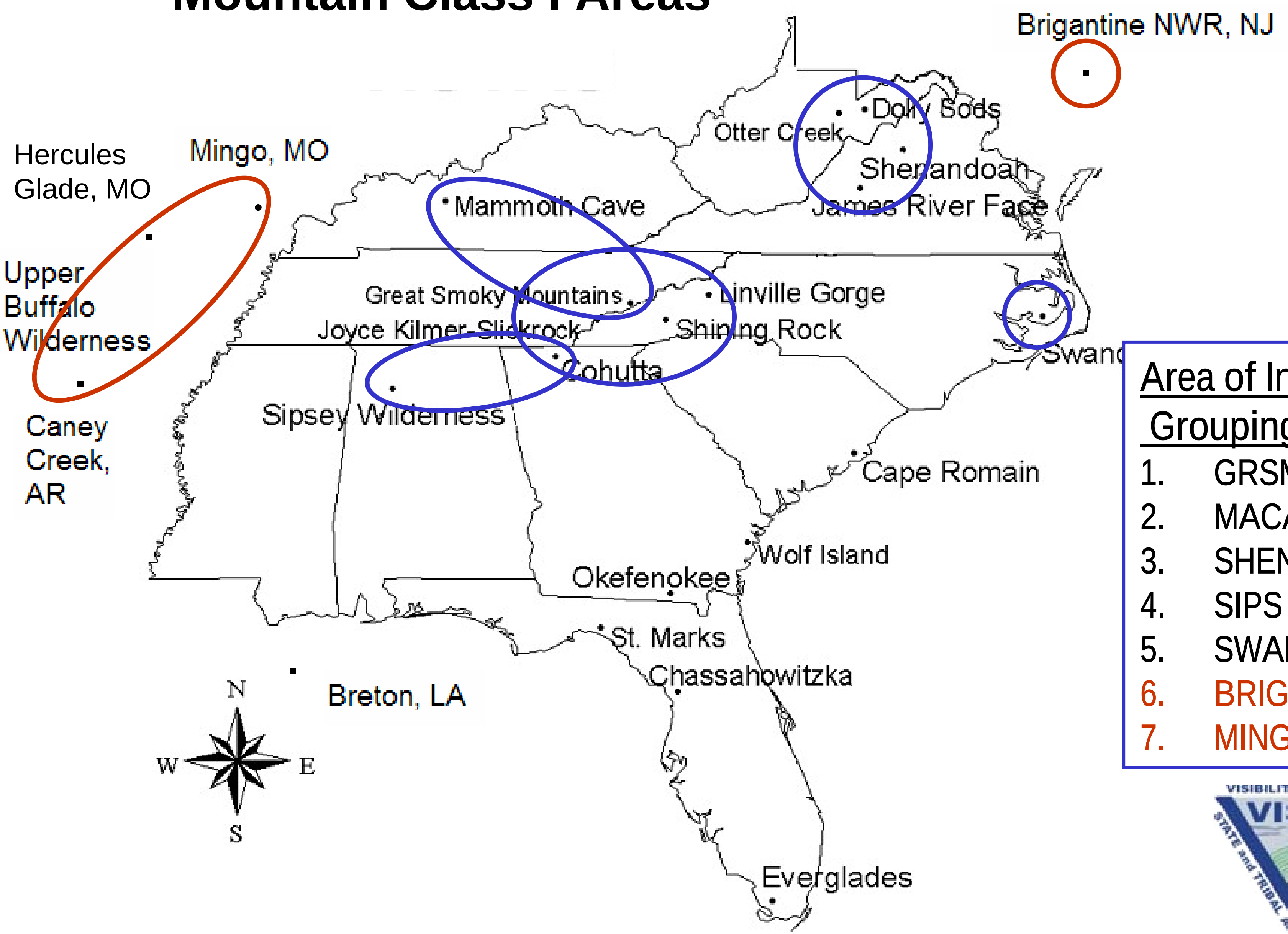
Shenandoah Group Contribution Assessment

Draft May 29, 2007

Mountain Class I Areas

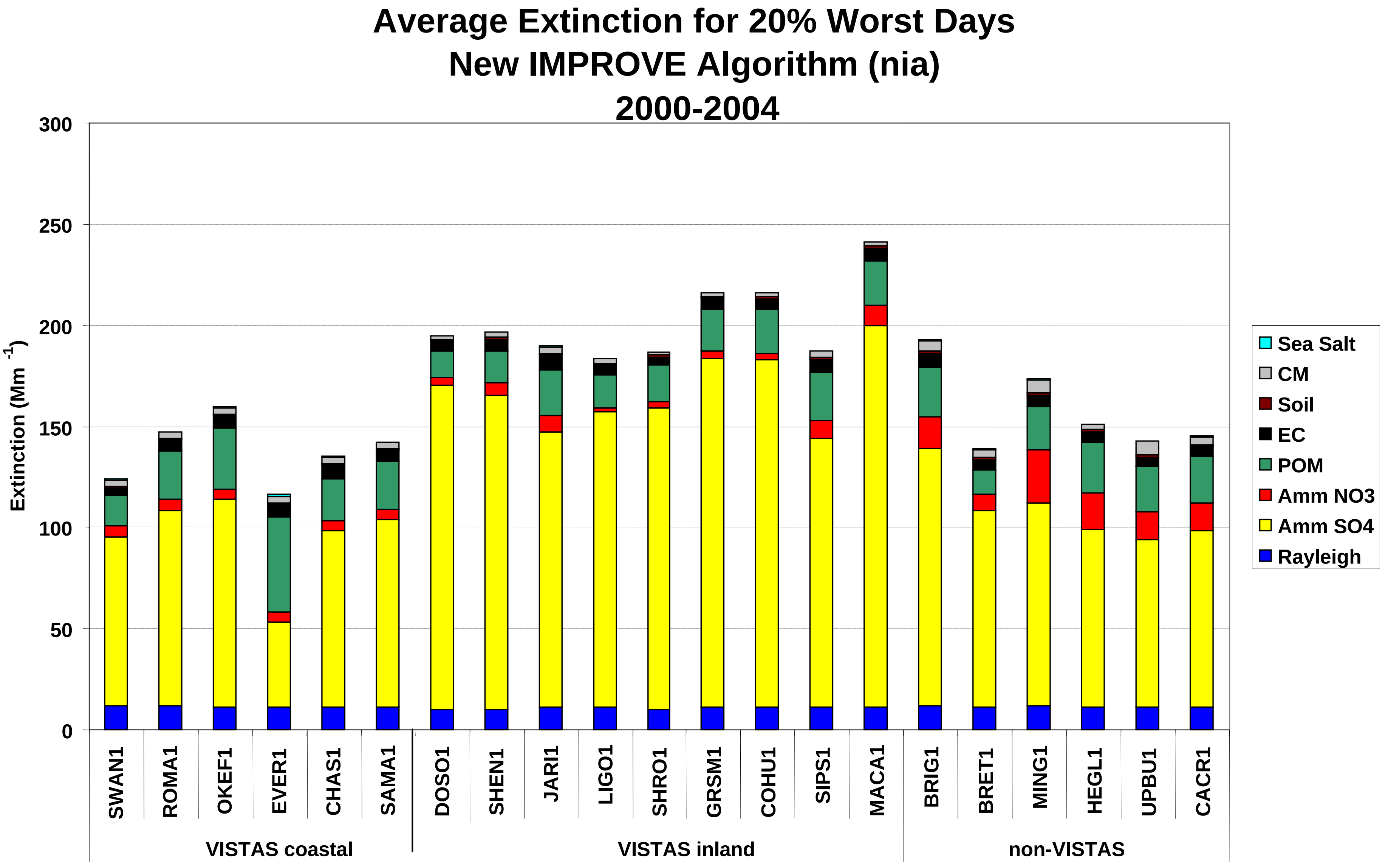


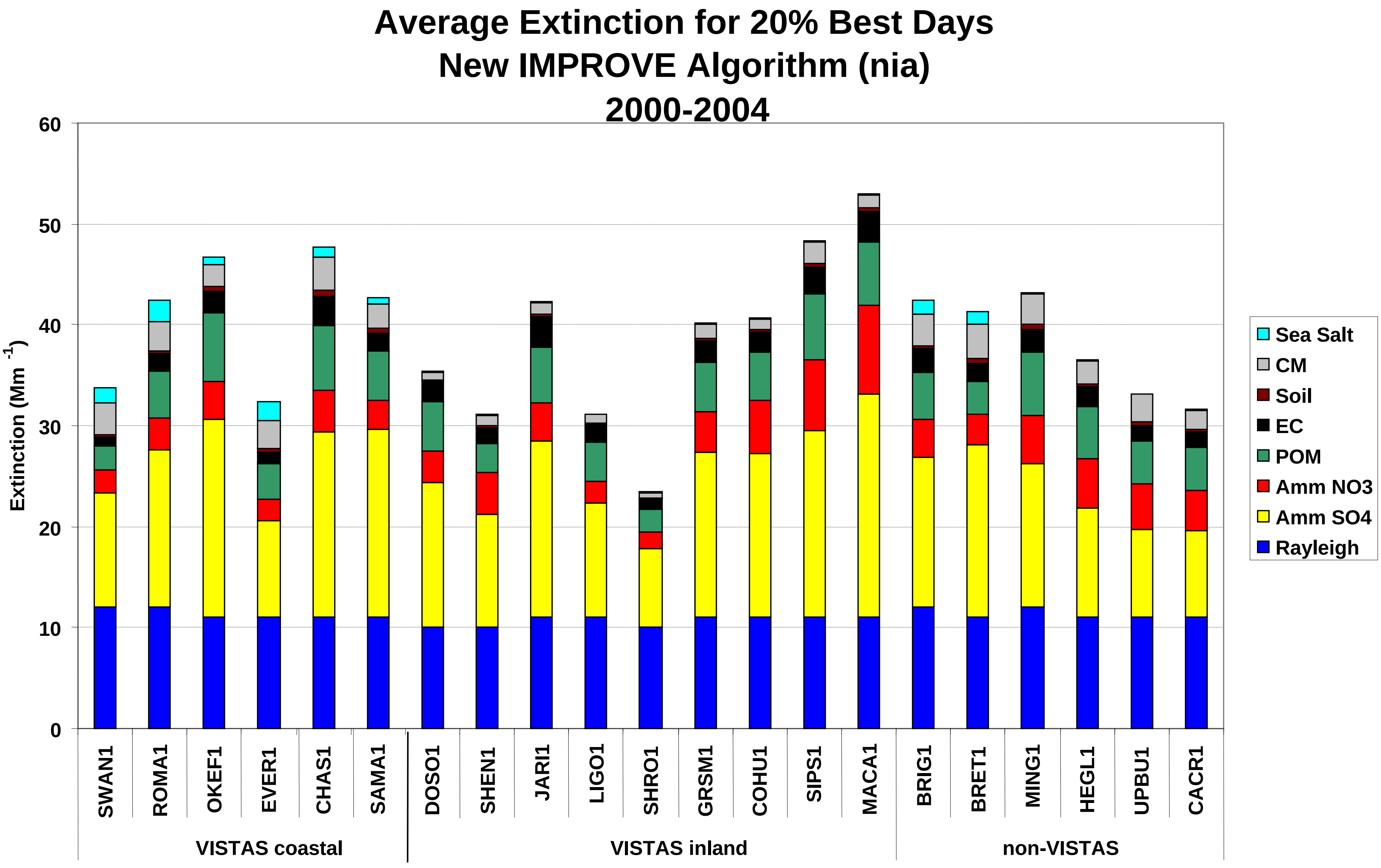
Area of Influence Groupings

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



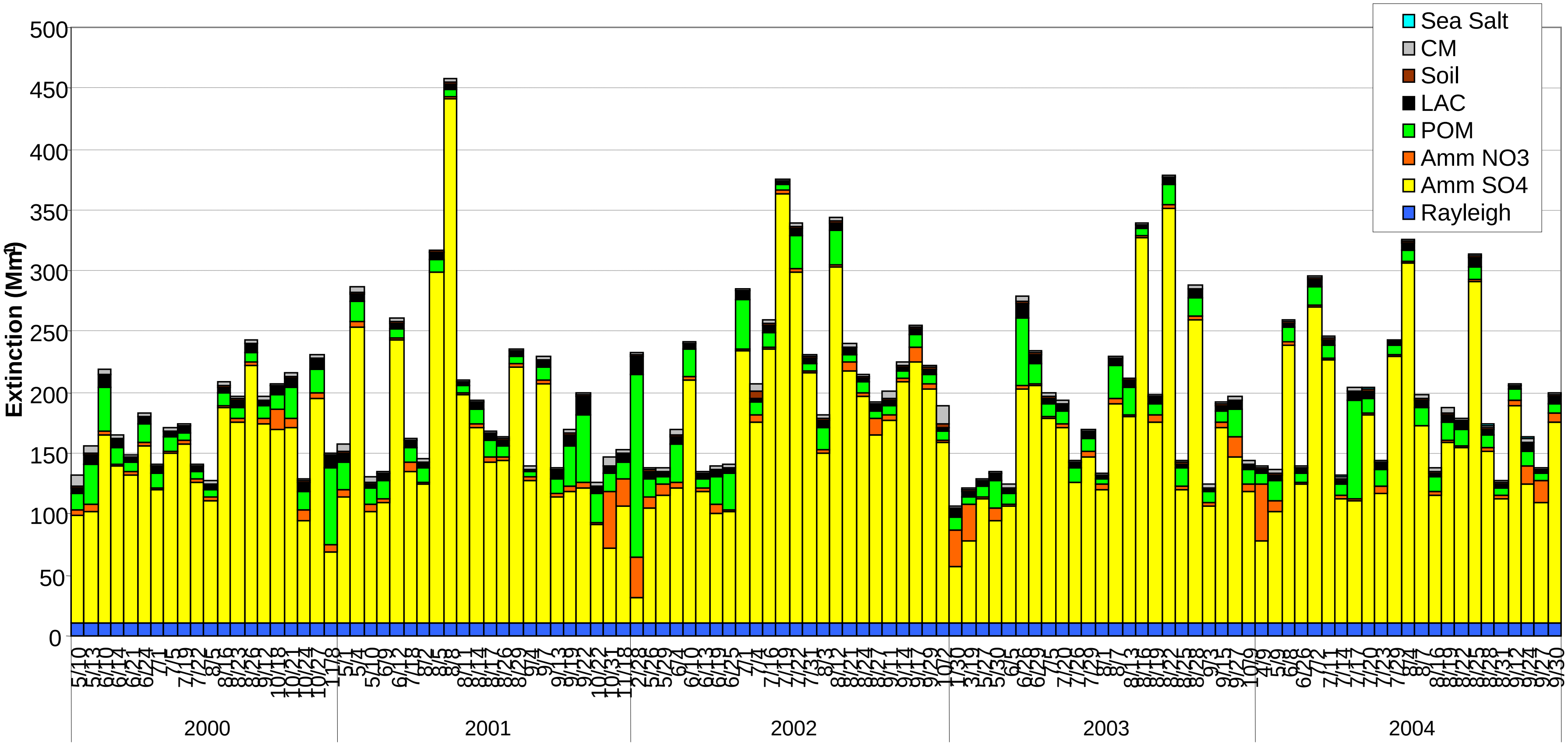
Average Extinction for 20% Best Days
New IMPROVE Algorithm (nia)
2000-2004
Extinction (Mm -1)
0
10
20
30
40
50
60
SWAN1
ROMA1
OKEF1
EVER1
CHAS1
SAMA1
DOSO1
SHEN1
JARI1
LIGO1
SHRO1
GRSM1
COHU1
SIPS1
MACA1
BRIG1
BRET1
MING1
HEGL1
UPBU1
CACR1
VISTAS coastal
VISTAS inland
non-VISTAS
Sea Salt
CM
Soil
EC
POM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

