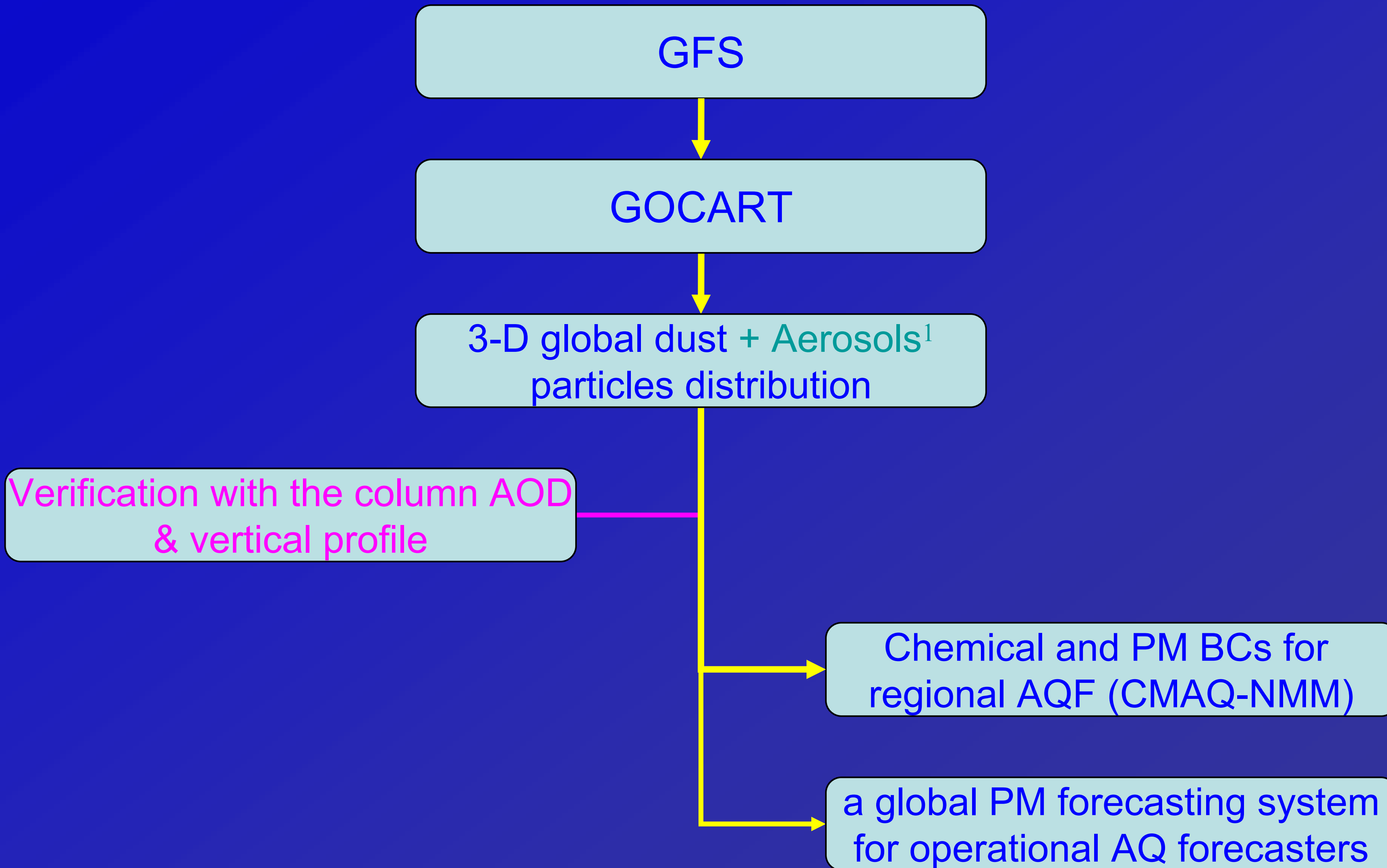

GFS
WRF-NMM
MET Fields
CHEM+PM LBCs
CMAQ
CHEM+PM Fields
GOCART
CHEM+PM LBCs
AQ users
PM Fields
NCEP

GFS-GOCART Offline System

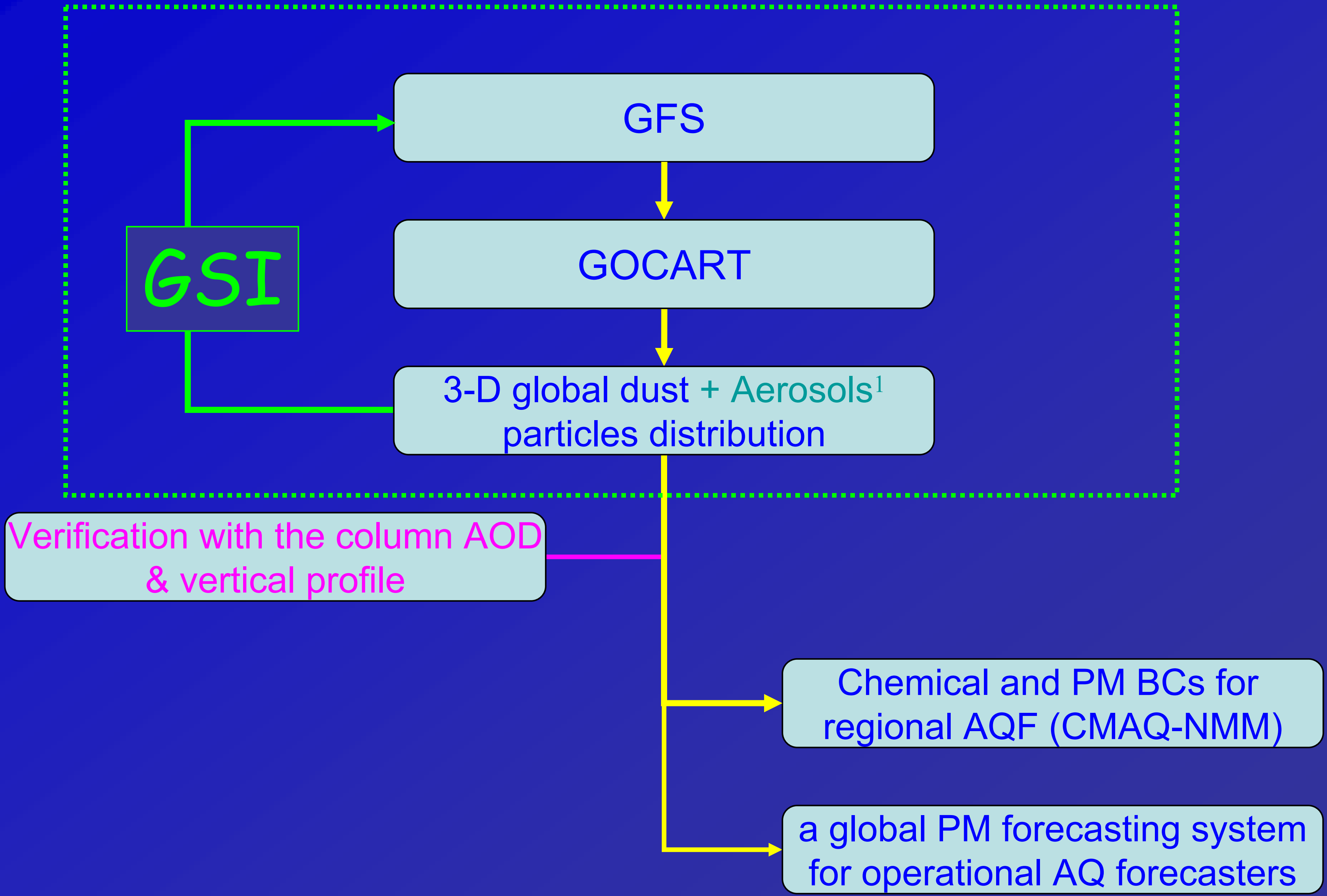
- GFS
  - NCEP/EMC Global Forecast System
- GOCART
  - NASA Goddard Global Ozone Chemistry Aerosol Radiation and Transport Model
- Steps
  - (1) dust modeling
  - (2) aerosol modeling

GOAL

- To serve as an initial benchmark for future inline work
- To provide initial first guess aerosol fields for AQF lateral boundary conditions
- To provide initial first guess aerosol fields for GSI development
- To meet NWS global dust forecasting goals, the WMO global dust warning system.



