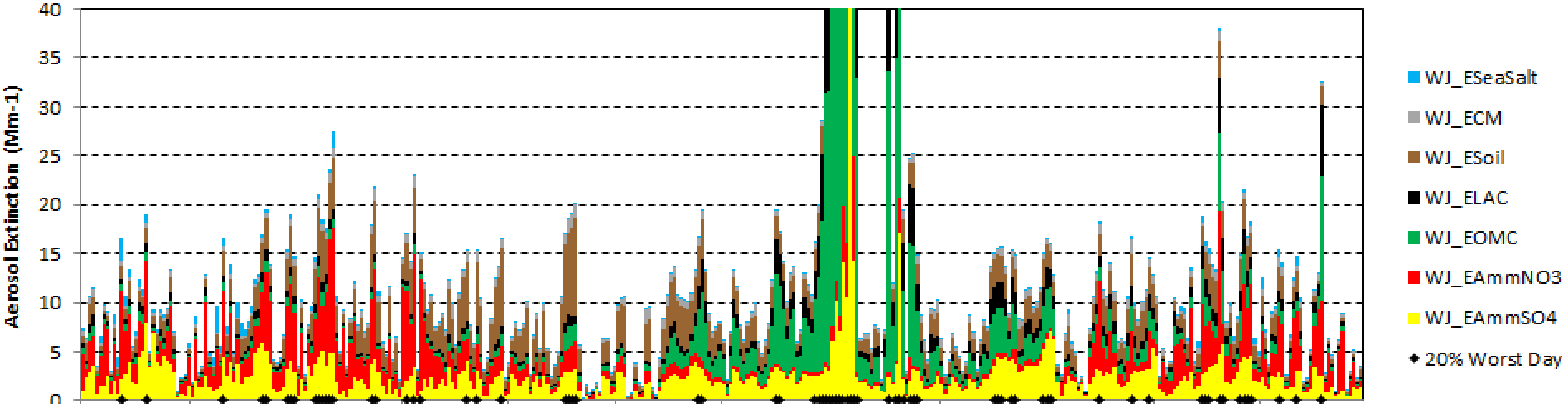


IDENTIFYING SOURCE CONTRIBUTIONS TO VISIBILITY IMPAIRMENT USING REGIONAL MODELING TOOLS

Ralph Morris and Ou Nopmongcol
Ramboll Environ

RAMBOLL ENVIRON

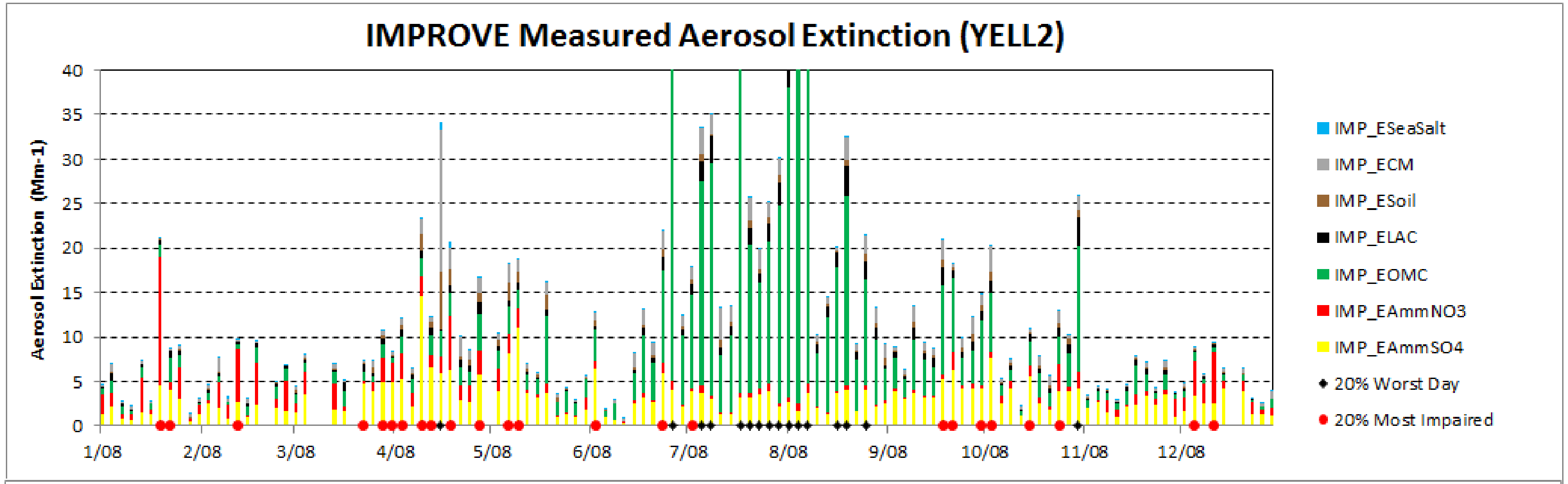
November 16, 2017

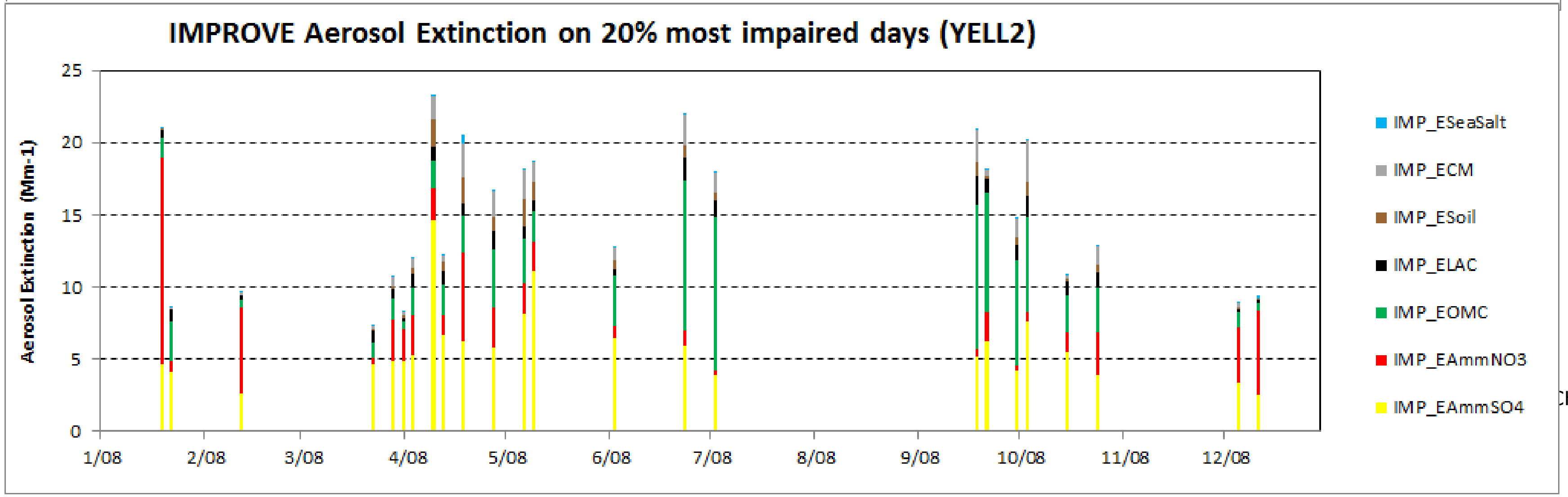
IMPORTANCE OF SOURCE CONTRIBUTIONS TO REGIONAL HAZE

- Goal of the Regional Haze rule (RHR) is no anthropogenic (man-made) visibility impairment at Class I areas by 2064
  - Knowing the contributions of U.S. anthropogenic (i.e., controllable), international anthropogenic and natural sources to visibility impairment is important
- IMPROVE measured PM data provides information on the PM species that contribute to visibility (i.e., AmmSO4, AmmNO3, EC, OMC, Soil and PMC), but not the sources
- EPA's new Most Impaired Days visibility metric attempts to limit the influence of background (long-term) and episodic (e3) natural conditions
  - Uses measured high Carbon (OMC+EC) and Dust (Soil+PMC) visibility impairment to screen out days influenced by Wildfires (WF) and Windblown Dust (WBD), respectively (e3 events)
  - Much improved over the Worst 20% Days (W20%) used in previous RHR SIPs
  - But imperfect and may not be consistent with reality or emission inventories/modeling

