Point Reyes NP

# REGIONAL MODELING TO SUPPORT REGIONAL HAZE PLANNING


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## Ramboll Environ


## October 19, 2017

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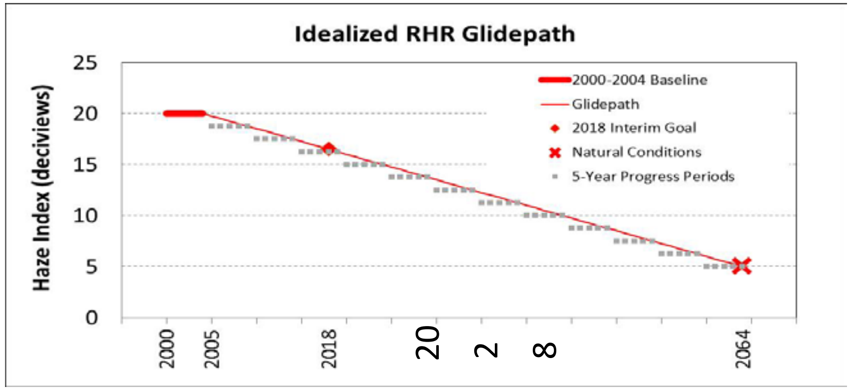
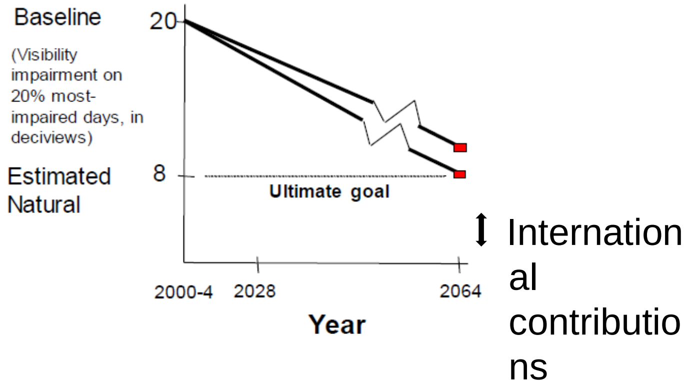
# USES OF MODELING IN REGIONAL HAZE PLANNING

- Modeling Regional Progress comparison to URP Glide Path



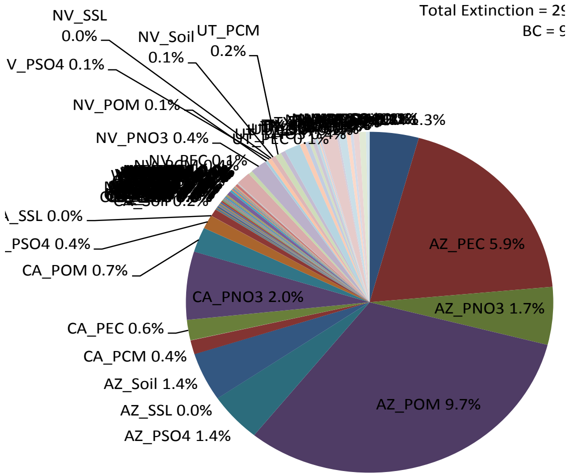

- Accounting for International Contributions to URP and RPGs



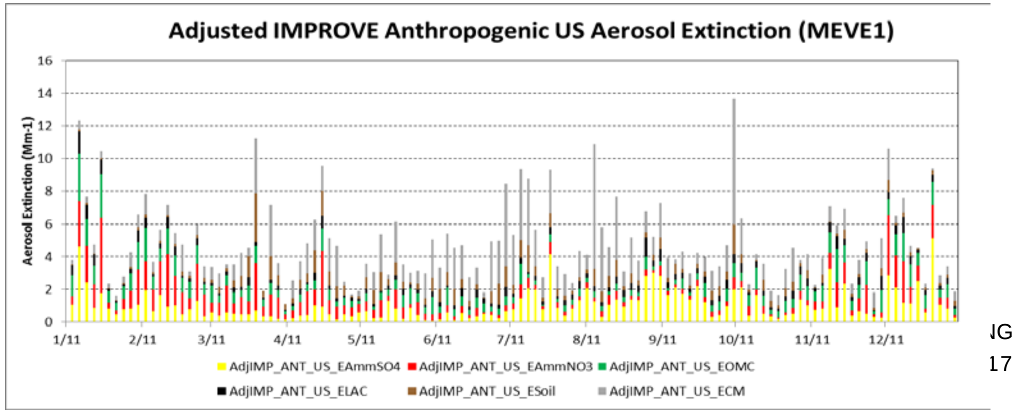

- Identify State and Source Contributions to Visibility Impairment

Example for 2008 Grand Canyon

- W20% = 30 Mm-1
- BC = 10 Mm-1 (30%)




- Identify U.S. anthropogenic contributions to visibility impairment

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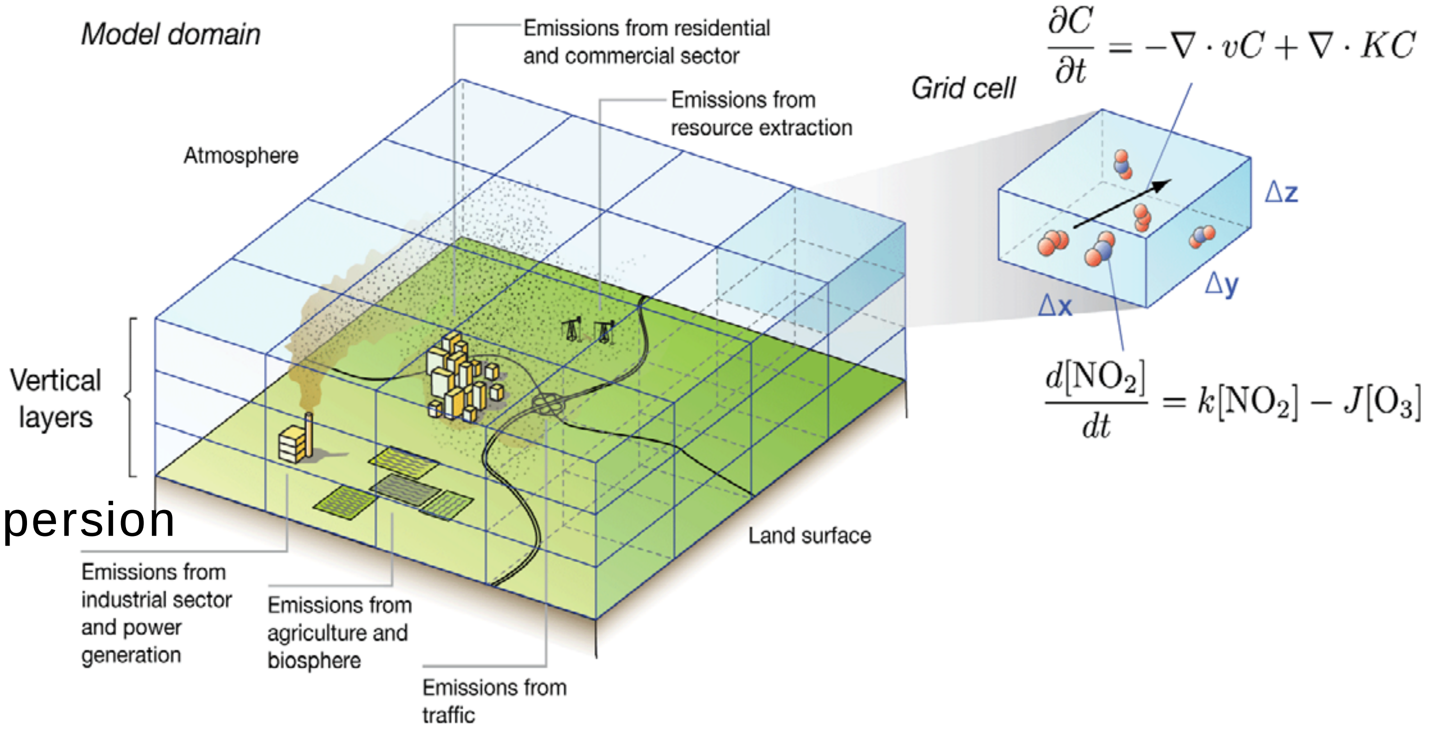
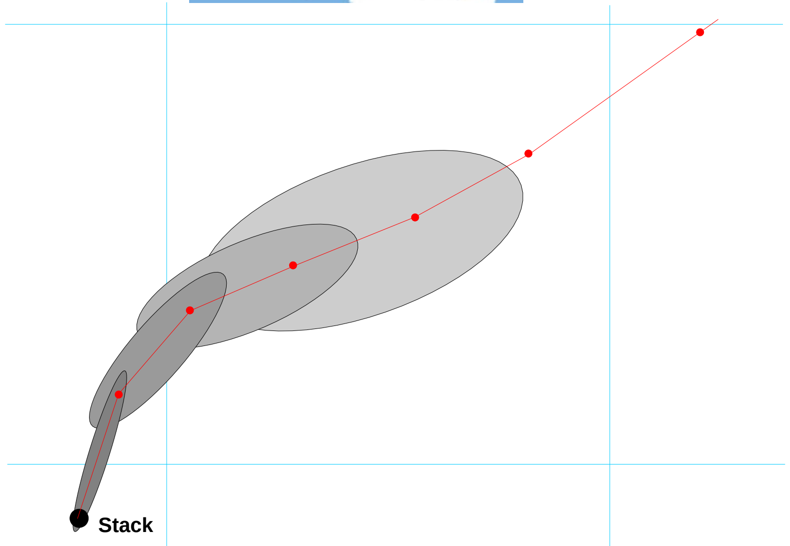
# PHOTOCHEMICAL GRID MODEL (PGM) STRUCTURE

