Appendix D-1

Area of Influence Analyses

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Area of Influence Analysis Southeastern VISTAS II Regional Haze Analysis Project

Documentation Report for Task 5

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Abbreviations/Acronym List

AoI	Area of Influence
ARL	Air Resources Laboratory
bext	Beta extinction
CIRA	Cooperative Institute for Research in the Atmosphere
CWT	Concentration weighted trajectory
d	Distance
EIS	Emission Inventory System
EPA	United States Environmental Protection Agency
ERG	Eastern Research Group, Inc.
EWRT	Extinction-weighted residence time
FIPS	Federal Information Processing Standard
FLM	Federal Land Manager
FR	Federal Register
FTP	File Transfer Protocol
GIS	Geographic Information System
GUI	Graphical User Interface
HYSPLIT	Hybrid Single Particle Lagrangian Integrated Trajectory
IMPROVE	Interagency Monitoring of Protected Visual Environments
km	Kilometers
m	Meters
NAAQS	National Ambient Air Quality Standards
NAICS	North American Industry Classification System
NAM-12	North American Mesoscale forecast data at the 12-km level
NOAA	National Oceanic and Atmospheric Administration
NO_x	Oxides of nitrogen
$PM_{2.5}$	Fine particle; primary particulate matter less than or equal to 2.5 microns in aerodynamic diameter
PSAT	Particulate Source Apportionment Technology
Q	Emissions
Q/d	Emissions over distance
Q/d^2	Emissions over distance squared
QA	Quality assurance
R	Programming software language called *R*
RHR	Regional Haze Rule
RT	Residence Time
SCC	Source Classification Code
SESARM	Southeastern States Air Resource Managers, Inc.
SIA	Second Improve Algorithm
SIP	State Implementation Plan
SO_2	Sulfur dioxide
TB	Terabytes
tpy	tons per year
UTC	Universal Time Coordinated
VISTAS	Visibility Improvement - State and Tribal Association of the Southeast

State Abbreviations

AL	Alabama
AR	Arkansas
FL	Florida
GA	Georgia
KY	Kentucky
LA	Louisiana
ME	Maine
MI	Michigan
MN	Minnesota
MO	Missouri
NC	North Carolina
NH	New Hampshire
NJ	New Jersey
NM	New Mexico
OK	Oklahoma
SC	South Carolina
TN	Tennessee
TX	Texas
VA	Virginia
VT	Vermont
WV	West Virginia

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1. Introduction

Southeastern States Air Resource Managers, Inc. (SESARM) has been designated by the United States Environmental Protection Agency (EPA) as the entity responsible for coordinating regional haze evaluations for the ten Southeastern states of Alabama, Florida, Georgia, Kentucky, Mississippi, North Carolina, South Carolina, Tennessee, Virginia, and West Virginia. The Eastern Band of Cherokee Indians and the Knox County, Tennessee local air pollution control agency are also participating agencies. These parties are collaborating through the Regional Planning Organization known as Visibility Improvement - State and Tribal Association of the Southeast (VISTAS) in the technical analyses and planning activities associated with visibility and related regional air quality issues. VISTAS analyses will support the VISTAS states in their responsibility to develop, adopt, and implement their State Implementation Plans (SIPs) for regional haze.

The state and local air pollution control agencies in the Southeast are mandated to protect human health and the environment from the impacts of air pollutants. They are responsible for air quality planning and management efforts including the evaluation, development, adoption, and implementation of strategies controlling and managing all criteria air pollutants (including fine particles and ozone) as well as regional haze. This project will focus on regional haze and regional haze precursor emissions. Control of regional haze precursor emissions will have the additional benefit of reducing certain criteria pollutants as well.

The 1999 Regional Haze Rule (RHR) identified 18 Class I Federal areas (national parks greater than 6,000 acres and wilderness areas greater than 5,000 acres) in the VISTAS region and required states to define long-term strategies to improve visibility in these areas. States were required to establish baseline visibility conditions for the period 2000-2004, natural visibility conditions in the absence of anthropogenic influences, and an expected rate of progress to reduce emissions and incrementally improve visibility to natural conditions by 2064. The original RHR required states to improve visibility on the 20% most impaired days and protect visibility on the 20% least impaired days.[1] The RHR requires states to evaluate progress toward visibility improvement goals every five years and submit revised SIPs every ten years.

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[1] RHR summary data is available at: http://vista.cira.colostate.edu/Improve/rhr-summary-data/

EPA finalized revisions to various requirements of the RHR in January 2017 (82 FR 3078) that were designed to strengthen, streamline, and clarify certain aspects of the agency's regional haze program including:

A. Strengthening the Federal Land Manager (FLM) consultation requirements to ensure that issues and concerns are brought forward early in the planning process.
B. Updating the SIP submittal deadlines for the second planning period from July 31, 2018 to July 31, 2021 to ensure that they align where applicable with other state obligations under the Clean Air Act. The end date for the second planning period remains 2028; that is, the focus of state planning will be to establish reasonable progress goals for each Class I area against which progress will be measured during the second planning period. This extension will allow states to incorporate planning for other federal programs while conducting their regional haze planning. These other programs include: the Mercury and Air Toxics Standards, the 2010 1-hour sulfur dioxide (SO_2) National Ambient Air Quality Standard (NAAQS); the 2012 annual fine particle ($PM_{2.5}$) NAAQS; and the 2008 and 2015 ozone NAAQS.
C. Adjusting interim progress report submission deadlines so that second and subsequent progress reports will be due by: January 31, 2025; July 31, 2033; and every ten years thereafter. This means that one progress report will be required midway through each planning period.
D. Removing the requirement for progress reports to take the form of SIP revisions. States will be required to consult with FLMs and obtain public comment on their progress reports before submission to the EPA. EPA will be reviewing but not formally approving or disapproving these progress reports.

The RHR defines "clearest days" as the 20% of monitored days in a calendar year with the lowest deciview index values. "Most impaired days" are defined as the 20% of monitored days in a calendar year with the highest amounts of anthropogenic visibility impairment. The long-term strategy and the reasonable progress goals must provide for an improvement in visibility for the most impaired days and ensure no degradation in visibility for the clearest days since the baseline period.

To inform the long-term strategy for visibility improvement, states often use an Area of Influence (AoI) analysis to help identify the areas and sources most likely contributing to poor visibility in the Class I areas. The AoI analysis involves running a backward trajectory model to determine the origin of the air parcels affecting visibility. This information is then spatially combined with emissions data to determine the sources or source sectors most likely contributing to the pollutant emissions.

This report describes the AoI Analysis, starting with the technical approach, followed by a walkthrough of the programming code used to generate the images and analysis.

2. Approach

Under this task, ERG identifies the 20% most impaired days for each Class I area in the VISTAS_12 modeling domain over the 2011-2016 period based on the IMPROVE monitoring website RHR summary of the 20% most-impaired visibility days.[2] Due to the presence of large SO_2 emission reductions during this six-year period, the AoI analysis was set up to look at: 1) each year individually; 2) two separate periods of 2011-2013 and 2014-2016; and 3) for all years combined.

The initial plan was to use the *R* programming language for all of the AoI analysis, which included running the Hybrid Single Particle Lagrangian Integrated Trajectory (HYSPLIT) model, plotting trajectories, and weighing residence time calculations. However, as the work proceeded, it became apparent that *R* would not provide all the features needed to accomplish this task. Where possible, ERG proceeded with free and open source software and tools to keep the analysis process as reproducible and transparent as possible. As such, several phases of the analysis are completed using multiple methods to provide states options for additional work and analysis they may wish to conduct. The draw backs of each approach used are discussed separately in the subsections for each phase of the analysis.

2.1 Identification of Sites

In addition to identifying the areas influencing visibility in Class I areas inside SESARM states, this analysis identifies areas from SESARM states that might have an influence on

[2] http://vista.cira.colostate.edu/Improve/rhr-summary-data/

visibility in Class I areas outside the SESARM states. Analysis started by examining the eighty-three (83) Interagency Monitoring of Protected Visual Environments (IMPROVE) monitor positions in Class I areas within the VISTAS 12 kilometer (km) modeling domain. The final number of Class I areas was reduced from 83 to 45 due to:

- *Exclusion of Central and Western States IMPROVE monitors*. To simplify the potential number of trajectories to be generated, SESARM approved a North Carolina Division of Air Quality recommendation which demonstrated that trajectories originating in Class I areas in several western states do not pass over a SESARM state and could be excluded from further analysis. These states are: Kansas; Nebraska; North Dakota; South Dakota; Colorado; Wyoming; and Montana. With the exclusion of these states, the number of IMPROVE monitors in the VISTAS 12km domain reduces to thirty-eight (38).
- *Class I Areas With No IMPROVE Monitor*. There are six (6) Class I areas in the VISTAS 12km modeling domain that do not have an IMPROVE monitor. Of the six, three are located in the SESARM states (Wolf Island, GA; Joyce Kilmer-Slickrock, NC/TN; and Otter Creek, WV) and three are located outside the SESARM states (Carlsbad Caverns, NM; Pecos Wilderness Area, NM; and Presidential Range-Dry River Wilderness, NH). For these Class I areas, the trajectory origin will be the centroid of the Class I area. Visibility data will be based on an appropriate IMPROVE monitor, as previously determined by the FLMs. This increased the number of trajectory origins to forty-four (44).
- *IMPROVE Monitor Relocation*. Additionally, the IMPROVE monitor for the Lye Brook Wilderness, VT area moved in 2012. Separate trajectory analysis was completed for each monitoring location. This increased the number of trajectory origins to forty-five (45).

One final adjustment was made to the origin of trajectories for three Class I areas (Breton Island, LA; Guadalupe Mountains National Park, TX; and Isle Royale National Park, MI). For these areas, the IMPROVE monitor lies just outside the Class I area. Thus, the origins of the trajectories were moved to the centroid of the Class I area to better represent the area. This resulted in 36 trajectories originating from the Class I Area IMPROVE monitor (including both of the Lye Brook Wilderness monitors) and nine (9) originating from the Class I area centroids (6 with no monitor, plus three relocated for monitors outside the Class I areas).

Table 2-1 presents the trajectory origins for each Class I area, noting whether the origin is the centroid or IMPROVE monitor location. Figure 2-1 presents the location of the trajectory origins, while Figure 2-2 presents a closer view of the SESARM states. Both figures also denote which Class I areas have trajectories originating from IMROVE monitors or centroids.

2.2 Identification of Dates for Analysis

To identify the 20% most impaired days for analysis, ERG downloaded the RHR Summary, "Daily Impairment Values Including Patched Values" (December 2018 version) dataset from the IMPROVE website.[3] IMPROVE is a collaborative association of state, tribal, and federal agencies, and international partners. The EPA is the primary funding source, with contracting and research support from the National Park Service. The Air Quality Group at the University of California, Davis is the central analytical laboratory, with ion analysis provided by Research Triangle Institute, and carbon analysis provided by Desert Research Institute. The RHR Summary data provides the means for the best, middle, and worst 20% visibility days. From this dataset, ERG was able to identify the 20% most impaired days for each Class I area in the VISTAS 12km modeling domain over the 2011-2016 period for AoI analysis. The RHR flags the data to indicate which group (i.e., best, worst). For consistency with the revised EPA guidance on tracking visibility[4], days were ranked based on the anthropogenic contribution only. The RHR Summary provides this ranking in the "Impairment_Group" column. Similarly, the anthropogenic portion of nitrate (anthro_eamm_no3) and sulfate (anthro_eamm_so4) were used for trajectory weighting described in Section 2.5.

In instances where all years are not available at an IMPROVE monitoring site, the 20% most impaired days from the year(s) available were analyzed. For example, Shining Rock Wilderness area does not have data for 2011, as a result, the trajectories for the AoI analysis only covered the 2012 to 2016 period.

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[3] "Daily Impairment Values Including Patched Values" under the "Regional Haze Rule Summary data through 1988-2017 (posted December 2018)" section. Internet address: http://vista.cira.colostate.edu/Improve/rhr-archived-data/

[4] US EPA, 2018. Technical Guidance on Tracking Visibility Progress for the Second Implementation Period of the Regional Haze Program. EPA-454/R-18-010. December 2018 available at: https://www.epa.gov/sites/production/files/2018-12/documents/technical_guidance_tracking_visibility_progress.pdf

Table 2-1. IMPROVE Monitors in the VISTAS_12 Domain

Class I Area	State	FIPS Code	IMPROVE Site Code	Trajectory Origin		
				Latitude	Longitude	Description
Acadia National Park	ME	23009	ACAD1	44.3771	-68.2610	IMPROVE Monitor
Bandelier Wilderness Area	NM	35028	BAND1	35.7797	-106.2664	IMPROVE Monitor
Big Bend NP	TX	48043	BIBE1	29.3027	-103.1780	IMPROVE Monitor
Bosque del Apache Wilderness Area	NM	35053	BOAP1	33.8695	-106.8520	IMPROVE Monitor
Boundary Waters Canoe Area Wilderness Area	MN	27075	BOWA1	47.9466	-91.4955	IMPROVE Monitor
Breton Wilderness	LA	22075	BRIS1	29.8895	-88.8524	Class I Centroid [b]
Brigantine Wilderness Area	NJ	34001	BRIG1	39.4650	-74.4492	IMPROVE Monitor
Caney Creek Wilderness Area	AR	05113	CACR1	34.4544	-94.1429	IMPROVE Monitor
Cape Romain Wilderness	SC	45019	ROMA1	32.9410	-79.6572	IMPROVE Monitor
Carlsbad Caverns NP	NM	48109	GUMO1[a]	32.1409	-104.5529	Class I Centroid
Chassahowitzka Wilderness Area	FL	12017	CHAS1	28.7484	-82.5549	IMPROVE Monitor
Cohotta Wilderness Area	GA	13213	COHU1	34.7852	-84.6265	IMPROVE Monitor
Dolly Sods Wilderness	WV	54093	DOSO1	39.1053	-79.4261	IMPROVE Monitor
Everglades NP	FL	12086	EVER1	25.3910	-80.6806	IMPROVE Monitor
Great Gulf Wilderness Area	NH	33007	GRGU1	44.3082	-71.2177	IMPROVE Monitor
Great Smoky Mountains NP	NC/TN	47009	GRSM1	35.6334	-83.9416	IMPROVE Monitor
Guadalupe Mountain NP	TX	48109	GUMO1	31.9236	-104.8846	Class I Centroid [b]
Hercules-Glades Wilderness Area	MO	29213	HEGL1	36.6138	-92.9221	IMPROVE Monitor
Isle Royale NP	MI	26083	ISLE1	48.0109	-88.8284	Class I Centroid [b]
James River Face Wilderness	VA	51163	JARI1	37.6266	-79.5125	IMPROVE Monitor
Joyce Kilmer-Slickrock Wilderness	NC/TN	47009	GRSM1[a]	35.4047	-83.9762	Class I Centroid
Linville Gorge Wilderness Area	NC	37011	LIGO1	35.9723	-81.9331	IMPROVE Monitor
Lye Brook Wilderness	VT	50003	LYBR1	43.1482	-73.1268	IMPROVE Monitor
		50025	LYEB1	42.9561	-72.9098	IMPROVE Monitor
Mammoth Cave NP	KY	21061	MACA1	37.1318	-86.1479	IMPROVE Monitor
Mingo Wilderness Area	MO	29207	MING1	36.9717	-90.1432	IMPROVE Monitor
Moosehorn Wilderness EDM	ME	23029	MOOS1	44.8362	-67.2276	IMPROVE Monitor
Okefenokee Wilderness Area	GA	13049	OKEF1	30.7405	-82.1283	IMPROVE Monitor
Otter Creek Wilderness	WV	54093	DOSO1[a]	38.9969	-79.6460	Class I Centroid
Pecos Wilderness Area	NM	35055	WHPE1 [a]	35.8944	-105.6453	Class I Centroid
Presidential Range-Dry River Wilderness	NH	33007	GRGU1[a]	44.1775	-71.3226	Class I Centroid
Salt Creek Wilderness Area	NM	35005	SACR1	33.4598	-104.4042	IMPROVE Monitor
San Pedro Parks Wilderness Area	NM	35039	SAPE1	36.0139	-106.8447	IMPROVE Monitor
Seney Wilderness Area	MI	26153	SENE1	46.2889	-85.9503	IMPROVE Monitor
Shenandoah NP	VA	51113	SHEN1	38.5229	-78.4348	IMPROVE Monitor
Shining Rock Wilderness Area	NC	37087	SHRO1	35.3937	-82.7744	IMPROVE Monitor
Sipsey Wilderness Area	AL	01079	SIPS1	34.3433	-87.3388	IMPROVE Monitor
St Marks Wilderness Area	FL	12129	SAMA1	30.0926	-84.1614	IMPROVE Monitor
Swanquarter Wilderness Area	NC	37095	SWAN1	35.4510	-76.2075	IMPROVE Monitor
Upper Buffalo Wilderness Area	AR	05101	UPBU1	35.8258	-93.2030	IMPROVE Monitor
Voyageurs National Park	MN	27137	VOYA2	48.4126	-92.8286	IMPROVE Monitor
Wheeler Peak Wilderness	NM	35055	WHPE1	36.5854	-105.452	IMPROVE Monitor
White Mountain Wilderness Area	NM	35027	WHIT1	33.4687	-105.5349	IMPROVE Monitor
Wichita Mountains Wilderness	OK	40031	WIMO1	34.7323	-98.7130	IMPROVE Monitor
Wolf Island Wilderness	GA	13049	OKEF1[a]	31.3451	-81.3058	Class I Centroid

[a] No IMPROVE Monitor is located at this Class I Area. As such, the nearby IMPROVE monitor was used as a surrogate.

