Air Resource Specialists, Inc.
VISTAS Conceptual Description Support Document

Prepared for the:

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September 20, 2007

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1.0 INTRODUCTION

The primary purpose of this document is to provide data, results and methods documentation for analysis performed by Air Resource Specialists, Inc. (ARS) in support of the Visibility Improvement State and Tribal Association of the Southeast (VISTAS).

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1.1 OVERVIEW

VISTAS is a collaborative effort of state governments, tribal governments, and various federal agencies established to initiate and coordinate activities associated with the management of regional haze, visibility and other air quality issues in the Southeastern United States. VISTAS is working to develop the technical basis for the Regional Haze Rule (RHR) promulgated in 1999 by the Environmental Protection Agency (EPA) to address visibility at 156 designated Class I areas. Specific objectives of analyses presented in this report to support the VISTAS states are:

- To describe current visibility conditions and particulate matter concentrations at Class I areas in the VISTAS region.
- To investigate the relative contributions of regional and local sources of emissions to fine particle concentrations and visibility in Class I areas.
- To understand the rate of improvement in visibility that would demonstrate a uniform rate of progress toward visibility improvement goals between current visibility conditions and natural background visibility conditions in 2064.

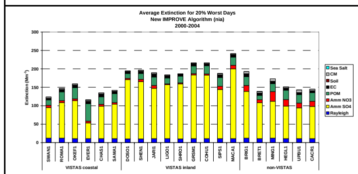
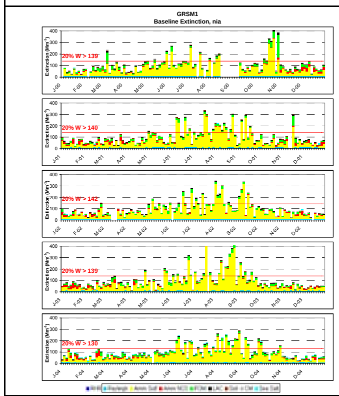
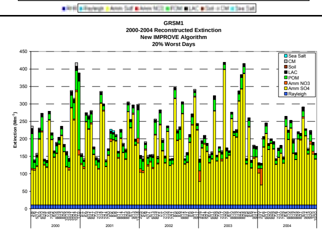
States and tribes are required to establish “reasonable progress goals” for each Class I area to improve visibility on the 20% haziest days and to prevent visibility degradation on the 20% clearest days. States are to evaluate their contributions to visibility impairment at Class I areas both within and outside the State and to develop long-term control strategies to reduce emissions of air pollutants that impair visibility. The national goal is to return visibility to natural background levels by 2064. Using the period 2000 to 2004 as the baseline period, States are to evaluate progress in improving visibility by 2018 and every 10 years thereafter. State

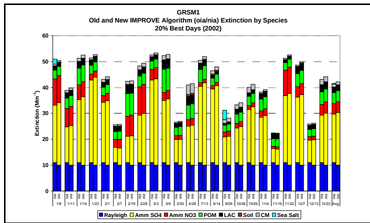
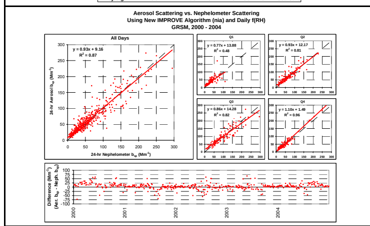
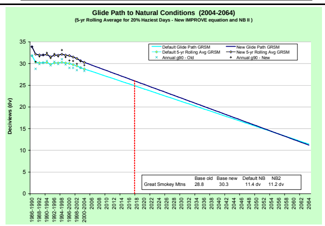
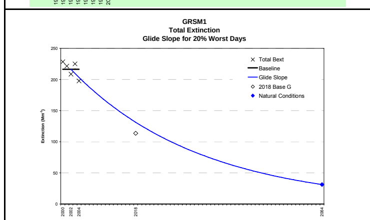
Implementation Plans for the first phase of the regional haze regulation are due in December 2007.

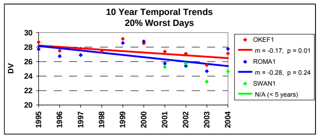
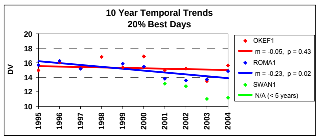
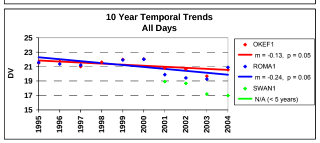
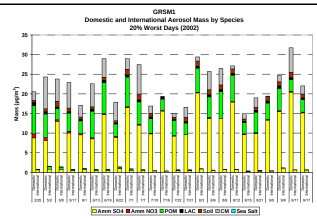
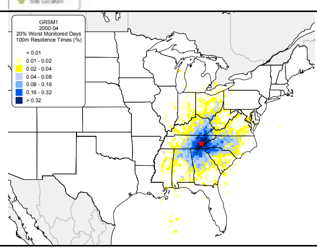
1.2 DATA SUMMARY PRODUCT FTP SITE

Methods descriptions and analysis results are provided in this document. Analysis results for VISTAS are also available on the ARS VISTAS project public ftp site (ftp://ftp.air-resource.com/VISTAS). Table 1-1 lists products currently available on the ftp site.

Table 1-1
Summary of Data Products Available on ARS VISTAS FTP Site

Sample	Path	Description
[data files]	…Aerosol_dataset_VISTAS_2000-2004/ SAMA1_daily_budgets_sub_nia.xls	Data sets including substituted data for VISTAS and neighboring Class I Areas, old and new IMPROVE algorithm.
	…Aerosol_stacked_bar_charts/ Average_BestWorstDays_2000-04/ VISTAS_nia_00-04_20070129.xls	Regional stacked bar charts depicting 20% best and worst days, extinction and mass, old and new algorithm.
	…Aerosol_stacked_bar_charts/ Timelines_AllDays_2000-04/ GRSM.pdf	Stacked bar charts depicting extinction for all monitored days during the baseline years, 2000-2004. For VISTAS sites requiring data substitution, two charts are provided, where the first page distinguishes substituted days from original days.
	…Aerosol_stacked_bar_charts/ Timelines_BestWorstDays_2000-04/ GRSM1_20bw_nia.xls	Stacked bar charts that selectively show just the 20% best and worst days for 2000-2004 baseline period.

	…Aerosol_stacked_bar_charts/ Timelines_nia_oia_comparison_2002/ GRSM1_nia_oia.xls	Regional and site specific stacked bar charts where extinction calculations using the new and old IMPROVE algorithm are presented side by side.
	…Nephelometer_Aeosol_Comparisons/ GRSM_neph.xls	Charts comparing collocated IMRPROVE nephelometers and IMPROVE aerosol samplers, old and new IMPROVE algorithm.
	…Glidepaths/ Revised Glide Path new IMPROVE equation_Reynolds.ppt	Deviview Glidepaths (developed by Scott Reynolds) by species depicting baseline conditions and estimated natural conditions for both the new and old algorithm.
	…Glidepaths/ Speciated_Glidepaths/ Glideslopes_GRSM1.xls	Glidepaths by species depicting baseline condition, 2018 modeled predictions and estimated natural conditions.

  	…IMPROVE_Trend_Charts/ Trends_DV.xls	10 Year temporal trends for sites grouped regionally, includes Standard Visual Range (SVR), Deciview (DV) and Mm^{-1}.
	…International_Attribution/ International_Attribution_mass_worst.xls	Comparison of domestic and international attribution of mass on 20% best and worst days, 2002.
	…Back_Trajectory_Analyis/ IMPROVE_ResidenceTimeMaps_2000-04_nia/ GRSM_2002_20high.bmp	Back trajectory maps for 20% worst extinction days.
	…Back_Trajectory_Analyis/ IMPROVE_ResidenceTimeMaps_2000-04_nia/ GRSM_2002_20high.bmp	Residence time maps for 20% worst days, 2000-2004.

2.0 ANALYTICAL METHODS

2.1 THE IMPROVE MONITORING NETWORK

The Interagency Monitoring of Protected Visual Environments (IMPROVE) monitoring program collects speciated $PM_{2.5}$, and $PM_{2.5}$ and PM_{10} total mass. IMPROVE is a nation-wide network which began in 1988 and expanded significantly in 2000 in response to the EPA's Regional Haze Rule (RHR). It is data from this program that states and tribes must use to track progress under the RHR.

The IMPROVE network collects 24-hour integrated filter samples every third day (Wednesdays and Saturdays prior to 2001). Each monitoring location operates four samplers (designated Module A through D) designed to quantify $PM_{2.5}$ and PM_{10} mass, and $PM_{2.5}$ mass constituents, including numerous trace elements, ions, Elemental Carbon (EC), and Organic Carbon (OC).

A map of the IMPROVE sites in and around the VISTAS region and their proximity to Class I areas is presented in Figure 2-1. A listing of IMPROVE sites, locations, and operational start dates is presented in Table 2-1. The list also includes start (and end) dates for collocated nephelometers, which are continuous monitoring instruments that make direct measurements of light scattering due to particles.

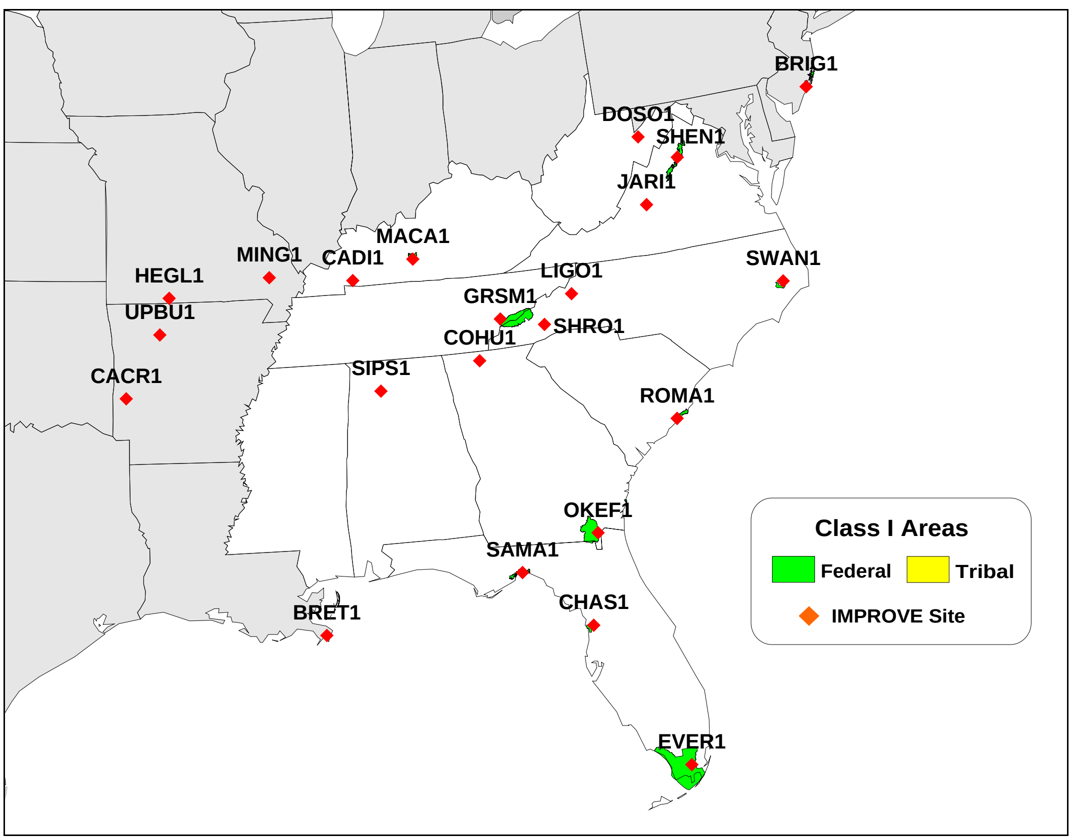


Figure 2-1. Map of Class I Areas and IMPROVE Monitoring sites in and around VISTAS.

Table 2-1
IMPROVE Aerosol Monitor Sites in and around the VISTAS Region

Region	State	Class I Area (Site)	Start Date	Latitude	Longitude	Nephelometer Start Date (- End Date)
VISTAS	AL	Sipsy Wilderness (SIPS1)	3/92	34.34	-87.34	--
	FL	Chassahowitzka NWR (CHAS1)	4/93	28.75	-82.55	--
		Everglades NP (EVER1)	9/88	25.39	-80.68	--
		St. Marks (SAMA1)	6/00	30.09	-84.16	--
	GA	Cohutta (COHU1)	5/00	34.79	-84.63	1/04 – 3/07
		Okefenokee NWR (OKEF1)	9/91	30.74	-82.13	1/93 – 6/97
	KY	Mammoth Cave NP (MACA1)	9/91	37.13	-86.15	1/93 - current
	NC	Linville Gorge (LIGO1)	3/00	35.97	-81.93	--
		Shining Rock Wilderness (SHRO1)	7/94	35.39	-82.77	4/94 – 9/99
		Swanquarter (SWAN1)	6/00	35.45	-76.21	--
	SC	Cape Romain NWR (ROMA1)	9/94	32.94	-79.66	1/04 - current
	TN	Great Smoky Mountains NP (GRSM1)	3/88	35.63	-83.94	4/93 - current
	VA	James River Face Wilderness (JARI1)	6/00	37.63	-79.51	10/00 – 12/03
		Shenandoah NP (SHEN1)	3/88	38.52	-78.43	1/00 - current
	WV	Dolly Sods Wilderness (DOSO1)	9/91	39.11	-79.43	10/93 – 12/97
Non-VISTAS	AR	Caney Creek (CACR1)	6/00	34.45	-94.14	1/93 – 12/97 9/04 - current
		Upper Buffalo Wilderness (UPBU1)	12/91	35.83	-93.20	--
	LA	Breton (BRET1)	6/00	29.12	-89.21	--
	MO	Hercules-Glades (HEGL1)	3/01	36.61	-92.92	--
		Mingo (MING1)	5/00	36.97	-90.14	--
	NJ	Brigantine NWR (BRIG1)	9/91	39.47	-74.45	--

The IMPROVE program has developed methods for estimating light extinction from speciated aerosol and relative humidity data. The three most common metrics used to describe visibility impairment are:

- **Extinction (b_{ext})** – Extinction is a measure of the fraction of light lost per unit length along a sight path due to scattering and absorption by gases and particles, expressed in inverse Megameters (Mm^{-1}). This metric is useful for representing the contribution of each aerosol species to visibility impairment and can be practically thought of as the units of light lost in a million meter distance.
- **Visual Range (VR)** – Visual range is the greatest distance a large black object can be seen on the horizon, expressed in kilometers (km) or miles (mi).

- **Deciview (dV)** – The deciview index was designed to be linear with respect to human perception of visibility. A one deciview change is approximately equivalent to a 10% change in extinction, whether visibility is good or poor. A one deciview change in visibility is generally considered to be the minimum change the average person can detect. This is the metric used for tracking regional haze in the RHR.

The IMPROVE network estimates light extinction based upon the measured mass of various contributing aerosol species. EPA's 2003 guidance (http://vista.cira.colostate.edu/improve/Publications/GuidanceDocs/guidancedocs.htm) for calculating light extinction is based on the original protocol defined by the IMPROVE program in 1988. In December 2005, the IMPROVE Steering Committee voted to adopt a revised algorithm for use by IMPROVE as an alternative to the original approach.

The elements and species measured by the IMPROVE network relevant for reconstructed light extinction are listed in Table 2-2.

Table 2-2

IMPROVE
Aerosol Elements and Species
Used to Reconstruct Light Extinction

Species	Composite Mass Algorithm *	Comment
Ammonium Sulfate $[(NH_4)_2SO_4]$	4.125× [S] -or- 1.375× $[SO_4]$	[S] is derived from the Teflon filter (A module). $[SO_4]$ is derived from the nylon filter (B module).
Ammonium Nitrate $[(NH_4)NO_3]$	1.29× $[NO_3]$	$[NO_3]$ is derived from the nylon filter (B module).
Particulate Organic Matter [POM]	1.4× [OC] (original algorithm) 1.8× [OC] (revised algorithm)	[OC] is derived from the quartz filter (C module).
Elemental Carbon [EC]	1.0[EC]	[EC] is derived from the quartz filter (C module).
Soil	2.20× [Al] + 2.49× [Si] + 1.63× [Ca] + 2.42× [Fe] + 1.94× [Ti]	Soil elements are derived from the Teflon filter (A module).
Coarse Mass [CM]	$[PM_{10}]$ - $[PM_{2.5}]$	$[PM_{10}]$ is derived from the Teflon filter (D module). $[PM_{2.5}]$ is derived from the Teflon filter (A module).
Sea Salt (revised algorithm only)	1.8× [Chl](Chloride) -or- 1.8×[Cl](Chlorine)	[Chl] and [Cl] are derived from the Teflon filter (A module). [Cl] only used if {Chl] is below the detection limit.

The original algorithm used by IMPROVE/regional haze guidance to reconstruct extinction (b_{ext}) is:

$$
\begin{aligned}
b_{ext} \approx\ & 3 \times f(RH) \times [\text{Amm. Sulfate}] \\
& + 3 \times f(RH) \times [\text{Amm. Nitrate}] \\
& + 4 \times [\text{POM}] \\
& + 10 \times [\text{EC}] \\
& + 1 \times [\text{Fine Soil}] \\
& + 0.6 \times [\text{CM}] \\
& + \text{Rayleigh Scattering (10)}
\end{aligned}
$$

Reconstructed b_{ext} is expressed in Mm^{-1}, dry extinction efficiencies (leading numbers) are expressed as m^2/g and species mass concentrations are expressed in $\mu g/m^3$. The f(RH) factor is a water growth term that is a function of climatologically representative monthly average relative humidity (RH). The f(RH) factors are designed to account for the absorption of water by sulfate and nitrate species. In the original IMPROVE algorithm, a constant value of 10 Mm^{-1} is also added to account for extinction due to scattering from molecules in a clean atmosphere (Rayleigh conditions).

The original IMPROVE algorithm produces reasonable estimates of light scattering over a broad range of conditions, but it tends to underestimate the highest extinction values and overestimate the lowest extinction values. The revised algorithm for estimating light extinction recommended for use by the IMPROVE steering committee is:

$$
\begin{aligned}
b_{ext} \approx\ & 2.2 \times f_s(RH) \times [\text{Small Amm. Sulfate}] + 4.8 \times f_L(RH) \times [\text{Large Amm. Sulfate}] \\
& + 2.4 \times f_s(RH) \times [\text{Small Amm. Nitrate}] + 5.1 \times f_L(RH) \times [\text{Large Amm. Nitrate}] \\
& + 2.8 \times [\text{Small POM}] + 6.1 \times [\text{Large POM}] \\
& + 10 \times [\text{EC}] \\
& + 1 \times [\text{Soil}] \\
& + 1.7 \times f_{ss}(RH) \times [\text{Sea Salt}] \\
& + 0.6 \times [\text{CM}] \\
& + 0.33 \times [NO_2(\text{ppb})] \\
& + \text{Rayleigh Scattering (Site Specific)}
\end{aligned}
$$

The revised algorithm splits ammonium sulfate, ammonium nitrate, and POM concentrations into small and large size fractions as follows:

$$
\text{For } [\text{Total}] < 20\mu g/m^3 \begin{cases} [\text{Large}] = \dfrac{[\text{Total}]}{20} \times [\text{Total}] \\ \\ [\text{Small}] = [\text{Total}] - [\text{Large}] \end{cases}
$$

$$
\text{For } [\text{Total}] \geq 20\mu g/m^3, [\text{Large}] = [\text{Total}]
$$

As noted in table 2-2, the organic mass concentration is 1.8 times the organic carbon mass concentration in the revised algorithm, where it was calculated as 1.4 times carbon mass in the original algorithm. The new algorithm contains three distinct water growth factors, designated f_S(RH), f_L(RH), and f_{SS}(RH) for water absorption due small and large sulfate and nitrate fractions, and for sea salt, respectively. New terms have also been added for sea salt and for absorption by gaseous NO_2. NO_2 is not available at most IMPROVE sites, and is not included in analysis presented here.

IMPROVE data are available on the IMPROVE Web site (http://vista.cira.colostate.edu/improve/) and the Visibility Information Exchange Web System (VIEWS) Web site (http://vista.cira.colostate.edu/views/). The starting data sets for analysis presented here are the IMPROVE RHR1 data set (updated 11/05), and the IMPROVE RHR2 data set (updated 3/06), where RHR1 is the IMPROVE designation indicating that extinction was calculated using the original/old IMPROVE algorithm, and RHR2 indicates that extinction was calculated using the revised/new IMPROVE algorithm.

VISTAS chose to use the new IMPROVE algorithm because it takes into account the most recent review of the science and because it is recommended by the IMPROVE Steering Committee. Comparisons between the old and new algorithm are presented in Section 3.1, but most analysis presented here uses the revised algorithm.

2.2 BACK TRAJECTORY MODELING

Back trajectory analyses were undertaken to identify the geographic source areas most likely to contribute to visibility impairment on the 20% worst visibility days at the Class I areas. Back trajectory analyses use interpolated measured or modeled meteorological fields to estimate the most likely central path over geographical areas that provided air to a receptor at a given time. The method essentially follows a parcel of air backward in hourly steps for a specified length of time. Back trajectories account for the impact of wind direction and wind speed on delivery of emissions to the receptor, but do not account for chemical transformation, dispersion and deposition of emissions.

