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WA 5-03: Assessment System (ABaCAS) Development Support

Task 10: User's Manual for FAST-CE 1.7

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1 Introduction

To conduct a comprehensive evaluation of the performance of different source apportionment approaches, a new standalone reduced-complexity tool named FAST-CE was developed to provide greater flexibility and transparency in the estimation of monetized benefits for O_3 and $PM_{2.5}$ reductions. This tool provides fast turnaround times for benefits estimation, which can be an alternative to the more time-intensive application of specific control strategies modeled with a photochemical transport model. With this tool, users can integrate source-receptor relationships generated by photochemical transport models and provide analysis for meeting requirements of regulatory demonstration that range in complexity. The flexible framework allows users to integrate more complex air quality surfaces generated by photochemical models applied with instrumented techniques, including source apportionment (SA) modeling technique (CAMx /OSAT & PSAT, etc.), source/receptor sensitivity modeling technique (DDM) (Dunker, Yarwood et al. 2002, Li, An et al. 2016), and response surface modeling technique (RSM).

1.1 Evaluation Principle

Various methods have been applied to characterize and quantify the relationship between emission sources and pollutant concentrations. For example, model source apportionment approaches like Ozone source apportionment technology (OSAT) and Particle source apportionment technology (PSAT) in Comprehensive Air Quality Model with Extensions (CAMx), or the Integrated Source Apportionment Method (ISAM) in the Community Multiscale Air Quality (CMAQ), augment the model by adopting a system of tracer species to track the sources of ozone or $PM_{2.5}$ and its precursor species for selected groupings of emissions categories and geographical regions (Li, An et al. 2016, Mojtaba, L. et al. 2018). The DDM integrates the sensitivity equations decoupled from the model equations and then calculates the sensitivity coefficients of the response of O_3 and $PM_{2.5}$ concentrations to changes in model inputs (e.g., initial concentrations, boundary conditions, emission rates, etc.) using mathematical technology, while RSM uses advanced mathematical statistical techniques to characterize the relationship between model outputs and input parameters in a highly economical manner.

Accordingly, based on the above principles and the gridded photochemical model source apportionment surfaces or photochemical model DDM sensitivity coefficients generated by them, FAST-CE can modulate those surfaces to generate a new air quality surface, visualize the change in the air quality surface, and conduct a comprehensive comparison among OSAT/PAST&ISAM, RSM, and DDM. The conceptual framework of FAST-CE is shown in Fig. 1.

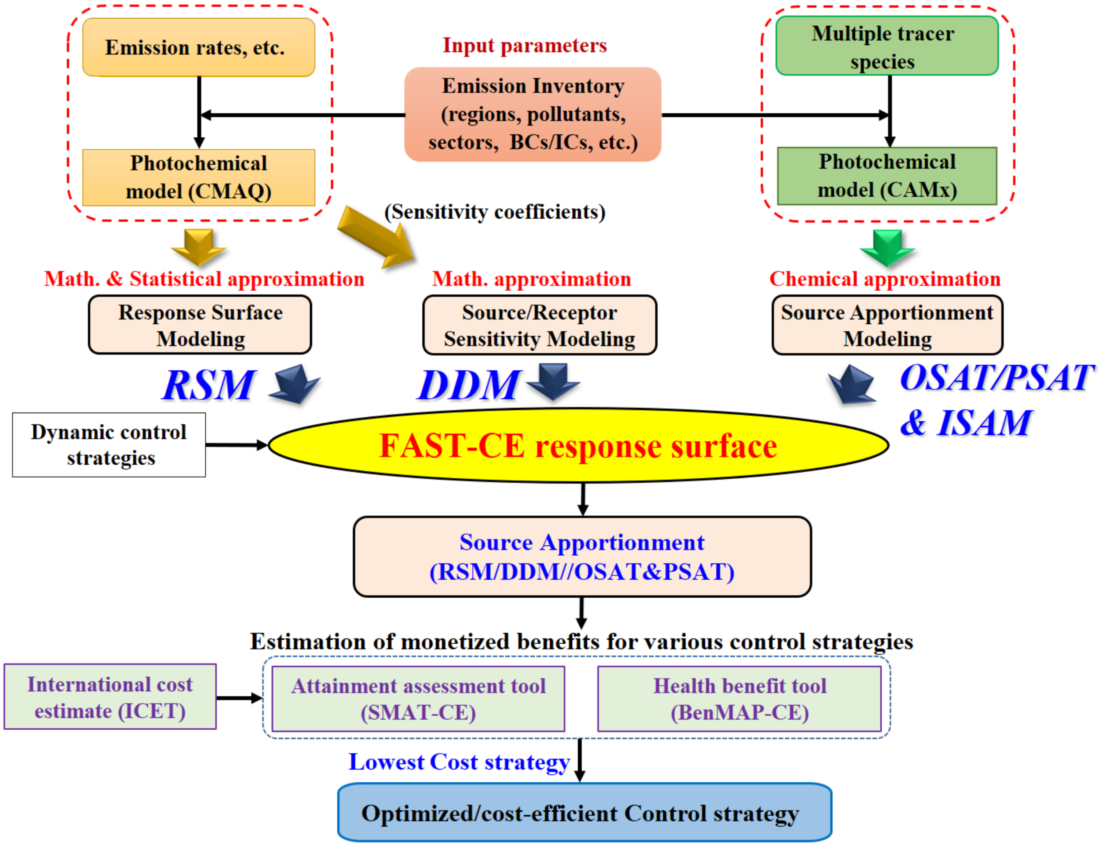


Fig. 1 The conceptual framework of FAST-CE

The methodology and processes of FAST-CE are listed as:

1) The source contribution method (e.g., OSAT/PSAT&ISAM, RSM and DDM method) and corresponding data are selected based on the research needs.
2) Combined with the source apportionment data generated by OSAT/PSAT&ISAM, RSM or DDM, the program will create scenarios contribution fields for each tag, and then sum up all scaled contribution tag fields, and finally create scenarios spatial field for SMAT-CE or BenMAP-CE;
3) The performance of FAST-CE is validated through scatter plots (e.g., normal scatter plots and color density scatter plots) which compare the user-generated FAST-CE results with the EPA validation data.

1.2 Computer Requirements

FAST-CE requires a computer with:

- Net Framework Version 4.6 or higher.
- 32-bit or 64-bit Windows 7/Windows 8/Windows 10.
- 4GB RAM or greater.
- 10 GB free disk space or greater.

1.3 Installing/Uninstalling FAST-CE

1.3.1 Installing FAST-CE

Download FAST-CE Software Package and corresponding example data from the ABaCAS website or Google Drive. They are available at the following links:

(1) ABaCAS website: http://abacas.see.scut.edu.cn/tools.

(2) Google Drive:

https://drive.google.com/open?id=1Xl3VqtlRXeBt_FrfHpuCZYumxjqMR9hL.

➢ Double click the package (e.g., FAST-CE 1.7.exe) to install the program (Fig. 2).

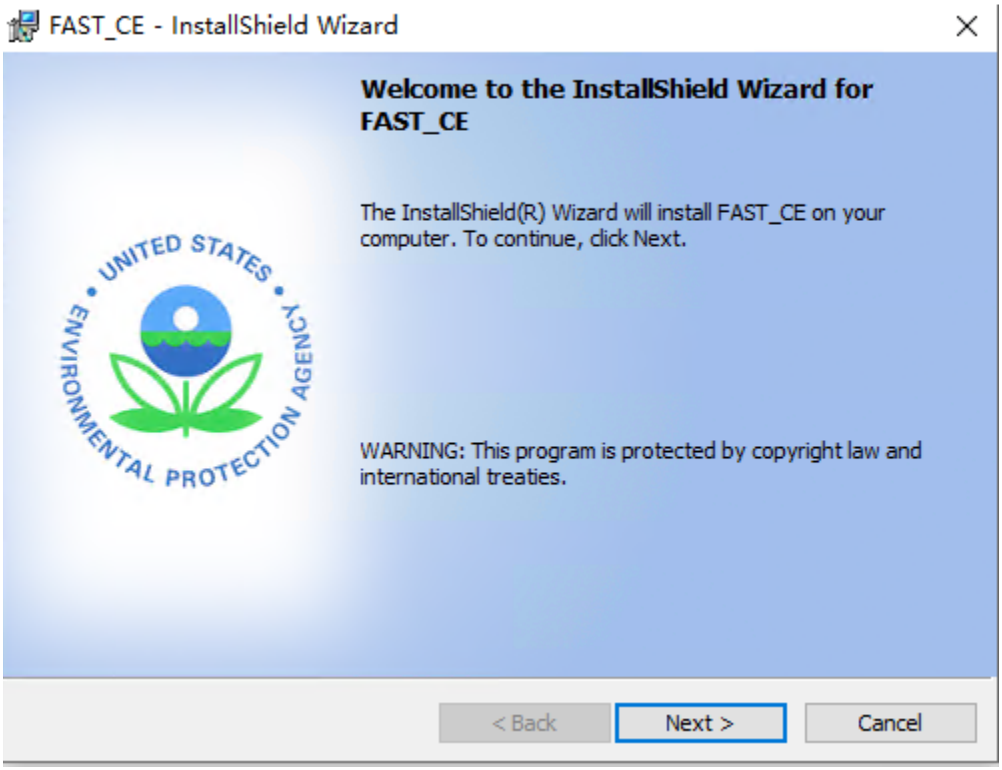


Fig. 2 Setup Window

➢ Click the "**Next**" button, select the "Change" if necessary, to specify a path rather than the default install path, as shown in Fig. 3.

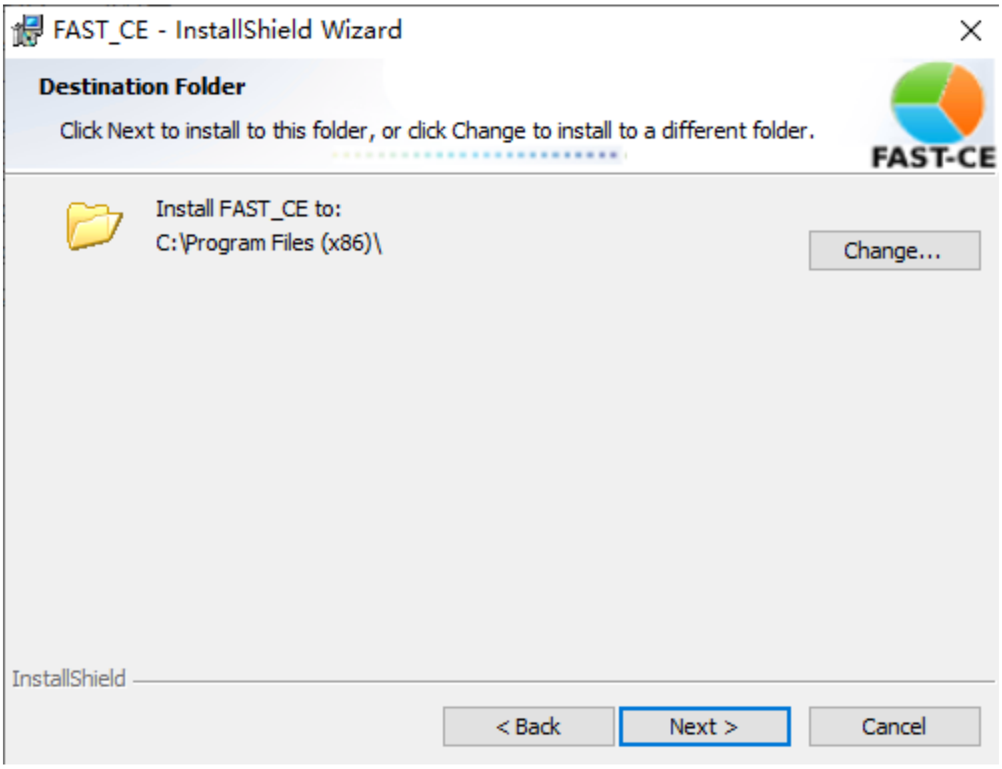


Fig. 3 Choose Install Path

➢ Click the "Next" button, the "Ready to Install" window will display as shown in Fig. 4.

