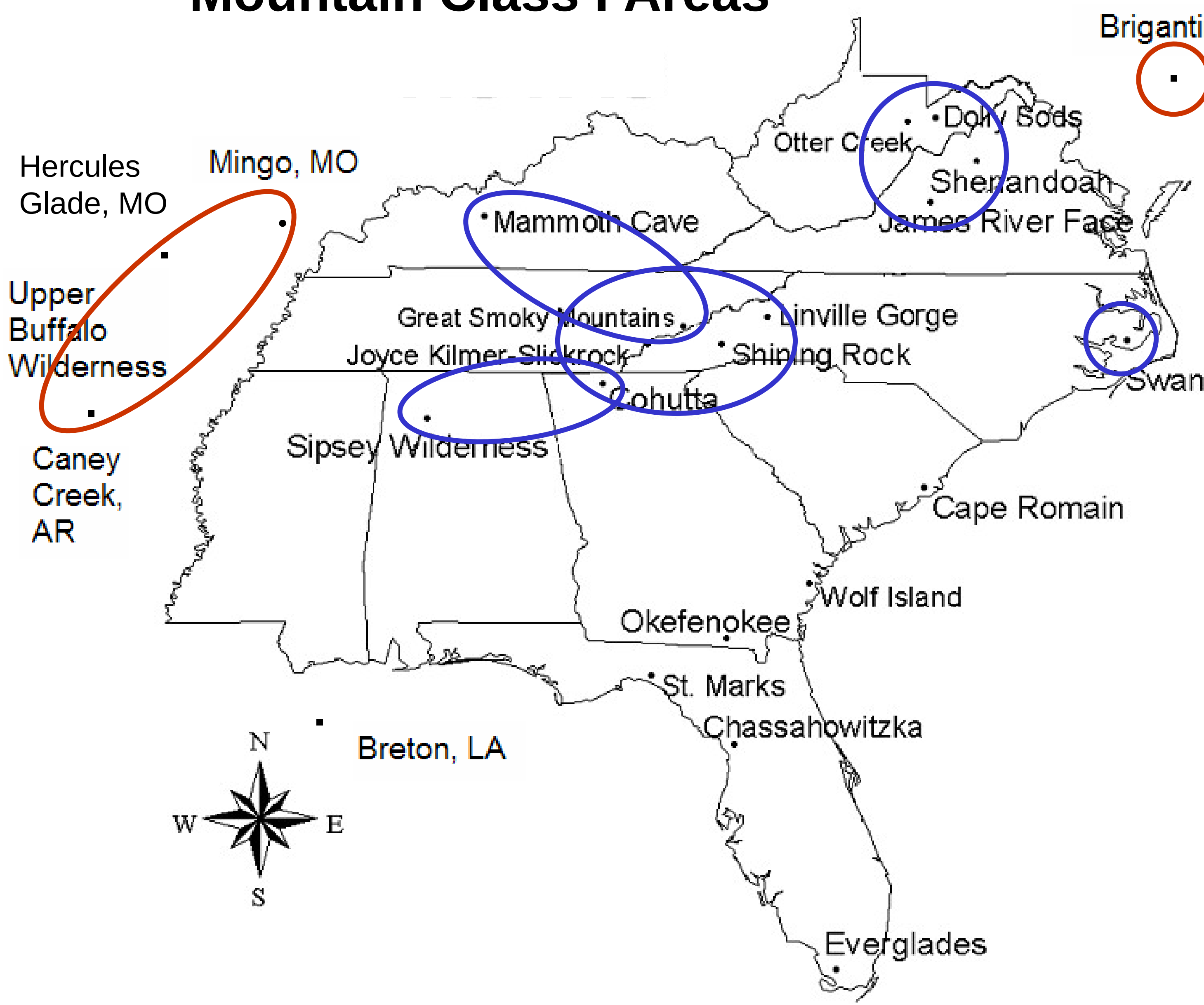
Mammoth Cave Contribution Assessment

Draft May 29, 2007

Mountain Class I Areas

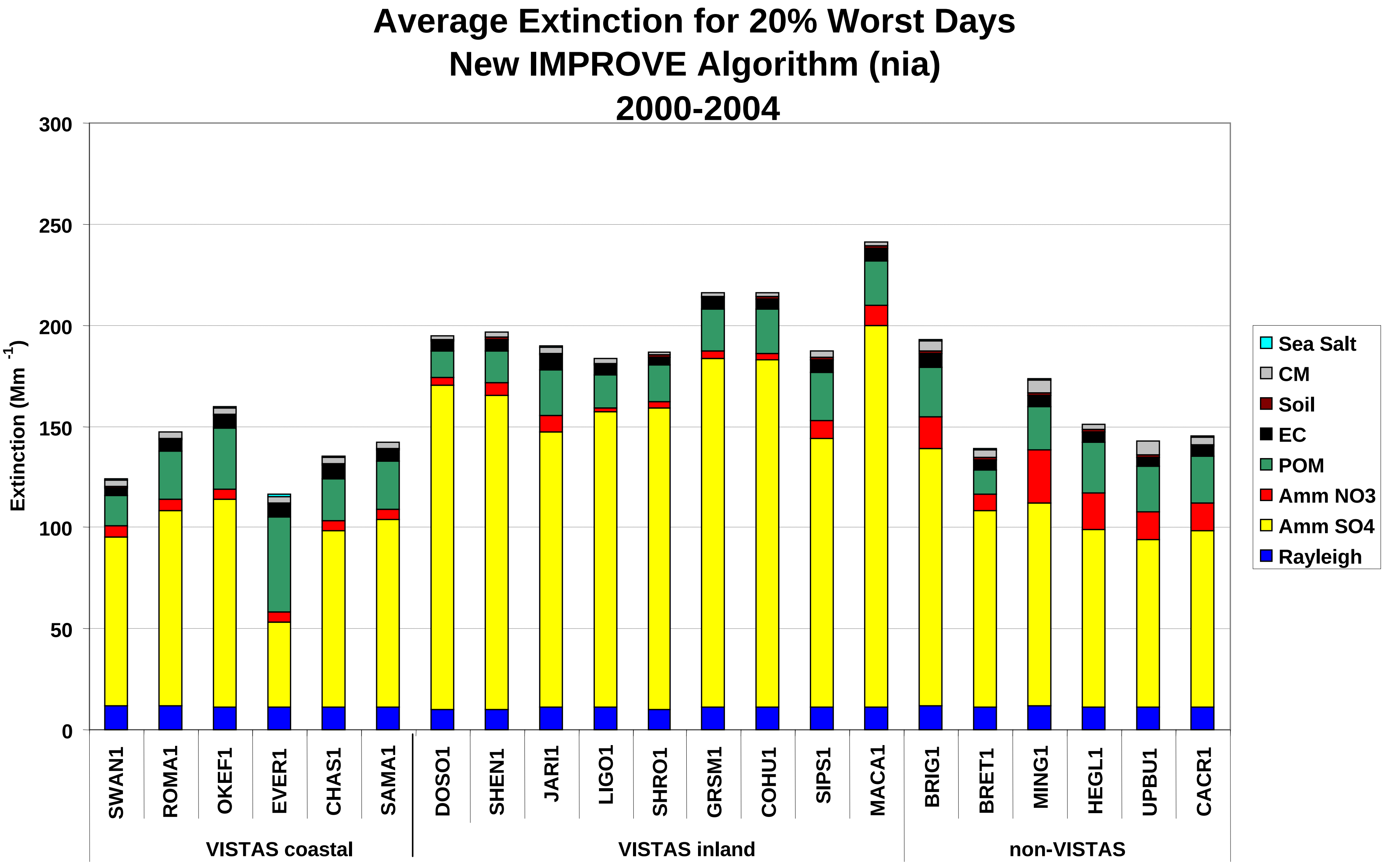


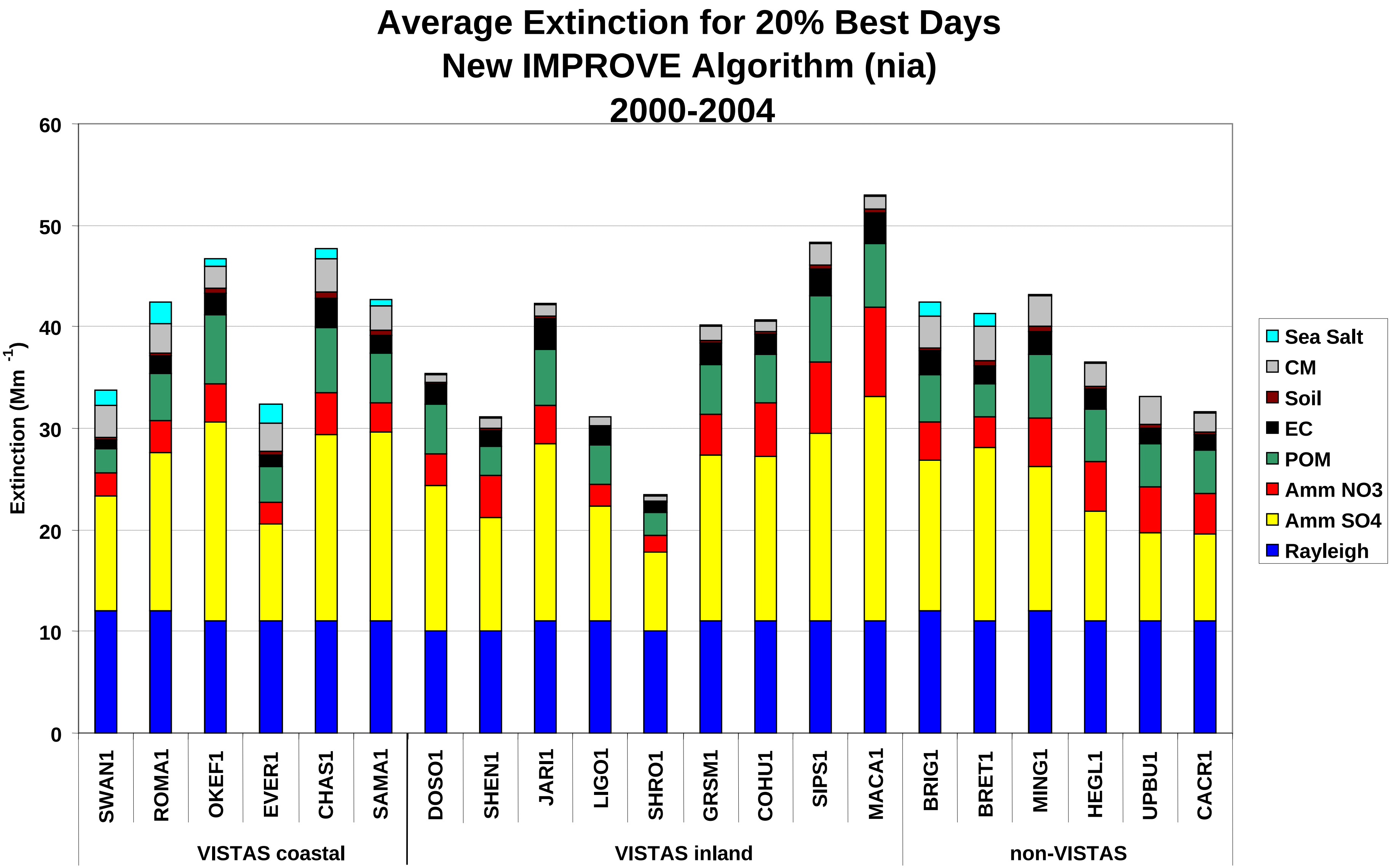
Area of Influence Groupings

1. GRSM (5)
2. MACA
3. SHEN (4)
4. SIPS
5. SWAN
6. BRIG
7. MING (4)

Objectives

- Pollutant Contributions: 2000-2004 20% Best and Worst Days
- New IMPROVE equation
  - Natural Background Calculations
- Glidepath and Progress in 2018
- Emissions Sensitivities
- Areas of Influence
  - Back Trajectory, Residence Time
  - Source Sector Emissions
  - List of Contributing Sources (states to supply)


Average Extinction for 20% Worst Days