[b] This Class I Area does have a dedicated IMPROVE Monitor. However, it is located outside the Class I Area boundary. The trajectory origin was altered to the Class I Area centroid.

Figure 2-1. IMPROVE Monitor Locations and Starting Points for HYSPLIT Trajectories in the VISTAS 12km Domain

Figure 2-2. IMPROVE Monitor Locations and Starting Points for HYSPLIT Trajectories in the VISTAS States

2.2.1 Emissions Data Collection

The 2028 emissions data used in the AoI analysis came from the Task 2A emissions inventory, which was prepared in August 2018, and was used for the Particulate Source Apportionment Technology (PSAT) tagging. Emissions were split into two distinct groups, by source category: Point and county-level (e.g., nonpoint, onroad, nonroad, prescribed fires, and total point emissions).

Oxides of nitrogen (NO_x) and SO_2 point source emissions were aggregated at the facility level. The aggregated emissions also included facility latitude and longitude,[5] which was used to calculate the distance between the point source and Class I area. The file also included additional information including Emission Inventory System (EIS) Facility ID, Facility Name, primary North American Industry Classification System (NAICS) code, Tier 1 description, and source classification codes (SCCs) (i.e., all SCCs present at the facility). After initial review of the data, the SESARM partners provided a list of revised facility emissions based on updated information. This included facilities that are scheduled to cease operations (in whole or part) before 2028, or other emissions adjustments that were not included in the original emissions inventory effort. Table 2-2 lists the facilities whose emissions were revised for the AoI analysis.

For source categories within the nonpoint, onroad, nonroad, and prescribed fire sectors,[6] the emissions were calculated at the county-level by summing the emission inventory databases by the state and county FIPS. Similarly, the point emissions were summed by the state and county FIPS reported for each facility. The point source files included airport and other nonroad emission sources reported to a specific latitude and longitude. These sources were separated into two distinct point source categories: 1) NONROAD_MAR for marine, air, and railroad source, and 2) NONROAD_OTHER for those sources with traditional nonroad SCC descriptions (e.g., construction). This was done to better separate the nonroad sources, in which NONROAD_MAR might require different federal actions for controls, as opposed to NONROAD_OTHER.

5 Emission estimates are often provided at the facility-level (often a facility-centroid), but can also be reported for separate emission release points. In cases where the facility-level coordinates are not reported, the latitude and longitude coordinates by facility emission release points are averaged.

6 Note that agricultural fires are included in the nonpoint inventory. Additionally, wildfires are not included in this analysis to be consistent with the Second Improve Algorithm (SIA) Impairment data, which excludes the impact of wildfires.

Table 2-2. Revised Facility Emissions for the AoI Analysis

FIPS Code	State	EIS Facility ID	Facility Name	Reason for 2028 Emissions Adjustment	NO_x 2028 (tpy)	NO_x 2028 Revised (tpy)	SO_2 2028 (tpy)	SO_2 2028 Revised (tpy)
01053	AL	7440211	Escambia Operating Company LLC	Permit Limit	349.3	349.3[a]	18,974.4	7,963.0
01053	AL	985111	Escambia Operating Company LLC	Facility Shutdown	149.6	0.0	8,589.6	0.0
01127	AL	7917311	Alabama Power - Gorgas	Facility Shutdown	3,976.4	0.0	1,410.9	0.0
01129	AL	1028611	PowerSouth Energy Coop - Lowman	Partial Shutdown	2,910.8	300.0	3,805.2	0.0
05059	AR	658911	Lake Catherine	Facility Shutdown	125.0	0.0	0.4	0.0
05069	AR	893911	White Bluff	Facility Shutdown	16,179.2	0.0	31,997.1	0.0
12047	FL	769711	White Springs Agricultural Chemicals, Inc	Permit Limit	112.4	112.4[a]	3,197.8	2,745.0
12057	FL	716411	Mosaic Fertilizer, LLLC	Permit Limit	159.7	159.7[a]	3,034.1	1,890.0
12105	FL	717711	Mosaic Fertilizer LLC	Permit Limit	310.4	310.4[a]	7,900.7	3,581.0
12105	FL	919811	Mosaic Fertilizer, LLC	Permit Limit	141.0	141.0[a]	4,425.6	3,614.0
13103	GA	3711211	GA Power Co PLT McIntosh	Facility Shutdown	447.1	0.0	127.3	0.0
13115	GA	3713211	GA Power Company - Plant Hammond	Facility Shutdown	864.9	0.0	772.5	0.0
21059	KY	5891711	Owensboro Municipal Utilities - Elmer Smith Station	Facility Shutdown	23.4	0.0	6.7	0.0
21177	KY	5196711	Tennessee Valley Authority - Paradise Fossil Plant	Facility Shutdown	2,927.4	0.0	2,990.2	0.0
24001	MD	7763811	Luke Paper Company	Permit Limit	3,607.0	3,607.0[a]	22,660.0	9,876.0
28059	MS	8232011	Mississippi Phosphates Corporation	Facility Shutdown	325.7	0.0	1,330.6	0.0
28073	MS	7154411	South Mississippi Electric Power Association, R D Morrow Plant	Fuel Switch	4,219.3	652.6	3,827.5	101.4
28121	MS	7288911	Pursue Energy Corporation Thomasville Gas Plant	Facility Shutdown	3.9	0.0	8,933.5	0.0
28141	MS	17942211	Mississippi Silicon[b]	New Source	0.0	836.0	0.0	648.0
31055	NE	6732411	Omaha Public Power District - North Omaha Power Station	Units Shutdown	6,961.2	50.0	14,530.0	5.0
39081	OH	8190811	W. H. Sammis Plant (0641160017)	Facility Shutdown	3,740.0	0.0	3,184.0	0.0
42007	PA	3853711	FIRSTENERGY GEN LLC/Bruce Mansfield PLT	Facility Shutdown	10,707.0	0.0	19,074.0	0.0
47001	TN	6196011	TVA Bull Run Fossil Plant	Facility Shutdown	964.2	0.0	622.5	0.0
47105	TN	4129211	Tate & Lyle, Loudon	Fuel Switch	883.3	252.5	472.8	110.2
48161	TX	Full_3497	Big Brown	Facility Shutdown	4,407.0	0.0	52,307.0	0.0

Table 2-2. Revised Facility Emissions for the AoI Analysis

FIPS Code	State	EIS Facility ID	Facility Name	Reason for 2028 Emissions Adjustment	NO_x 2028 (tpy)	NO_x 2028 Revised (tpy)	SO_2 2028 (tpy)	SO_2 2028 Revised (tpy)
48331	TX	13408411	Sandow 5 Generating Plant	Facility Shutdown	0.8	0.0	0.0	0.0
48331	TX	4204811	Sandow Steam Electric Station	Facility Shutdown	1,055.0	0.0	20,013.0	0.0
48331	TX	Full_52071	Sandow 5	Facility Shutdown	1,042.0	0.0	1,255.0	0.0
48449	TX	Full_6147	Monticello	Facility Shutdown	7,199.0	0.0	44,287.0	0.0
48487	TX	7927311	Oklaunion Power Station	Facility Shutdown	5,513.0	0.0	1,679.0	0.0
Revised Totals					**79,305.0**	**6,771.0**	**281,408.4**	**30,533.6**

[a] No emission changes.

[b] New facility added for this analysis, and not included in the final Task 2A point source emissions inventory.

2.3 Trajectories

For this study, the HYSPLIT model[7] developed by the National Oceanic and Atmospheric Administration's (NOAA) Air Resources Laboratory (ARL) was used to identify areas most likely influencing visibility.

2.3.1 Meteorological Data

The analysis started by collecting the meteorological and air quality data needed to complete the task. For the meteorology data, ERG downloaded the North American Mesoscale forecast data at the 12-km level (NAM-12) hybrid sigma-pressure data from NOAA ARL File Transfer Protocol (FTP) Server (ftp://arlftp.arlhq.noaa.gov/nams). The extent of the domain is presented in Figure 2-3.

The meteorological files include 40 pressure levels in the vertical, and output for every hour of the day. The files available from NOAA ARL are in a HYSPLIT ready format for individual dates starting in March 2010. ERG downloaded December 29, 2010 through December 31, 2016 for use in the back trajectories. Due to the total size of all the meteorology files (2.23 TB), these data were provided to the SESARM states via hard drive transfer.

[7] Stein, A. F., Draxler, R. R., Rolph, G. D., Stunder, B. J. B., Cohen, M. D., and Ngan, F., (2015). NOAA's HYSPLIT atmospheric transport and dispersion modeling system, Bull. Amer. Meteor. Soc., 96, 2059-2077, http://dx.doi.org/10.1175/BAMS-D-14-00110.1

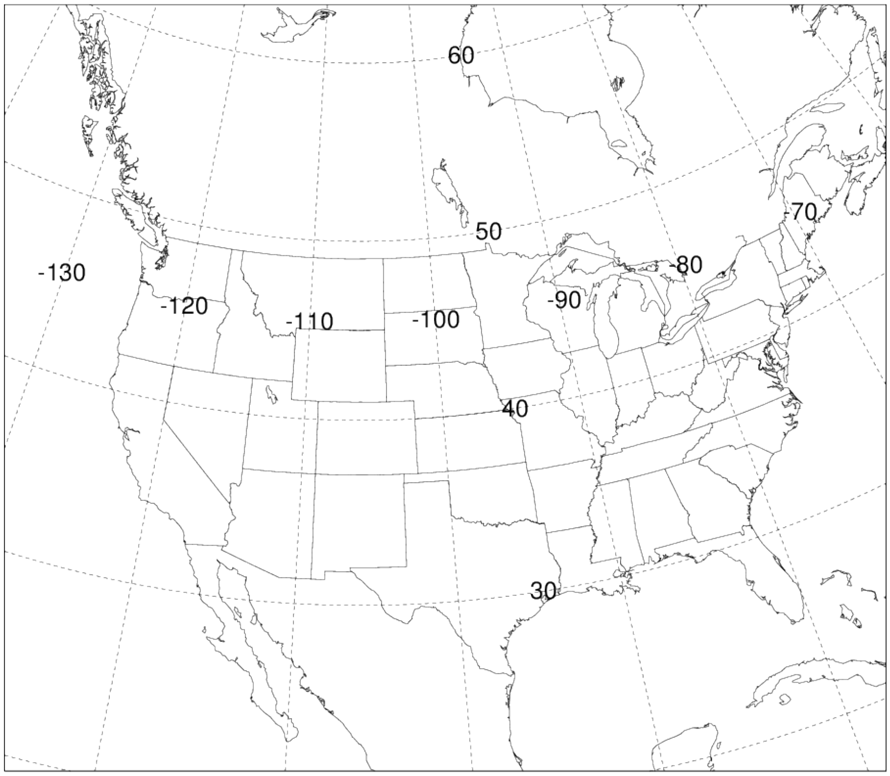


Figure 2-3. NAM 12km (Sigma-Pressure Hybrid) Modeling Domain

2.3.2 Trajectory Set up

The HYSPLIT runs included starting heights of 100 meters (m), 500 m, 1,000 m, and 1,500 m. Trajectories were run 72 hours backwards in time for each height at each location.

Trajectories were run with start times of 12AM (midnight of the start of the day), 6AM, 12PM, 6PM, and 12AM (midnight at the end of the day) local time. ERG converted these times from local time of the Class I area to Universal Time Coordinated (UTC), adjusting the data as necessary, and accounting for the shift from daylight saving time to standard time.

As mentioned in Section 2.0, the initial plan was to run the trajectories from within the *R* programming software. While several packages exist to run HYSPLIT from *R* (e.g., SplitR, opentraj), all were designed to work with reanalysis data[8] and not daily meteorological data files, and the daily NAM 12km hybrid was not an option for the meteorological files in any of the

[8] The reanalysis data is the NOAA data reformatted for HYSPLIT.

packages available. In lieu of running HYSPLIT with *R*, ERG developed a python script that created all the necessary control files to run HYSPLIT. HYSPLIT was then run outside its Graphical User Interface (GUI) via a batch script. The python code and batch script used to run HYSPLIT are available in Appendices A and B, respectively, and include instruction on how to run them. This scripted method was necessary for running the 148,468 (37,117 start times modeled, at 4 different heights) trajectories for each site for the AoI analysis.

R was used to combine the HYSPLIT output files (tdump files) into a single file. Plots of the trajectories by height by year (Figure 2-4) and height by season (Figure 2-5) were generated using *R* (via the openair[9] package). The *R* code used to generate the plots can be found in Appendix C. Additional plots can also be generated by modifying the "type" variable.

[9] Carslaw, D.C. and Ropkins, K. (2012). "openair — An *R* package for air quality data analysis." Environmental Modelling & Software, 27–28(0), pp. 52–61. ISSN 1364-8152, doi: 10.1016/j.envsoft.2011.09.008.