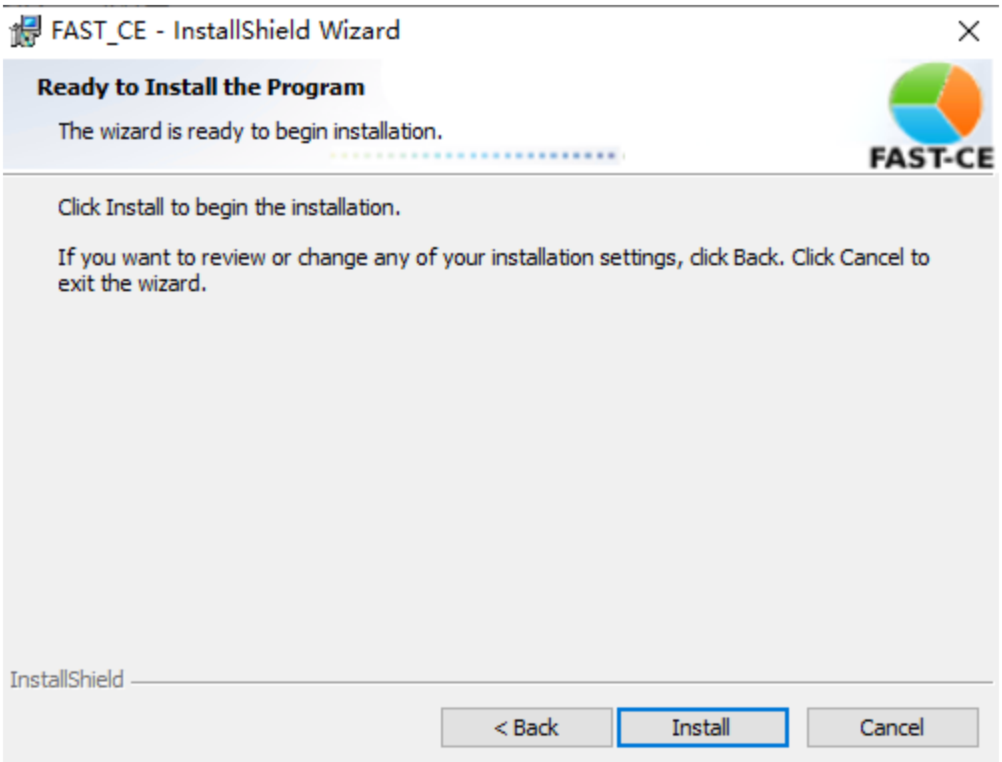


Fig. 4 Ready to Install

➤ Click the "**Install**" button and FAST-CE will be installed.

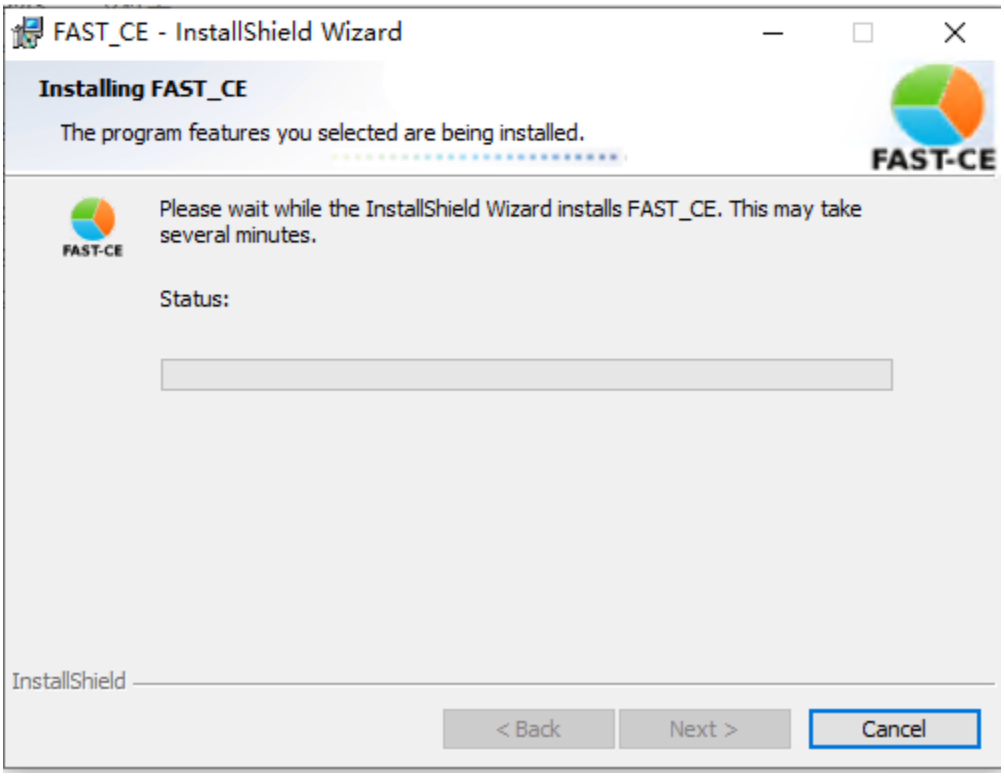


Fig. 5 Installation Process

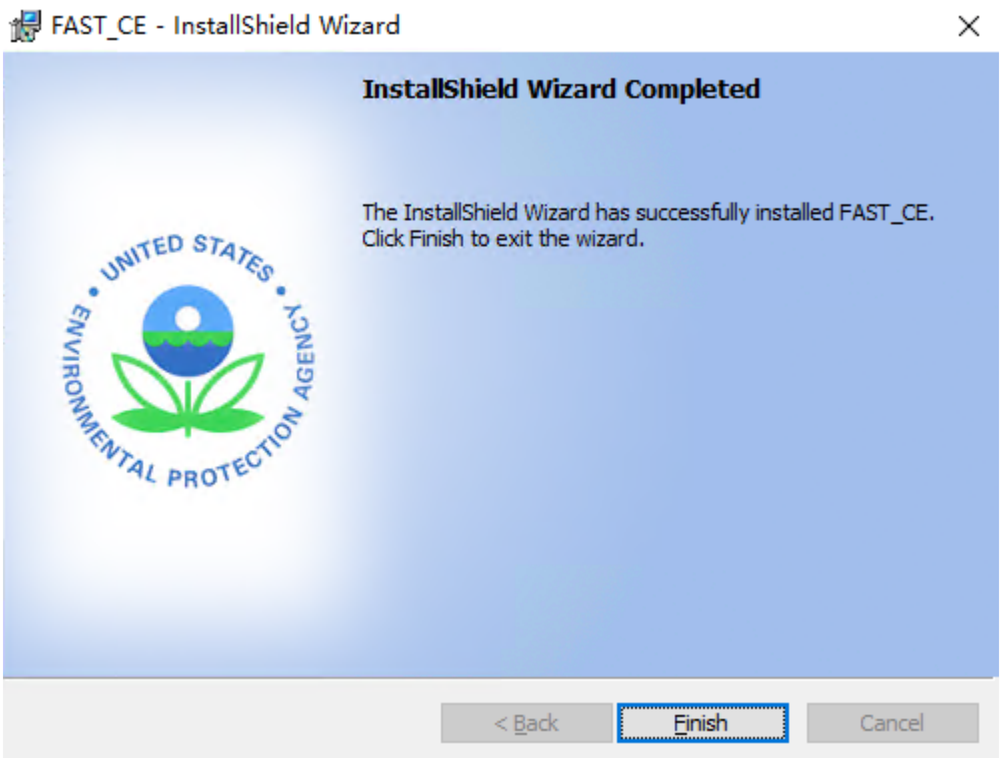


Fig. 6 Complete Installation

➤ Click the "**Finish**" button and complete the installation process.

1.3.2 Installing FAST-CE Data Installer

- After finishing the installation, please unzip the corresponding FAST-CE example data executable file(e.g., FAST-CE 1.7 Data.exe) to My Documents directory under \My Documents\My FAST-CE Files\Data* to replace the old Data folder.
- Double click the example data executable file to install the program (Fig. 7). It is recommended not to change the default install path because it is the path where FAST-CE reads the example data.

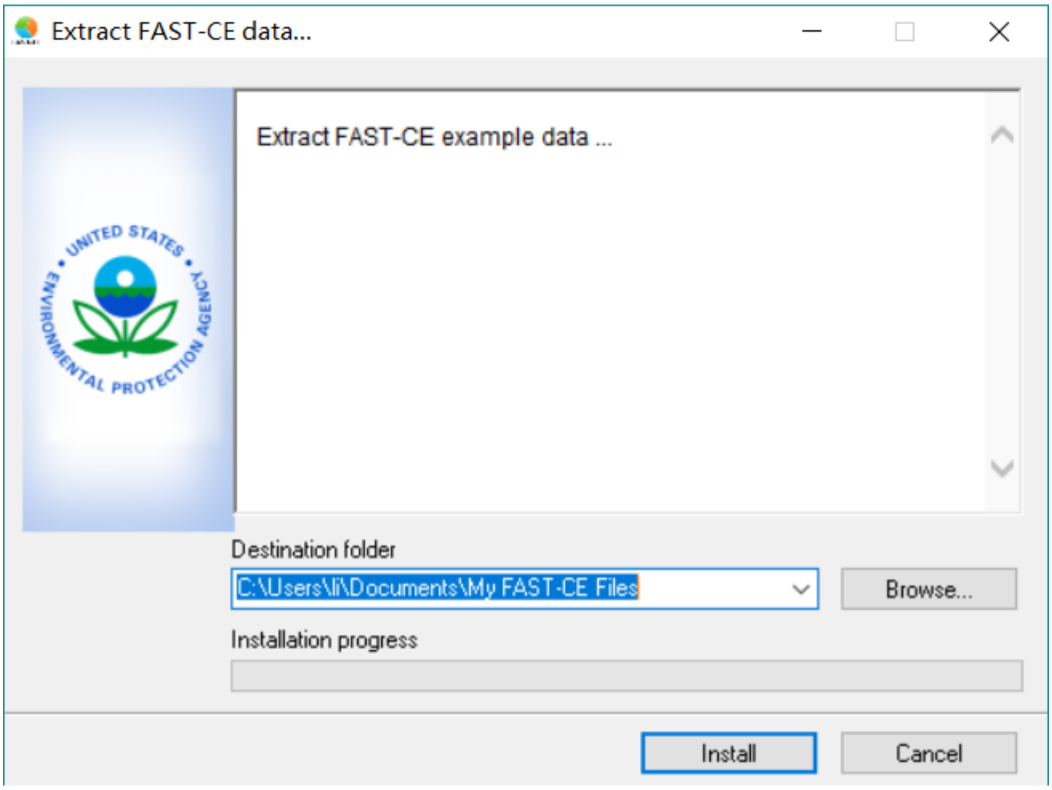


Fig. 7 Choose Install Path

- Click the "**Install**" button and the FAST-CE Data will be extracted.