[1] The aerosol modeling will be added later



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NCEP Air Quality Forecast System (AQF)

- GFS
  - NCEP/EMC Global Forecast System
- WRF-NMM
  - NCEP Weather Research and Forecasting Mesoscale Model Non-hydrostatic Mesoscale Model
- CMAQ
  - US EPA Community Multiscale Air Quality modeling system

GFS-GOCART Aerosols

1. Output concentrations and optical thickness of
   - Dust
     - 0.1 – 1.0 µm   1.0 – 1.8 µm   1.8 – 3.0 µm
     - 3.0 – 6.0 µm   6.0 – 10.0 µm
   - Sulfate
     - SO_2, Sulfate, DMS, and MSA
   - black carbon
     - hydrophobic and hydrophilic
   - organic carbon
     - hydrophobic and hydrophilic
   - sea-salt aerosols
     - 0.1 – 0.5 µm   0.5 – 1.5 µm   1.5 – 5.0 µm   5.0 – 10. µm

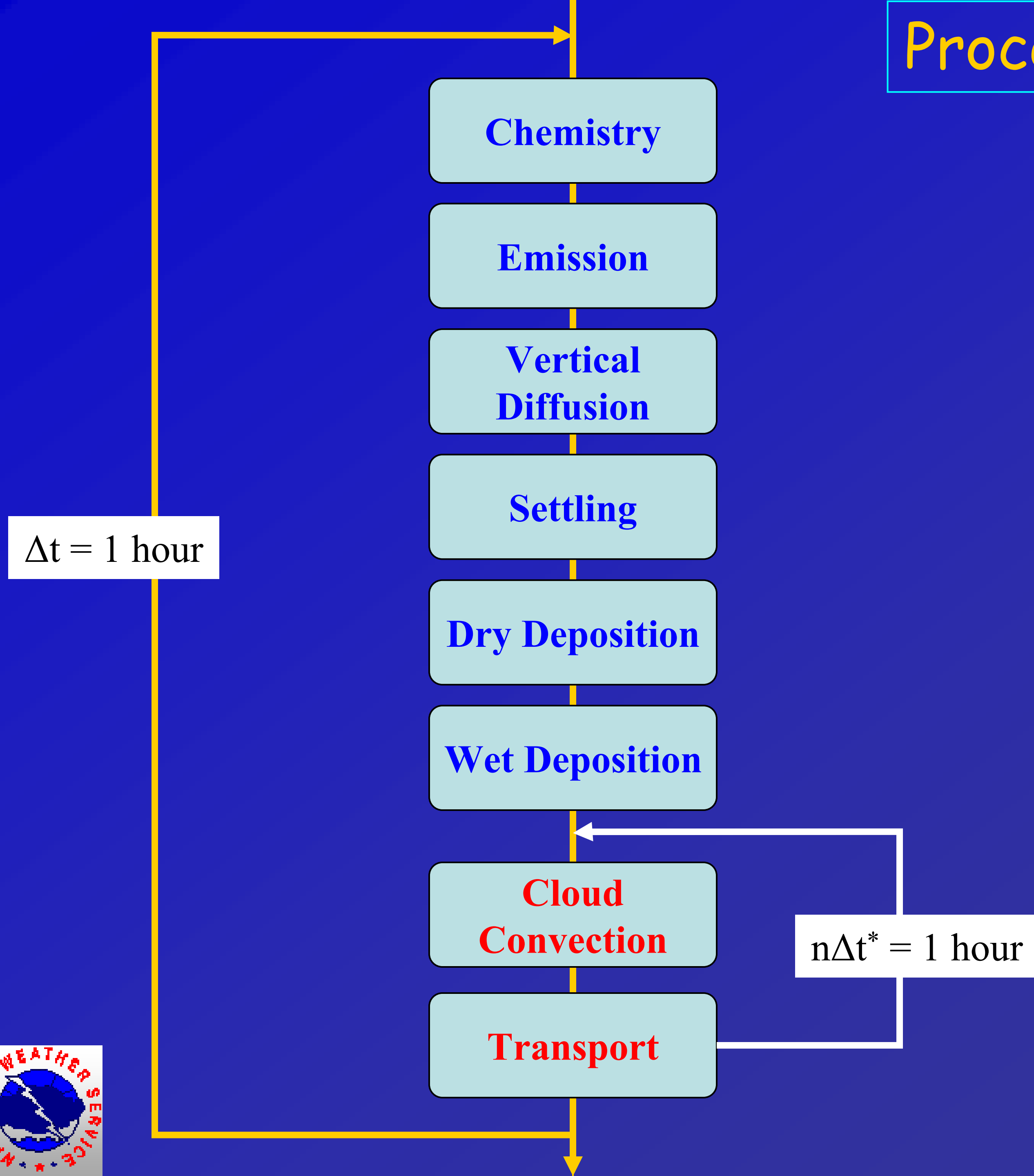
Source Functions

- Emissions:
  - Dust, function of surface topographic depression, surface wetness, and surface wind speed (Ginoux et al. 2001)
  - Seasalt, function of wind speed (Gong et al. 2003)
  - Biomass burning, from Global Fire Emissions Database (GFED2.1 1x1)
  - Volcanic emissions* are from Global Emissions Inventory Activity (GEIA)
  - Anthropogenic emissions (David Streets)

GFS-GOCART Processes

- Advection: flux form semi-lagrangian (Lin and Rood 1996)
- Boundary layer turbulent mixing (2^{nd} closure scheme; Helfand and Labraga 1988)
- Dry deposition: the resistance method (Wesely 1989; Walcek et al. 1986)
- Wet deposition: rainout (Giorgi and Chameides 1986), washout (Dana and Hale 1976), convective scavenging with moist convection (Allen et al. 1996), and evaporation below the cloud
- Simple sulfur chemistry (4 rxns) with prescribed OH, NO_3, and H_2O_2 monthly averaged fields from IMAGES

Processes Called



NCEP Air Quality Forecast System

- CONUS (ozone) became operational model on September 18, 2007
- Developmental model; operational* + PM Chemistry
- CMAQ v4.5 driven by the WRF/NMM at 12 km
- NEI (2001), BEIS3, Mobile 6
- AERO3: Aerosol Module with SOA (no sea salt)
- Updated ISORROPIA for numerical stability at low relative humidity
- Euler Backward Iterative (EBI) Solver for CB4
- Asymmetric Convective Model (ACM-2) PBL parameterizations