NEW EPA MOST IMPAIRED DAYS VS. OLD W20% VIS METRIC

2008 Yellowstone Daily IMPROVE Visibility Data



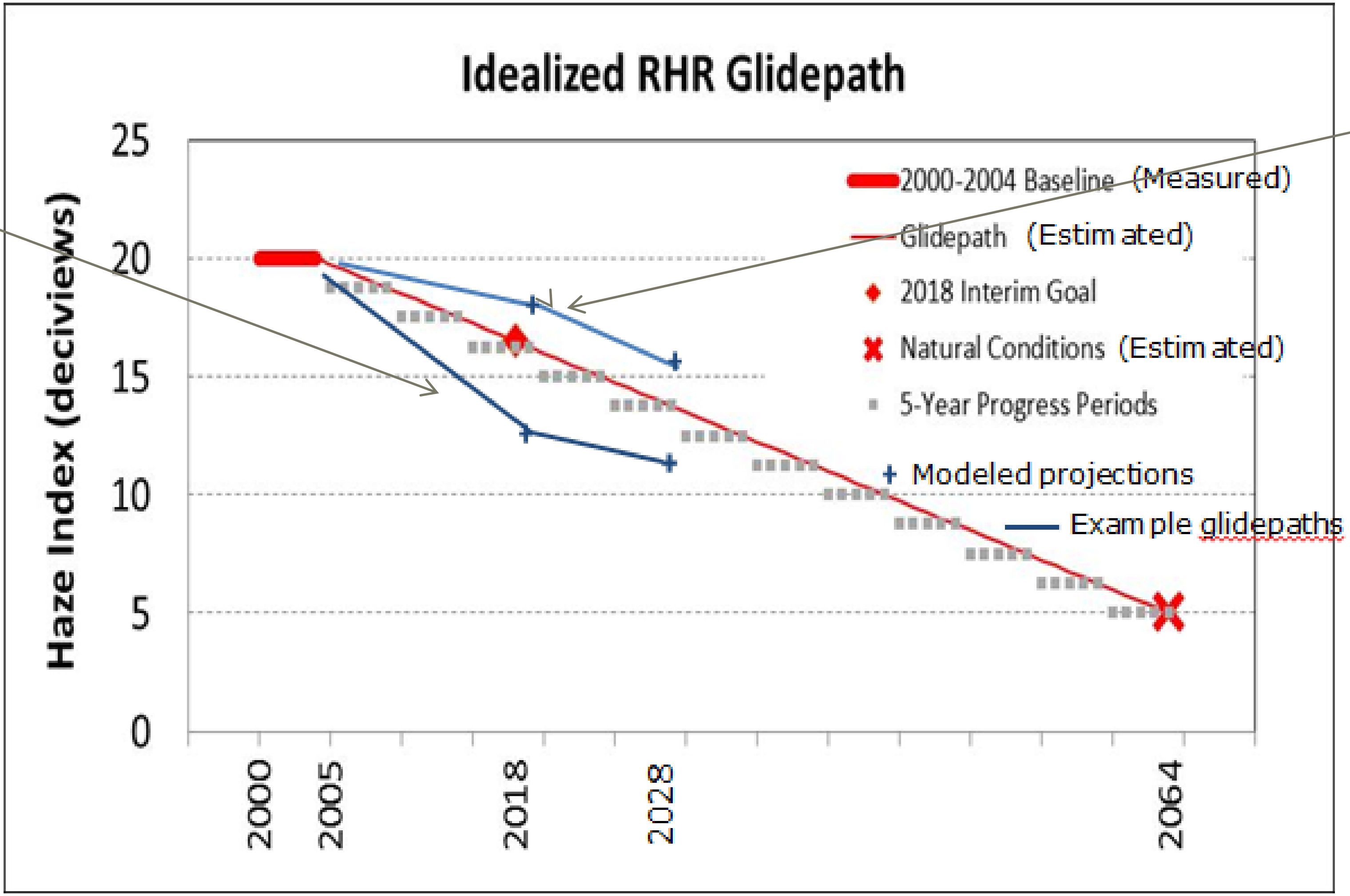


Old W20% Days Visibility Metric (black dots) dominated by summer wildfire days (green OC signature)

New Most Impaired Days (red dots and bottom panel) eliminates many (but not all) days dominated by wildfires

UNIFORM RATE OF PROGRESS (URP) GLIDEPATH
Regional Models used to Project Future Year (FY) Visibility

Model FY Visibility at or below the URP Glidepath – on path toward natural conditions

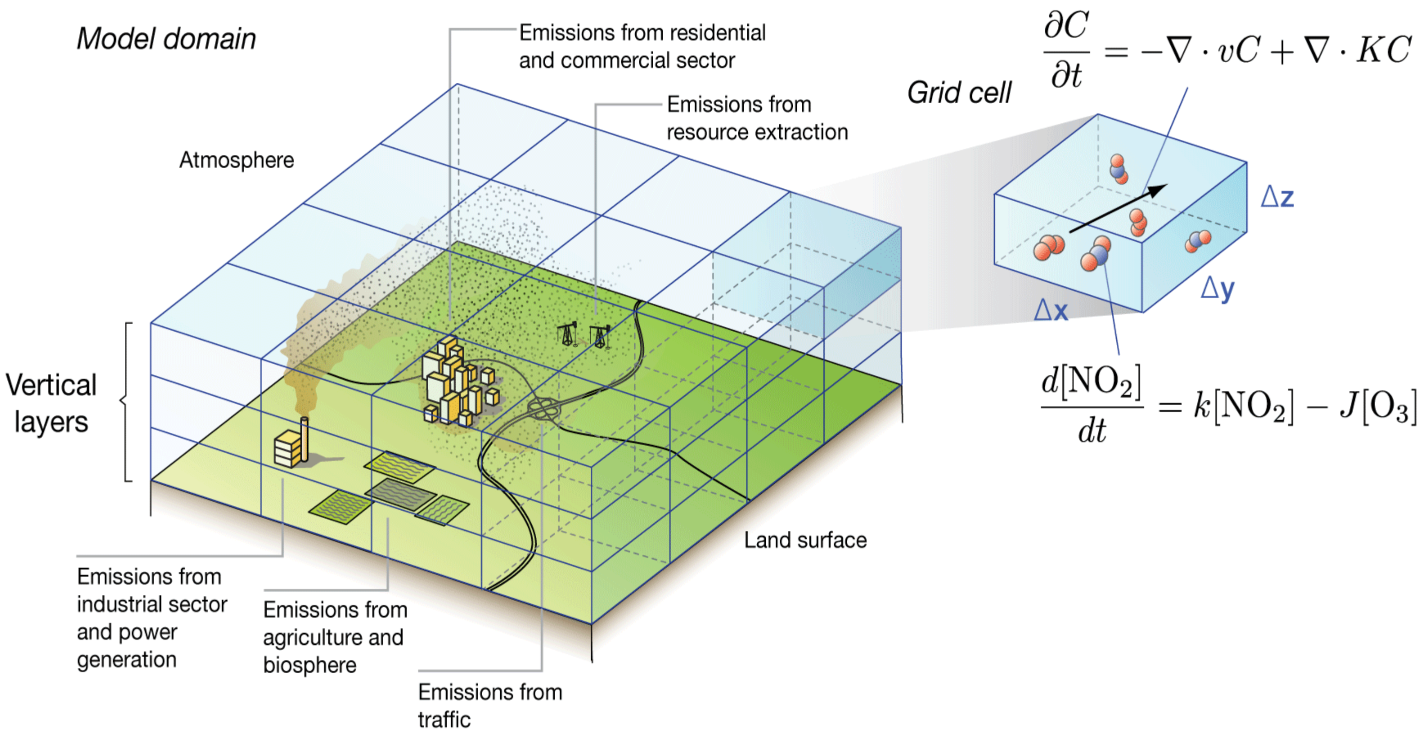


Model FY Visibility above the URP Glidepath – are more controls needed?

PHOTOCHEMICAL GRID MODEL (PGM) STRUCTURE

PGM Used to Project 2028 Visibility & Compare to Glidepath

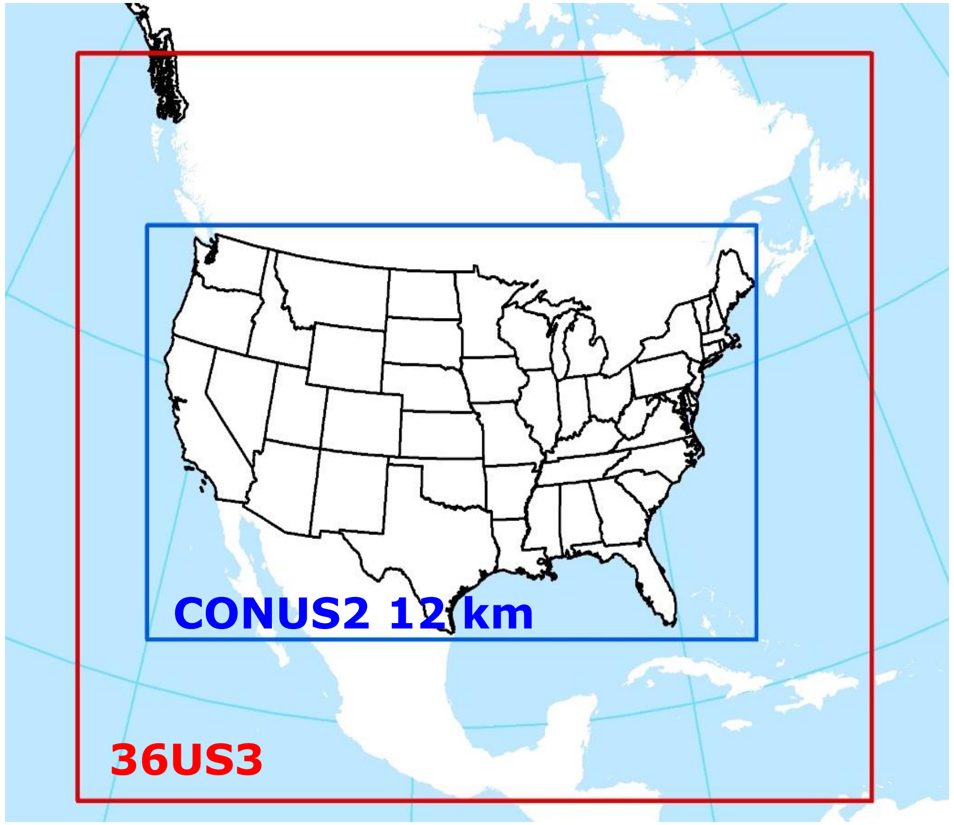
- Domain divided into a array of grid cells
  - Vertically stacked boxes
- Treat all sources
- 3-D meteorology
- Boundary Condition (BC)
  - Transport from outside
- Full-science 3-D transport/dispersion and chemistry
  - Photochemistry
  - Aqueous-Phase Chemistry
  - Aerosol Thermodynamics