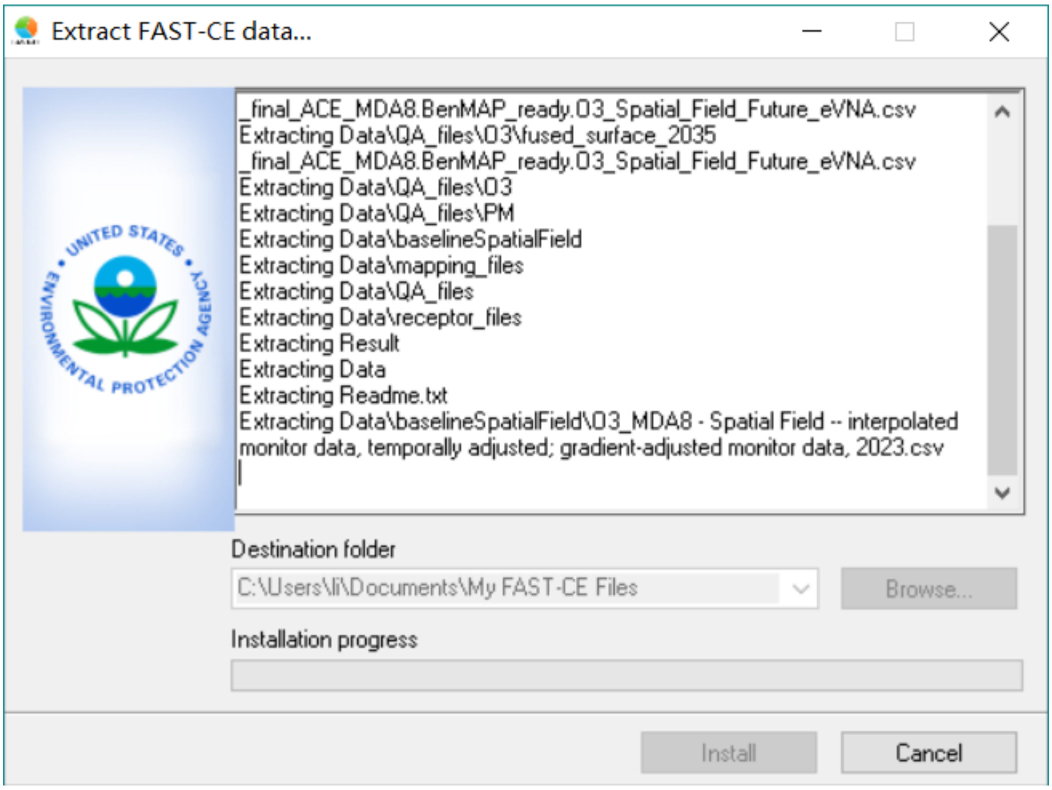


Fig. 8 Installation Process

- When the data extraction is completed, the installation window will be closed automatically.

1.3.3 Uninstalling FAST-CE

- Go to Control Panel.
- Select FAST-CE and click Change/Remove, the pop-up window below will appear.

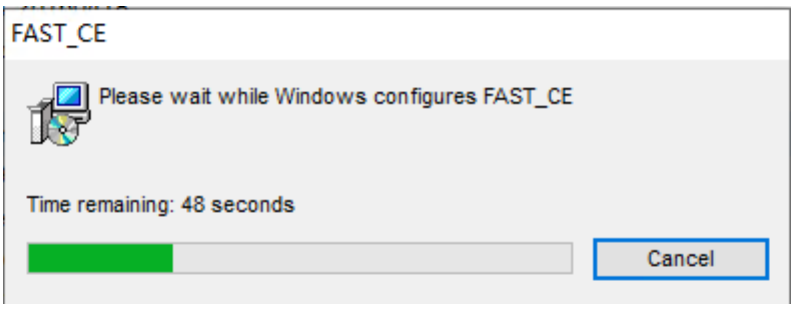


Fig. 9 Uninstallation Process

- After a few seconds, uninstallation will finish.

1.4 Contacts for Comments and Questions

For comments and questions, please contact the following：

(1) Prof. Yun (Dustin) Zhu at South China University of Technology, Environmental Simulation and Information Laboratory via email at zhuyun@scut.edu.cn;

(2) The Center for Community Modeling and Analyses System (CMAS) at the University of North Carolina at Chapel Hill via email at cmas@unc.edu.

2 Terminology and File Types

The first section of this chapter explains the common terms used in this user's manual and users can refer to other sections in this manual to find more detailed information about them if necessary. Section 2.2 describes the necessary format for externally generated model and monitor data files that can be read into FAST-CE in detail.

2.1 Common Terms

- **OSAT/PSAT:** Ozone source apportionment technology (OSAT) and Particle source apportionment technology (PSAT) are source apportionment modeling approaches in Comprehensive Air Quality Model with Extensions (CAMx), which augment the model by adopting a system of tracer species to track the sources of ozone or $PM_{2.5}$ and its precursor species for selected groupings of emissions categories and geographical regions.
- **RSM:** RSM is a "reduced form" model of a complex air quality model (e.g. CMAQ) - "meta-model", based on a systematically selected set of model runs, statistical techniques can be used to represent the relationship between model inputs and outputs (e.g. emissions control and concentrations of PM & ozone). Once the "response surface" has been generated, it can be used to simulate the change in secondary air pollutant concentrations due to a range of changes in emissions without re-running the computationally expensive photochemical air quality model. It can be also used to derive analytical representations of model sensitivities to changes in model inputs.
- **CMAQ (Community Multi-Scale Air Quality):** A state-of-the-art air quality model able to model ambient particulate levels, as well as other pollutants, including ozone. The grid-size of CMAQ is approximately 36 kilometers by 36 kilometers.

2.2 File Types

2.2.1 File Types for OSAT/PSAT/APCA/ISMA method

- **CAMx Model data input for OSAT/PSAT**: A netCDF formatted file for each tracer that contains tag information.
- **Receptor Region File:** A *.csv file which defines the grids of the analyzed receptors and is used to aggregate the grid concentration values to the level of those specified receptor regions. The columns in this file indicate in turn: region ID, grid column, grid row, grid region ratio, region code, and region name. The region ID, region code, and region name can be customized by users. Information such as grid columns, rows, and region ratios need to be calculated and obtained by ArcGIS.
- **Mapping File:** A *.csv file, which is used to link the tagged variables of CAMx model data with control factors (Region, Pollutant, Source) for FAST-CE. The columns in this file indicate in turn: tagged variables of CAMx model data, names

used to identify different items, region, source, and pollutant. The names used to identify different items can be customized by users, and the control factors (Region, Pollutant, Source) were derived from the emission file.

- **Baseline Spatial Field File:** A *.csv file contains the baseline spatial field information, which is generally created by SMAT-CE. For O_3 analysis, it contains 14 headers (Table 1), while for $PM_{2.5}$ analysis, it contains 32 headers (Table 2). The meaning of each header can refer to User's Manual for SMAT-CE.

Table 1 The headers of Baseline Spatial Field File for O_3 analysis

No.	Header name	No.	Header name
1	_id	8	i_f_o3(eVNA)
2	_type	9	b_o3_model
3	lat	10	f_o3_model
4	long	11	ppb
5	date	12	days
6	ga_conc	13	referencecell
7	i_b_o3(eVNA)	14	rrf

Table 2 The headers of Baseline Spatial Field File for $PM_{2.5}$ analysis

No.	Header name	No.	Header name
1	_id	17	f_crustal_mass_q_ga
2	gridcell_lat	18	f_EC_mass_q_ga
3	gridcell_long	19	f_NH4_mass_q_ga
4	quarter	20	f_Ocmb_mass_q_ga
5	b_pm25_ann_q_DV_ga	21	f_SO4_mass_q_ga
6	f_pm25_ann_q_DV_ga	22	f_NO3_mass_q_ga
7	b_blank_mass_q_ga	23	f_water_mass_q_ga
8	b_crustal_mass_q_ga	24	f_salt_mass_q_ga
9	b_EC_mass_q_ga	25	rrf_crustal_q_ga
10	b_NH4_mass_q_ga	26	rrf_ec_q_ga
11	b_Ocmb_mass_q_ga	27	rrf_nh4_q_ga
12	b_SO4_mass_q_ga	28	rrf_oc_q_ga
13	b_NO3_mass_q_ga	29	rrf_so4_q_ga
14	b_water_mass_q_ga	30	rrf_no3_q_ga
15	b_salt_mass_q_ga	31	rrf_salt_q_ga
16	f_blank_mass_q_ga	32	rrf_water_q_ga

Baseline Species Spatial Field File: This option is only for PM analysis, which allows the user to set up PM species spatial field data. This data file is also created by SMAT-CE. It contains 24 headers (Table 3) and the meaning of each header can refer to the User's Manual for SMAT-CE.

Table 3 The headers of Baseline Species Spatial Field File

No.	Header name	No.	Header name
1	_id	13	fsalt_ga
2	gridcell_lat	14	blank_mass_ga
3	gridcell_long	15	don_ga
4	quarter	16	i_so4_ga
5	pm25_mass_frac_ga	17	i_no3r_ga
6	fcr_ga	18	i_ocb_ga
7	fec_ga	19	i_ec_ga
8	fnh4_ga	20	i_crustal_ga
9	focm_ga	21	i_don_ga
10	fso4_ga	22	i_nh4_ga
11	fno3_ga	23	i_no3_ga
12	fwater_ga	24	i_salt_ga

- **Cases & Emission File:** A *.csv formatted file describes information of base & control cases and corresponding emission data. It contains 3 headers: "Case Name", "Pollutant" and "Emission Path". The "Emission Path" is used to link to the emission file which defines the total emissions by tag for all the baseline and policy scenarios (e.g., ACE 2025, 2030, 2035).
- **Validation Configuration File:** A *.csv formatted file that describes the configuration for FAST-CE cases and QA cases contains 3 headers: "FAST-CE Case", "QA Case", and "QA File". The "FAST-CE Case" is the case name of FAST-CE analysis, which is consistent with the control case of "Cases & Emission File". The "QA Case" is the user-defined name to each QA analysis and "QA File" is the origin EPA ACE results file.