2000-2004 Reconstructed Extinction

New IMPROVE Algorithm

20% Worst Days

Shenandoah, VA

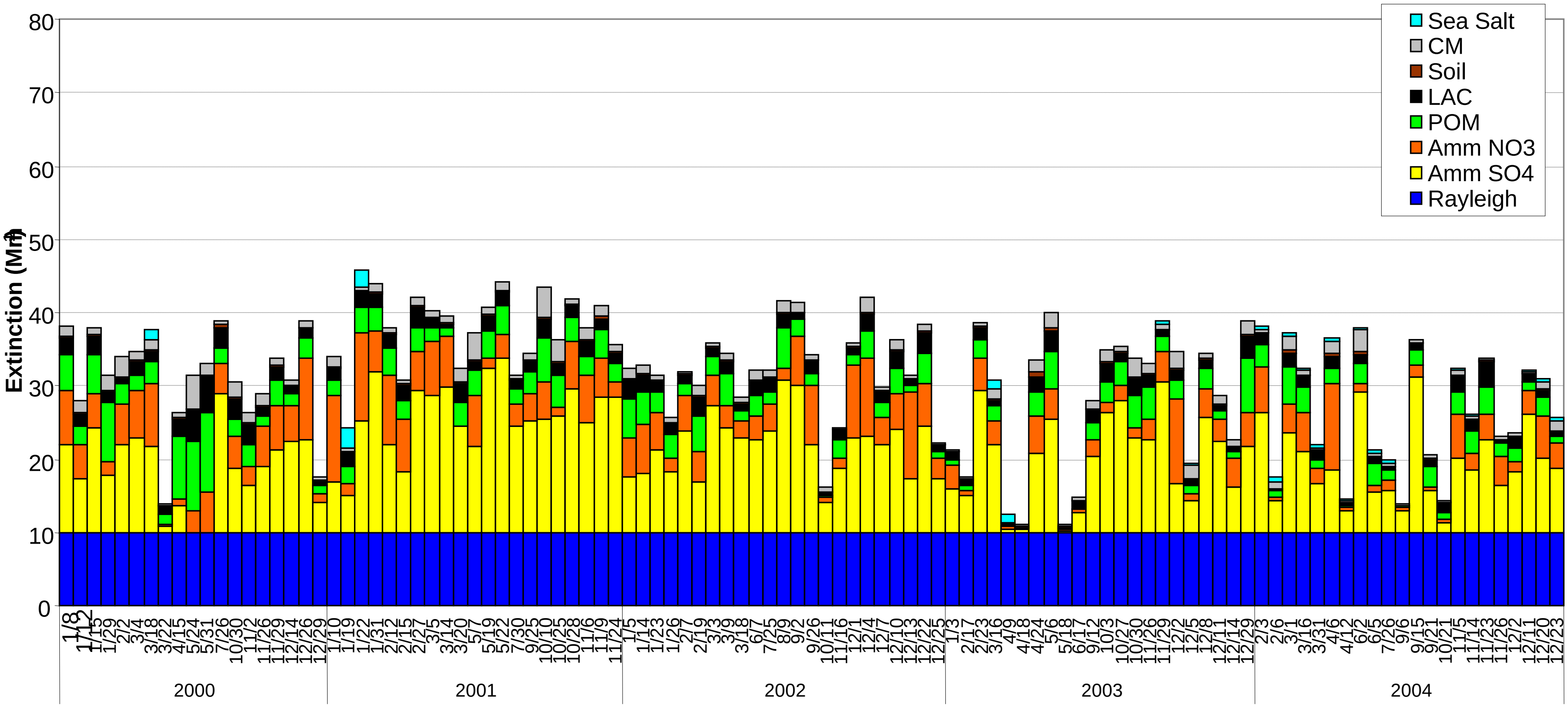


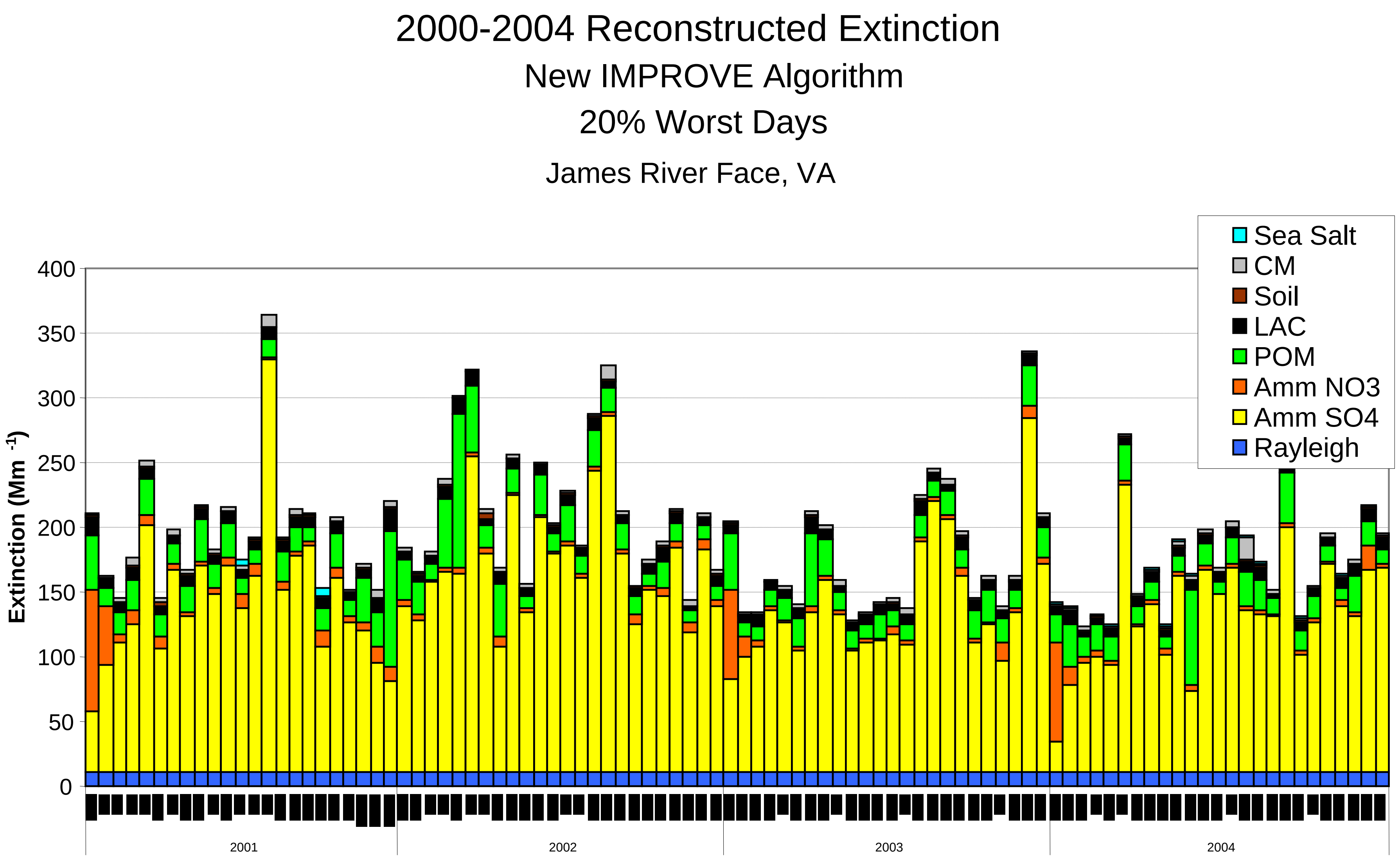
2000-2004 Reconstructed Extinction

New IMPROVE Algorithm

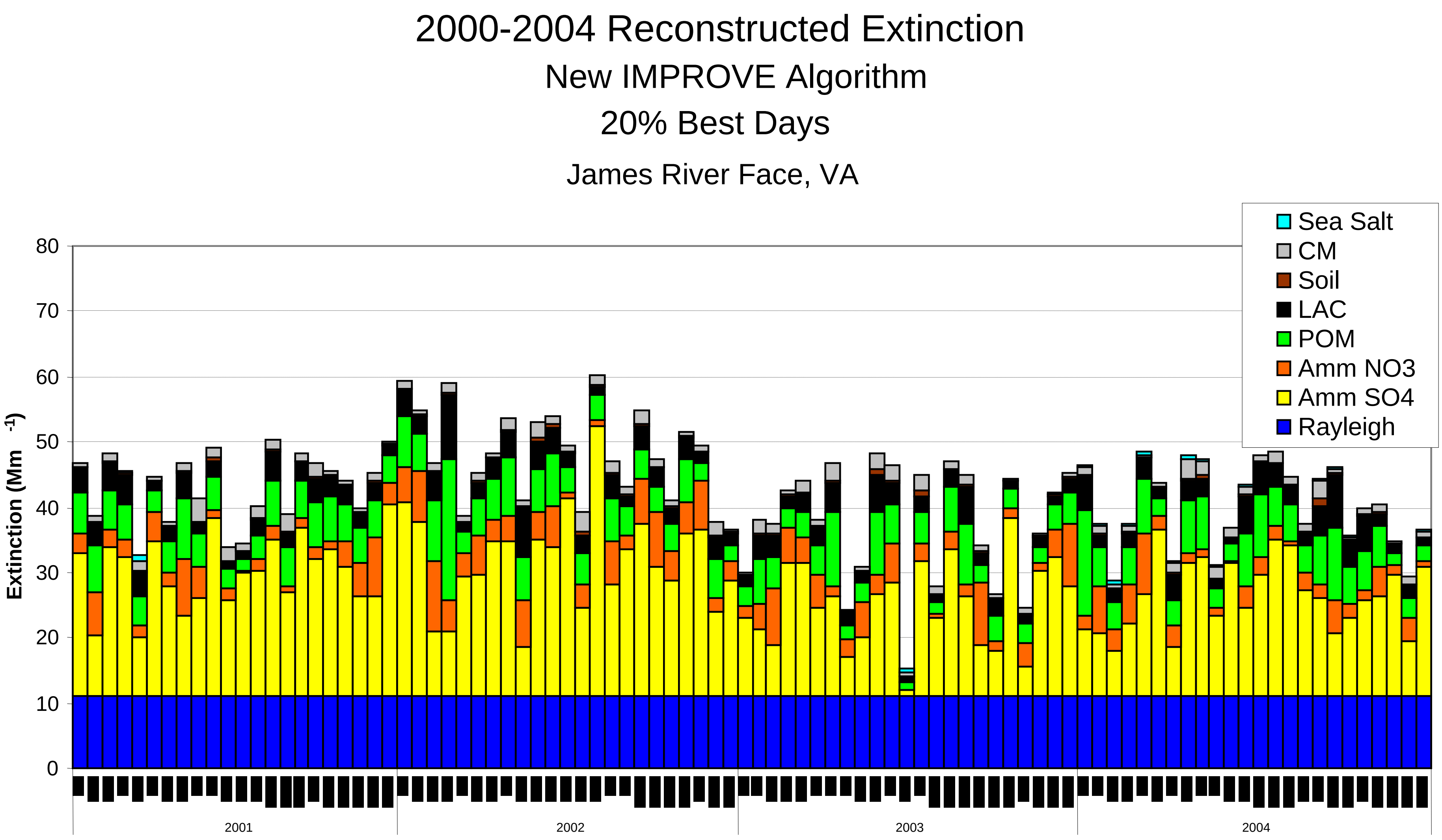
20% Best Days

Shenandoah, VA





2000-2004 Reconstructed Extinction
New IMPROVE Algorithm
20% Worst Days
James River Face, VA
Sea Salt
CM
Soil
LAC
POM
Amm NO3
Amm SO4
Rayleigh
Extinction (Mm -1)
400
350
300
250
200
150
100
50
0
2001
2002
2003
2004



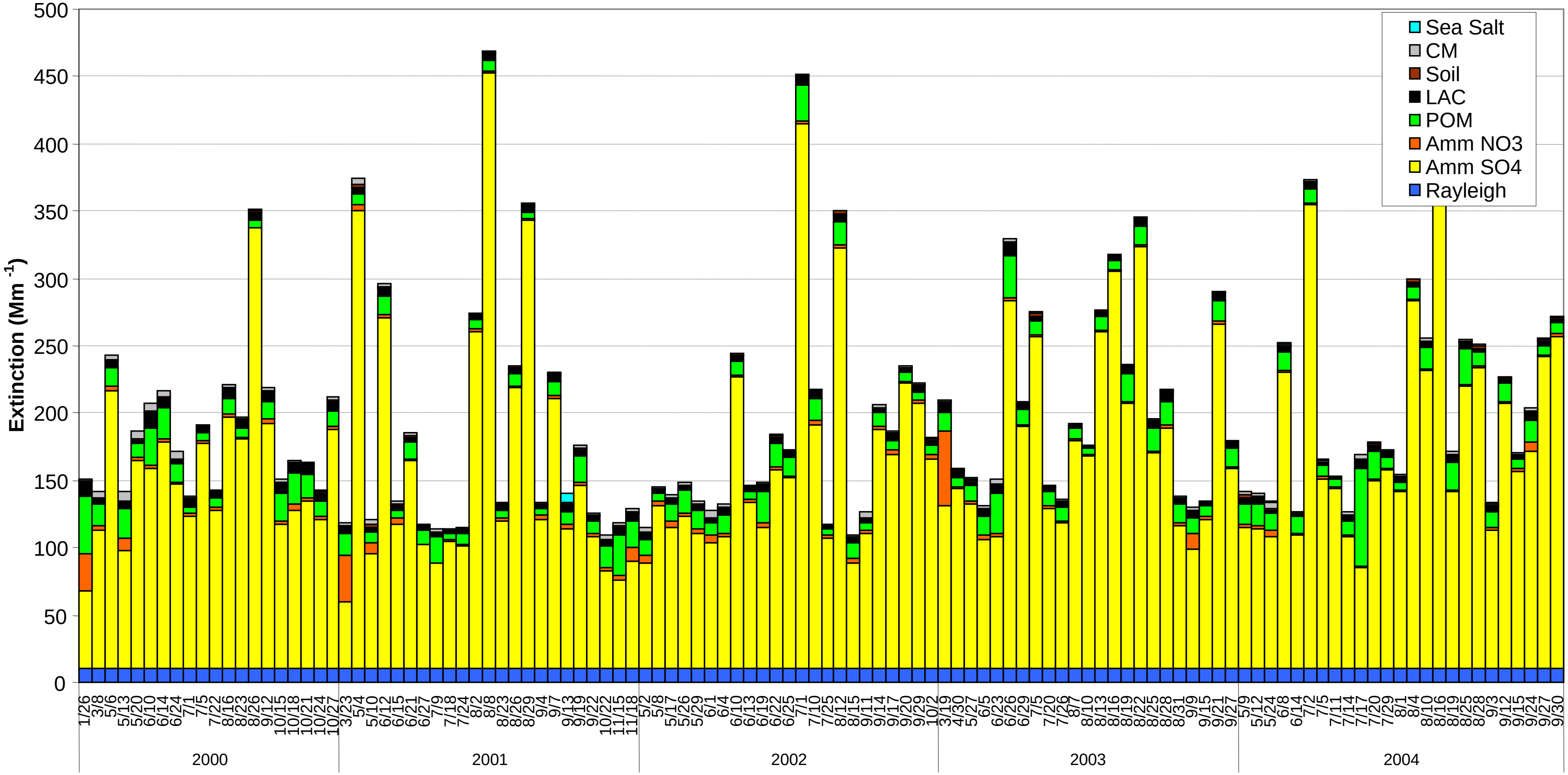
2000-2004 Reconstructed Extinction
New IMPROVE Algorithm
20% Best Days
James River Face, VA
Sea Salt
CM
Soil
LAC
POM
Amm NO3
Amm SO4
Rayleigh
Extinction (Mm -1)
80
70
60
50
40
30
20
10
0
2001
2002
2003
2004

2000-2004 Reconstructed Extinction

New IMPROVE Algorithm

20% Worst Days

Dolly Sods, WV



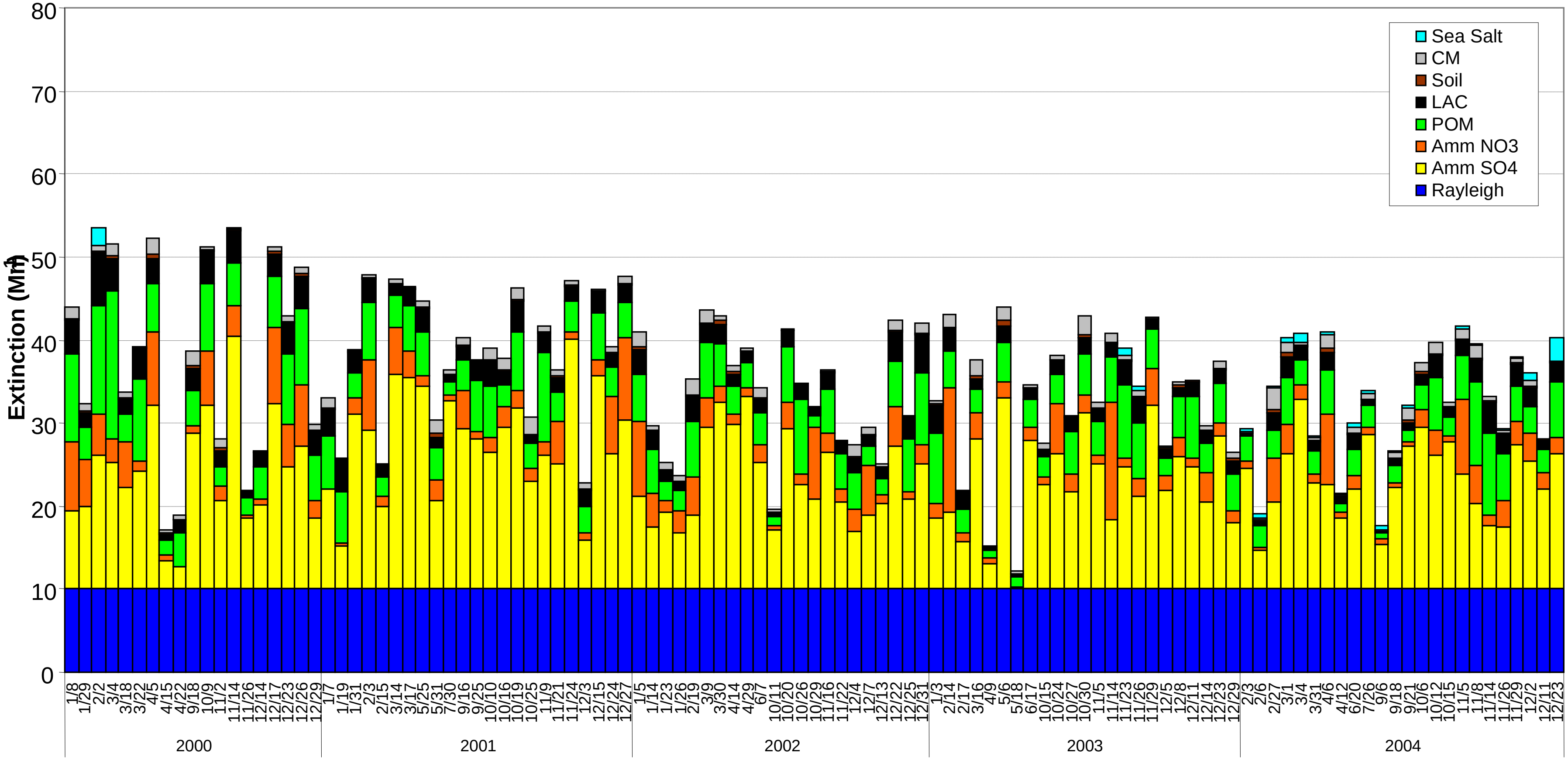
Dolly Sods and Otter Creek Wilderness Areas share an IMPROVE monitor

2000-2004 Reconstructed Extinction

New IMPROVE Algorithm

20% Worst Days

Dolly Sods, WV



Conclusions: Contributions

- On 20% Worst Days
  - SO4 dominates light extinction
  - Organic carbon generally second largest contribution; fire indicated on few days
  - NO3 contribution comparatively small
- SO4 also dominates 20% Best Days
- Conclude: Focus on reducing SO2 emissions

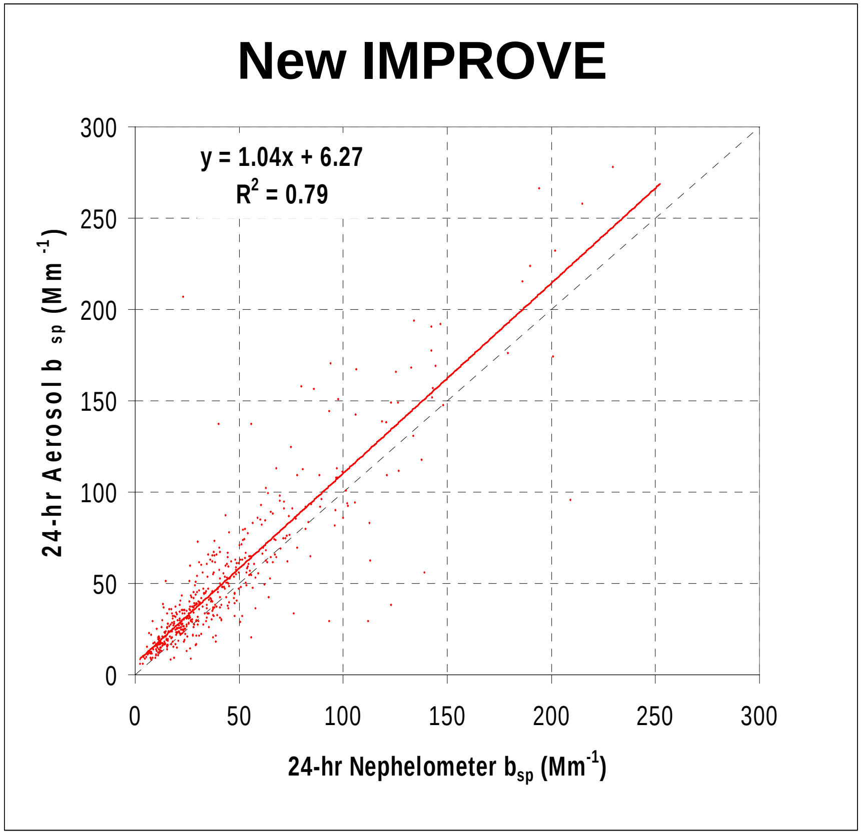
New IMPROVE Equation

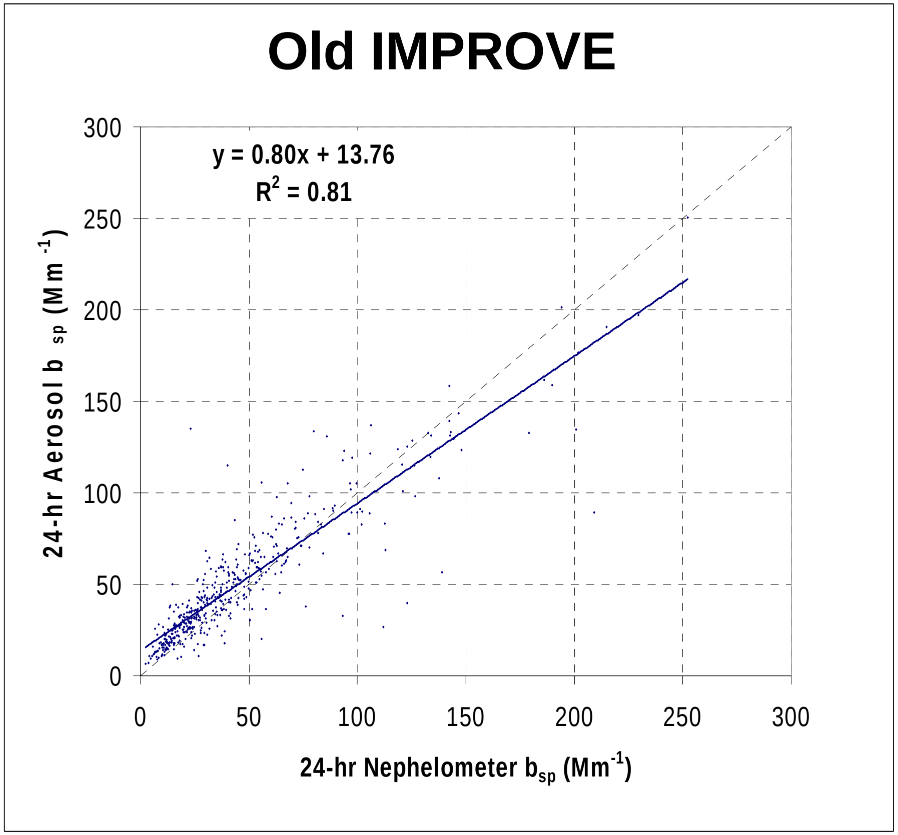
- Endorsed by IMPROVE Steering Committee as accounting for latest science
  - Defines two terms each for SO4, NO3, and OC with higher extinction efficiencies (b_{ext}) associated with high mass and lower b_{ext} associated with low mass
  - Increases mass multiplier for organic carbon from 1.4 to 1.8
  - 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