- Domain divided into a array of grid cells
  - o Vertically stacked boxes
- Treat all sources
- 3-D meteorology
- Boundary Condition (BC)
  - o Transport from outside
- Full-science 3-D transport/dispersion and chemistry
  - o Photochemistry
  - o Aqueous-Phase Chemistry
  - o Aerosol Thermodynamics

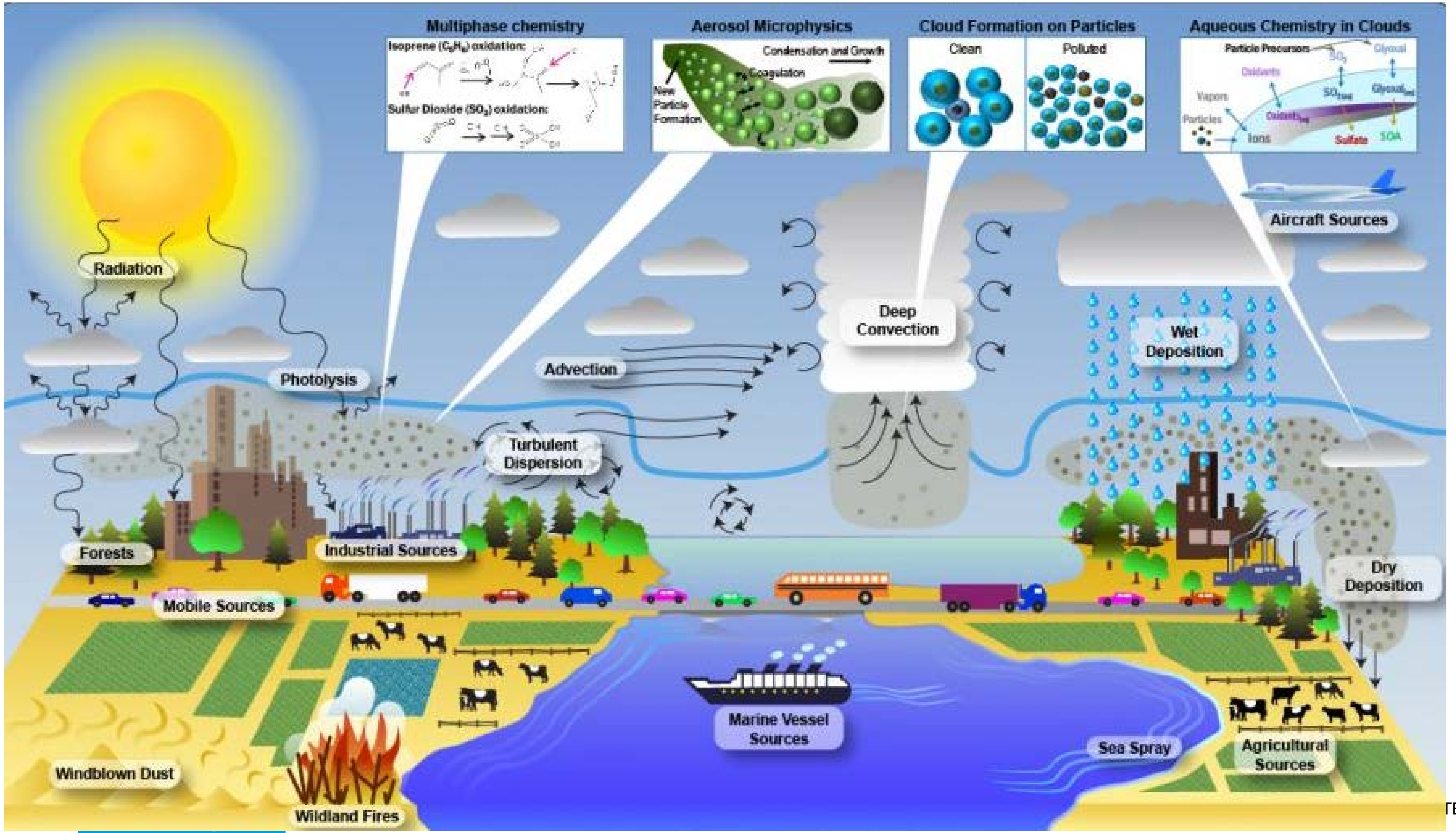


# CMAQ AND CAMX -- TWO MOST WIDELY USED PGMS IN U.S.

- Similar basic model formulation and model inputs
  - CMAQ-to-CAMX and CAMx-to-CMAQ processors
- Community Multiscale Air Quality (CMAQ) modeling system
  - Developed by U.S. EPA (https://www.epa.gov/cmaq)
  - First released in 1998 current CMAQ v5.2 released June 2017
  - Several features not available in CAMx:
    - In-line lighting, sea salt and windblown dust emissions
    - Bi-directional ammonia emissions
- Comprehensive Air-quality Model with extensions (CAMx)
  - Developed by Ramboll Environ (http://www.camx.com/)
  - First released in 1996 current CMAQ v6.4 December 2016
  - Several features not available in CMAQ:
    - Two-way grid nesting
    - Plume-in-Grid
    - Advanced ozone and PM Source Apportionment

# PROCESSES TREATED IN A PGM




- Emissions
  - Point & Area
  - Anthropogenic and Natural
- 3-D Transport and Dispersion
- Chemistry
  - Gas & Aqueous
  - Aerosol
- Deposition
  - Wet & Dry

Source: https://www.epa.gov/cmaq

# PGM MODELING STEPS

- Identify purpose of Photochemical Grid Model (PGM) modeling study
- Modeling Protocol – Road map for PGM application and Informational Document for Interested Parties
    - Conceptual Model (identify processes important for application)
    - Episode Selection (e.g., 2016 calendar year)
    - Domain Selection (e.g., 36US3 and 12 km CONUS2)
    - Meteorological Modeling (e.g., Weather Research Forecast [WRF] model)
    - Emissions Sources and Processing/Modeling (e.g., SMOKE and other programs)
    - Boundary Conditions (BCs, from Global Chemistry Model)
    - Model Performance Evaluation (comparison with observed concentrations)
    - Future-Year Modeling (future year emission projections)
    - Future Year Air Quality and Visibility Projections

# EPISODE AND DOMAIN SELECTION

- Previous round of RHR modeling (2018 milestone year) used the 2002 modeling year within the 2000-2004 Baseline period
  - For this round of RHR modeling (2028 milestone year), several modeling years may be used with 2016 likely being used for Western States
- First round of RHR modeling WRAP used 36 km CONUS and 12 km WESTUS domains, with a majority of runs using just 36 km CONUS domain (2–week simulation)
  - New round likely use 36US3 and 12 km CONUS2 domains

<u>2002</u>

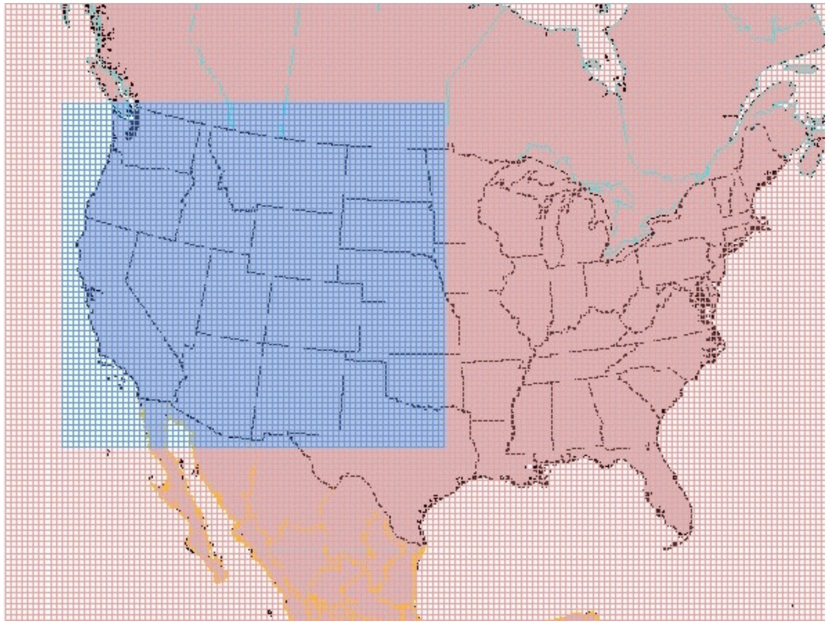
36km: 148x112

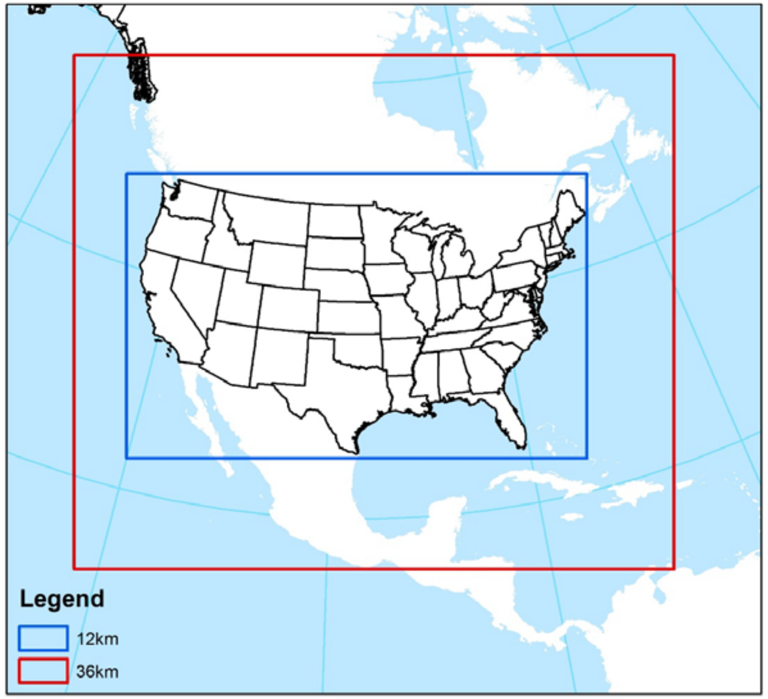
12km: 207x186

NZ = 19

1.0M grid cells

(0.3M 36 km)