New IMPROVE Algorithm (nia)
2000-2004
Extinction (Mm -1)
300
250
200
150
100
50
0
Sea Salt
CM
Soil
EC
POM
Amm NO3
Amm SO4
Rayleigh
SWAN1
ROMA1
OKEF1
EVER1
CHAS1
SAMA1
DOSO1
SHEN1
JARI1
LIGO1
SHRO1
GRSM1
COHU1
SIPS1
MACA1
BRIG1
BRET1
MING1
HEGL1
UPBU1
CACR1
VISTAS coastal
VISTAS inland
non-VISTAS

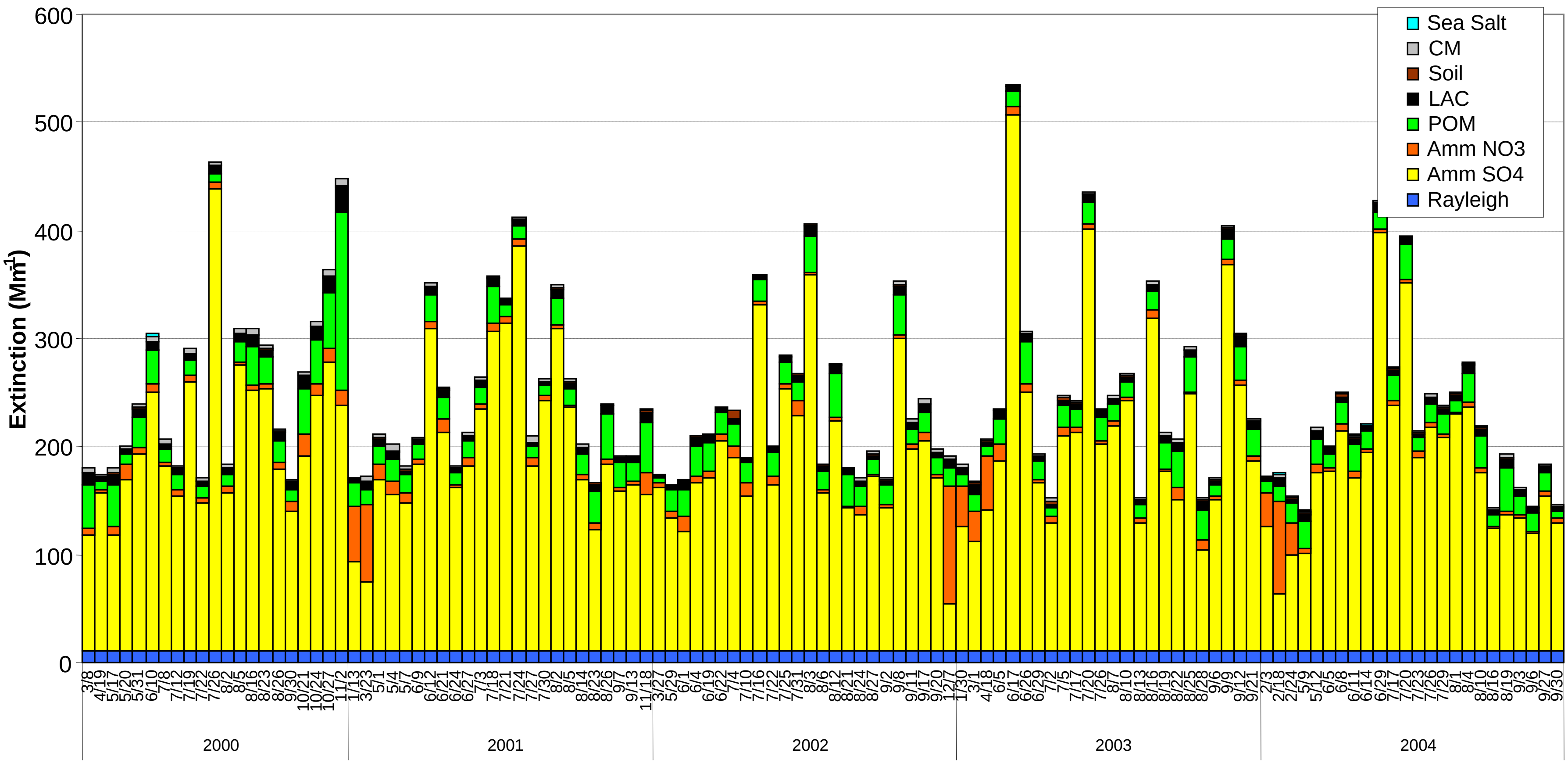

Average Extinction for 20% Best Days
New IMPROVE Algorithm (nia)
2000-2004
Extinction (Mm -1)
0
10
20
30
40
50
60
SWAN1
ROMA1
OKEF1
EVER1
CHAS1
SAMA1
DOSO1
SHEN1
JARI1
LIGO1
SHRO1
GRSM1
COHU1
SIPS1
MACA1
BRIG1
BRET1
MING1
HEGL1
UPBU1
CACR1
VISTAS coastal
VISTAS inland
non-VISTAS
Sea Salt
CM
Soil
EC
POM
Amm NO3
Amm SO4
Rayleigh