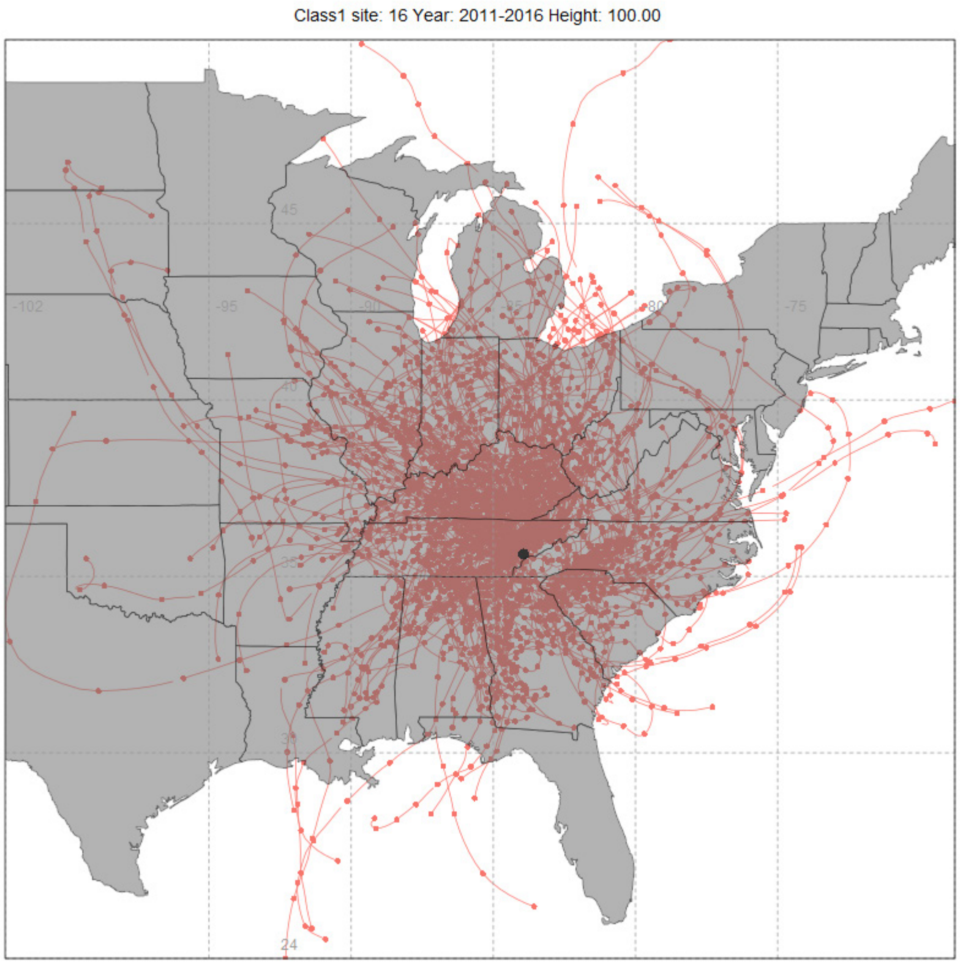


Figure 2-4. Example Trajectory Plot, 100m Trajectories by Year, for Great Smoky Mountain National Park. (Created with *R*)

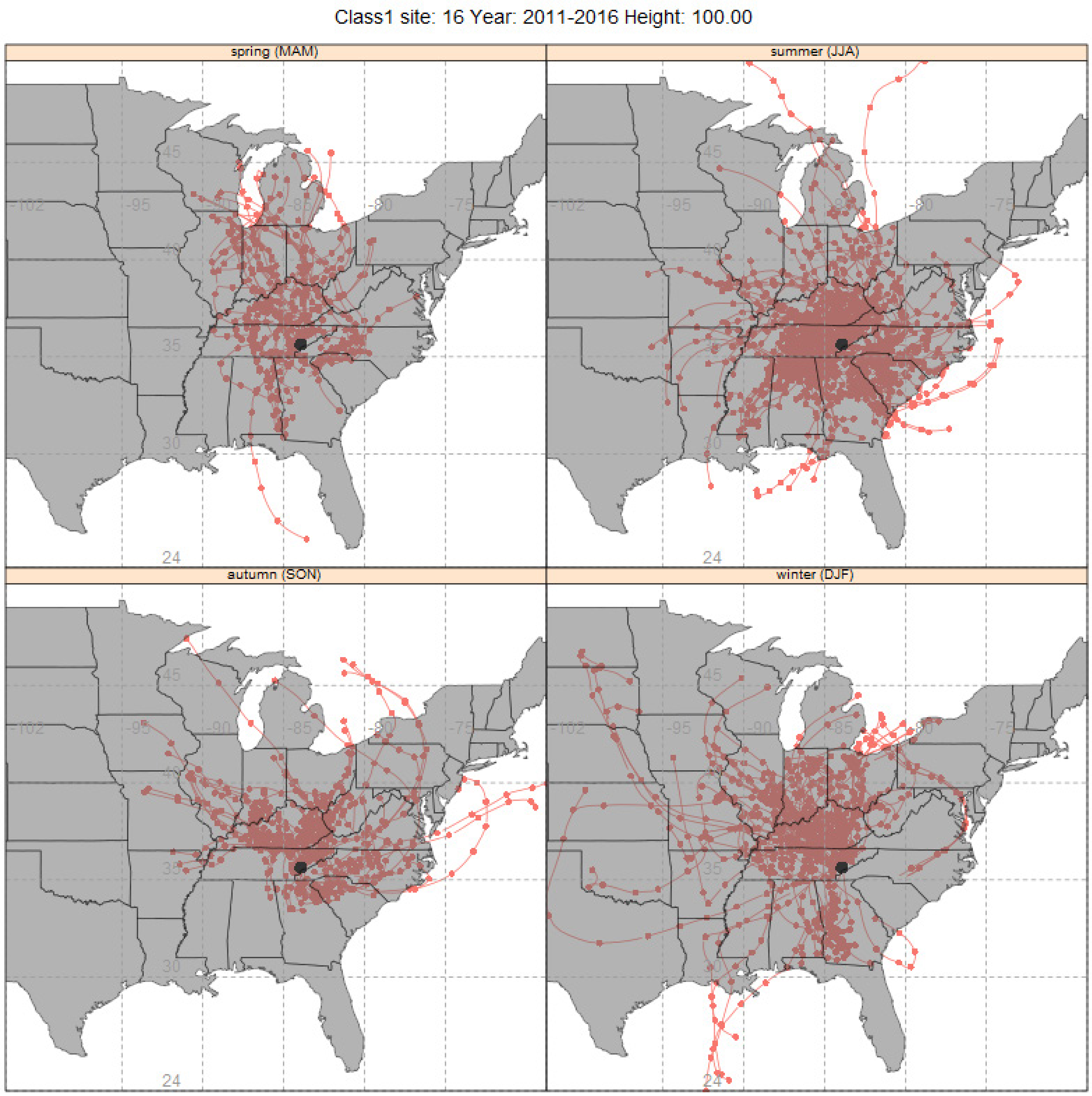


Figure 2-5. Example Trajectory Plot, 100m Trajectories by Season, for Great Smoky Mountain National Park. (Created with *R*)

The files of the trajectory endpoints for each starting height were also converted to ArcGIS and plotted using ArcGIS (Figure 2-6), and all shapefile and base layers were delivered to SESARM.

These back trajectories for the 20% most impaired days were then used to develop residence time (RT) plots.

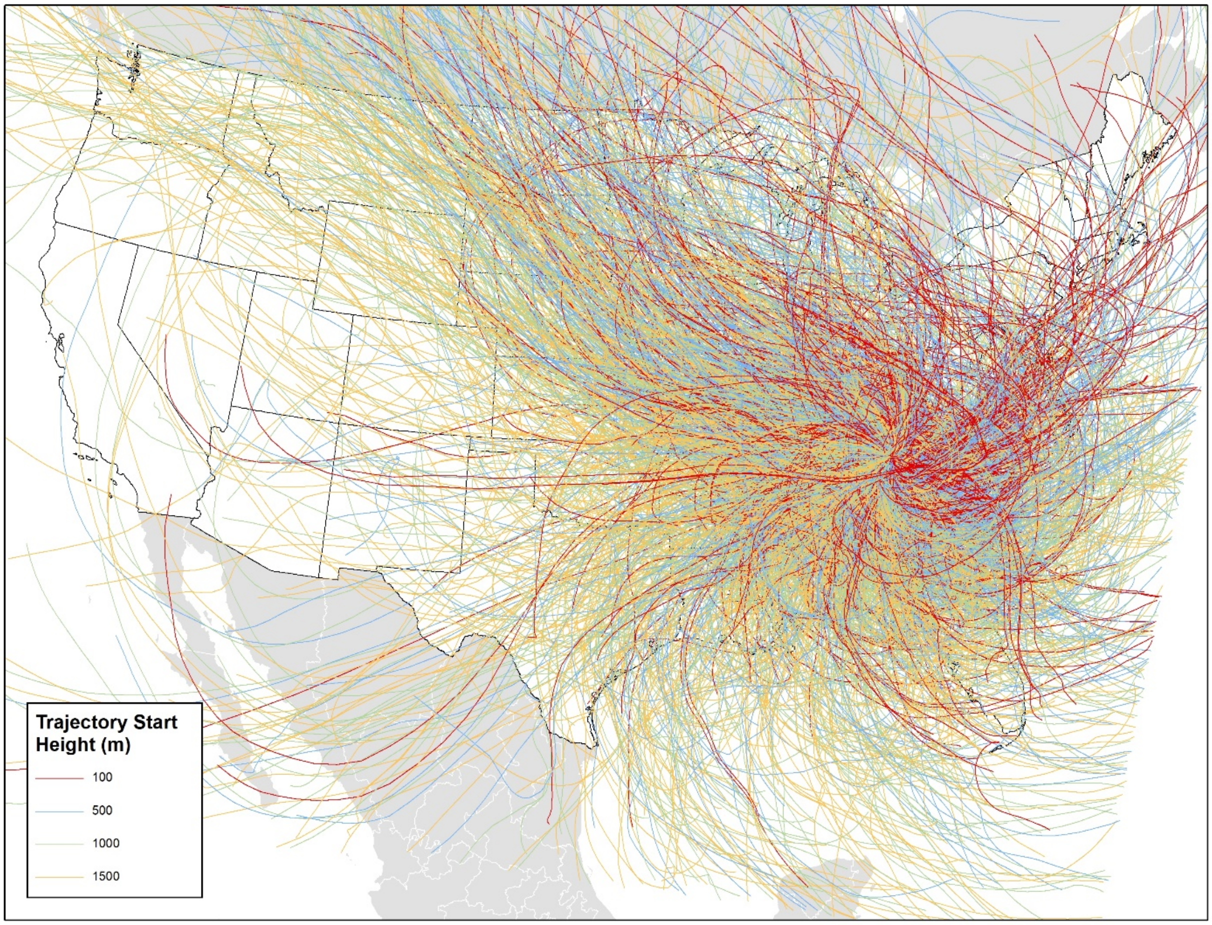


Figure 2-6. Example Trajectory Plot for Great Smoky Mountain National Park. Plot was Created with GIS, for the 20% Most Impaired Days.

2.4 Residence Time

The RT plots define the geographic areas with the highest probability of influencing the monitor on the 20% most impaired visibility days. The RTs for point sources were calculated as the number of trajectory hours that pass through each of the 12km modeling domain grid cell (i.e., the number of hourly trajectory end points in each cell) using *R* (Appendix C) and custom geographic information system (GIS) scripts (Appendix D). The analysis was expanded to the EPA's 12US2 domain, which cover the entire continental United States, from the VISTAS 12km domain. This ensured the analysis for western Class I areas took into account their entire source region, and did not artificially weight results on sources within the VISTAS 12km domain only.

The *R* script was used to look at the various breaks of the data to review for any outlying years, or if emission controls installed midway through the review period affected, extinction-weighted residence time (EWRT). Figure 2-7 shows an example RT plot produced by the *R* code.

ArcGIS was used to develop final RT and EWRT values that were exported to shapefiles and joined with the emissions data for the AoI analysis spreadsheets (Section 2.6). Figure 2-8 shows a similar residence time plot as the R files, as plotted in GIS version, with a wide view of the modeling domain at the top, and a close up of the Class I area at the bottom. RT was also calculated for the modeling grid using a custom GIS script, described in Appendix E, for comparison and quality assurance (QA) purposes.

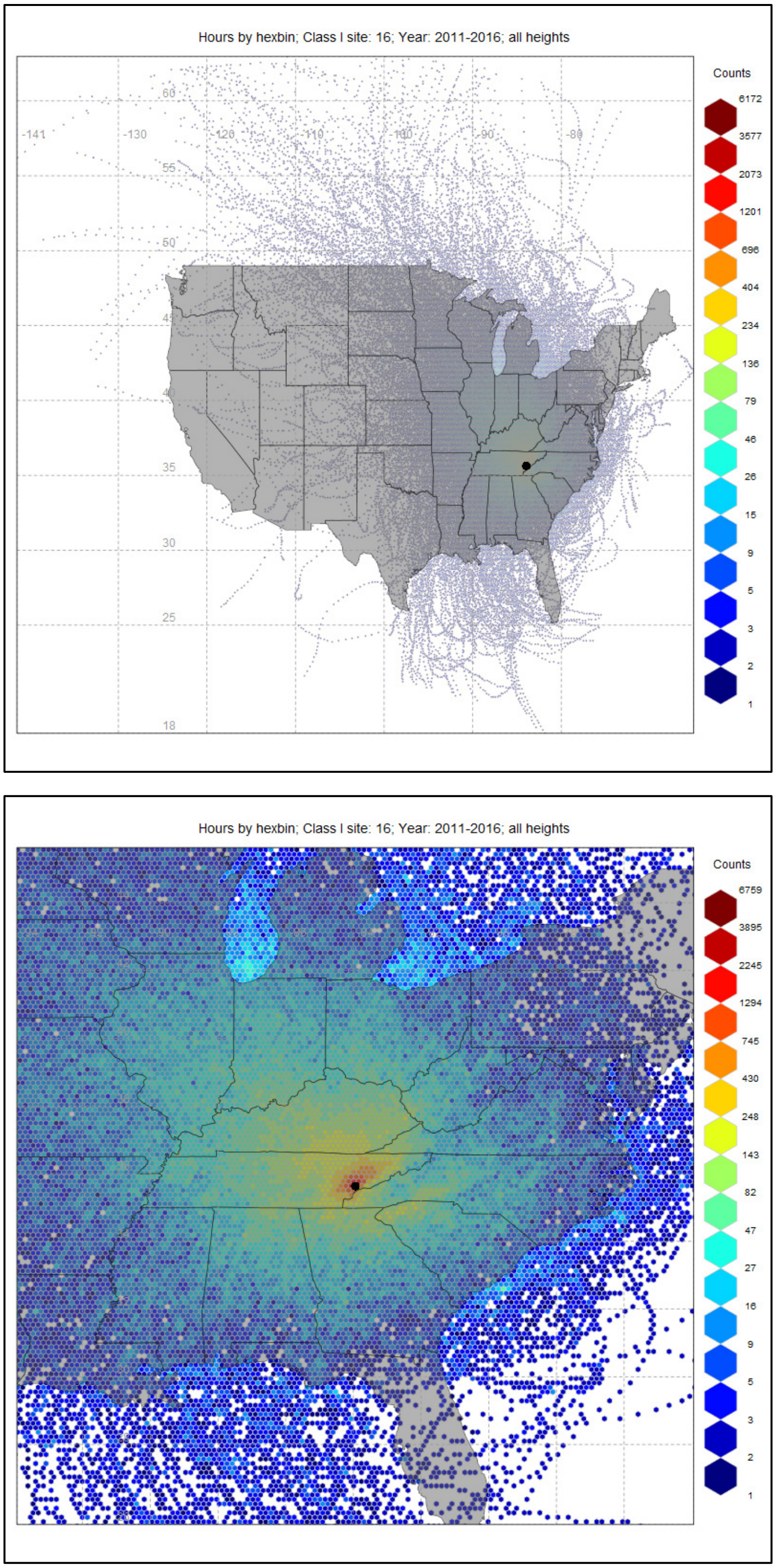
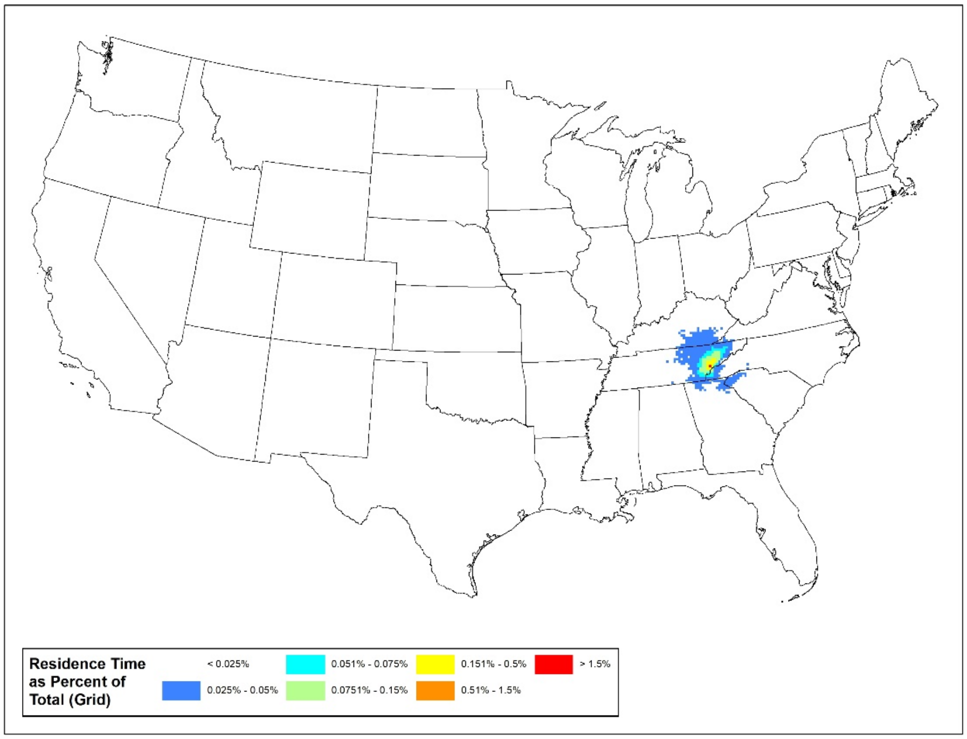


Figure 2-7. Example Residence Time, Per 12km Modeling Grid Cell, Plot for Great Smoky Mountain National Park. (Full view (top), Class I zoom (bottom); Plot was Created with R)