<u>2016</u>

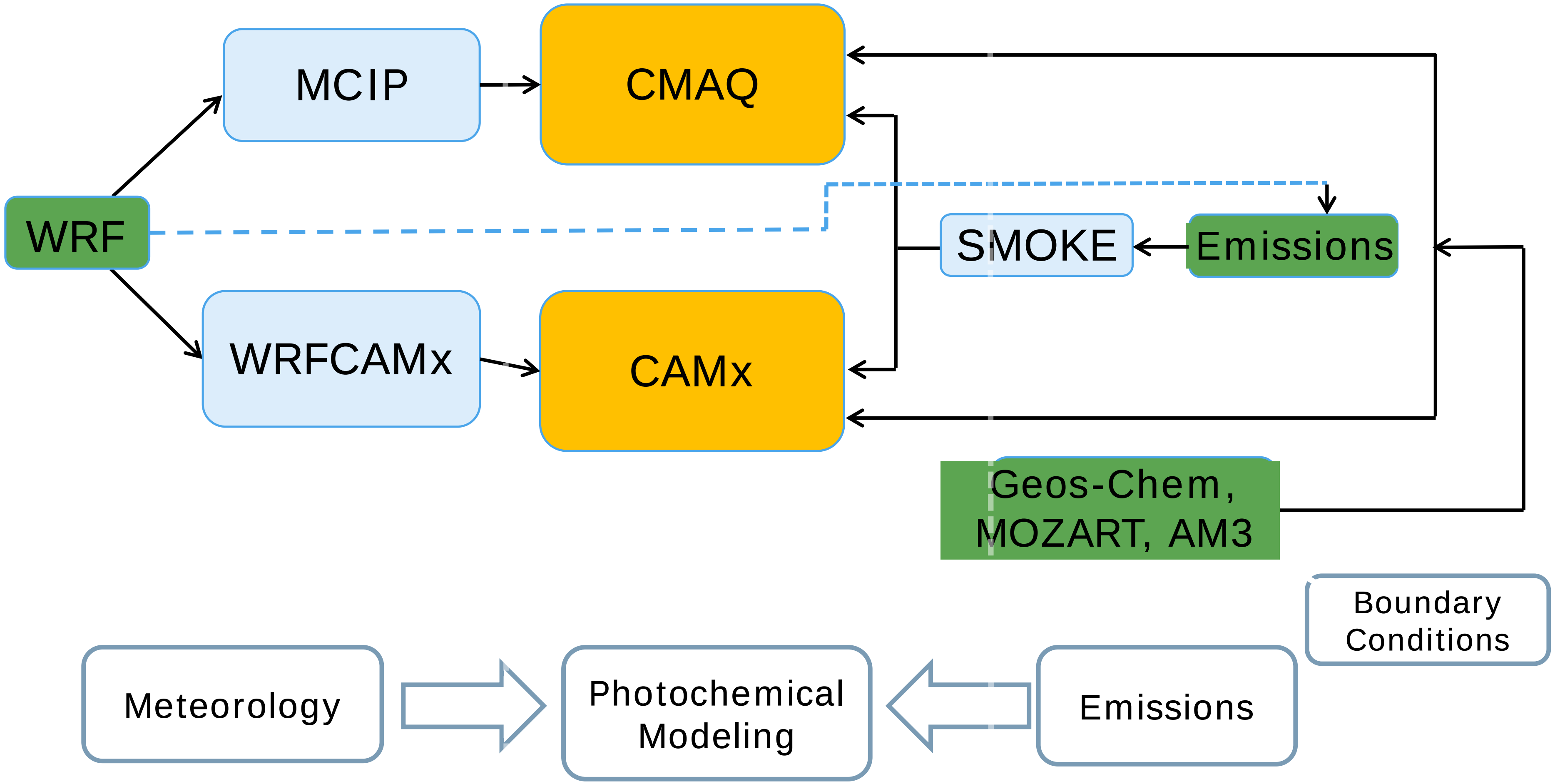
36km: 172x148

12km: 396x246

NZ = 25?

3.1M grid cells

# THREE MAIN PGM INPUTS: (1) METEOROLOGY; (2) EMISSIONS; AND (3) BOUNDARY CONDITIONS

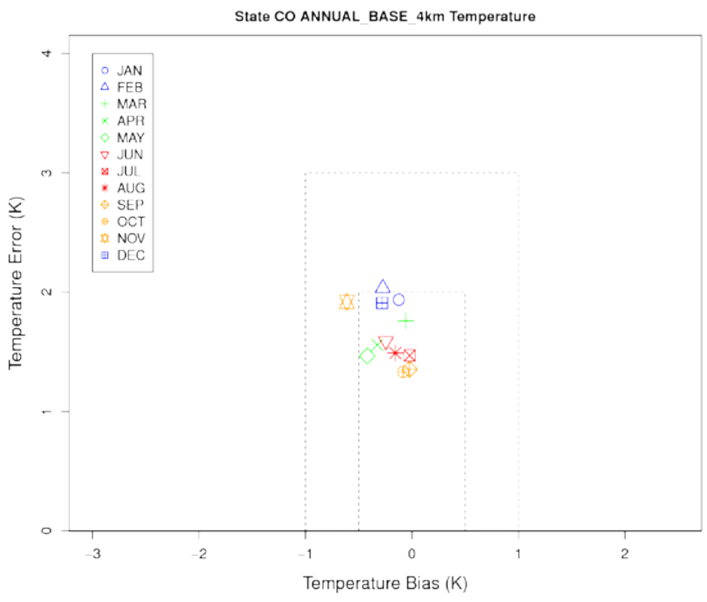


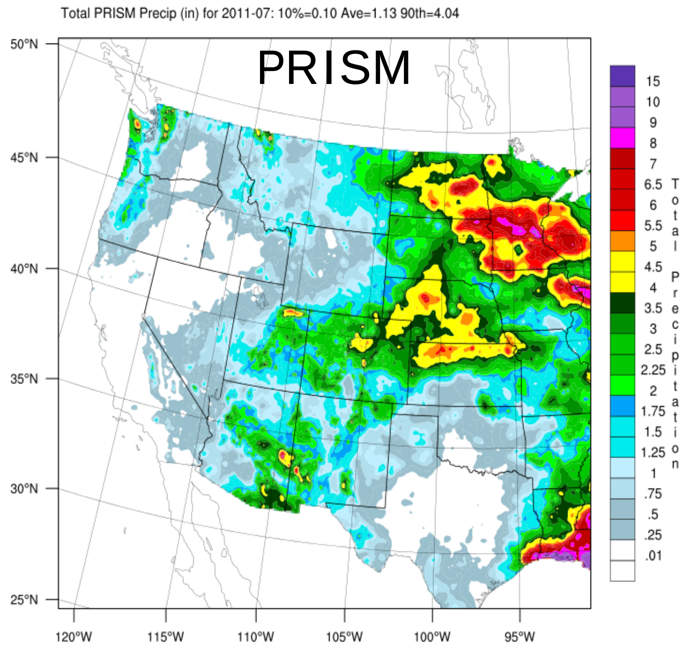
# WRF METEOROLOGICAL MODELING – KEY INPUTS