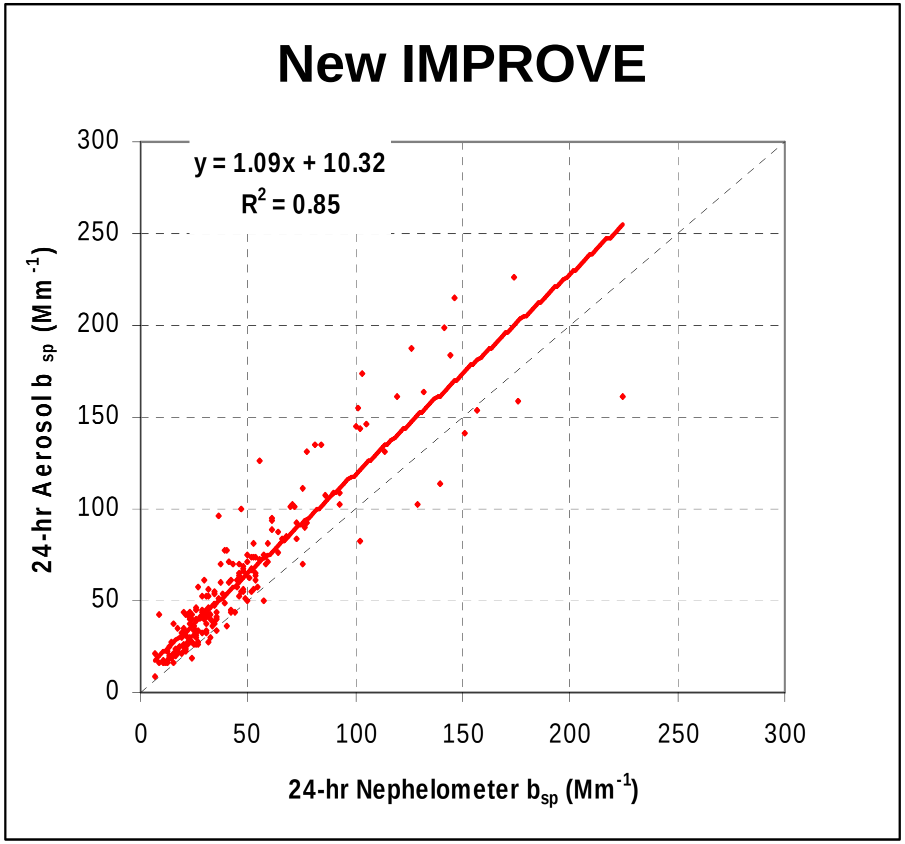
- Light scattering measured by nephelometer and calculated using new IMPEOVE equation show good correlation
  - Original equation under estimated scattering on highest days and over estimated scattering on lowest days
- New equation generally indicates higher extinction on 20% worst days and lower extinction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

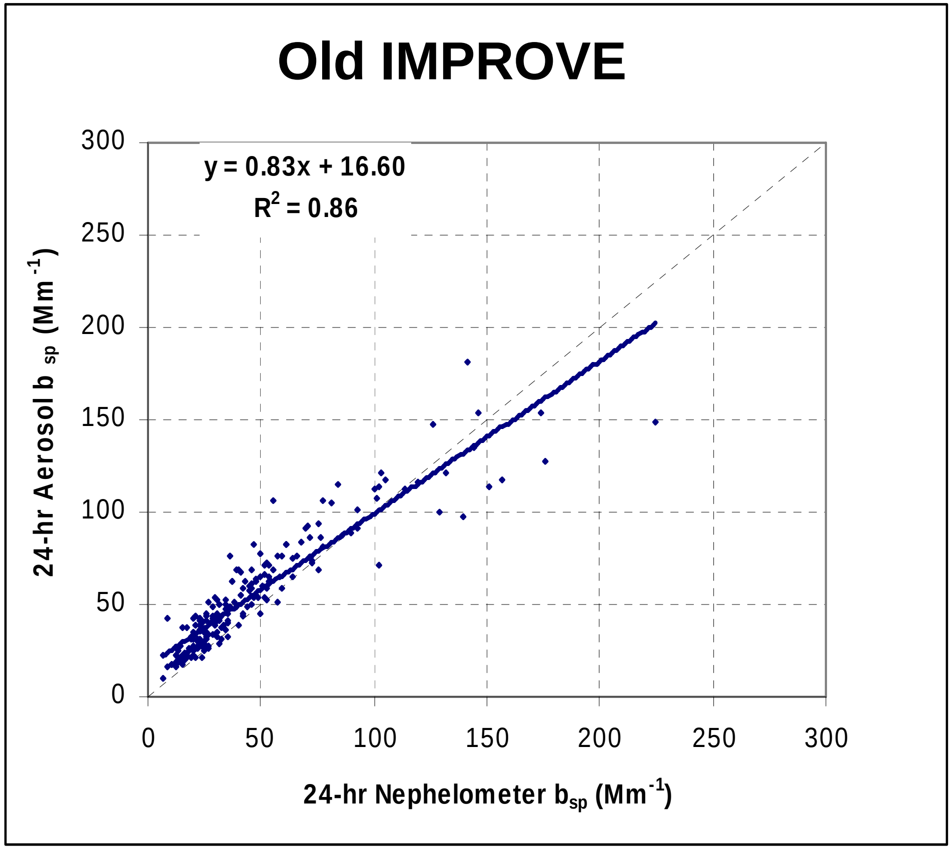
Aerosol Scattering vs. Nephelometer Scattering Using New or Old IMPROVE Algorithm and Daily f(RH) Shenandoah, VA 1996 - 2004





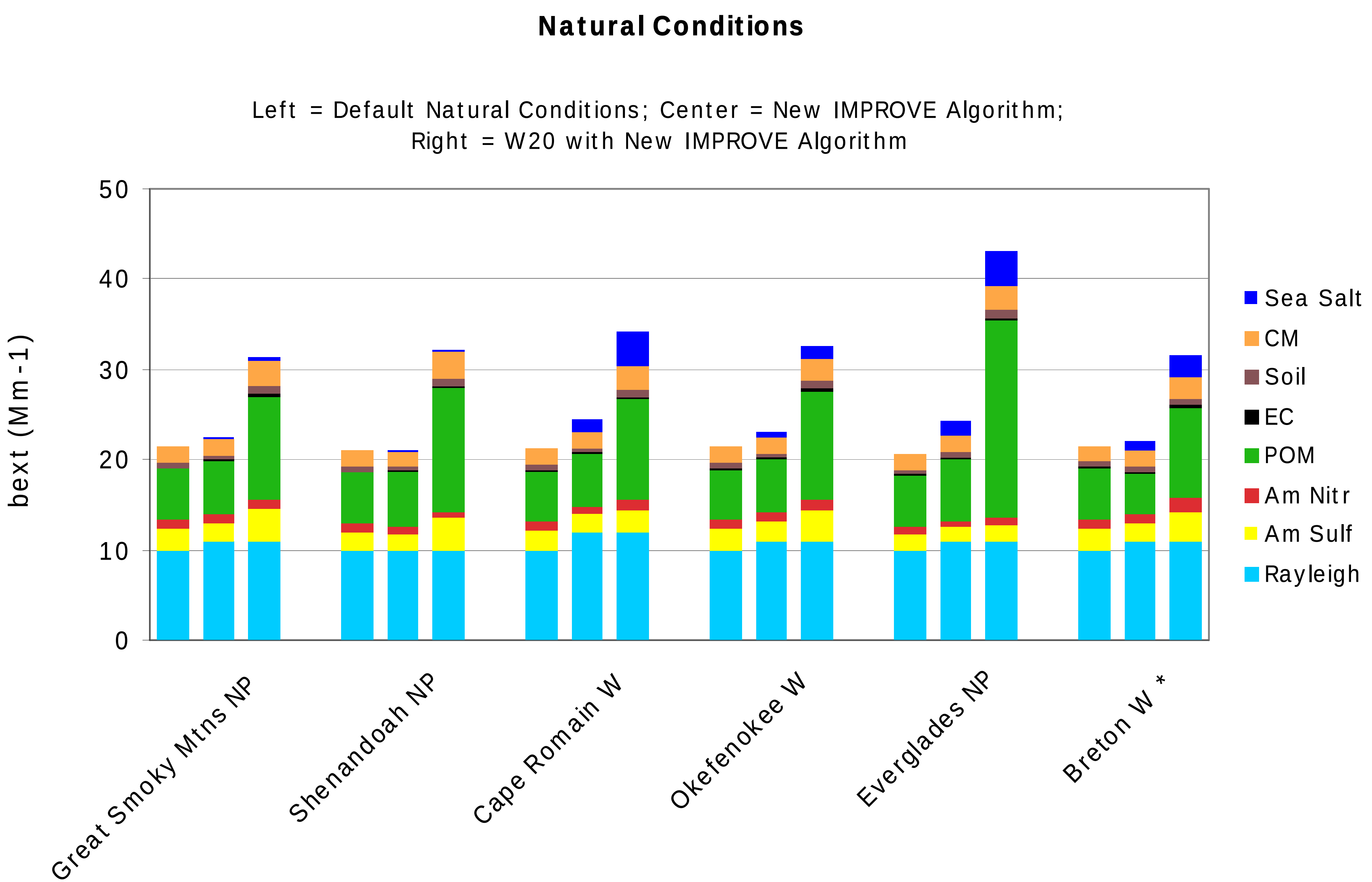
Aerosol Scattering vs. Nephelometer Scattering Using New or Old IMPROVE Algorithm and Daily f(RH) James River Face, VA 2000 - 2004



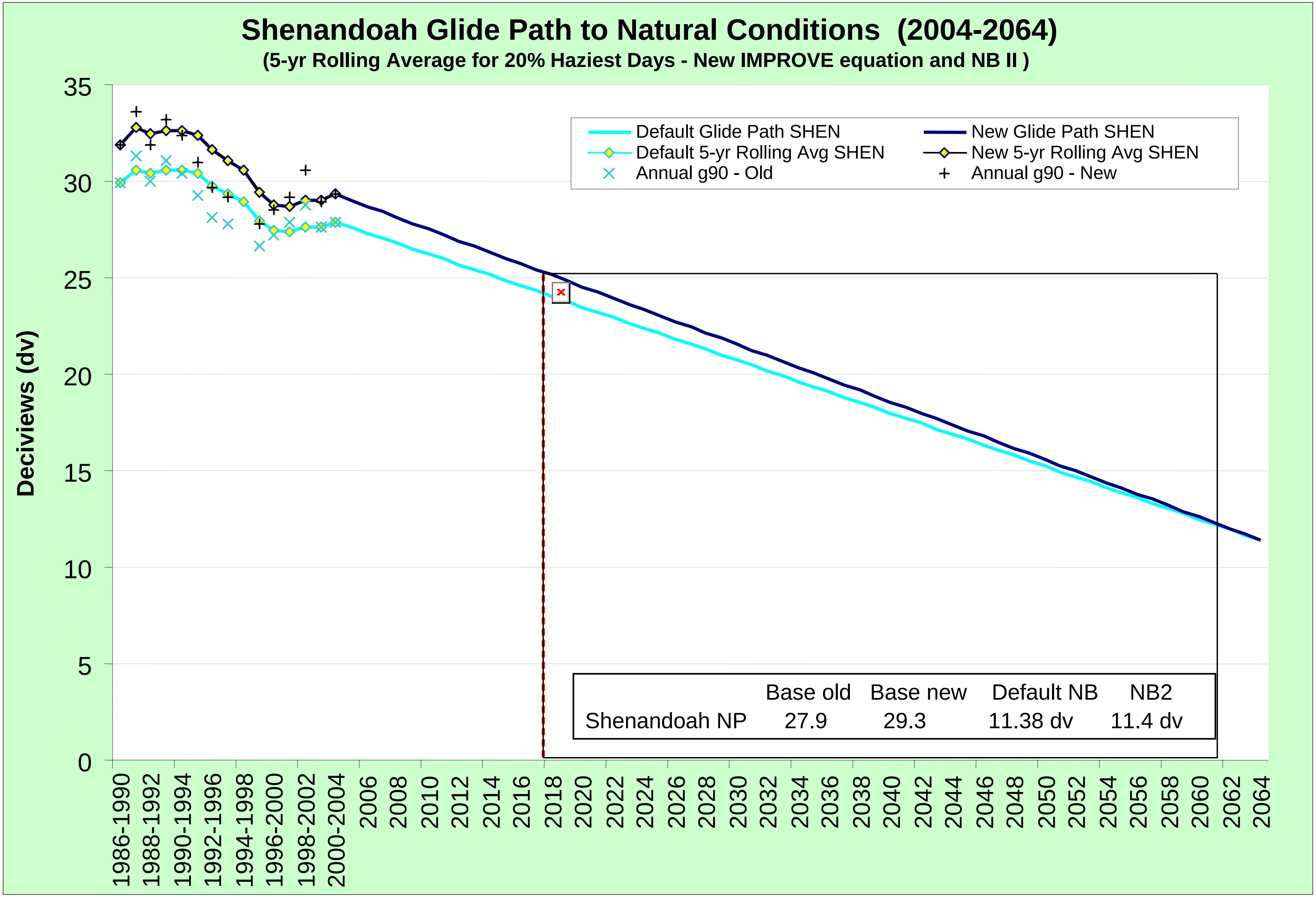


Natural Background Visibility

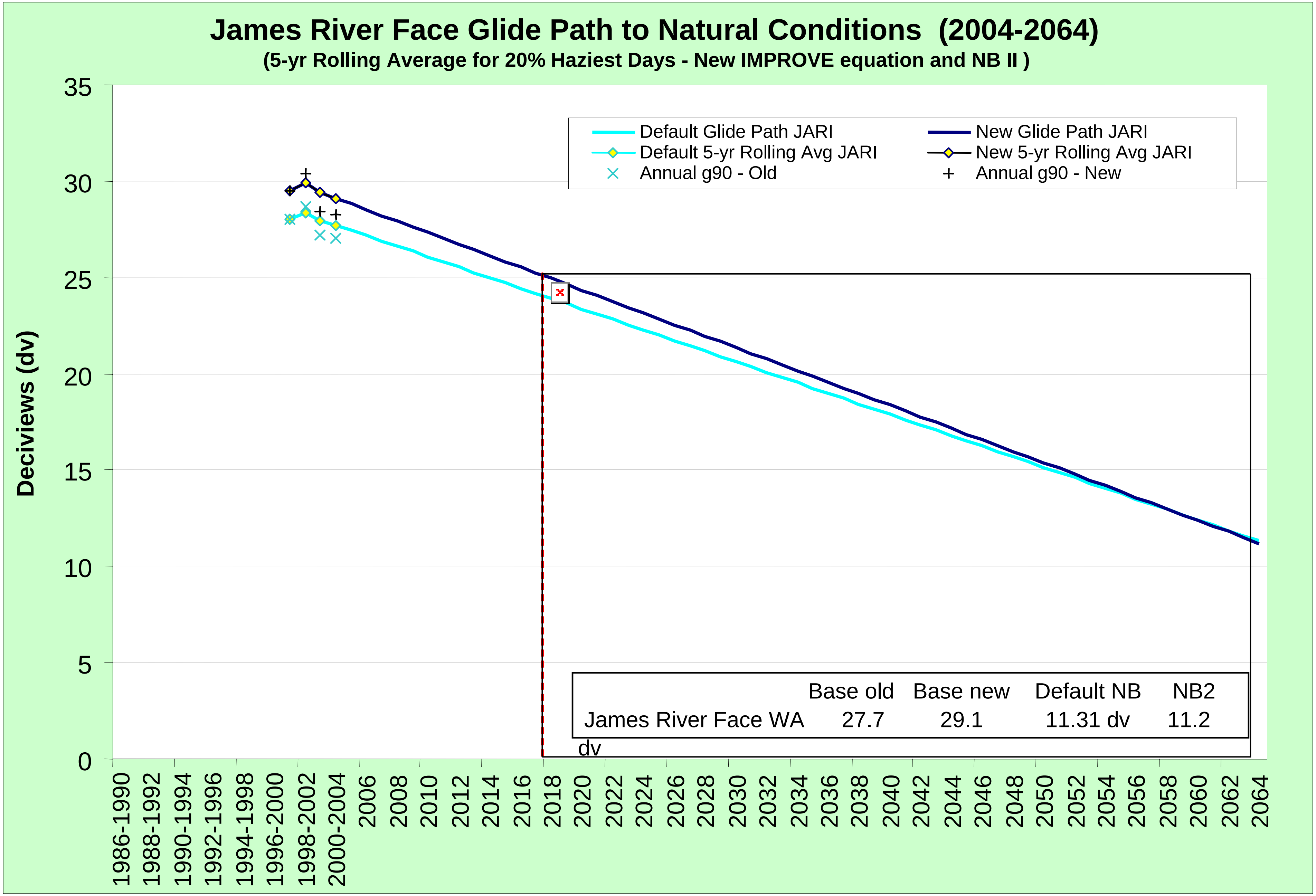
- Tombach reviewed for VISTAS the original assumptions by Trojonis et al. 1990 used to define natural background levels of visibility impairing pollutants and recent scientific developments. He also made recommendations for changes in assumptions. (Tombach and Brewer, 2005)
- Hand and Malm (2005) reviewed 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)
0
10
20
30
40
50
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



Shenandoah Glide Path to Natural Conditions (2004-2064)
(5-yr Rolling Average for 20% Haziest Days - New IMPROVE equation and NB II)
Deciviews (dv)
Default Glide Path SHEN
New Glide Path SHEN
Default 5-yr Rolling Avg SHEN
New 5-yr Rolling Avg SHEN
Annual g90 - Old
Annual g90 - New
Base old
Base new
Default NB
NB2
Shenandoah NP
27.9
29.3
11.38 dv
11.4 dv


James River Face Glide Path to Natural Conditions (2004-2064)
(5-yr Rolling Average for 20% Haziest Days - New IMPROVE equation and NB II)
Default Glide Path JARI
New Glide Path JARI
Default 5-yr Rolling Avg JARI
New 5-yr Rolling Avg JARI
Annual g90 - Old
Annual g90 - New
Deciviews (dv)
35
30
25
20
15
10
5
0
Base old
Base new
Default NB
NB2
James River Face WA
27.7
29.1
11.31 dv
11.2
dv
1986-1990
1988-1992
1990-1994
1992-1996
1994-1998
1996-2000
1998-2002
2000-2004
2006
2008
2010
2012
2014
2016
2018
2020
2022
2024
2026
2028
2030
2032
2034
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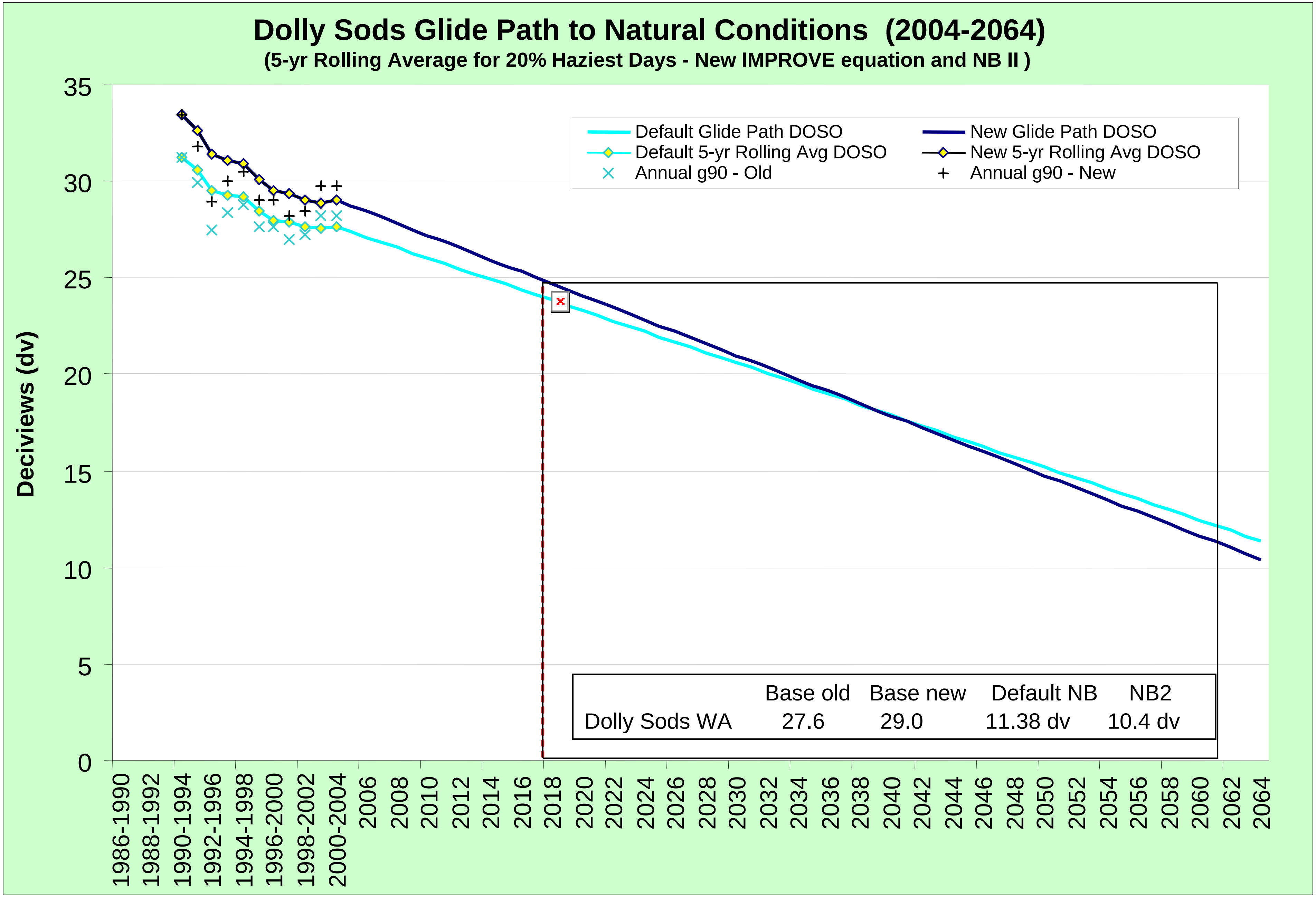
2046
2048
2050
2052
2054
2056
2058
2060
2062
2064