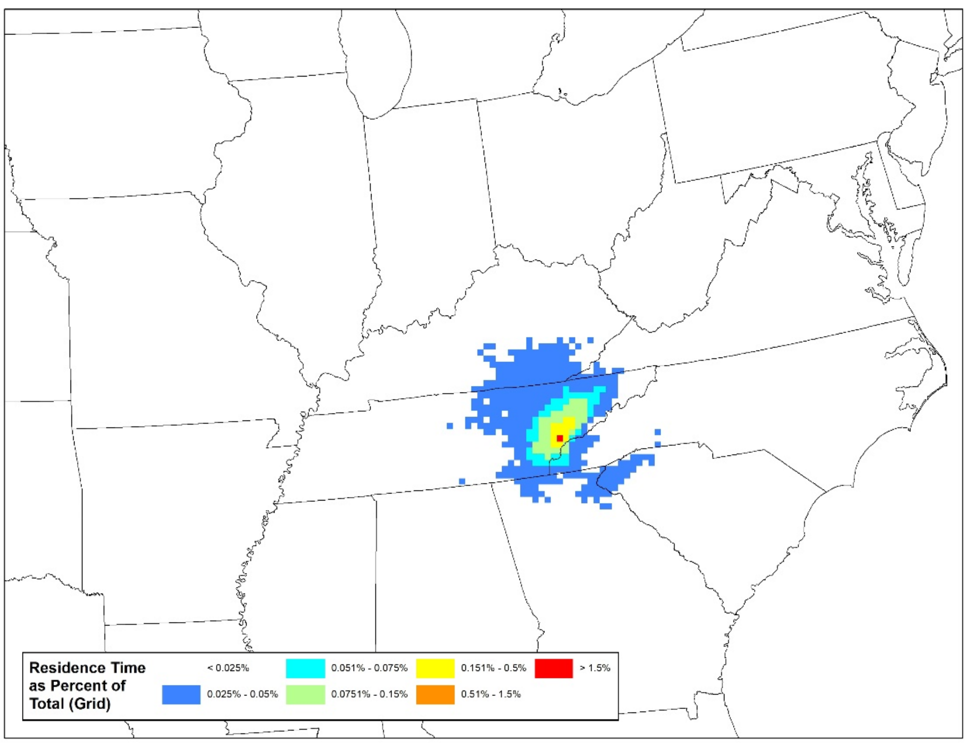


Figure 2-8. Example Residence Time, Per 12km Modeling Grid Cell, Plot for Great Smoky Mountain National Park, zoomed in on Class I area. (Full view (top), Class I zoom (bottom); Plot was Created with GIS)

The RTs for county-level source sectors were calculated as the number of trajectory hours that passed through the county, as opposed to grid cells. This was completed in GIS using a custom script, provided in Appendix E.

2.5 Extinction-Weighted Residence Time

The trajectory residence time was also weighted by ammonium sulfate and ammonium nitrate and used to produce separate sulfate and nitrate EWRT plots. This allows separate analysis for sulfate and nitrate that is weighted toward the days influenced most by those constituents and not days most influenced by other constituents, like organic carbon.

In this project, the Concentration Weighted Trajectory (CWT)[10] approach was used to develop the EWRT, substituting the extinction values for the concentration. The extinction attributable to each pollutant is paired with the trajectory for that day. The mean weighted extinction of the pollutant species for each grid cell is calculated according to:

$$\bar{E}_{ij} = EWRT = \frac{1}{\sum_{k=1}^{N} \tau_{ijk}} \sum_{k=1}^{N} (bext_k)\, \tau_{ijk}$$

Where:

i and *j* are the indices of grid

k the index of trajectory

N the total number of trajectories used in analysis

b_{extk} is the 24-hour extinction attributed to the pollutant measured upon arrival of trajectory k, and

τ_{ijk} the number of trajectory hours that pass through each grid cell (i, j) (where "i" is the row and "j" is the column).[11]

---

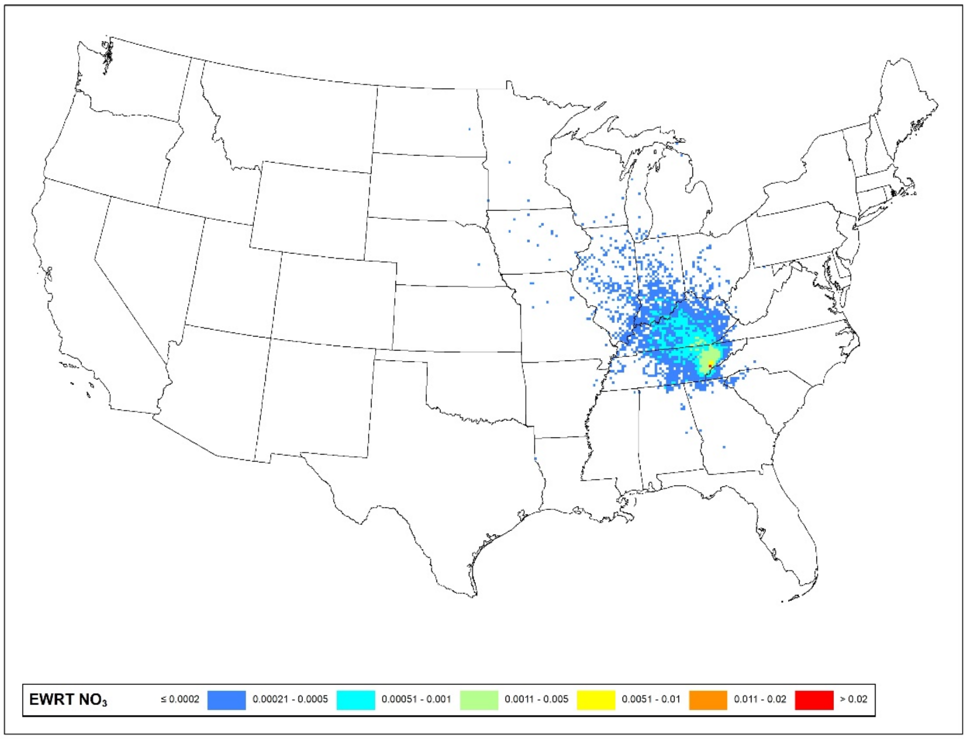
[10] Hsu, Y.-K., T. M. Holsen and P. K. Hopke (2003). "Comparison of hybrid receptor models to locate PCB sources in Chicago". In: Atmospheric Environment 37.4, pp. 545–562. DOI: 10.1016/S1352-2310(02)00886-5

[11] Carslaw, D.C. (2015). The openair manual — open-source tools for analyzing air pollution data. Manual for Version 1.1-4, King's College London. http://www.openair-project.org/PDF/OpenAir_Manual.pdf

The higher the value of the EWRT ($\bar{E_{ij}}$), the more likely that the air parcels passing over cell (i, j) would cause higher extinction at the receptor site for that light extinction species. Since this method uses the extinction value for weighting, trajectories passing over large sources are more discernible from those passing over moderate sources.

Figure 2-9 presents the EWRT for ammonium nitrate extinction for the Great Smoky Mountain National Park for the 20% most impaired days from 2011 to 2016. The figure provides a view of the full modeling domain (top) and an image focused on the Class I Area (bottom). Figure 2-10 show the EWRT for ammonium nitrate extinction as a percentage of the total ammonium nitrate, with a full domain view and Class I area view. Figure 2-11 shows the weighted ammonium sulfate EWRT, and Figure 2-12 shows the weighted ammonium sulfate EWRT as a percent of the total ammonium sulfate.

EWRT were performed using *R* (Appendix C) and custom GIS scripts (Appendix D). The *R* calculation process is memory intensive and was only run at a slightly coarser grid resolution for initial analysis to determine if any time period displayed a significantly different EWRT pattern. The GIS produced EWRT values were used to develop the spreadsheet of source contribution.



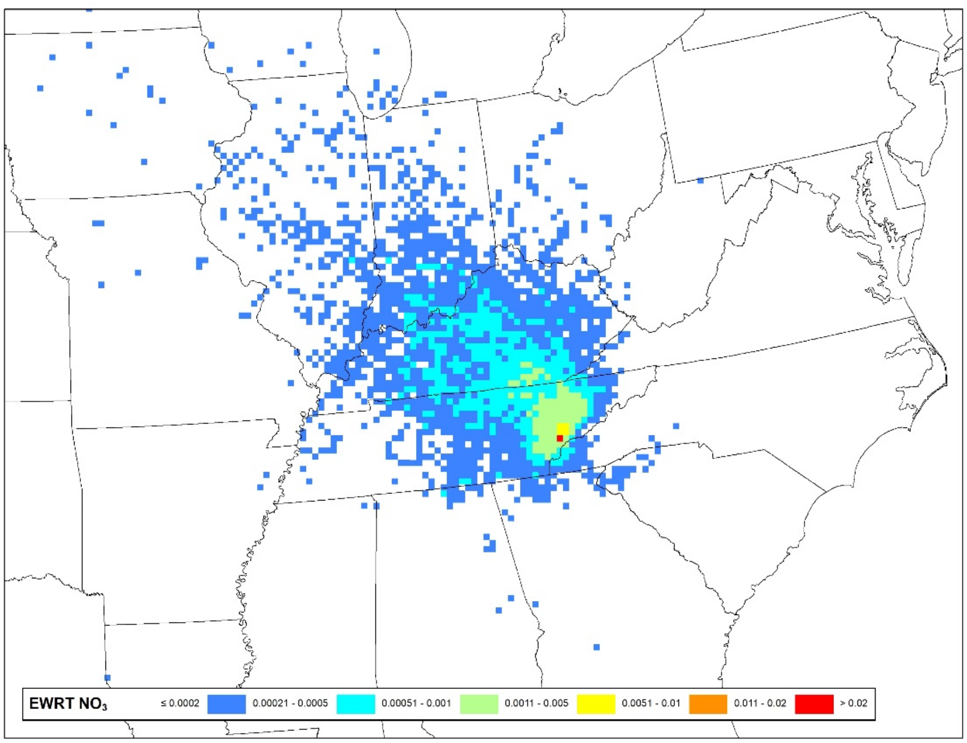
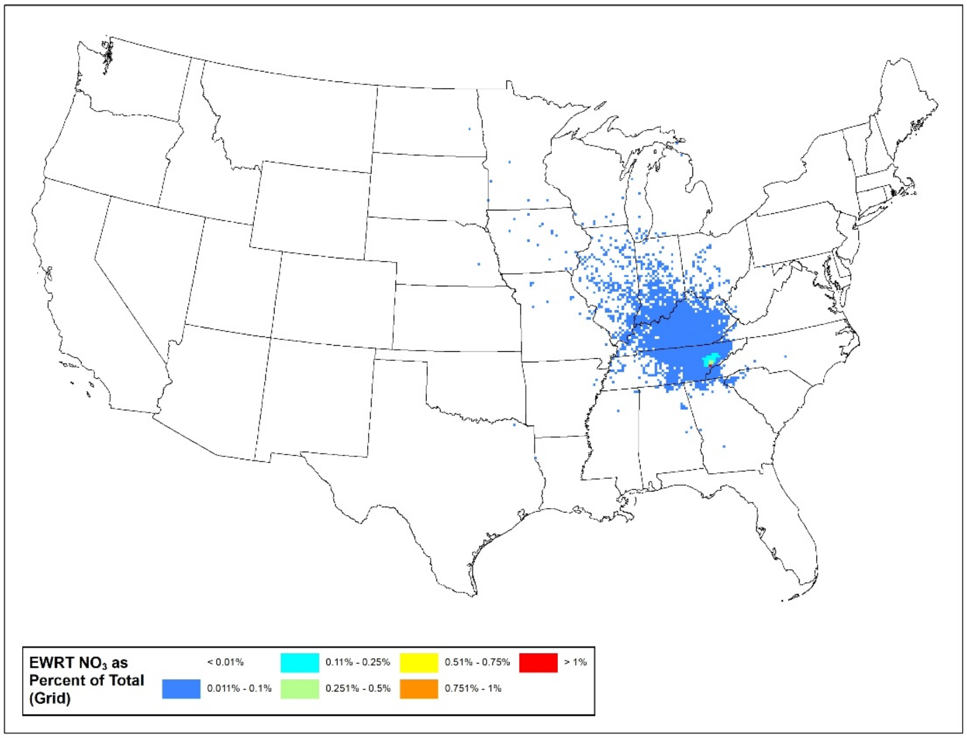


Figure 2-9. Example EWRT for Ammonium Nitrate Extinction, Per 12km Modeling Grid Cell, Plot for Great Smoky Mountain National Park. Based on All Years. (Full view (top), Class I zoom (bottom); Plot was Created with GIS)



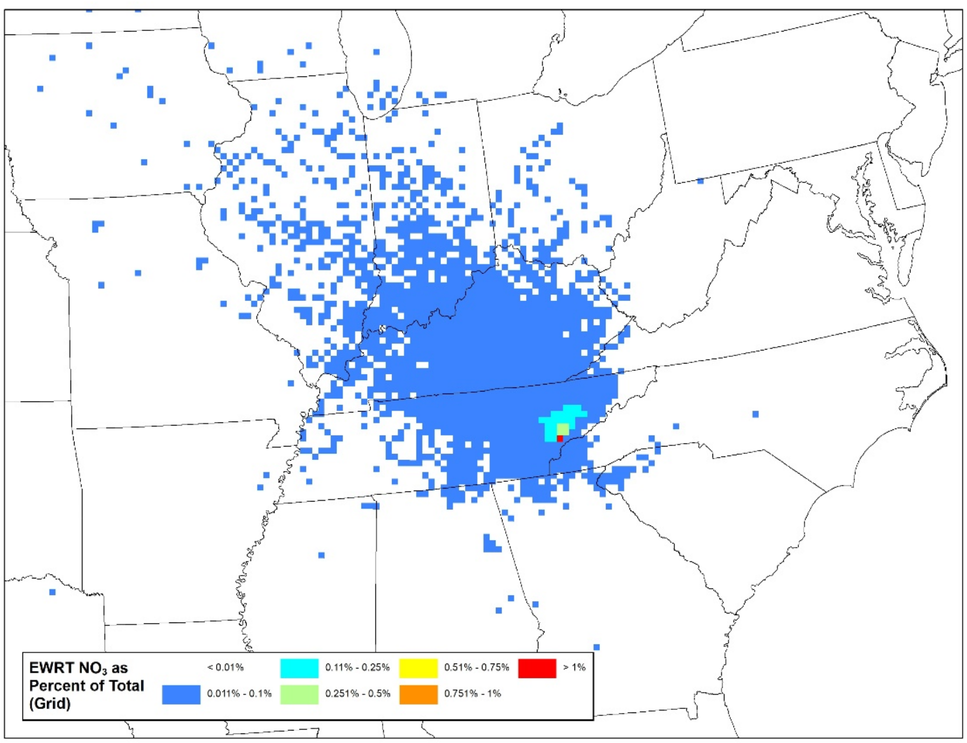
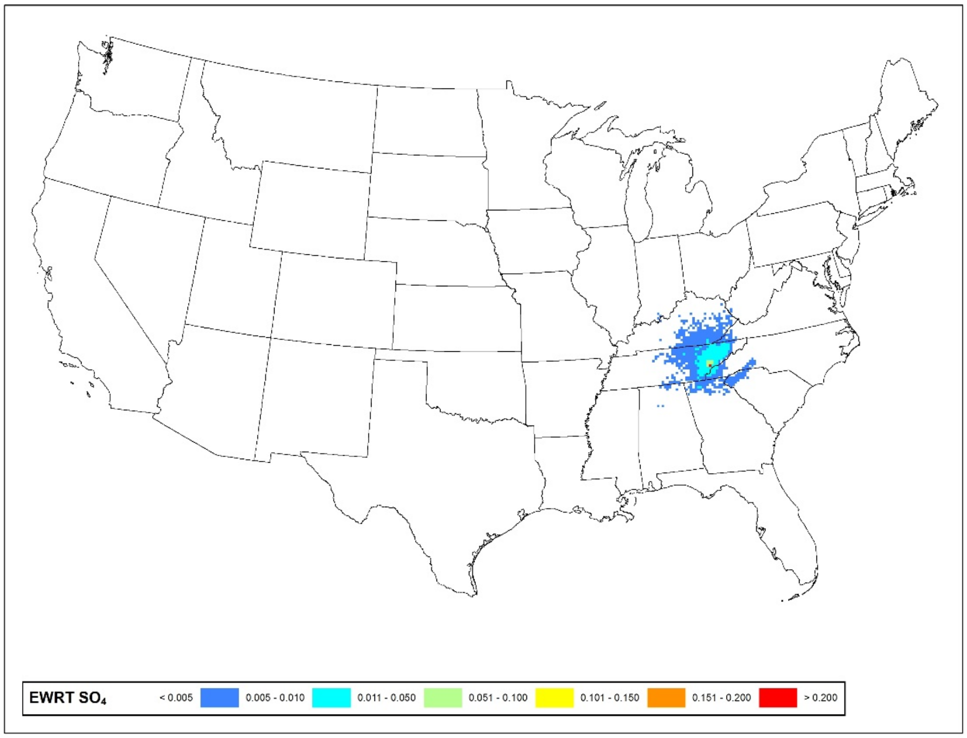


Figure 2-10. Example EWRT, as a percentage of the total, for Ammonium Nitrate Extinction, Per 12km Modeling Grid Cell, Plot for Great Smoky Mountain National Park. Based on All Years. (Full view (top), Class I zoom (bottom); Plot was Created with GIS)



.