Trajectories were generated using the Hybrid-Single Particle Lagrangian Integrated Trajectory (HYSPLIT) model developed by the National Oceanic and Atmospheric Administration's (NOAA) Air Resources Laboratory (ARL). HYSPLIT uses archived 3-dimensional meteorological fields generated from observations and short-term forecasts. HYSPLIT can be run to generate forward or backward trajectories using several available meteorological data archives.

The data archives used in this analysis were the National Weather Service's National Centers for Environmental Prediction Eta Data Assimilation System (EDAS). The EDAS fields are archived by the ARL across the continental U.S., including a buffer zone, at a horizontal resolution of 80 km before 2004, and at a horizontal resolution of 40 km starting in 2004. Detailed information regarding the trajectory model and these data sets can be found on NOAA's Web site (http://www.arl.noaa.gov/ready/hysplit4.html).

The major model parameters selected for these analyses are presented in Table 2-3. The choice of these parameters affects the trajectories generated and the final attribution analyses based on them. In particular, trajectories tend to become increasingly uncertain the further back in time they are used. Vertical motion in the model is sometimes best represented by following actual vertical motion measurements (represented by model data), surfaces of constant entropy, or surfaces of constant pressure, depending on the meteorological conditions at a given location and time. The impact of receptor height (or end height) on an individual trajectory is also important. Low-ending trajectories represent air parcels nearer to ground level and high-ending trajectories may better represent boundary layer flow above the local terrain. Specific back trajectory analyses performed by ARS for VISTAS are described in Section 3.6.1.

Table 2-3
Back Trajectory Model Parameters

Model Parameter:	**Value**
Trajectory duration	72 hours backwards in time
Top of model domain	14,000 meters
Vertical motion option	used model data
Meteorological Field	EDAS
End Times	0600, 1200, 1800 and 2400 EST
End Heights	100 and 500 m

3.0 VISIBILITY CONDITIONS

The Regional Haze Rule sets a 60 year timeline for states to improve visibility within Federal Class I Areas (CIAs) from "baseline" (2000-2004) levels to "natural conditions" by 2064. The following sections describe some of the major components for tracking reasonable progress at each CIA in the VISTAS region. Analyses include comparisons of the old and new IMPROVE algorithms, determination of baseline (2000-2004) conditions, determination of the glide slope between baseline and natural conditions, and determination of geographic source areas using back trajectory analysis.

3.1 COMPARISON OF OLD AND NEW IMPROVE ALGORITHM

One of the most compelling reasons for developing the revised IMPROVE algorithm was to reduce the biases in light scattering estimates at the high and low extremes, when compared to nephelometer measurements. Nephelometers make a direct measurement of light scattering due to particles and are collocated with the IMPROVE aerosol samplers at some IMPROVE sites. These measurements can be compared to light scattering derived from the particulate data.

Figure 3-1 presents scatter plots for the GRSM1 site comparing measured light scattering (nephelometer) and reconstructed light scattering calculated using the revised (New) and original (old) IMPROVE algorithms. A stacked bar chart for the most recent year of comparable record, in this case 2004 at the GRSM1 site, is included in Figure 3-2. Nephelometers make continuous hourly measurements of light scattering and RH. For these comparisons hourly nephelometer scattering is averaged into daily values, and aerosol light scattering is calculated using daily f(RH) based upon measured RH, as opposed to the IMPROVE method of using climatologically representative monthly average RH. Also light absorbing carbon (LAC) is not included in the reconstructed extinction because nephelometers measure atmospheric scattering but do not measure atmospheric absorption. For reconstructed extinction, coarse mass scattering was also scaled by a factor of 0.5 to account for the tendency of a nephelometer to underestimate coarse mass scattering. Charts are included for each VISTAS nephelometer site in Appendix A for both the total available data set and each quarter separately.

The GRSM1 site has one of the longest periods of nephelometer data in the VISTAS region, and has been in operation since 1993. In general, the original algorithm tends to under estimate light scattering on those days with high scattering and over estimate scattering on days with low values. The new algorithm is more accurate as it does not have the same biases, but the data is less precise, with more spread in the data and generally slightly lower correlation.

Figures 3-3 and 3-4 present comparisons of the average 20% worst and best days in the 2000-2004 baseline period at VISTAS and neighboring sites calculated using both the revised and original IMPROVE algorithm. For the worst days, extinction calculations using the new algorithm are higher than extinction calculations using the old algorithm Difference in total extinction range between 8 Mm^{-1} (BRET1) and 35 Mm^{-1} (MACA1). For the best days, the calculated extinction values were within 3 Mm^{-1} of each other.

Figure 3-5 presents a comparison of the 20% worst days in 2002 at the GRSM1 site calculated using both the new and old IMPROVE algorithm. The 20% best and worst days are very similar using either the original and revised algorithms. In the case of GRSM1, 9/23 was a worst day in 2002 using the old algorithm, but this one day is traded for 7/22 when extinction is calculated using the new algorithm. Other days change in magnitude, but the same days are still counted among the 20% worst days. Additional plots comparing extinction calculated using the old and new IMPROVE algorithms for 20% best and worst days in 2002 at all VISTAS sites are available in Appendix B.

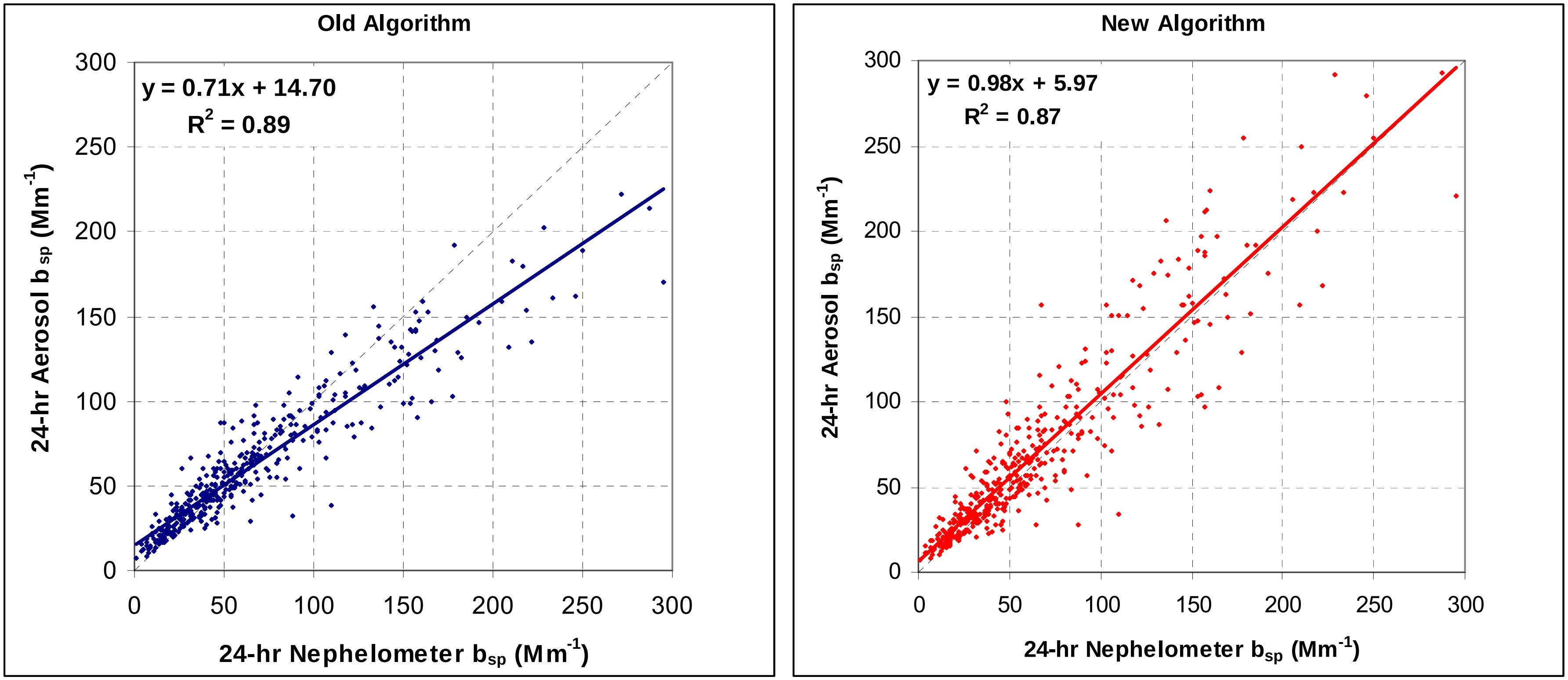


Figure 3-1. Comparison of measured light scattering (nephelometer) and light scattering calculated using the original (old) and revised (new) IMPROVE algorithms for the GRSM1 site, 1993-2004.

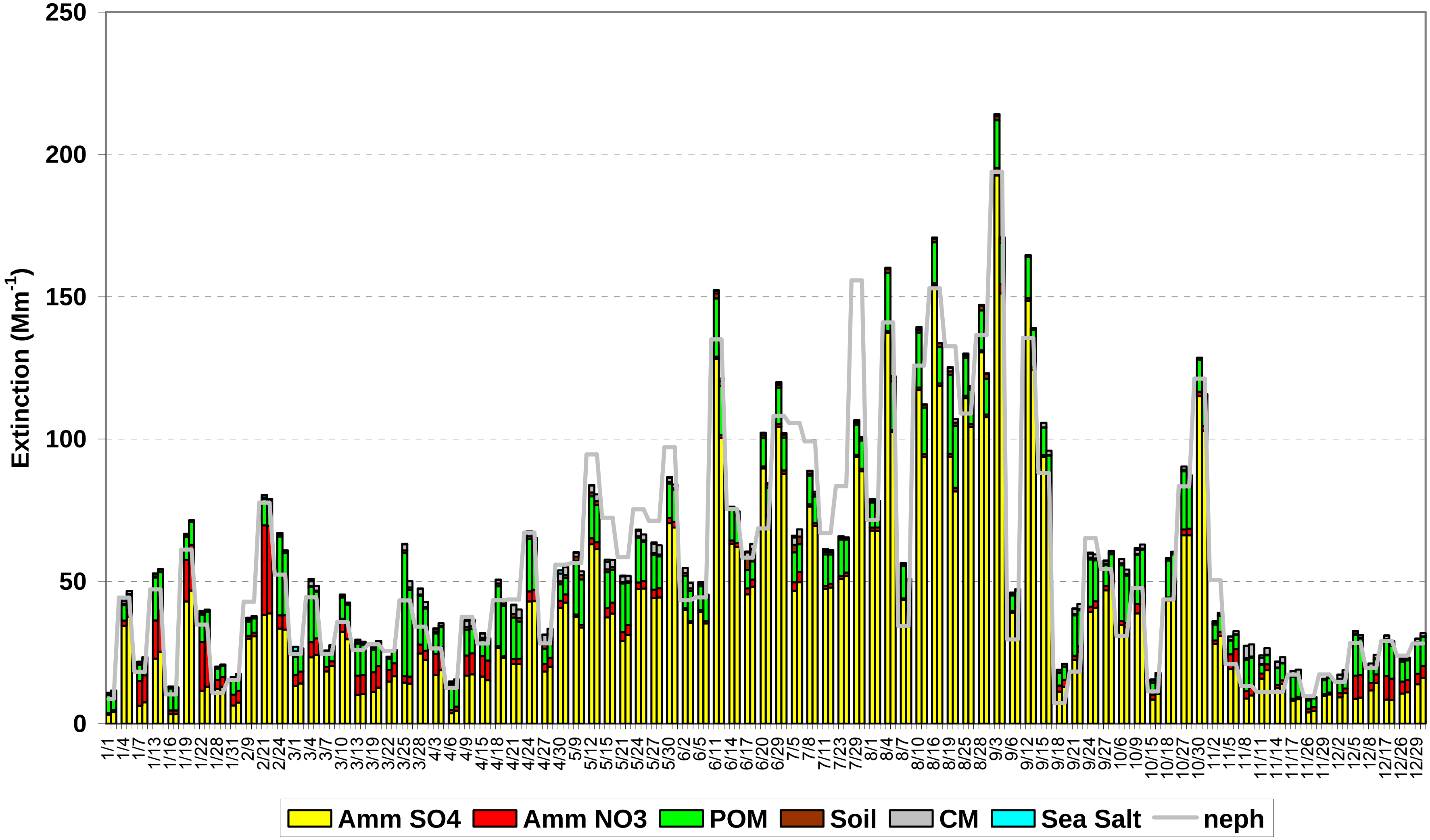


Figure 3-2. Stacked bar chart comparing extinction calculated using the new IMPROVE algorithm(left), the old IMPROVE algorithm (right), and measured light scattering (grey line) in 2004.

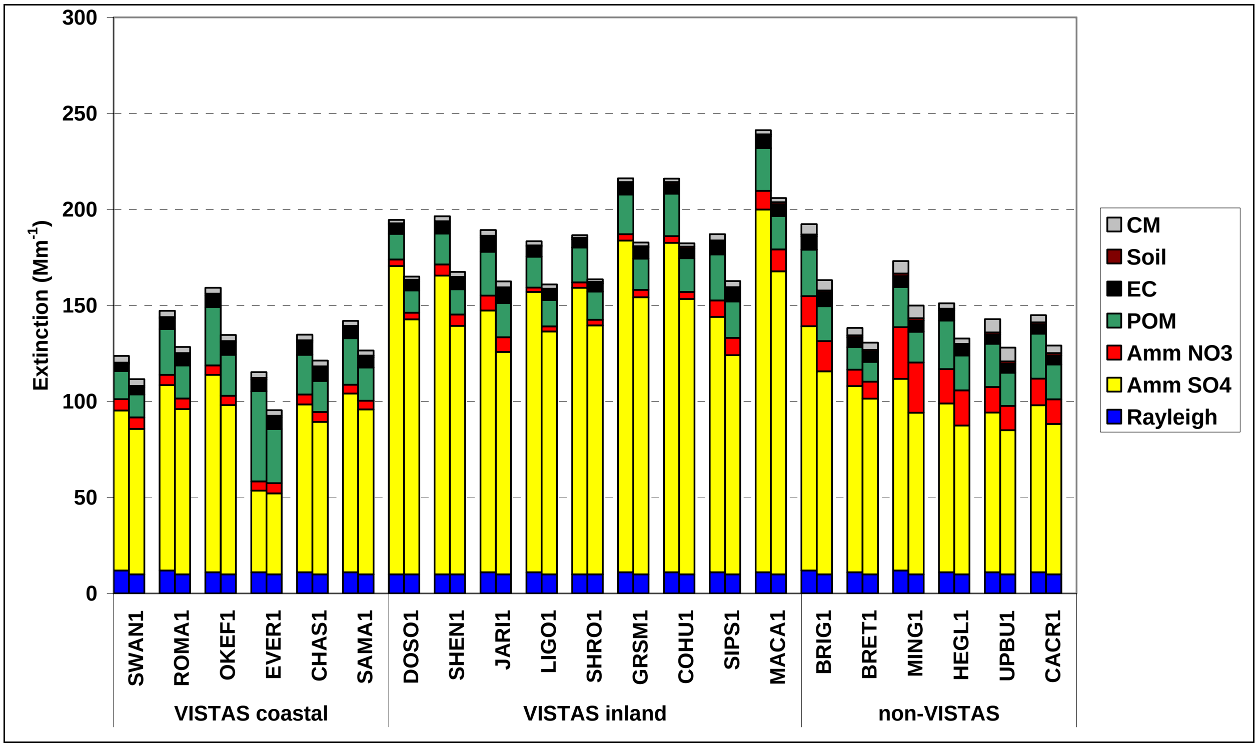


Figure 3-3. Stacked bar chart comparing light extinction calculated using both the new (left) and old (right) IMPROVE algorithm for the average of the 20% worst visibility days in 2000-2004 at VISTAS and neighboring Class I areas.

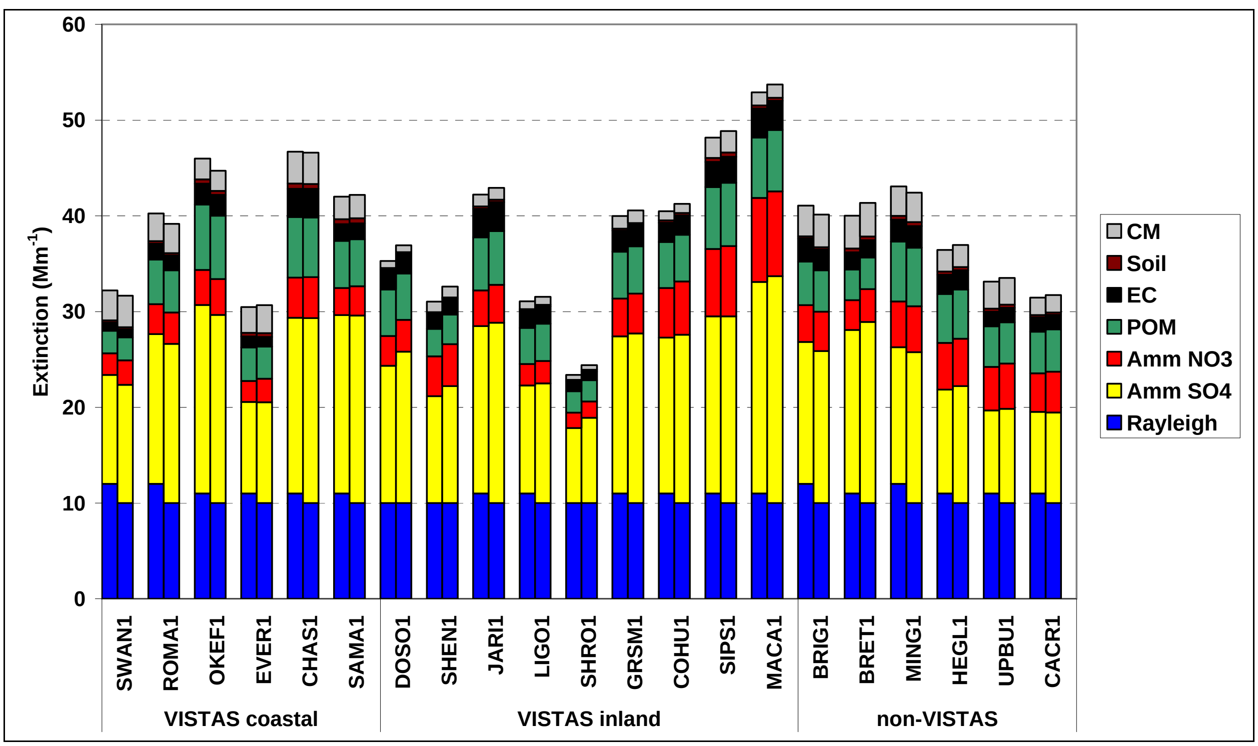


Figure 3-4. Stacked bar chart comparing light extinction calculated using both the new (left) and old (right) IMPROVE algorithm for the average of the 20% best visibility days in 2000-2004 at VISTAS and neighboring Class I areas.

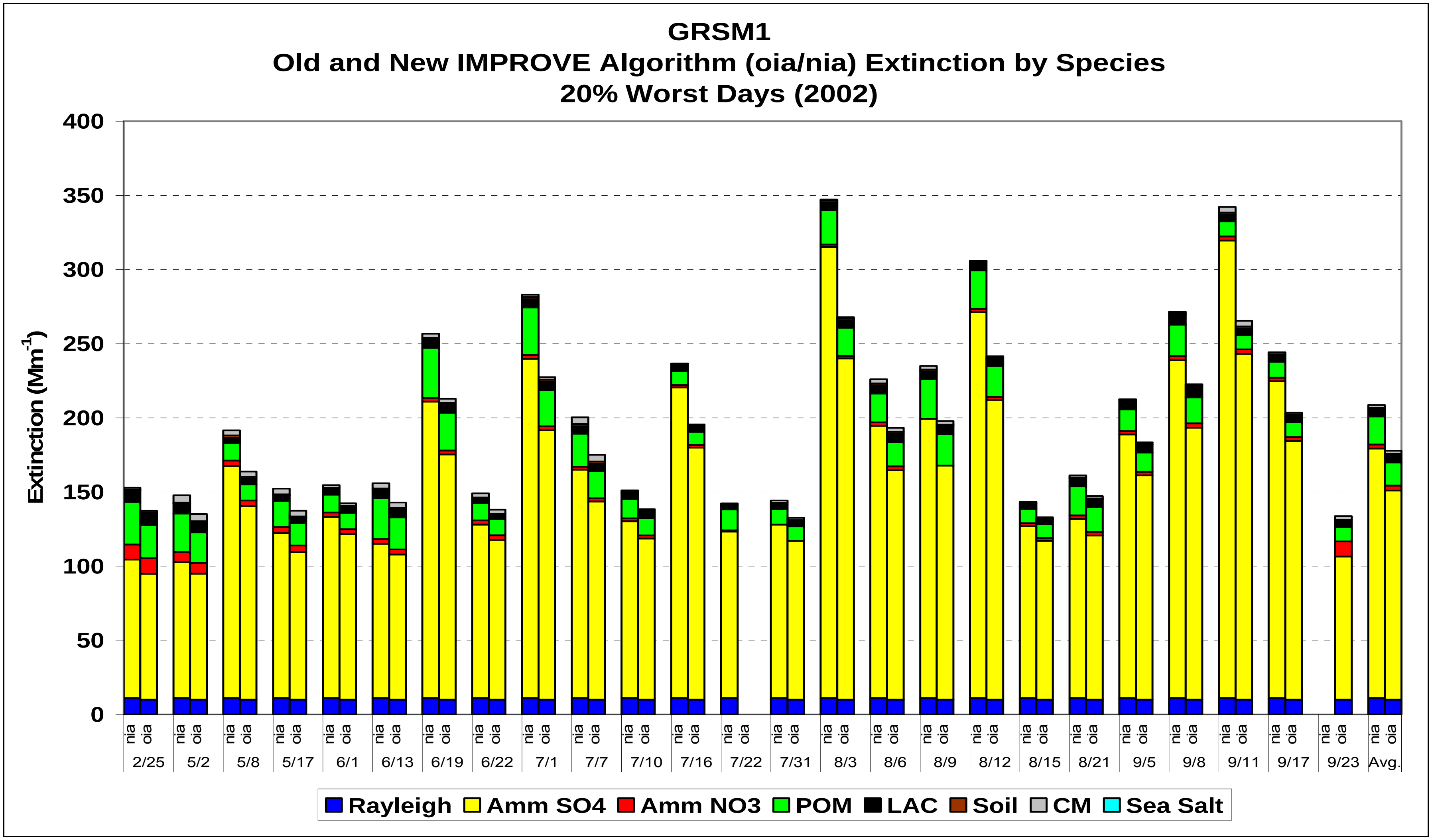


Figure 3-5. Stacked bar chart comparing 20% worst days in 2002 at the GRSM1 site calculated using both the new (left) and old (right) IMPROVE algorithm.