Dolly Sods Glide Path to Natural Conditions (2004-2064)
(5-yr Rolling Average for 20% Haziest Days - New IMPROVE equation and NB II)
Deciviews (dv)
Default Glide Path DOSO
New Glide Path DOSO
Default 5-yr Rolling Avg DOSO
New 5-yr Rolling Avg DOSO
Annual g90 - Old
Annual g90 - New
Base old
Base new
Default NB
NB2
Dolly Sods WA
27.6
29.0
11.38 dv
10.4 dv

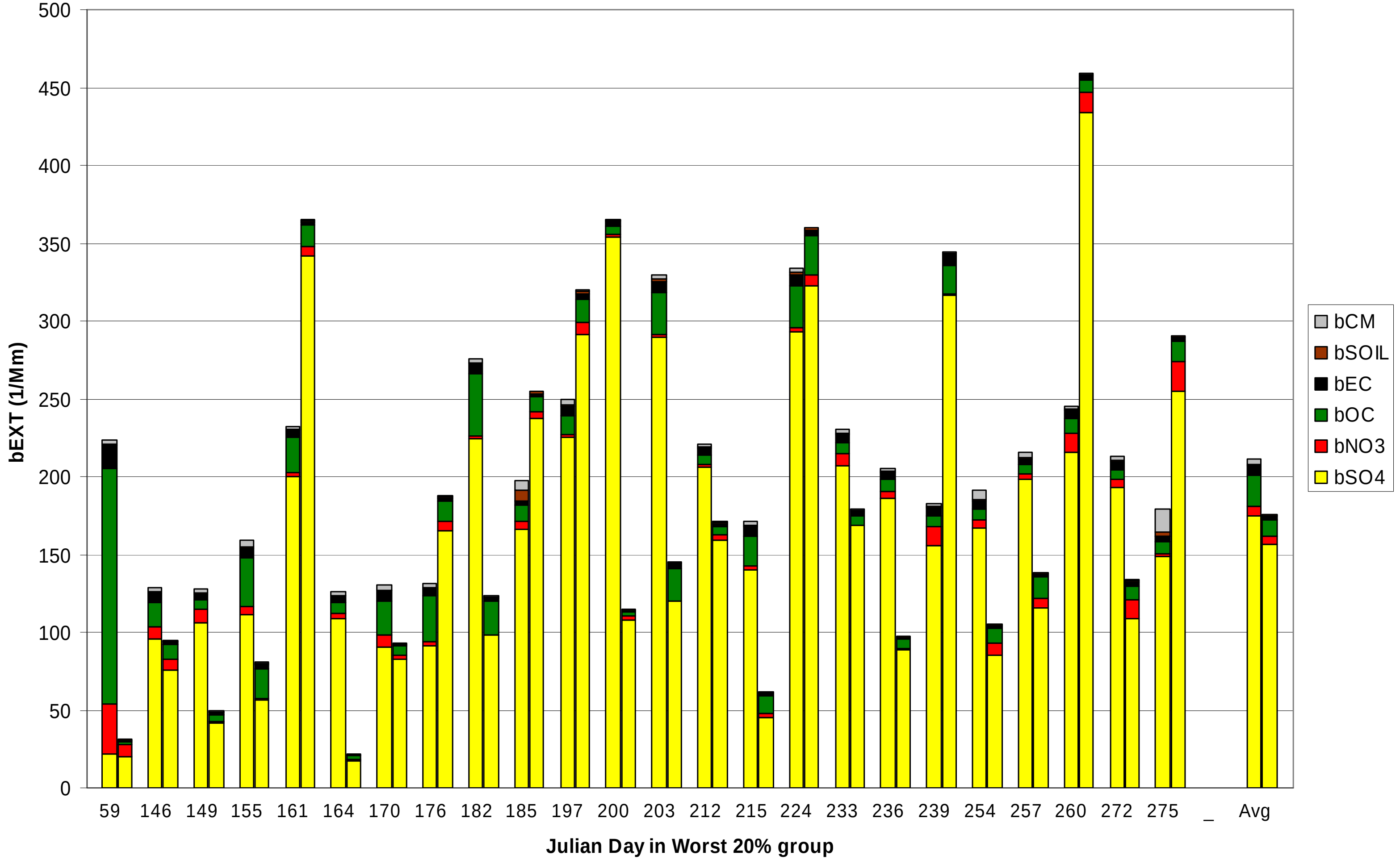
VISTAS 2018 Base G2 Visibility Projections (Delivered Mar 2007)

- 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

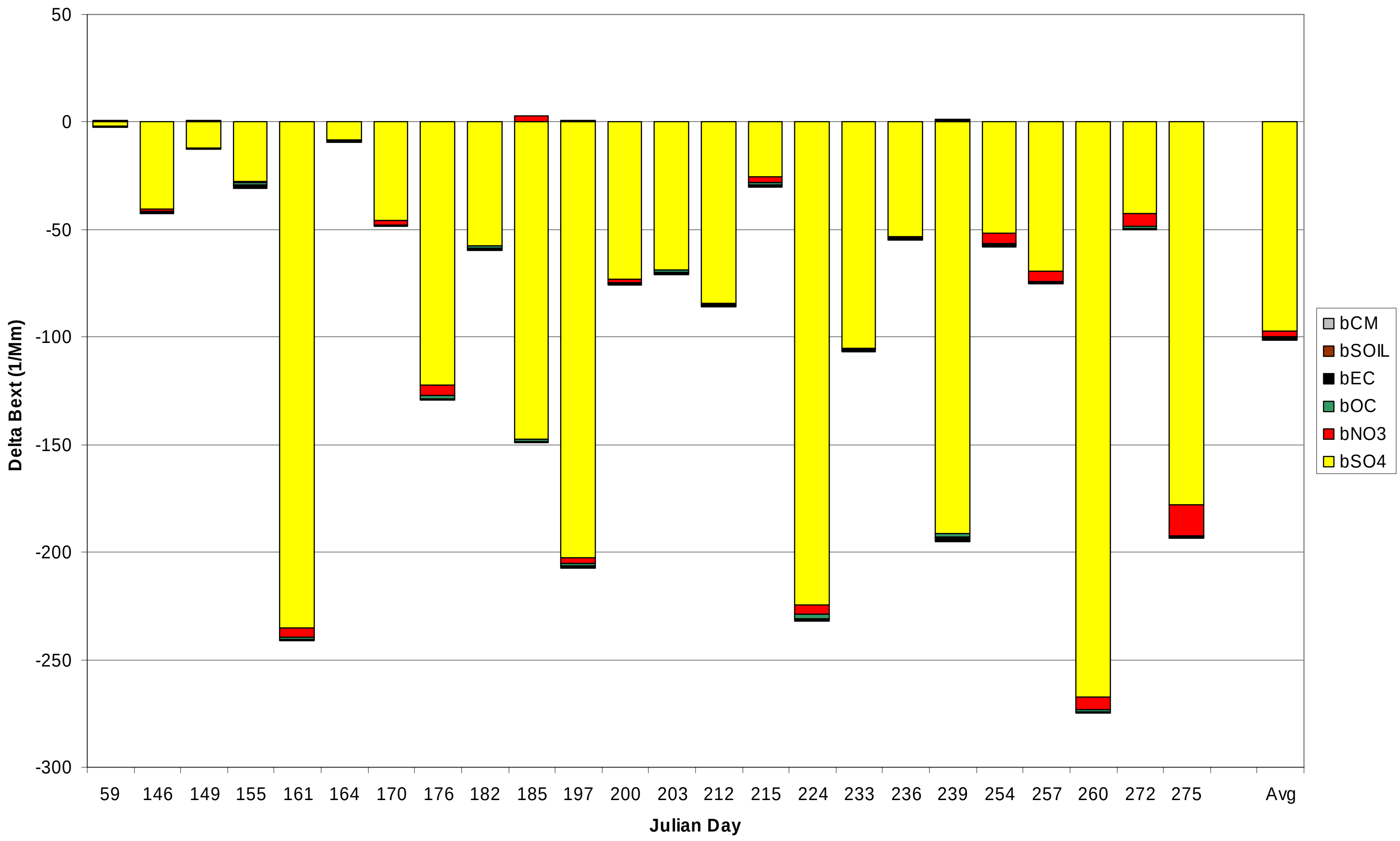
Observations (left) vs Modeled Base G2a (right)

Shenandoah, VA



Modeled Responses to 2018 Base G2a Emissions on 20% Haziest Days

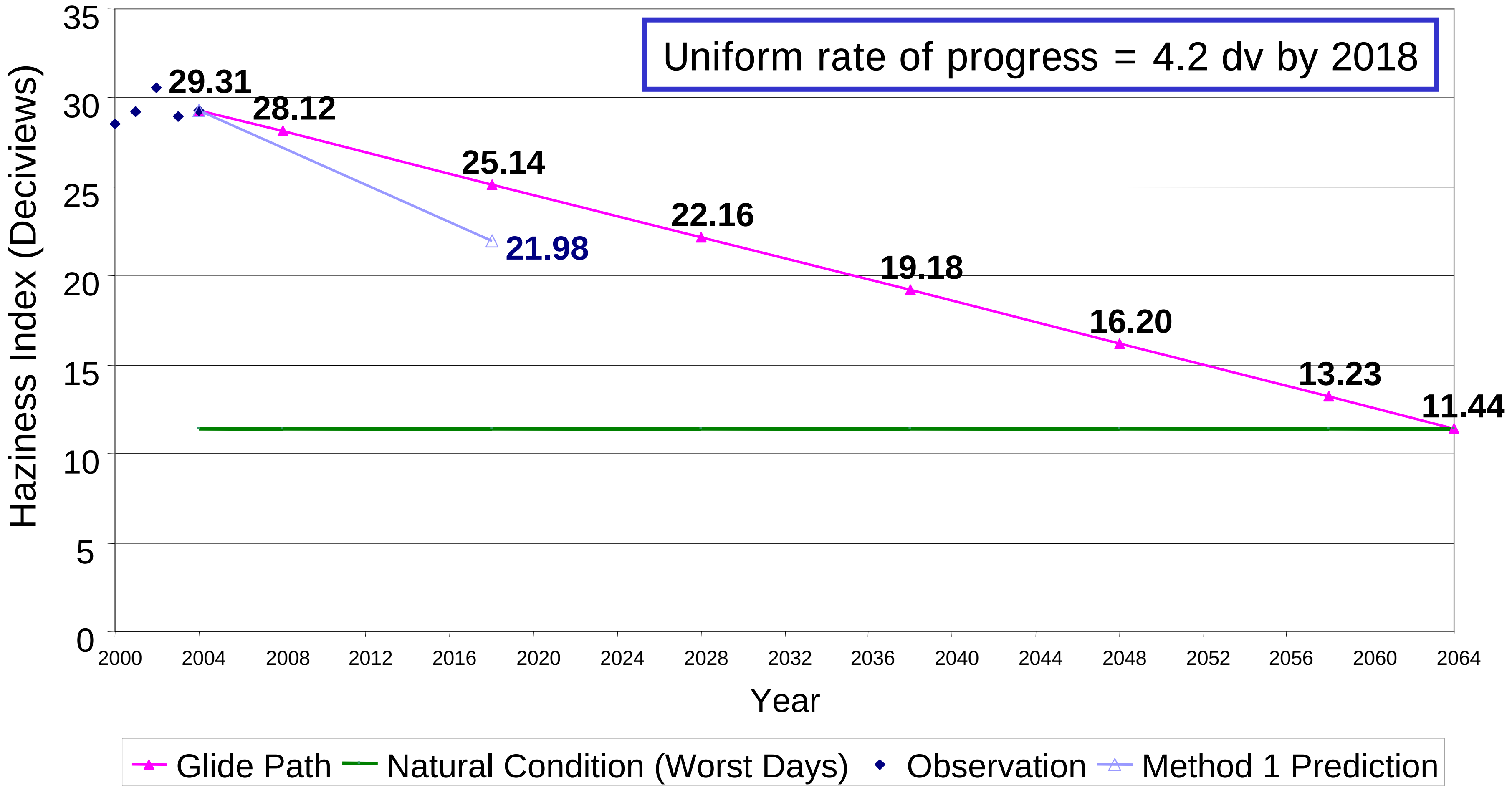
Shenandoah, VA



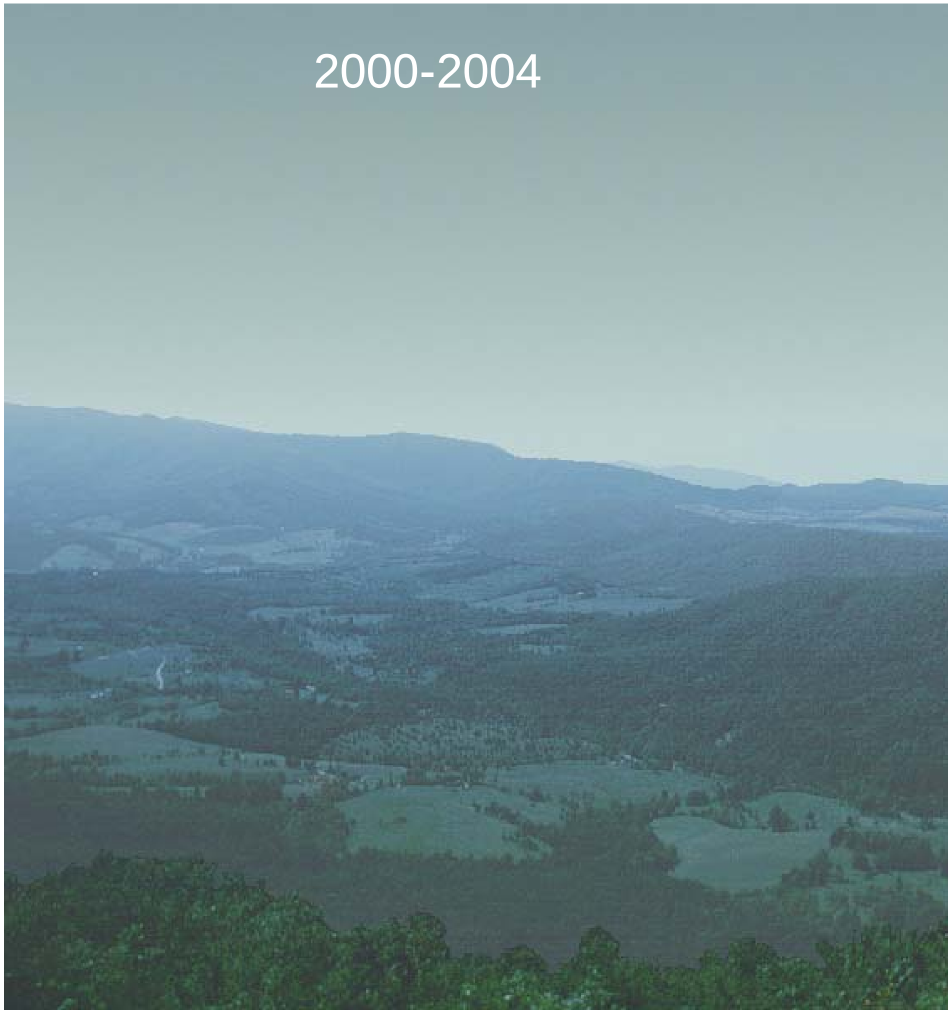
Uniform Rate of Progress Glide Path (Base G2a projections)

Shenandoah - 20% Worst Days

New IMPROVE equation



Visibility at Shenandoah on 20% Haziest Days

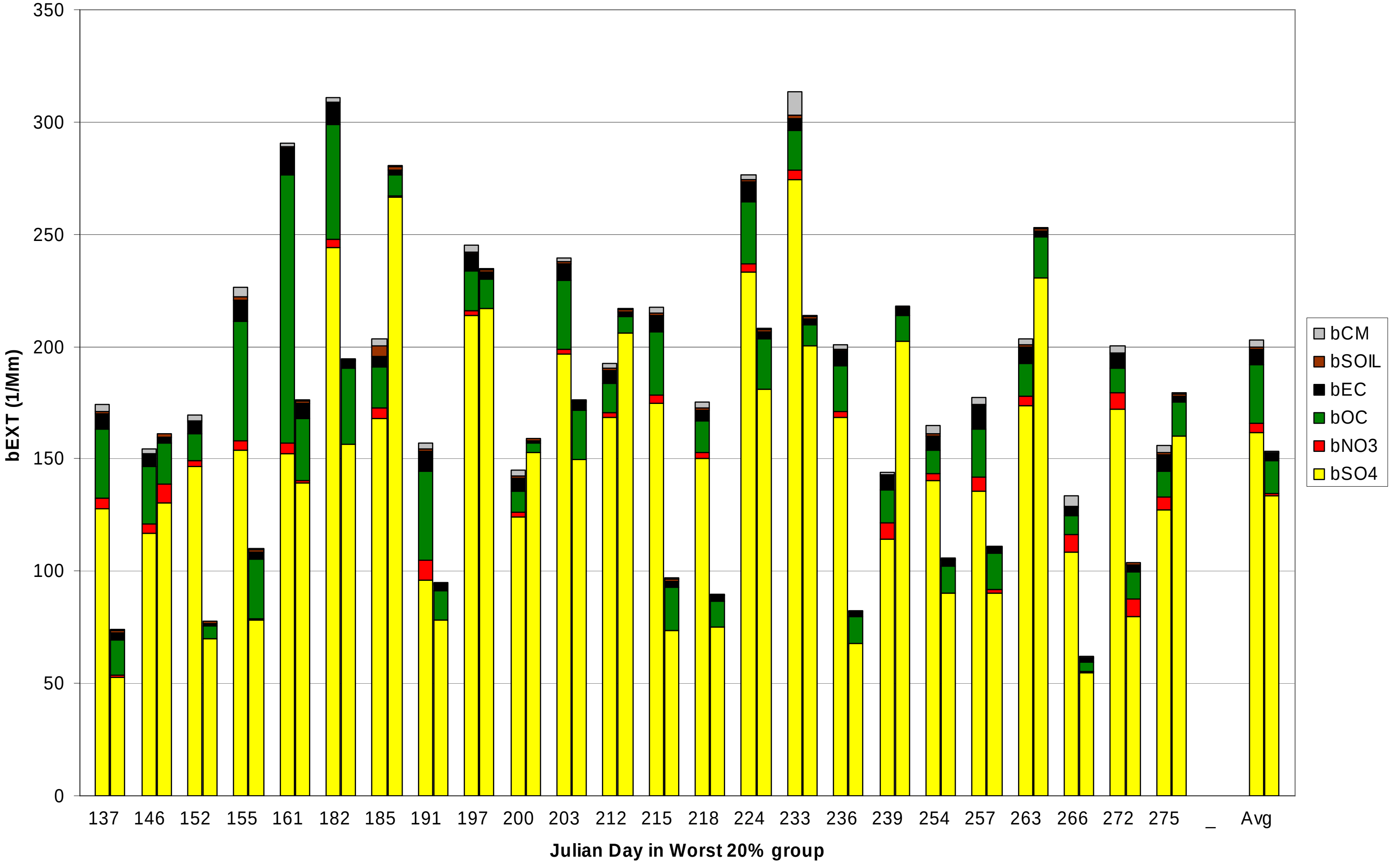


Visibility at Shenandoah – Natural Conditions

Model Performance 20% Haziest Days in 2002

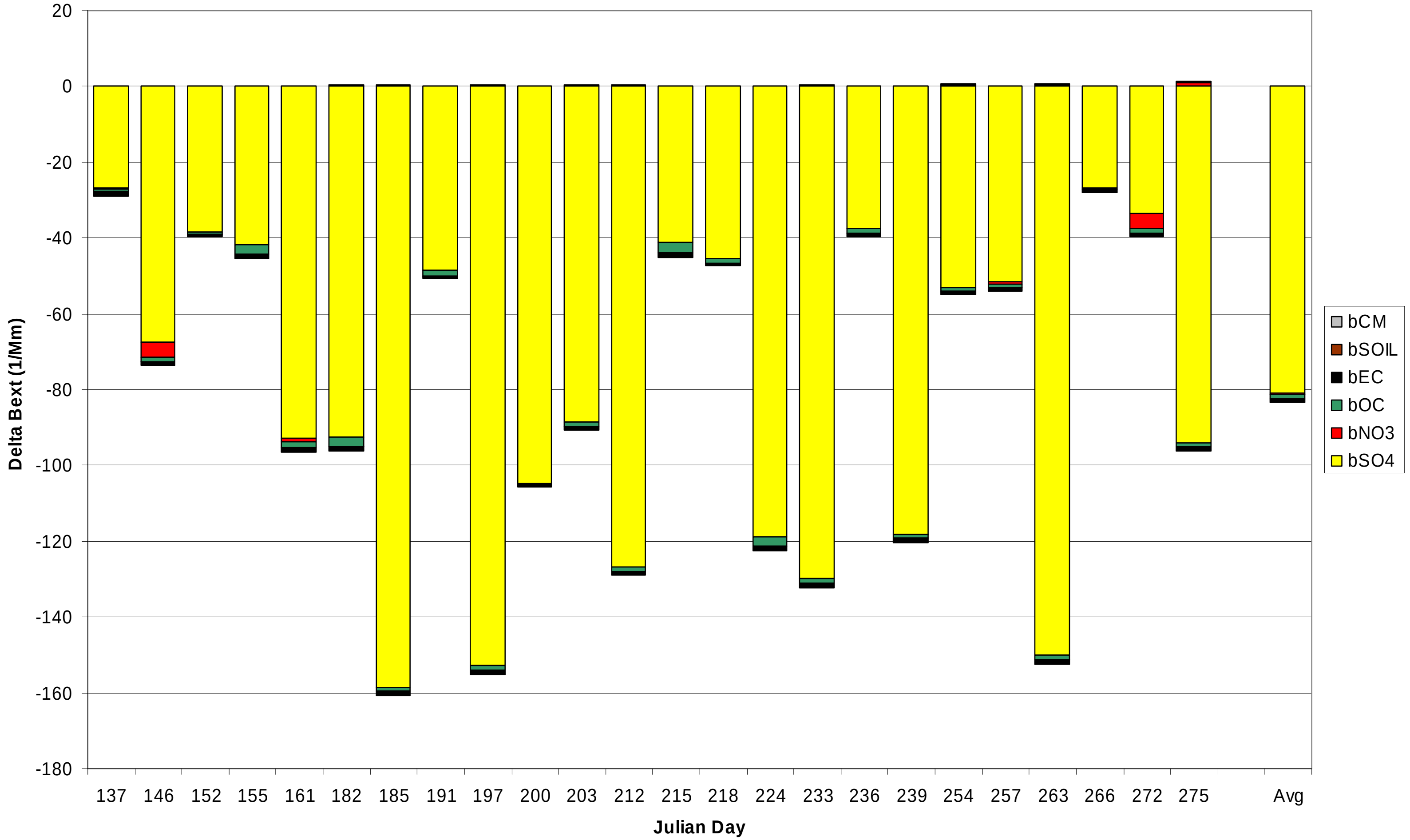
Observations (left) vs Modeled Base G2a (right)