2.2.2 File Types for RSM method

- **RSM Input File:** A pre-run RSM file, created by RSM-VAT.
- **Receptor Region File:** A separate *.txt file that defines the grids of the analyzed receptors. The meaning of each column is the same as the "Receptor Region File" of the OSAT/PSAT/APCA/ISMA method.
- **Emission Matrix File:** A *.csv file used to set up RSM base & control cases contains 2 headers: "Case Name" and "Emission Path". The case name can be defined by the user and the "Emission Path" is the path of corresponding "FactorsInfo" file which describes the information of emission factor, including the attribute, size, and source of each factor.

Table 4 presents the type, name, extension, and data source of the files.

Table 4 File types used by FAST-CE

Filename	File Extension	Source
CAMx Model data input	netcdf	CAMx
Receptor Region File	*.csv or *.txt	RSM-VAT
Mapping File	*.csv	User-defined
Baseline Spatial Field File	*.csv	SMAT-CE
Baseline Species Spatial Field File	*.csv	SMAT-CE
Cases & Emission File	*.csv	User-defined
Validation Configuration File	*.csv	User-defined
RSM Input File	*.rsm	RSM-VAT
Emission Matrix File	*.csv	User-defined

3 Quick Start

This chapter provides the steps required to run FAST-CE for various analyses. The Quick Start will use EPA's Affordable Clean Energy (ACE) data set to demonstrate how to run each of the FAST-CE analysis modules. These steps will use the default settings and do not describe the configuration settings for each analysis. For details of the configuration settings for the individual FAST-CE modules, refer to the User's Guide chapter for each module.

3.1 Load a Previous Project

Click File→**Open Project** on the FAST-CE Home Page to launch a Windows Explorer window. Use this window to navigate to the directory where FAST-CE project (*. proj) files are saved to load a previous project.

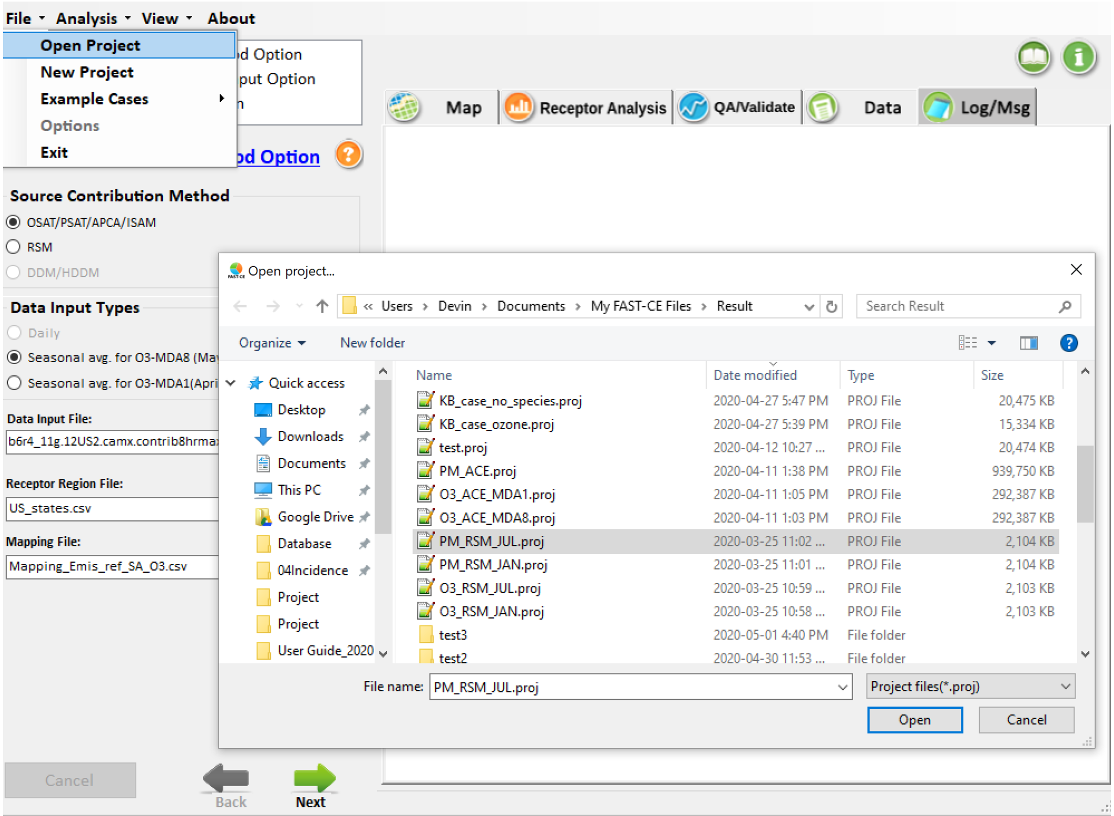


Fig. 10 Load a previous project

3.2 PM Analysis Quick Start

The steps below describe how to use FAST-CE to conduct source contributions and create SMAT-CE air quality surface flexibly and in real-time for $PM_{2.5}$.

Step 1. Click **Analysis→PM** menu on the top of FAST-CE Home Page to launch the PM Analysis module window.

Step 2. The **Source Contribution Method Option** window display first. This window sets the source contribution method (e.g., OSAT/PSAT/APCA/ISAM), data input types (e.g., Monthly), input files of selected source contribution method, receptor region file and mapping file for $PM_{2.5}$ analysis. FAST-CE calculates fraction contribution for each tag in each grid-cell based on the input files.

Use the default settings in the **Source Contribution Method Option** window.

- Click on the [Source Contribution Method Option]() hyperlink to display an electronic version of the User's Manual for this window.

Source Contribution Method. Sets the source contribution method. There are three sets of source contribution methods for users to select. The default selected is OSAT/PAST/APCA/ISAM.

Data Input Types: Sets the data type of input files. It provides three options: Daily, Monthly and Annual.

Data Input File: For OSAT/PAST/APCA/ISAM option, sets the SA tags IOAPI files (e.g., inputs 12 monthly $PM_{2.5}$ Source Appointment (SA) tag files for Monthly option specified in Data Input Types). For RSM option, sets the rsm file (*.rsm) that contains the response parameters between emission and air quality.

Receptor Region File: Sets the information of grid cells that located in those regions of interest.

Mapping File: Only for OSAT/PAST/APCA/ISAM option. Sets a mapping between the variables in Source Appointment (SA) tag files and the variables in emission file.

- Click the **Next** arrow at the bottom right of the **Source Contribution Method Option** window to proceed to the next step.

Step 3. The **Emission & Spatial Field Input Option** window sets the baseline spatial field files and emission files. FAST-CE multiplies the baseline spatial field data by fractional contribution for each tag that calculated in last step, and then multiplies the appropriate emission ratio from emission files to create a scaled contribution tag fields, then finally sums up all scaled contribution tag fields to output future scenario spatial field data (including quarterly& annual for PM).

Use the default settings in the **Source Contribution Method Option** window.

- Click on the **Emission & Spatial Field Input Option** hyperlink to display an electronic version of the User's Manual for this window.
- **Include PM Species.** Inputs the baseline quarterly $PM_{2.5}$ spatial field that created by SMAT-CE (e.g., xxx Quarterly PM25 Spatial Field (eVNA).csv, xxx represents the project name of SMAT-CE) when this option is checked. Or sets the baseline air quality surface by users when this option is not checked.
- **SMAT-CE adjustment.** Only for **Include PM Species** option, sets the baseline quarterly species fraction spatial field that created by SMAT-CE (e.g., xxx Quarterly Avg Spec Frac Spatial Field (eVNA).csv, xxx represents the project name of SMAT-CE).
- Click the **Next** arrow at the bottom right of the **Emission & Spatial Field Input Option** window to proceed to the next step.

Step 4. The **QA/Validation Input Option** window sets the validation configuration file. This step is optional, and the default is checked. For OSAT/PAST/APCA/ISAM option specified in the **Step 2**, this option validates the FAST-CE results with SMAT-CE results. For RSM option specified in the **Step 2,** this option verifies RSM predictions with those CMAQ simulations that not included in RSM creation.

Use the default settings in the QA/Validation Input Option window.

- Click on the **QA/Validation Input Option** hyperlink to display an electronic version of the User's Manual for this window.
- Click the **Next** arrow at the bottom right of the **QA/Validation Input Option** window to complete the PM Analysis configuration and run the FAST-CE project.
- Click **OK** in the pop-up window to input a project name and create a project (*. proj) file for this tutorial exercise.

The PM Analysis will complete after a few minutes and the results of this analysis will be presented in MAP, Receptor Analysis, QA/Validate and Data module on the right of current window. See Chapter 6 for details on how to analyze the results.

3.3 Ozone Analysis Quick Start

The steps below describe how to use FAST-CE to conduct source contributions and create SMAT-CE air quality surface flexibly and in real-time for O_3.

Step 1. Click **Ozone Analysis** on the SMAT-CE Start Page to launch the Ozone Analysis module window. Click **Analysis→Ozone** menu on the top of FAST-CE Home Page to launch the Ozone Analysis module window.

Step 2. The **Source Contribution Method Option** window display first. This window sets the source contribution method (e.g., OSAT/PSAT/APCA/ISAM), data input types (e.g., Daily), input files of selected source contribution method, receptor region file and mapping file for Ozone analysis. FAST-CE calculates fraction contribution for each tag in each grid-cell based on the input files.

Use the default settings in the **Source Contribution Method Option** window.

- Click on the **Source Contribution Method Option** hyperlink to display an electronic version of the User's Manual for this window.
- **Source Contribution Method.** Sets the source contribution method. There are three sets of source contribution methods for users to select. The default selected is OSAT/PAST/APCA/ISAM.
- **Data Input Types:** Sets the data type of input files. It provides three options: Daily, Seasonal avg. for O_3-MDA8 (May-Sept) and Seasonal avg. for O_3-MDA1 (April-OCT).
- **Data Input File:** For OSAT/PAST/APCA/ISAM option, sets the SA tags IOAPI files. For RSM option, sets the rsm file (*.rsm) that contains the response parameters between emission and air quality.
- **Receptor Region File:** Sets the information of grid cells that located in those regions of interest.
- **Mapping File:** Only for OSAT/PAST/APCA/ISAM option. Sets a mapping between the variables in SA tag files and the variables in emission file.
- Click the **Next** arrow at the bottom right of the **Source Contribution Method Option** window to proceed to the next step.

Step 3. The **Emission & Spatial Field Input Option** window sets the baseline spatial field files and emission files. Note that the baseline spatial field file (e.g., xxx - Spatial Field -- interpolated monitor data, temporally adjusted; gradient-adjusted monitor data, 2023.csv, xxx stands for the project name of SMAT-CE) could be created by SMAT-CE. FAST-CE multiplies the baseline spatial field data by fractional contribution for each tag that calculated in last step, and then multiplies the appropriate emission ratio from emission files to create a scaled contribution tag fields, then finally sums up all scaled contribution tag fields to output future scenario spatial field data (including MDA1&MDA8 for Ozone).