3.2 RHR DATA COMPLETENESS

Once extinction has been calculated for each species at a monitoring site, the Regional Haze Rule provides some provisions for handling missing data. Treatment of missing data is necessary because the RHR requires that the baseline period average (2000-2004) contain at least 3 complete years of data. RHR guidance requirements for IMPROVE aerosol data completeness include the following conditions:

- Individual samples must contain all species required for the calculation of light extinction (sulfate, nitrate, organic carbon, elemental carbon, soil, coarse mass, and, for the new IMPROVE algorithm, chloride or chlorine)
- Individual seasons must contain at least 50% of all possible daily samples
- Individual years must contain at least 75% of all possible daily samples
- Individual years must not contain more than 10 consecutive missing daily samples
- The baseline period (2000-2004) must contain at least 3 complete years of data

RHR guidelines provide provisions to fill in missing data under specific circumstances. There are currently two methods routinely used in preparing the RHR data set to substitute data for missing samples:

- The use of a surrogate in the data set:
  - Total sulfate is generally determined as 3 times the sulfur measured on the A module filter. If sulfur is missing, the sulfur measurement from the B module filter is used to calculate sulfate.
  - For the new IMPROVE algorithm, sea salt is calculated from chloride measured on the B module filter. If chloride is missing or below detection limit, the chlorine measurement from the A module filter is used to calculate sea salt.
- The application of "patching" missing data described by the RHR guidance:
  - Missing samples not substituted using a surrogate as described above can be patched, or replaced, by a seasonal average if the patching exercise passes a series of tests outlined in the guidance document.

Once these methods have been applied to the data, the resulting complete years are eligible for use in calculation of baseline conditions and tracking progress under the RHR. Further details can be found in the RHR guidance document for tracking progress (http://www.epa.gov/ttn/oarpg/t1/memoranda/rh_tpurhr_gd.pdf).

3.2.1 Additional Data Substitutions

Table 3-1 summarizes data completeness for the 2000-2004 baseline years for IMPROVE sites in and around the VISTAS region. After routine RHR data substitutions, five IMPROVE monitoring sites in the VISTAS states (CHAS1, SAMA1, COHU1, SHRO1 and SWAN1), and two regional site (BRET1 and MING1) did not achieve RHR data completeness requirements. VISTAS performed additional data substitutions for these sites. Additional substitutions included estimating missing species from other on-site measurements and appropriately scaling data collected at selected donor sites which had favorable long-term comparisons. Additional substitutions were also made for the CHAS1 site, because it is the only VISTAS site that met RHR baseline period requirements, but still had 2003 and 2004 as incomplete years. Additional substitutions for the MING1 site were performed separately by UCDavis. Details of data substitutions performed by ARS for VISTAS are outlined below.

Table 3-1

RHR Data Completeness From IMPROVE Data Sets for 2000-2004 Baseline Years for Sites in and Around the VISTAS Region

Region	State	Site	2000	2001	2002	2003	2004	2000-04 Count
VISTAS	AL	SIPS1	0	1	1	1	1	4
	FL	CHAS1	1	1	1	0	0	3
		EVER1	0	1	1	1	1	4
		SAMA1*	0	0	1	1	0	2
	GA	COHU1*	0	0	1	0	1	2
		OKEF1	1	1	1	1	1	5
	KY	MACA1	1	1	1	1	1	5
	NC	LIGO1	0	1	1	1	1	4
		SHRO1*	0	0	0	1	1	2
		SWAN1*	0	1	1	0	0	2
	SC	ROMA1	1	1	1	1	1	5
	TN	GRSM1	1	1	1	1	1	5
	VA	JARI1	0	1	1	1	1	4
		SHEN1	1	1	1	1	1	5
	WV	DOSO1	1	1	1	1	1	5
Non-VISTAS	AR	CACR1	0	0	1	1	1	3
		UPBU1	1	1	1	1	1	5
	LA	BRET1*	0	0	0	0	0	0
	MO	HEGL1	0	0	1	1	1	3
		MING1*	0	1	0	0	0	1
	NJ	BRIG1	1	1	1	1	1	5

* Indicates site has <3 complete years for RHR baseline calculations
0 indicates an incomplete year with no substitutions made
1 indicates a complete RHR year

Figure 3-6 presents a flow chart of the VISTAS data substitution methods, and details for these methods are described below. The starting data set was the RHR2 IMPROVE data using the new IMPROVE algorithm. This data set includes the routine surrogate and patched data substitutions allowed by RHR guidance. Note that only years deemed incomplete under RHR guidance were candidates for additional data substitutions. Years deemed complete were not changed, even thought there may have been missing individual samples during those years.

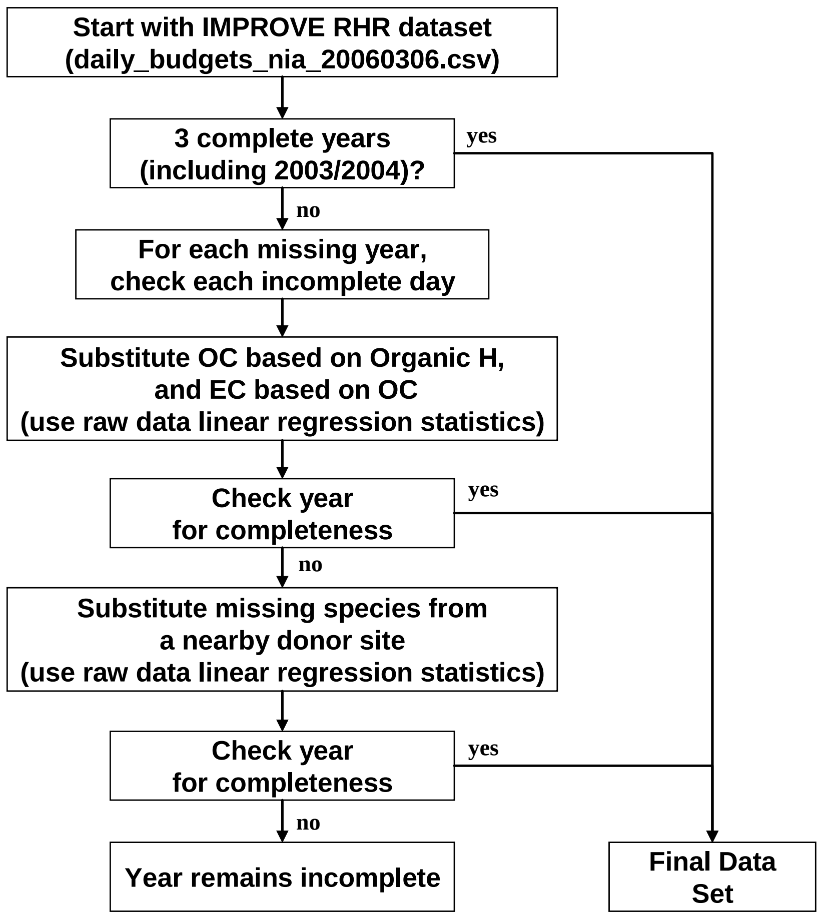


Figure 3-6. Flow chart of data substitution methods used.

3.2.1.1 Carbon Substitutions

The first substitution method relied on using a surrogate for carbon mass measurements when the C module data was not available. Hydrogen (H) is measured on the A module filter, and is assumed to be primarily associated with organic carbon and inorganic compounds such as ammonium sulfate. Organic carbon (OC) can be estimated using the historical comparison between estimated organic H and OC. Organic H is estimated by subtracting the portion of H that is assumed to be associated with the inorganic compounds from the total H (Org_H = H – 0.24*S). Once OC has been estimated using this method, elemental carbon (EC) mass is determined using long-term comparisons between OC and EC at the site.

Figure 3-7 presents sample comparisons for data collected at the Shining Rock Wilderness Area (SHRO1) site in North Carolina during the second quarter between 2000-2004 for OC vs. organic H, and EC vs. OC. Statistics were calculated and applied quarterly to account for seasonal variations.

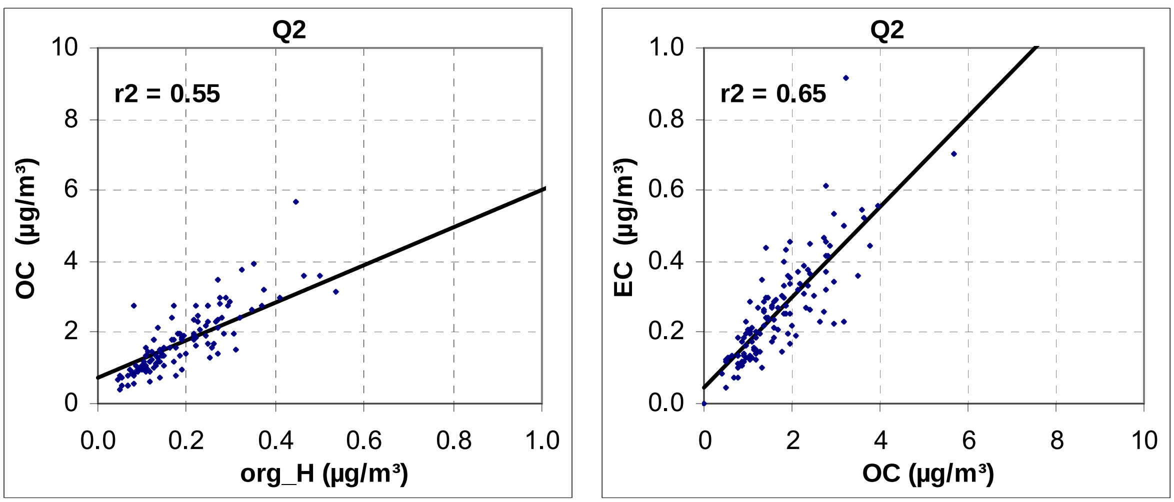


Figure 3-7. Comparison of OC and Estimated Organic H, and EC and OC at SHRO1, NC Using Second Quarter Raw OC and Organic H Data, 2000-2004

3.2.1.2 Donor Site Substitutions

In VISTAS, the carbon data substitution methods were not sufficient to complete the required years. A second method involved identification of another nearby IMPROVE site (or, in the case of BRET1, a nearby SEARCH site) which had the most favorable long-term comparisons and similar regional characteristics to be used as a donor site.

Figure 3-8 presents a sample inter-site mass comparison by species for data collected during the second quarter, 2000-2004, between the Shining Rock Wilderness Area (SHRO1) site and the Great Smoky Mountains National Park (GRSM1) site in Tennessee. Component specific correlations were calculated and applied quarterly. Note that only species missing in a given sample were substituted based on donor site data. Species collected at the site were not replaced with data from a donor site.

For BRET1 substitutions, chloride/chlorine was not available from the GFP SEARCH site. In this case, sea salt could not be calculated from the GFP data, so seasonal averages of sea salt from the BRET1 site were used as substitutes. Missing coarse mass at the SEARCH site was also substituted using SEARCH methodologies prior to use as a donor for the BRET1 site.

3.2.1.3 Data Completeness Following Substitutions

Table 3-2 indicates the years that required some degree of substitution, where a 2 indicates a substituted year, a 1 indicates the year was already complete under RHR guidelines, and dashes indicate the year did not meet RHR guidelines and no additional substitutions were made. The table also lists sites that were selected as donor sites. The minimum data requirement of 3 complete years was met for each site, and additional substitutions beyond these requirements were made with the exception of the year 2000, which was not substituted at any site either because monitoring started in late 2000, or the additional substitutions did not fill in enough data to make a complete RHR year.

Figure 3-9 presents bar charts by year for the SAMA1 site depicting substituted data. The original RHR data is indicated in blue, and substituted data by species in specific colors. Substituted days are also indicated by a black bar underneath the day. The red line indicates the threshold above which days are counted in the 20% worst days for that year. A red line is not included for any year that was incomplete and not substituted. In the case of SAMA1, substitutions were made for the years 2001 and 2004. In 2001, data from the CHAS1 site was scaled and substituted for about 33% of monitored days, mostly for mid-April through May, and August through mid-September. In 2004, about 34% of the days have some degree of substitution, but most of these days only required the OC/EC substitutions from the organic H collected at the SAMA1 site. The substituted days are mostly between June and November, but only a very small portion of extinction for these days was substituted with most data being salvaged from the samples actually collected at the site.

The substituted data are available on the VIEWS website, http://vista.cira.colostate.edu/views/web/documents/substitutedata.aspx, and a key for the substituted data files is included in Appendix C. Additional charts and tables for all VISTAS substituted sites are included in Appendix D.

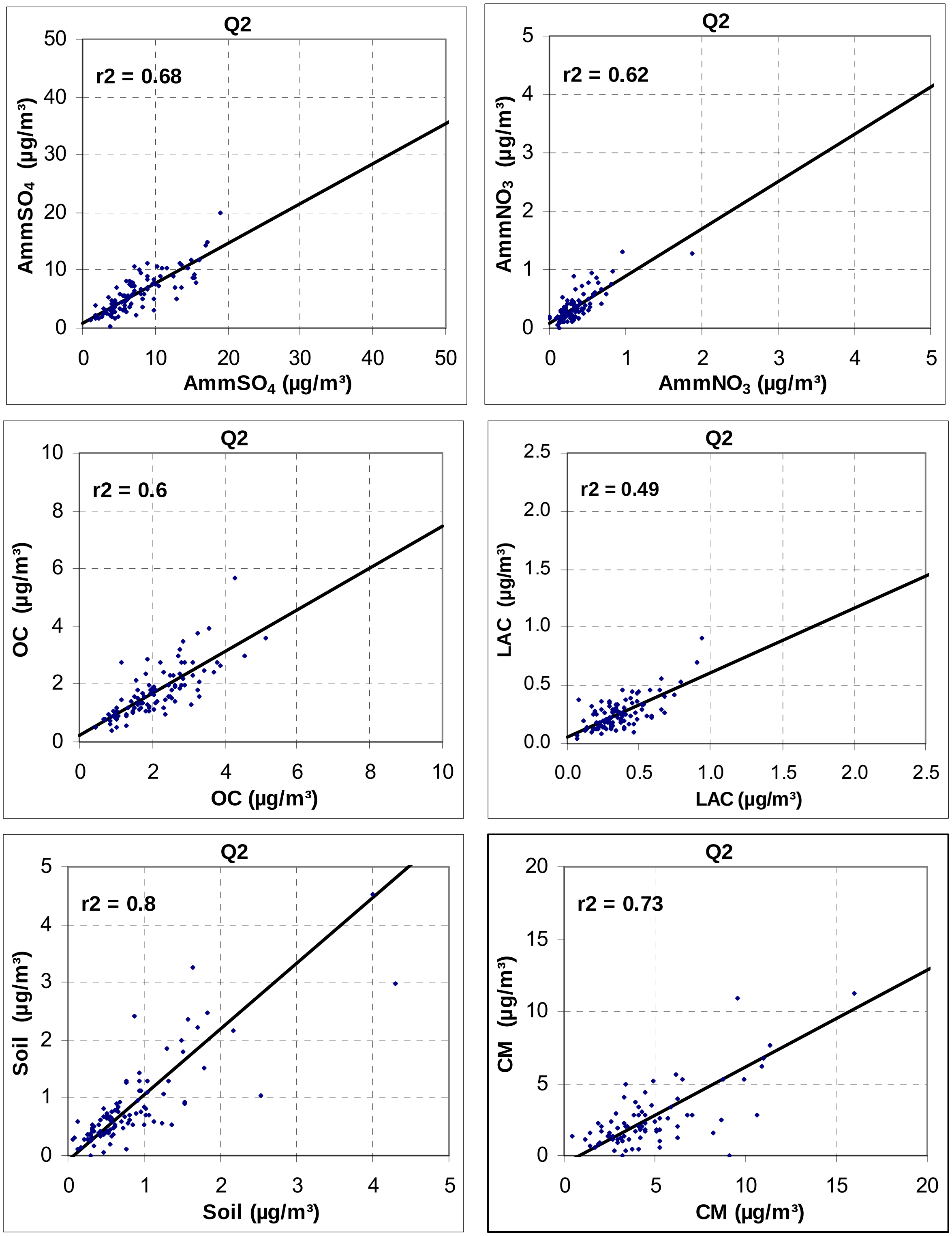


Figure 3-8. Comparison of Aerosol Species Mass Between SHRO1, NC (y-axis) and GRSM1, TN (x-axis).

Table 3-2
Data Completeness Following Data Substitution

State	Site	Donor Site	2000	2001	2002	2003	2004	2000-04 Count
FL	CHAS1	SAMA1	1	1	1	2	2	5
	SAMA1*	CHAS1	--	2	1	1	2	4
GA	COHU1*	GRSM1	--	2	1	2	1	4
NC	SHRO1*	GRSM1	--	2	2	1	1	4
	SWAN1*	ROMA1	--	1	1	2	2	4
LA	BRET1*	GFP	--	2	2	2	2	4

-- indicates an incomplete year with no substitutions made
1 indicates a complete RHR year
2 indicates a year is considered complete with some substituted values

SAMA1 (CHAS1 donor)
Baseline Extinction, New IMPROVE Algorithm

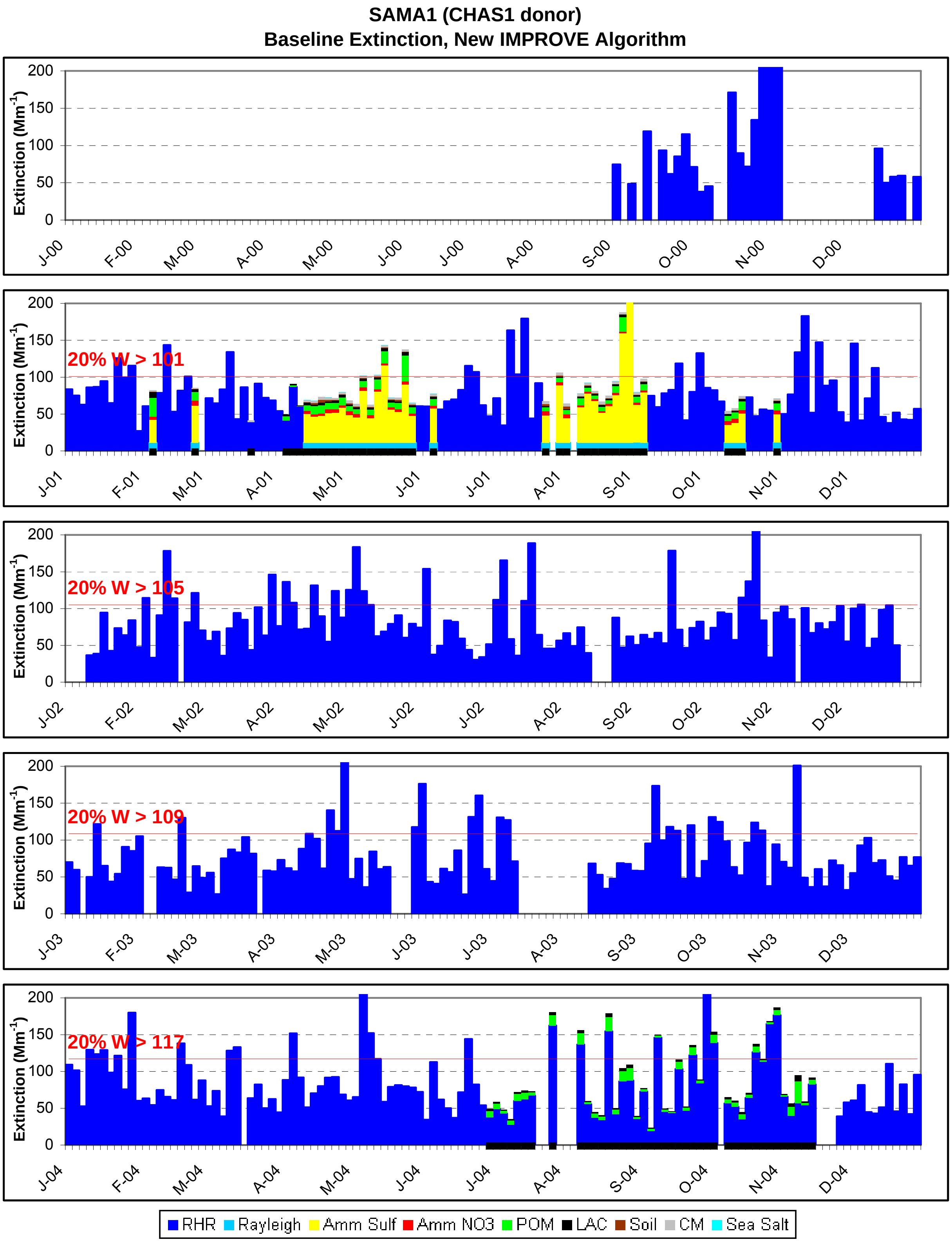


Figure 3-9. 2000-2004 annual bar charts indicating substituted data at the SAMA1 site. RHR data are indicated in blue, and substituted data by species in specific colors. Substituted days are also indicated by a black bar underneath the day. The red line indicates the threshold above which days are counted in the 20% worst days for that year.