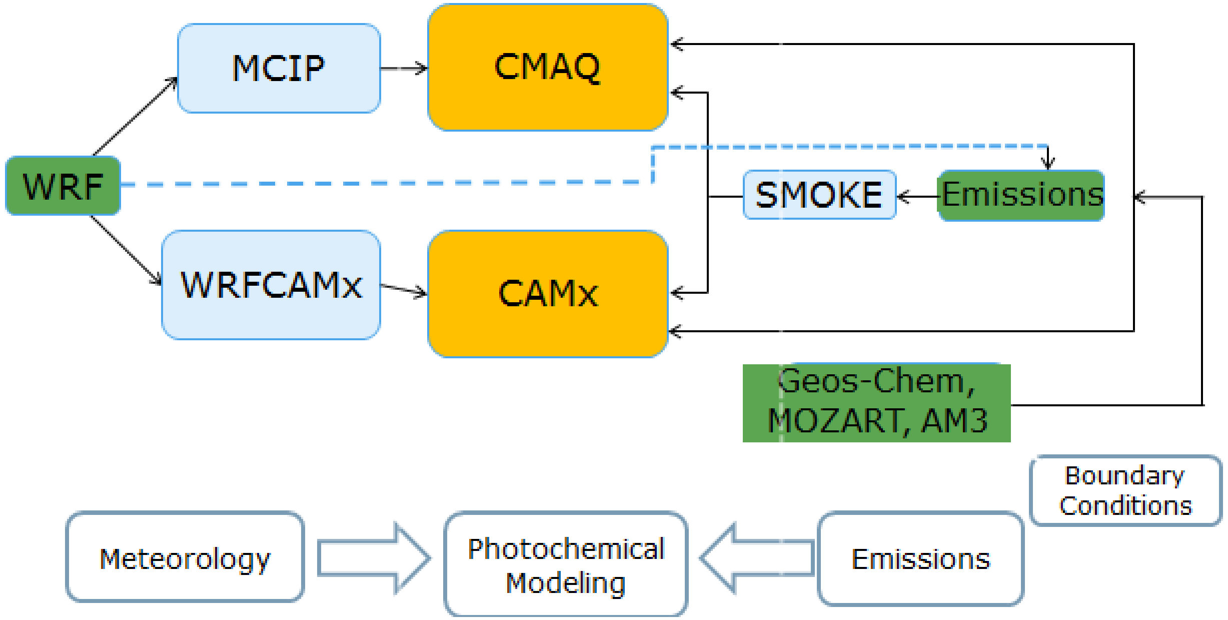
PGM MODELING FOR 2021 RHR SIPS

Base Year (BY) and Future Year (FY -- 2028) Modeling

- RHR SIP Base Year under consideration (e.g., 2011; 2014; 2016)
  - 36US3 36 km & 12 km CONUS2 Domains?

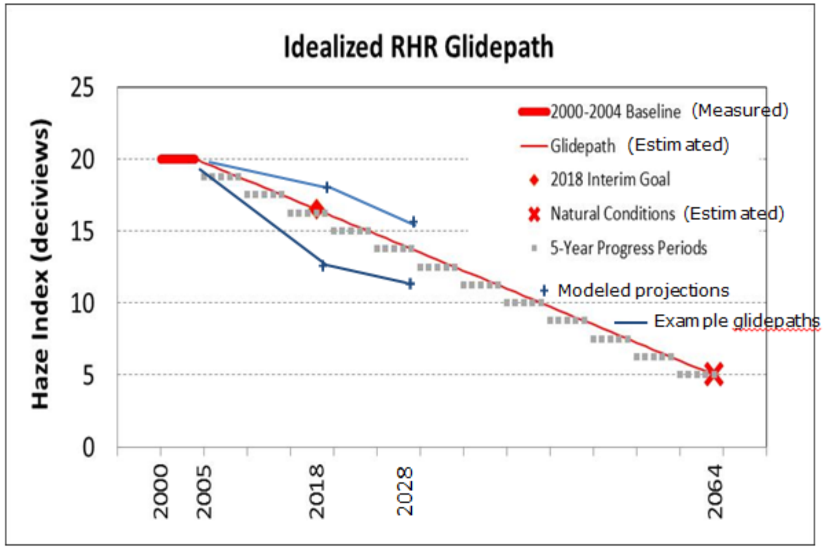


- CMAQ and/or CAMx PGM Models
  - WRF Meteorology
  - SMOKE Emissions
  - Global PGM Boundary Conditions:
    - GEOS-Chem, MOZART/CAM-chem, AM3/AM4



PGM MODELING PROCEDURES FOR 2021 RHR SIPS
Project 2028 FY Visibility and Compared with URP Glidepath

- Development of Modeling Protocol
- Base Year (BY) Inputs
  - Meteorological (WRF
  - Emissions (e.g., SMOKE)
  - Boundary Conditions (BCs; e.g., GEOS-Chem)
  - PGM BY Simulation and Model Performance Evaluation (MPE)
    - Diagnostic tests to improve model performance
- Project Future Year (FY -- 2028) Emissions
  - PGM FY Simulation
- FY Visibility Projections
  - Use relative change in BY to FY PGM results to scale observed BY components of visibility impairment (e.g., SO4)
    - Relative Response Factors (RRFs)
    - RRF = PGM(FY)/PGM(BY)
- Compare FY Visibility Projection with URP Glidepath



POTENTIAL USES OF SOURCE CONTRIBUTIONS IN RHR SIP

Several Uses of PGM BY & FY Source Apportionment

- Base Year (BY) Simulation
  - Identification of States that contribute to current visibility impairment at Class I Areas as part of the collaboration/coordinating process
  - Identify of source sectors and individual sources that contribute to current year impairment
  - Identify natural, U.S. anthropogenic and international anthropogenic emissions contributions
    - Modeled Most Impaired Days visibility metric, Natural Conditions, and International Contributions
- Future Year (FY) Simulation
  - Identification of Sources that contribute the most to FY visibility impairment – sources that when controlled would provide the greatest visibility improvements
  - Identify natural, U.S. anthropogenic and international anthropogenic emissions contributions
    - Modeled FY Natural Conditions and International Contributions
- BY and FY Simulation
  - Alternative Glidepaths based on modeled U.S. anthropogenic visibility impairment

SOURCE APPORTIONMENT (SA) VS. SENSITIVITY METHODS
What Are Source Contributions vs. How will They Change

- SA Methods allocate ozone/PM concentrations to Source Groups for a given model simulation (fixed atmospheric chemistry conditions)
  - For example, what is the contribution of Source Groups to visibility impairment under BY base case conditions
  - The contributions of ozone/PM due to all Source Groups adds up to total ozone/PM concentration
- Sensitivity Methods estimate the change in ozone/PM due to change in model parameter, such as a Source Group's emissions
  - Brute Force (zero-out) is the most common sensitivity method
    - Base Case and Source Group emissions zero-out or reduction case
  - For secondary species (e.g., SO4, NO3, NH4, SOA, O3), the sum of contributions due to all zero-out Source Groups will not equal total concentration

SOURCE APPORTIONMENT VS. SENSITIVITY METHODS

Advantages and Disadvantages of SA vs. Sensitivity

- The selection of SA or Sensitivity Methods depend on the question to be answered and logistical considerations
  - SA tends to be more computationally efficient than Sensitivity
  - SA tends to be conservative (i.e., higher source impacts) compared to sensitivity
  - When using Brute Force Sensitivity for PM with small emission changes, model "noise" can be comparable to impacts
    - ISORROPIA aerosol thermodynamic module is highly optimized with lots of branching that can give different solutions in Base Case and Emission Perturbation Case
- SA and Sensitivity Methods tend to be consistent; Source Group contribution rankings tend to be similar

PARTICULATE SOURCE APPORTIONMENT TECHNOLOGY (PSAT)