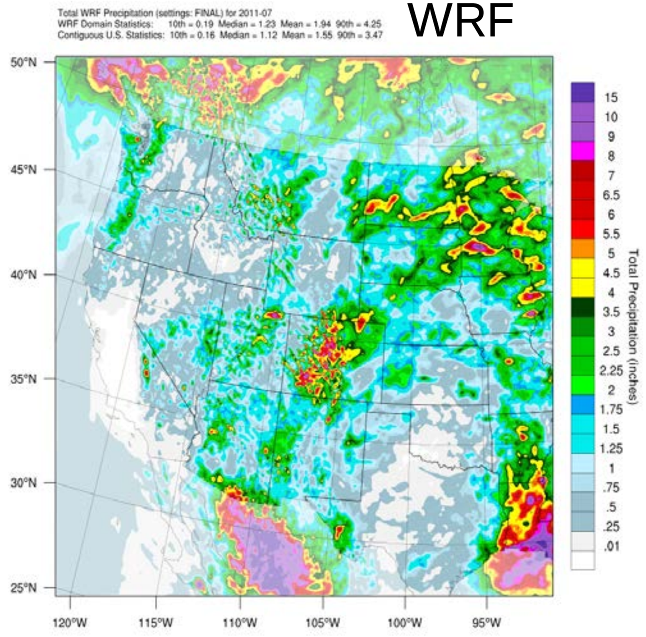
- Numerical Weather Prediction Model (Forecast vs. Hindcast mode)
- WRF modeling domains defined slightly larger than PGM
  - o WRF can generate modelling artifacts near boundaries as boundary conditions (BCs) come into dynamic balance with WRF numerical algorithms
- Analysis Fields : Used for BCs and 3-D Analysis Nudging (WS, WD, T and RH) for coarser (e.g., 36 and 12 km) domains (OBSGRID can be used to refine analysis fields)
  - o NAM (12 km); ECMWF-ERA5 (31 km; 2006-2016); NAR, GFS, etc.
- Observation Nudging: for finer grids (4 km and smaller): WS, WD, RH and T
- Planetary Boundary Layer (PBL): YSU, MYJ(TKE), ACM2(EPA)
- Land Surface Model (LSM): NOAH, New NOAH multiphase, Pleim-Xiu (EPA)
- Cumulus Parameterization: Multi-scale Kain-Fritsch (MSKF), KF, Grell

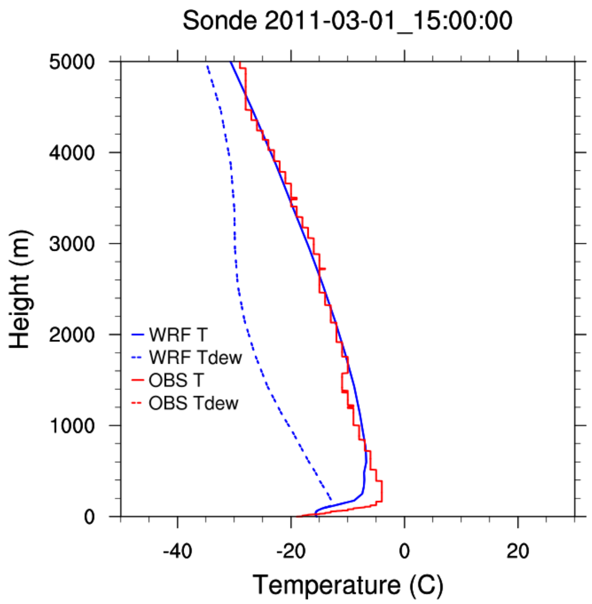
# WRF MODEL PERFORMANCE EVALUATION

- Surface Meteorological Observations (WS, WD, T and RH) [AMET, METSTAT]
  - o Compare against simple and complex model performance benchmarks
  - o Evaluate for subregions and at specific sites
- Upper-Air Observations (WS, WD, T and Td)
- Precipitations (PRISM Fields) – Jul 2011



# PGM EMISSION INPUTS – ANTHROPOGENIC EMISSIONS

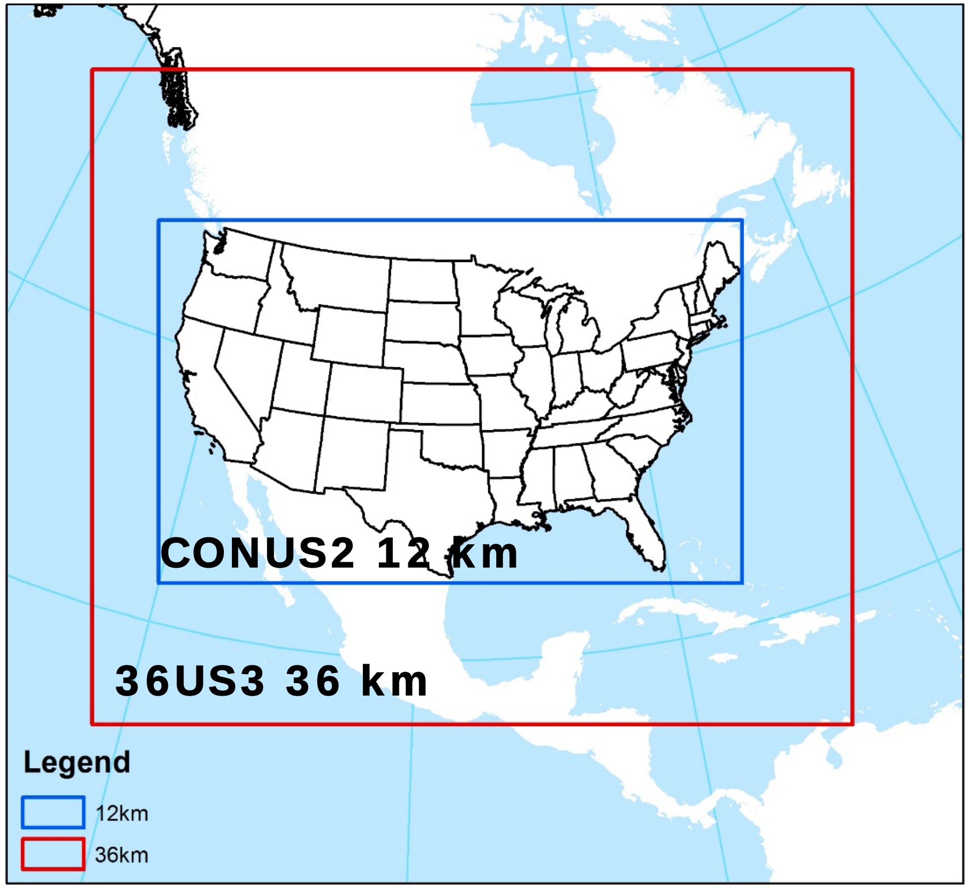
- Two input files for PGMs:
  - 2-D gridded hourly speciated surface layer emissions
  - Point source emissions (stack parameters and hourly speciated emissions)
    - 3-D emissions inputs can also be used but produce very large files
- Emissions Processing vs. Emissions Modeling
  - Most anthropogenic emissions use the Sparse Matrix Kernel Emissions (SMOKE) tool to process the National Emissions Inventory (NEI) county level annual emissions for PGMs.
    - Surrogate distributions (e.g., population) used to spatial aggregate to grid cells
    - Temporal profiles used to allocate monthly and hour of day
    - Speciation profiles by SCC (SPECIATE 4.5) use to speciate emissions to chemical species in PGM
  - Emissions Modeling Used for some Anthropogenic Source Categories
    - Electrical Generating Unit (EGU) hourly CEM data
    - SMOKE-MOVES uses gridded hourly WRF meteorological data with MOVES lookup table emission factors to generate day-specific hourly gridded on-road mobile source inputs
      - Can also interface with TDM activity data (e.g., Denver ozone SIP)
    - Aircraft and Commercial Marine may also be “modeled”

# PGM EMISSION INPUTS – NATURAL EMISSIONS

- Most natural emission sources use emissions modeling
- Biogenic emissions depend on temperature and solar radiation so used WRF gridded hourly data and information on leaf biomass
    - MEGAN and SMOKE-BEIS biogenic emission models
- Open land fires are highly episodic and require processing/modeling (WF, Rx, Ag)
    - Fire Inventory from NCAR (FINN), BlueSky/SMARTFIRE, FETS
- Windblown Dust -- wind speed and landuse (disturbed vs. undisturbed) dependant
- Lightning NOx – tied to convective activity
- Sea Salt – spray zone and wind speed
- Ocean Dimethyl Sulfide (DMS) – most abundant natural occurring sulfur emissions
- Volcanos – sulfur leakage and eruptions

# BOUNDARY CONDITIONS

- Incoming concentrations (transport) into outer coarse domain (e.g., 36US3) defined from Global Chemistry Models:
  - GEOS-Chem – Harvard
  - MOZART, CAM-Chem – NCAR
  - AM3, AM4 – Princeton GFDL
  - CMAQ-HEMI – EPA/ORD
- Global model emissions and use of coarse grid resolution results in increased uncertainties compared to US-based PGMs
- Processor maps global model results to PGM BCs for coarsest PGM domain
- BCs for finer grid domains obtained from next coarser grid