3.3 EXTINCTION TRENDS

10-year extinction trends for the period 1995-2004 were computed for each site that had at least 5 years of complete data. Emissions reductions were implemented in the eastern US during this period under the Acid Rain provisions of the 1990 Clean Air Act Amendments and under the NOx SIP call for ozone. Theil slopes were calculated to determine the trend, and p-values were calculated using Mann-Kendall trend analysis to determine the significance of each slope. Lower p-values indicate higher confidence levels in the computed slopes.

Figure 3-10 is a map indicating 10-year annual average extinction trends for sites with at least 5 years of complete data. For sites in and around VISTAS, the BRIG1 and SHEN1 sites indicated insignificant trends (p-value < 0.20) and 8 sites showed decreasing trends (using p-value<0.20 as indicator). No sites indicated increasing trends.

Figure 3-11 presents 10-year trend plots for a regional group of sites. The legend indicates the slope and p-value for the 20% worst days, 20% best days, and all monitored days. For these plots the GRSM1 and SHRO1 sites were the only sites with sufficient data for trend calculation, but annual observations for other sites are included on the plot for reference. Additional trend plots for other regional groupings of sites are included in Appendix E, represented in terms of SVR, dV and Mm^{-1}.

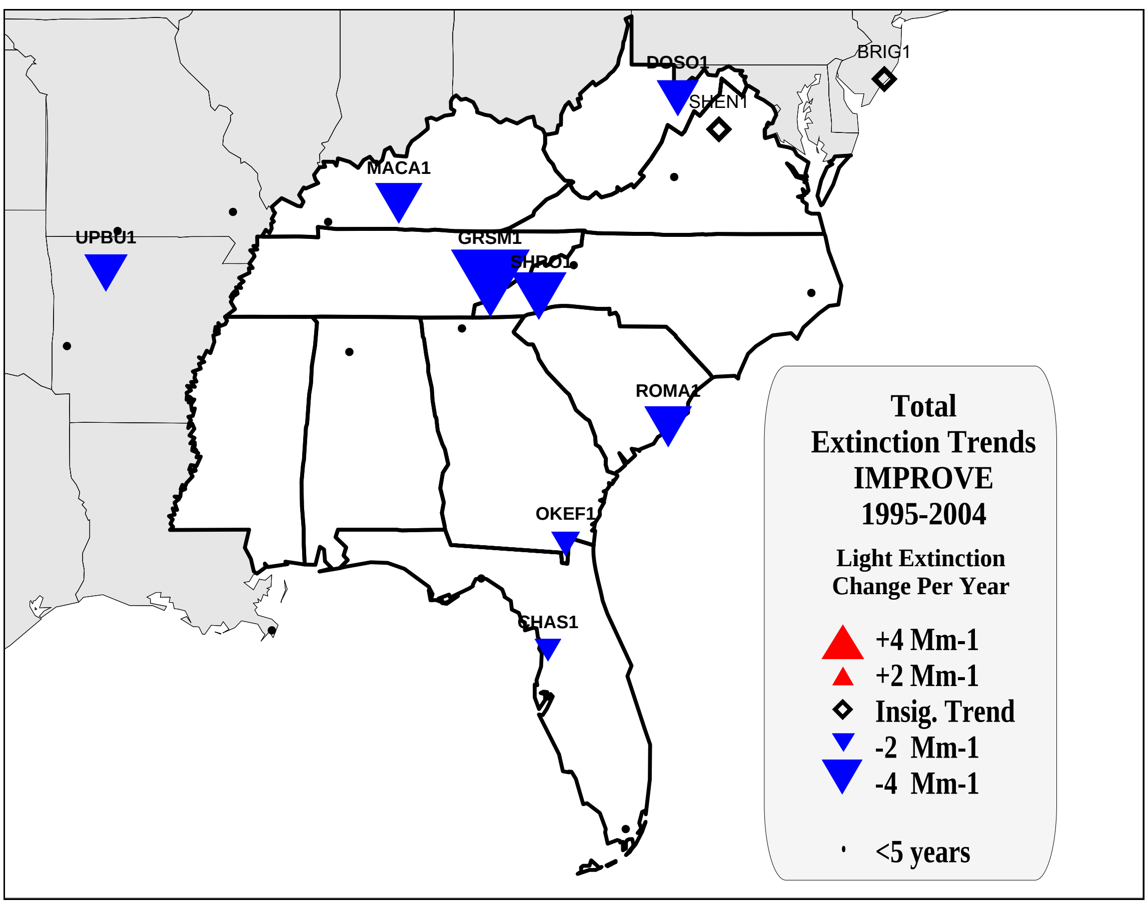


Figure 3-10. 10-year annual average extinction trends for sites in and around VISTAS Blue triangles indicate decreasing trends and blank diamonds indicate insignificant trends (p-value<0.20). No sites showed increasing trends.

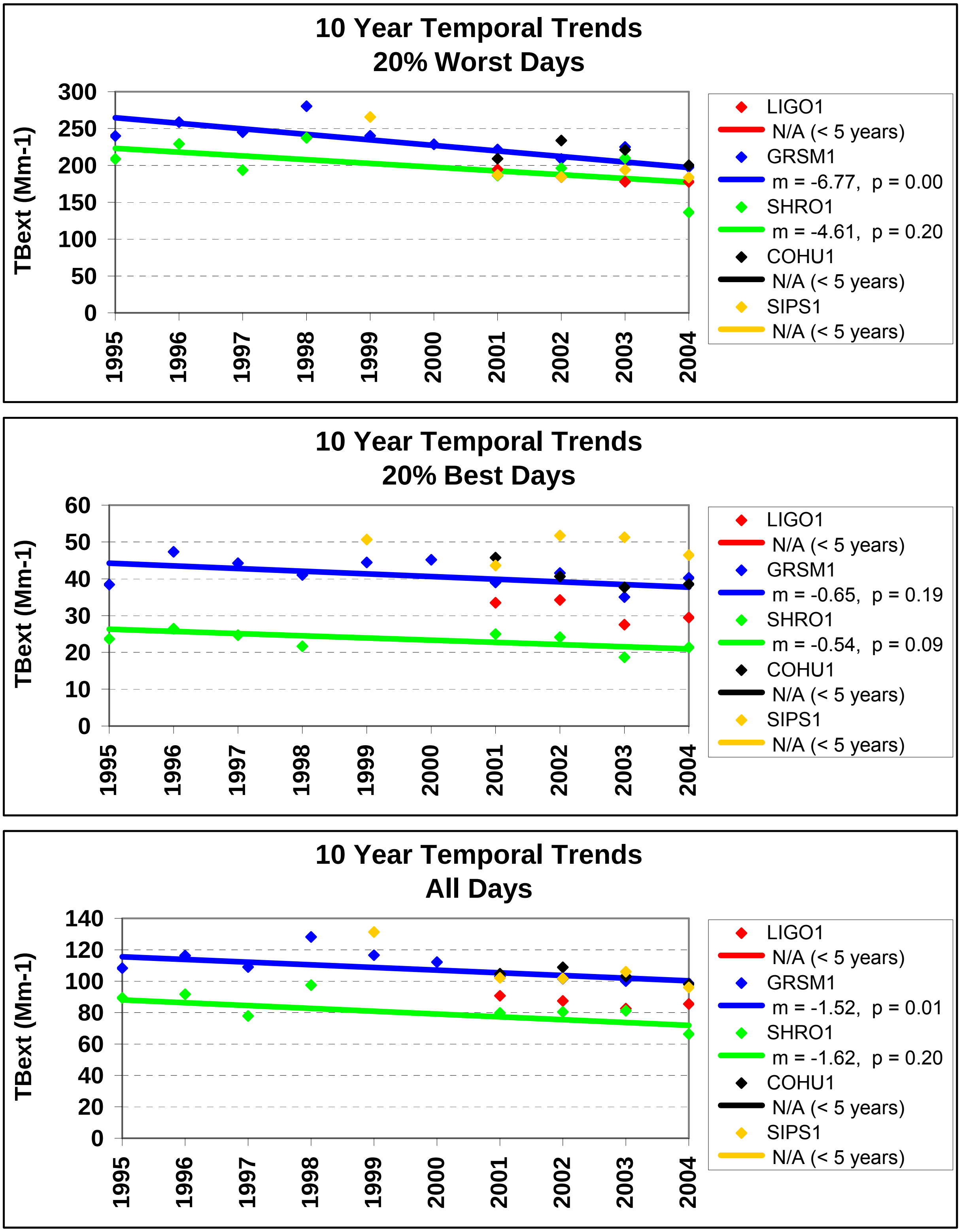


Figure 3-11. 10-year trend plots for a regional grouping of sites. Slopes and p-values are indicated in the legend.

3.4 BASELINE (2000-2004) AND NATURAL (2064) VISIBILITY CONDITIONS

Baseline (2000-2004) visibility conditions were determined using the new revised IMPROVE algorithm to select the 20% worst and best visibility days, and using VISTAS substituted data when appropriate.

Natural background visibility as defined in EPA guidance (http://vista.cira.colostate.edu/views/Web/RHR/RHR_Planning.aspx) is based on annual average concentrations of fine particle components. The same annual average natural background mass concentrations are assumed for all Class I areas in the eastern US (separate values are estimated for the western US). Natural background visibility for the 20% worst days is estimated by assuming that fine particle concentrations for natural background are normally distributed and the 90th percentile of the annual distribution represents natural background visibility on the 20% worst days. These assumptions are somewhat over simplified because the distribution of visibility conditions is likely not a normal distribution and the 92nd percentile of a normal distribution would be a better representation of the mean of the 20% worst days than the 90th percentile[16]. EPA's guidance did not estimate the contributions of individual fine particle components to natural background visibility on the 20% worst days. Following development of the new IMPROVE algorithm, a workgroup under the IMPROVE Steering Committee recommended revised assumptions to estimate natural background visibility on the 20% worst days (http://vista.cira.colostate.edu/TSS/Tools/WOEChecklist.aspx). For each Class I area, the natural background distribution of each fine particle component is assumed to be the same as the current (2000-2004) distribution of that component. Original errors in NC2 calculations were corrected by Scott Copeland, USFS, in August, 2007.

For visualization purposes, haze conditions using images available for several of the VISTAS sites were simulated using ARS' WinHaze Visual Air Quality Modeler (Ver. 2.9.6). Figure 3-12 presents a spit image depicting simulated baseline conditions and 2018 projected conditions at the GRSM1 site. There is a discernable difference in visibility between these time periods. Figure 3-13 depicts the estimated natural conditions goal for the GRSM1 site. These images were not generated using Scott Copeland's revised numbers. Images for all VISTAS sites available through the WinHaze program (12 sites) are included in Appendix F.

Tables 3-3 and 3-4 present the average baseline conditions for individual species, including the percent contribution to aerosol extinction (Rayleigh not included), and 2064 natural condition estimates generated using the revised calculations discussed in Section 2.5, updated in August, 2007. Figures 3-14 and 3-15 present stacked bar charts indicating species contributions to light extinction (Mm^{-1}) for the average of the 20% worst and best visibility days for 2000-2004 at VISTAS regional sites. Figures 3-16 and 3-17 indicate species contribution to mass ($\mu g/m^3$) on the 20% worst and best extinction days.

Ammonium sulfate is the largest contributor to visibility impairment on the 20% haziest days in the baseline 2000-2004 period (69-74%) at all the IMPROVE sites in the VISTAS region except Everglades National Park in Florida, where Ammonium sulfate is a close second to Particulate Organic Material, POM (40 and 45%, respectively). Particulate Organic Material (also referred to as organic carbon) is the second largest contributor to aerosol extinction at all other sites, contributing to between 13 and 18% of aerosol extinction on the worst days. Baseline conditions for 20% worst days at the inland sites (182.2 - 241.4 Mm^{-1}) average higher than conditions measured at the coastal sites (116.4 - 147.3 Mm^{-1}).

Ammonium sulfate is also the largest contributor to visibility impairment on the 20% best days (45-59%), with large contributions from ammonium nitrate (9-21%) POM (11-19%). Sea salt is not a factor on the 20% worst days, but for the 20% best days it contributes to between 2 and 7% of the aerosol extinction at the VISTAS coastal sites.

Ammonium sulfate, CM and POM are the largest contributors to total mass on the 20% best and worst days. CM, although it is a factor for total mass, has a low extinction efficiency and does not contribute significantly to aerosol extinction. Ammonium sulfate contributes more significantly to aerosol extinction because it readily absorbs water vapor in the air.

Figures 3-18 and 3-19 present stacked bar charts including all samples days at the GRSM1 and ROMA1 sites in the 2000 through 2004 baseline period. The red line is a threshold line, above which days are counted in the 20% worst days. Figures 3-20 and 3-21 select just the 20% worst and best days at the GRSM1 site, and Figures 3-22 and 3-23 select the 20% worst and best visibility days at the ROMA1 site. The same charts are presented for additional Class I areas in Appendix G.

For the GRSM1 site, the 20% haziest days are most likely to occur in the summer, and the 20% best days occur most frequently during the winter. For coastal ROMA1 site, the 20% haziest days can occur year round, with the summer days being dominated by ammonium sulfate, while the worst days that occur between October and February have large contributions from ammonium sulfate, POM and sometimes ammonium nitrate.

Figure 3-12. 2000-2004 baseline conditions and 2018 projected conditions at the GRSM1 site simulated using WinHaze Visual Air Quality Modeling program.

Figure 3-13. 2064 natural conditions at the GRSM1 site simulated using WinHaze Visual Air Quality Modeling program.

Table 3-3
Baseline (2000-2004) and Natural Background Visibility Conditions
20% Worst Visibility Days

	Site	2000-04 Component Extinction (Mm-1) (% of aerosol extinction)							2000-04 Baseline			2064 Natural Conditions	
		Amm. SO_4	Amm. NO_3	POM	LAC	Soil	CM	Sea Salt	b_{ext} (Mm^{-1})	dV	VR (km)	b_{ext} (Mm^{-1})	dV
VISTAS coastal	SWAN1	83.5 (74%)	5.8 (5%)	14.8 (13%)	3.7 (3%)	0.6 (1%)	3.5 (3%)	0.2 (0%)	124.2	24.7	31.5	32.6	11.5
	ROMA1	96.5 (71%)	5.3 (4%)	23.8 (18%)	5.7 (4%)	0.6 (0%)	3.2 (2%)	0.2 (0%)	147.3	26.5	26.6	34.2	12.1
	OKEF1	102.9 (69%)	4.9 (3%)	30.3 (20%)	6.2 (4%)	0.8 (1%)	3.1 (2%)	0.2 (0%)	159.4	27.1	24.5	31.7	11.2
	EVER1	42.5 (40%)	4.8 (5%)	47.1 (45%)	5.9 (6%)	0.9 (1%)	3.0 (3%)	1.2 (1%)	116.4	22.3	33.6	42.7	12.1
	CHAS1	87.6 (71%)	5.2 (4%)	20.7 (17%)	6.7 (5%)	0.9 (1%)	3.0 (2%)	0.2 (0%)	135.2	25.8	28.9	30.5	11.0
	SAMA1	93.1 (71%)	4.5 (3%)	24.2 (18%)	5.6 (4%)	0.8 (1%)	2.6 (2%)	0.2 (0%)	142.1	26.3	27.5	33.1	11.7
VISTAS inland	DOSO1	160.5 (87%)	3.4 (2%)	13.4 (7%)	4.7 (3%)	0.8 (0%)	1.7 (1%)	0.1 (0%)	194.6	29.0	20.1	28.4	10.4
	SHEN1	155.5 (83%)	5.8 (3%)	16.1 (9%)	5.7 (3%)	0.7 (0%)	2.5 (1%)	0.1 (0%)	196.5	29.3	19.9	32.3	11.4
	JARI1	136.4 (76%)	7.8 (4%)	22.8 (13%)	7.4 (4%)	0.8 (0%)	3.0 (2%)	0.2 (0%)	189.5	29.1	20.6	30.8	11.1
	LIGO1	146.0 (85%)	2.3 (1%)	16.1 (9%)	5.2 (3%)	0.8 (0%)	2.2 (1%)	0.1 (0%)	183.6	28.8	21.3	30.9	11.2
	SHRO1	149.0 (87%)	2.7 (2%)	14.6 (8%)	3.6 (2%)	0.9 (0%)	1.3 (1%)	0.1 (0%)	182.2	28.5	21.5	31.8	11.5
	GRSM1	172.7 (84%)	3.4 (2%)	20.6 (10%)	5.7 (3%)	0.8 (0%)	1.9 (1%)	0.2 (0%)	216.3	30.3	18.1	30.8	11.1
	COHU1	171.6 (84%)	3.5 (2%)	22.1 (11%)	5.1 (2%)	1.0 (0%)	1.8 (1%)	0.1 (0%)	216.0	30.3	18.1	29.8	10.8
	SIPS1	133.0 (75%)	8.5 (5%)	24.0 (14%)	6.5 (4%)	0.8 (0%)	3.2 (2%)	0.3 (0%)	187.3	29.0	20.9	30.1	10.9
	MACA1	188.9 (82%)	9.7 (4%)	22.3 (10%)	6.2 (3%)	0.9 (0%)	2.2 (1%)	0.1 (0%)	241.4	31.4	16.2	30.7	11.1
non-VISTAS	BRIG1	127.1 (70%)	15.7 (9%)	24.2 (13%)	7.0 (4%)	1.0 (1%)	5.4 (3%)	0.4 (0%)	192.7	29.0	20.3	35.7	12.1
	BRET1	97.0 (76%)	8.5 (7%)	11.7 (9%)	5.2 (4%)	1.0 (1%)	3.8 (3%)	0.7 (1%)	139.0	26.0	28.2	33.7	11.9
	MING1	100.2 (61%)	27.8 (17%)	21.8 (13%)	5.9 (4%)	1.4 (1%)	6.6 (4%)	0.2 (0%)	175.9	28.3	22.2	32.4	11.6
	HEGL1	87.9 (63%)	17.9 (13%)	25.3 (18%)	5.2 (4%)	0.9 (1%)	2.8 (2%)	0.2 (0%)	151.2	26.7	25.9	31.9	11.2
	UPBU1	83.2 (63%)	13.3 (10%)	22.5 (17%)	4.7 (4%)	1.2 (1%)	6.8 (5%)	0.2 (0%)	142.9	26.3	27.4	32.3	11.5
	CACR1	87.1 (65%)	13.8 (10%)	23.4 (17%)	4.8 (4%)	1.1 (1%)	3.7 (3%)	0.2 (0%)	145.1	26.4	27.0	32.1	11.6

Table 3-4
Baseline (2000-2004) and Natural Background Visibility Conditions
20% Best Visibility Days