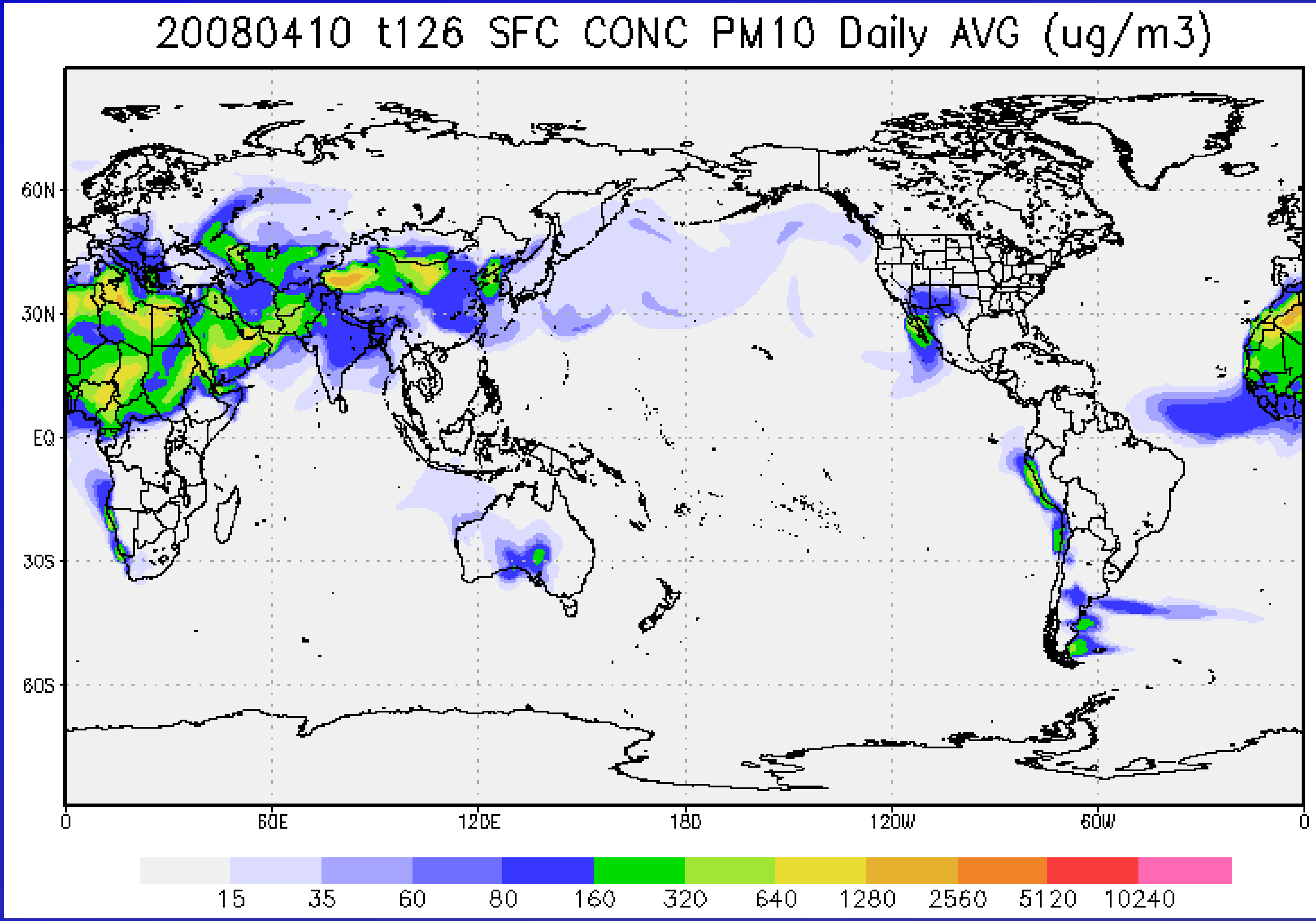
(http://www.cmascenter.org/index.cfm)

Preliminary study on the impact of long-range transport from the Asia dust storm outbreak on the AQF domain

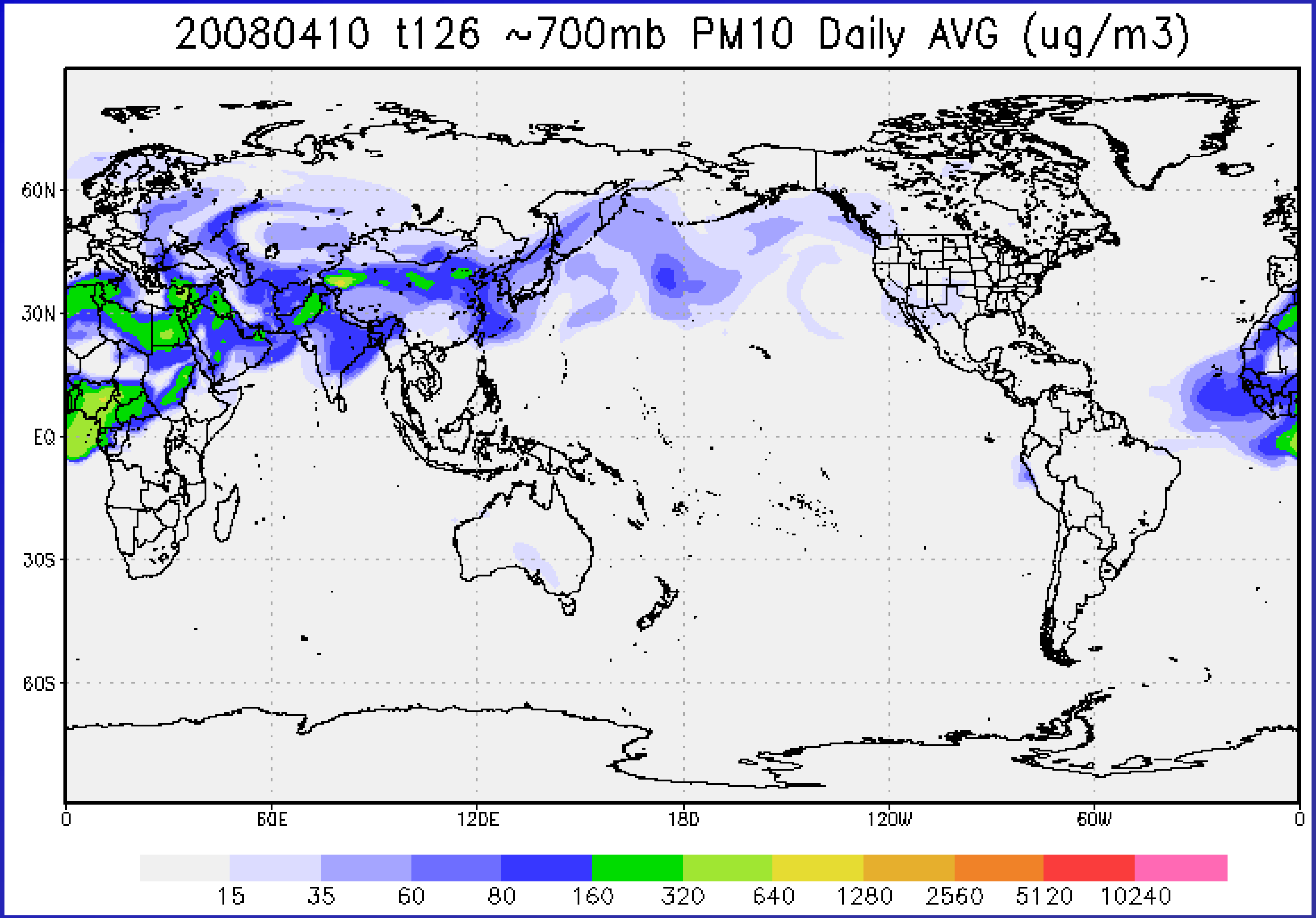
Experiment

- April 1, 2008 to April 10, 2008
  - GFS-GOCART simulation indicates that in early April of 2008 the dust storm occurred in Taklimakan and Gobi desert leads to dust transportation across the Pacific to the North America
- GFS-GOCART dust simulation at T126 resolution (~1°x1°)
- AQF tracer simulation with every 3-hours GFS-GOCART dust LBCs