PSAT Estimates Source Contributions to Visibility

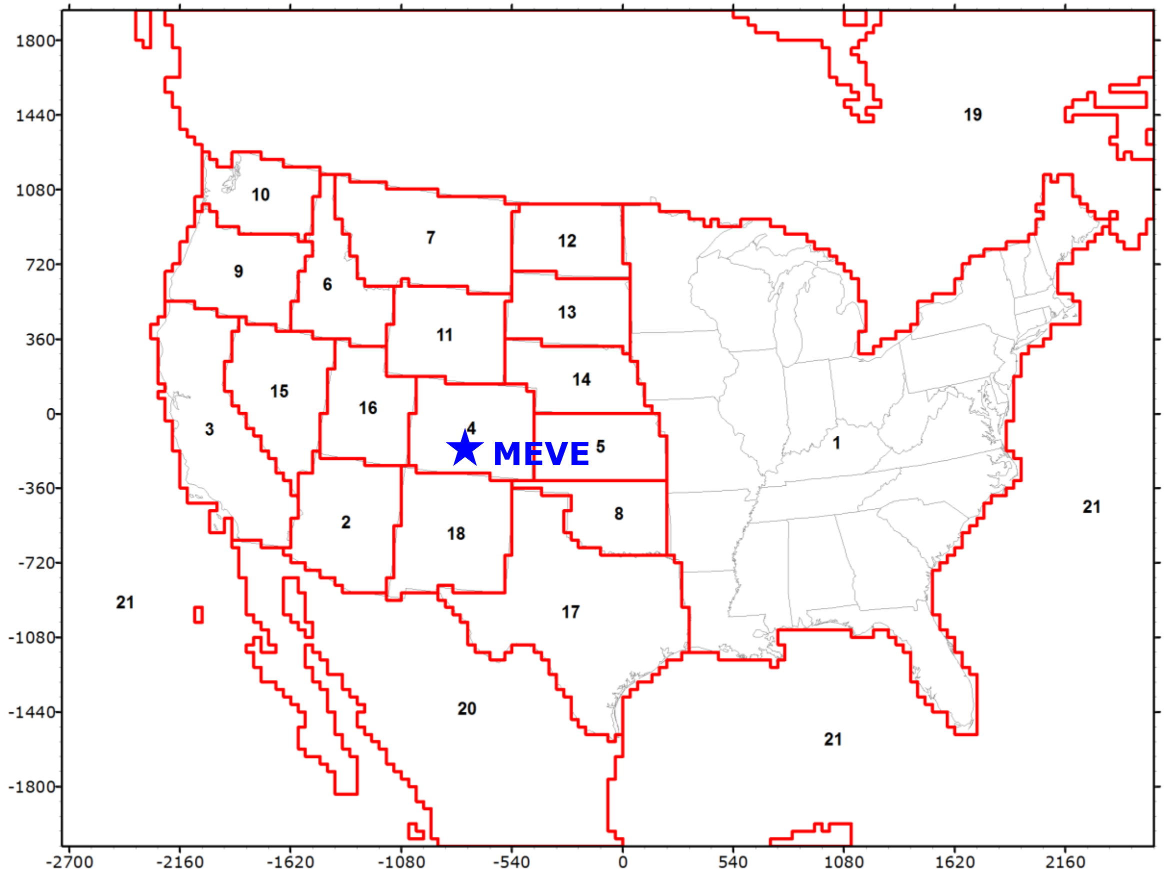
- PSAT uses tagged species that run in parallel to host model (CAMx PGM) to calculate contributions of PM concentrations from user-defined Source Groups (Source Regions/Categories)
- PSAT can use up to five families of PM tracers:
  - Sulfate (2 Tracers): SO2 and PS4
  - Nitrate/Ammonium (8 Tracers): NIT, RGN, TPN, NTR, HN3, PN3, NH3, PN4
  - Primary PM (6 Tracers): PEC, POA, PFC, PFN, PCC, PCS
  - SOA (14 Tracers): ARO, ISP, TRP, SQT, CG1-4, POA1-4, PPA
  - Mercury (3 Tracers): HGE, HGM, PHG
- Because of its small contribution and high expense, PSAT SOA frequently not used
  - Standard CAMx model output can be used to operationally define SOA from biogenic (SOAB) vs. anthropogenic (SOAA) precursors

PSAT TAGGED SPECIES SOURCE APPORTIONMENT
Example How PSAT Works for Sulfate (SO4)

- Two tagged reactive tracer species for SO2 and SO4 are emitted from each user-defined Source Group
  - SO4 formed (ΔSO4) in CAMx is allocated to Source Groups based on the relative contribution of SO2 precursors from all Source Groups
    - Source Group SO2 and SO4 are decayed based on its share of host model SO2 and SO4 loss
  - The sum of all Source Group's SO2 and SO4 reactive tracers equals the total CAMx concentration
- PSAT Traces Secondary PM Formation Back to its Primary Precursor:
  - SO4 → SO2; NO3 → NOx; NH4 → NH3
  - In Visibility Analysis using PSAT, NH4 Source Apportionment Not Used
    - Improve Equation Assumes SO4 and NO3 are completely neutralized by NH4 (AmmSO4, AmmNO3)
    - Level of NH3/NH4 affects level of NO3

BASE YEAR STATE CONTRIBUTIONS TO IMPAIRMENT

Example from 2008 WestJumpAQMS CAMx PSAT

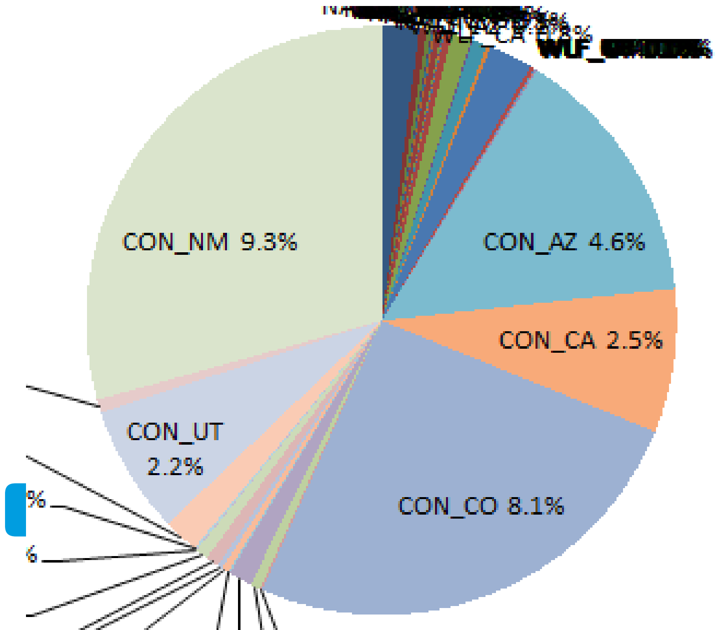


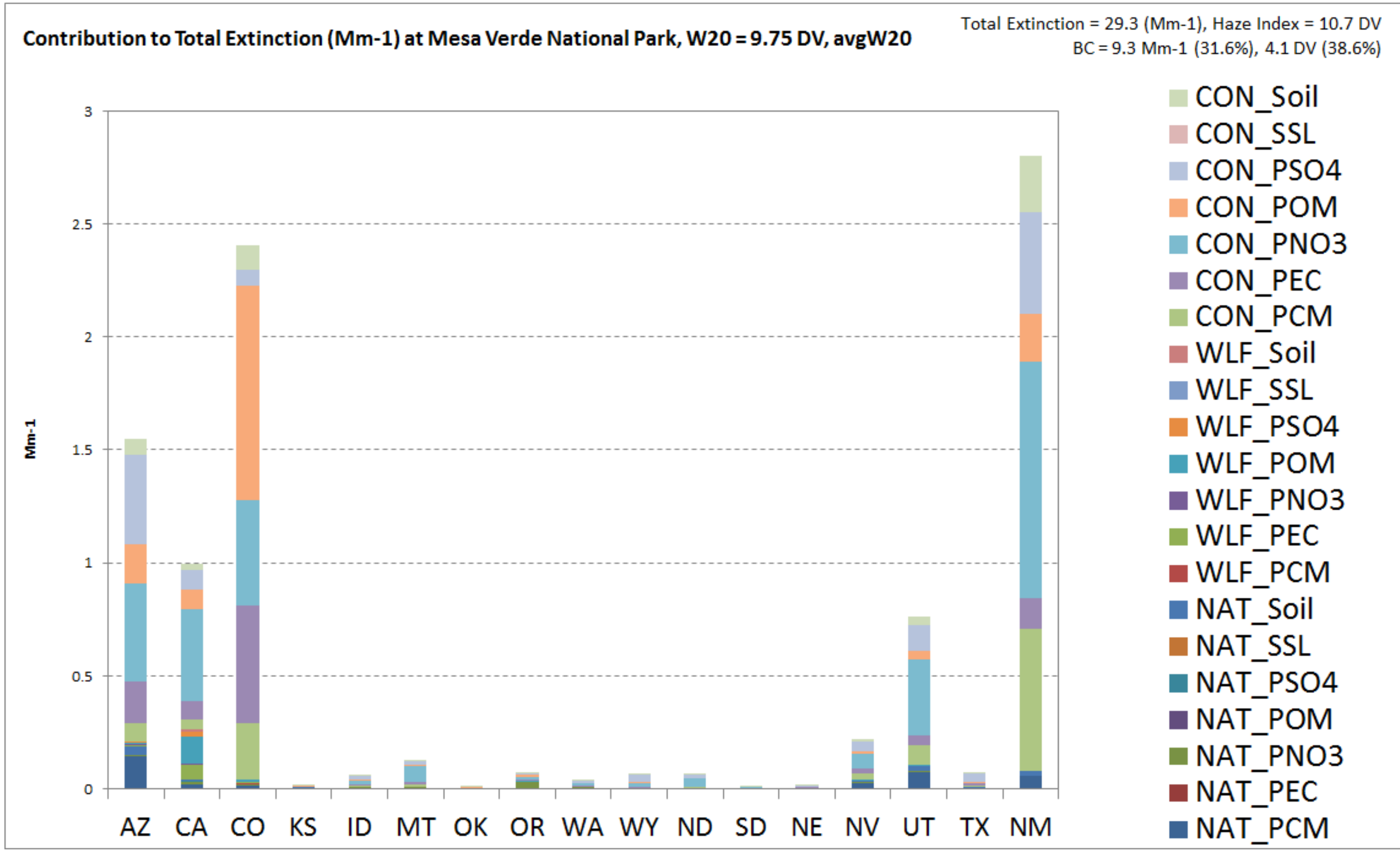
- 2008 PSAT State-Specific Modeling
  - 21 Source Regions
    - 17 Western States, EUSA, Mex, Can, Offshore
  - 5 Source Categories
    - CON = Controllable (Anthropogenic)
    - NAT = Natural
    - 3-Types of Fires (WF, Rx, Ag)
  - Boundary Conditions (BCs) + IC
  - 107 Source Groups (=21 x 5 + 2)
- Post-Process 2008 SA Output
  - SO4, NO3, EC, POA, PMF, PMC, SOAA and SOAB at Class I Areas
  - IMPROVE extinction equation
  - W20% Visibility Days