2000-2004 Reconstructed Extinction

New IMPROVE Algorithm

20% Worst Days

Mammoth Cave, KY

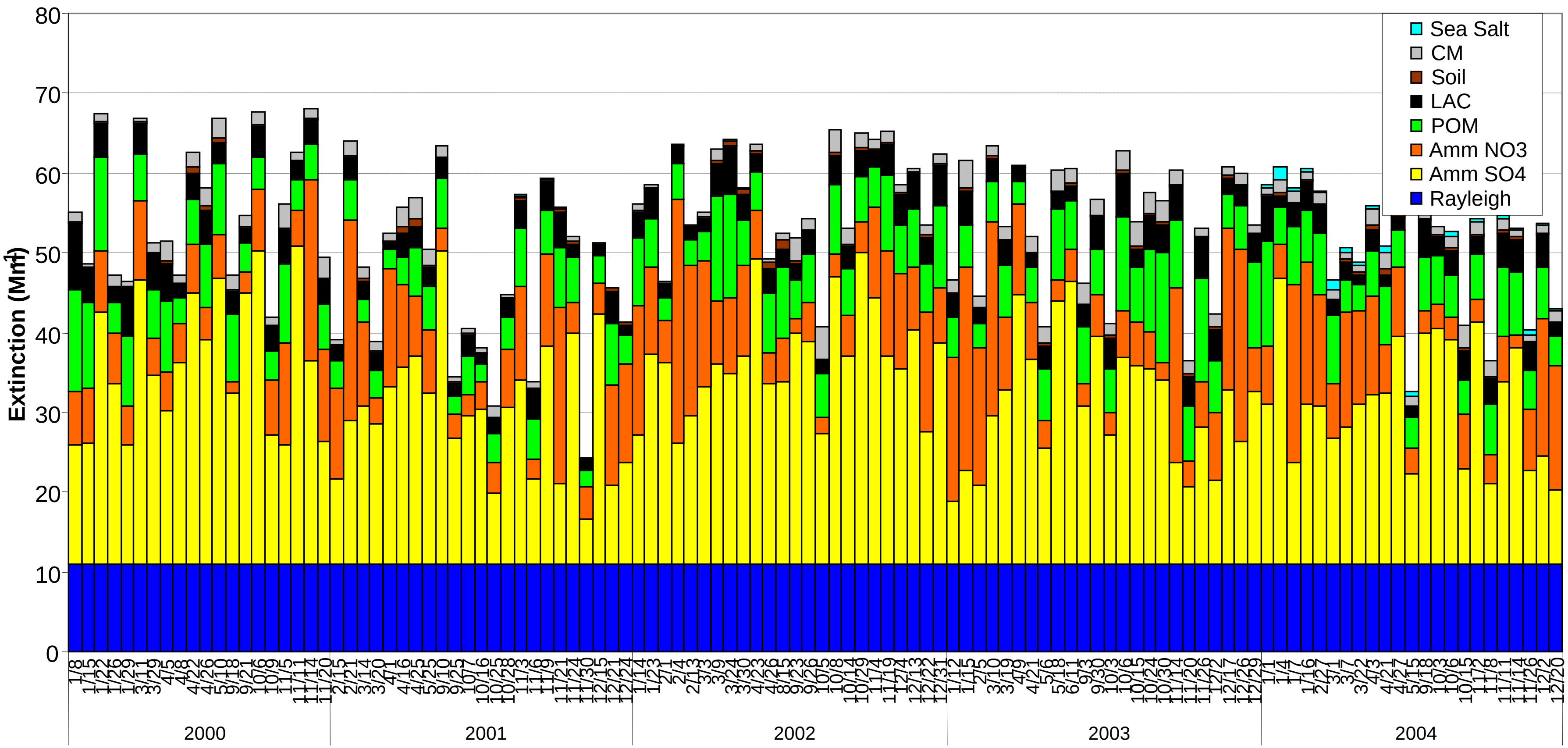


2000-2004 Reconstructed Extinction

New IMPROVE Algorithm

20% Best Days

Mammoth Cave, KY



Conclusions: Contributions

- On 20% Worst Days
  - SO_4 dominates light extinction most days
  - Organic carbon smaller contribution; fire indicated on few days
  - NO_3 contribution on some winter days
- SO_4 also dominates 20% Best Days
- Conclude: Focus on reducing SO_2 emissions

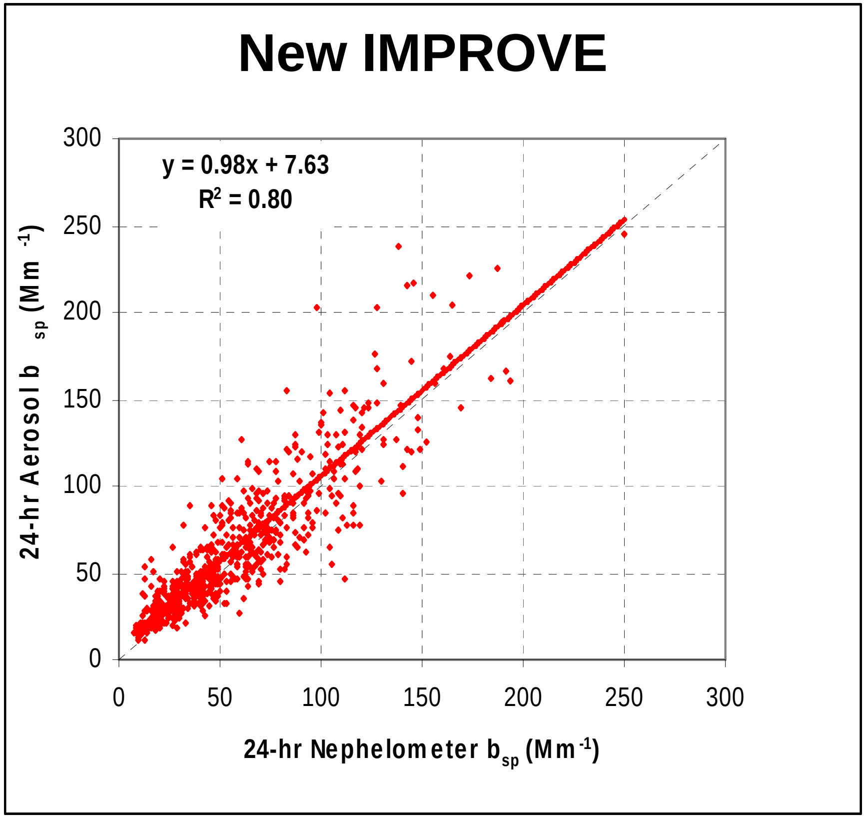
New IMPROVE Equation

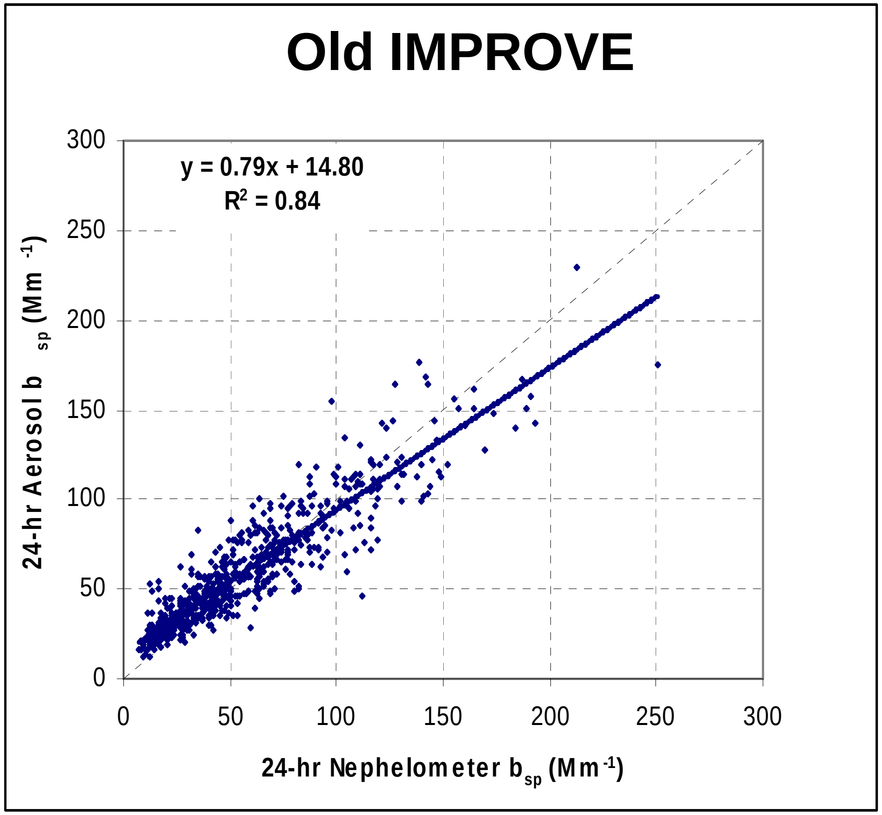
- Endorsed by IMPROVE Steering Committee as accounting for latest science
  - Defines two terms each for SO4, NO3, and OC with higher extinction efficiencies (b_{ext}) associated with high mass and lower b_{ext} associated with low mass
  - Increases mass multiplier for organic carbon from 1.4 to 1.8
  - Adds term for fine mass sea salt
  - Adds term for absorption due to NO2 (only if NO2 measurements available)
  - Calculates site specific Rayleigh scattering

New IMPROVE Equation

- Light scattering measured by nephelometer and calculated using new IMPEOVE equation show good correlation
  - Original equation under estimated scattering on highest days and over estimated scattering on lowest days
- New equation generally indicates higher extinction on 20% worst days and lower extinction on 20% best days