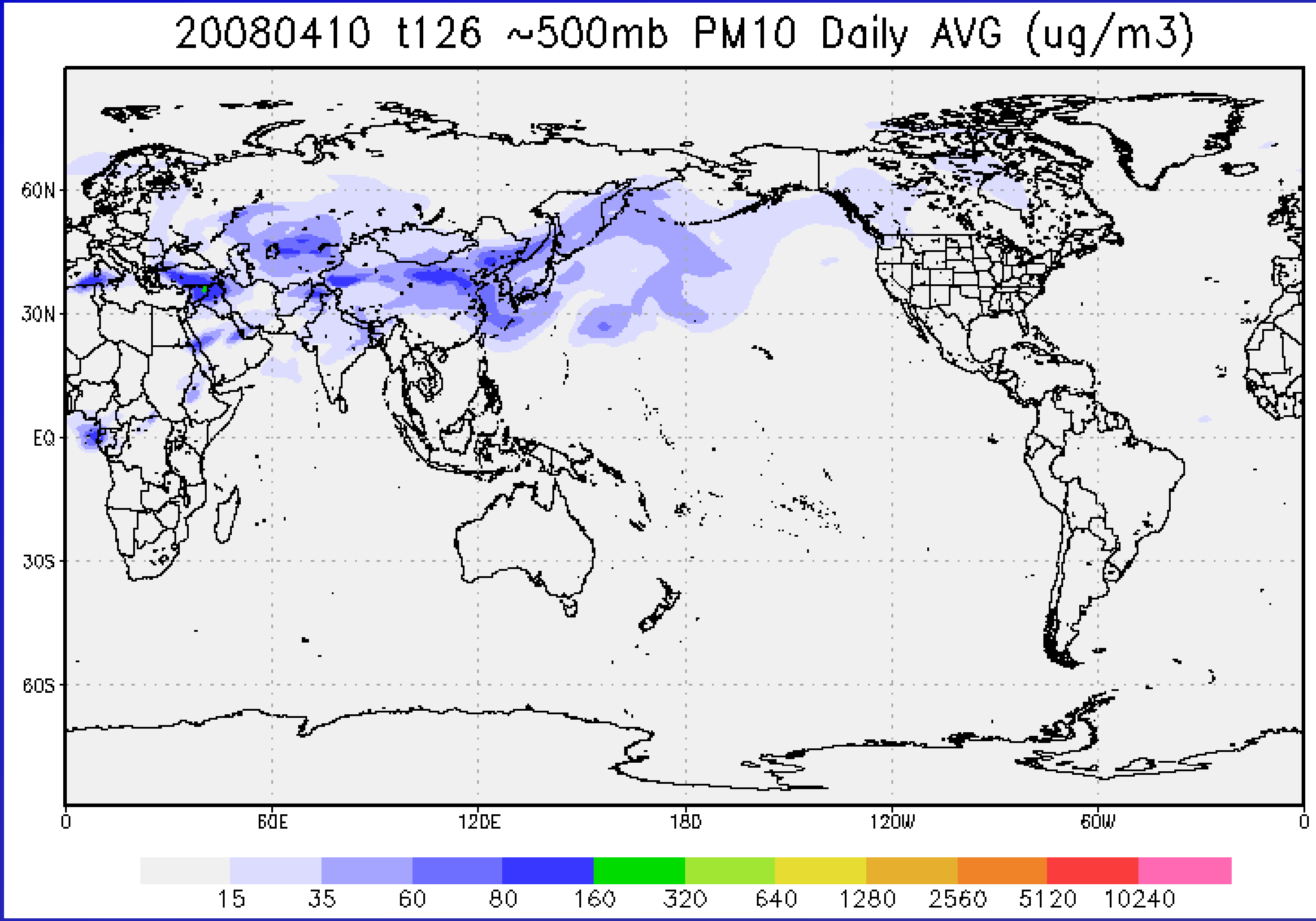
Global Daily Mean Dust concentration (PM10) at Surface Layer



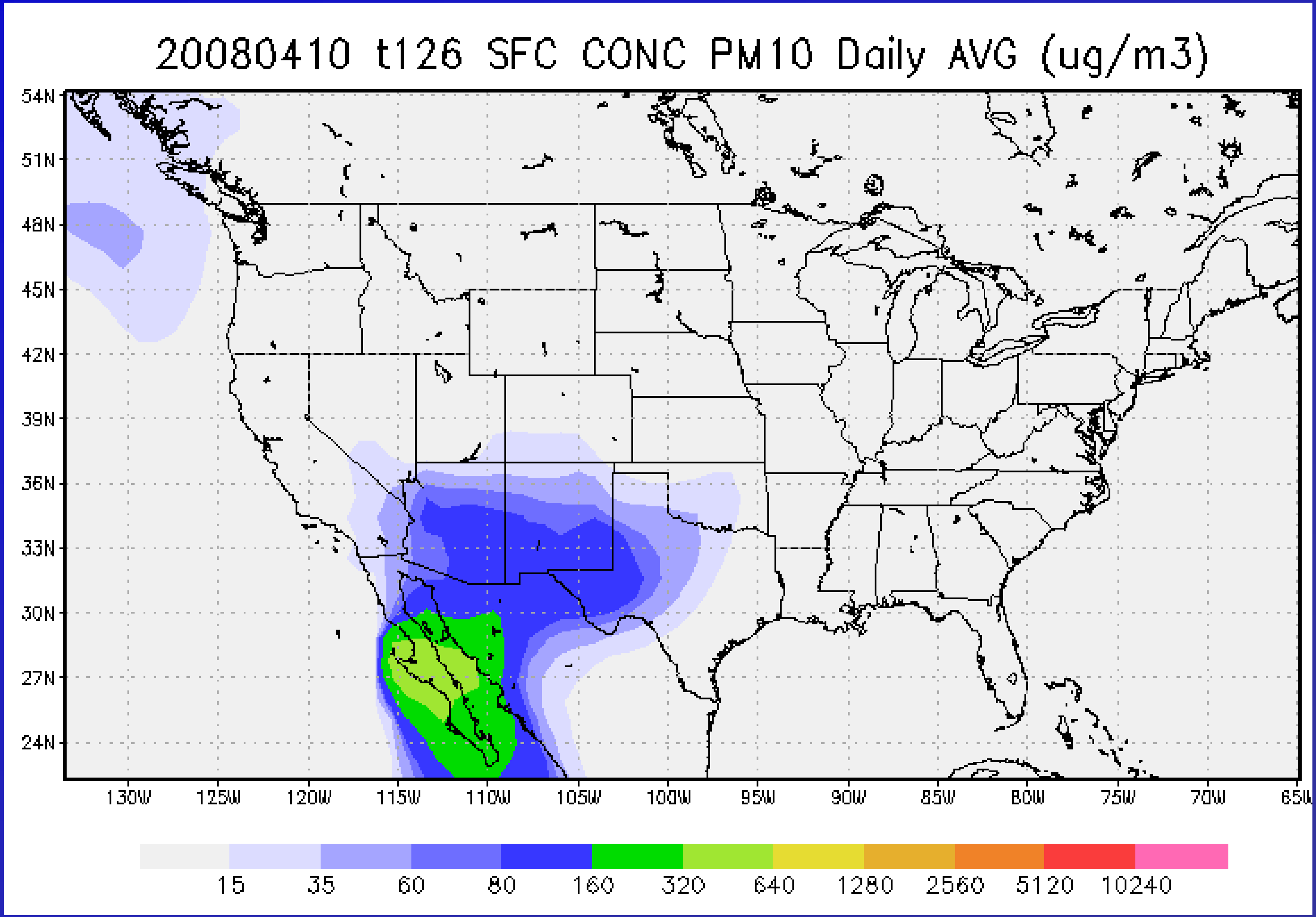
Global Daily Mean Dust concentration (PM10) ~ 700 mb