	Site	2000-04 Component Extinction (Mm-1) (% of aerosol extinction)							2000-04 Baseline			2064 Natural Conditions	
		Amm. SO_4	Amm. NO_3	POM	LAC	Soil	CM	Sea Salt	b_{ext} (Mm^{-1})	dV	VR (km)	b_{ext} (Mm^{-1})	dV
VISTAS coastal	SWAN1	11.3 (52%)	2.3 (10%)	2.3 (11%)	0.8 (4%)	0.2 (1%)	3.2 (15%)	1.5 (7%)	33.6	12.0	116.3	17.3	5.5
VISTAS coastal	ROMA1	15.7 (51%)	3.1 (10%)	4.7 (15%)	1.7 (5%)	0.3 (1%)	2.9 (10%)	2.2 (7%)	42.4	14.3	92.2	18.1	5.9
VISTAS coastal	OKEF1	19.7 (55%)	3.7 (10%)	6.8 (19%)	2.2 (6%)	0.4 (1%)	2.2 (6%)	0.7 (2%)	46.7	15.2	83.8	17.1	5.3
VISTAS coastal	EVER1	9.6 (45%)	2.2 (10%)	3.5 (16%)	1.1 (5%)	0.4 (2%)	2.7 (13%)	1.9 (9%)	32.3	11.7	121.0	16.9	5.2
VISTAS coastal	CHAS1	18.3 (50%)	4.2 (11%)	6.3 (17%)	2.9 (8%)	0.6 (2%)	3.3 (9%)	1.0 (3%)	47.6	15.5	82.1	18.1	5.9
VISTAS coastal	SAMA1	18.6 (59%)	2.8 (9%)	4.9 (16%)	1.7 (6%)	0.5 (2%)	2.3 (7%)	0.6 (2%)	42.4	14.3	92.2	17.2	5.4
VISTAS inland	DOSO1	14.3 (56%)	3.1 (12%)	4.9 (19%)	2.1 (8%)	0.2 (1%)	0.7 (3%)	0.1 (0%)	35.4	12.3	110.5	14.5	3.6
VISTAS inland	SHEN1	11.2 (53%)	4.2 (20%)	2.9 (14%)	1.6 (8%)	0.2 (1%)	1.1 (5%)	0.1 (1%)	31.2	10.9	125.4	13.8	3.1
VISTAS inland	JARI1	17.5 (56%)	3.7 (12%)	5.6 (18%)	3.0 (9%)	0.2 (1%)	1.2 (4%)	0.1 (0%)	42.3	14.2	92.5	15.5	4.4
VISTAS inland	LIGO1	11.3 (56%)	2.2 (11%)	3.8 (19%)	1.8 (9%)	0.2 (1%)	0.8 (4%)	0.1 (1%)	31.2	11.1	125.4	15.1	4.1
VISTAS inland	SHRO1	7.0 (58%)	1.5 (12%)	2.1 (17%)	0.9 (7%)	0.2 (1%)	0.4 (3%)	0.1 (1%)	22.2	7.7	176.6	12.9	2.5
VISTAS inland	GRSM1	16.4 (56%)	3.9 (14%)	4.9 (17%)	2.2 (8%)	0.2 (1%)	1.3 (5%)	0.2 (1%)	40.2	13.6	97.3	15.8	4.5
VISTAS inland	COHU1	16.1 (55%)	5.2 (18%)	4.8 (16%)	2.0 (7%)	0.2 (1%)	1.0 (3%)	0.1 (0%)	40.5	13.7	96.6	15.4	4.3
VISTAS inland	SIPS1	18.5 (50%)	7.1 (19%)	6.5 (17%)	2.6 (7%)	0.4 (1%)	2.1 (6%)	0.1 (0%)	48.3	15.6	81.0	16.6	5.0
VISTAS inland	MACA1	22.1 (53%)	8.8 (21%)	6.3 (15%)	3.0 (7%)	0.3 (1%)	1.4 (3%)	0.1 (0%)	53.0	16.5	73.8	16.5	5.0
non-VISTAS	BRIG1	14.8 (49%)	3.9 (13%)	4.5 (15%)	2.4 (8%)	0.2 (1%)	3.2 (11%)	1.4 (4%)	42.4	14.3	92.2	17.3	5.4
non-VISTAS	BRET1	17.0 (57%)	3.1 (10%)	3.2 (11%)	1.8 (6%)	0.4 (1%)	3.4 (11%)	1.1 (4%)	41.1	14.0	95.2	17.1	5.3
non-VISTAS	MING1	14.3 (46%)	4.6 (15%)	6.2 (20%)	2.3 (7%)	0.4 (1%)	3.1 (10%)	0.1 (0%)	42.9	14.4	91.1	17.1	5.4
non-VISTAS	HEGL1	10.8 (42%)	4.9 (19%)	5.1 (20%)	2.0 (8%)	0.3 (1%)	2.3 (9%)	0.2 (1%)	36.6	12.8	106.9	16.0	4.7
non-VISTAS	UPBU1	8.7 (39%)	4.6 (21%)	4.2 (19%)	1.5 (7%)	0.3 (2%)	2.8 (13%)	0.1 (0%)	33.2	11.7	117.9	15.2	4.1
non-VISTAS	CACR1	8.5 (41%)	4.0 (20%)	4.3 (21%)	1.5 (7%)	0.2 (1%)	1.8 (9%)	0.2 (1%)	31.6	11.2	123.7	15.3	4.2

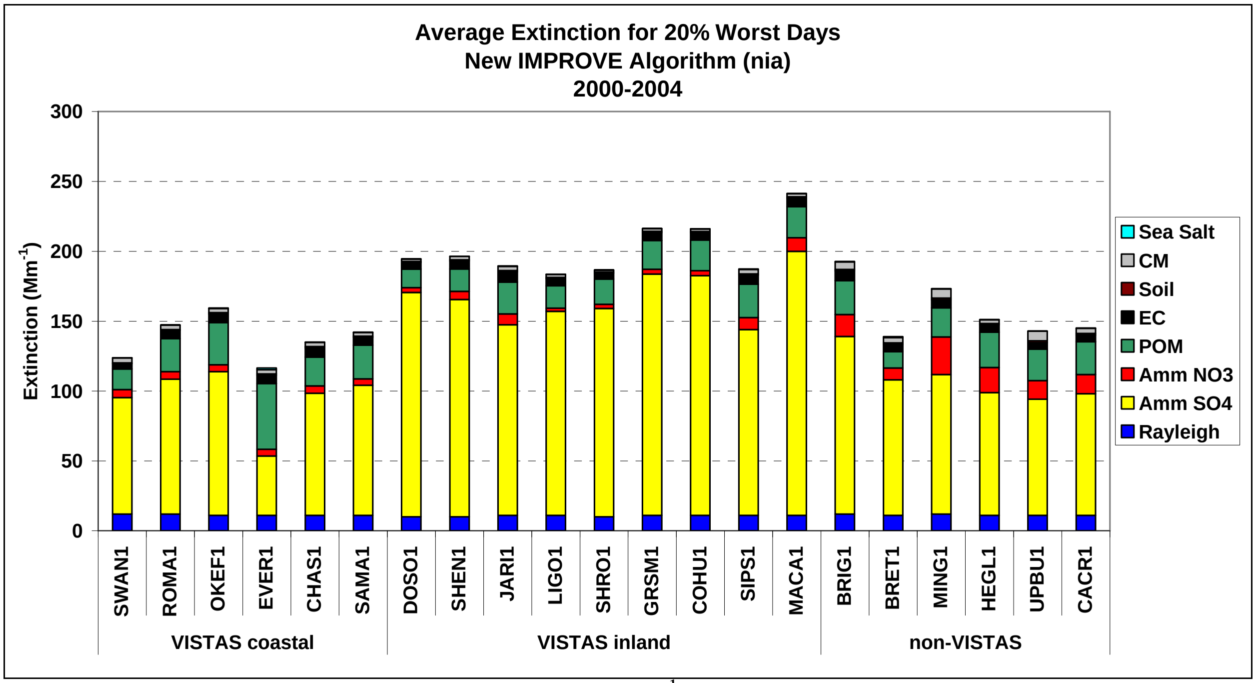


Figure 3-14. Contributions to light extinction (Mm^{-1}) for the average of the 20% worst visibility days in 2000-2004 at VISTAS and neighboring Class I areas.

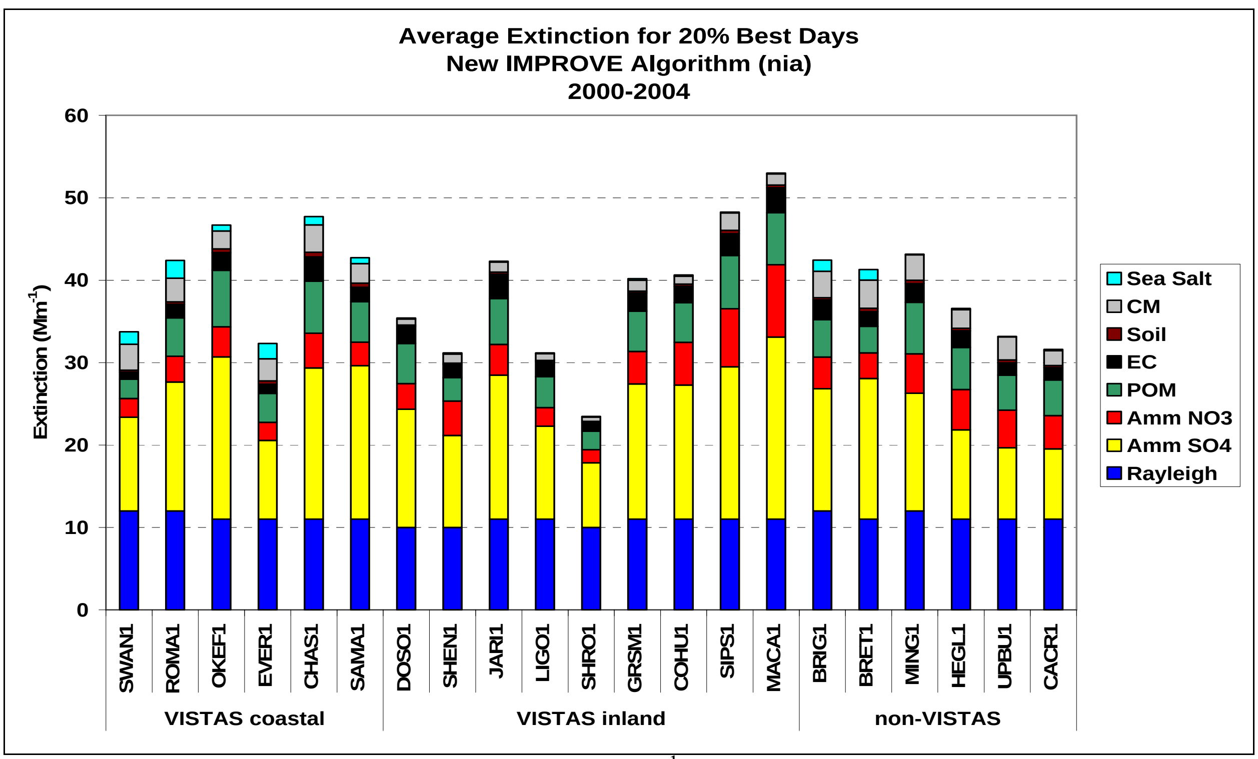


Figure 3-15. Contributions to light extinction (Mm^{-1}) for the average of the 20% best visibility days in 2000-2004 at VISTAS and neighboring Class I areas.

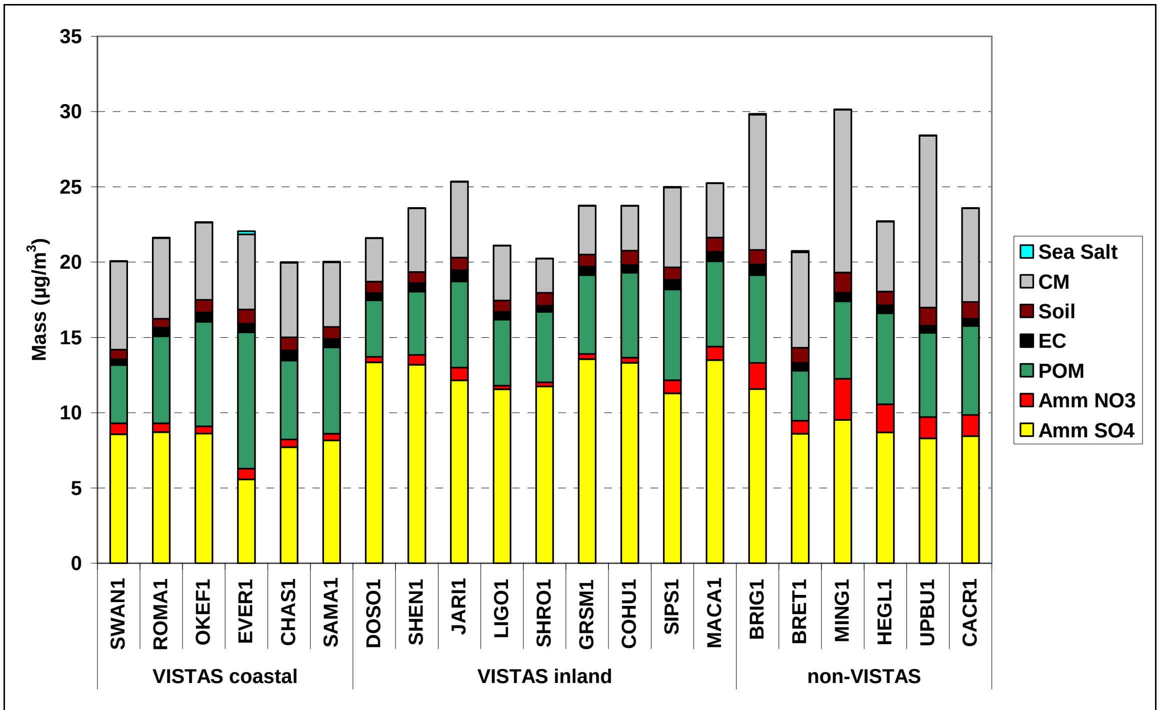


Figure 3-16. Contributions to mass (μg/m^3) for the average of the 20% worst visibility days in 2000-2004 at VISTAS and neighboring Class I areas.

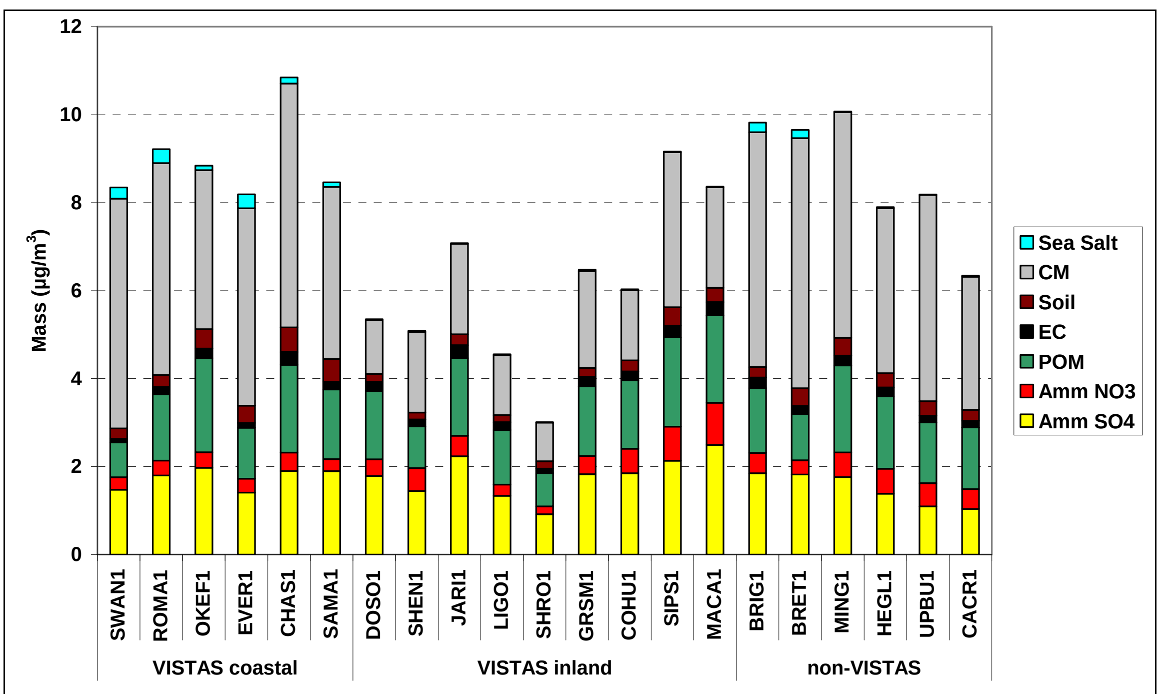


Figure 3-17. Contributions to mass (μg/m^3) for the average of the 20% best visibility days in 2000-2004 at VISTAS and neighboring Class I areas.

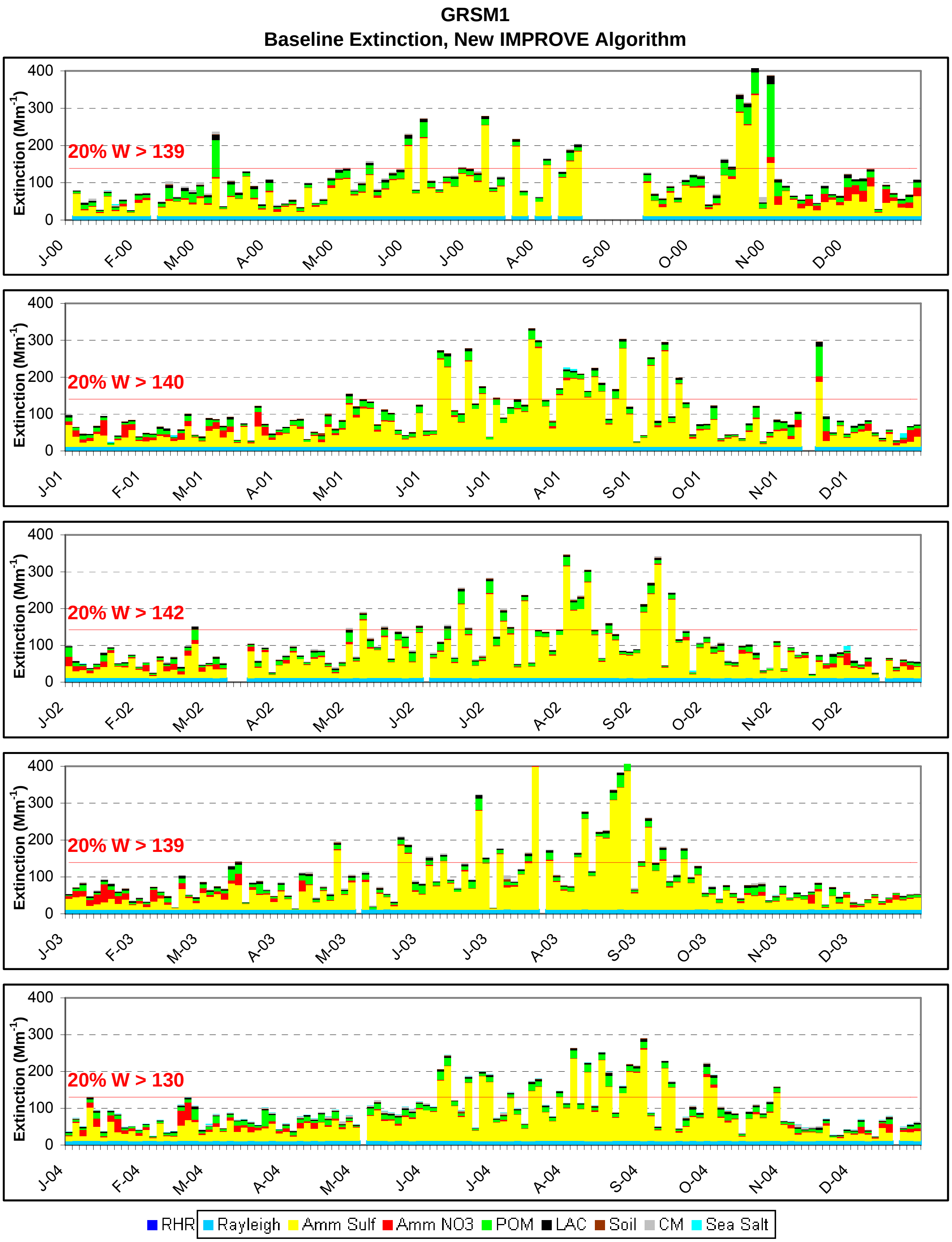


Figure 3-18. Bar charts by year indicating speciation of all data collected at the GRSM1 site. The red line indicates the threshold above which days are counted in the 20% worst days.

Figure 3-19. Bar charts by year indicating speciation of all data collected at the ROMA1 site. The red line indicates the threshold above which days are counted in the 20% worst days.

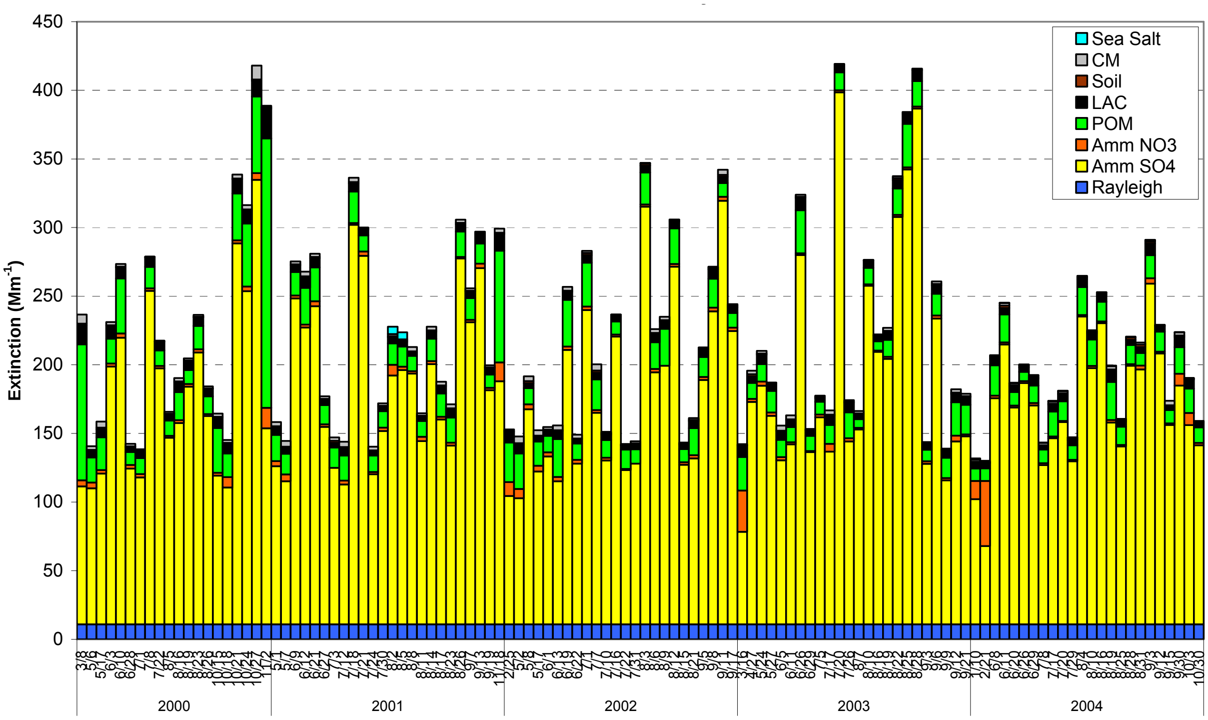


Figure 3-20. Contributions to light extinction (Mm^{-1}) for the 20% worst visibility days in 2000-2004 at the GRSM1 site.