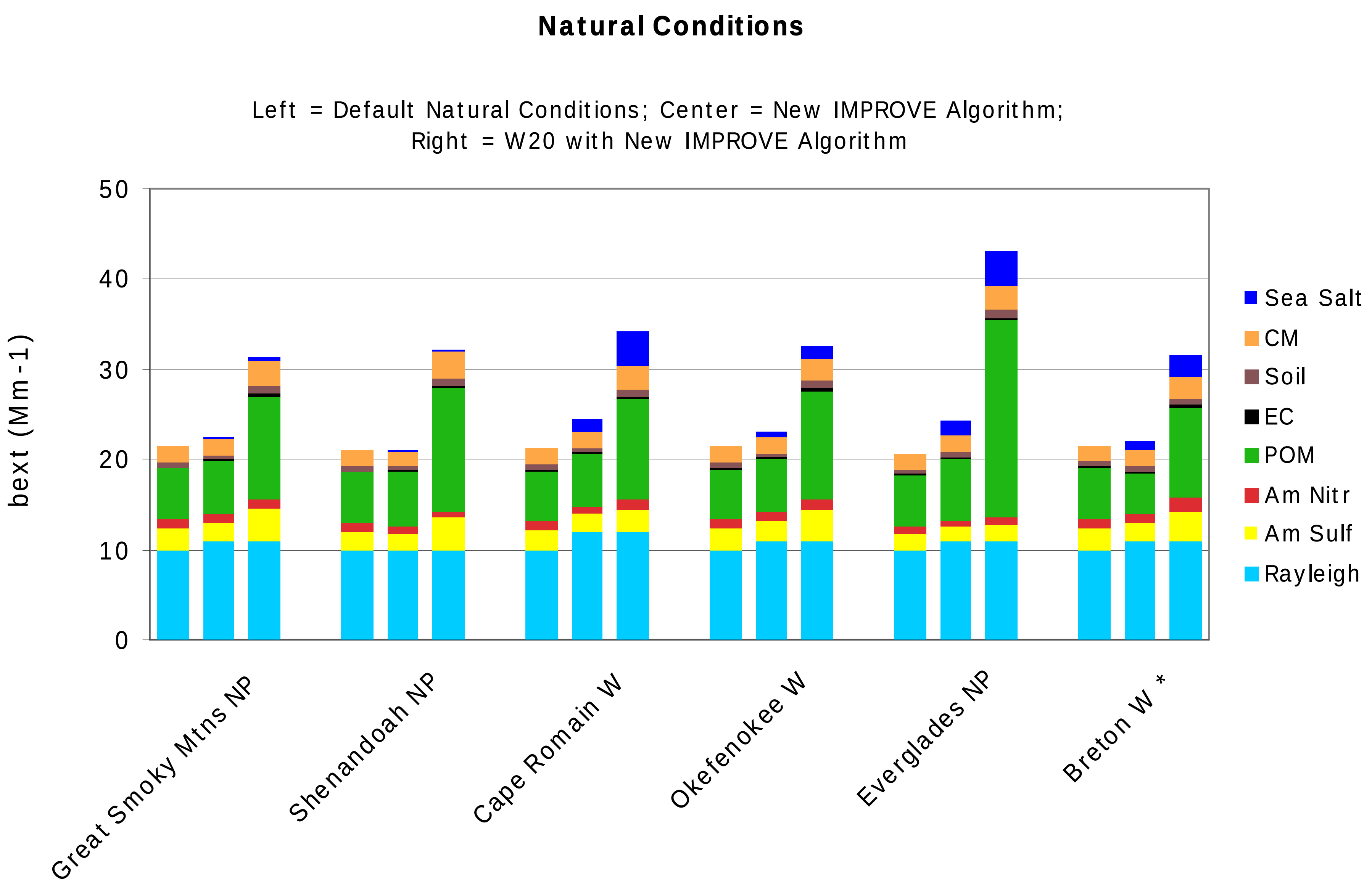
Aerosol Scattering vs. Nephelometer Scattering Using New or Old IMPROVE Algorithm and Daily f(RH) Mammoth Cave, KY 1995 - 2004





Natural Background Visibility

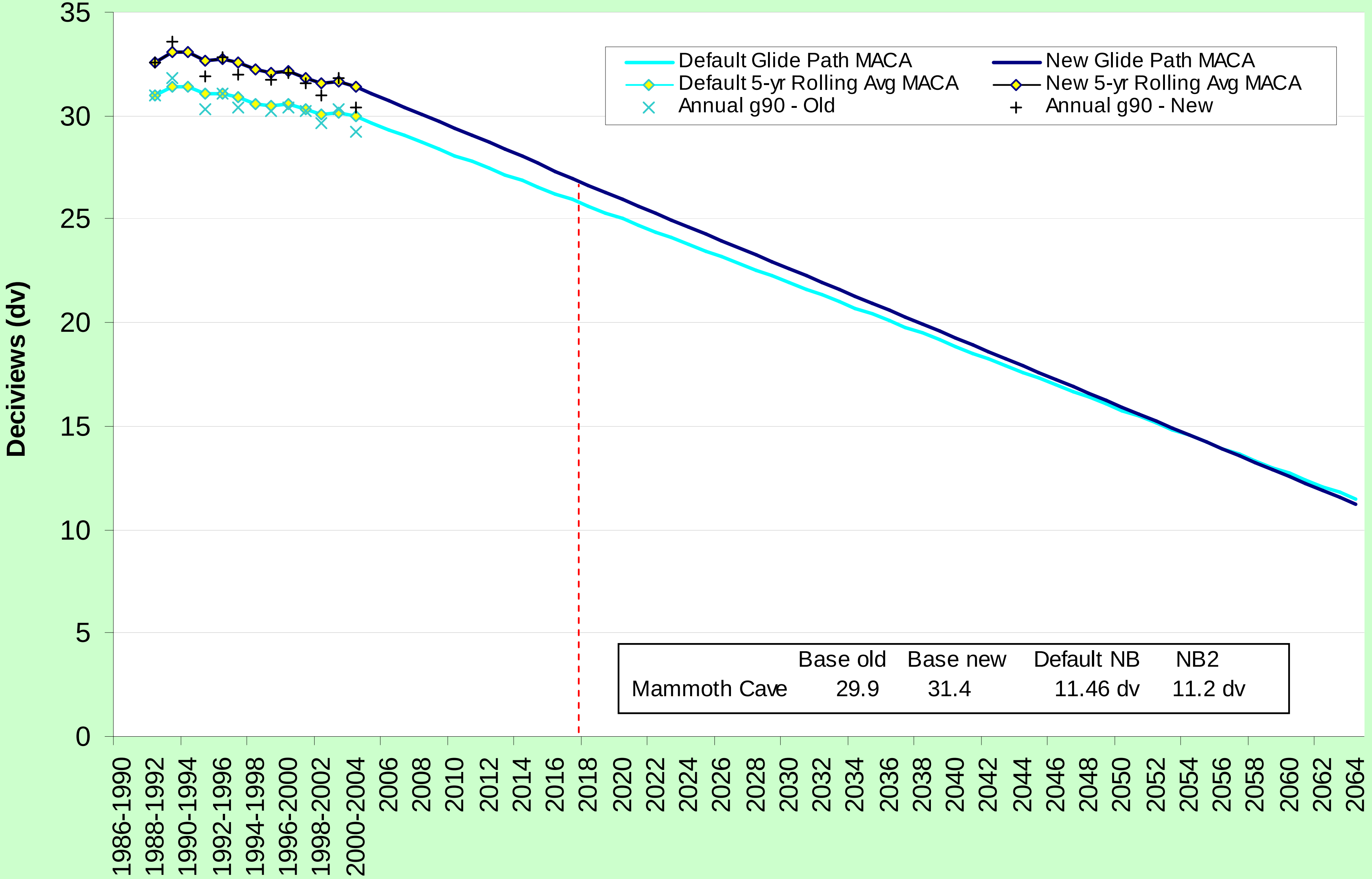
- Tombach reviewed for VISTAS the original assumptions by Trojonis et al. 1990 used to define natural background levels of visibility impairing pollutants and recent scientific developments. He also made recommendations for changes in assumptions. (Tombach and Brewer, 2005)
- Hand and Malm (2005) reviewed assumptions for calculating light extinction in the original IMPROVE equation and made recommendations for revisions.
- The IMPROVE Steering Committee reviewed and approved new equation for calculating light extinction (2005).
- Ames (2006) reviewed methods to project natural background levels for 20% worst visibility days using the new IMPROVE equation and IMPROVE approved revised methods
- Revised glide paths calculated for reaching natural background conditions at Class I areas by 2064.



Natural Conditions
Left = Default Natural Conditions; Center = New IMPROVE Algorithm;
Right = W20 with New IMPROVE Algorithm
bext (Mm-1)
50
40
30
20
10
0
Great Smoky Mtns NP
Shenandoah NP
Cape Romain W
Okefenokee W
Everglades NP
Breton W *
Sea Salt
CM
Soil
EC
POM
Am Nitr
Am Sulf
Rayleigh

Glide Path to Natural Conditions (2004-2064)