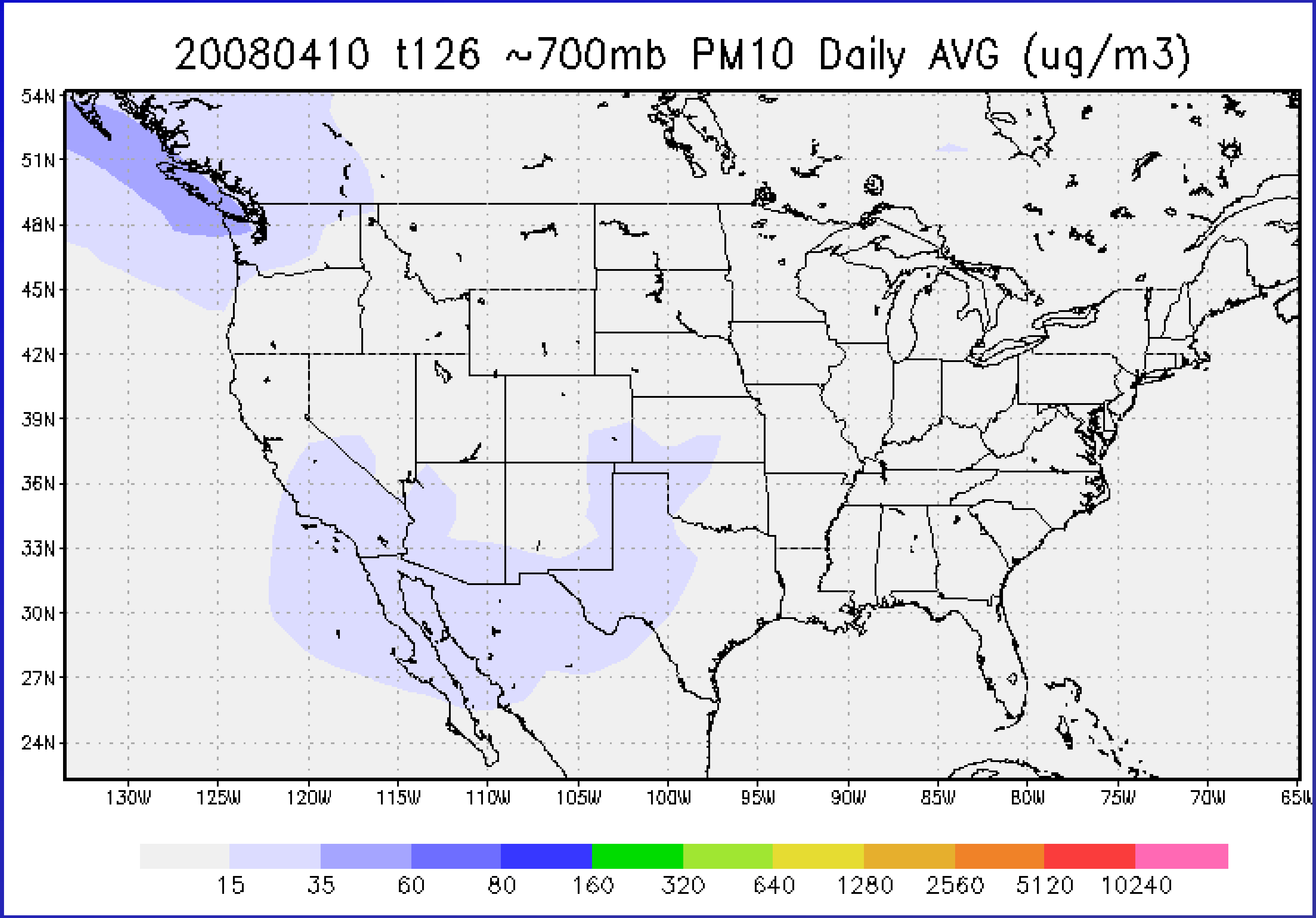
Global Daily Mean Dust concentration (PM10) ~ 500 mb