# PGM MODEL SIMULATION

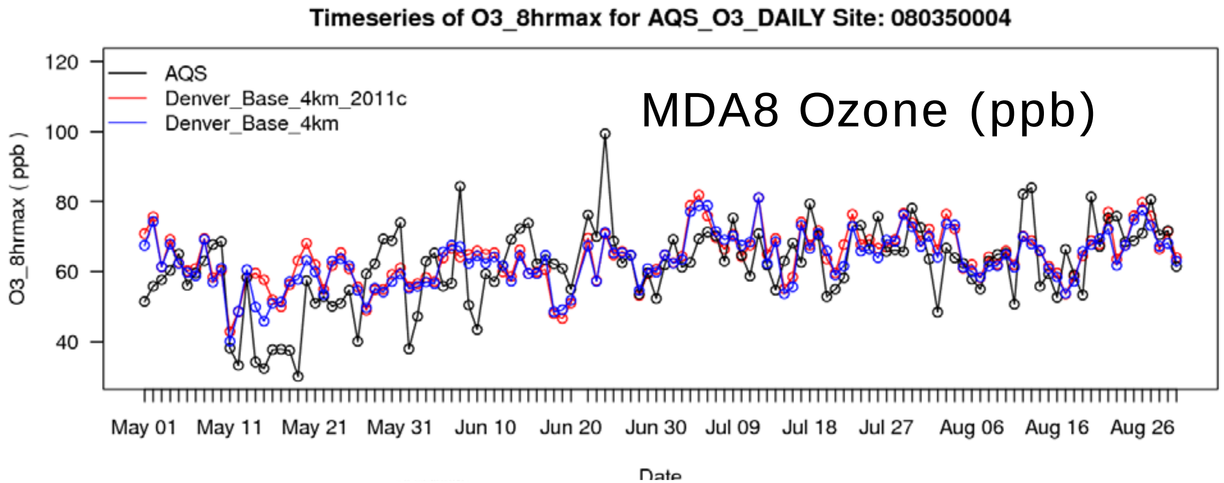
- Other assorted PGM inputs and options:
  - Ozone Column
    - Affects photolysis rates
  - Land cover information
    - Affects dry deposition and albedo
    - Snow cover from WRF
  - Chemical Mechanisms
    - CB6 used most often
  - Other options
    - PPM advection, etc.
  - Probing Tools
    - Source Apportionment
    - DDM sensitivity
    - Process Analysis

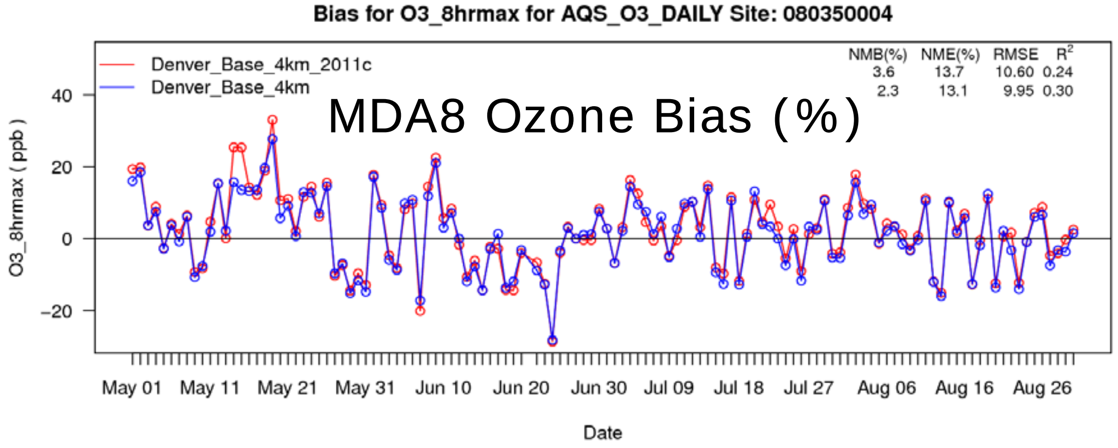
- Typically run PGM for year to address Regional Haze Rule on Linux Cluster with multiple cores (CPUs)
- Several multi-processing options:
  - MPI domain decomposition (CMAQ, CAMx)
    - Overhead associated with decomposition and reforming domain
  - OpenMP compiler directives (CAMx)
  - Splitting run period into segments
    - Run each Quarter in parallel with ~15 day spin-up
- Optimal multi-processing configuration depends on computer hardware (e.g., # nodes) and domain configuration

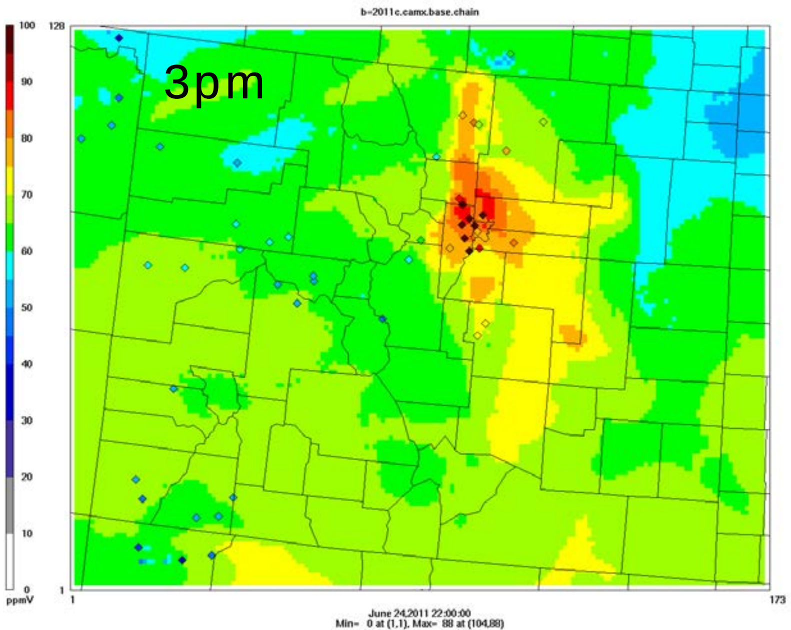
# PGM MODEL PERFORMANCE EVALUATION (MPE)

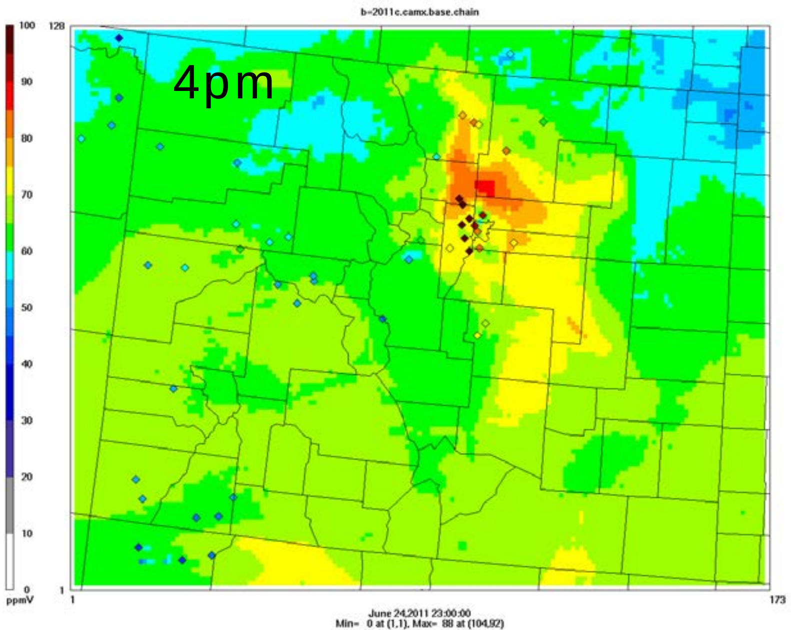
- Surface ambient air concentrations monitoring networks
  - AQS, IMPROVE, CASTNet, other
  - PM, Speciated PM ($SO_4$, $NO_3$, $NH_4$?, EC, OV, OPMF, PMC), Ozone, $NO_2$, NOx, CO, $SO_2$, $NH_3$, $HNO_3$
  - Visibility from RCFM and direct (e.g., nephelometer)
  - NADP Wet Deposition (CASTNet Dry Deposition?)
- Ozonesonde (Boulder, CO and TrinidadHead, CA in west)
- Special Study data (aircraft, enhanced sites, etc.)
- Model Performance Goals and Criteria (EPA, Boylan and Russell, Simon et al., Emery et al.)
- Graphical Displays of Model Performance
  - Time Series
  - Scatter Plots (Density Plots)
  - Q-Q Plots
  - Spatial Maps
  - Soccer Plots/Bugle Plots
  - Box & Whisker Plots
  - Bakergrams
  - Taylor Diagrams
- In the end, need Expert Judgement on adequacy of PGM based on MPE and what components it is most and least reliable for

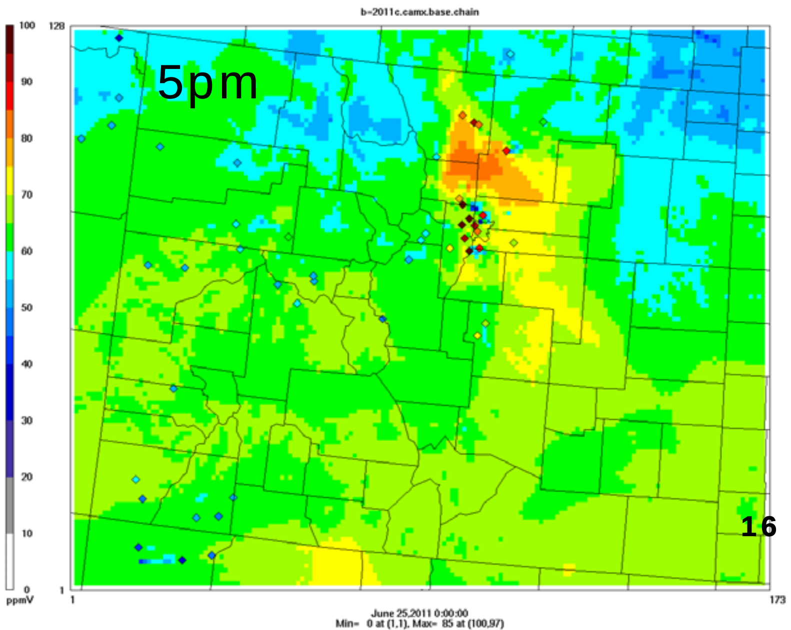
# EXAMPLE OZONE TIME SERIES PLOT (CHATFIELD, CO) AND SPATIAL MAPS WITH HOURLY OBSERVED OZONE (JULY 25, 2011)