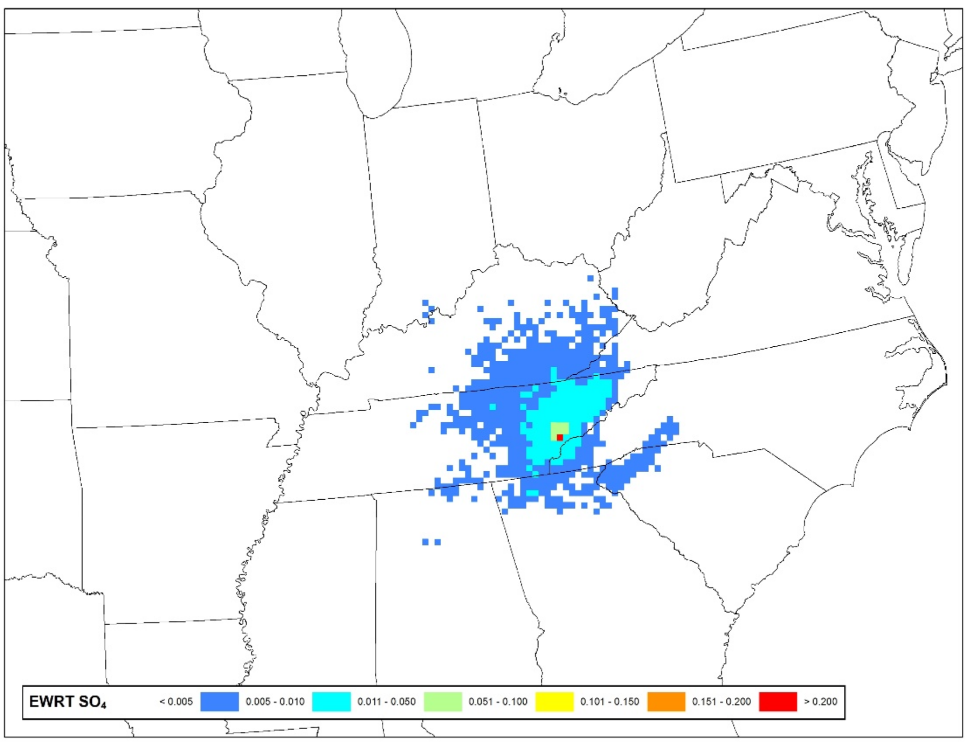
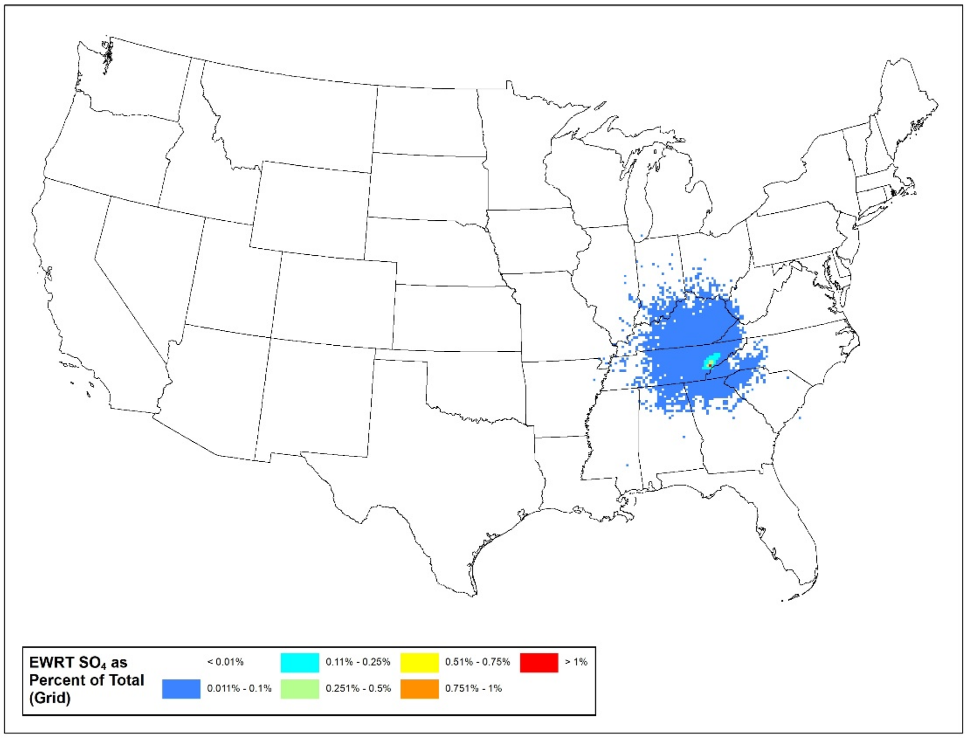


Figure 2-11. Example EWRT for Ammonium Sulfate Extinction, Per 12km Modeling Grid Cell, Plot for Great Smoky Mountain National Park. Based on All Years. (Full view (top), Class I zoom (bottom); Plot was Created with GIS)



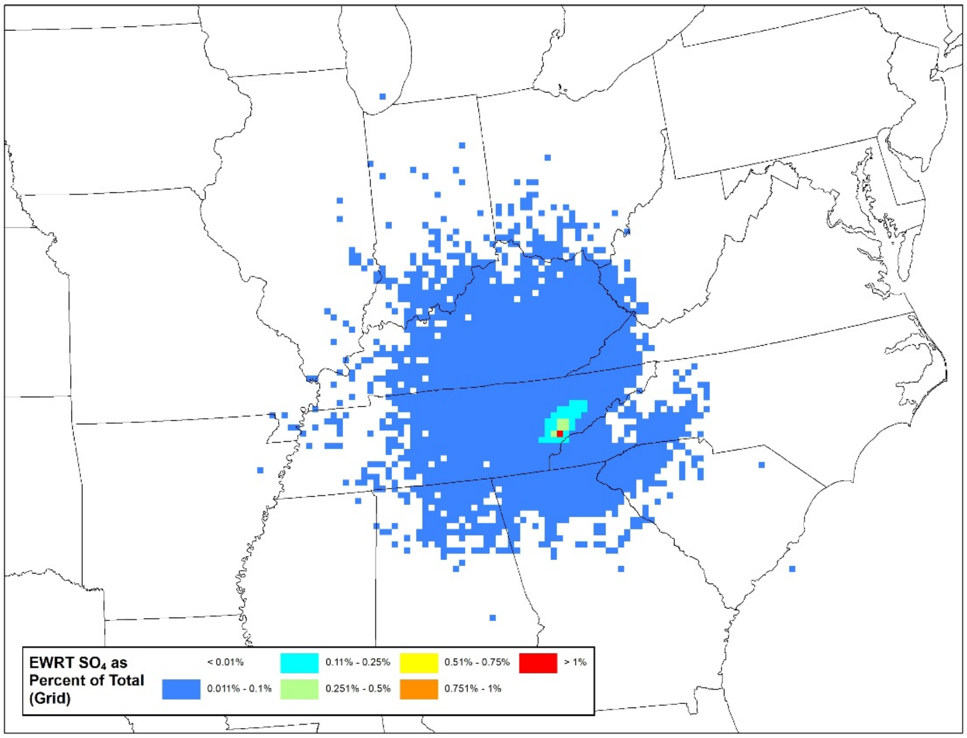


Figure 2-12. Example EWRT, as a percentage of the total, for Ammonium Sulfate Extinction, Per 12km Modeling Grid Cell, Plot for Great Smoky Mountain National Park. Based on All Years. (Full view (top), Class I zoom (bottom); Plot was Created with GIS)

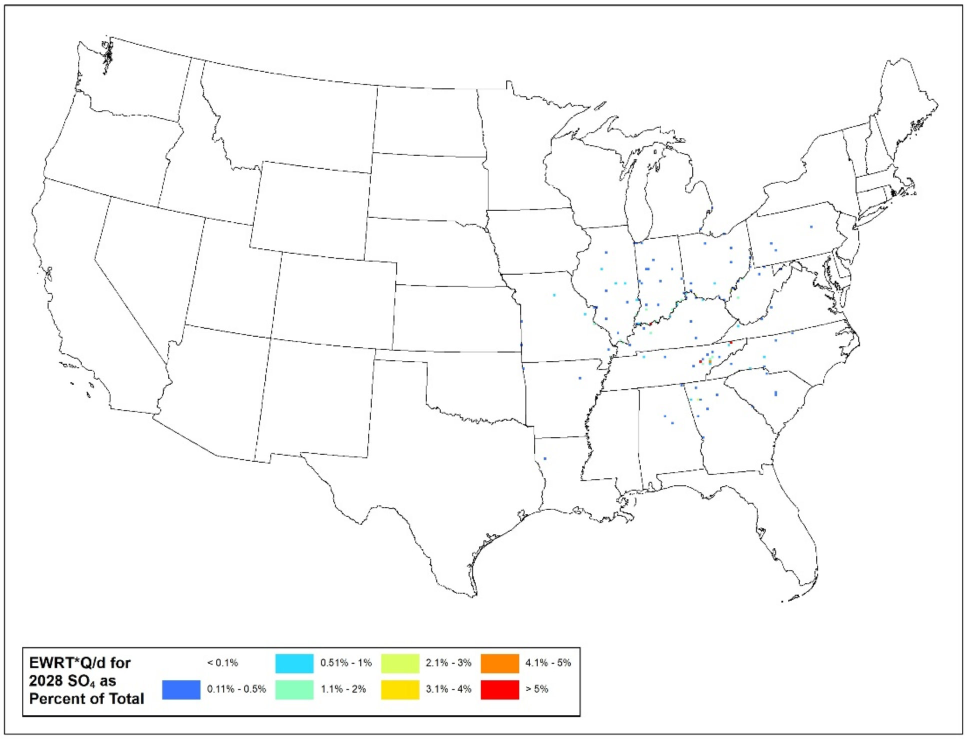
2.6 Contributor Identification

The final phase of the analysis combined the EWRT values with the emission data to determine the sources most likely contributing to elevated extinction levels. ArcGIS was used to spatially join the emissions data with the gridded EWRT data to obtain the EWRT value corresponding to each point source. This new layer was extracted from ArcGIS and brought into an Access database to be paired with other data elements.

In the database, the data were further joined with the distance (d) from the point source (average of all emission release points) to the trajectory origin in kilometers, which was calculated using R. The facility emissions (Q, in tons per year) were then divided by the distance (d, in kilometers) to the trajectory origin; for a final value (Q/d). This was then multiplied by the facility's sulfate or nitrate EWRT grid values (i.e., EWRT *(Q/d)). Next, the sulfate and nitrate EWRT *(Q/d) values were summed for all point sources at each Class I area and used to normalize the sulfate and nitrate contributions from each individual source. This information allows the individual facilities to be ranked from highest to lowest based on sulfate and/or nitrate contributions.

This data was further paired with additional point source metadata that defined the facility (i.e., Facility ID, Facility Name, State, County, Federal Information Processing Standard (FIPS), NAICS, and industry description). Spreadsheets for individual Class I areas were then exported from the database for further analysis by the states. Plots of the EWRT *(Q/d), as a percentage of the total, were generated based on the grid total emissions and distance to the class I area. Figure 2-13 shows an example of these plots for the Great Smoky Mountain National Park. The figure includes a wide view of the entire continental United States, and a closer view in the vicinity of the Class I area.

Users of the data should note that while point sources account for most of the sulfate extinction, these sources only account for a portion of the nitrate extinction. Much of the nitrate extinction can be attributable to the onroad and nonpoint sectors. As such, a similar analysis for county level data was conducted, that included county total point source contributions. This allows the point source contribution to be directly compared to the other source categories.



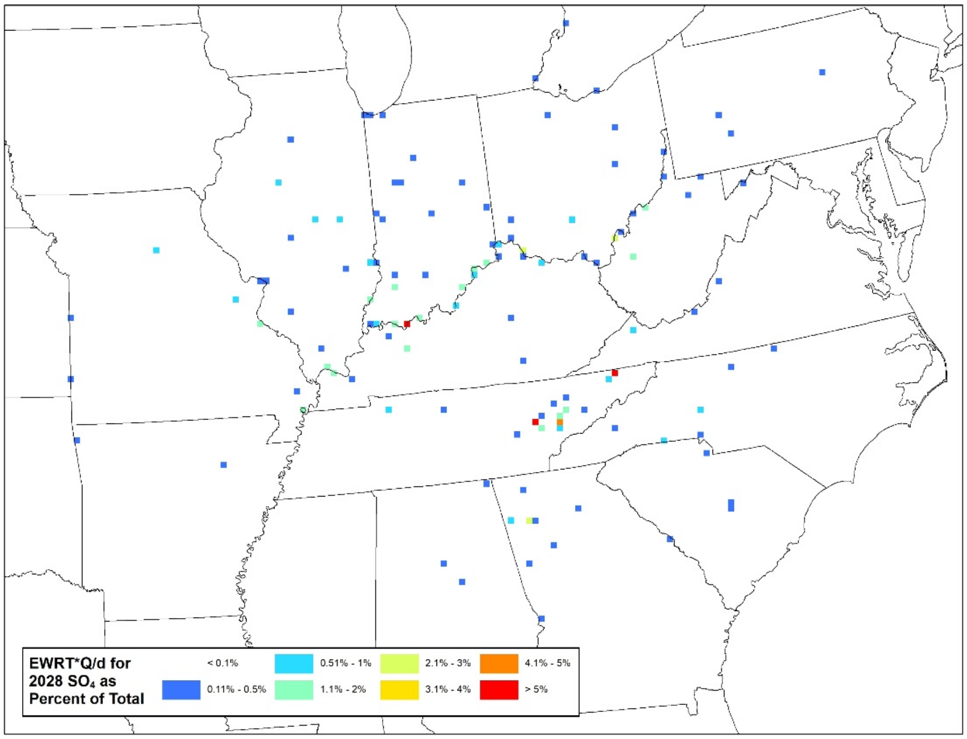


Figure 2-13. Example EWRT*(Q/d) for Ammonium Sulfate Extinction for 2028, Per 12km Modeling Grid Cell, Plot for Great Smoky Mountain National Park. Based on All Years. (Full view (top), Class I zoom (bottom); Plot was Created with GIS)

Similar analysis was conducted to rank SO_2 and NO_x emissions contributions for the county-level sources (nonpoint, onroad, nonroad, fires, and total point source sectors). The process was similar to the process for point sources previously described, except calculations of RT and EWRT were completed at the county-level as opposed to grids.

The analysis also added new columns to normalize the EWRT*(Q/d) by the area of each county to develop a metric to compare the contributions from counties on a relative basis. The existing calculation had a propensity to attribute higher contributions to larger counties simply because they typically contained more emission sources and more hourly trajectory end points. Normalizing the contribution by the area of the county (i.e., EWRT*(Q/d) per square kilometer) provides a sense of the source emission density within the county. This allows county contributions to be directly compared, without large counties being weighted more heavily by simply having more emission sources and more hourly trajectory end points.