CONUS Daily Mean Dust concentration (PM10) at Surface Layer



CONUS Daily Mean Dust concentration (PM10) ~ 700 mb



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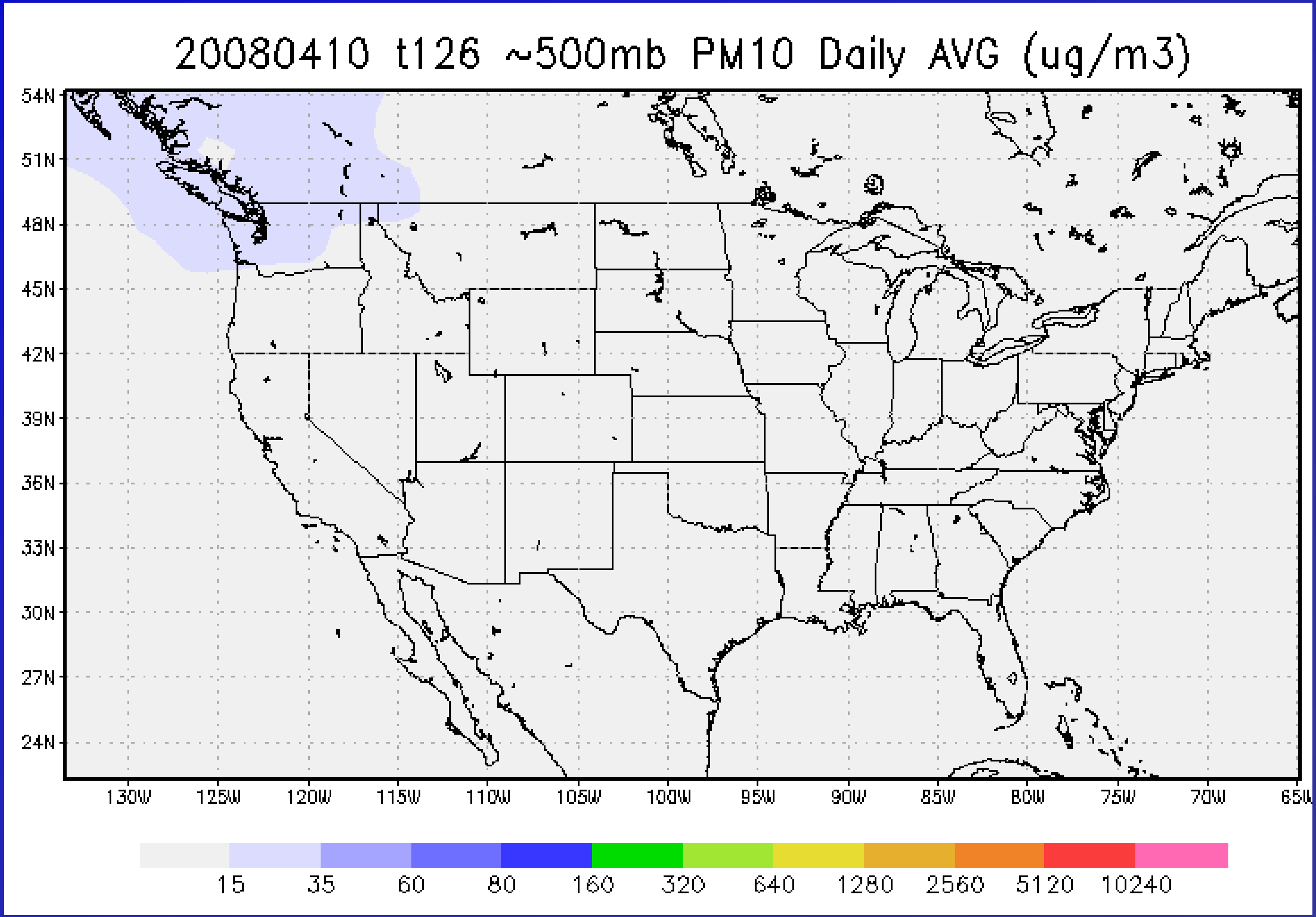
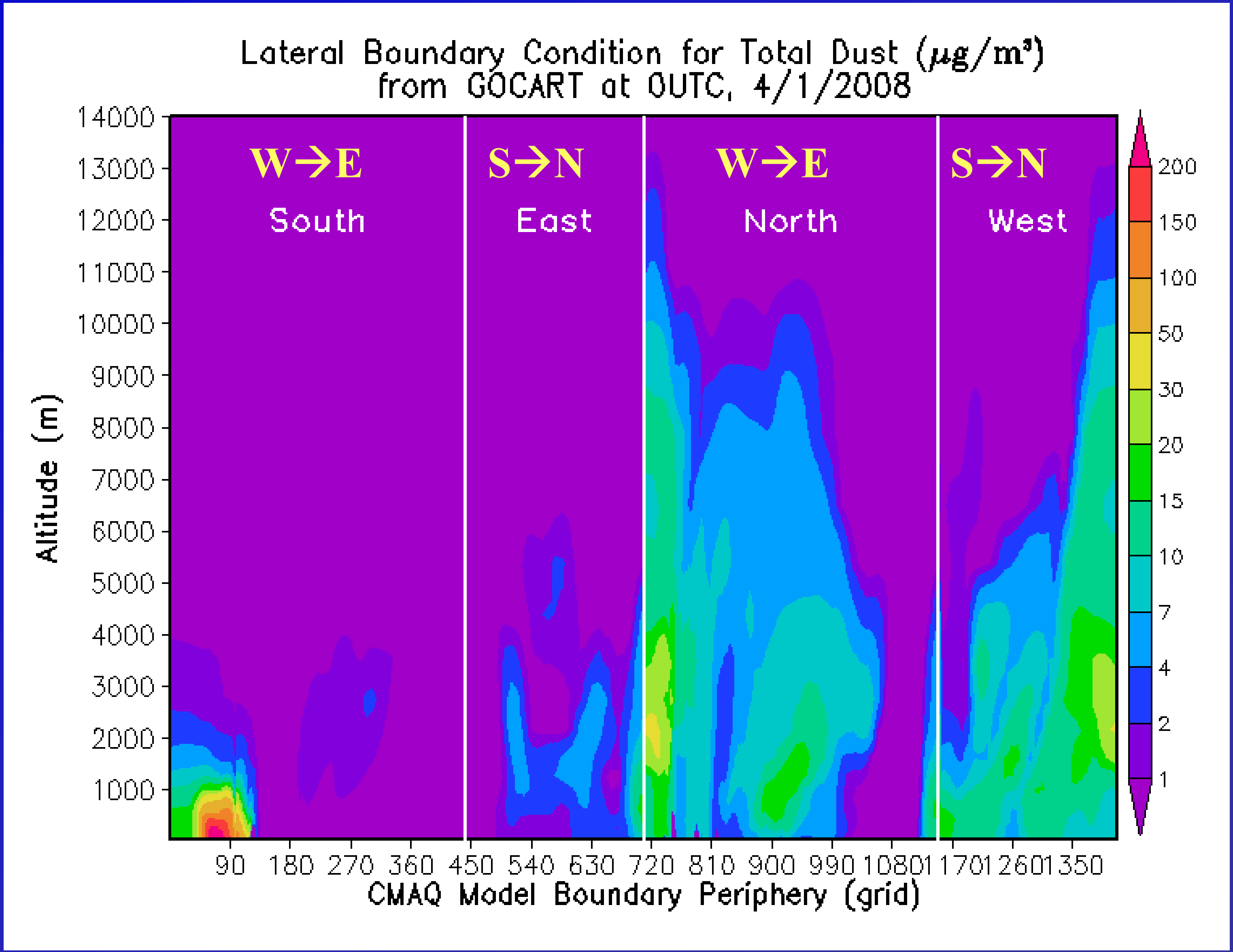
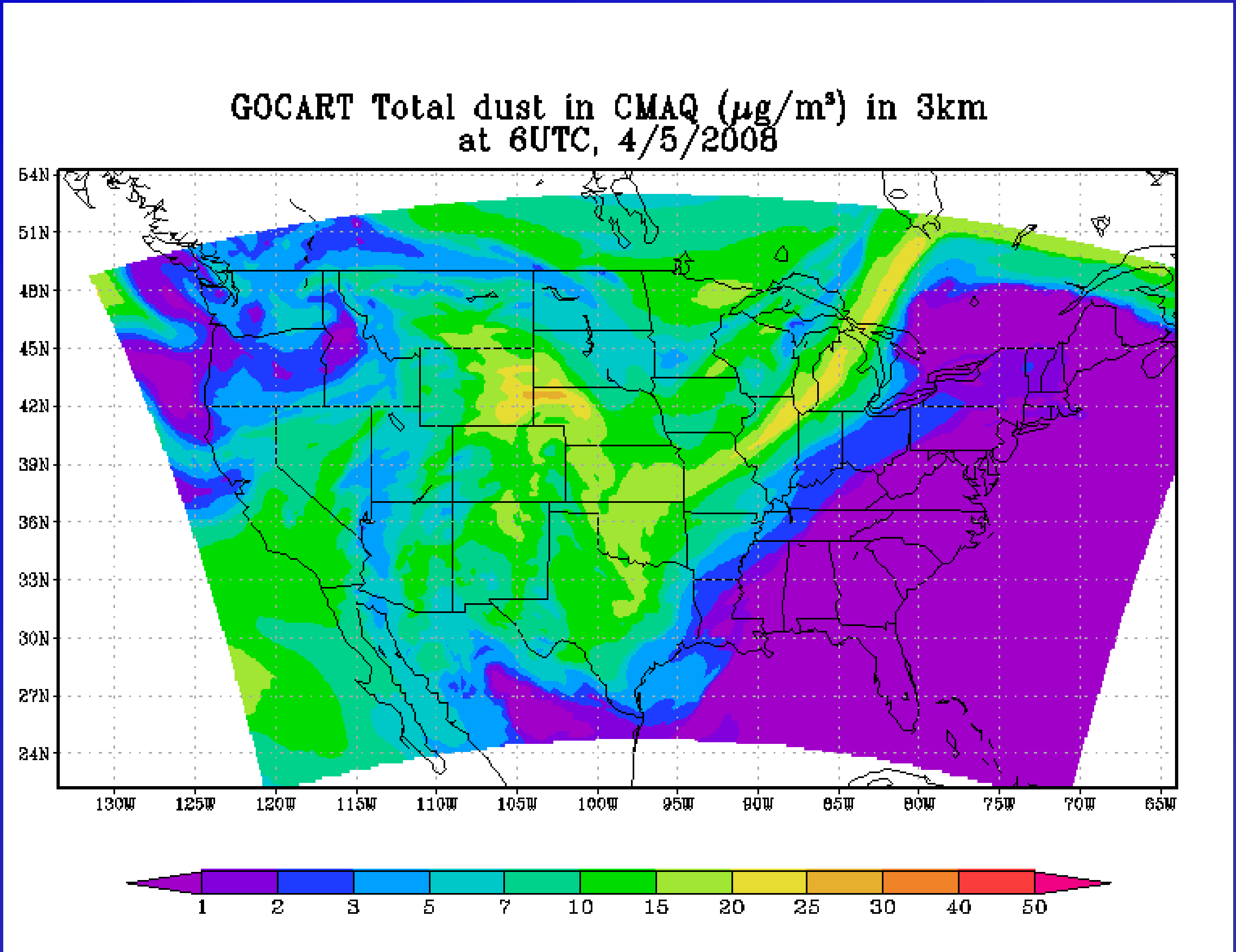