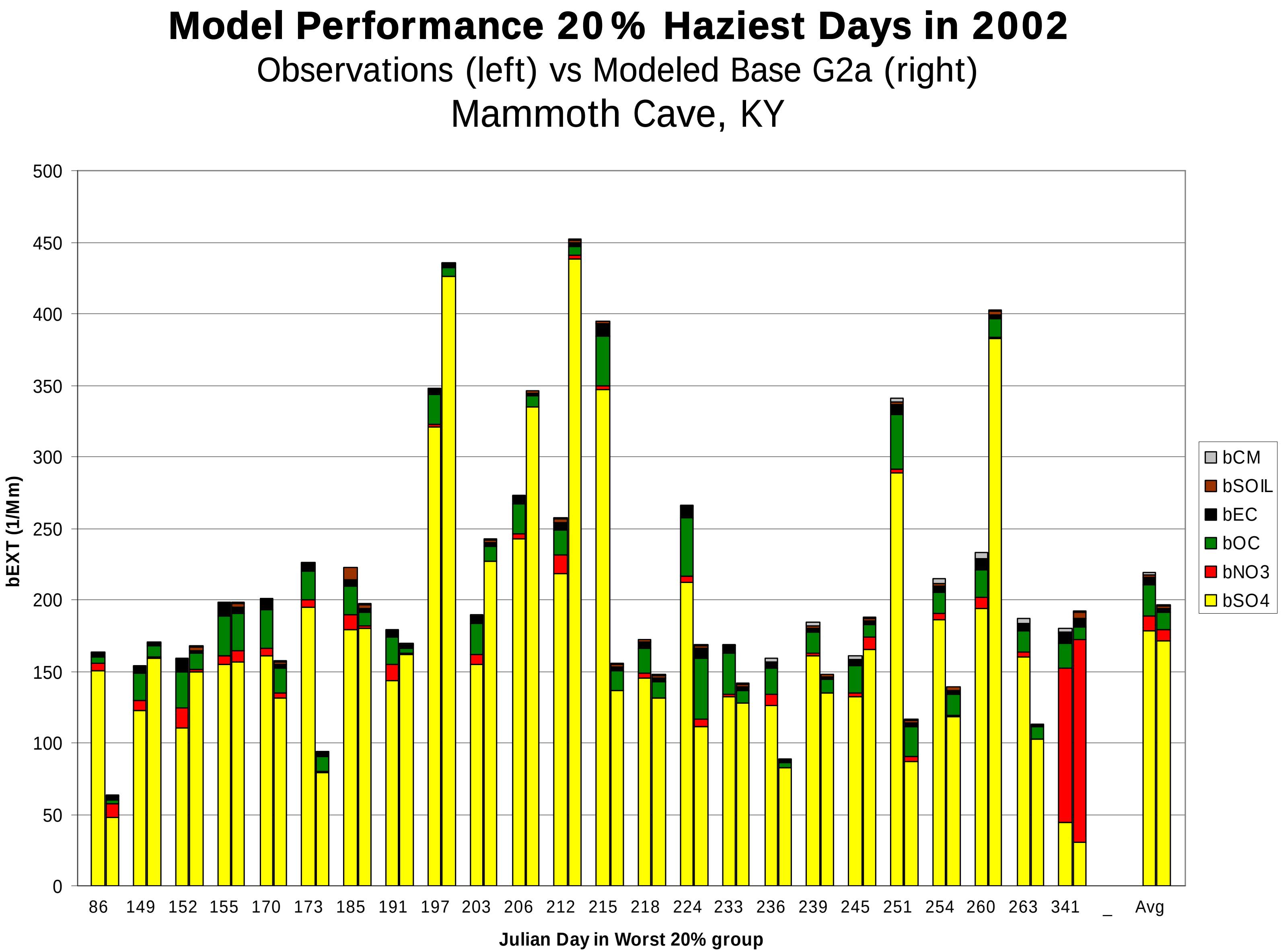
(5-yr Rolling Average for 20% Haziest Days - New IMPROVE equation and NB II)



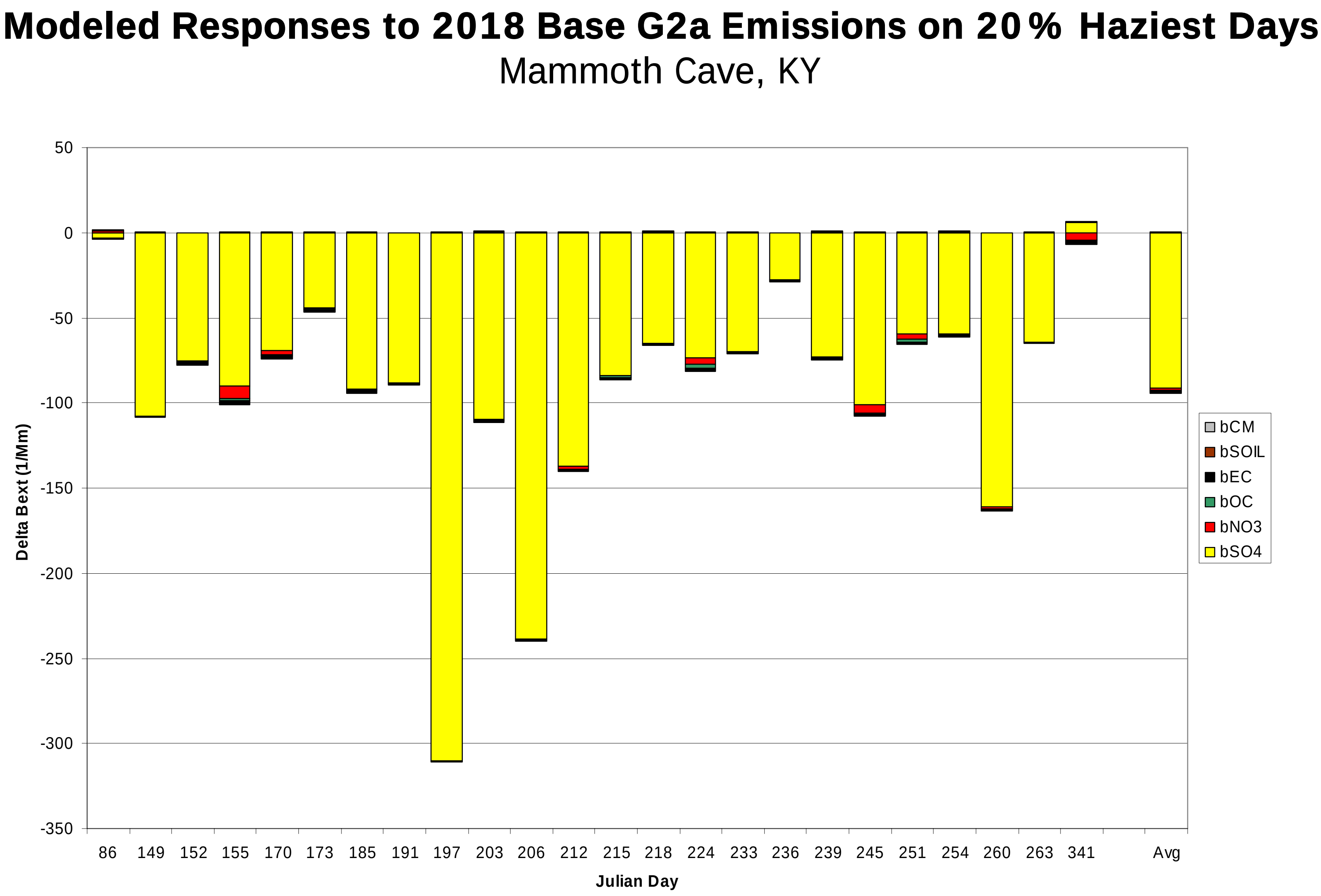
	Base old	Base new	Default NB	NB2
Mammoth Cave	29.9	31.4	11.46 dv	11.2 dv

VISTAS 2018 Base G2 Visibility Projections (Delivered Mar 2007)

- CMAQ Air Quality Model 2018 Run
  - Accounts for Clean Air Interstate Rule (utility controls)
  - Does not include controls for BART (Best Available Retrofit Technology)
  - VISTAS states inventories as of Feb 2007
  - Inventories for neighboring states effective Aug 2006



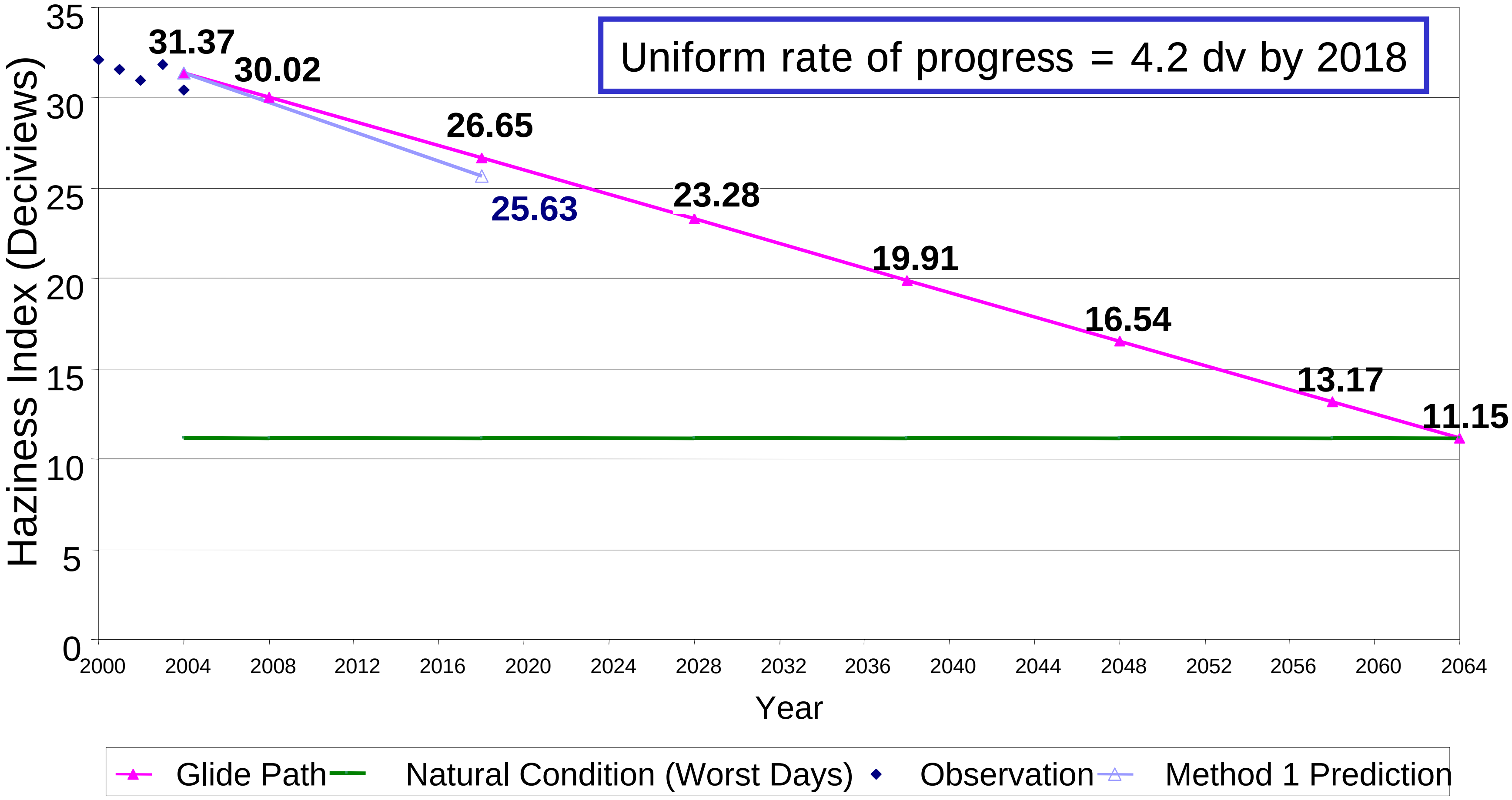
Model Performance 20% Haziest Days in 2002
Observations (left) vs Modeled Base G2a (right)
Mammoth Cave, KY
bEXT (1/Mm)
0
50
100
150
200
250
300
350
400
450
500
86
149
152
155
170
173
185
191
197
203
206
212
215
218
224
233
236
239
245
251
254
260
263
341
_
Avg
Julian Day in Worst 20% group
bCM
bSOIL
bEC
bOC
bNO3
bSO4