2008 STATE-SPECIFIC CONTRIBUTIONS TO VISIBILITY

Example State Contributions for Mesa Verde W20% Days

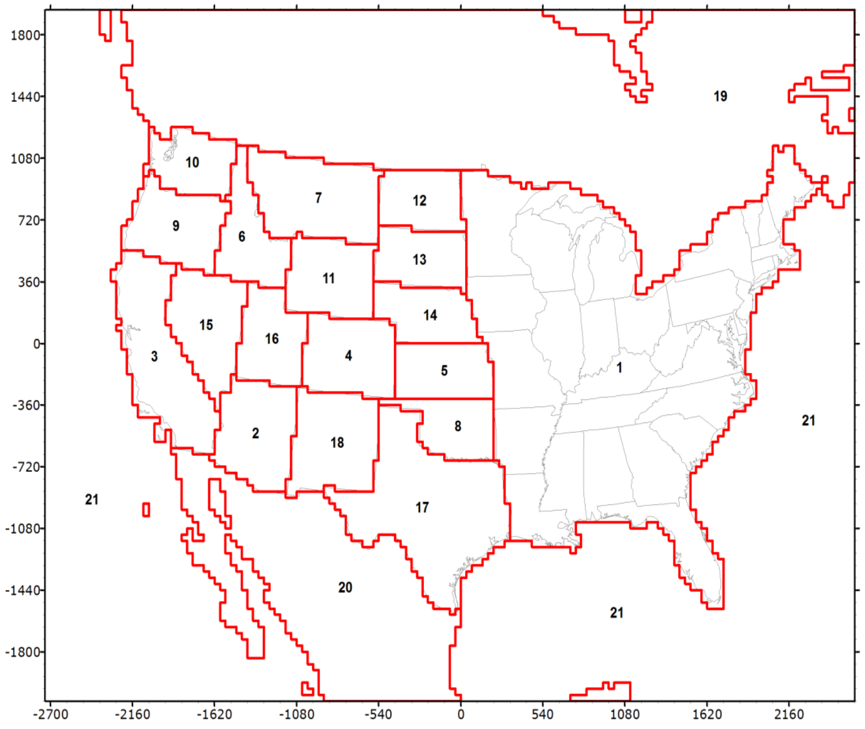
- W20% = 29.3 Mm^{-1} (10.7 dv)
  - BC = 9.3 Mm^{-1} (32%)
  - Anthropogenic Contributions:
    - NM = 2.72 Mm^{-1} (9%)
    - CO = 2.50 Mm^{-1} (8%)
    - AZ = 1.33 Mm^{-1} (5%)
    - CA = 0.73 Mm^{-1} (3%)
    - UT = 0.65 Mm^{-1} (2%)





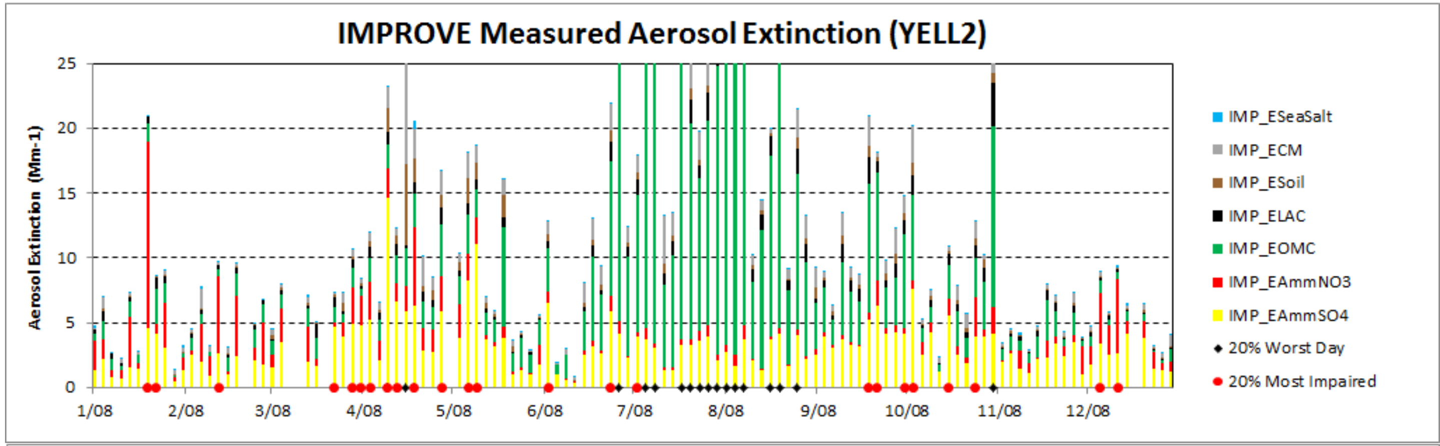
PSAT MOST IMPAIRED DAYS VISIBILITY
Use PSAT to Define Controllable Most Impaired Days

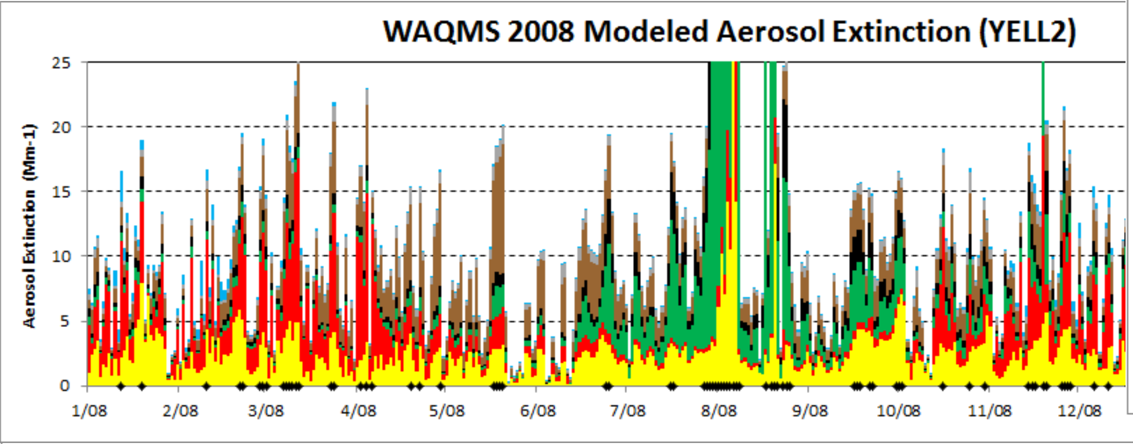
- 2008 CAMx PSAT source apportionment modeling for West-wide Jump-start Air Quality Modeling Study (WestJumpAQMS; https://www.wrapair2.org/WestJumpAQMS.aspx)
- 2011 CAMx PSAT source apportionment modeling for Western Air Quality Study (WAQS) available through the Intermountain West Data Warehouse (IWDW; http://views.cira.colostate.edu/tsdw/)
- Controllable:
  - U.S. Anthropogenic Emissions
  - U.S. Agricultural Burning
- Uncontrollable:
  - Biogenic, Sea Salt, Lightning, WBD
  - Wildfires and Prescribed Burns
  - Non-U.S. Anthropogenic Emissions (Mex/Can)
  - Boundary Conditions (BCs, International Transport)
    - International Transport (BCs) includes both Anthropogenic and Natural sources