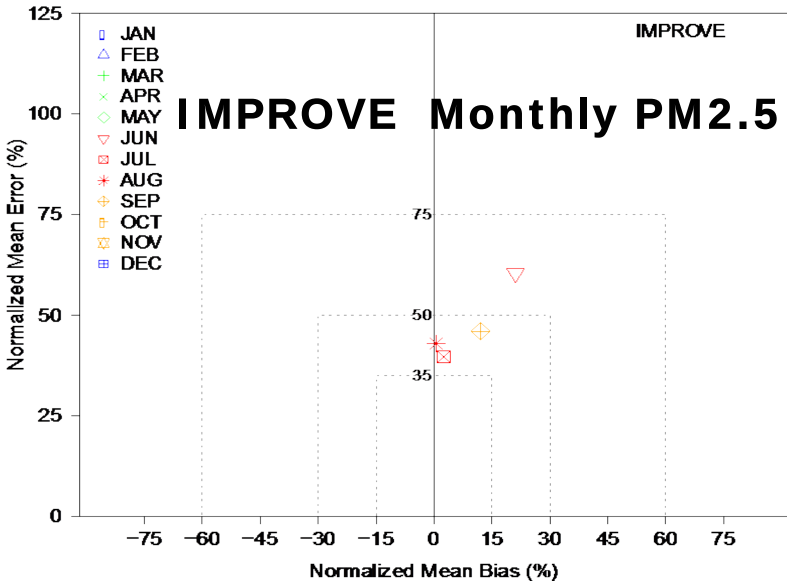



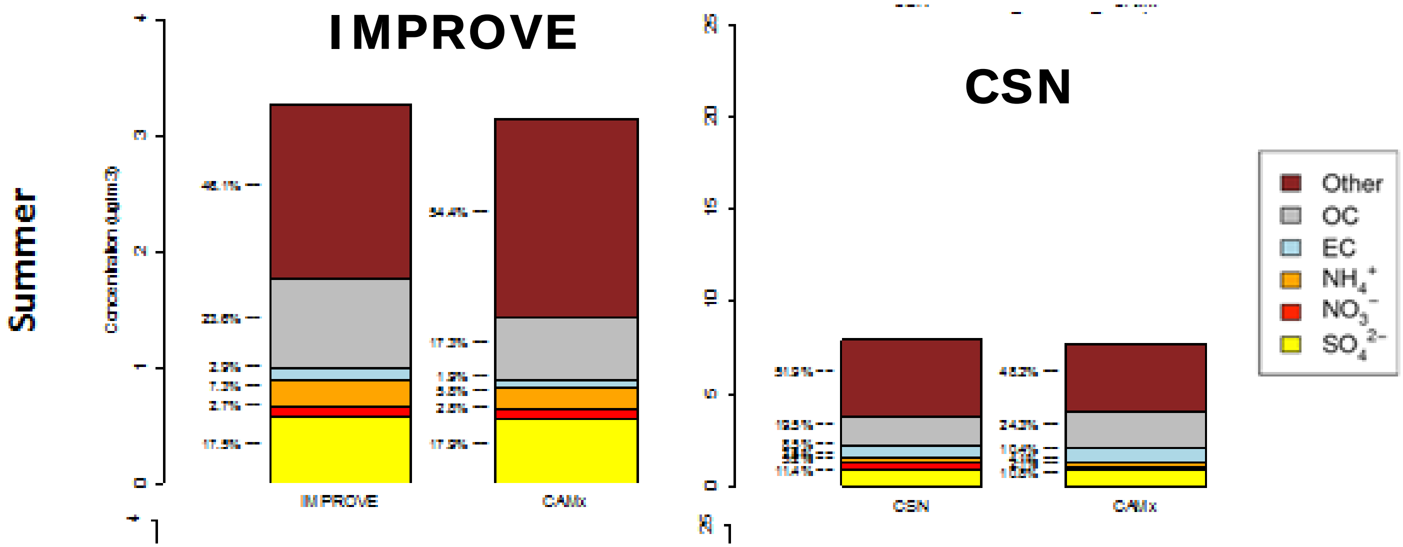



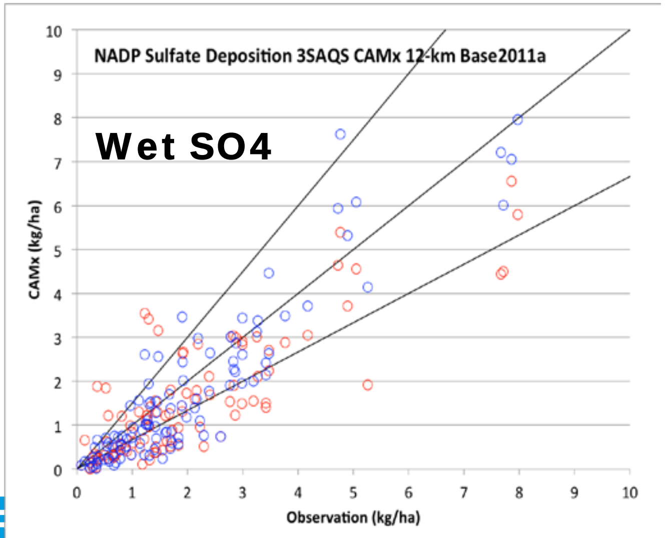



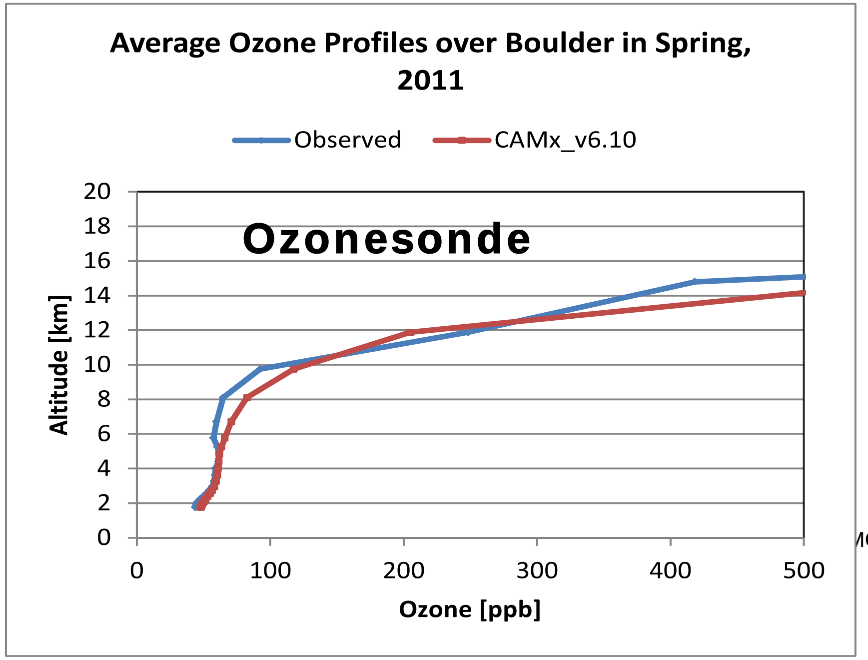
# EXAMPLE PGM MPE FROM WAQS CAMX 2011 BASE CASE




| Annual 2011 | R-Sq | NMB | NME | FB | FE | Mean_Obs | Mean_Mod |
|---|---|---|---|---|---|---|---|
| UNADJ | 0.70 | -23.7% | 37.9% | -37.0% | 55.2% | 1.97 | 1.50 |
| PRECIP ADJ | 0.84 | -13.1% | 28.7% | -32.6% | 46.4% | 1.97 | 1.71 |