James River Face, VA



Modeled Responses to 2018 Base G2a Emissions on 20% Haziest Days

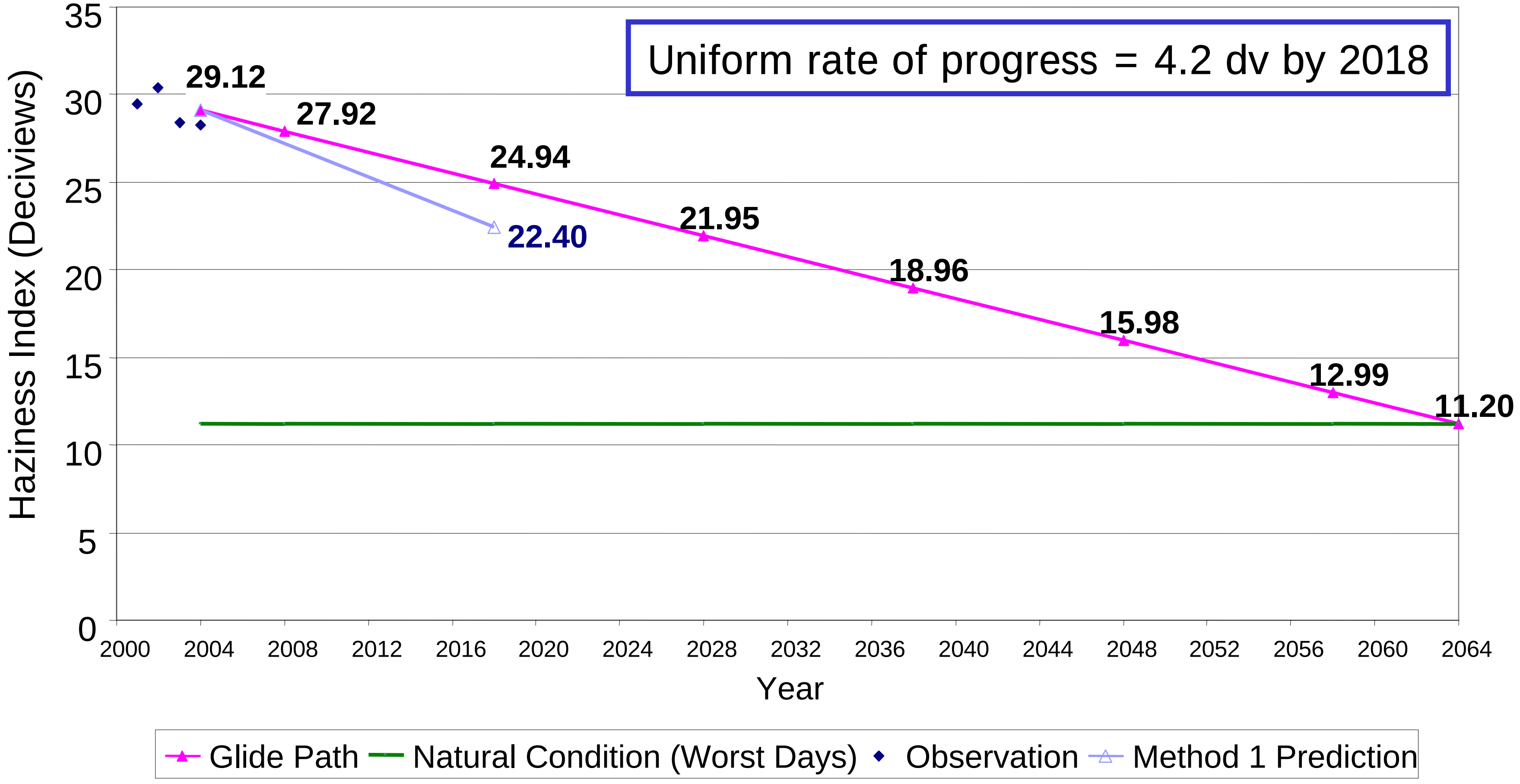
James River Face, VA

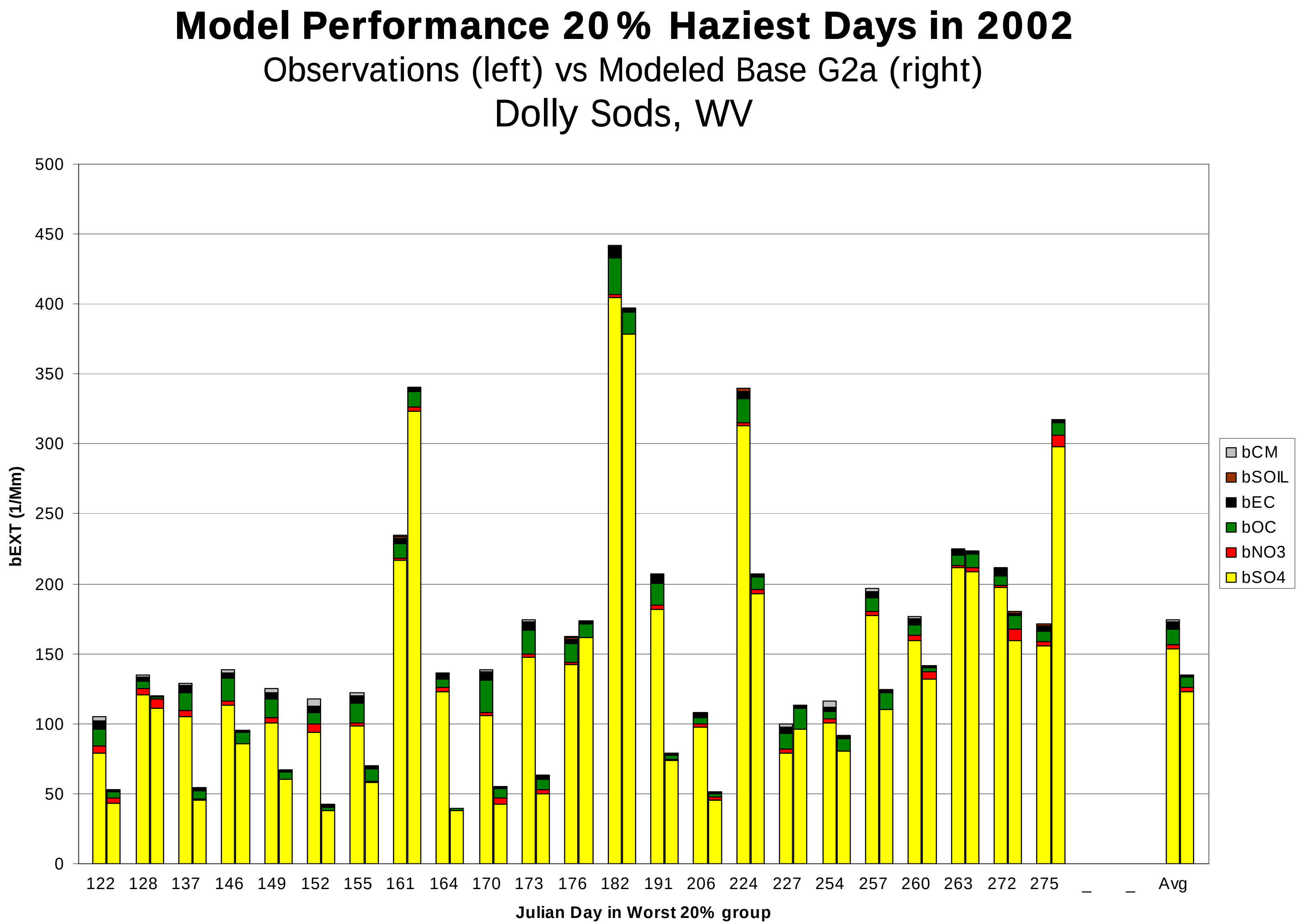


Uniform Rate of Progress Glide Path (Base G2a projections)

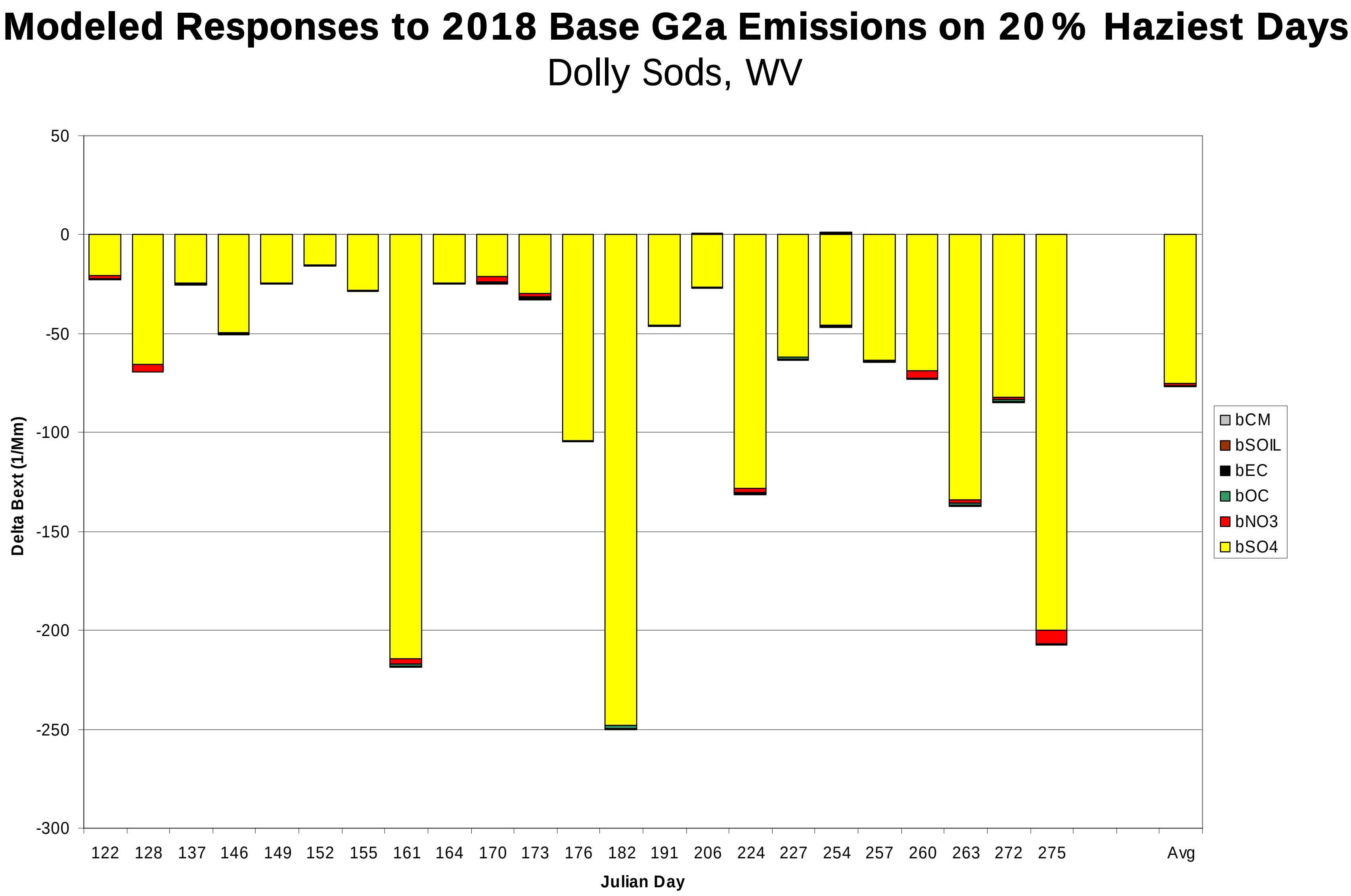
James River Face - 20% Worst Days

New IMPROVE equation





Model Performance 20% Haziest Days in 2002
Observations (left) vs Modeled Base G2a (right)
Dolly Sods, WV
bEXT (1/Mm)
0
50
100
150
200
250
300
350
400
450
500
122
128
137
146
149
152
155
161
164
170
173
176
182
191
206
224
227
254
257
260
263
272
275
_
_
Avg
Julian Day in Worst 20% group
bCM
bSOIL
bEC
bOC
bNO3
bSO4

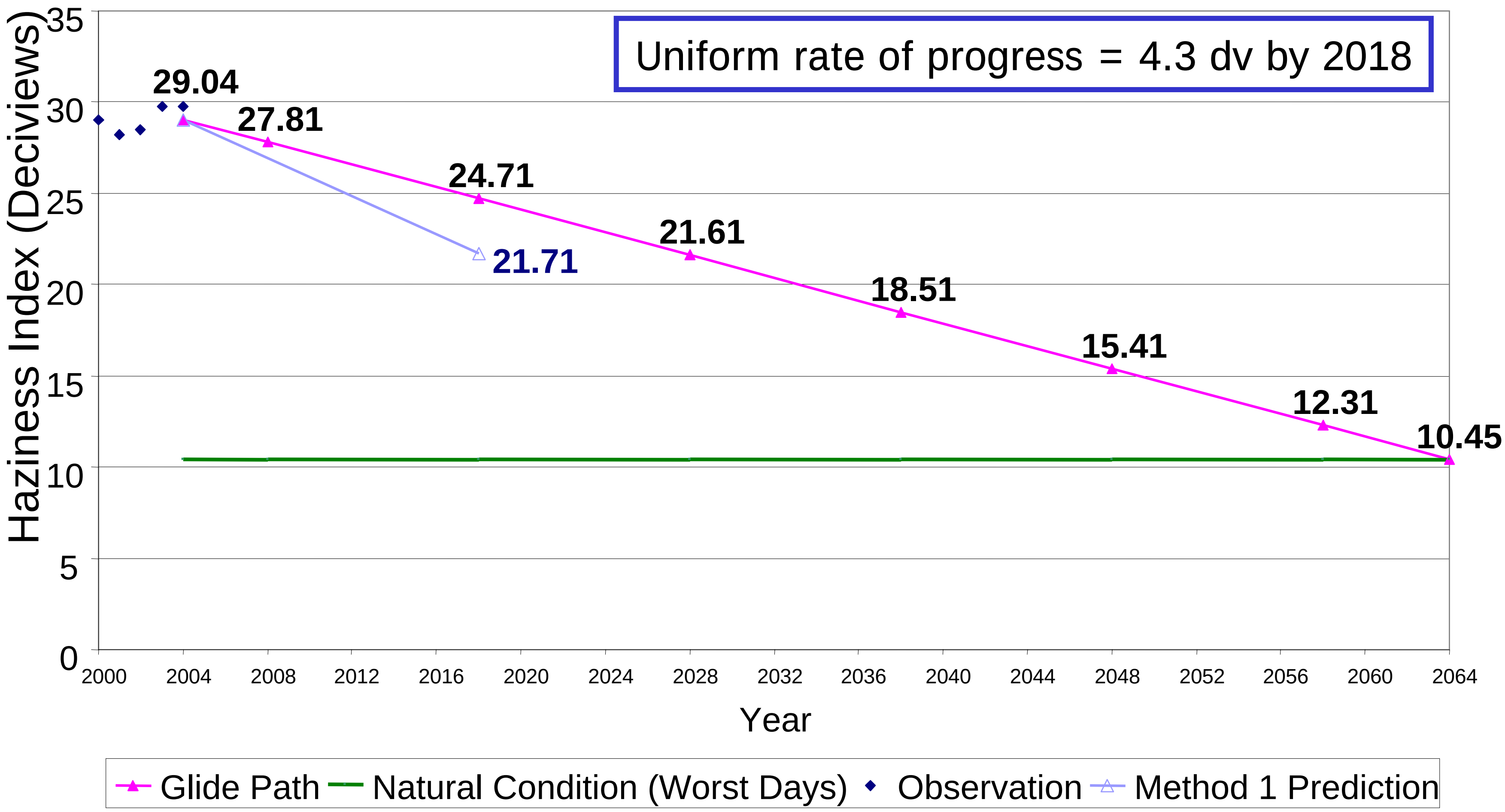


Modeled Responses to 2018 Base G2a Emissions on 20% Haziest Days
Dolly Sods, WV
50
0
-50
-100
-150
-200
-250
-300
Delta Bext (1/Mm)
122
128
137
146
149
152
155
161
164
170
173
176
182
191
206
224
227
254
257
260
263
272
275
Avg
Julian Day
bCM
bSOIL
bEC
bOC
bNO3
bSO4

Uniform Rate of Progress Glide Path (Base G2a projections)