Modeled Responses to 2018 Base G2a Emissions on 20% Haziest Days
Mammoth Cave, KY
50
0
-50
-100
-150
-200
-250
-300
-350
Delta Bext (1/Mm)
86
149
152
155
170
173
185
191
197
203
206
212
215
218
224
233
236
239
245
251
254
260
263
341
Avg
Julian Day
bCM
bSOIL
bEC
bOC
bNO3
bSO4

Uniform Rate of Progress Glide Path

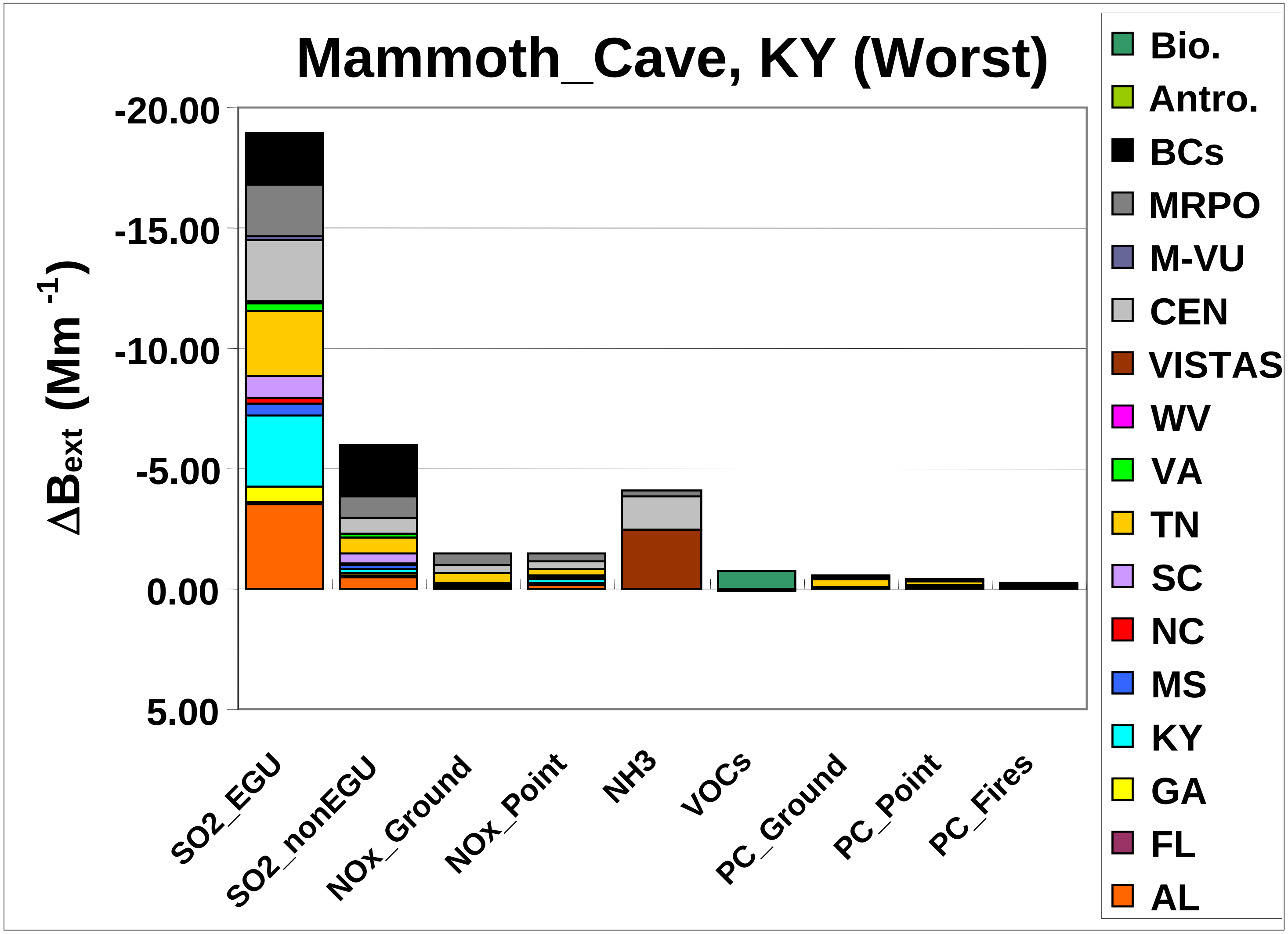
Mammoth Cave - 20% Worst Days

New IMPROVE equation



VISTAS Source Sector Emissions Sensitivities (Delivered Jan 2006)

- Evaluated responses to emissions reductions for specific pollutants and source sectors
- Greatest visibility improvement from further reducing SO_2 emissions from utilities and industries



Mammoth_Cave, KY (Worst)
ΔBext (Mm -1)
-20.00
-15.00
-10.00
-5.00
0.00
5.00
SO2_EGU
SO2_nonEGU
NOx_Ground
NOx_Point
NH3
VOCs
PC_Ground
PC_Point
PC_Fires
Bio.
Antro.
BCs
MRPO
M-VU
CEN
VISTAS
WV
VA
TN
SC
NC
MS
KY
GA
FL
AL

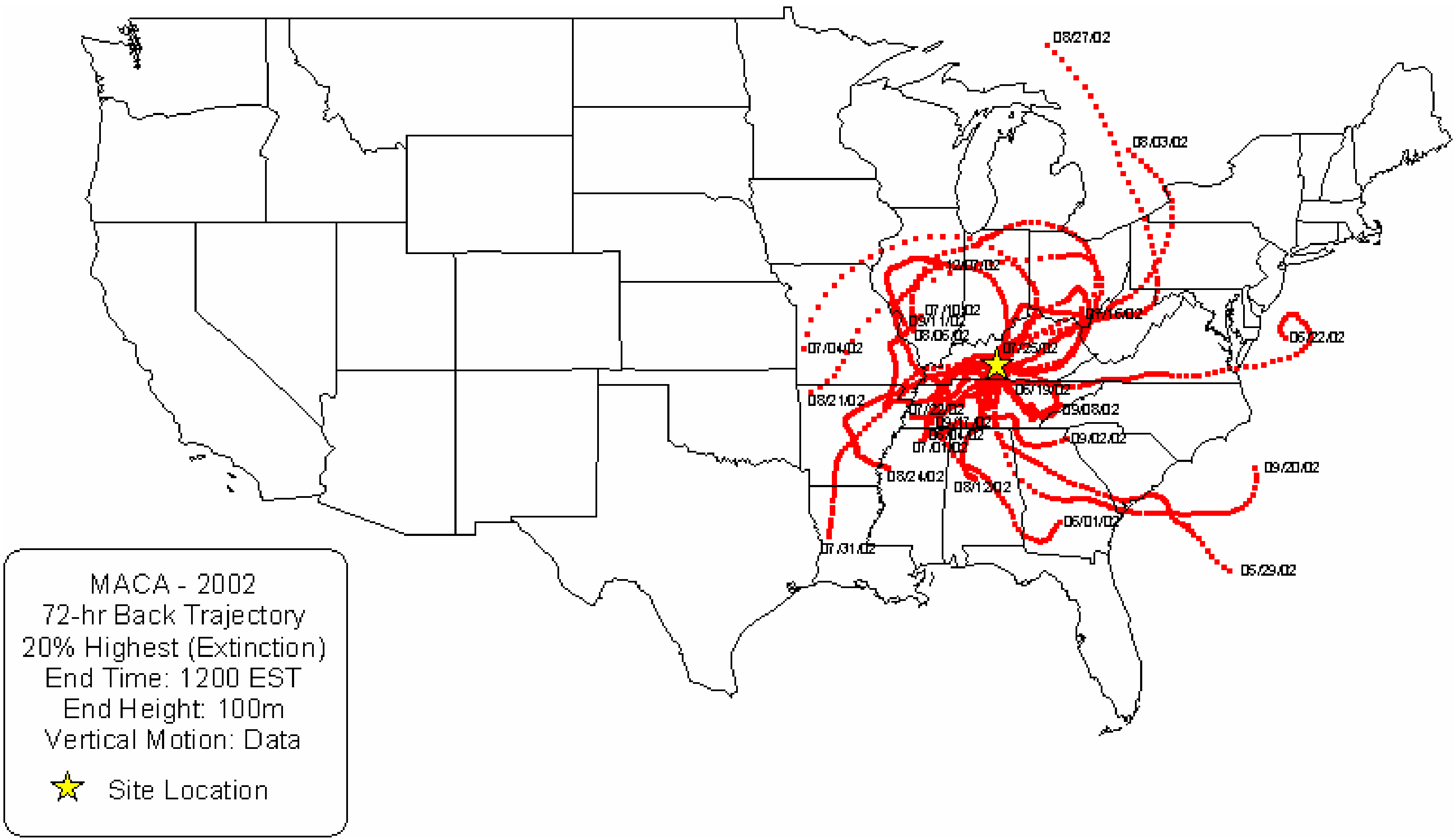
Conclusion: Source Sector Emissions Sensitivities