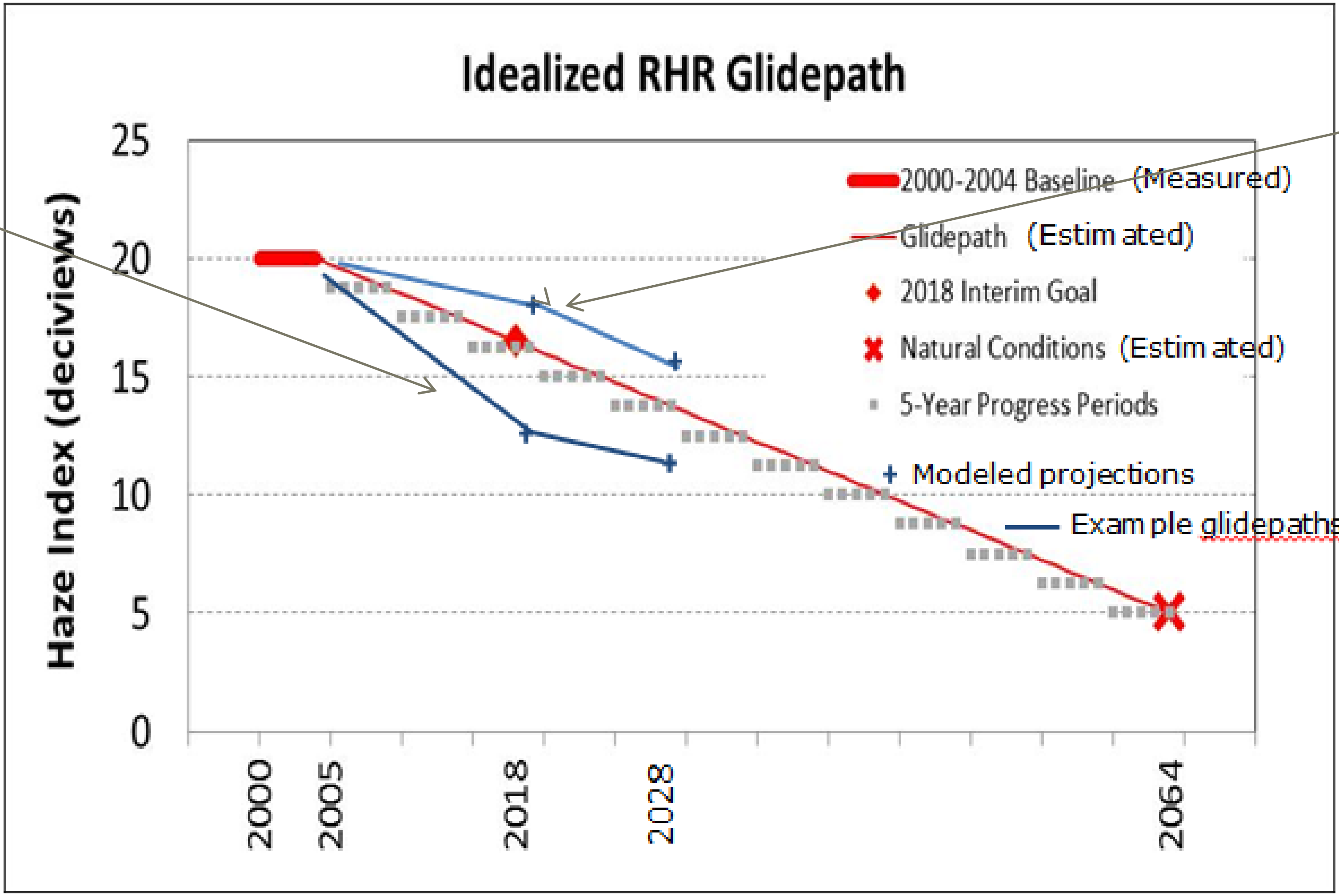


# USING PGM TO PROJECT FUTURE YEAR VISIBILITY

- Use PGM modeling results for Base Year (BY, e.g., 2016) and Future Year (FY, e.g., 2028) to scale current years (CYs) IMPROVE PM2.5 concentrations through Relative Response Factors (RRFs)
  - o RRF = PGM(FY) / PGM(BY)
  - o PM2.5(FY) = IMPROVE_PM2.5(CY) x RRF
  - o Separate RRFs for:
    - ➢ Most Impaired and Clearest Days
    - ➢ IMPROVE Site (Class I Area)
    - ➢ PM2.5 Species (SO4, NO3, EC, OCM, PMF and PMC)
  - o Use IMPROVE visibility equation with extinction coefficients and f(RH) to convert concentrations (µg/m$^3$) into light extinction (Mm$^{-1}$)
  - o Convert to deciview for developing Reasonable Progress Goals (RPGS) comparisons to Uniform Rate of Progress (URP) Glide Path

# COMPARISON OF MODELED RPGS WITH URP GLIDE PATH

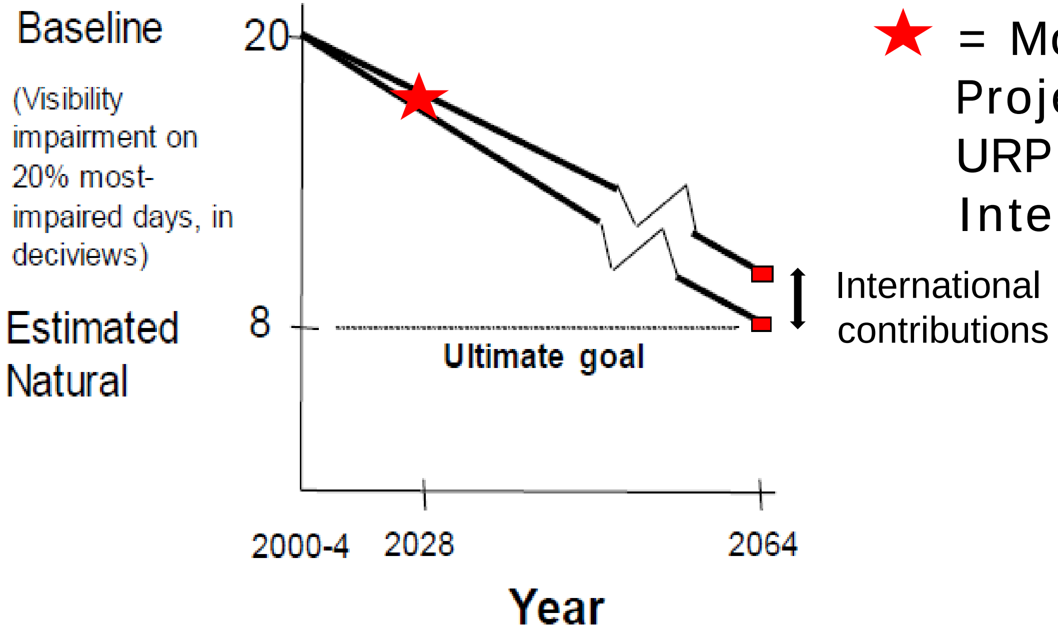
Model FY RPG below the URP Glide Path. On path towards natural conditions in 2064. Still need 4-factor analysis and why additional controls are not reasonable.




Model FY RPG above the URP Glide Path. Need to justify why additional controls not reasonable to be at or below the URP

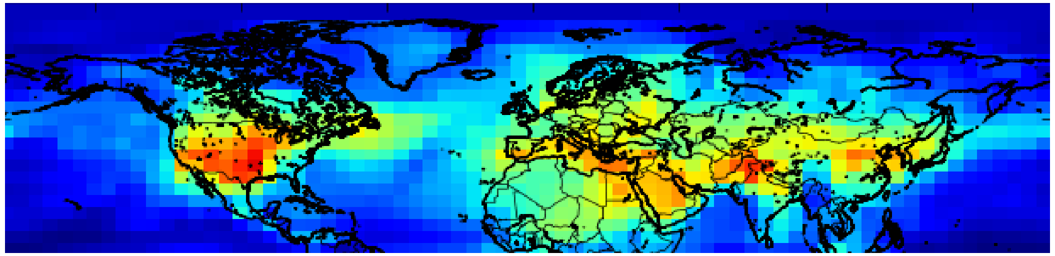
# IMPORTANCE OF INTERNATIONAL CONTRIBUTIONS

- In Western U.S. (and especially Alaska and Hawaii), visibility impairment is clearer and closer to natural conditions than eastern U.S.
- Even if EPA's new Most Impaired Days visibility metric removes (limits) contributions from Wildfires (WF) and Windblown Dust (WBD) storms, uncontrollable emissions from outside of the U.S. may highly affect visibility impairment and make it difficult for the modeled FY visibility RPGs to be at or below the URP Glide Path
- EPA draft visibility guidance suggests adding the international anthropogenic emissions contributions to the 2064 Natural conditions to adjust the URP Glide Path to account for uncontrollable international anthropogenic emissions




★ = Model 2028 FY Visibility Projections that would be below URP Glide Path accounting for International contributions

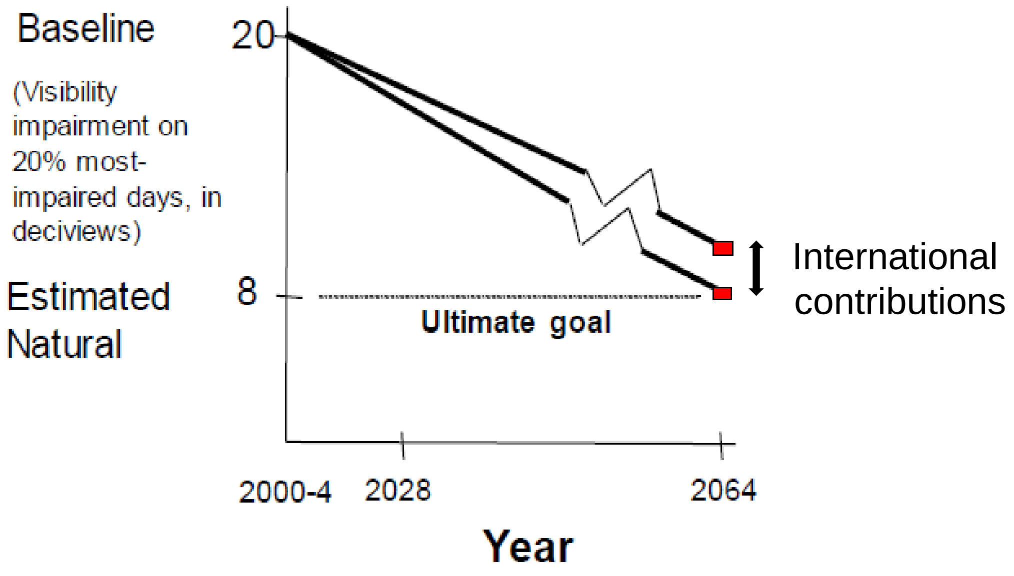
# EPRI STUDY TO EXAMINE INTERNATIONAL CONTRIBUTIONS