Dolly Sods - 20% Data Days

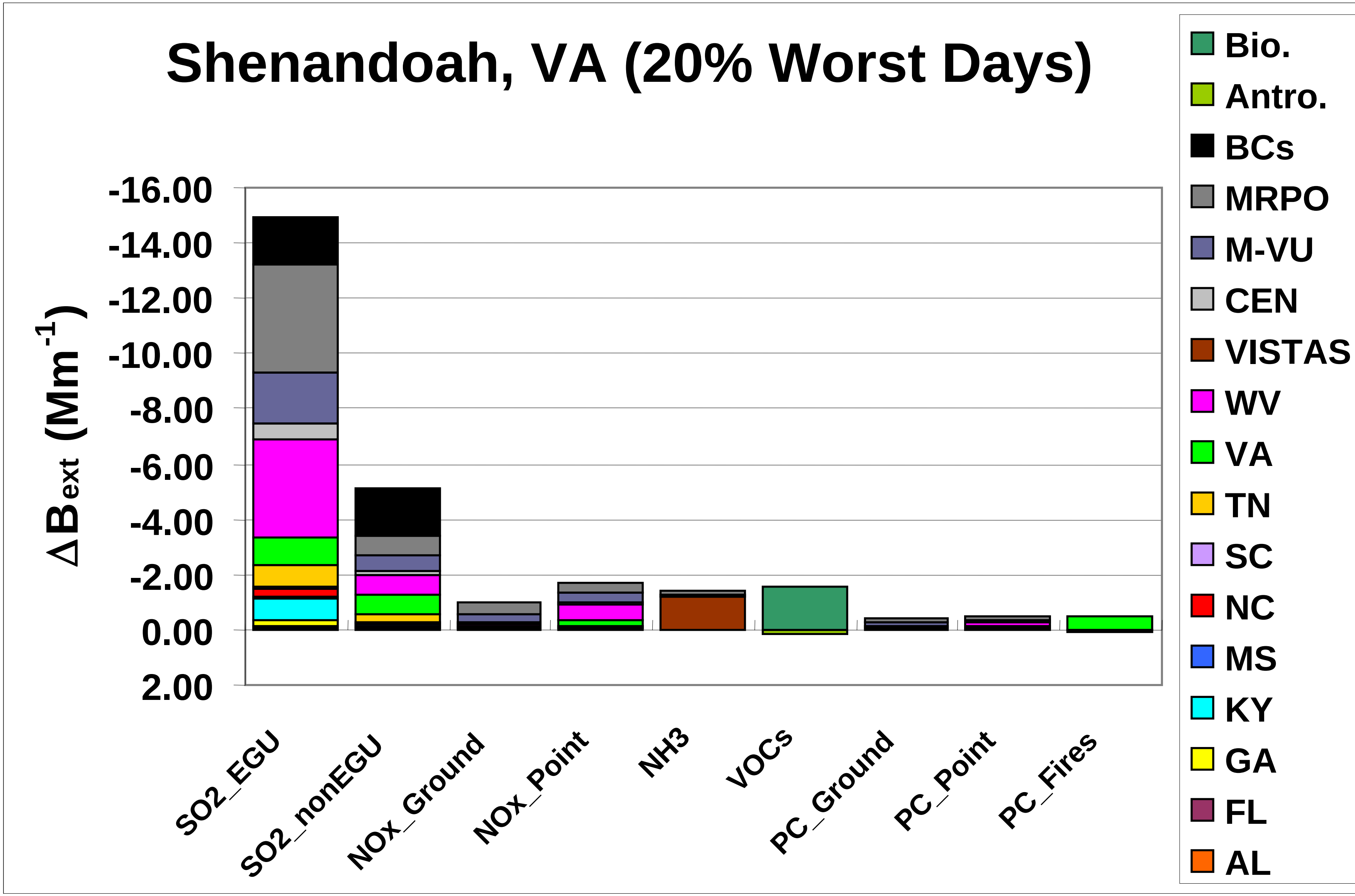
New IMPROVE equation



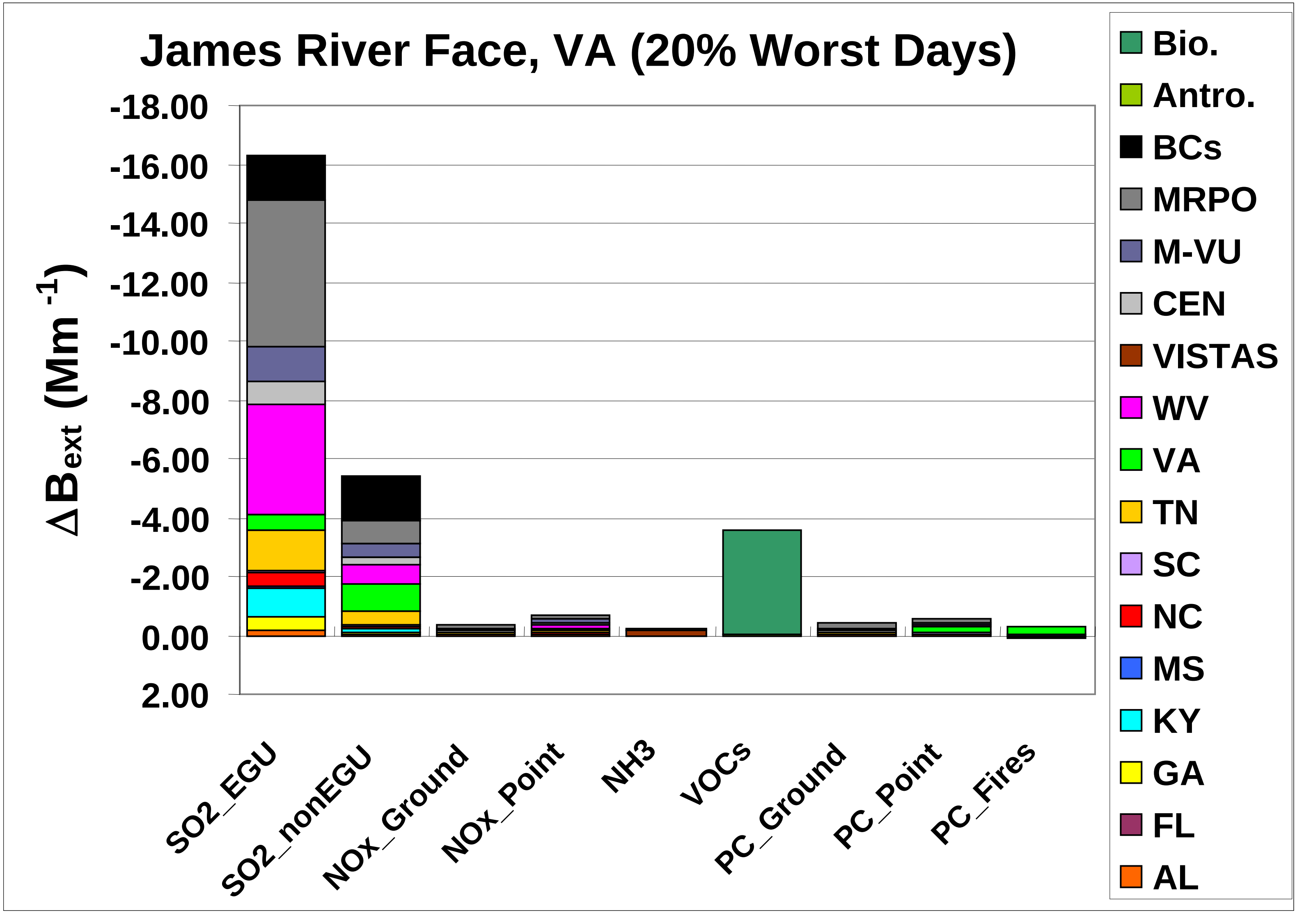
Rate of progress for Otter Creek is same as rate of progress for Dolly Sods

VISTAS Source Sector Emissions Sensitivities (Delivered Jan 2006)

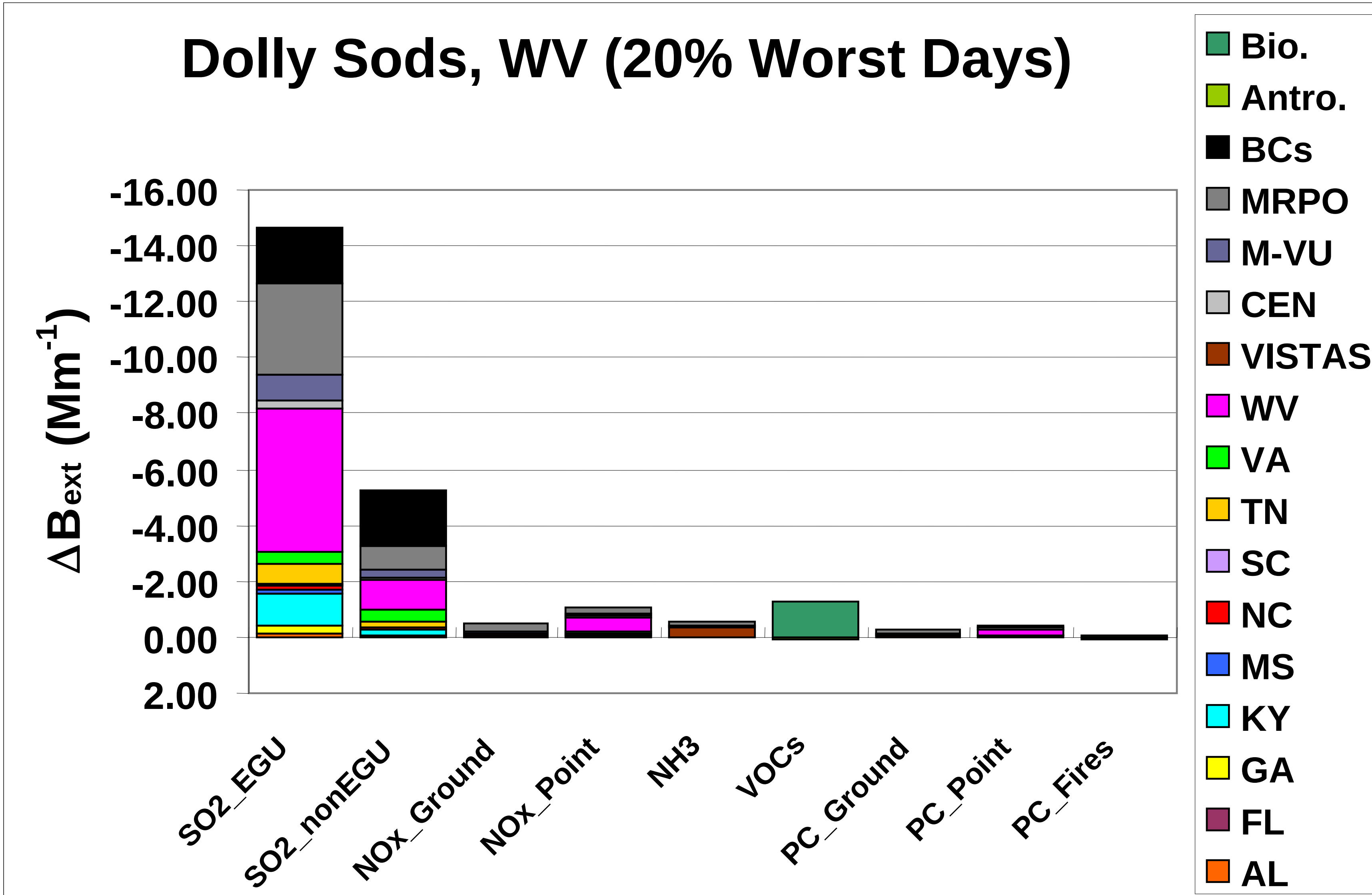
- Evaluated responses to emissions reductions for specific pollutants and source sectors
- Greatest visibility improvement from further reducing SO_2 emissions from utilities and industries



Shenandoah, VA (20% Worst Days)
ΔB ext (Mm-1)
-16.00
-14.00
-12.00
-10.00
-8.00
-6.00
-4.00
-2.00
0.00
2.00
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



James River Face, VA (20% Worst Days)
ΔB_ext (Mm^-1)
-18.00
-16.00
-14.00
-12.00
-10.00
-8.00
-6.00
-4.00
-2.00
0.00
2.00
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



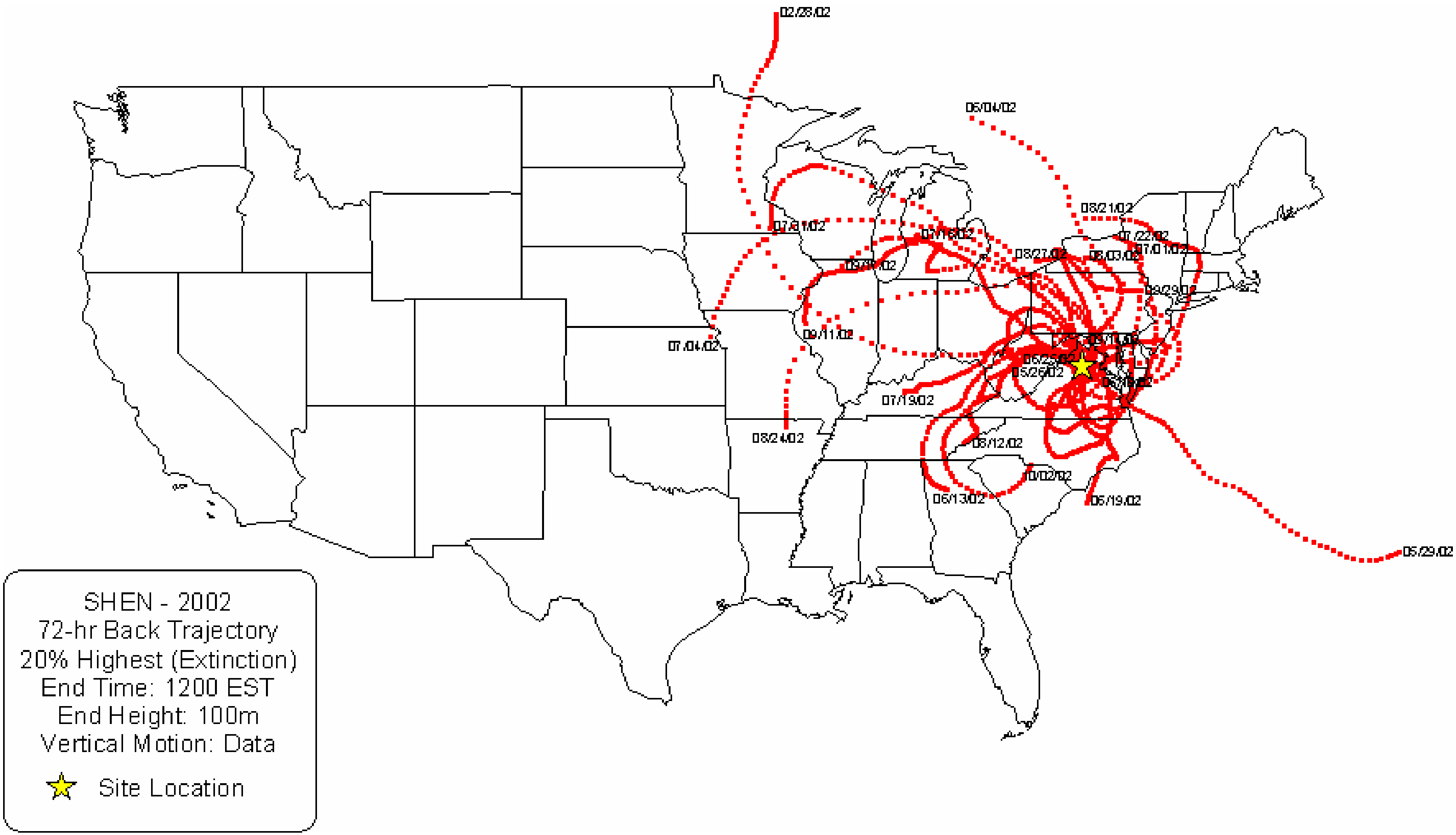
Emissions sensitivities for Otter Creek are the same as for Dolly Sods

Conclusion: Source Sector Emissions Sensitivities

- Reductions in SO_2 emissions from EGU and non-EGU show largest improvements in visibility
  - WV largest contributor
  - SO_2 from KY, VA, MRPO, MANE-VU, and Boundary Conditions (outside VISTAS 12 km domain) also contribute
- Small benefits from reducing NO_x, anthropogenic VOC or primary carbon

VISTAS Geographic Areas of Influence

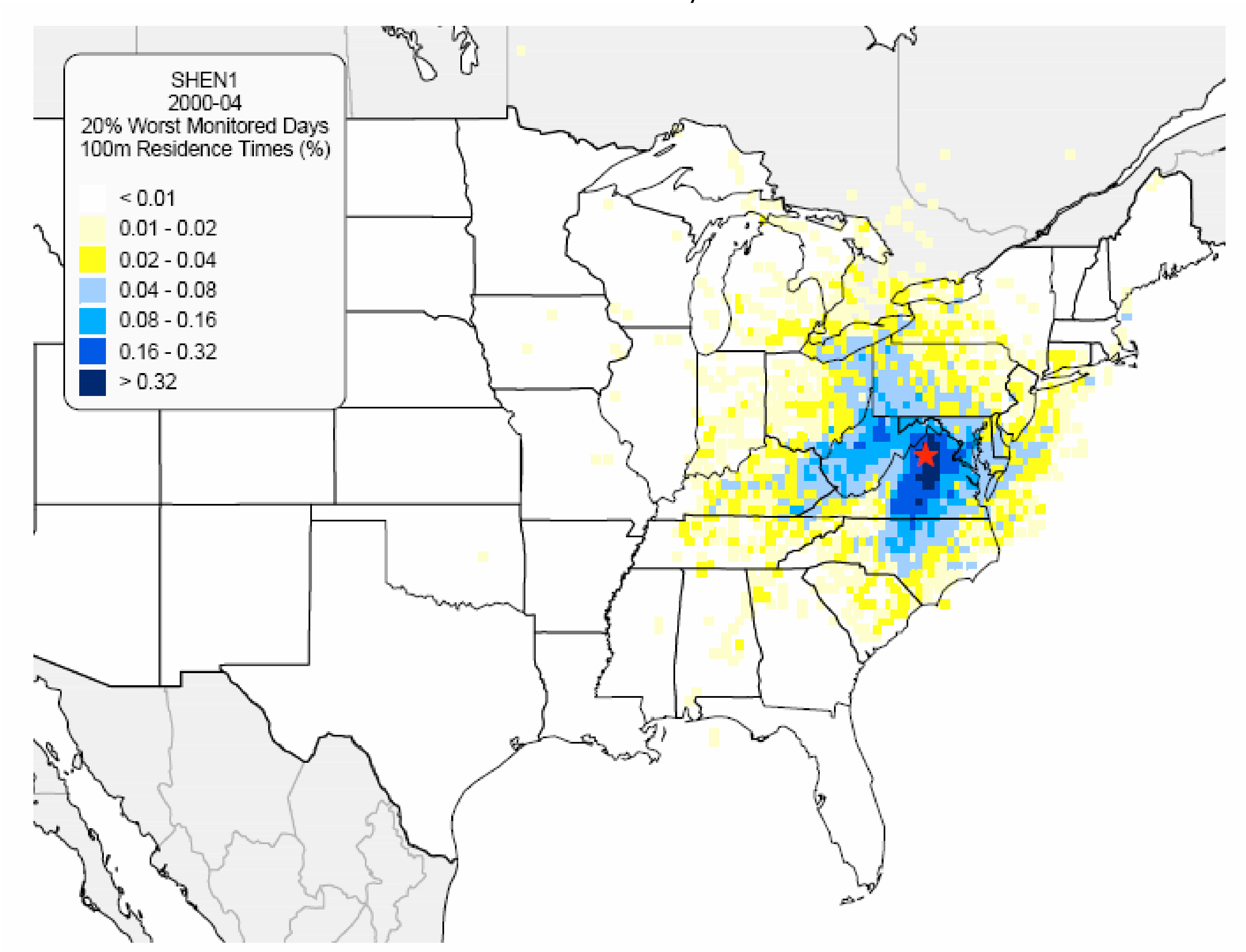
- Hysplit model used to generate back trajectories for Class I areas (Air Resource Specialists)
  - Back trajectories for individual 20% worst days in 2002
    - Helpful for evaluating model performance in 2002
  - Residence time plots for 20% worst days in 2000-2004 indicate probable contribution
    - Helpful to understand geographic area most likely to influence Class I areas
  - SO2 Area of Influence defined from residence weighted by SO4 extinction and considering SO2 emissions



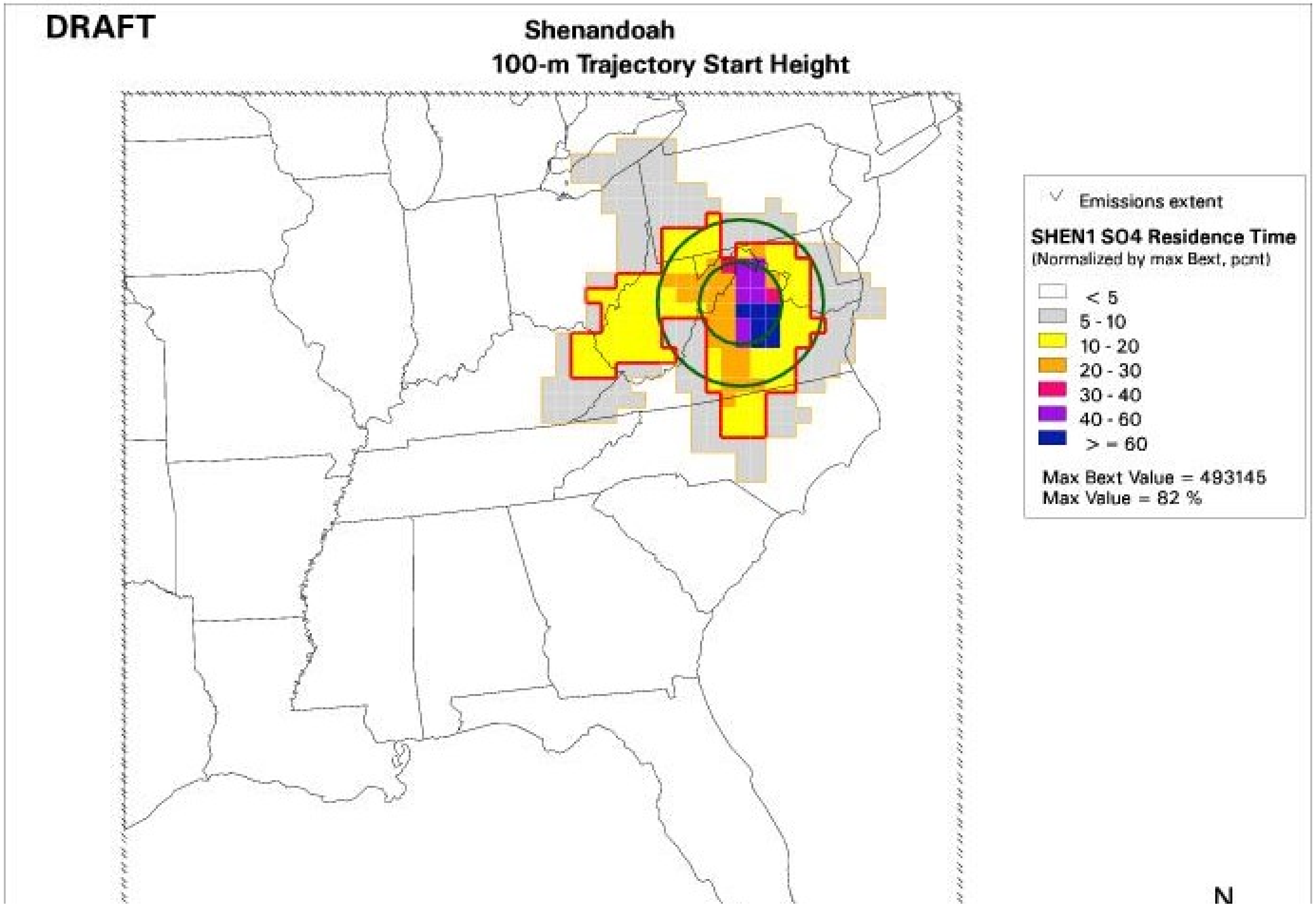
02/28/02
06/04/02
08/21/02
08/27/02
08/29/02
07/04/02
09/11/02
07/19/02
08/24/02
08/12/02
10/02/02
06/13/02
06/19/02
06/29/02
SHEN - 2002
72-hr Back Trajectory
20% Highest (Extinction)
End Time: 1200 EST
End Height: 100m
Vertical Motion: Data
Site Location