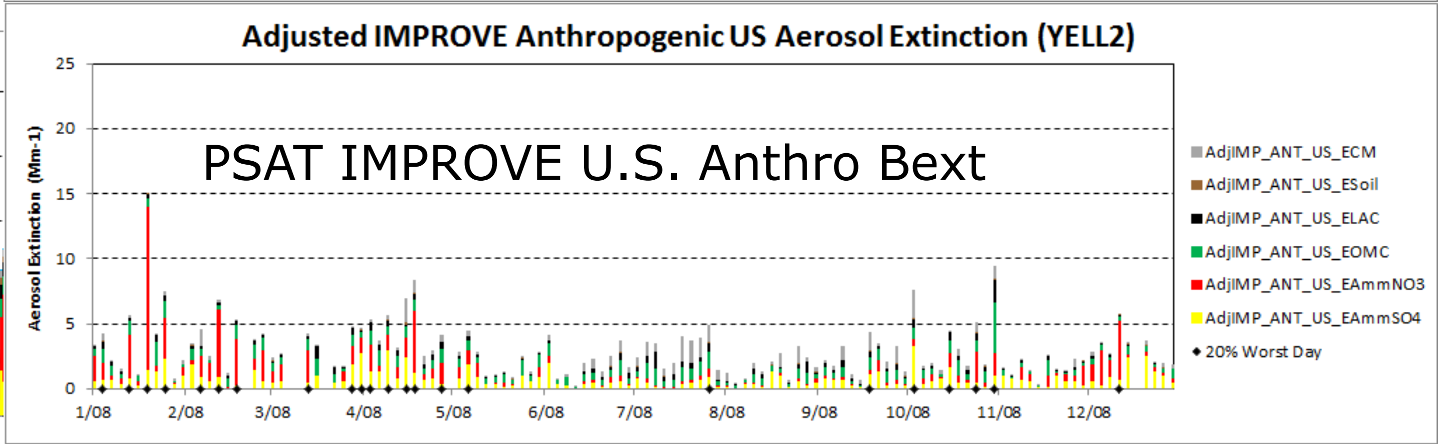


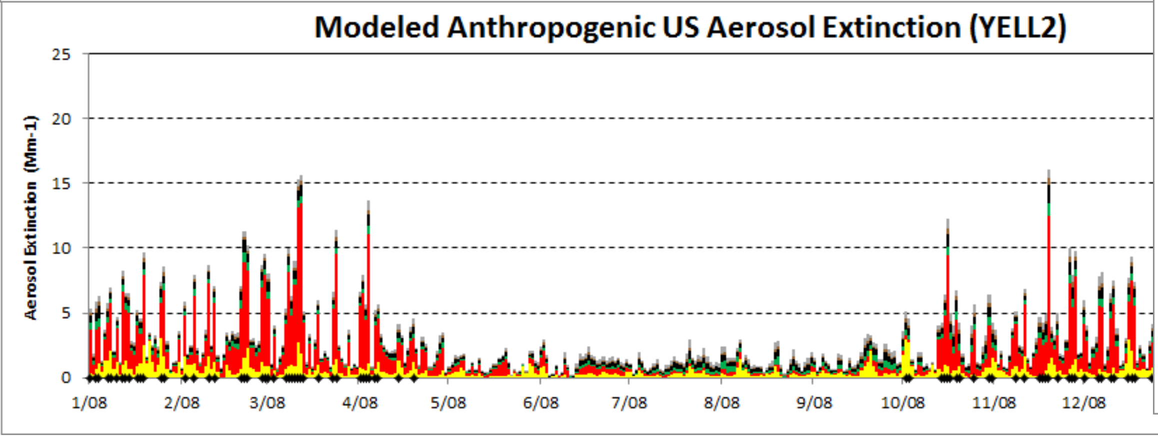
MODEL MOST IMPAIRED DAYS

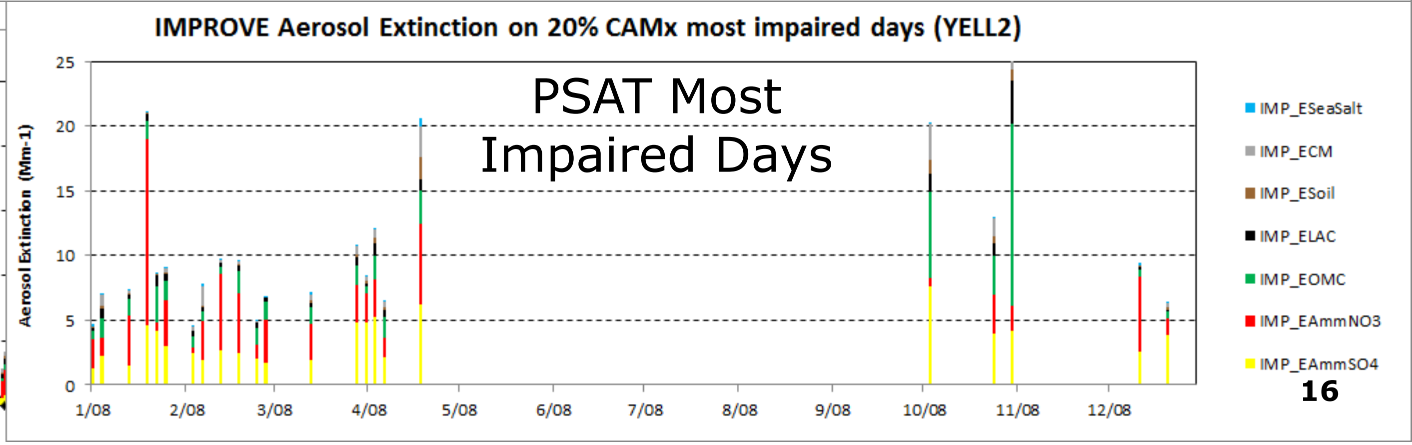
- Daily PSAT Controllable/Total Extinction Ratios Applied to IMPROVE Measured Extinction
  - SO4, NO3, EC, OA, PMF, PMC
  - Rank Controllable Extinction to find 20% Modeled Most Impaired Days