This analysis was completed in GIS using the same calculation method as the point sources. The calculation of "d" was from the centroid of the county to the trajectory origin, in km. Similar to point sources, the final spatial join was made between the county-level EWRT, emissions, and source information for each sector. All county and emissions source identifying information was joined in an Access database with calculations of Q/d and Q/d^2 values, EWRT, EWRT*(Q/d), fraction and sum contributions, and any other source information. The database was then used to generate individual spreadsheets for each Class I area.

Appendix A

Using Python to Generate HYSPLIT Control Files

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INTRODUCTION

Producing Control files through the HYSPLIT GUI involves manual input of modeling parameters for each trajectory run. Python scripts provide an efficient way to create large numbers of HYSPLIT bat files in a fraction of the time. These files can be used to generate trajectory outputs in succession, rather than one at a time.

STEP BY STEP INSTRUCTIONS

This section goes through the Python script for generating Control files for each run.

1. Set paths for inputs and outputs
   a. Lines 20-31
   b. These lines should be adjusted to reflect the location of input/output files on your computer or networks.
2. Define model variables for HYSPLIT runs
   a. Lines 34-43
   b. These lines indicate heights to be modeled and other parameters.
   c. Lines 41-43 are standard lines in the Control file and should not be adjusted.
3. getNewDate function
   a. Returns the date values for the additional days of meteorology files. This corresponds to the hours indicated on line 37 and the number of met files set on line 40. Adjustments to this function would need to be made if these lines changed.
4. getCoords function
   a. Returns the latitude and longitude coordinates of a site by looking up the classID in a file defined on line 31 as "siteLookup"
5. Writing the bat file
   a. The script loops through the dayOf and nextDay files and assigns the input values needed and calls the two functions described in steps 3 and 4 above.
   b. A bat file is created and opened, and the input values are written to the file.
   c. The file is then closed.
   d. Note: If a file already exists in the directory, it will be overwritten.

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Appendix B

Running HYSPLIT with Batch Files

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1. Running HYSPLIT Outside of the GUI

After the batch files to run HYSPLIT have been created, a batch file can be used to run HYSPLIT outside of its graphical user interface (GUI). First, the generated batch file must be placed in the HYSPLIT working directory on the computer.

Next, the user needs to generate a list of the batch file to run. The file can be developed in a text editor and needs to contain the following line on separate lines for each file that needs to be run: call <batch file name>. Where <batch file name> is the name of the batch file, without the brackets. This file can then be saved as with the .bat extension and subsequently run by double clicking on the file.

2. Included Code

GetBatchFileNames.bat and **RunAll_HYSPLIT.bat**. **GetBatchFileNames.bat** is a simple script that obtains a specific set of batch files from the current directory and places them in a list. **RunAll_HYSPLIT.bat** is a batch file that then runs all the files in the list created by **GetBatchFileNames.bat**.

GetBatchFileNames.bat: This code, shown in Figure B-1, utilizes a windows command (dir /b) to list the files in a directory and pipe the results into a file named *All_years.txt*. The flag "/b" with the dir command lists bare format for the command, which omits headers and summary information. The script also utilizes the wildcard "*" to limit the additions to the file to ensure only the files desired are added to the list. For this project, all batch files names start with the year. In line 1 of the code, all the files that start with "11" are added to the file. These lines can be edited to accommodate any regular pattern of filename used. The first line contains a single ">" to write to the file, and a double ">>" needs to be used to append to the same file without overwriting what was previously there.

GetBatchFileNames.bat

```
1 dir /b 11* > All_years.txt
2 dir /b 12* >> All_years.txt
3 dir /b 13* >> All_years.txt
4 dir /b 14* >> All_years.txt
5 dir /b 15* >> All_years.txt
6 dir /b 16* >> All_years.txt
```

Figure B-1. Contents of the GetBatchFileName.bat file

RunAll_HYSPLIT.bat: This code, shown in Figure B-2, performs actions based on the file names in *All_years.txt.* The code runs HYSPLIT run batch file (line 5), and then moves the plot (line 7), tdump (lines 9-10), and CONTROL file (lines 12-13) created during the run from the HYSPLIT working directory to a project directory. Users will need to adjust the directories to match their HYSPLIT working directory and working directory.

To run the code, the user will need to first open *All_years.txt* and remove the .bat from the file names in the list. This can be accomplished by hitting the Control and H keys at the same time to open the "Find and Replace" window. The phrase .bat can be entered in the find box, and the replace box left blank for the task. Next users will need to edit **RunAll_HYSPLIT.bat** to reflect their directory structure. Once that is complete, the user can close the editor, and double click the file to run.

```
RunAll_HYSPLIT.bat
1  setlocal
2  echo starting HYSPLIT runs
3  for /F "tokens=*" %%a in (All_years.txt) do (
4     echo %%a
5     call %%a.bat
6
7     move C:\hysplit4\working\*.ps C:\hysplit4\working\SESARM_OUT\
8
9     ren %%a %%a.tdump
10    move C:\hysplit4\working\*.tdump C:\hysplit4\working\SESARM_OUT\
11
12    copy CONTROL %%a.CONTROL
13    move C:\hysplit4\working\*.CONTROL C:\hysplit4\working\SESARM_OUT\
14 )
```

Figure B-2. Contents of the script RunAll_HYSPLIT.bat

Specifically, each line does the following:

Line 2: echoes "starting HYSPLIT runs" to the command window

Line 3: starting line of the for loop

Line 4: echoes the file name that is being run

Line 5: runs HYSPLIT via the previously created batch files

Line 7: moves the plot file to the project directory

Line 9: renames the tdump file to the run *<file name>.tdump*

Line 10: moves the renamed file to the working directory

Line 12: copies the created control file to *<file name>.CONTROL*

Line 13: moves the created control file to the working directory

Appendix C

AoI Analysis with *R*

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INTRODUCTION

R is an open source statistical computing and graphing software.[12] The *R* software's base functionality is enhanced by the use of custom functions or collection of functions known as packages. The HYSPLIT_plots_09092018.R script utilizes several packages to process and visualize the trajectory data. Appendix E contains the MeteoInfo procedure for analyzing the meteorological information with the spatial allocation information.

STEP BY STEP INSTRUCTIONS

The following section goes through the process of importing HYSPLIT output into *R* through plotting the trajectory images for several subsets of the data. The plotting is mainly achieved via the function included in the openair package[13], which includes several options for plot types.

The openair package is capable of completing the residence time and concentration weighted trajectory (CWT) analysis as well. However, an update to a package it was dependent on at the start of the project in summer 2018 created a bug in this processing in the latest version of openair. ERG is currently working on applying the intermediate patch and will provide an update of this code when it has been implemented and tested.

1. Installation
   a. Download base *R* from https://cloud.r-project.org/ for your operating system.
      i. Installation instructions are included on the download site.
      ii. It is recommended that you download RStudio desktop (https://www.rstudio.com/products/rstudio/download/#download) to have a graphical user interface (GUI) to run *R*. This software is also free to download and use.
2. Open HYSPLIT_plots_12162018.R
   a. At line 30, correct the path name to match your system.
      i. This should be the path to the folders for the project.
      ii. The script assumes this is the directory with a subfolder for each Class I area.
      iii. Each Class I folder should have the following folders:
         1. /HYSPLIT_OUTPUT/02_TDUMP/: folder with the HYSPLIT tdump files
         2. /ANALYSIS_PLOTS/: folder to save generated images
3. If using *R* Studio:
   a. Highlight the lines 10 through 22, and click run at the top left to install the need packages and pull in the air quality data.
   b. Next lines 38-130 can be run to regenerate all the analysis.

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12 https://www.r-project.org/; Wang, Y.Q., 2014. MeteoInfo: GIS software for meteorological data visualization and analysis. Meteorological Applications, 21: 360-368.

13 http://davidcarslaw.github.io/openair/; Carslaw, D.C., Ropkins, K. (2012). "openair — An *R* package for air quality data analysis." Environmental Modelling & Software, 27–28(0), 52–61. ISSN 1364-8152, doi: 10.1016/j.envsoft.2011.09.008.

        i. This code loops through all the Class I area folders (01-43). Merges all the tdump files together, and then generates the trajectory plots.

   c. If you want to run new plots for one area:
        i. Skip down to line 166 and change the list of sites to the desired Class I area ID.
        ii. Highlight line 160 through the end, and click run.
        iii. The highlight the code with the plot you would like to generate.
        iv. The code can also be adjusted to run various iteration of the plots:
            1. Type can be changes to any of the variables to generate plot by those categories. (as in line 167).
            2. Multiple values of type can be specified (as in line 157).

Appendix D

AoI Analysis with Python and ArcGIS

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INTRODUCTION

R is used to format data from HYSPLIT tdump into yearly CSV files by Class 1 site IDs. This combined file can be processed using a Python script to find the count of trajectories by county, and to calculate the sulfate and nitrate extinction-weighted residence time (EWRT) for each county within the area of interest. A second version of the code was produced to complete the same calculations for the modeling grid.

STEP BY STEP INSTRUCTIONS

This section goes through, in order, the *R* and Python scripts used in the county analysis. ArcPy is used in the Python script and requires an ESRI users license.

1. Open HYSPLIT_combineYears.R
   a. This script assumes that the HYSPLIT .tdump files are separated by year into individual folders.
   b. Place the *HYSPLIT_combineYears.R* script in the folder with the files and run. CSV files will be written to the same folder. File naming convention: ***Rcombined_<ID>_<YR>.csv***
   c. Repeat this process year ran in HYSPLIT.
   d. Future Update: This script could be modified to run without having to separate the TDUMP files by year.
2. Open HYSPLIT_AllYears.R
   a. This file combines all the year files created using HYSPLIT_combineYears.R. The output csv file created in step 1 should be moved to a new folder with the *HYSPLIT_AllYears.R* script.
   b. All files for each of the Class 1 IDs will be read in a written to one file, combining all of the years into the same file for processing. File naming convention: ***AllYears_Rcombined_<ID>.csv***
   c. Future Update: Combine the scripts used in steps 1 and 2 into a single *R* script.
3. **County_PointCounts_EWRT.py**
   a. This final step of the analysis is running the *County_PointCounts_EWRT.py* Python script. This script pulls in the all years combined text files for each of the Class 1 areas and spatially relates the trajectory outputs to the counties within the area of interest using arcpy.
   b. The arcpy workspace is specified on line 15 and the overwrite is set to True so that existing files will be overwritten.
   c. Directories should be changed to reflect your own working directories, or paths created to match what is currently in the script.
   d. Check the county shapefile and variable names on lines 23-25.
   e. Line 30 assigns an excel file containing the beta extinction. Check the file name and directory. This file must be converted to a table so that it may be used as a look up table later in the script.
   f. The script then iterates through each file in the file list and creates shapefiles and joins with the county to get information on a county basis.

g. Lines 94-112 execute the EWRT calculations for each county and export the final data to a CSV file. File naming convention: AllYears_Rcombined_<ID>_EWRT_final.csv

Appendix E

AoI Analysis with MeteoInfo

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INTRODUCTION

MeteoInfo is an open source software that was developed to view an analyze meteorological and spatial information.[14] MeteoInfo has a "trajStat" plugin that preforms the AoI trajectory analysis (i.e., residence time and concentration weighted trajectory (CWT)). MeteoInfo also has additional spatial analysis functions that are not discussed here, but may be of interest to states looking for an open source alternative to ArcGIS.

STEP BY STEP INSTRUCTIONS

The following section goes through the process of importing HYSPLIT output into MeteoInfo through the CWT calculations used in the AoI analysis.

1. Installation
    a. Download files from http://www.meteothinker.org/downloads/index.html
    b. Select the directory for installation.
    c. Unzip MeteoInfo in install directory
    d. Unzip TrajStat in to MeteoInfo\plugins\
    e. Open MeteoInfo by double clicking MeteoInfoMap.exe in the install directory
    f. Go to Plugin>Plugin Manager> to add the TrajStat plugin to MeteoInfo
2. Set map base layer
    a. Add a new layer
        i. \BaseLayers\CensusStates_proj2.shp is the continental US on the standard modeling projection.
    b. For convenience, VISTAS_Template.mip has been created as a starting point.
        i. Go to Project> Open and navigate to the save location of the template.
        ii. Click Open to open the template map (Figure E-1).

[14] http://www.meteothinker.org/#; Wang, Y.Q., 2014. MeteoInfo: GIS software for meteorological data visualization and analysis. Meteorological Applications, 21: 360-368.

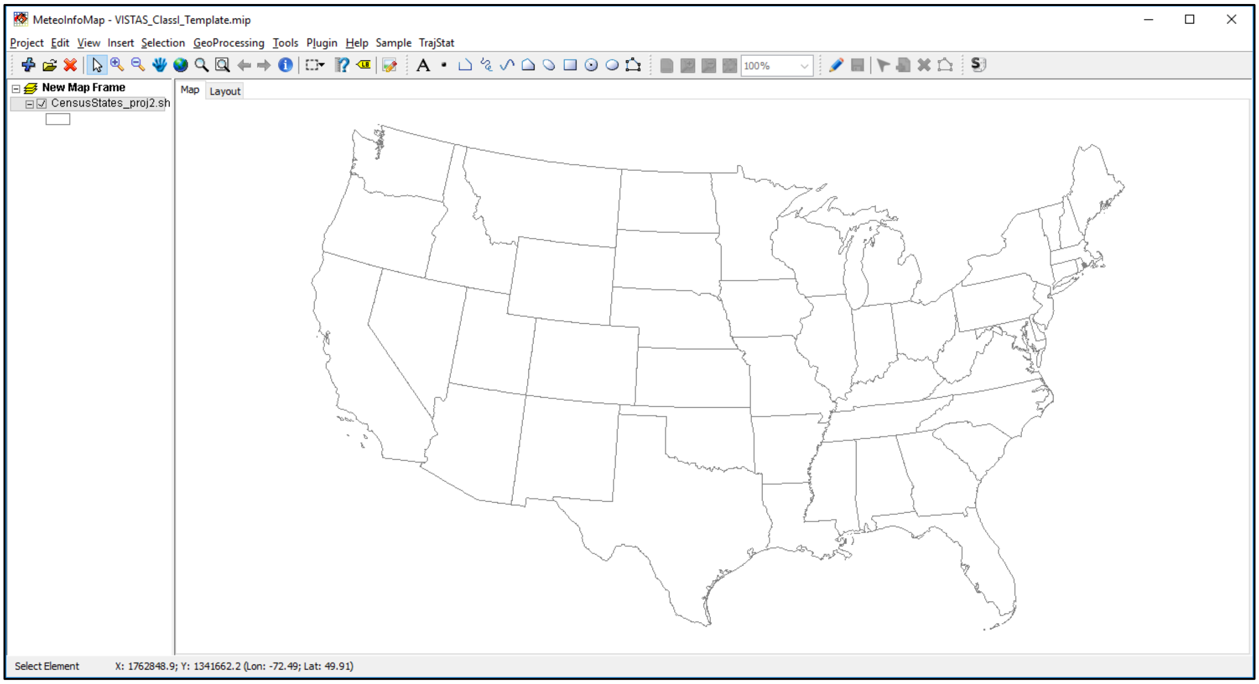

Figure E-1. MeteoInfo with the VISTAS Template Map File (VISTAS_Template.mip) Opened

3. Check projection
    a. Select View > Projection to open the projection menu.
    b. From this menu you can adjust the projection of the map (Figure E-2).