Residence Time for 20% Worst Days in 2000-2004

Shenandoah, VA



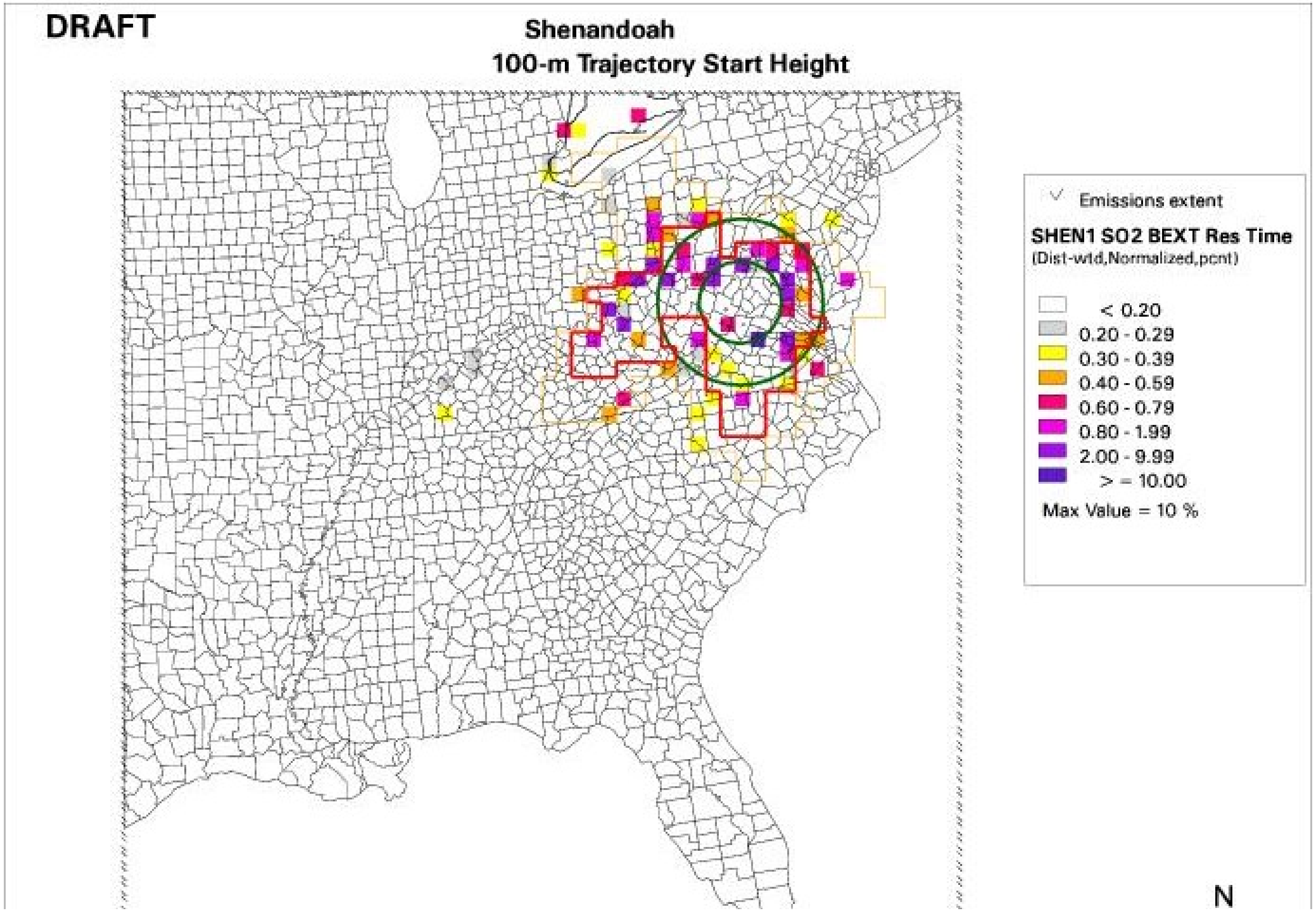
SO2 Area of Influence for Shenandoah, VA



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%.

2018 SO2 Emissions weighted by Residence Time

Shenandoah, VA



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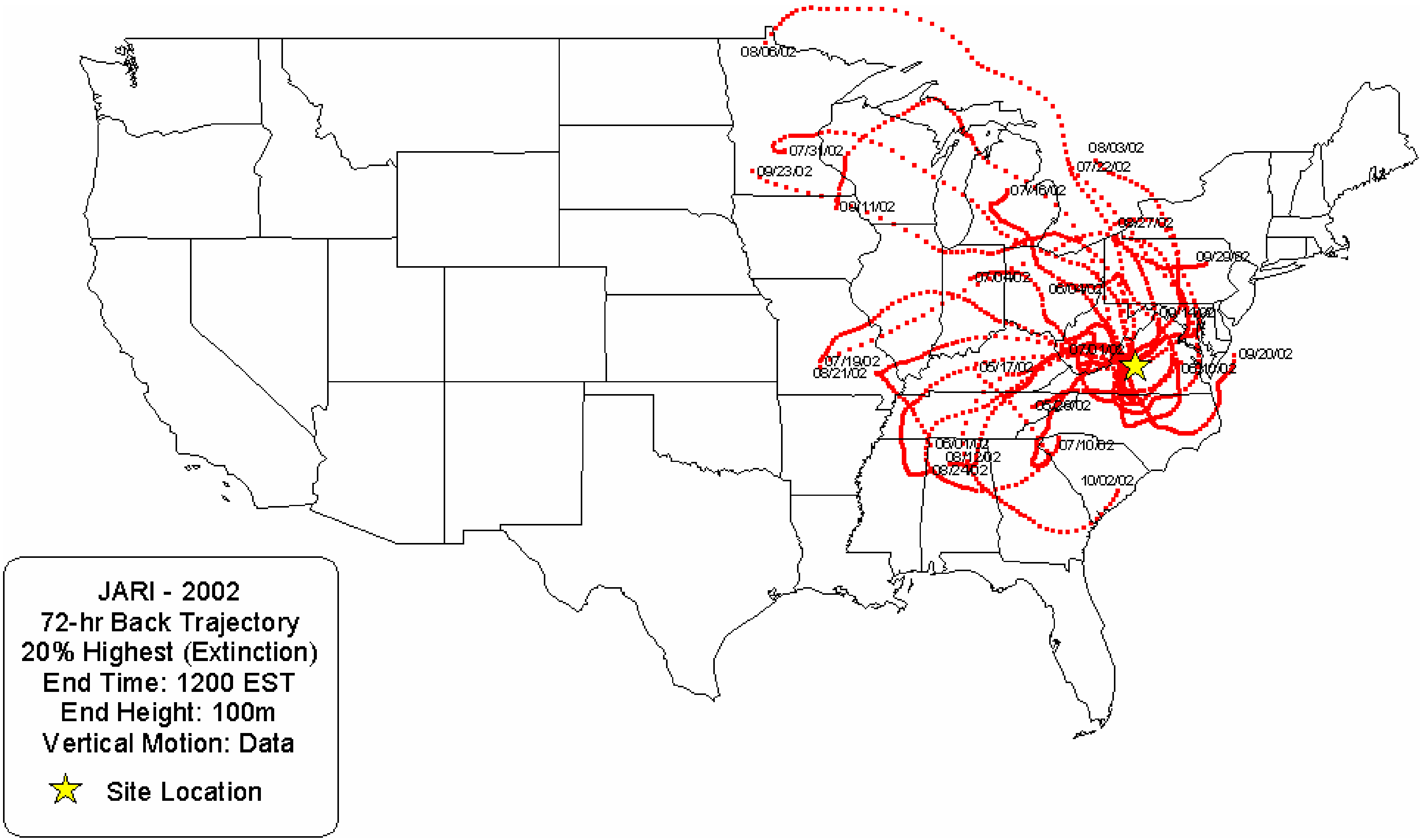
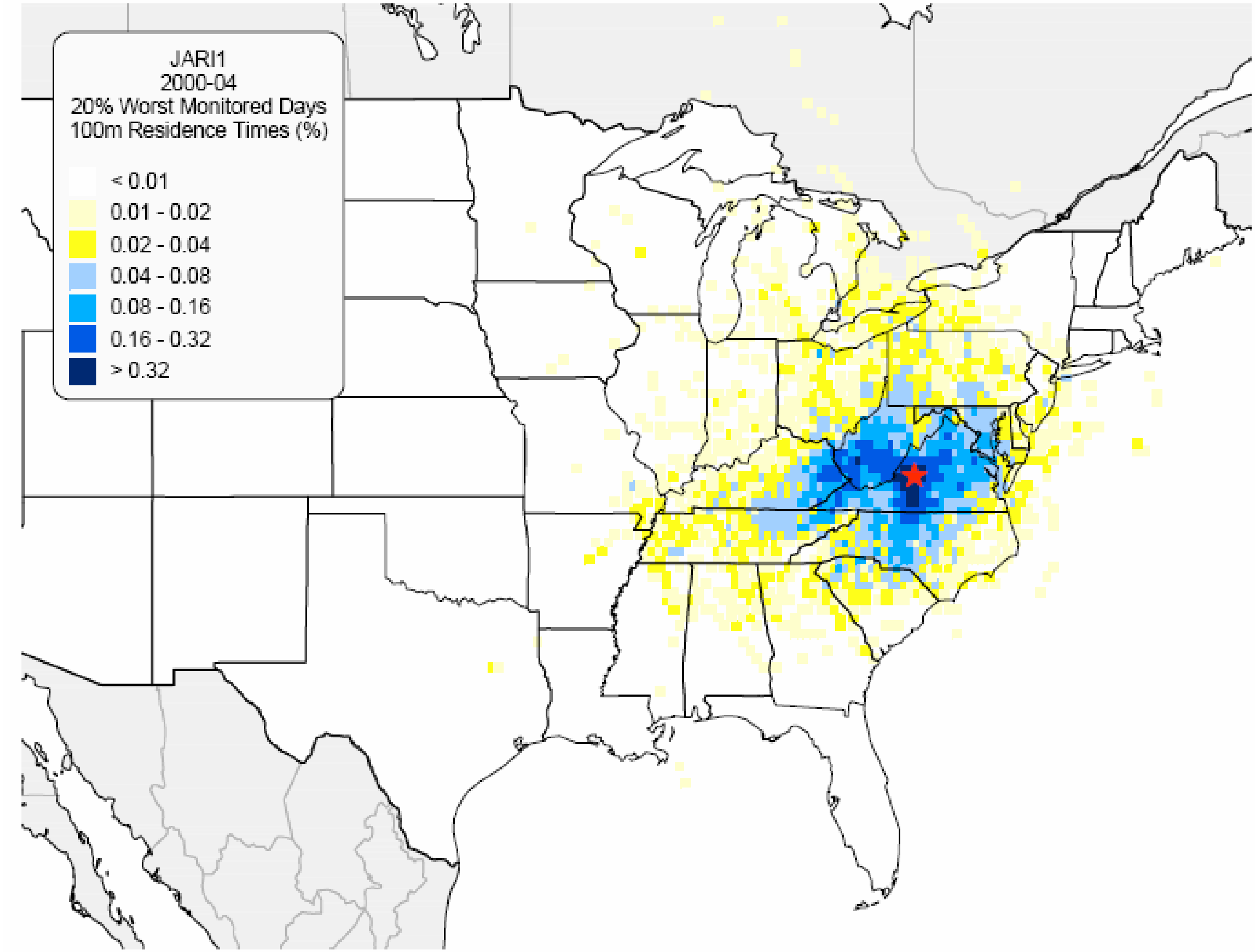
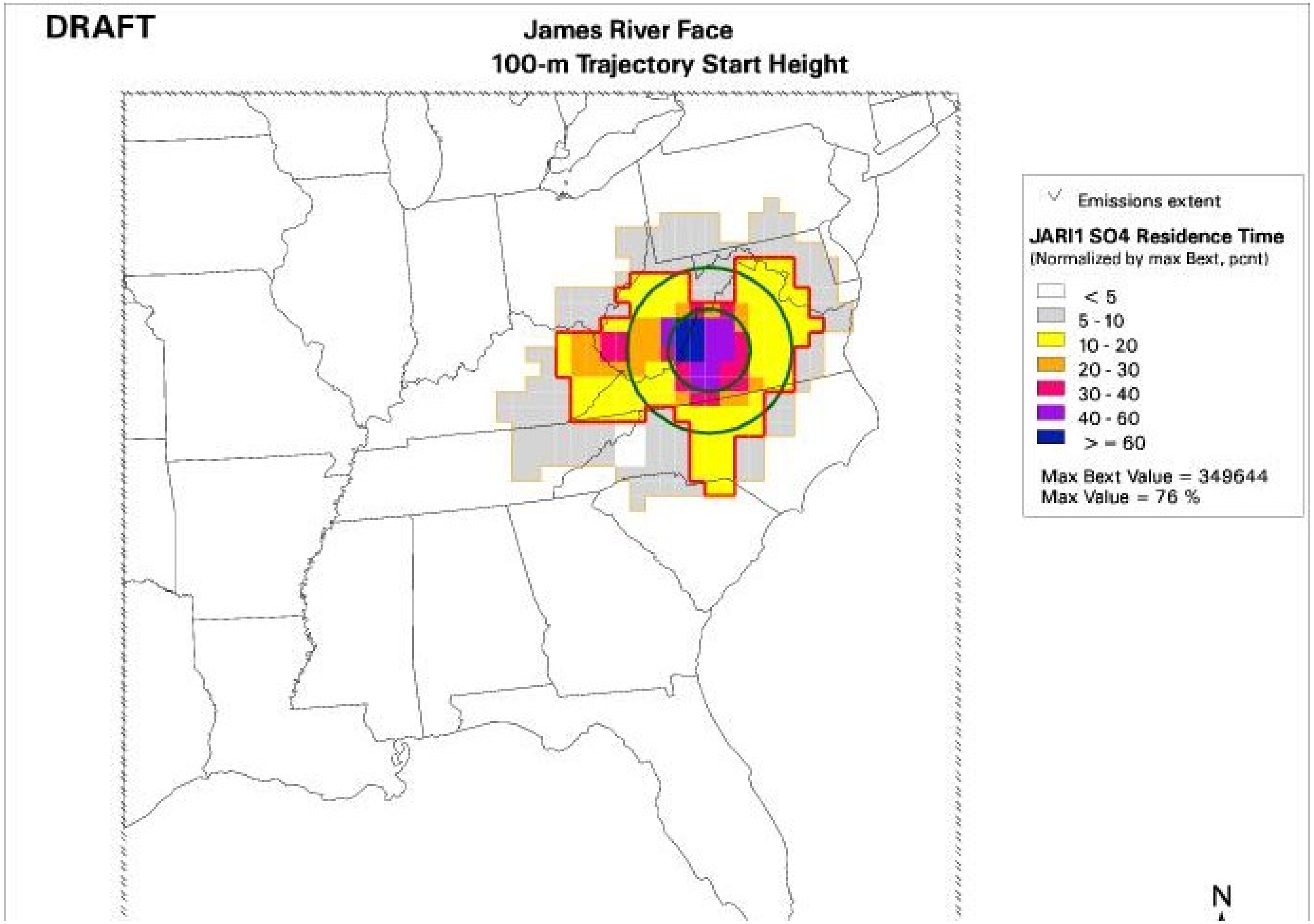

JARI - 2002
72-hr Back Trajectory
20% Highest (Extinction)
End Time: 1200 EST
End Height: 100m
Vertical Motion: Data
Site Location
08/06/02
07/31/02
09/23/02
09/11/02
08/03/02
07/22/02
07/16/02
09/29/02
07/04/02
06/04/02
07/01/02
09/20/02
07/19/02
08/21/02
05/17/02
05/28/02
06/01/02
08/12/02
08/24/02
07/10/02
10/02/02

Residence Time for 20% Worst Days in 2000-2004

James River Face, VA



SO2 Area of Influence for James River Face, VA



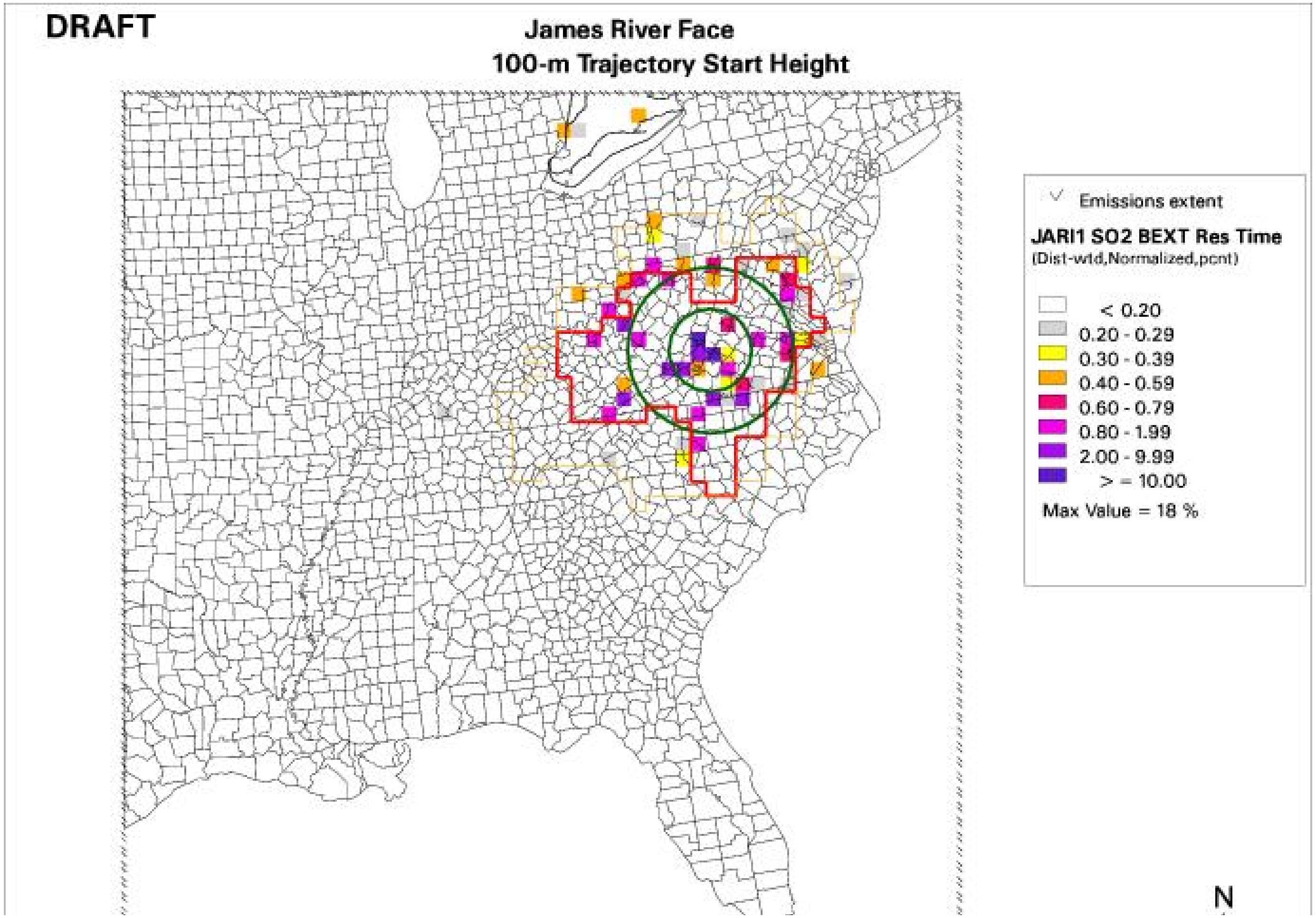
Green circles indicate 100-km and 200-km radii from Class I area.

Red line perimeter indicate Area of Influence with Residence Time ≥ 10%

Orange line perimeter indicate Area of Influence with Residence Time ≥ 5%.