- Reductions in SO_2 emissions from EGU and non-EGU show largest improvements in visibility
  - Several VISTAS states contribute
  - Contributions from CENRAP, MRPO and Boundary Conditions (outside VISTAS 12 km domain)
- Small benefits from reducing NO_x, anthropogenic VOC or primary carbon
- For 20% worst days that occur in winter, reducing NH_3 would be more effective than reducing NO_x to reduce NH4NH3

VISTAS Geographic Areas of Influence

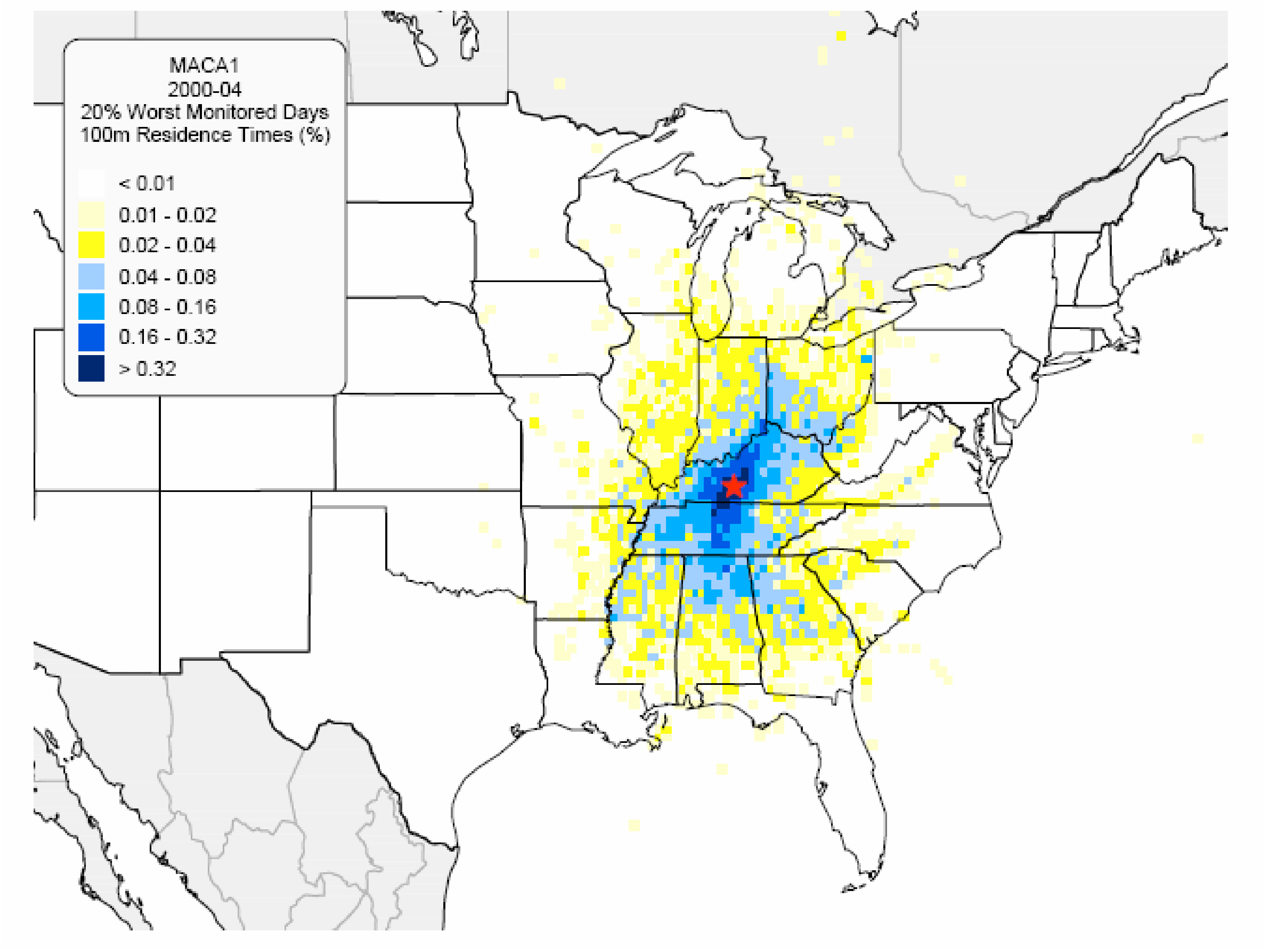
- Hysplit model used to generate back trajectories for Class I areas (Air Resource Specialists)
  - Back trajectories for individual 20% worst days in 2002
    - Helpful for evaluating model performance in 2002
  - Residence time plots for 20% worst days in 2000-2004 indicate probable contribution
    - Helpful to understand geographic area most likely to influence Class I areas
  - SO_2 Area of Influence defined from residence weighted by SO_4 extinction and considering SO_2 emissions