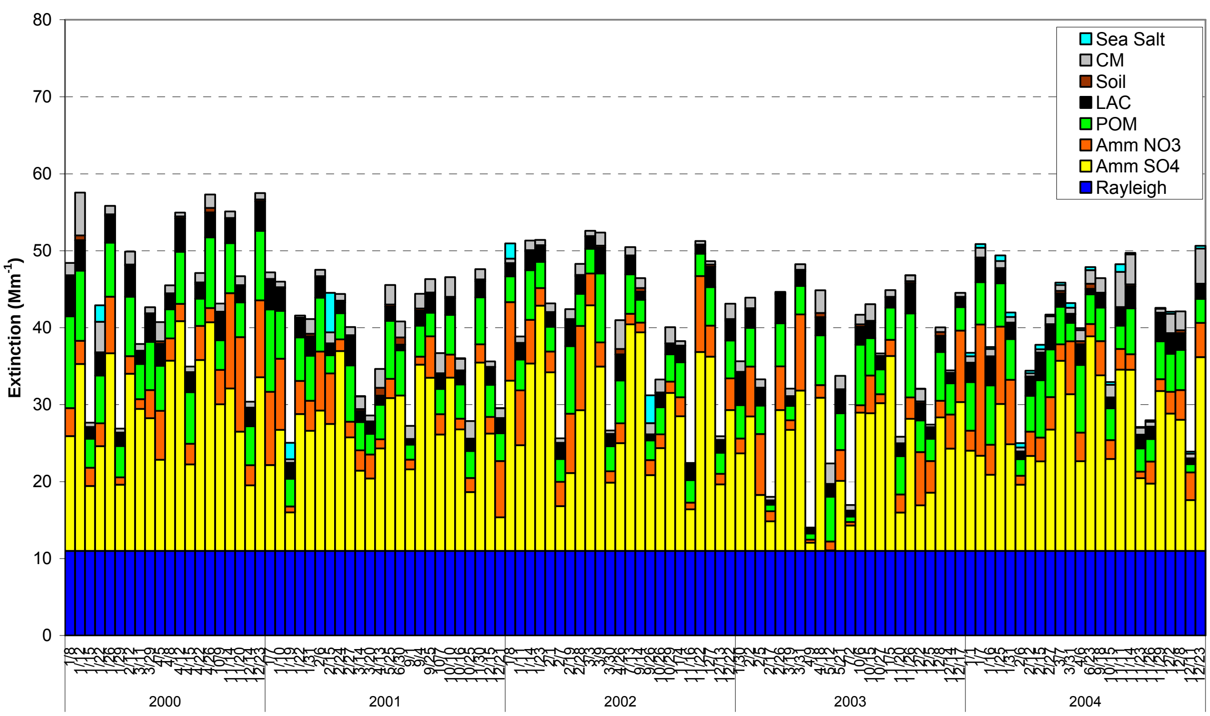


Figure 3-21. Contributions to light extinction (Mm^{-1}) for the 20% best visibility days in 2000-2004 at the GRSM1 site.

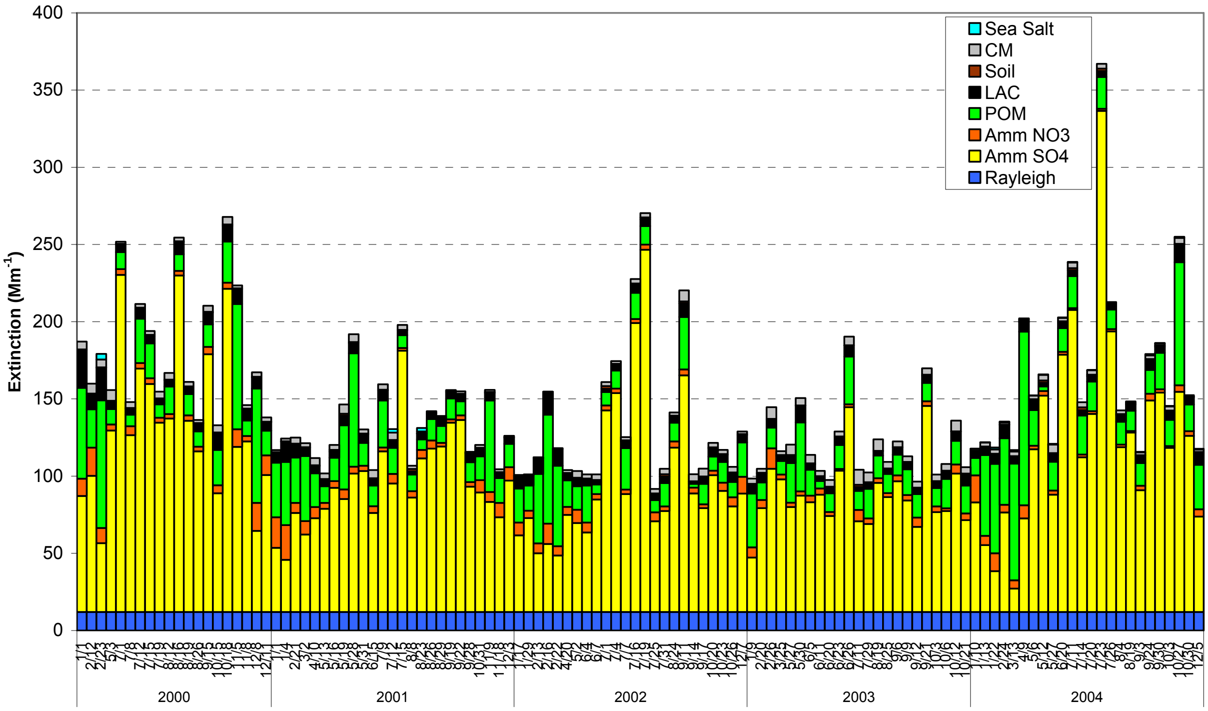


Figure 3-22. Contributions to light extinction (Mm^{-1}) for the 20% worst visibility days in 2000-2004 at the ROMA1 site.

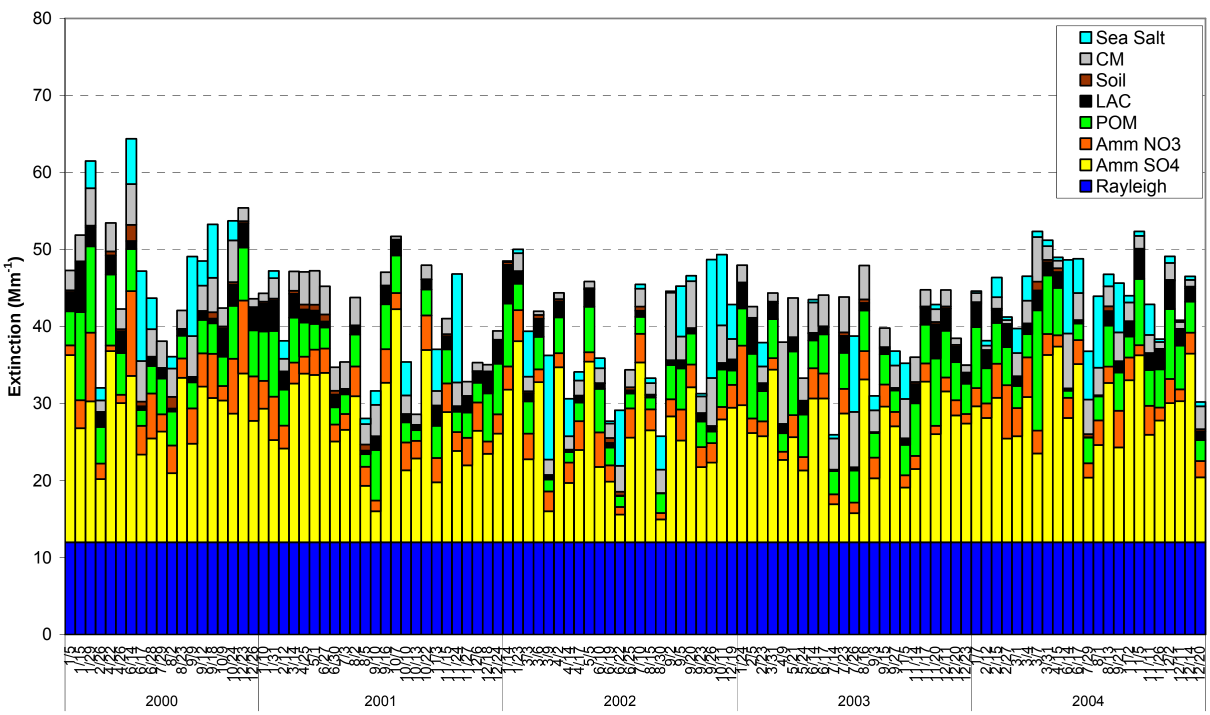


Figure 3-23. Contributions to light extinction (Mm^{-1}) for the 20% best visibility days in 2000-2004 at the ROMA1 site.

3.5 GLIDEPATHS

The RHR guidance requires reasonable progress to be tracked using the Haze Index (deciviews), which is determined as a logarithmic transformation of the sum of all light extinction terms in the IMPROVE light extinction algorithm. The rate of visibility improvement between baseline conditions in 2000-2004 and natural background conditions in 2064 is defined as the glidepath for the uniform rate of progress toward visibility goals. Glidepaths calculated using the original and revised IMPROVE algorithm for the GRSM1 and ROMA1 sites are presented in Figures 3-24 and 3-25 and for other Class I areas in Appendix H. Natural conditions for the glidepath using the original IMPROVE equation are EPA default calculations, and natural conditions for the path using the revised IMPROVE equations are the revised natural condition calculations discussed in Section 2.5, updated in August, 2007. Current conditions at the interior sites are poorer than at the coastal sites and thus a higher rate of improvement is required in each decade to achieve a uniform rate of progress toward natural background conditions in 2064.

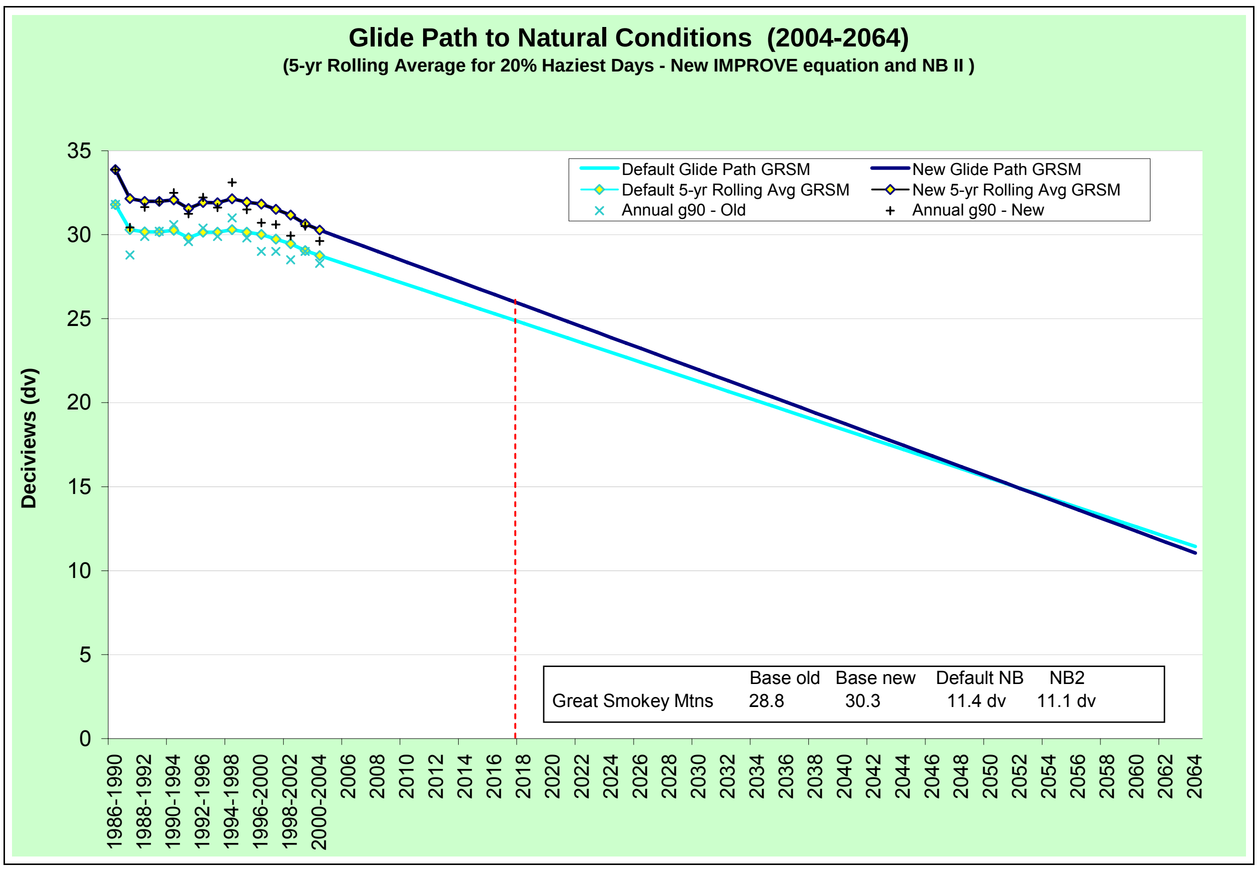


Figure 3-24. DV Glidepaths for the GRSM1 site, calculated using both the original IMPROVE algorithm using EPA default natural conditions (Default NB) and the new IMPROVE algorithm using the revised estimate of natural background conditions (NB2).

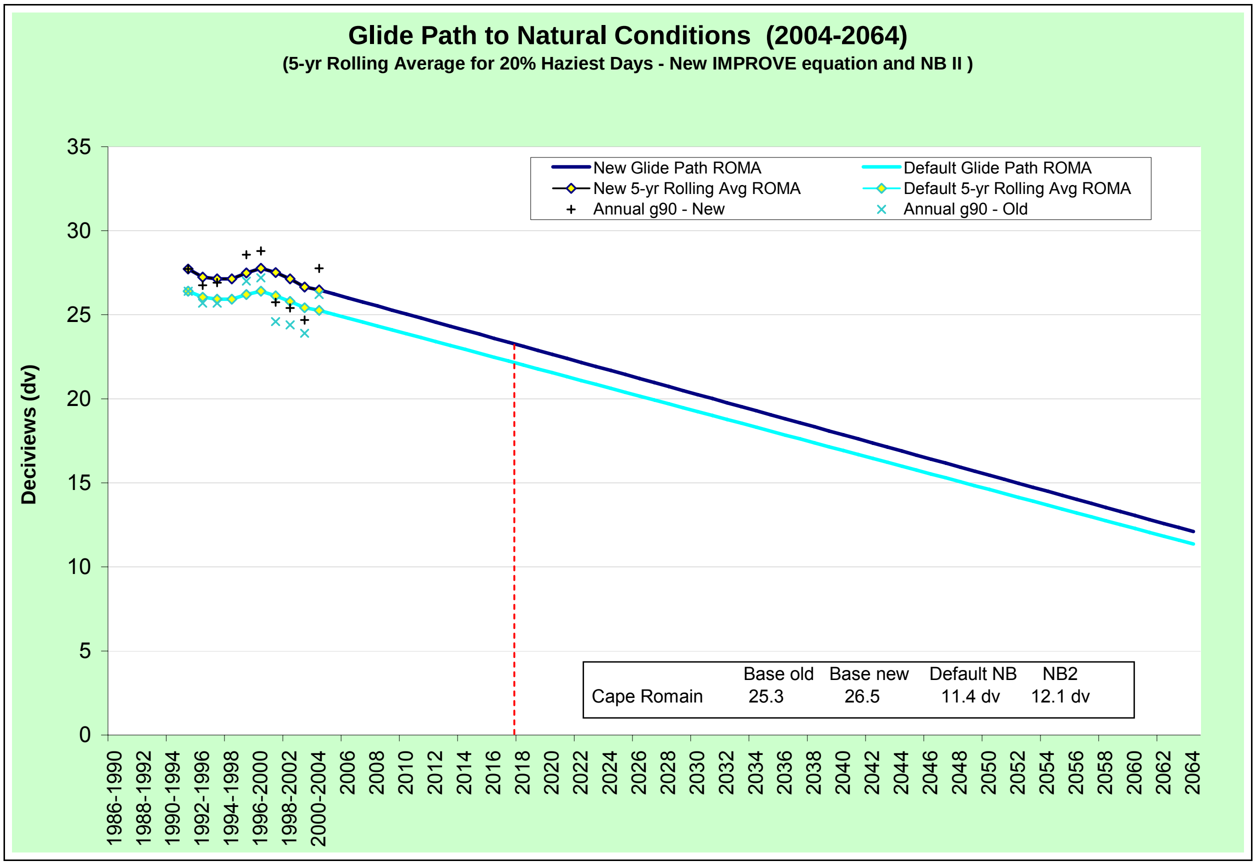


Figure 3-25. DV Glidepaths for the ROMA1 site, calculated using both the original IMPROVE algorithm using EPA default natural conditions (Default NB) and the new IMPROVE algorithm using the revised estimate of natural background conditions (NB2).

The glidepath defined using deciview does not provide information regarding the relative contributions of individual species to overall visibility. This information is useful because some species (sulfate and nitrate) originate from largely anthropogenic sources, while others (organic carbon, elemental carbon) originate from a mixture of both anthropogenic and natural sources.

To look at individual species contribution, species specific glidepaths were constructed using extinction in a manner similar to that outlined in RHR guidance for total deciviews. Figures 3-26 through 3-29 present glidepath charts for total extinction and for ammonium sulfate, ammonium nitrate and POM extinction at the GRSM1 site, and figures 3-30 through 3-33 present the glidepaths for the ROMA1 site. The dV glidepath is linear as defined in the RHR, which, because it is a logarithmic transformation of extinction data, translates to a curved line when converted to total extinction in Mm^{-1}. The dV contribution can not be constructed for individual species, so linear approximations in Mm^{-1} are used for the species specific glidepaths to approximate progress goals. 2018 projected extinction values were provided by ENVIRON based on CMAQ modeling of the 2018 Base G1 inventory. Natural conditions presented here do not use the revised NC2 numbers that became available in August, 2007 but differences between the original set provided by IMPROVE, and the revised set were minimal. Plots for each site in and around the VISTAS region are included in Appendix I.

For total extinction, the projected 2018 value at the GRSM1 site is well below the glidepath to natural conditions. This is in large part due to the substantial improvement in projected ammonium sulfate values, from 173 Mm^{-1} to 70 Mm^{-1} in 2018. POM needs little improvement to reach natural conditions, and projected 2018 values fall slightly below the glidepath. For Ammonium nitrate, baseline conditions are low, and are similar to estimated natural conditions. Projected 2018 nitrate values are actually higher than the baseline emissions, but still low at 9 Mm^{-1} when compared to the baseline ammonium sulfate emissions of 173 Mm^{-1}.

At the ROMA1 site, the baseline is lower than for the GRSM1 site, and the projected 2018 value for total extinction at the ROMA1 site is on the glidepath. Projected ammonium sulfate is below the glidepath, with a projected value of 54 Mm^{-1} in 2018. POM again needs little improvement to reach natural conditions, and projected 2018 values are on the glidepath. For ammonium nitrate, projected 2018 values are lower than the baseline emissions, slightly above the glidepath, but still low, with projected 2018 values of 5 Mm^{-1}.