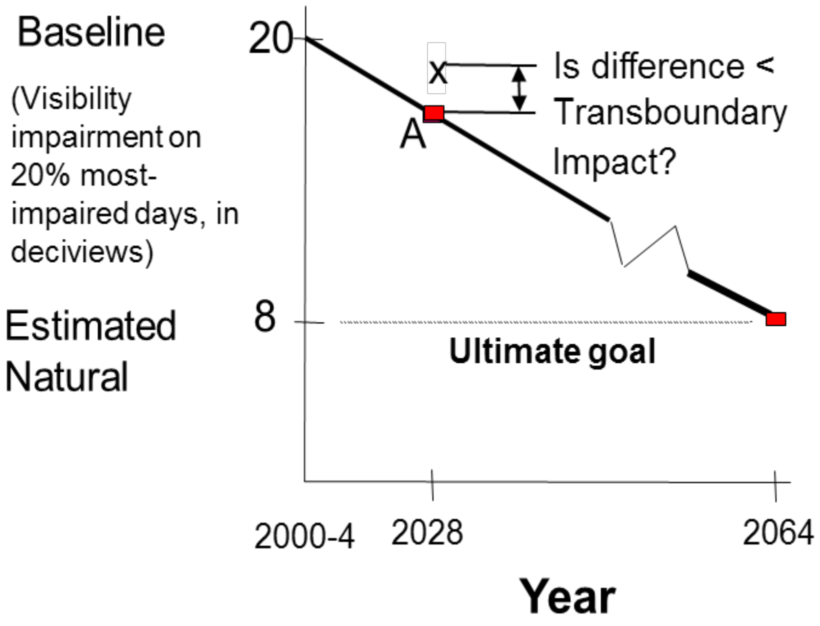
- GEOS-Chem global chemistry model
  - o 2016 Baseline Scenario -- 2016 meteorology and 2016 emissions
  - o 2028 Base Case Scenario -- 2016 meteorology and 2028 emissions
  - o 2028 ZROW Scenario -- No non-U.S. anthropogenic emissions (Zero-Out Rest of World, ZROW)
- CAMx 36/12 km simulations
  - o 2016 Baseline, 2028 Base Case and 2028 ZROW Scenarios
- Calculate contribution of International Anthropogenic Emissions to visibility impairment on Most Impaired Day in 2028

# SHOULD INTERNATIONAL CONTRIBUTIONS BE ADDED TO 2064 NATURAL CONDITIONS FOR URP GLIDE SLOPE OR SUBTRACTED FROM 2028 MODELING RESULT

Add International Anthropogenic Contribution to 2064 Natural Conditions




Shown Modeled 2028 Visibility Projections With (x) and Without (A) International Contributions

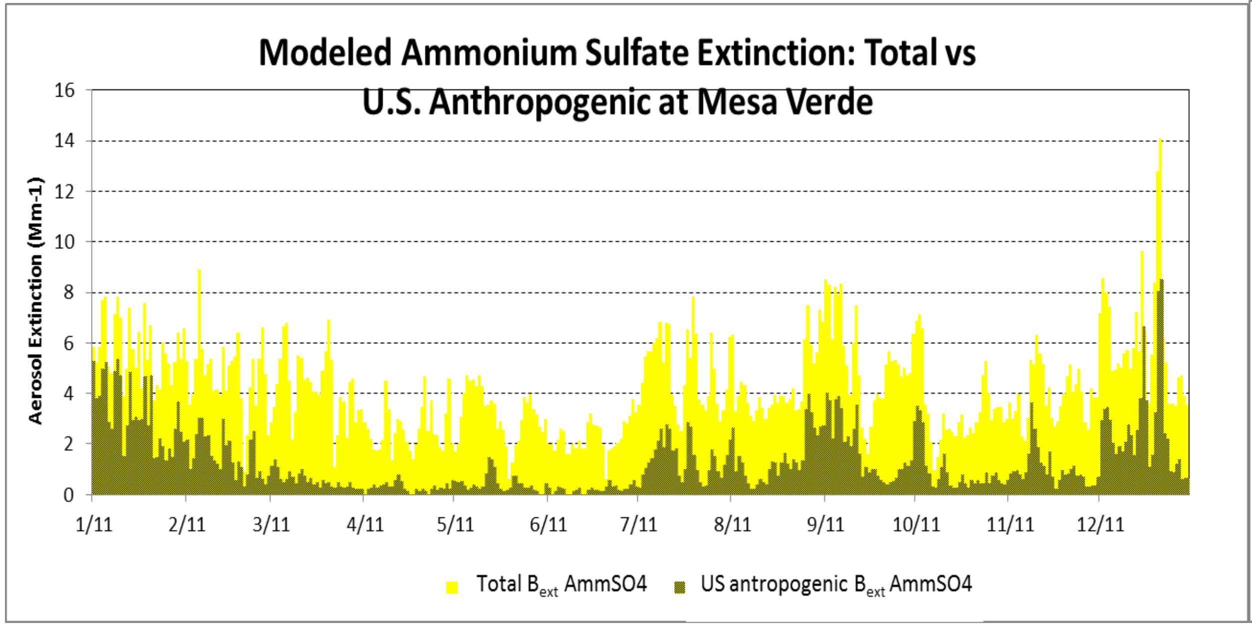


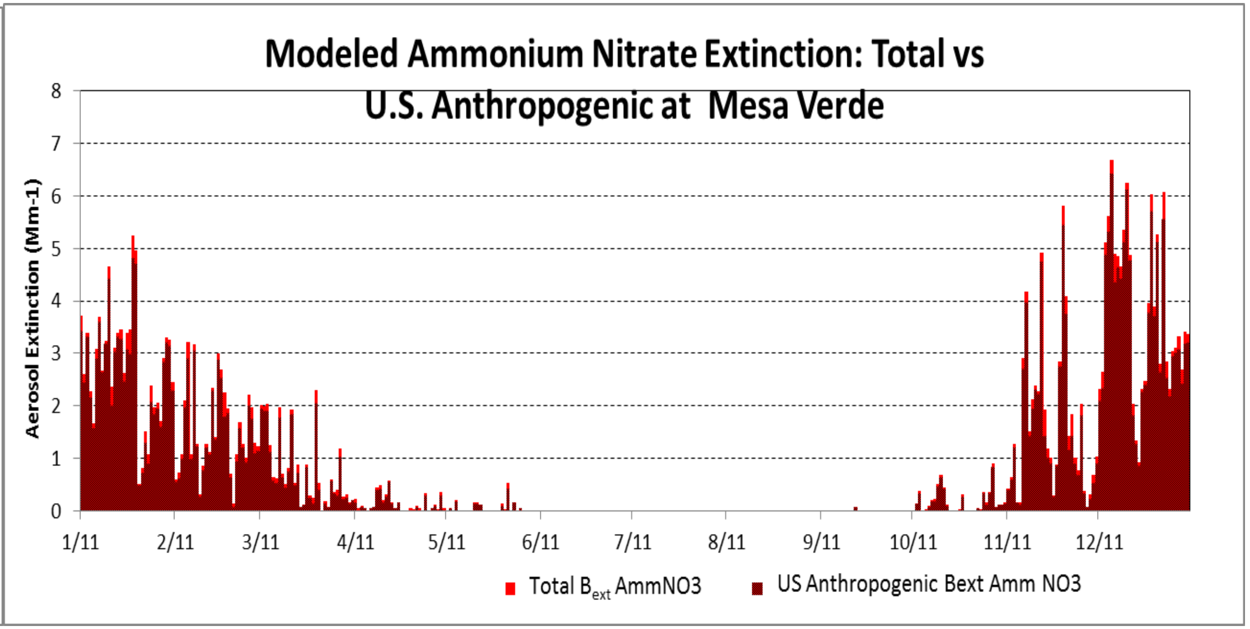
# ADDITIONAL OPTIONAL ANALYSIS THAT COULD BE OBTAINED FROM GEOS-Chem / CAMx MODELING

- Perform Natural Emissions Model Simulation
  - Zero-out all (U.S. and International) anthropogenic emissions
  - Provides model floor visibility and another estimate of natural background
- 2016 PM Source Apportionment Modeling
  - State anthropogenic contributions to visibility
  - Wildfires, WBD and International contributions
  - Modeled Most Impaired Days
- 2028 PM Source Apportionment modeling
  - State, WF, WBD, Intl, etc. contributions
  - U.S. Anthropogenic emissions visibility impairment Glide Slope
- Source Apportionment subject of next WRAP Teach-In November 16, 2017

# DISCONNECT BETWEEN MODELING AND EPA'S NEW MOST IMPAIRED DAYS VISIBILITY METRIC

- EPA's New Most Impaired Days visibility metric filters days for Carbon and Dust to screen out high Wildfire and Dust days and implicitly assumes Sulfate and Nitrate are controllable
- 2011 MOZART/CAMx modeling indicates that a majority of the Ammonium Sulfate light extinction is due to sources outside of the U.S.




Dark Shading = U.S. Anthropogenic

Revisit this issue in Nov 16, 2017 Teach-In on Source Apportionment

# THANK YOU