Use the default settings in the **Source Contribution Method Option** window.

- Click on the [**Emission & Spatial Field Input Option**]() hyperlink to display an electronic version of the User's Manual for this window.
- Click the **Next** arrow at the bottom right of the **Emission & Spatial Field Input Option** window to proceed to the next step.

Step 4. The **QA/Validation Input Option** window sets the validation configuration file. This step is optional, and the default is checked. For OSAT/PAST/APCA/ISAM option specified in the **Step 2**, this option validates the FAST-CE results with SMAT-CE results. For RSM option specified in the **Step 2,** this option verifies RSM predictions with those CMAQ simulations that not included in RSM creation.

Use the default settings in the QA/Validation Input Option window.

- Click on the **QA/Validation Input Option** hyperlink to display an electronic version of the User's Manual for this window.
- Click the **Next** arrow at the bottom right of the **QA/Validation Input Option** window to complete the Ozone Analysis configuration and run the FAST-CE project.
- Click **OK** in the pop-up window to input a project name and create a project (*.proj) file for this tutorial exercise.

The Ozone Analysis will complete after a few minutes and the results of this analysis will be presented in MAP, Receptor Analysis, QA/Validate and Data module on the right of current window. See Chapter 6 for details on how to analyze the results.

4 Main Interface

The main interface of FAST-CE is shown in Fig. 11.

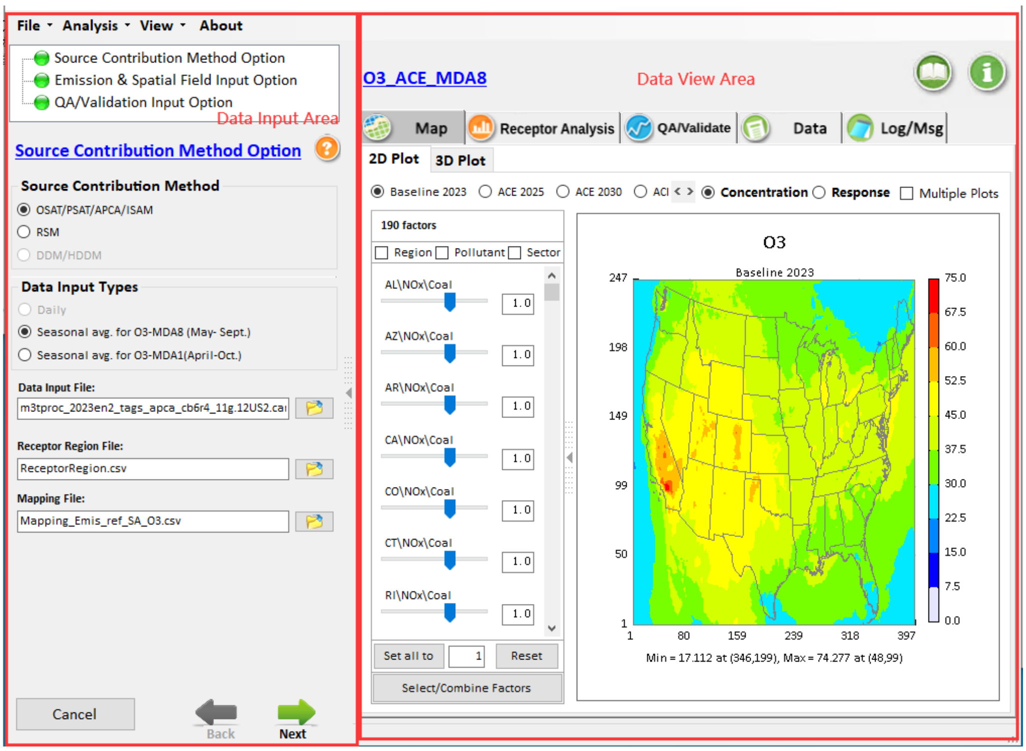


Fig. 11 Main Interface of FAST-CE

- Click the **File** button on the toolbar of the main interface, there are three options that users can choose.
  1) Go to **File**, click **Open Projec**t button, locate the *.proj file and open it.
  2) Click the **New Project** button to create a new project.
  3) Click the **Save Project** button to save a created project.
- Click the **View** button on the toolbar of the main interface, there are two options that users can choose.
  1) Click the **Setting Viewer** button to view the setting interface.
  2) Click the **Data Viewer** button to view the visual analysis interface.
- Click the **Analysis** button to select the target pollutant (e.g., PM, Ozone) to be analyzed.
- Click the **About** button to see the version and copyright information of FAST-CE.
- To complete a FAST-CE case, users should configure three streamline options to input data and configure the calculation parameters step by step. The three options are called Source Contribution Input Option, Emission & Spatial Field Input Option, and QA/Validation Input Option.

5 Run FAST-CE

5.1 Source Contribution Input Option

This option allows the user to select different source contribution methods and set up the input data and parameter configurations. FAST-CE 1.7 includes two kinds of source contribution methods: **OSAT/PSAT/APCA/ISMA** and **RSM** method. The GUI and input data are different for different methods.

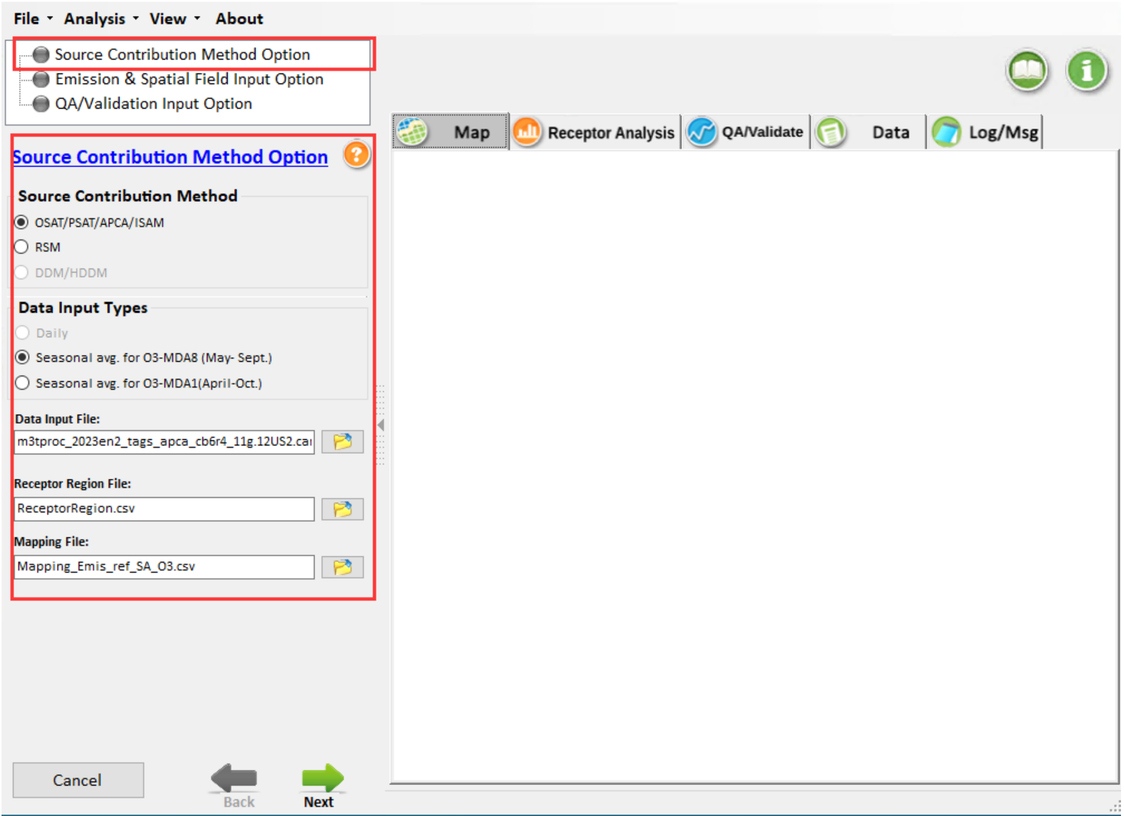


Fig. 12 Source Contribution Input Option

5.1.1 Input option for OSAT/PSAT/APCA/ISMA method

For the OSAT/PSAT/APCA/ISMA methods, there are 4 necessary sub-options: **Data Input Types**, **Data Input File**, **Receptor Region File**, and **Mapping File**.

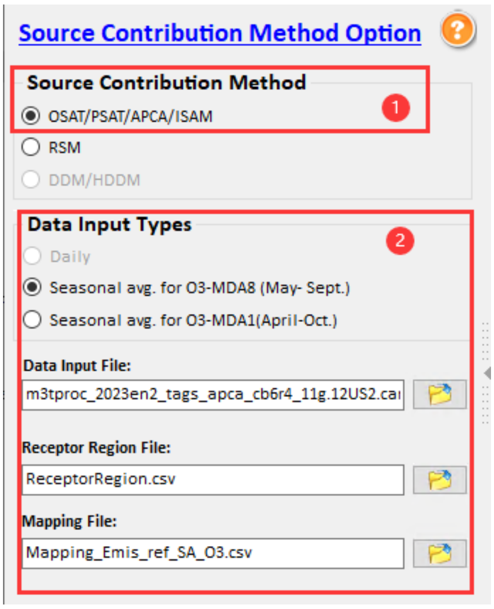


Fig. 13 Input option for OSAT/PSAT/APCA/ISMA method

- **Data Input Type:** allows the user to specify the format of the input file (Daily, Seasonal Average for O_3-MDA8 (May-Sept.), Seasonal Average for O_3-MDA1 (April-Oct.).

- **Data Input File:** allows the user to specify the file name and path of the input model data. The **OSAT/PSAT** method requires the Comprehensive Air Quality Model with Extensions (CAMx) model data. The **ISAM** method requires the Community Multiscale Air Quality (CMAQ) model data.
- **Receptor Region File:** A *.csv file which defines the grids of the analyzed receptors.
- **Mapping File:** A *.csv file, which is used to link the tagged variables of CAMx model data with control factors (Region, Pollutant, Source) of FAST-CE.