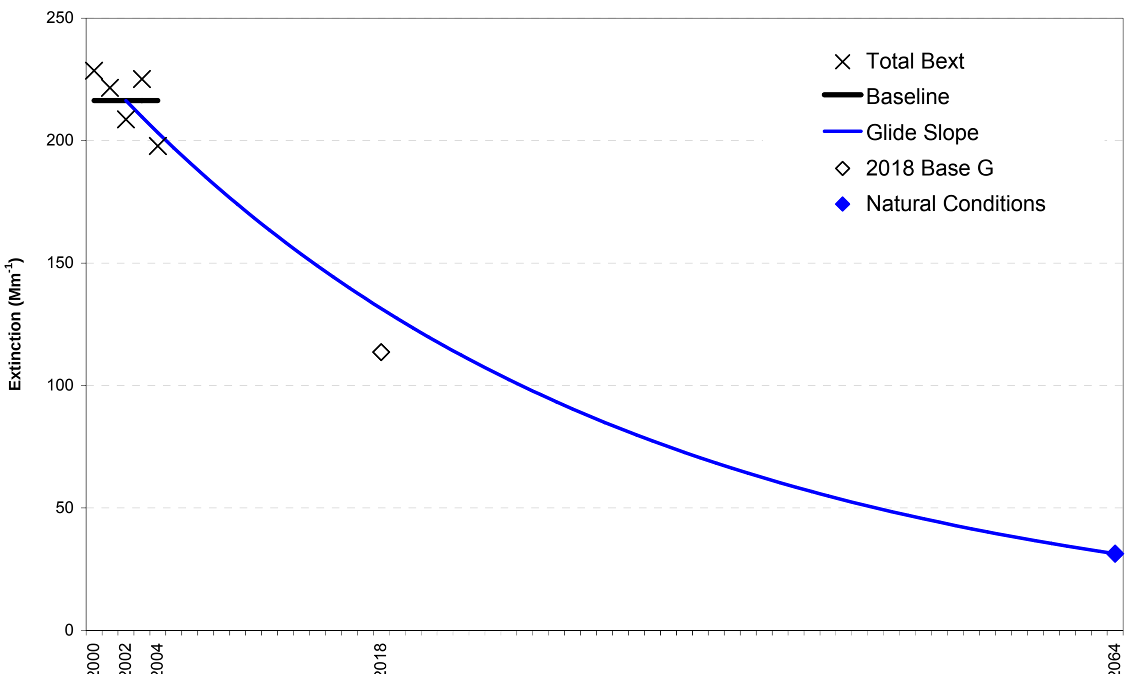


Figure 3-26. Glidepath depicting total b_{ext} (Mm^{-1}) for 20% worst days at the GRSM1 site.

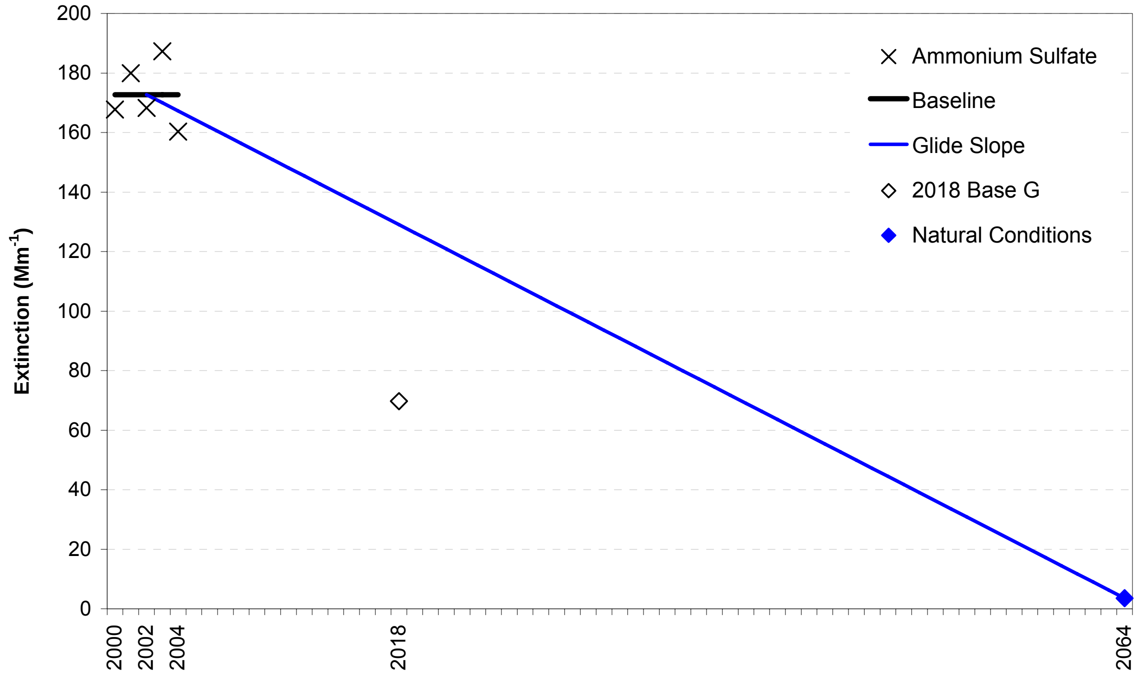


Figure 3-27. Glidepath depicting Ammonium Sulfate for 20% worst days at the GRSM1 site.

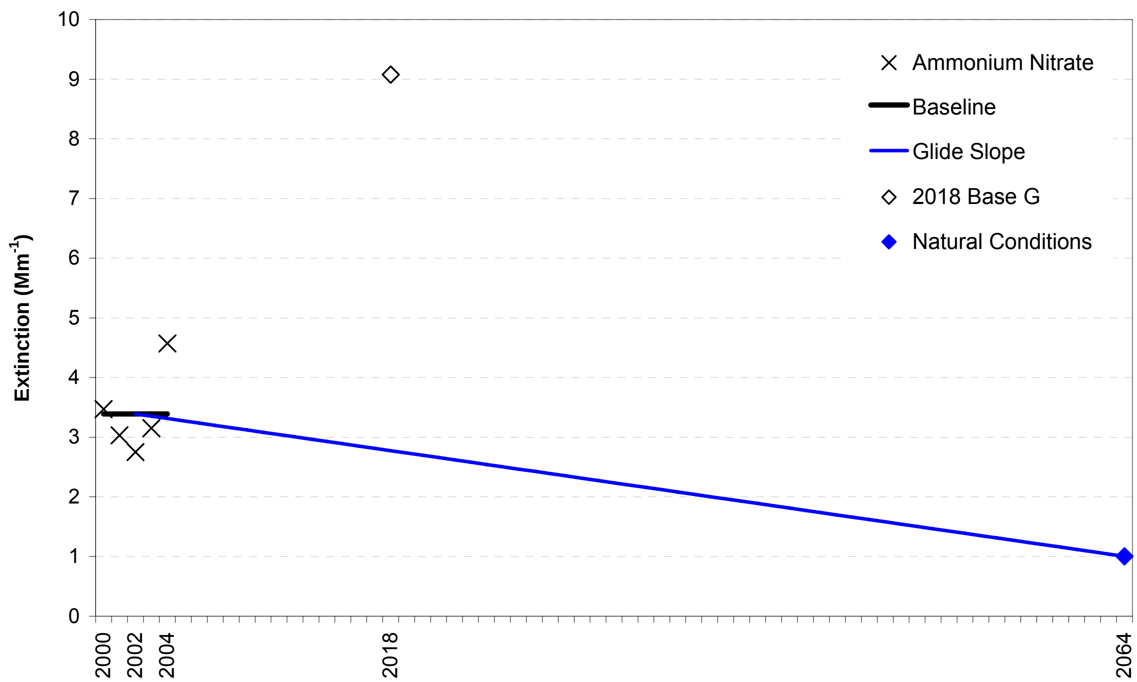


Figure 3-28. Glidepath depicting Ammonium Nitrate for 20% worst days at the GRSM1 site.

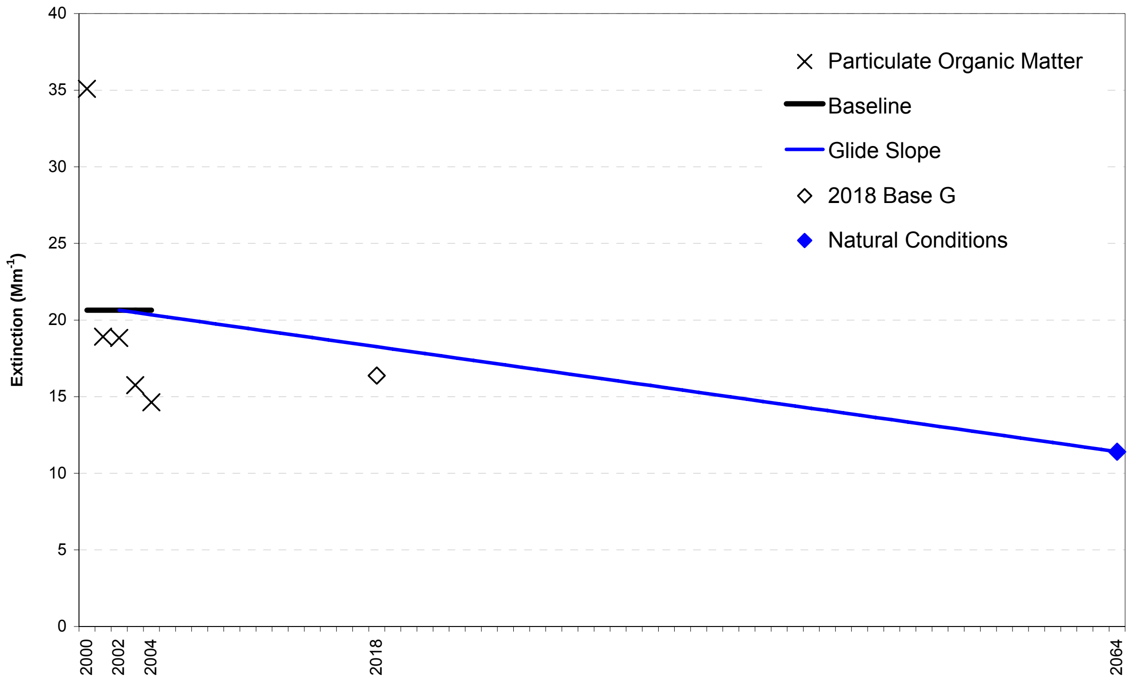


Figure 3-29. Glidepath depicting Particulate Organic Material for 20% worst days at the GRSM1 site.

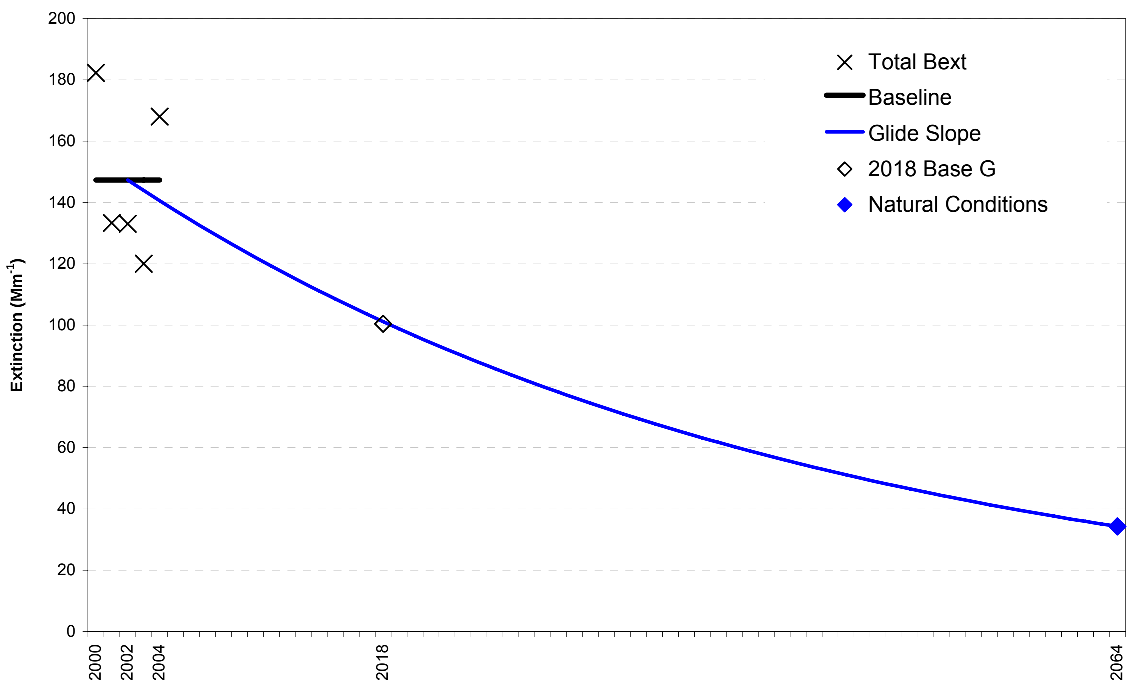


Figure 3-30. Glidepath depicting total b_{ext} (Mm^{-1}) for 20% worst days at the ROMA1 site.

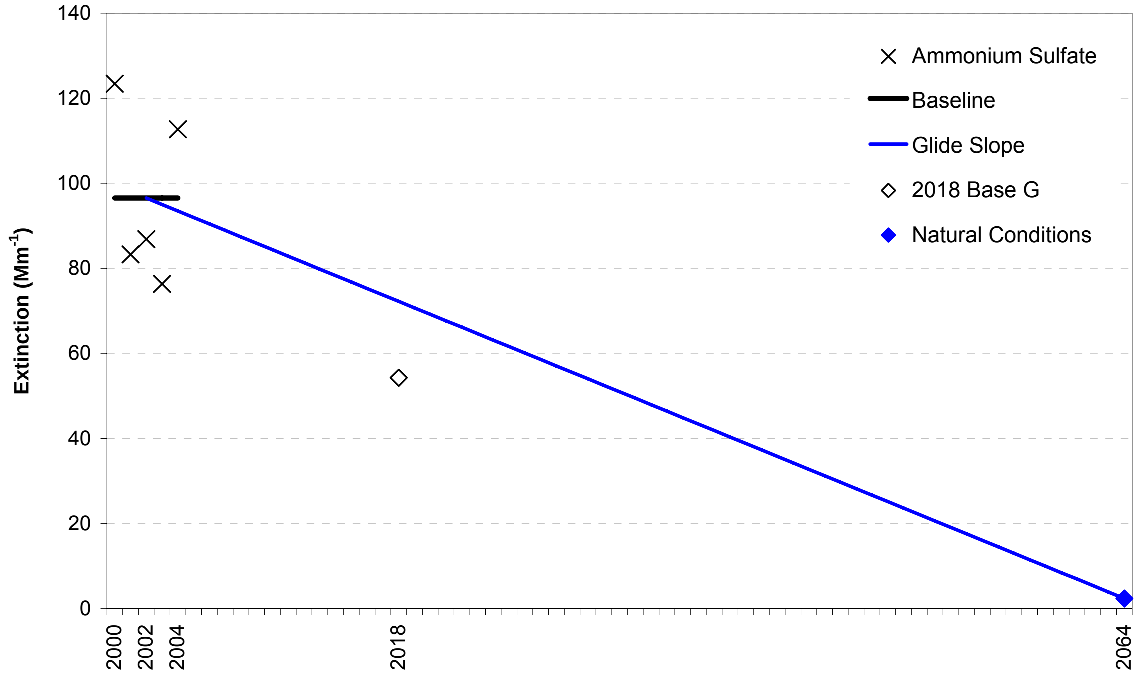


Figure 3-31. Glidepath depicting Ammonium Sulfate for 20% worst days at the ROMA1 site.

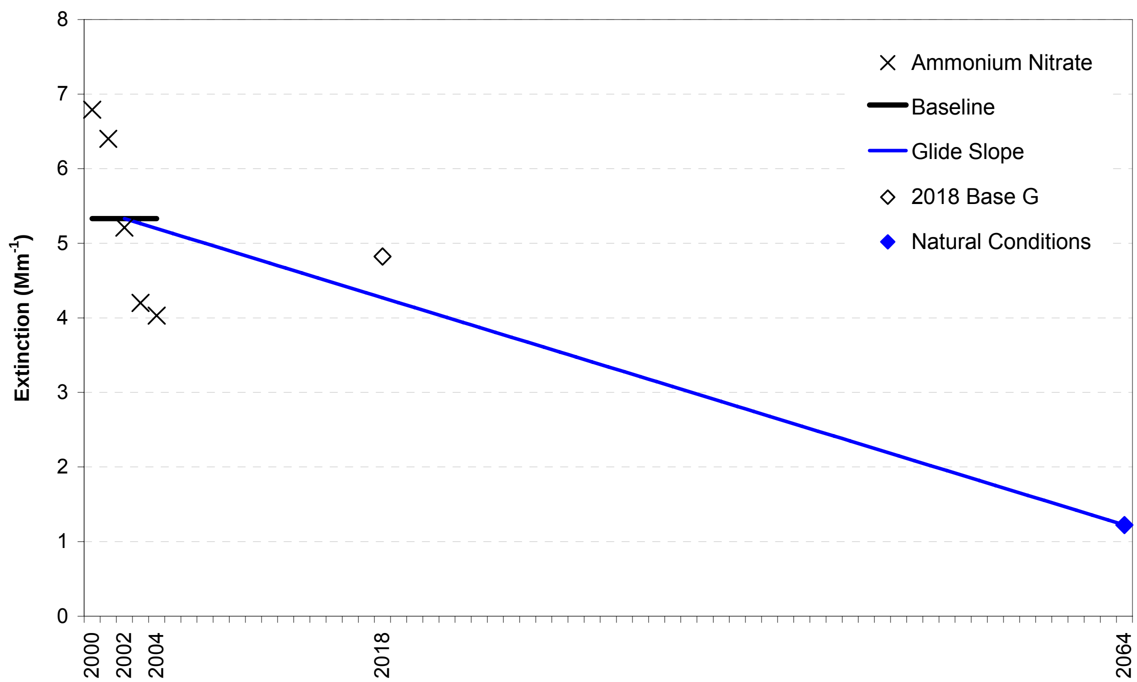


Figure 3-32. Glidepath depicting Ammonium Nitrate for 20% worst days at the ROMA1 site.

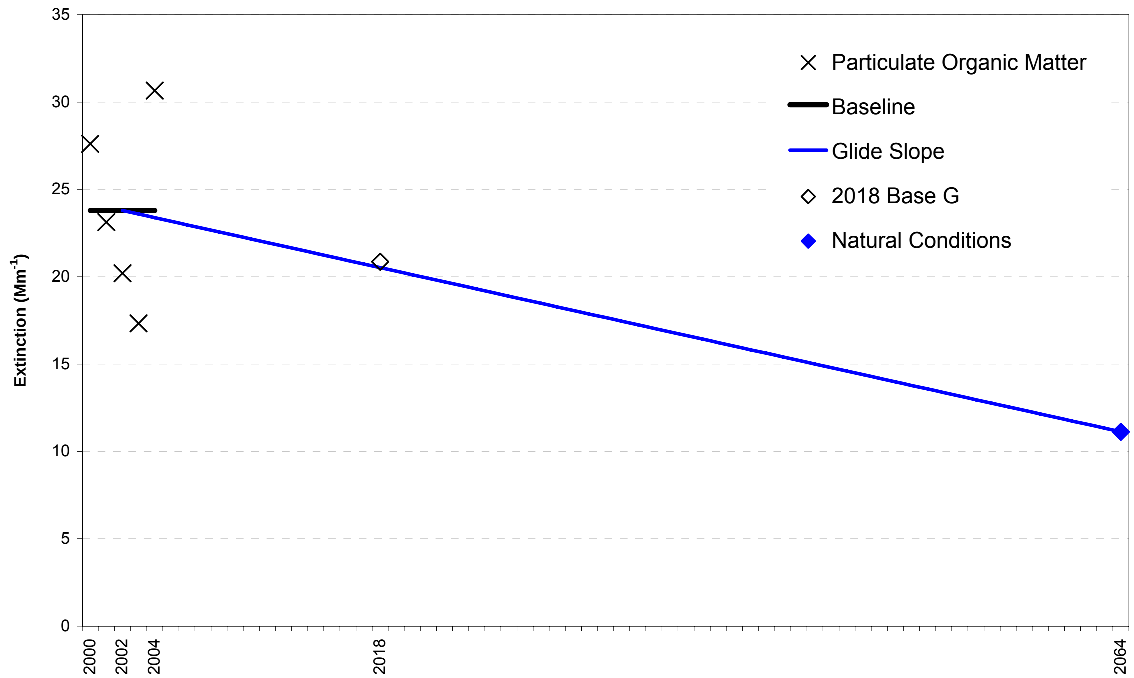


Figure 3-33. Glidepath depicting Particulate Organic Material for 20% worst days at the ROMA1 site.

3.6 ATTRIBUTION ANALYSIS

An attribution analysis was performed to allow states to understand what source regions impact Class I areas in the VISTAS region. The analysis included construction of back trajectory and residence time maps, and comparisons of international and domestic mass attribution.

3.6.1 Back Trajectory Maps

For the year 2002, back trajectories were computed for IMPROVE monitoring sites in and around the VISTAS region. These analyses used the VISTAS substituted data set, with extinction calculated using the original IMPROVE algorithm. The original algorithm was used because the maps were generated and mapped before VISTAS made the decision to use the revised algorithm, but the days identified as the 20% worst days are similar, if not exactly the same, between algorithms. Each hourly point for back trajectories with end dates corresponding to the 20% worst visibility days was plotted on a map. A back trajectory map for the 20% worst measured extinction days at the GRSM1 sites is presented in Figure 3-34. Back trajectory maps for all VISTAS sites are included in Appendix J.