Back Trajectories for 20% Worst Days for 2002
Mammoth Cave, KY

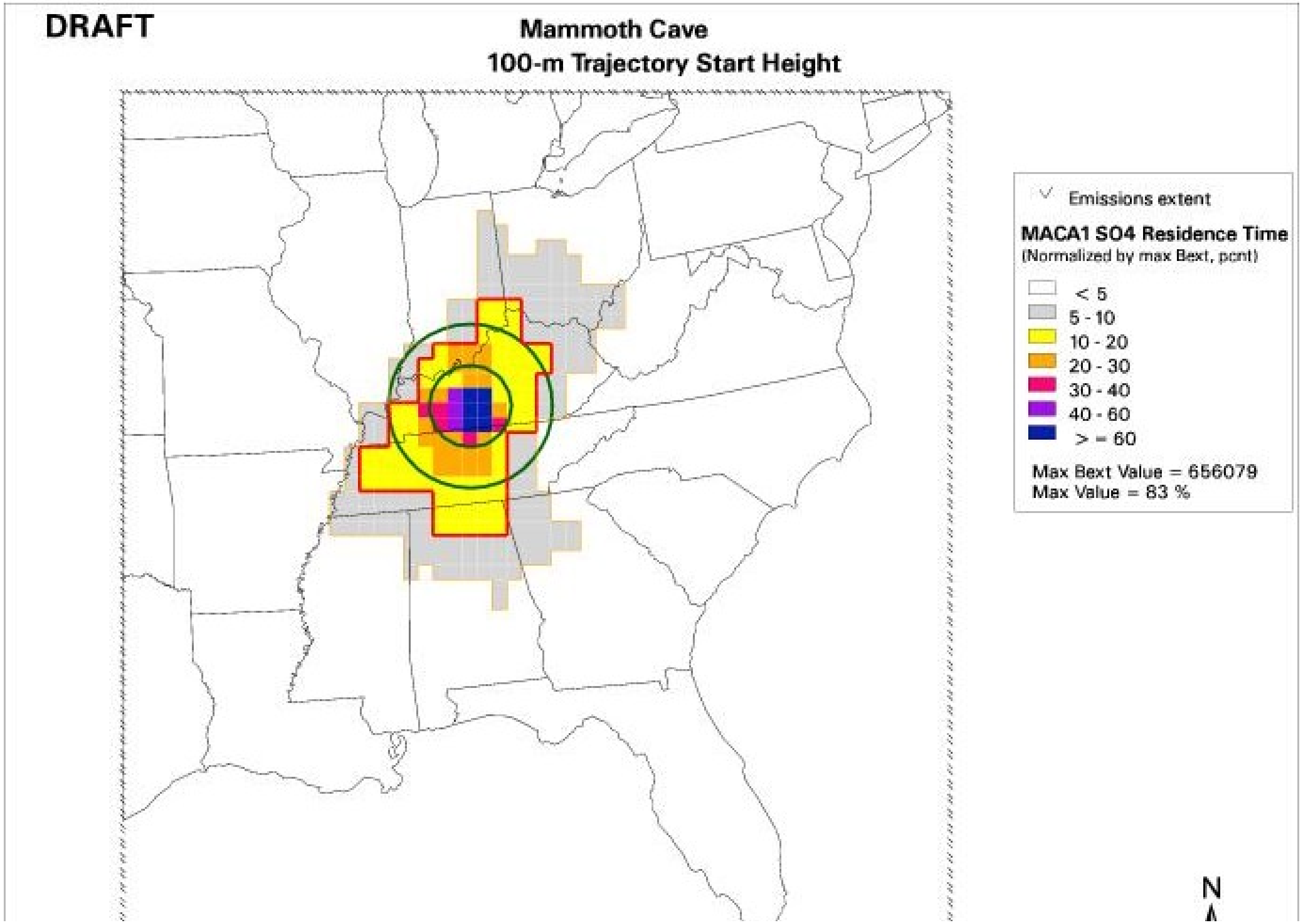


Residence Time for 20% Worst Days in 2000-2004

Mammoth Cave, KY



SO2 Area of Influence for Mammoth Cave, KY

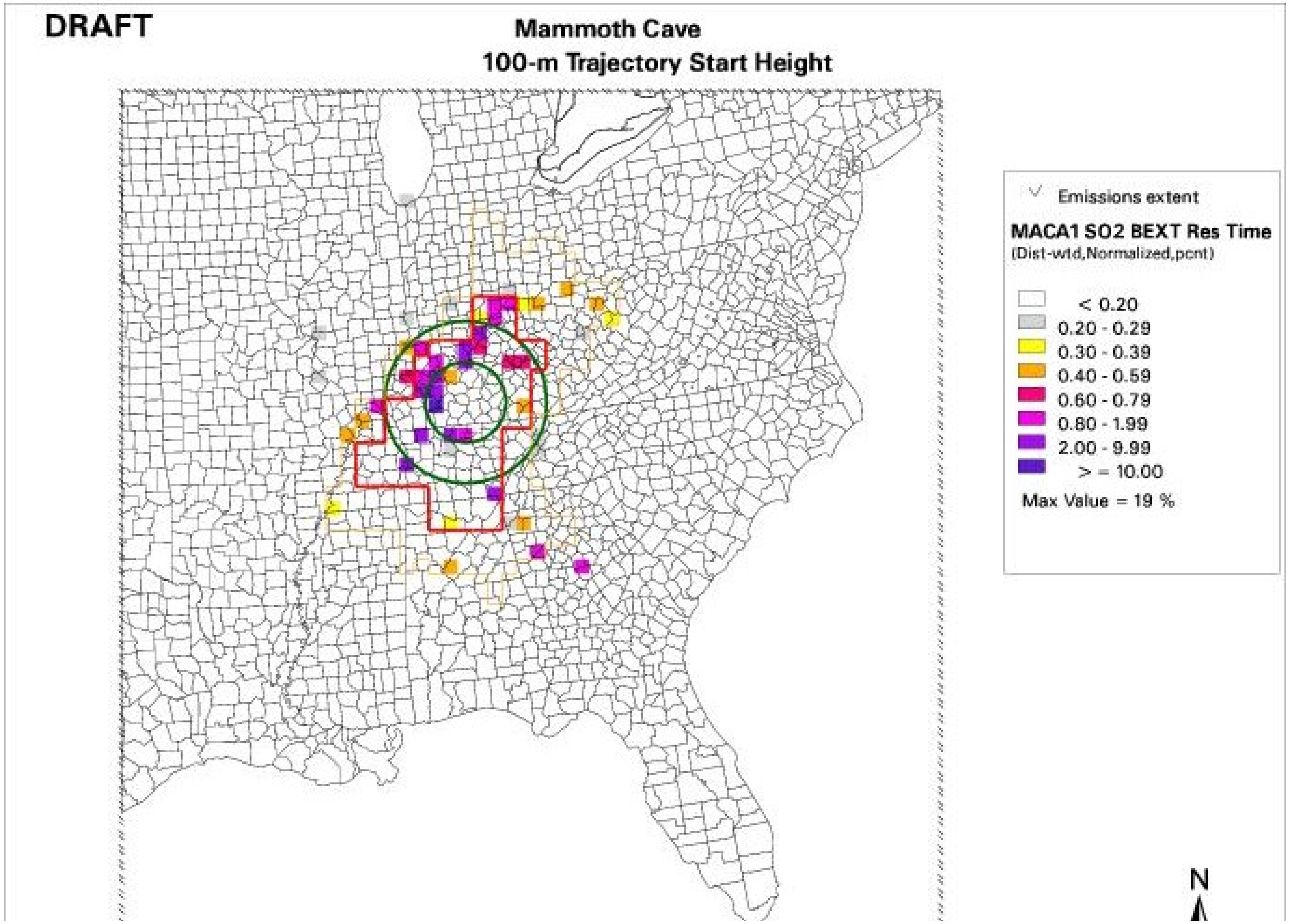


Green circles indicate 100-km and 200-km radii from Class I area.

Red line perimeter indicate Area of Influence with Residence Time $\geq$ 10%

Orange line perimeter indicate Area of Influence with Residence Time $\geq$ 5%.

2018 SO2 Emissions weighted by Residence Time
Mammoth Cave, KY



Green circles indicate 100-km and 200-km radii from Class I area.
Red line perimeter indicate Area of Influence with Residence Time ≥ 10%.
Orange line perimeter indicate Area of Influence with Residence Time ≥ 5%.

Reasonable Progress Analysis

- States consider 4 Statutory Factors to determine what controls are reasonable
  - Costs of Compliance
  - Time to Comply
  - Remaining Useful Life
  - Energy and Other Environmental and Impacts

Annual 2018 BaseG2 Emissions (%) Within Area of Influence
Mammoth Cave, KY

Tier	VOC	NOX	CO	SO2	PM-10	PM-2.5	NH3
Fuel Comb. Elec. Util.	1%	25%	1%	66%	8%	18%	1%
Fuel Comb. Industrial	1%	16%	2%	19%	3%	6%	0%
Fuel Comb. Other	4%	7%	3%	5%	3%	8%	0%
Chemical & Allied Product Mfg	2%	1%	1%	1%	1%	1%	1%
Metals Processing	1%	1%	5%	3%	3%	7%	0%
Petroleum & Related Industries	1%	0%	0%	1%	0%	0%	0%
Other Industrial Processes	7%	5%	1%	3%	8%	10%	1%
Solvent Utilization	45%	0%	0%	0%	0%	0%	0%
Storage & Transport	6%	0%	0%	0%	1%	1%	0%
Waste Disposal & Recycling	3%	1%	2%	0%	3%	7%	0%
Highway Vehicles	17%	20%	48%	0%	1%	2%	9%
Off-highway	12%	24%	36%	1%	2%	4%	0%
Miscellaneous	1%	0%	3%	0%	69%	35%	87%
VISTAS Total	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**

Annual 2018 BaseG2 Emissions (%) Within Area of Influence
Mammoth Cave, KY

Tier	SO2
Fuel Comb. Elec. Util.-Coal	66%
Fuel Comb. Elec. Util.-Oil	0%
Fuel Comb. Elec. Util.-Gas	0%
Fuel Comb. Elec. Util.-Other	0%
Fuel Comb. Elec. Util.-Internal Combustion	0%
Fuel Comb. Industrial-Coal	14%
Fuel Comb. Industrial-Oil	3%
Fuel Comb. Industrial-Gas	2%
Fuel Comb. Industrial-Other	1%
Fuel Comb. Industrial-Internal Combustion	0%
Fuel Comb. Other-Commercial/Institutional Coal	2%
Fuel Comb. Other-Commercial/Institutional Oil	2%
Fuel Comb. Other-Commercial/Institutional Gas	0%
Fuel Comb. Other-Misc. Fuel Comb. (Except Residential)	0%
Fuel Comb. Other-Residential Wood	0%
Fuel Comb. Other-Residential Other	1%

4 Statutory Factors

- For Utilities and Industrial Boilers
  - Switch to fuel with lower sulfur content
    - Coal or Oil
  - Post-combustion controls
    - Flue Gas Desulfurization
  - Modification trigger PSD review?

4 Statutory Factors (continued)

- Costs of Compliance
  - Fuel switch for coal or oil
    - May have to blend low S fuel to maintain boiler performance
    - Price difference for lower S fuel
    - Cost of boiler modifications for lower S fuel
    - <$1000/ton

4 Statutory Factors (continued)

- Costs of Compliance
  - Flue Gas Desulfurization
    - Construction costs: absorber tower, sorbent, waste handling facility
    - Operational and maintenance costs
    - Costs per ton vary with boiler size, type, facility
    - Utility costs range $1,000 - $5,000/ton
    - Industrial costs range $3,000 - $20,000+/ton

4 Statutory Factors (continued)

- Time for Compliance
  - 2+ years for fuel switching
  - 3+ years for post-combustion control (dependent on market and availability of labor and materials)
- Remaining Useful Life
  - Facility specific

4 Statutory Factors (continued)

- Energy and Non-Air Environmental Impacts
  - Lower sulfur fuel may affect boiler operations
  - FGD slightly reduces energy production
    - Burn more coal per unit energy produced
    - Increase disposal of sludge, wastewater
    - Increase carbon emissions
      - CO_2 is released as byproduct from $CaSO_4$ formation