5.1.2 Input option for RSM method

For the **RSM** method**,** there are 2 necessary sub-options: **Input RSM File** and **Receptor Region File.**

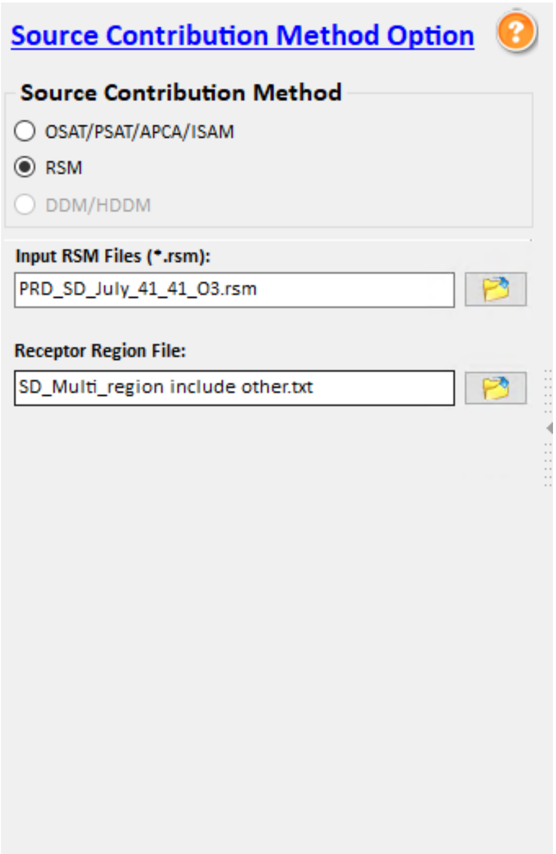


Fig. 14 Input option for RSM method

- **Input RSM File:** Specify the path and name of a pre-run RSM file, created by RSM-VAT.
- **Receptor Region File:** Specify the path and name of a *.txt file which defines the grids of the analyzed receptors.

5.2 Emission & Spatial Field Input Option

In this option, users should set up one or more control cases and provide corresponding emission data files. Different source contribution methods require different kinds of input files.

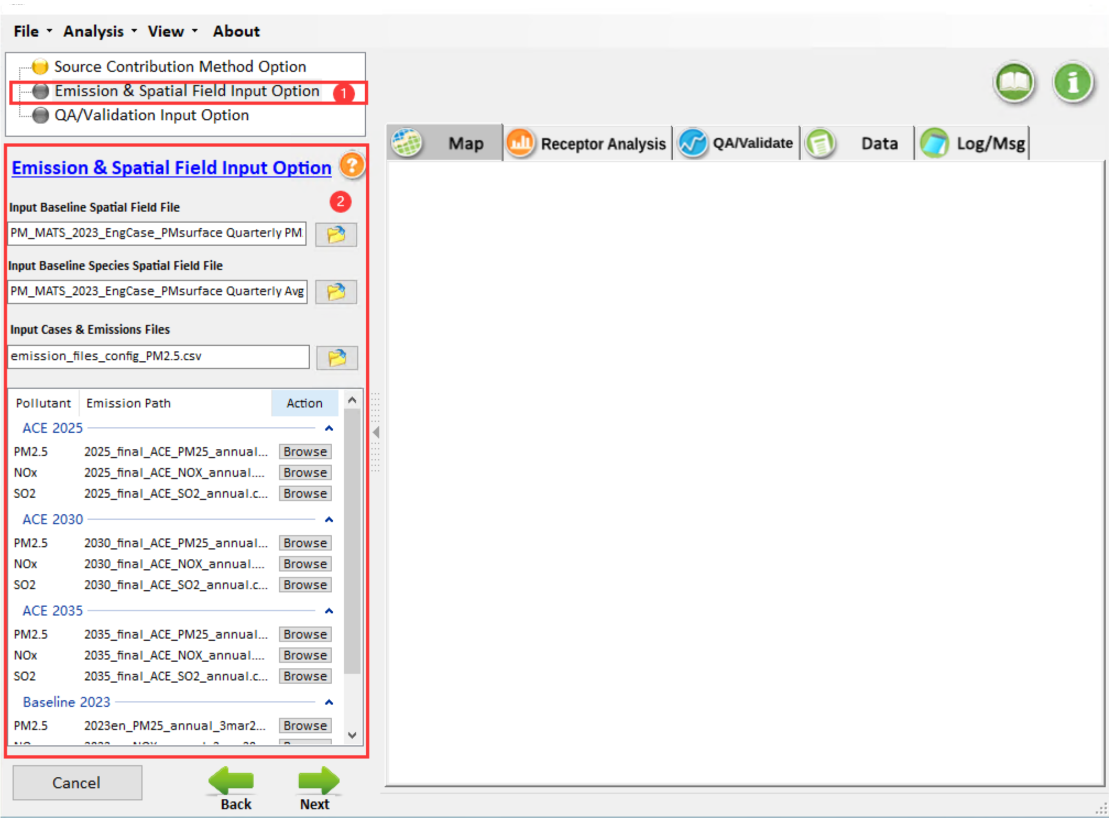


Fig. 15 Emission & Spatial Field Input Option

5.2.1 Emission & Spatial Field Input option for OSAT/PSAT/APCA/ISMA method

For OSAT/PSAT/APCA/ISMA method, there are 3 necessary sub-options: Input Baseline Spatial Field File, Input Baseline Species Spatial Field File, and Input Cases & Emission Files.

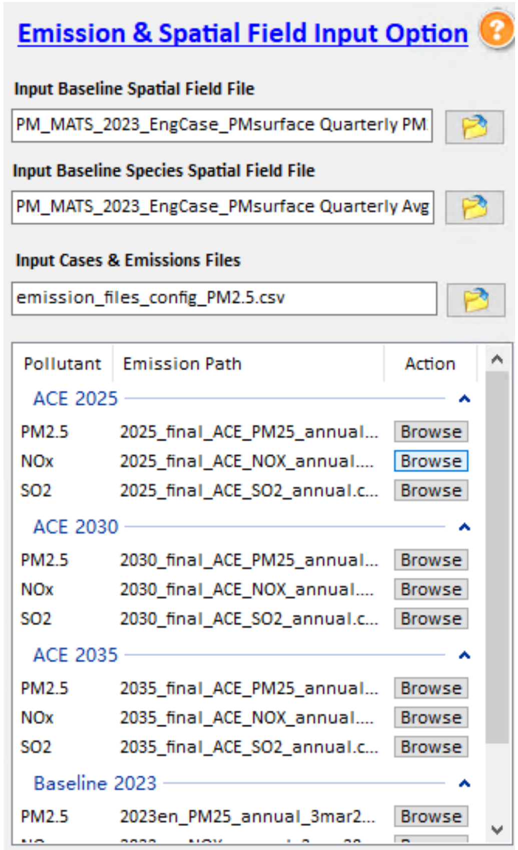


Fig. 16 Emission & Spatial Field Input Option for OSAT/PSAT/APCA/ISMA method

- **Input Baseline Spatial Field File:** Allow the user to set up the baseline spatial field data, which is generally created by SMAT-CE.
- **Input Baseline Species Spatial Field File:** This option is only for PM analysis, which allows the user to set up the spatial field data of PM species. This data file is also created by SMAT-CE.
- **Input Cases & Emission Files:** A *.csv formatted file describes the configuration information of base & control cases and corresponding emission data.

5.2.2 Emission & Spatial Field Input option for RSM method

For the **RSM** method**,** users need to set up the **Input Emission Matrix for RSM** option.

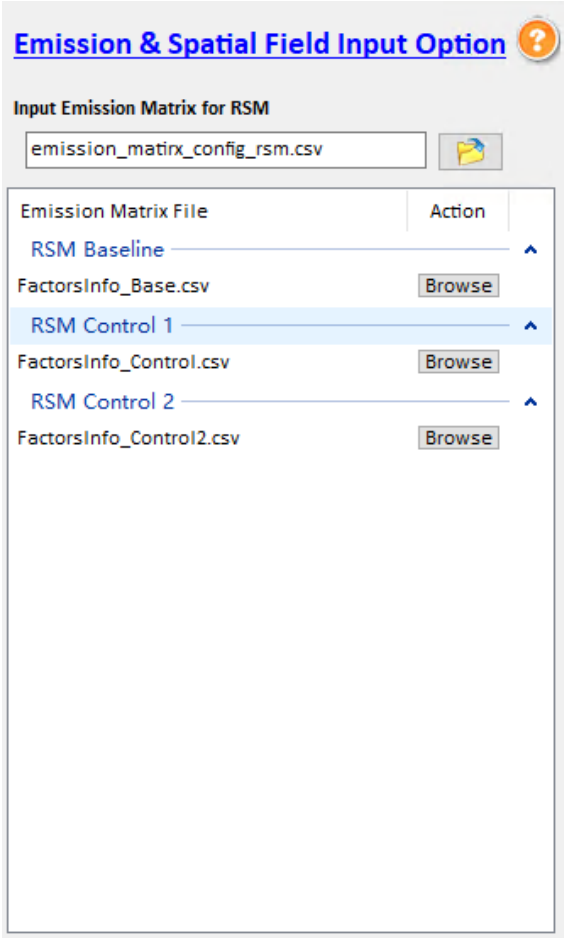


Fig. 17 Emission & Spatial Field Input Option for RSM method

- **Emission Matrix for RSM:** A *.csv file which exhibits the emission matrix of the baseline case and control cases for RSM analysis.

5.3 QA/Validation Input Option

To validate the results of FAST-CE, the QA/Validation Input Option module allows users setting up validation cases. In this option, users need to input a Validation Configuration File, *.csv formatted file that describes QA data files for each FAST-CE case.

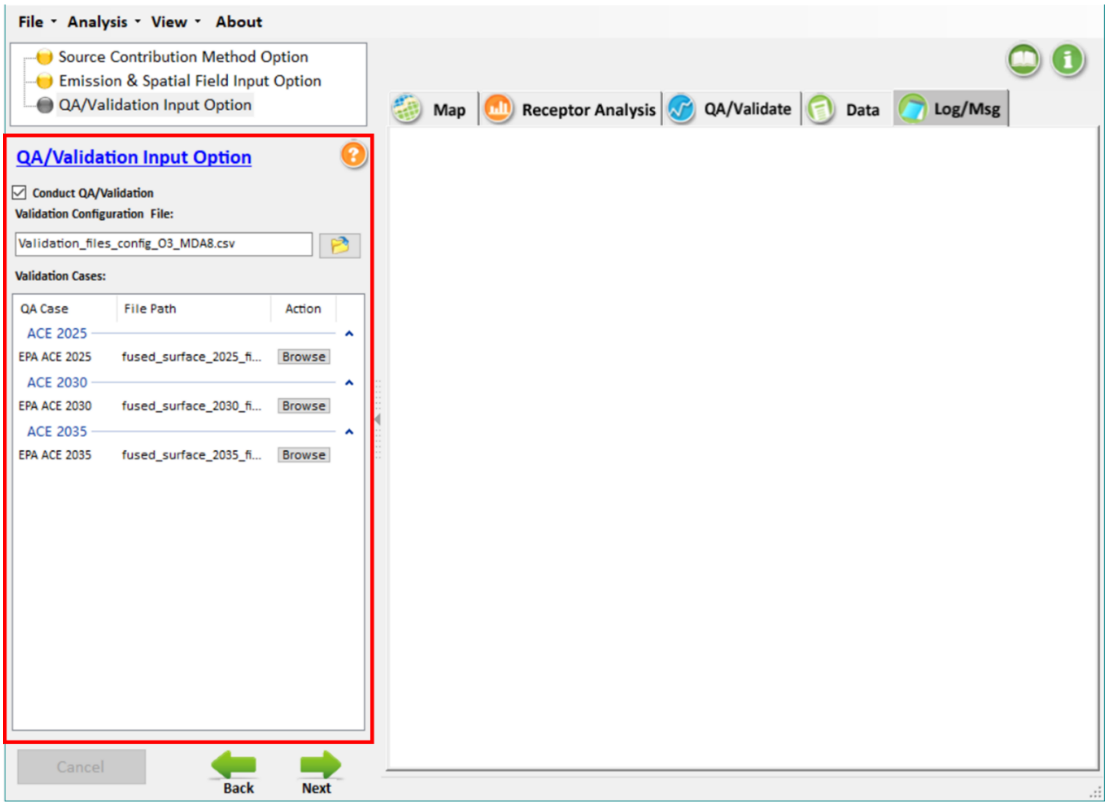


Fig. 18 QA/Validation Input Option

After the input settings are completed, users click "Next" to start running FAST-CE. Users can view the running messages through "Log/Msg", as shown in Fig. 19.