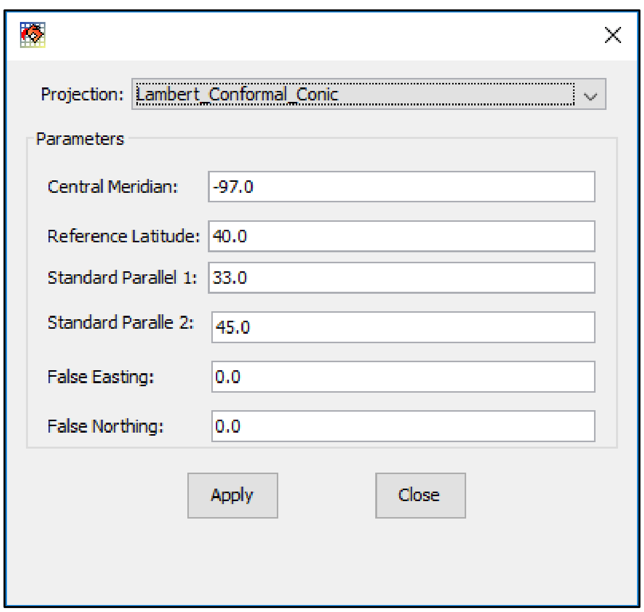

Figure E-2. MeteoInfo Projection Menu

4. Importing HYSPLIT output (converting .tdump files to .TGS)
   a. Select "Convert to TGS Files" from the TrajStat Menu (Figure E-3)

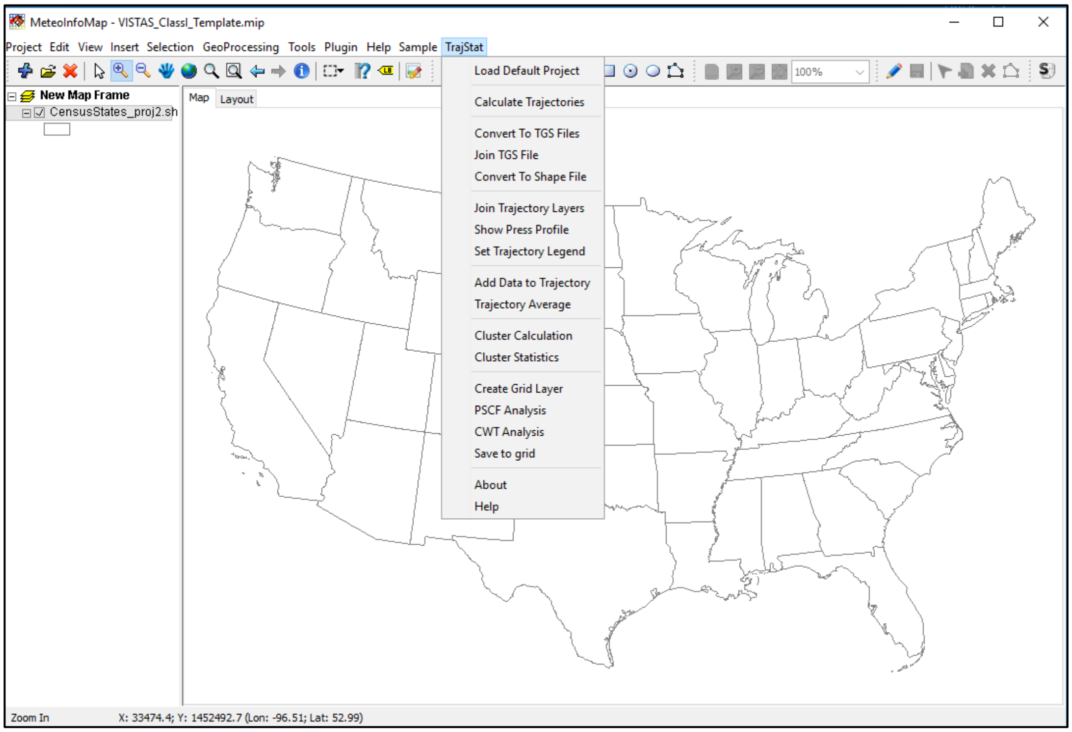

Figure E-3. MeteoInfo TrajStat Menu

   b. Navigate to folder with the .tdump files from HYSPLIT
   c. Select all trajectories for to be considered in the analysis
      i. You can hold control while you click to select multiple files
      ii. Or hit control+A to select all files in a folder (Figure E-4)

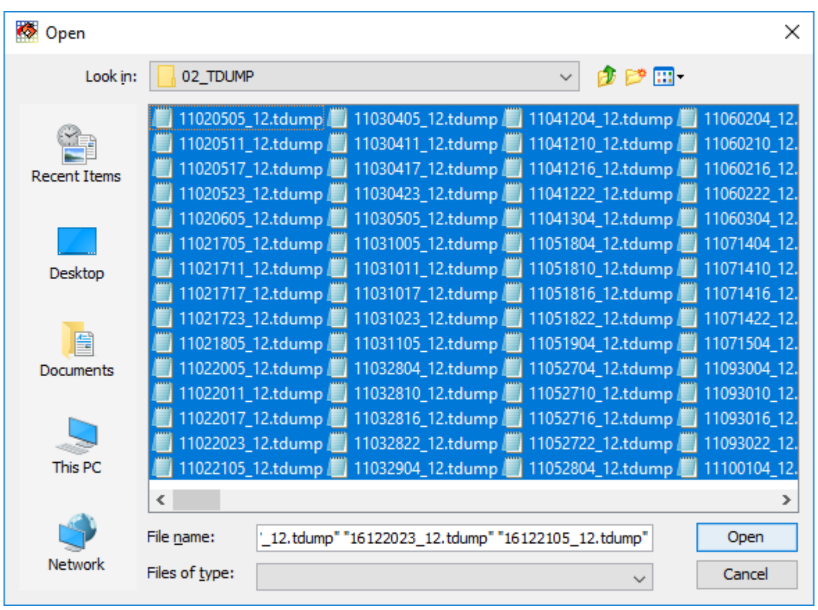

Figure E-4. Selecting HYSPLIT Files for Import into MeteoInfo

   d. Select 'Open'
   e. It will create the TGS files in the same directory as the TDUMP files.
5. Combine into a single TGS
   a. Select "Join TGS File" from TrajStat Menu (Figure E-5)
   b. Navigate to the folder with the TGS files
   c. Select all TGS for to be considered in the analysis
      i. You can hold control while you click to select multiple files
      ii. Or hit control+A to select all files in a folder

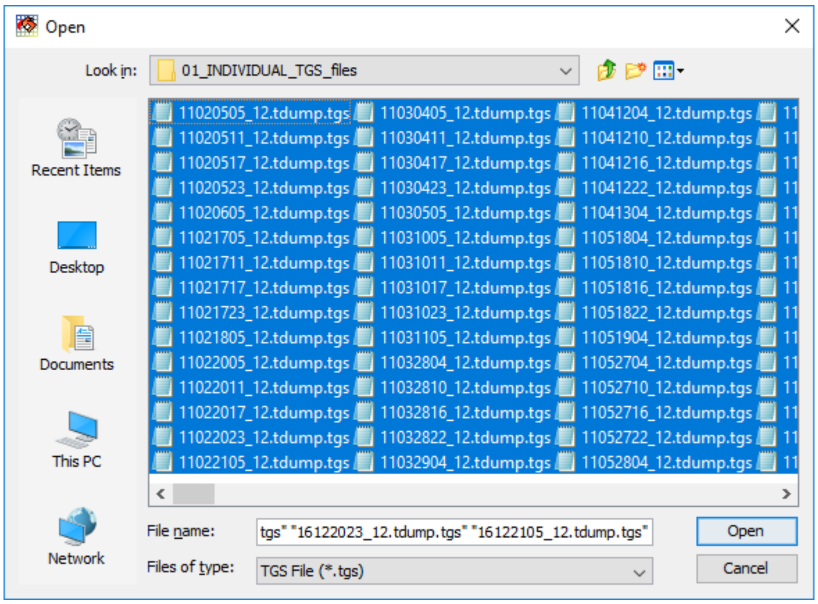

Figure E-5. Selecting tgs Files to Join

   d. Click 'Open'
   e. In the next window, enter the name you want to save the file as, including the extension .tgs (Figure E-6)

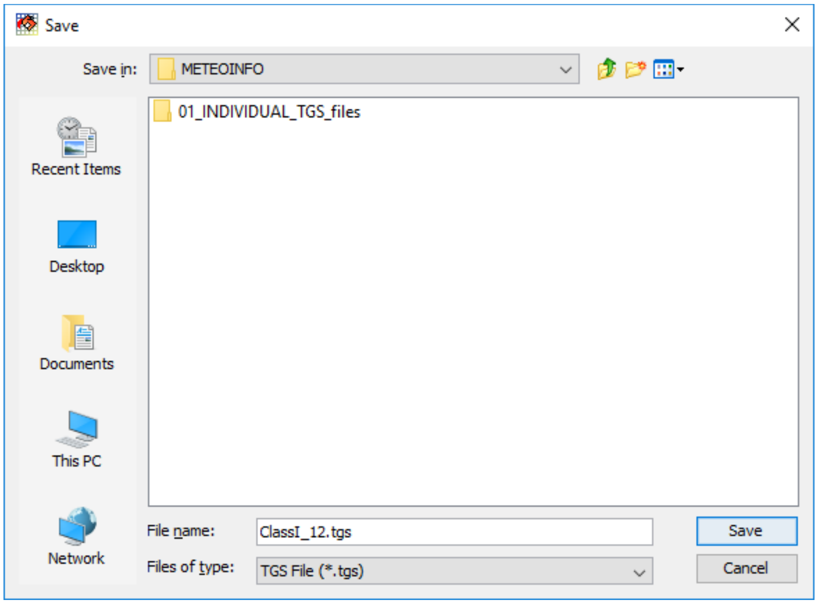

Figure E-6. Saving Joined tgs File

6. Convert to shapefile
    a. Select “Convert to Shape File” from TrajStat menu (Figure E-7)

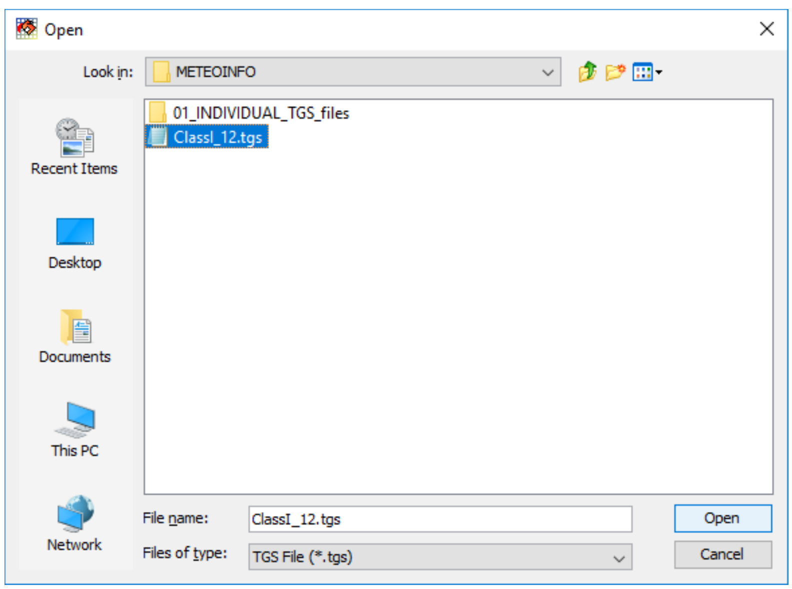

Figure E-7. Converting Joined tgs File to a Shapefile

    b. Will save as the shapefile with the same name as the TGS file.
7. Add extinction data
    a. Select “Add Data to Trajectory” from the TrajStat menu (Figure E-8)
    b. Navigate to the file with the extinction information
        i. File should be either a csv or txt file

ii. Date should be included, and formatted as yyyyMMDD or YYYY-MM-DD (option shown in)

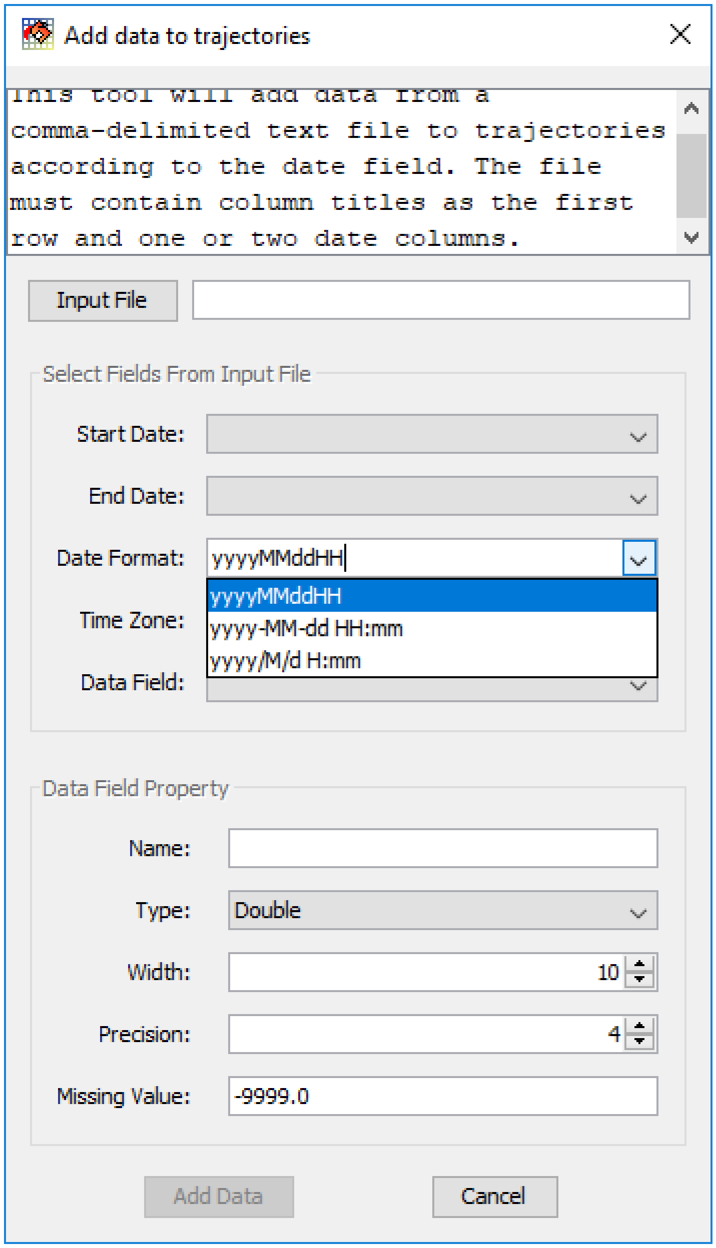

Figure E-8. Screen to Add Data to the Trajectory Shapefile

c. Set date field, and note the format in the "Date Format" drop down.
d. Select field to add, adjusting the field format and Time Zone as necessary (Figure E-9).
   i. You can add air quality information or other identifying fields (e.g., Class I area name) to the file at this point.

ii. If using the AQ files provided, the "MeteoInfoDate" field is the trajectory start time in GMT.