2018 SO2 Emissions weighted by Residence Time

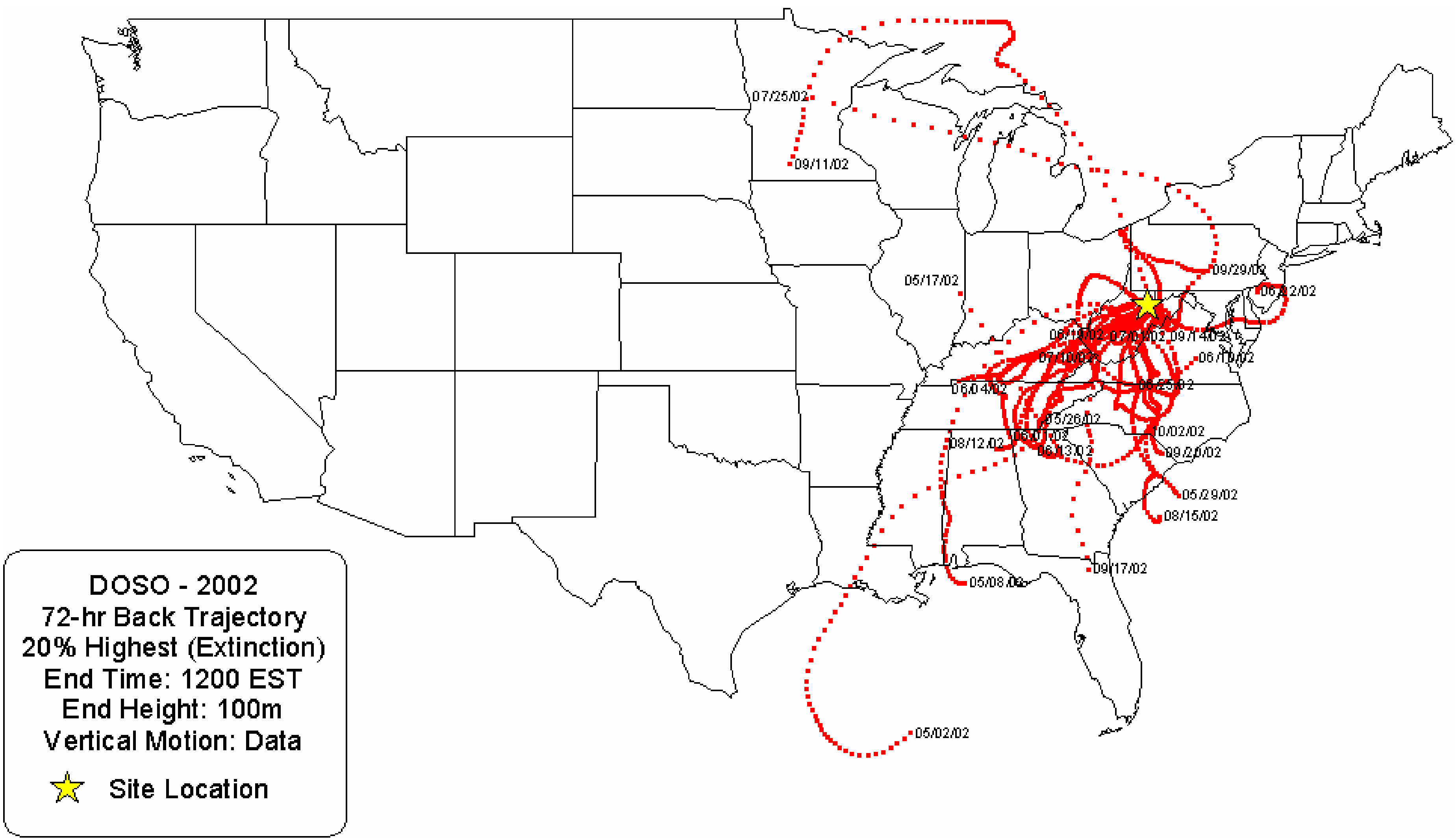
James River Face, VA



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

Red line perimeter indicate Area of Influence with Residence Time ≥ 10%.

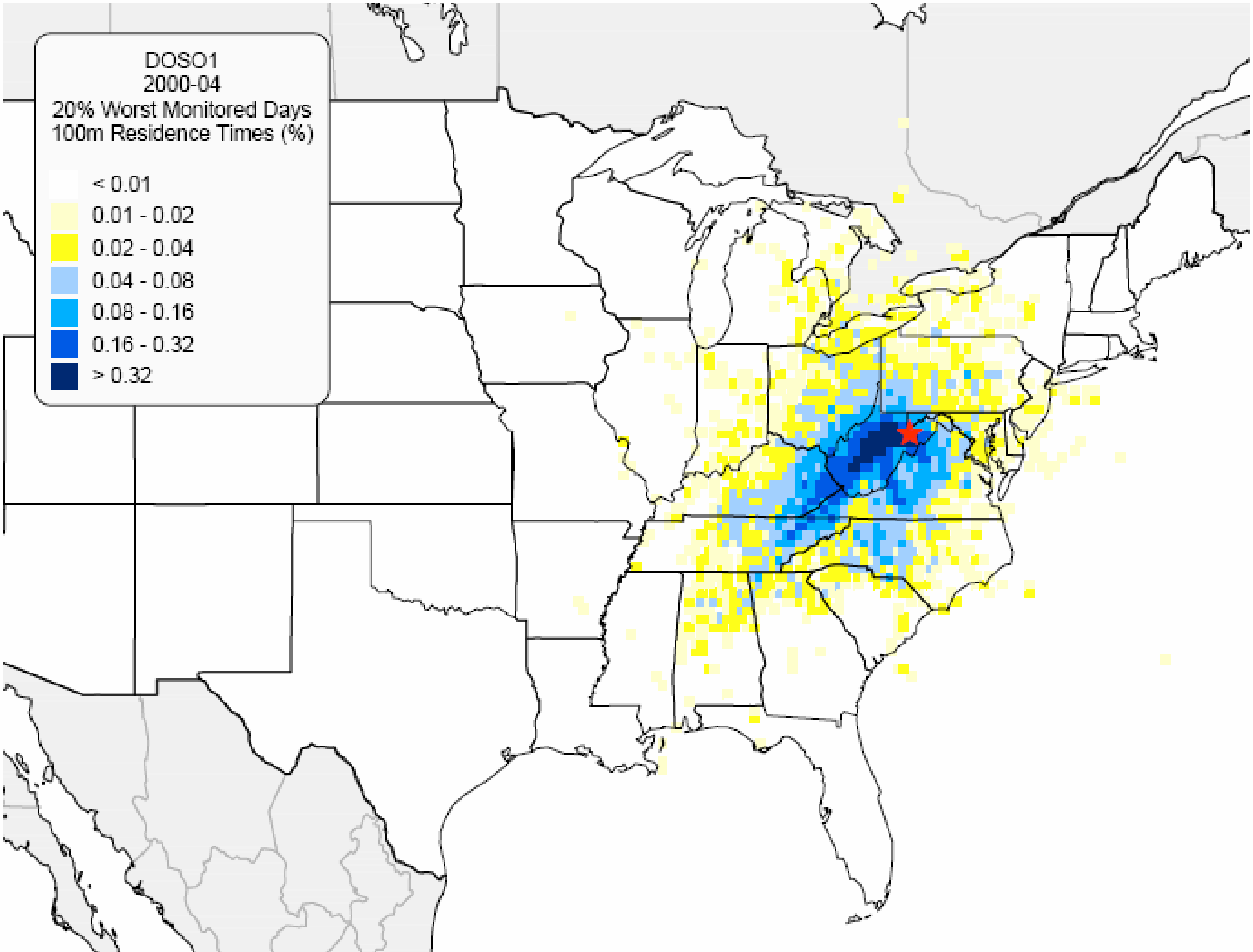
Orange line perimeter indicate Area of Influence with Residence Time ≥ 5%.



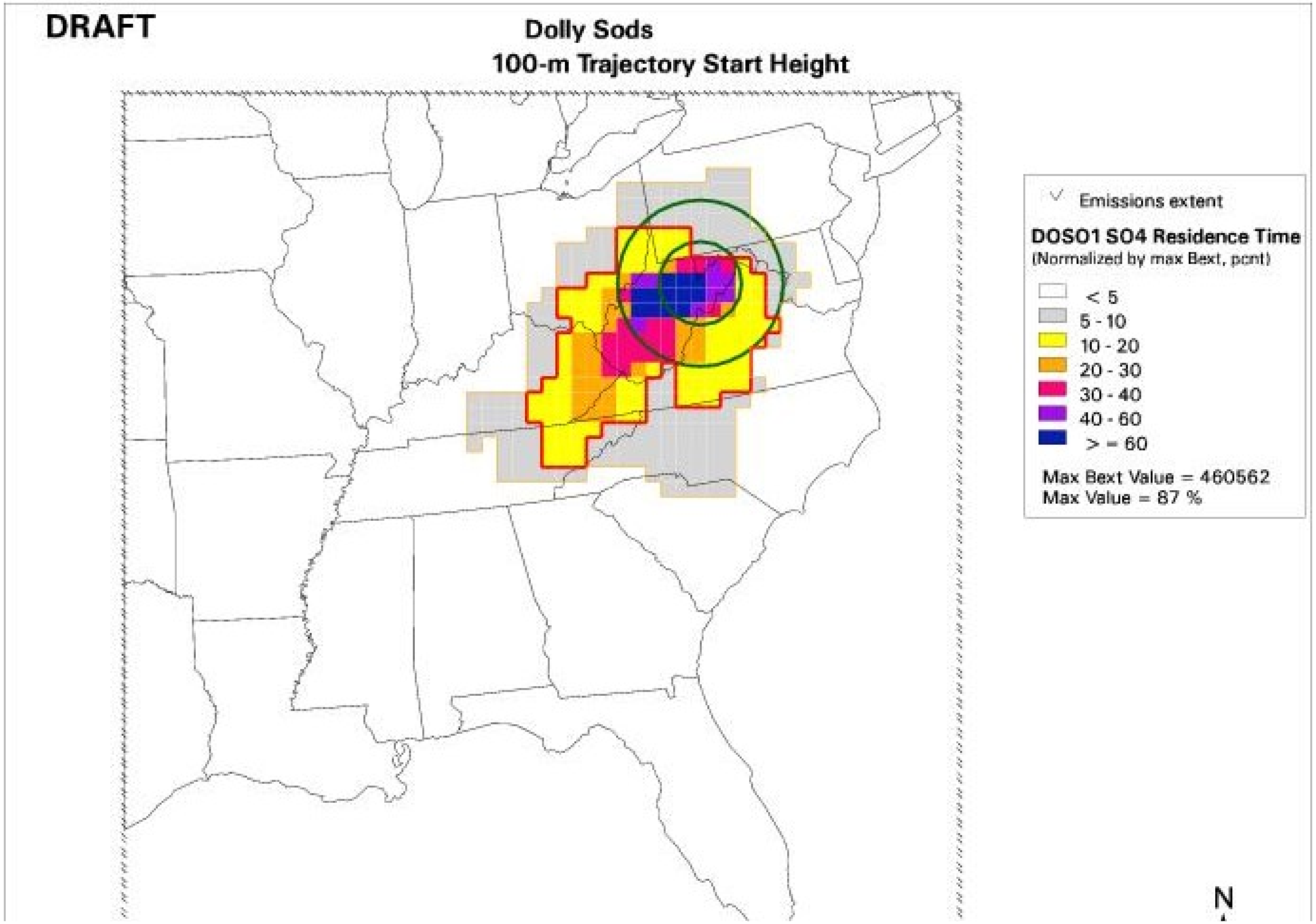
DOSO - 2002
72-hr Back Trajectory
20% Highest (Extinction)
End Time: 1200 EST
End Height: 100m
Vertical Motion: Data
Site Location
07/25/02
09/11/02
05/17/02
09/29/02
07/10/02
06/04/02
06/25/02
05/26/02
10/02/02
08/12/02
06/13/02
09/20/02
05/29/02
08/15/02
09/17/02
05/08/02
05/02/02

Residence Time for 20% Worst Days in 2000-2004

Dolly Sods, WV



SO2 Area of Influence for Dolly Sods, WV



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

Red line perimeter indicate Area of Influence with Residence Time ≥ 10%

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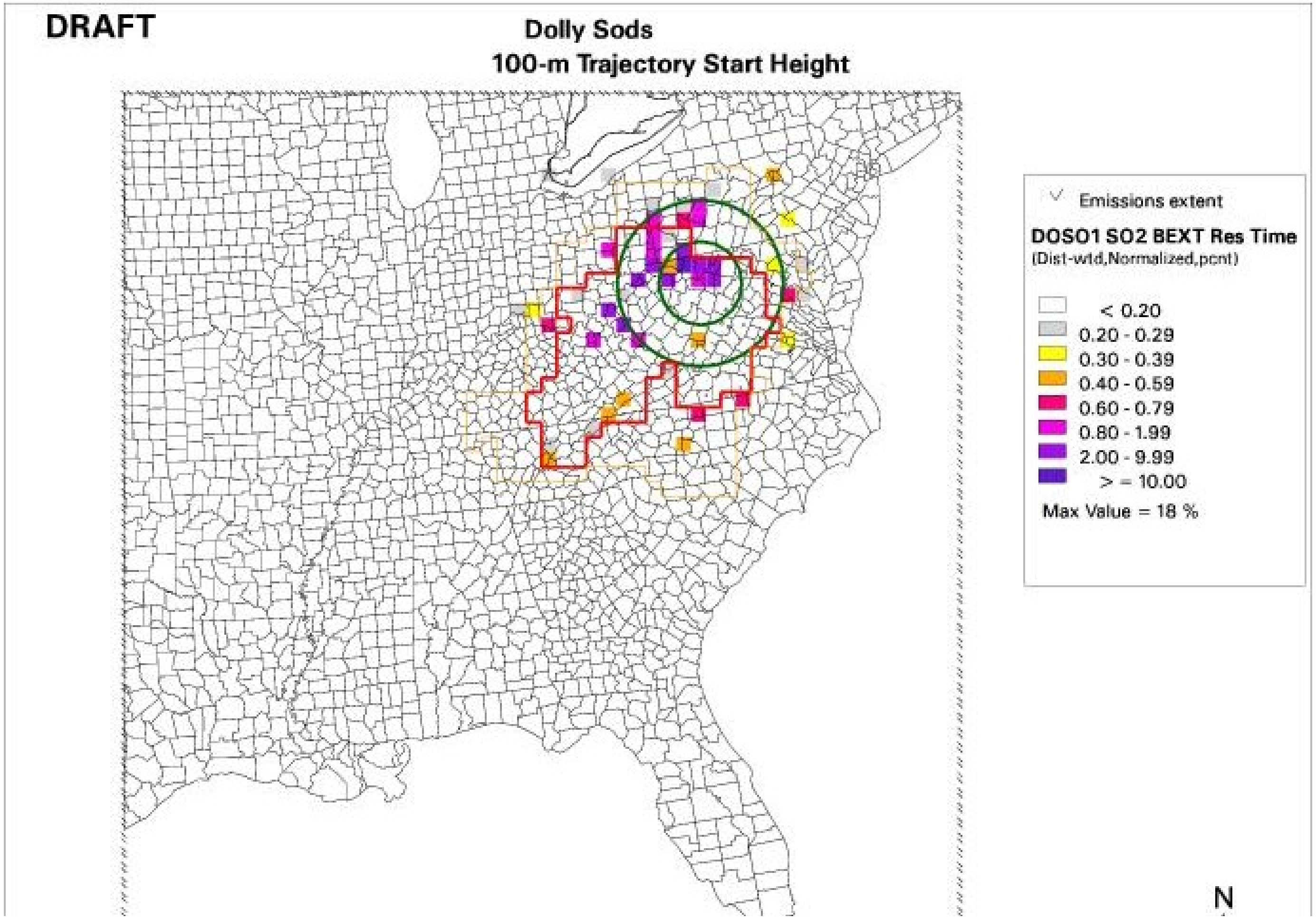
2018 SO2 Emissions weighted by Residence Time
Dolly Sods, WV



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%.

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
Shenandoah, VA

Tier	VOC	NOX	CO	SO2	PM-10	PM-2.5	NH3
Fuel Comb. Elec. Util.	1%	26%	1%	53%	14%	25%	1%
Fuel Comb. Industrial	1%	17%	2%	28%	5%	6%	0%
Fuel Comb. Other	7%	9%	4%	6%	7%	14%	1%
Chemical & Allied Product Mfg	2%	1%	1%	2%	1%	1%	1%
Metals Processing	1%	2%	4%	4%	3%	6%	0%
Petroleum & Related Industries	1%	0%	0%	2%	0%	0%	0%
Other Industrial Processes	3%	6%	0%	5%	9%	10%	1%
Solvent Utilization	39%	1%	0%	0%	0%	1%	0%
Storage & Transport	6%	0%	1%	0%	1%	1%	0%
Waste Disposal & Recycling	4%	2%	3%	0%	4%	9%	0%
Highway Vehicles	19%	20%	45%	0%	2%	2%	10%
Off-highway	16%	18%	37%	1%	3%	7%	0%
Miscellaneous	0%	0%	1%	0%	50%	18%	85%
VISTAS Total	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**

Annual 2018 BaseG2 Emissions (%) Within Area of Influence
Shenandoah, VA

Tier	SO2
Fuel Comb. Elec. Util.-Coal	51%
Fuel Comb. Elec. Util.-Oil	1%
Fuel Comb. Elec. Util.-Gas	0%
Fuel Comb. Elec. Util.-Other	0%
Fuel Comb. Elec. Util.-Internal Combustion	1%
Fuel Comb. Industrial-Coal	22%
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	1%
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	2%

Annual 2018 BaseG2 Emissions (%) Within Area of Influence
James River Face, VA

Tier	VOC	NOX	CO	SO2	PM-10	PM-2.5	NH3
Fuel Comb. Elec. Util.	1%	26%	1%	53%	15%	27%	1%
Fuel Comb. Industrial	1%	17%	2%	28%	4%	6%	0%
Fuel Comb. Other	7%	8%	4%	6%	7%	14%	1%
Chemical & Allied Product Mfg	2%	1%	1%	2%	1%	1%	1%
Metals Processing	1%	2%	4%	4%	3%	5%	0%
Petroleum & Related Industries	0%	0%	0%	2%	0%	0%	0%
Other Industrial Processes	4%	5%	0%	4%	9%	11%	1%
Solvent Utilization	39%	1%	0%	0%	0%	1%	0%
Storage & Transport	7%	0%	0%	0%	1%	1%	0%
Waste Disposal & Recycling	4%	2%	4%	0%	5%	9%	0%
Highway Vehicles	19%	21%	47%	0%	2%	2%	11%
Off-highway	14%	17%	36%	1%	3%	5%	0%
Miscellaneous	1%	0%	2%	0%	50%	18%	85%
VISTAS Total	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**

Annual 2018 BaseG2 Emissions (%) Within Area of Influence
James River Face, VA

Tier	SO2
Fuel Comb. Elec. Util.-Coal	51%
Fuel Comb. Elec. Util.-Oil	1%
Fuel Comb. Elec. Util.-Gas	0%
Fuel Comb. Elec. Util.-Other	0%
Fuel Comb. Elec. Util.-Internal Combustion	1%
Fuel Comb. Industrial-Coal	23%
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	1%
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	2%

Annual 2018 BaseG2 Emissions (%) Within Area of Influence
Dolly Sods, WV

Tier	VOC	NOX	CO	SO2	PM-10	PM-2.5	NH3
Fuel Comb. Elec. Util.	1%	25%	1%	53%	15%	26%	1%
Fuel Comb. Industrial	1%	17%	1%	27%	4%	5%	0%
Fuel Comb. Other	6%	8%	4%	6%	7%	14%	1%
Chemical & Allied Product Mfg	2%	0%	1%	2%	1%	1%	1%
Metals Processing	1%	2%	5%	4%	3%	6%	0%
Petroleum & Related Industries	0%	0%	0%	2%	0%	0%	0%
Other Industrial Processes	4%	6%	0%	5%	9%	11%	1%
Solvent Utilization	41%	1%	0%	0%	0%	1%	0%
Storage & Transport	6%	0%	1%	0%	1%	1%	0%
Waste Disposal & Recycling	4%	2%	3%	0%	4%	9%	0%
Highway Vehicles	19%	21%	47%	0%	2%	2%	13%
Off-highway	14%	17%	36%	0%	2%	5%	0%
Miscellaneous	1%	0%	2%	0%	52%	20%	81%
VISTAS Total	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**

Annual 2018 BaseG2 Emissions (%) Within Area of Influence
Dolly Sods, WV

Tier	SO2
Fuel Comb. Elec. Util.-Coal	52%
Fuel Comb. Elec. Util.-Oil	1%
Fuel Comb. Elec. Util.-Gas	0%
Fuel Comb. Elec. Util.-Other	0%
Fuel Comb. Elec. Util.-Internal Combustion	0%
Fuel Comb. Industrial-Coal	23%
Fuel Comb. Industrial-Oil	3%
Fuel Comb. Industrial-Gas	1%
Fuel Comb. Industrial-Other	0%
Fuel Comb. Industrial-Internal Combustion	0%
Fuel Comb. Other-Commercial/Institutional Coal	3%
Fuel Comb. Other-Commercial/Institutional Oil	1%
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	2%

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 (fuel contracts)
  - 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