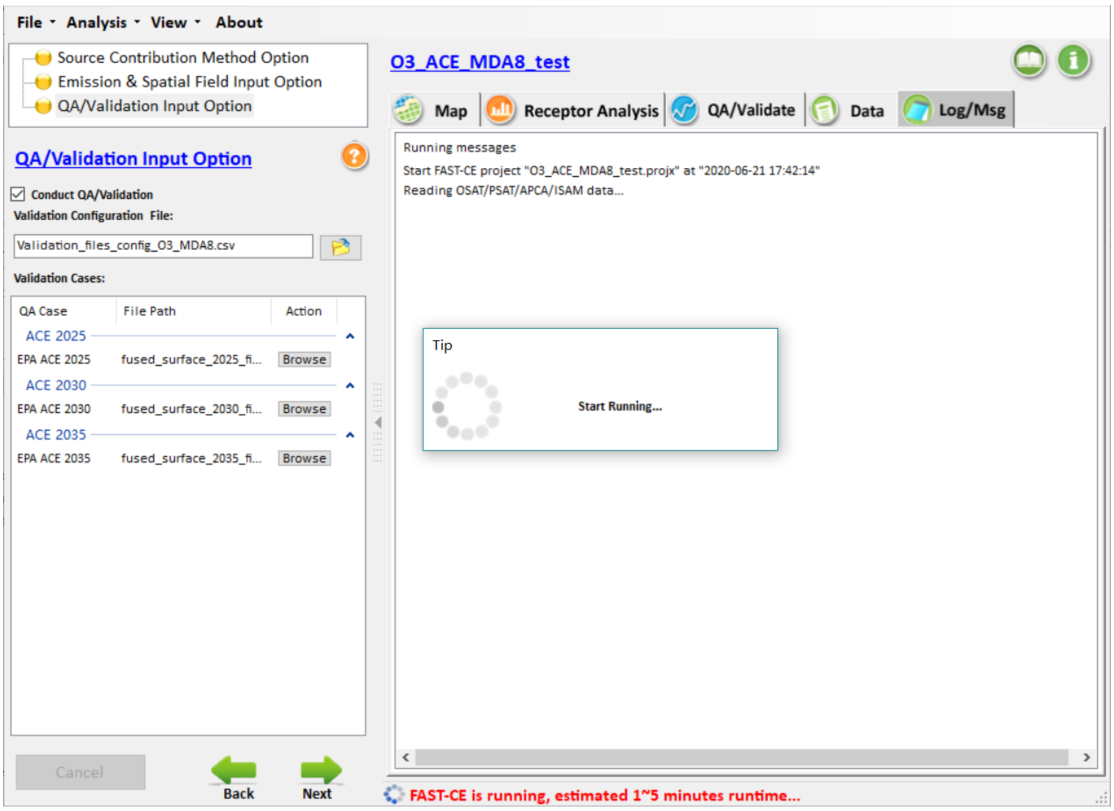


Fig. 19 Running FAST-CE

6 Operation Results

When the FAST-CE running is finished, the system provides four kinds of ways to display the source contribution analysis results, including **Map**, **Receptor Analysis, QA/Validate, and Data,** as shown in Fig. 20.

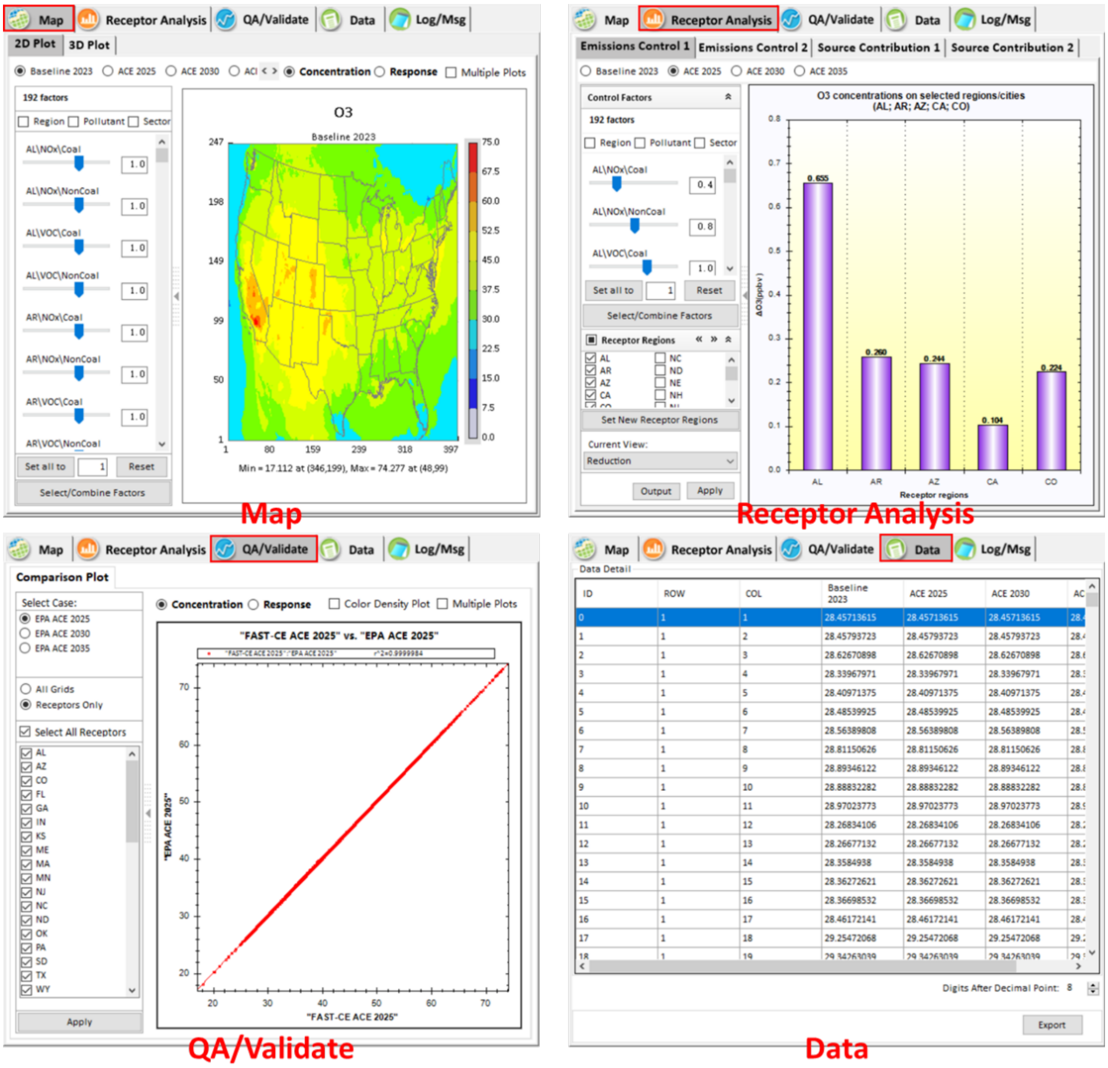


Fig. 20 Data Viewer of the FAST-CE results

6.1 Map

Under the **Map** module, users may explore the concentration/response distribution of different control scenarios. Options include the display of 2D or 3D plot types, adjustment of emission factors grouped by region, pollutant, and sector for base and control cases were provided in this module, as shown in Fig. 21.

To visualize the results, FAST-CE allows the user to:

- Select 2D/3D plot
- Configure color legend
- Show concentration or response value of base/control cases

➢ Customize the value of control factors to display the corresponding results

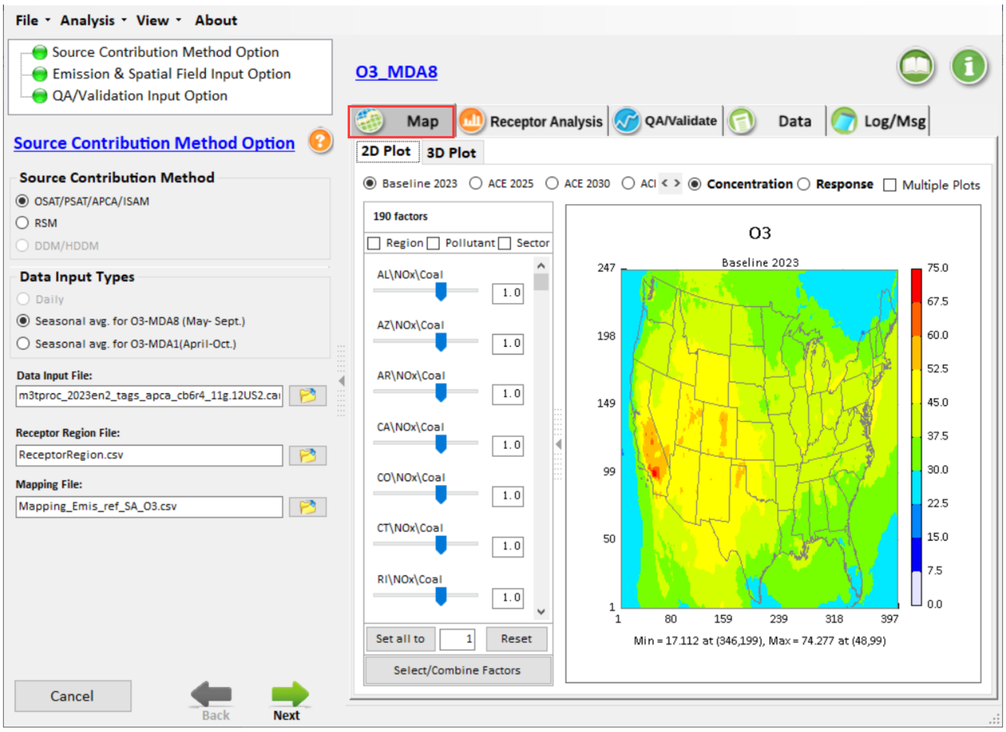


Fig. 21 Map view of FAST-CE results

6.1.1 Select 2D/3D plot

Select "**2D Plot**" or "**3D Plot**" to show a specific plot type. In general, both 2D and 3D plots will display the distribution of Concentration/Response values and show the min/max value on the bottom, and the legend scale on the right.