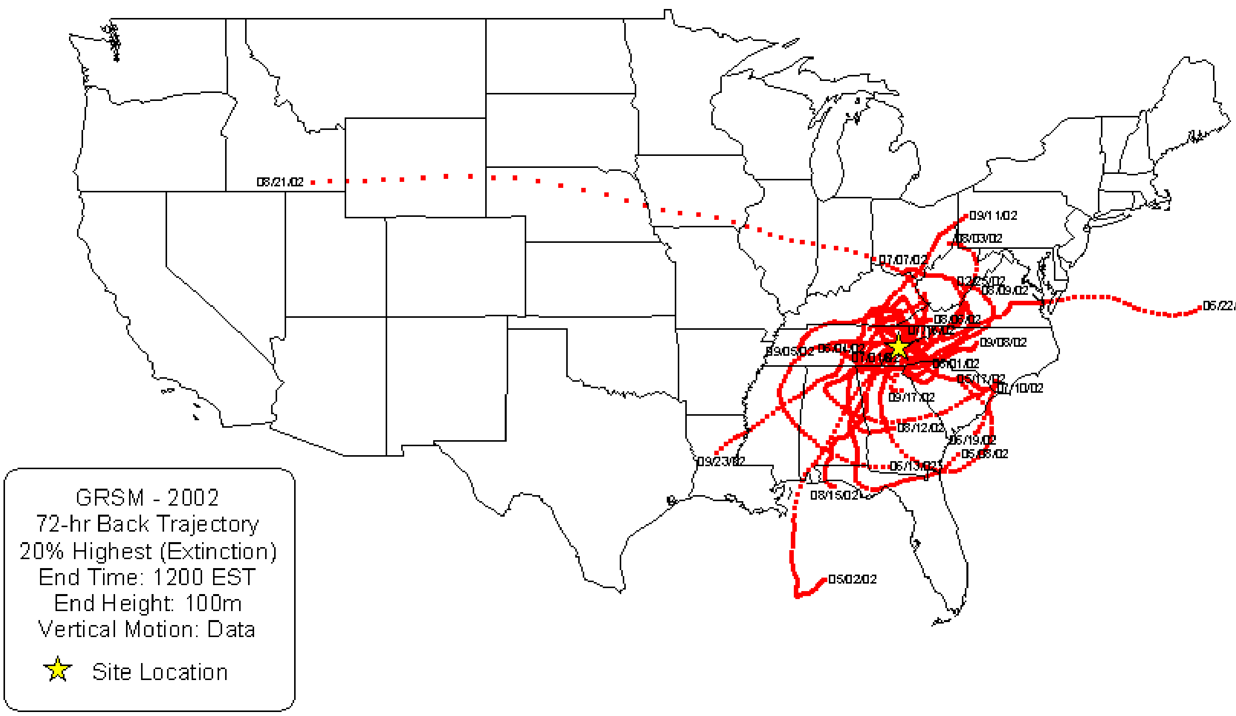


Figure 3-34. Back trajectories for the 20% Worst extinction days at the Great Smoky Mountains National Park (GRSM1) IMPROVE monitoring site.

3.6.2 Residence Time Maps

Residence time maps were constructed using 2000-2004 back trajectories. 20% worst extinction days were determined using the substituted IMPROVE RHR2 (new IMPROVE algorithm, updated 3/06) data set. Each hourly point for back trajectories with end dates corresponding to the 20% worst visibility days was counted and summed into ¼ degree horizontal grid cells of latitude and longitude. The percent of hourly points in each grid cell was calculated and mapped using color gradients, where darker colors indicate regional areas where air parcels spent the most time before reaching the IMPROVE monitors. A residence time map for the 20% worst measured extinction days at the GRSM1 site for trajectories with end heights of 100m is presented in Figure 3-31. 100m and 500m residence time Maps for all VISTAS and regional sites are included in Appendix K.

Residence time over an area is indicative of general flow patterns, but since it does not account for emissions and removal processes, it does not necessarily imply specific areas contributed significantly to haze compounds at a receptor site.

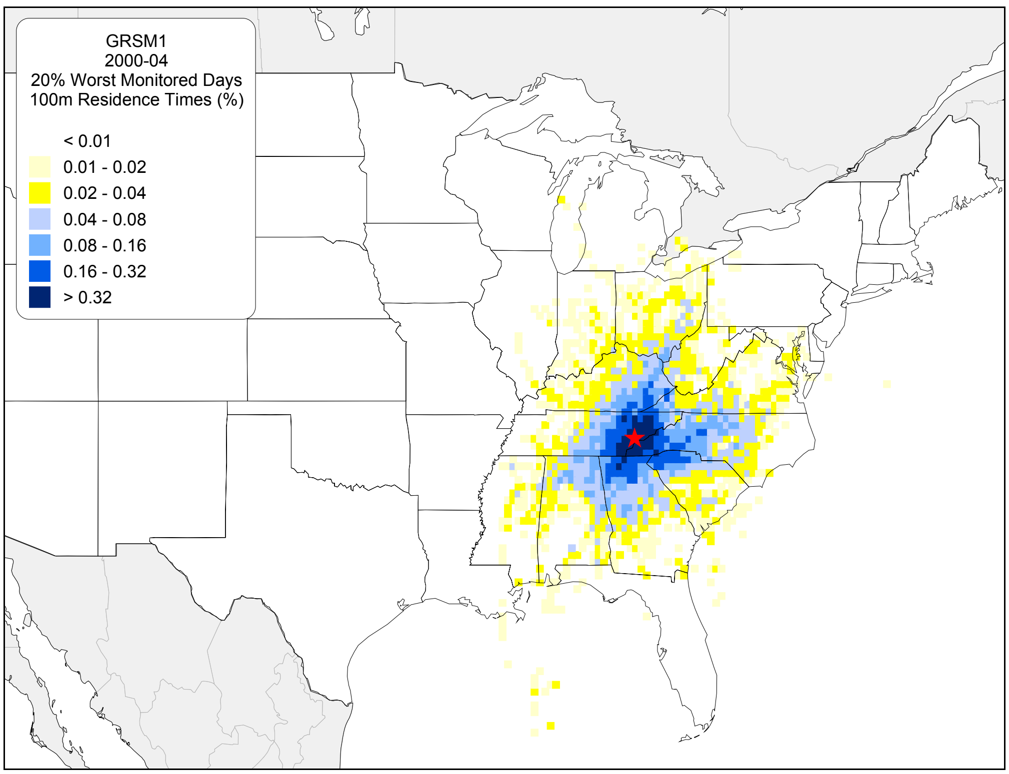


Figure 3-35. Residence times for 72-hour back trajectories with 100m end heights for 20% worst extinction days at the GRSM1 IMPROVE monitoring site.

3.6.3 <u>Extinction-Weighted Residence Time</u>

For the years 2000-2004 ARS generated extinction-weighted residence time data for each IMPROVE sites in and around the VISTAS region. These analyses used the VISTAS substituted data set, with extinction calculated using the original IMPROVE algorithm. The original algorithm was used because these data files were generated prior to VISTAS decision to use the new algorithm, and it was determined that updating these data with the revised algorithm would not affect interpretation. Each hourly point for back trajectories with end dates corresponding to one the 20% worst visibility days were weighted with calculated extinction values for that day. Trajectory data were weighted by total extinction, and by extinction components including ammonium sulfate (AmmSO4), ammonium nitrate (AmmNO3), particulate organic material (POM), Light Absorbing Carbon (LAC), Soil, and Coarse Mass (CM). The extinction values associated with hourly points were summed into 1 degree horizontal grid cells of latitude and longitude.

These extinction-weighted residence time data files were provided to ENVIRON to use in conjunction with emissions information to relate emissions and transport to components of haze, and to apply distance weighting to estimate removal processes. These charts are available from ENVIRON.

3.6.4 International Contributions

To account for contribution to mass measured at VISTAS sites from international emissions, VISTAS generated model results with zeroed out Mexican and Canadian emissions, and boundary conditions (as defined by the GEOS-CHEM global model). The difference between the model run with and without the international emissions was used to represent species mass attributable to international sources.

Figure 3-36 and 3-37 present stacked bar charts separating domestic and international attribution of mass on the 20% worst and best extinction days in 2002 at the GRSM1 site, and Figures 3-38 and 3-39 present charts for the ROMA1 site. For this comparison all sulfate and nitrate were assumed to be fully neutralized by particulate NH_4^+ (similar to IMPROVE monitoring network assumptions). Negative numbers in the international results indicated that species concentration went up when the non-US anthropogenic emissions were removed. The negative impacts were usually small, and these values were set to zero for purposes of this comparison. Domestic contributions were computed as the difference between total measured mass and international modeled mass.

International attribution at the GRSM1 site ranges between 2 and 7% of total mass on the 20% worst days. Magnitudes on the 20% best days were similar, but accounted for up to 41% of total measured mass. At the ROMA1 site, attribution was between 0 and 18% on the worst days, and up to 21% on the best days. Similar charts for the other Class I areas are included in Appendix L.

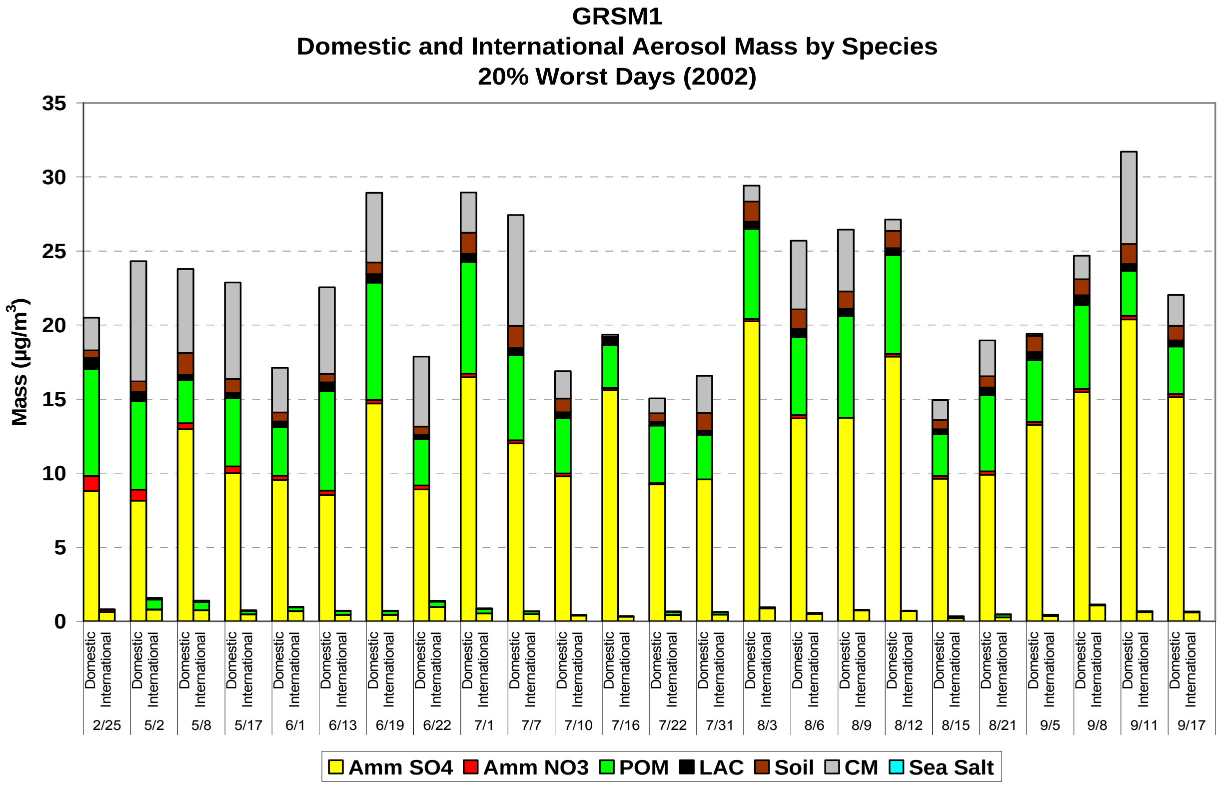


Figure 3-36. Stacked bar charts of mass at the GRSM1 site depicting domestic and international contributions to the 20% worst days in 2002.

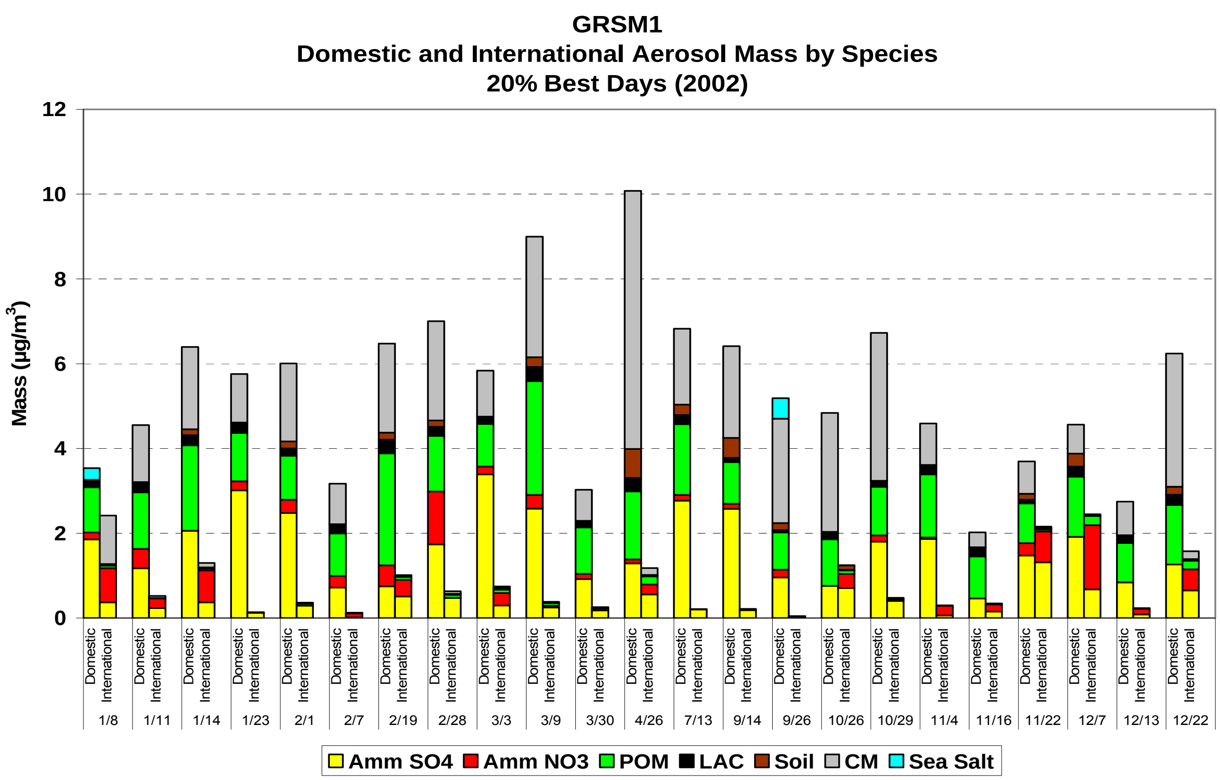


Figure 3-37. Stacked bar charts for mass at the GRSM1 site depicting domestic and international contributions to the 20% best days in 2002.

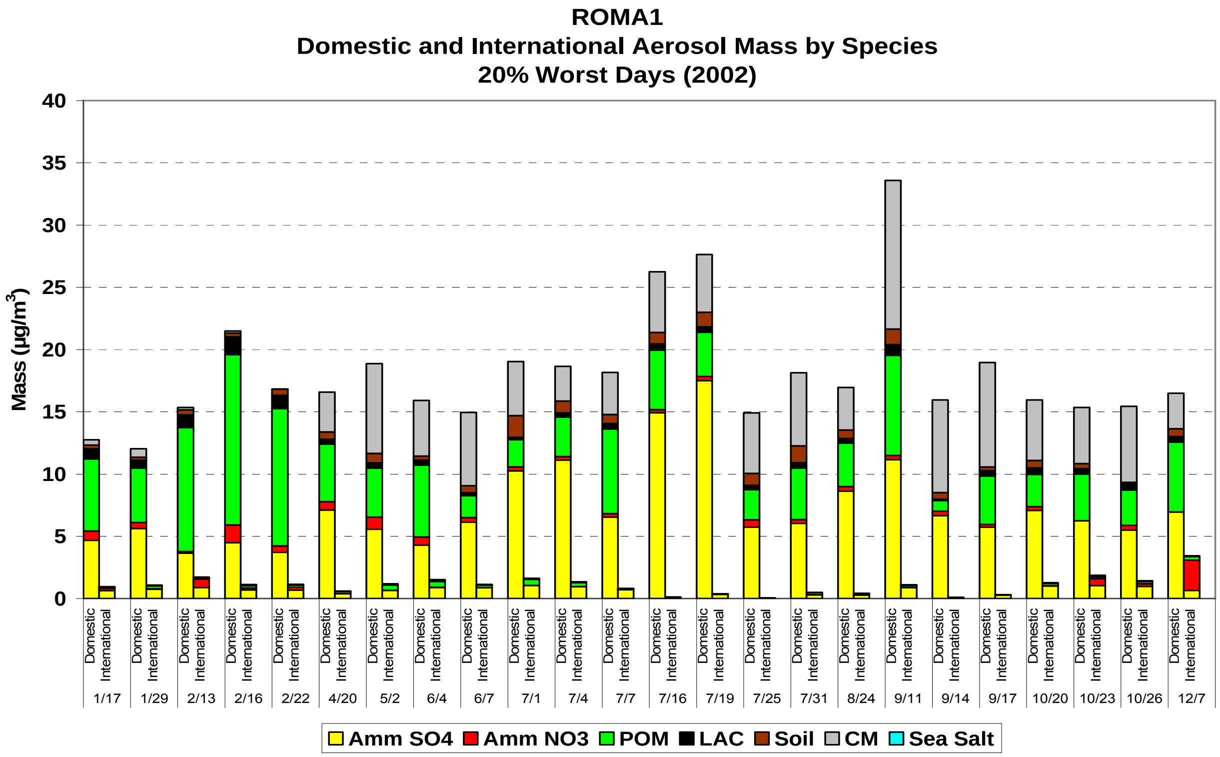


Figure 3-38. Stacked bar charts of mass at the ROMA1 site depicting domestic and international contributions to the 20% worst days in 2002.

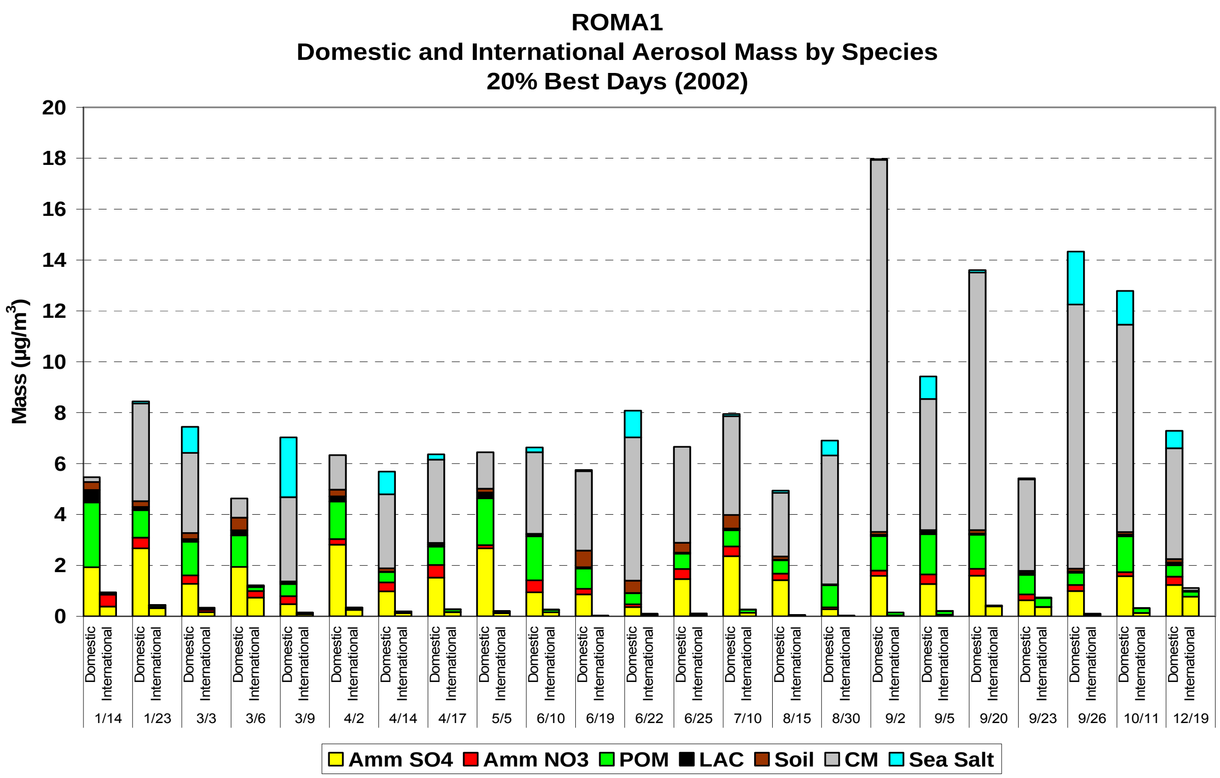


Figure 3-39. Stacked bar charts for mass at the ROMA1 site depicting domestic and international contributions to the 20% best days in 2002.