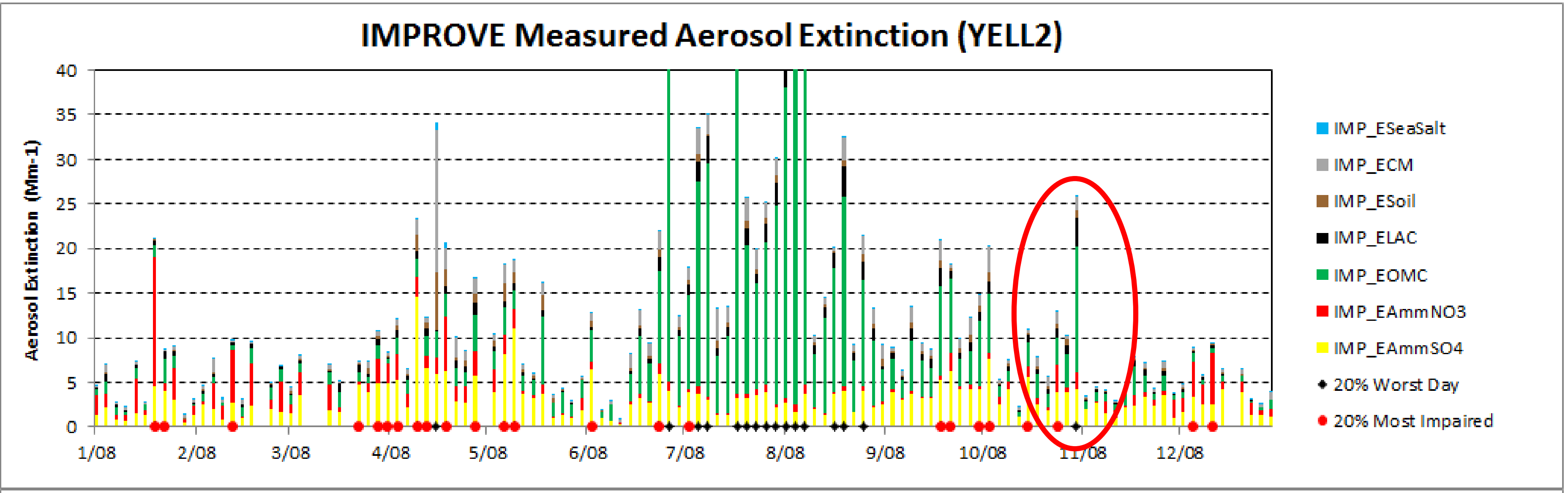


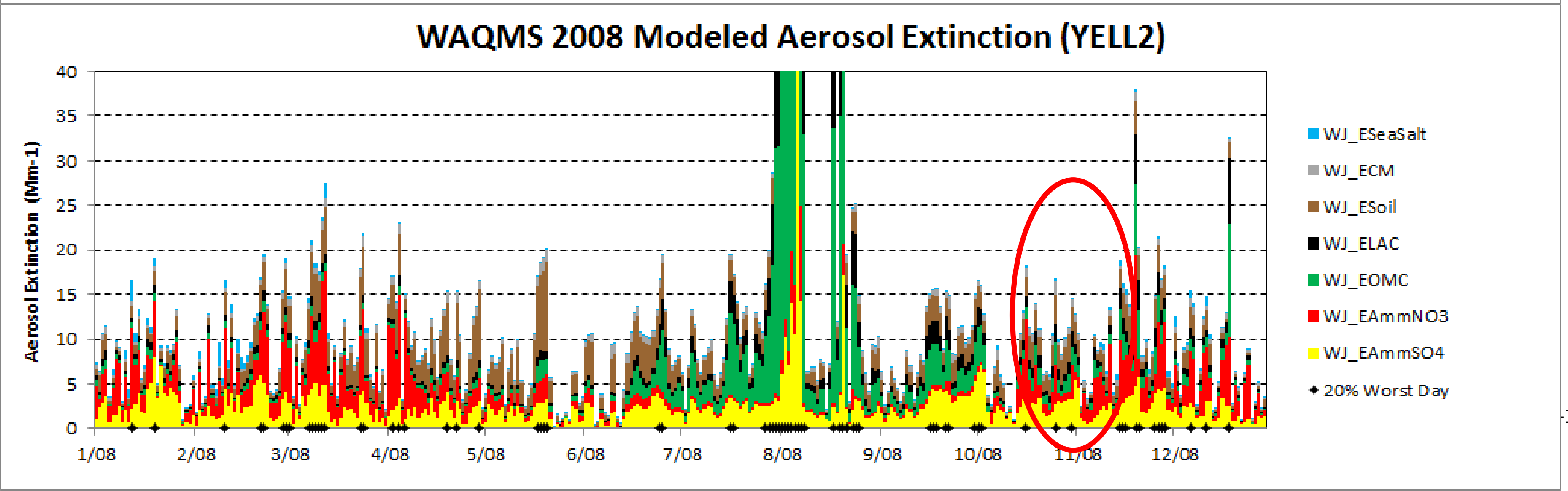




2008 YELLOWSTONE -- IMPROVE AND CAMX EXTINCTION

Model Captures Most High Observed WF Impacts

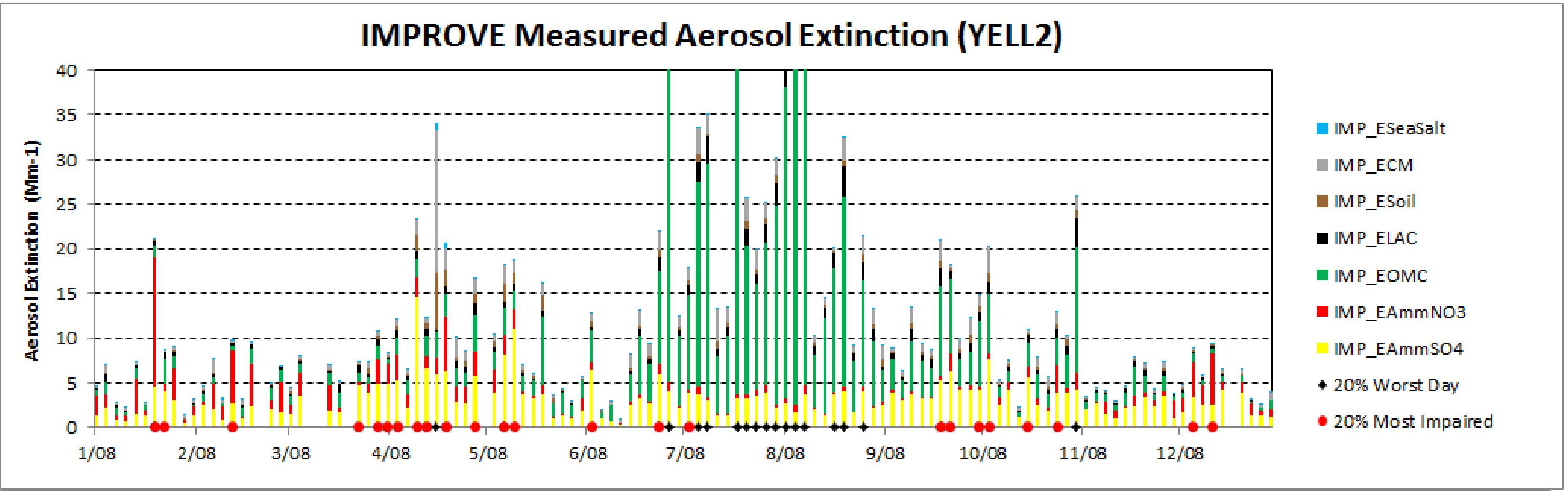


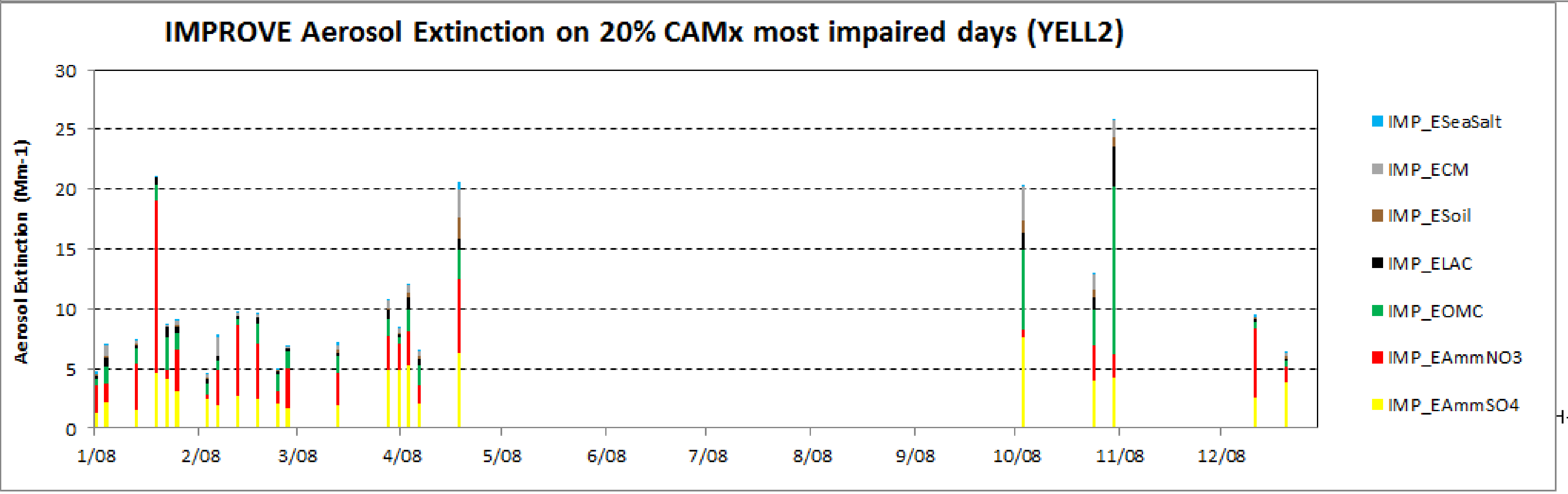


- Model sees Wildfire impacts Jul-Aug-Sep
- Fails to model observed Wildfire impact on Oct 30
  - Allows Wildfire impacts to leak into PSAT Most Impaired Days metric

2008 YELLOWSTONE – PSAT MOST IMPAIRED DAYS

PSAT Controllable Extinction Applied to IMPROVE

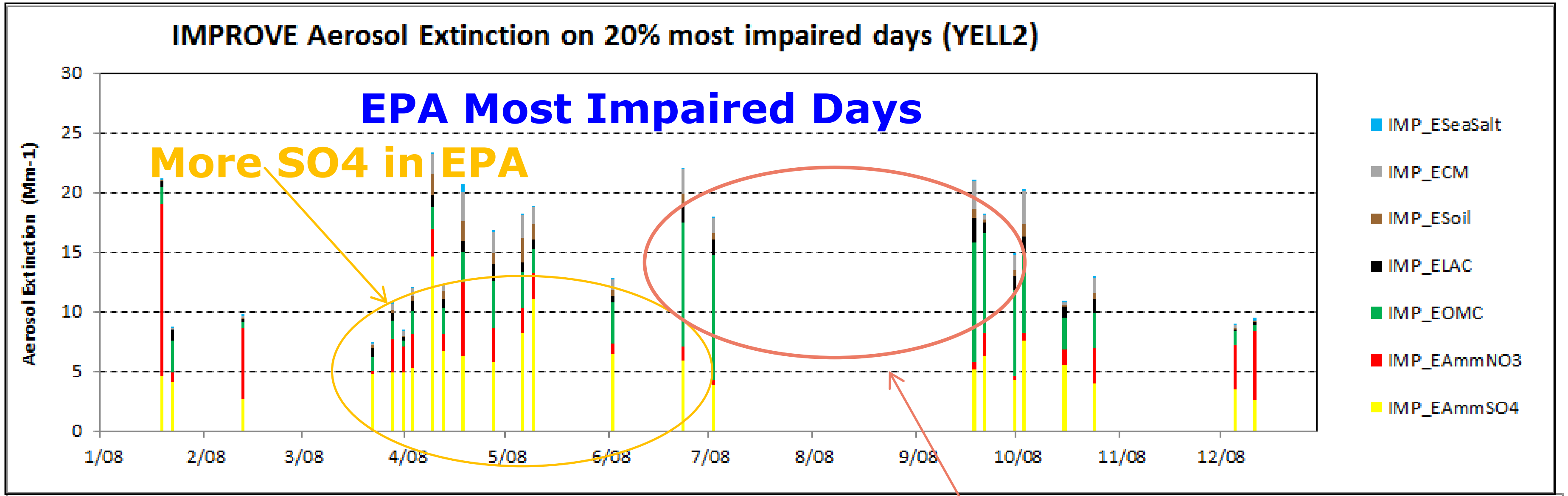


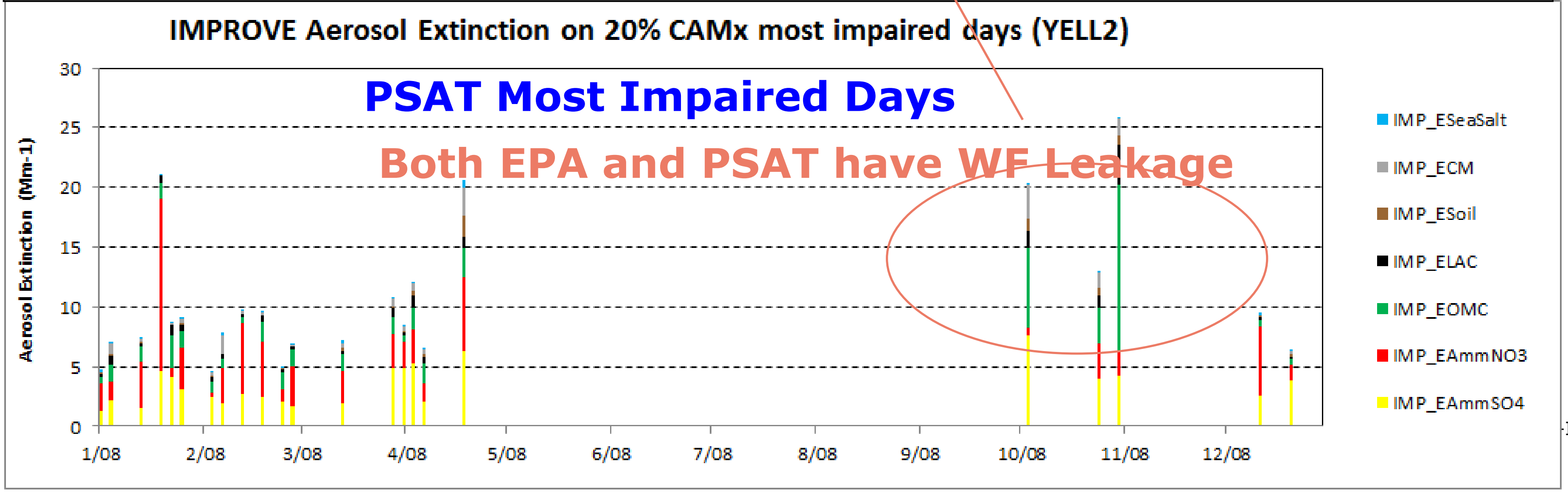


- CAMx PSAT fails to identify Wildfire influenced days in Oct
  - Accuracy of wildfire emissions and their impacts at IMPROVE monitors important
  - Major dust storm emissions are even more uncertain