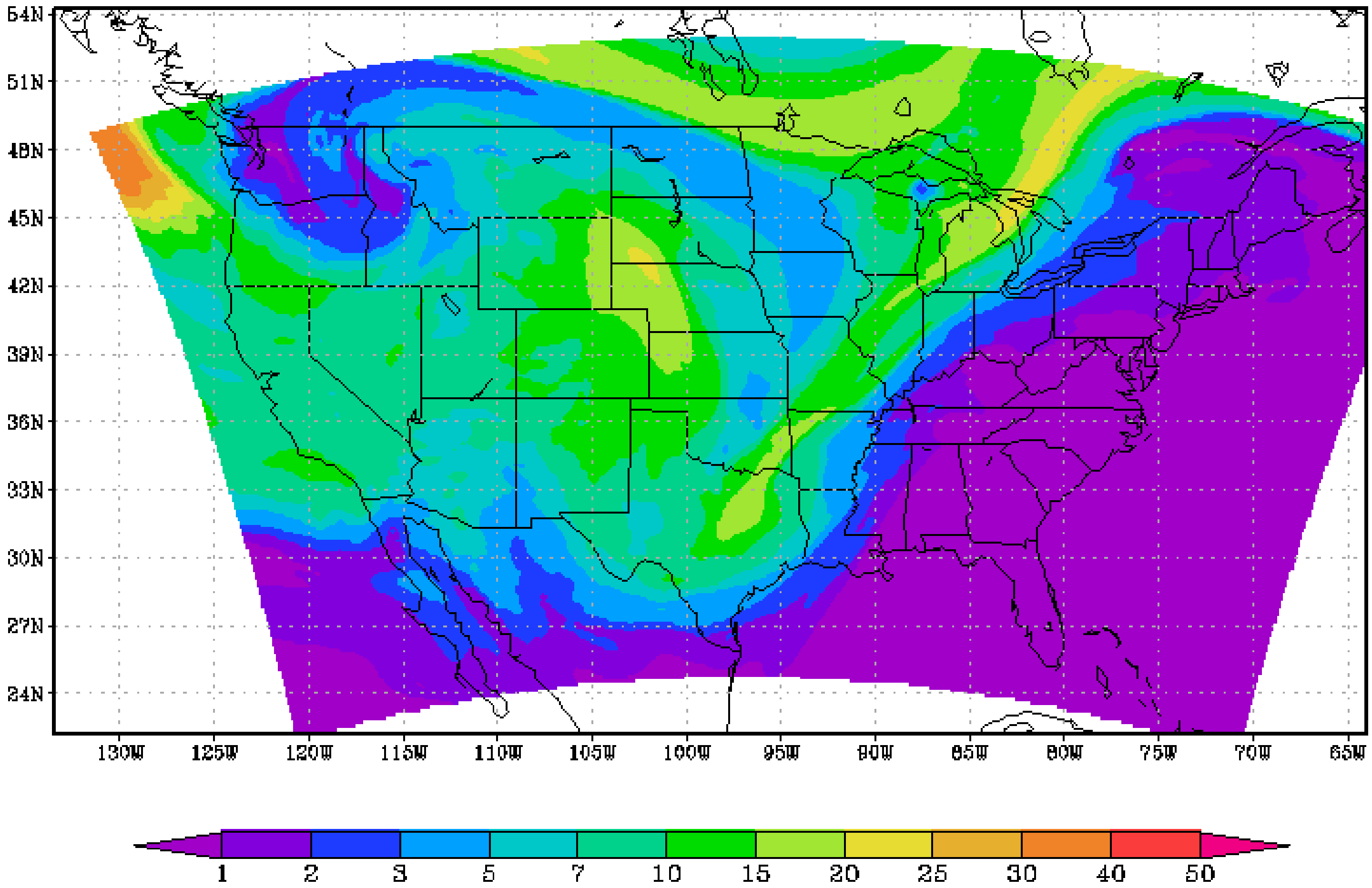


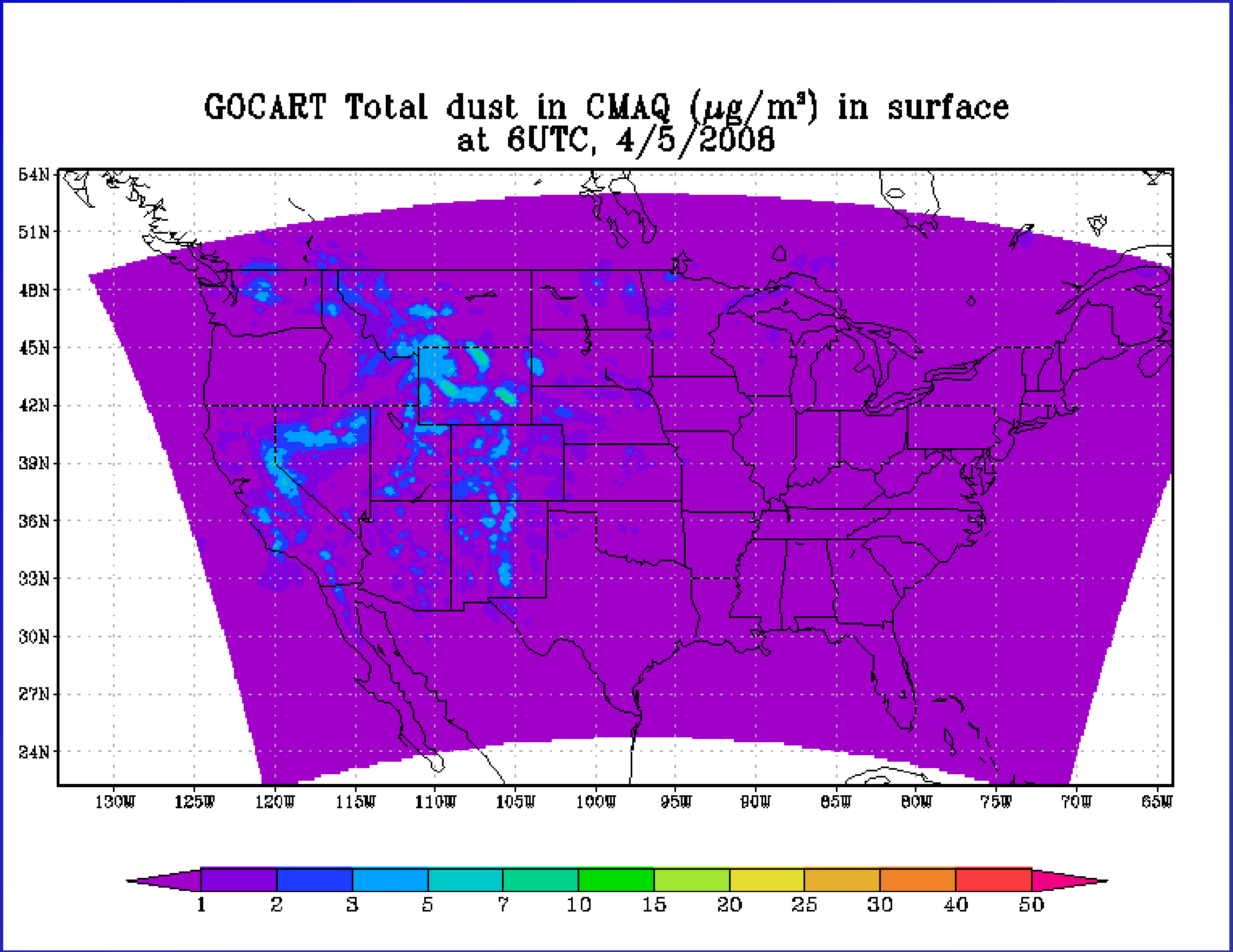
The main dust inflow to the 5X domain is through western and northern boundaries.



The strongest influence of GOCART dust is in the altitude around 3km in this event

GOCART Total dust in CMAQ ($\mu g/m^3$) in 5.5km at 6UTC, 4/5/2008





Surface PM10 enhancement due to GOCART dust can be as high as 20-25 $\mu g/m^3$

SUMMARY

- The offline global dust and aerosol model (GFS-GOCART) is under development at the NCEP
- The AQF simulation with GFS-GOCART LBCs shows the Asian dust intrusion can increase CONUS PM background at the surface
- The main intrusion to AQF modeling domain is through the northern and western boundaries, and low-middle troposphere
- The results showed the diurnal pattern of dust distribution at surface layer, possibly due to connective mixing and the diurnal fluctuation of PBL.
- The upper troposphere shown consistent influence from the northern and western LBCs

Future Development

- Model evaluation and near-realtime verification
  - AERONET*, MODIS*, GOES, OMI
  - Lidar, CALIPSO, OMI-profile
- Improve computation efficiency
  - Parallelize the code
  - Reduce vertical layer (no integration above 200mb)
  - T382 (0.31°x0.31°; ~35km; 1152x576 grids) runs, to understand the benefit of using a higher resolution
- Migrate to near real-time source function
  - Biomass burning emissions derived from MODIS and/or GOES
- More complex but still a simple chemistry
- The real-time observations for the development of the aerosol data assimilation (GSI)

Verification of GFS+GOCART Data Sources

- Total column** aerosol optical thickness (depth)
  - **AERONET** (http://aeronet.gsfc.nasa.gov/index.html)
  - **MODIS** (http://modis.gsfc.nasa.gov, NESDIS)
  - **GOES** (NESDIS)
  - **OMI**

  ** Can not distinguish surface layer aerosol and upper air dust layer
- Vertical profile of extinction coefficient
  - **Lidar** (NOAA/CAS Howard Univ., MPLNET: http://mplnet.gsfc.nasa.gov/); ship- or land-based
    - Aerosol Vertical Structure
    - Aerosol Backscatter, Extinction, and Optical Depth Profiles
  - **CALIPSO** (http://www-calipso.larc.nasa.gov)

Verification

- Possible verification cases