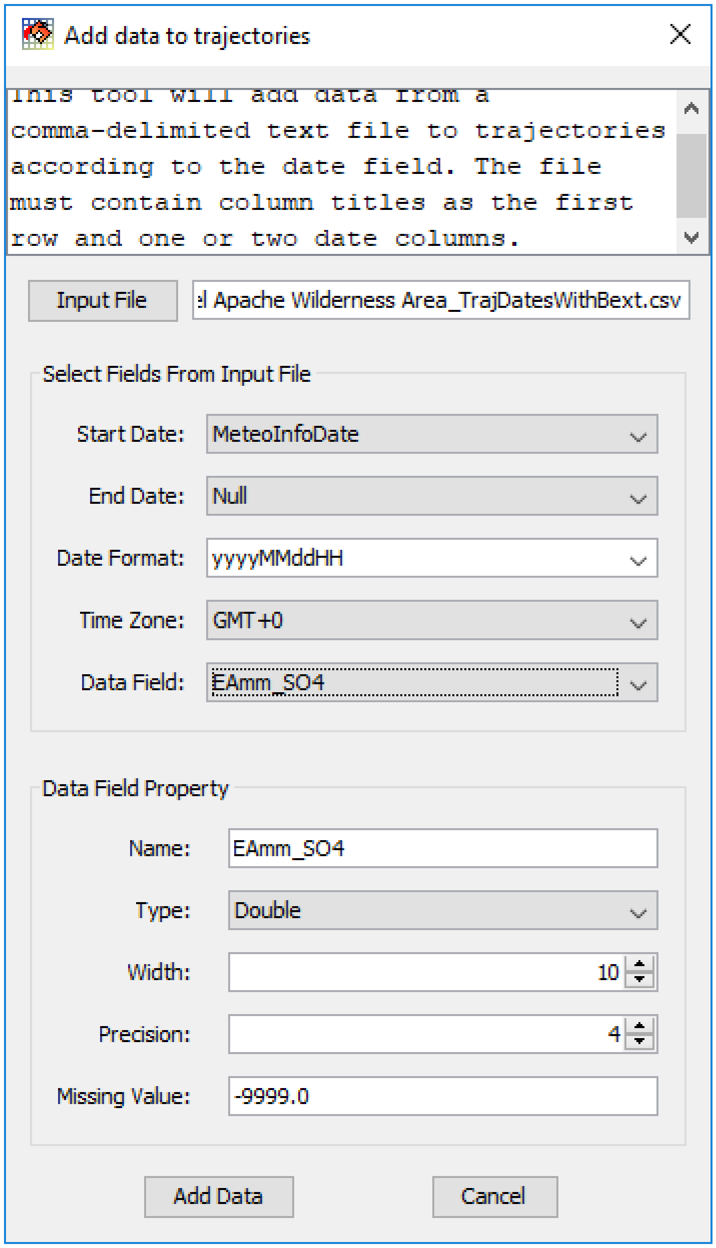

Figure E-9. Screen to Add Data to the Trajectory Shapefile, Addition of Ammonium Nitrate Extinction Values

8. Add grid
   a. Select "Create Grid Layer" from TrajStat menu to open the grid menu (Figure E-10).
      i. If starting from the VISTAS_template.mip, the file is in the same projection that is used for modeling. This will allow you to use the same grid specification as the modeling to define the grid.

b. Select "Same as Map" and enter the bottom left and top right coordinates (in meters) and then enter the cell size in meters.
c. Select CWT as type.
d. Set the desired precision for the CWT field.
e. Click 'Create Layer' to generate the grid.
    i. A navigation window will open, select save location and name.
    ii. After it is generated, you can click "Create Layer" to create a second grid for a second weighting scheme.
    iii. The grids are automatically added to the maps. (Figure E-11)

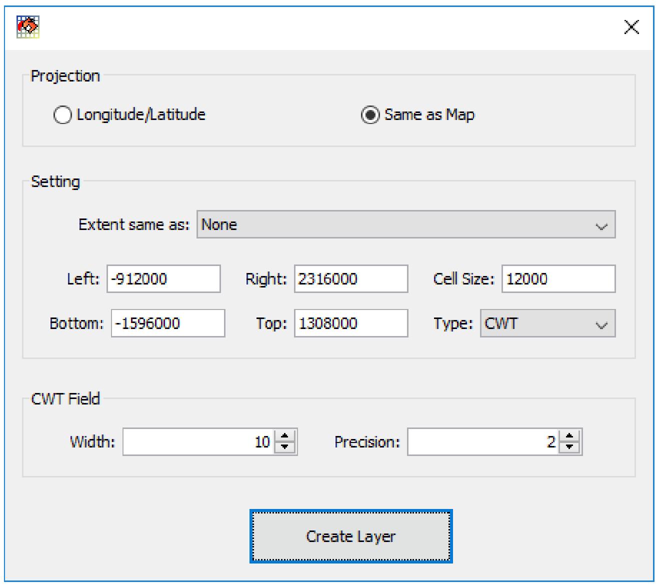

Figure E-10. Screen to Add Uniform Grid to the Map File

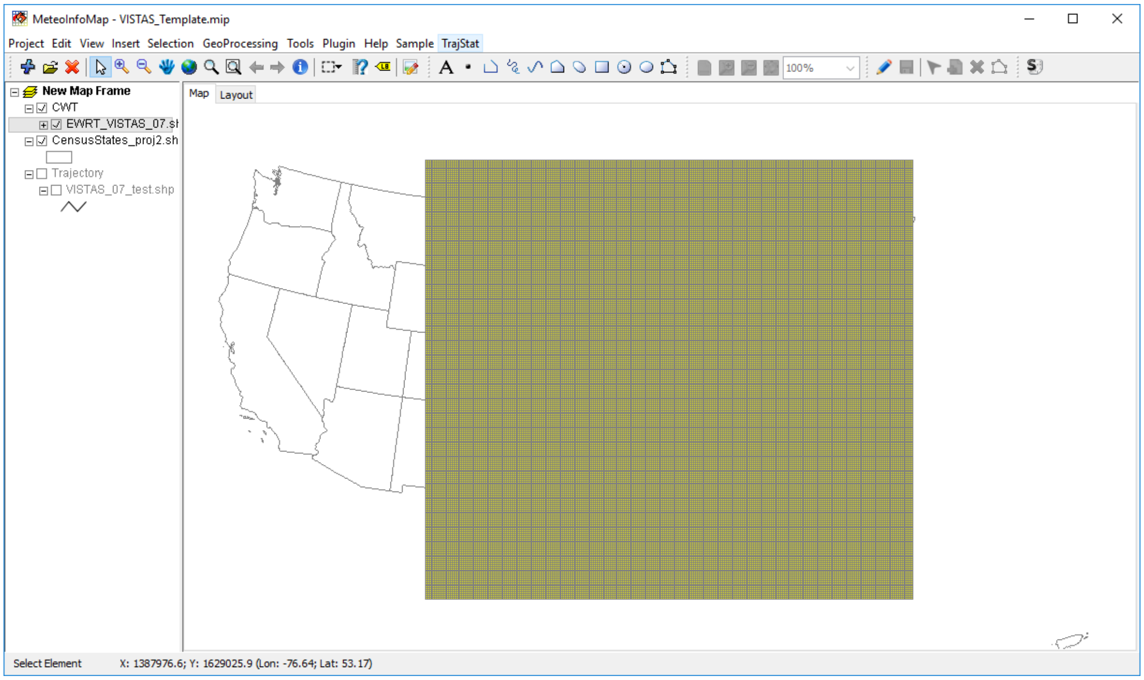

Figure E-11. Resulting Grid is Automatically Added to the Map

9. Concentration/Extinction weighted trajectory (CWT) Analysis
    a. Select CWT Analysis from the TrajStat menu to open the CWT analysis window (Figure E-12)
    b. For CWT Layer - Select layer to generate the CWT based on (i.e., the grid layer)
    c. For Field: Select the field for the Concentration/Extinction weighting)
    d. Click "Get Nij" to get trajectory counts per grid cell
    e. Click "Cal CWT" to calculate the Extinction Weighted Trajectory
    f. Optional: Click "Weight CWT" to calculate a weighted CWT (weighted even more to cell with higher counts)
    g. Close window when completed
    h. The data will have been added to the gird shapefiles.
    i. Adjust the map to show the CWT analysis
        i. Right Click on the layer to open the layer menu (Figure E-13) and select properties to open the layer property window (Figure E-14).
        ii. From the layer property window, select "Graduated Color" as the legend type and the desired variable (Nij = residence time, CWT, or weighted CWT). Then Click OK.
        iii. The map will update to show your final plot (Figure E-15), which can be saved (via the save picture Icon on the tool bar). Otherwise the data is in a shapefile format, which can be brought into ArcGIS.

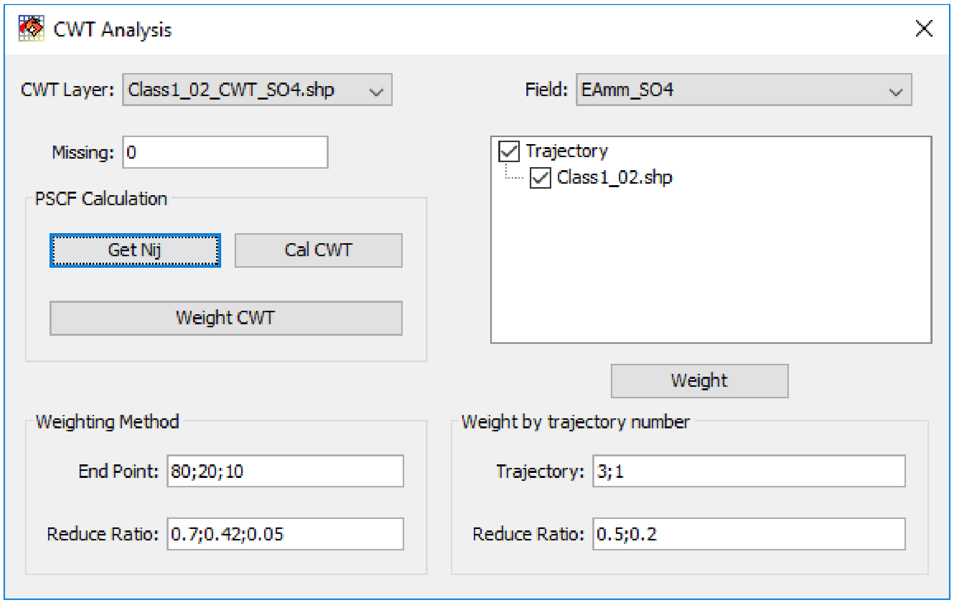

Figure E-12. CWT Analysis Window

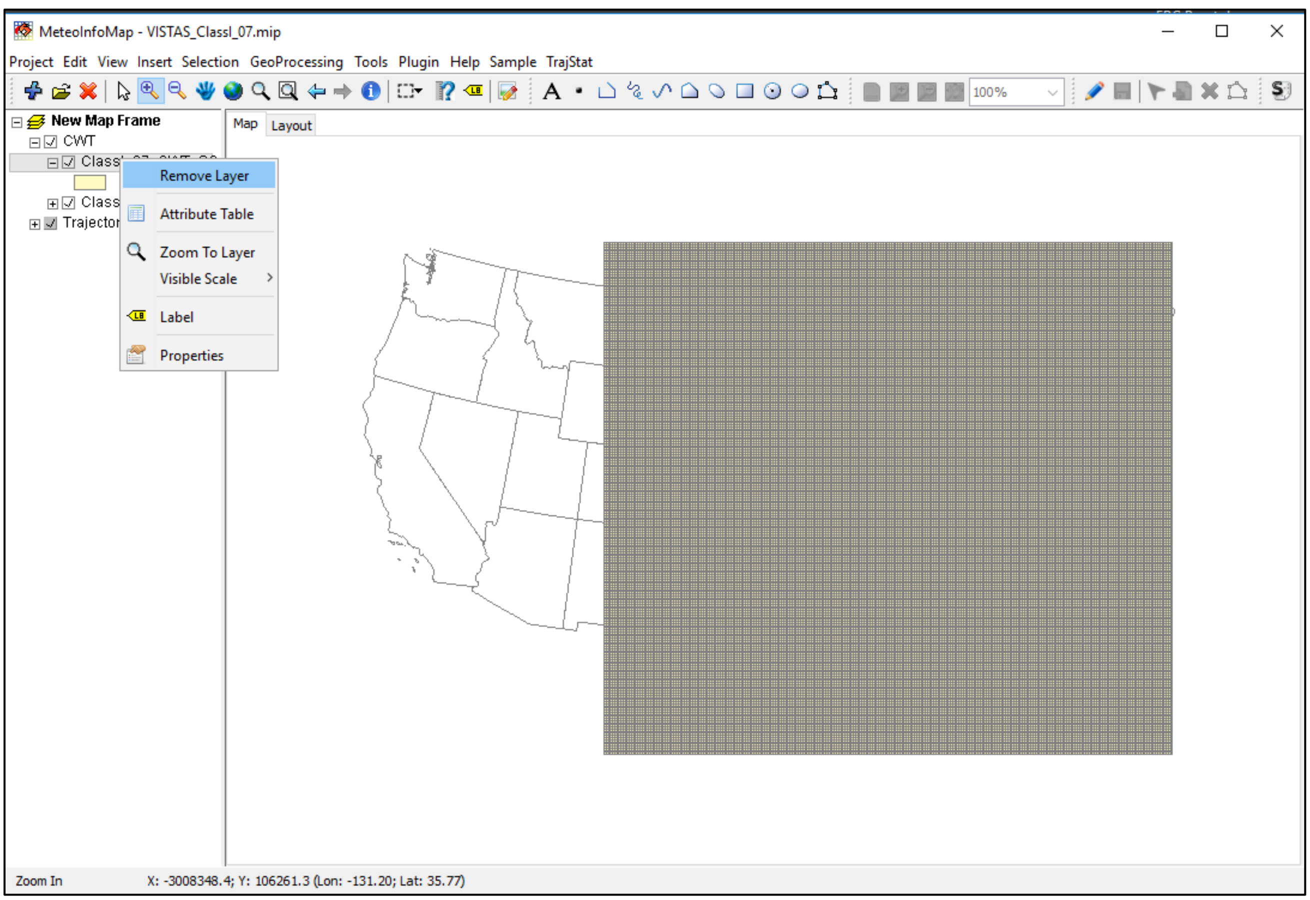

Figure E-13. Select Layer Properties to Shade Grid According to the CWT Results

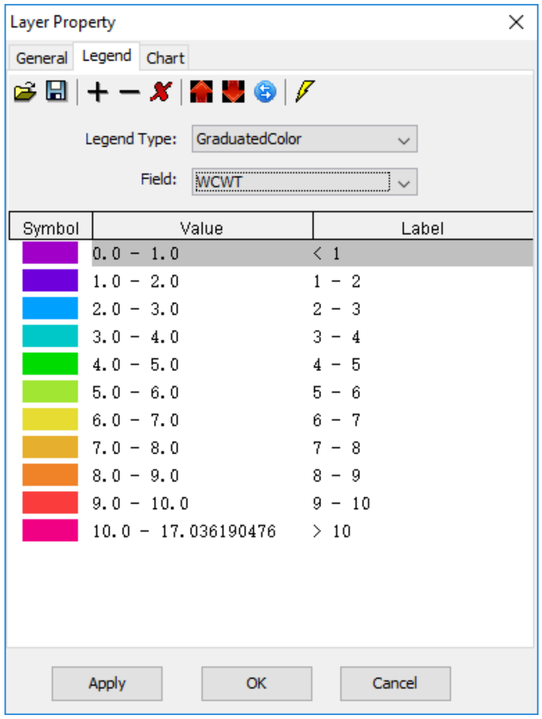

Figure E-14. Select Layer Properties Window to Apply Color Shading Based on Value to the Layer

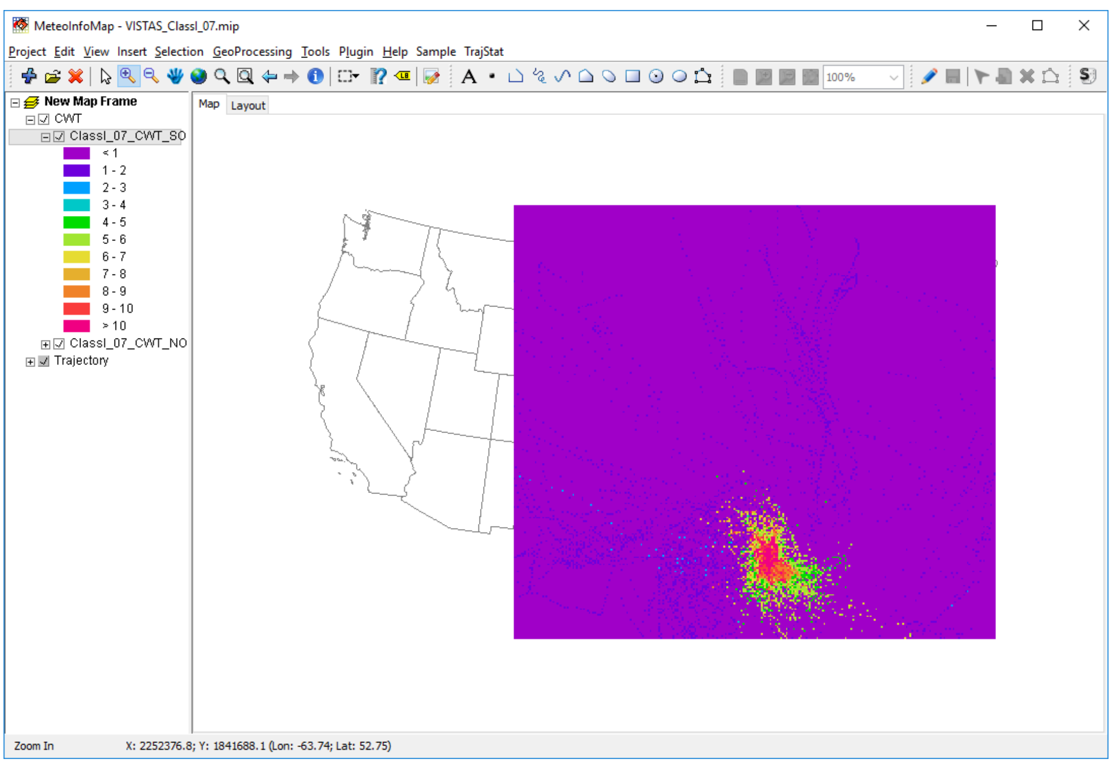

Figure E-15. Gradient Color Plot of the Weighted CWT

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