2008 YELLOWSTONE – EPA VS. PSAT MOST IMPAIRED DAYS

More Consistencies w/ PSAT/EPA than Old W20% Days

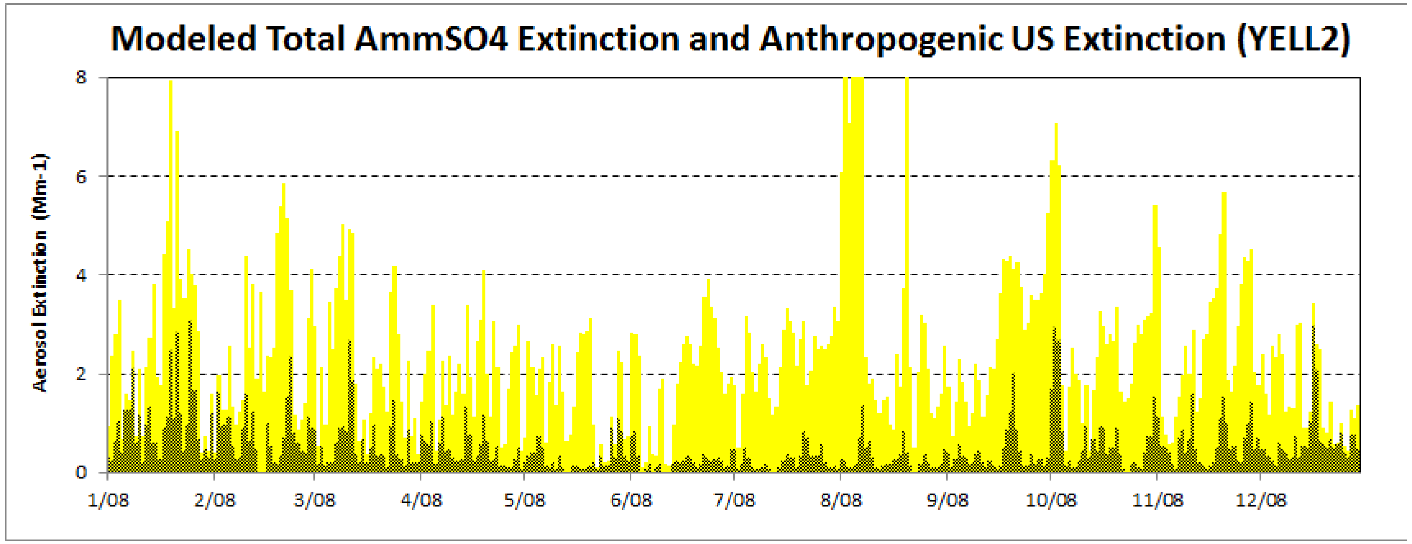




- Both approaches show big improvement over haziest W20% days
  - Reduces wildfire and dust storm impacts
- Moves days from hot summer to cooler seasons
  - Both approaches pick up more nitrate than W20% Days
  - EPA Most Impaired Days has more sulfate

MODEL/EPA INCONSISTENCIES IN UNCONTROLLABLE SOURCES
Visibility Projections and URP Glidepath Comparison

- 2008 and 2011 PSAT modeling estimates most of the SO4 visibility extinction at western U.S. Class I areas comes from outside of the U.S. (International Sources)

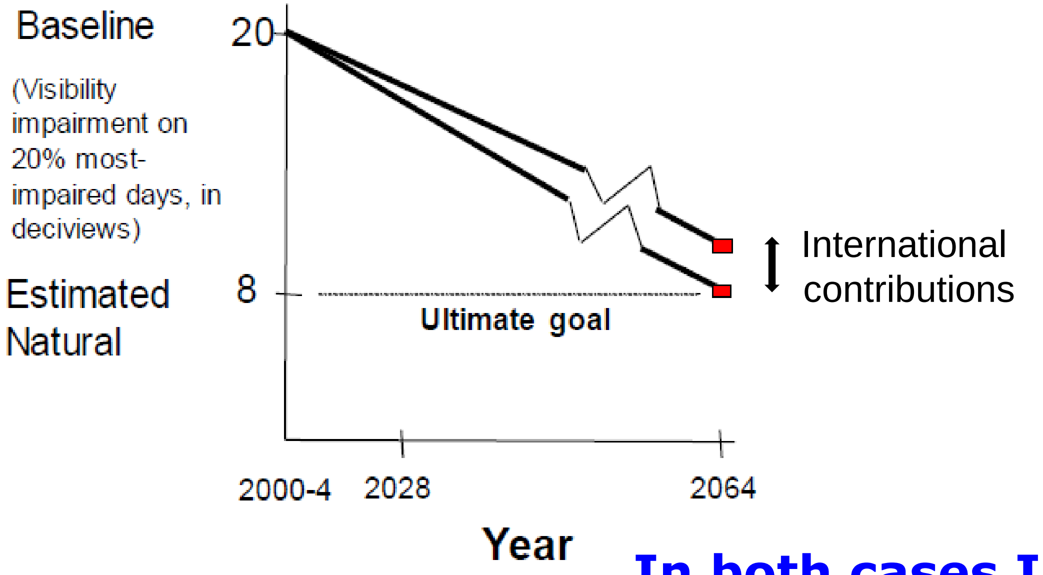


- High international SO4 not accounted for in EPA URP Glidepath
  - EPA Most Impaired Days implicitly assumes all SO4 controllable
  - Background natural conditions based on SO4 from ~1980s when International and Offshore SO2 emissions were much lower

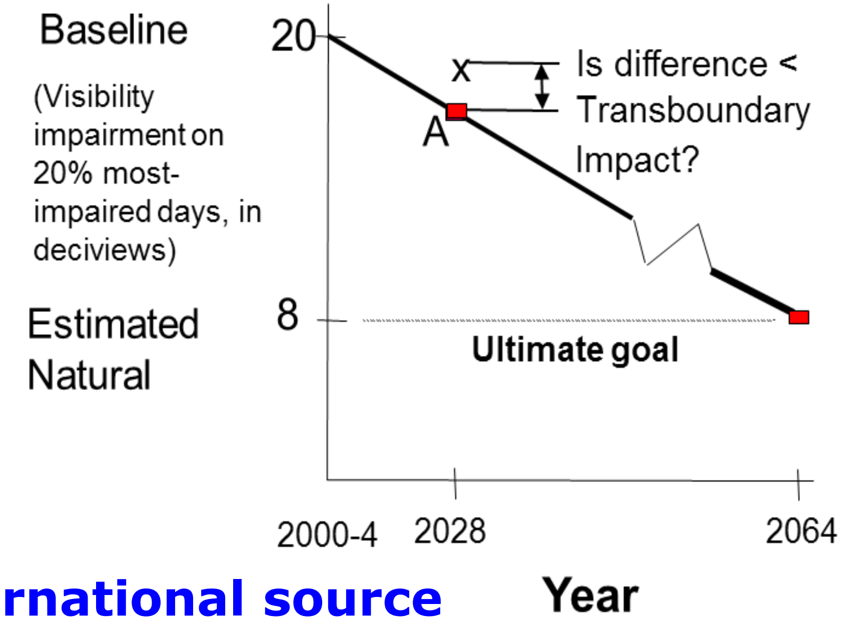
TREATMENT OF INTERNATIONAL CONTRIBUTIONS

Using Modeled Source Contributions in URP

- EPA draft Guidance suggests adding the international anthropogenic emissions extinction to the 2064 Natural Conditions in the URP Glidepath



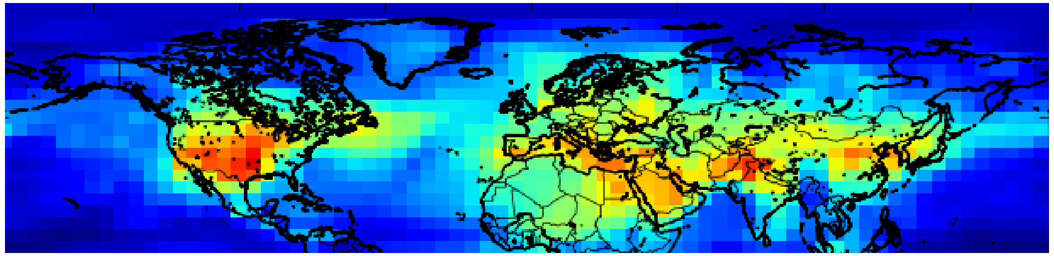
- Others have suggested subtracting the International anthropogenic emissions extinction from the modeled 2028 projection when comparing to the URP Glidepath



In both cases International source contributions are needed

EPRI STUDY TO EXAMINE INTERNATIONAL CONTRIBUTIONS

BF Sensitivity Application



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

EPRI STUDY TO EXAMINE INTERNATIONAL CONTRIBUTIONS
Additional Analysis 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 Glidepath

TREATMENT OF AMMONIUM IN RHR PROCESS

Ammonium (NH4) PM2.5 Not Fully Accounted For

- The IMPROVE reconstructed mass extinction equation for visibility assumes that Sulfate and Nitrate are fully neutralized by ammonium:
  - AmmSO4 = $[(NH_4)_2SO_4]$ = 1.375 x $[SO_4]$
  - AmmNO3 = $[NH_4NO_3]$ = 1.29 x $[NO_3]$
- Nitrate will not be PM2.5 without Ammonium, or other neutralizing cation
  - SO4 is a particle without Ammonium
- The PSAT NH4 source apportionment is not used in the visibility calculations
  - If AmmNO3 formation is Ammonia limited, using IMPROVE visibility equation will not identify the source precursors that will most effectively reduce visibility impairment due to AmmNO3
  - Importance of Ammonia precursors in visibility impairment is understated
    - Ammonia also important in Nitrogen deposition issues

CONCLUSIONS
Use of Source Apportionment for RH Planning

- There are a variety of uses of Regional Model Source Apportionment Tools for assisting in Regional Haze Rule SIPs:
  - Contributions of U.S. Anthropogenic (Controllable) emissions in BY and FY
  - Contributions of BY/FY International Anthropogenic Emissions
  - Estimates of Natural Conditions under BY and FY emission conditions
  - Calculation of alternative Glidespaths and FY Model Projections
    - US Total Anthropogenic Extinction and by Species (SO4, NO3, EC, OA, PMF, PMC)
  - Modeled PSAT Most Impaired Days visibility metric
- Results can be used in planning (e.g., coordination among states), control strategy identification and part of demonstration of reasomable progress goals (RPGs) toward natural conditions

THANK YOU