  - Saharan dust events (HU, land- and ship-based lidar)
  - Long distance transport of Asian aerosols and dusts
  - Selected sites in various continents (MPLNET, AERONET, CALIPSO)
  - US air quality campaign; TEXAQS, AEROSE
  - Special lidar observation events, e.g., summer of 2007 at Howard University Greenbelt site (land-based lidar, A-train)
  - Daily real time comparison with NESDIS products

NCEP Global Forecasting System (GFS)

- Spectral triangular 382 (approximately 35 km resolution)
- Hybrid σ-p coordinate, 64 layers from surface to ~ 0.2 mb
- Spectral computation for horizontal discretization, finite difference for vertical discretization with conservations of momentum, mass, potential temperature, and total energy.
- Leapfrog time scheme with semi-implicit in linear forcing.
- Spectral higher order horizontal diffusion.
- Strong wind damping in linear spectral forcing.
- Navy Research Lab ozone physics algorithm (production and destruction are parameterized from monthly and zonal mean dataset derived from NRL 2D ozone chemistry model)
- Non-local boundary layer diffusion scheme (Hong and Pan, 1996)
- Noah Land Surface Model
- Simplified Arakawa and Schubert scheme for convective cumulus parameterization
- SBUV/2 assimilation for stratospheric ozone (above 250 mb).
- 66 min wall-clock time for 7.5 days T382L64 simulation using 13 nodes (32 CPU per node)
- 3D VAR Global Data Assimilation System (GDAS)

http://www.emc.ncep.noaa.gov/gmb/moorthi/gam.html
http://wwwt.emc.ncep.noaa.gov/gmb/gdas

WRF Non-hydrostatic Mesoscale Model

- Hybrid sigma-pressure coordinate.
- The grid staggering is the Arakawa E-grid.
- The model uses a forward-backward scheme for horizontally propagating fast waves, implicit scheme for vertically propagating sound waves, Adams-Bashforth scheme for horizontal advection, and Crank-Nicholson scheme for vertical advection.
- RRTM radiation or GFDL longwave radiation,MM5 short wave
- Noah Land Surface Model
- Mellor-Yamada-Janjic PBL scheme
- Kain-Fritsch cumulus scheme
- Ferrier micro-physics scheme
- 12 km 60 NMM hybrid sigma - pressure levels
- June 2007: Changes to landuse & roughness to address moist biases in Pac NW

(http://www.dtcenter.org/wrf-nmm/users/docs/user_guide/WPS)