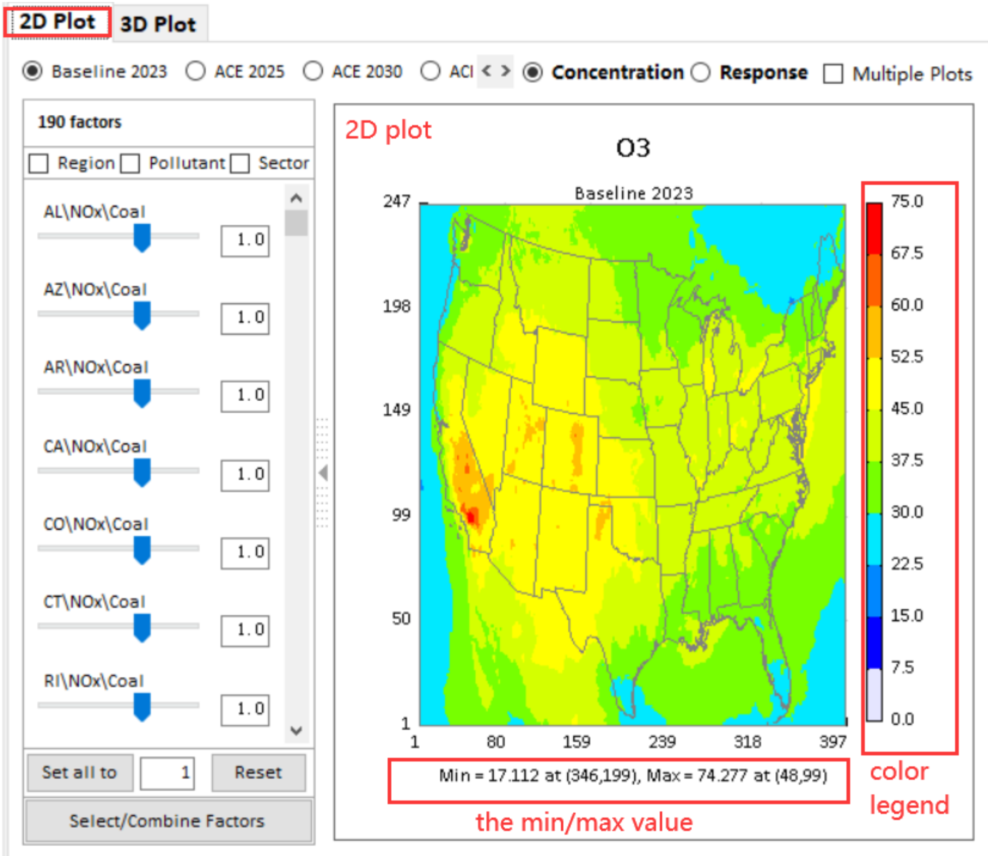


Fig. 22 2D plot

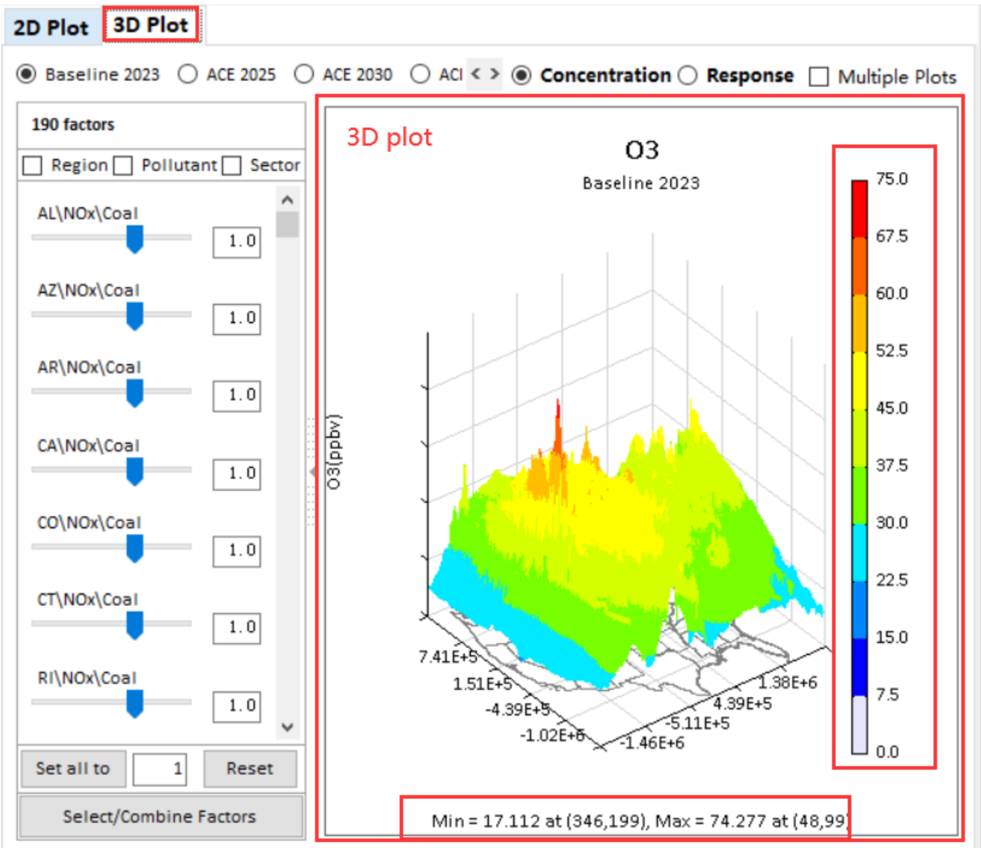


Fig. 23 3D plot

6.1.2 Configure color legend

Double-click on the color legend, to activate a pop-up configuration window as shown in Fig. 24. Users can select a different color palette and new legend scale values.

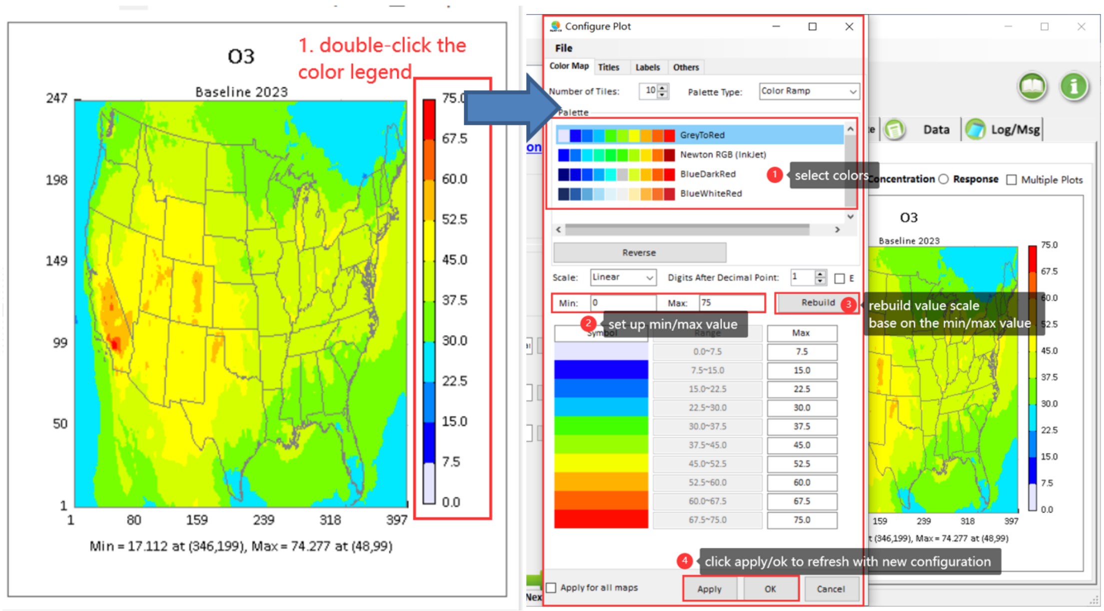


Fig. 24 Configure color legend

6.1.3 Show concentration or response value of base/control cases

Users can select either the Concentration or the Response option on the top of the map to display the concentration or response results of different cases as shown in Fig. 25.

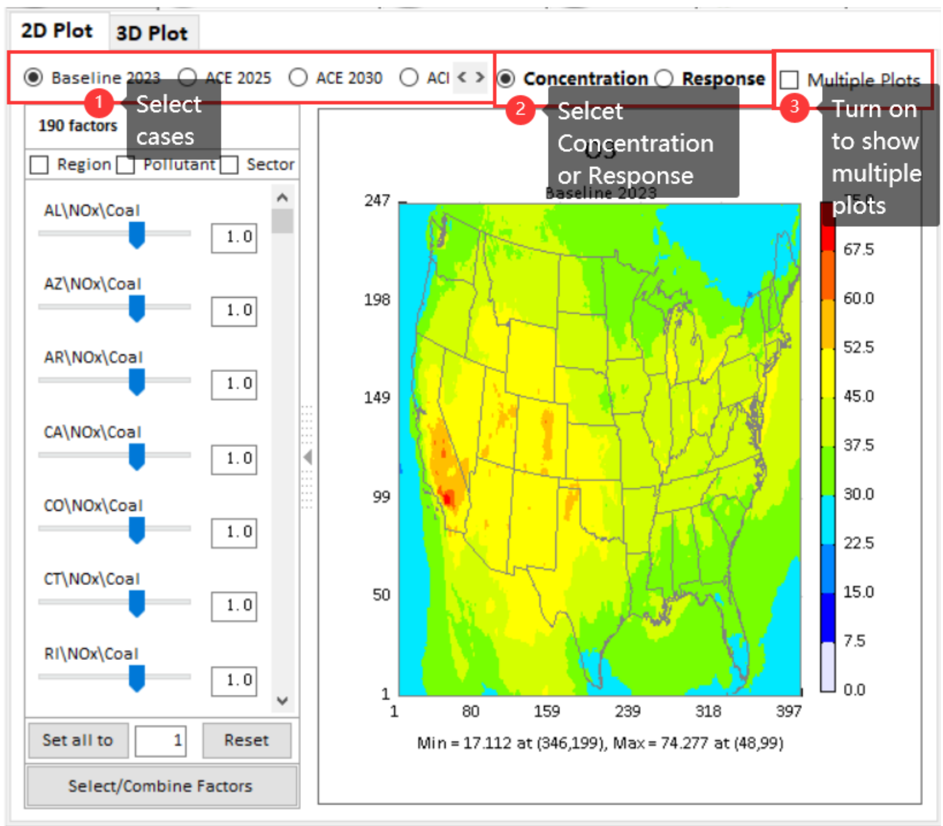


Fig. 25 Show concentration value of base/control cases

If the user selects the Response button, FAST-CE will show the distribution of the difference between base case and control case as shown in Fig. 26.

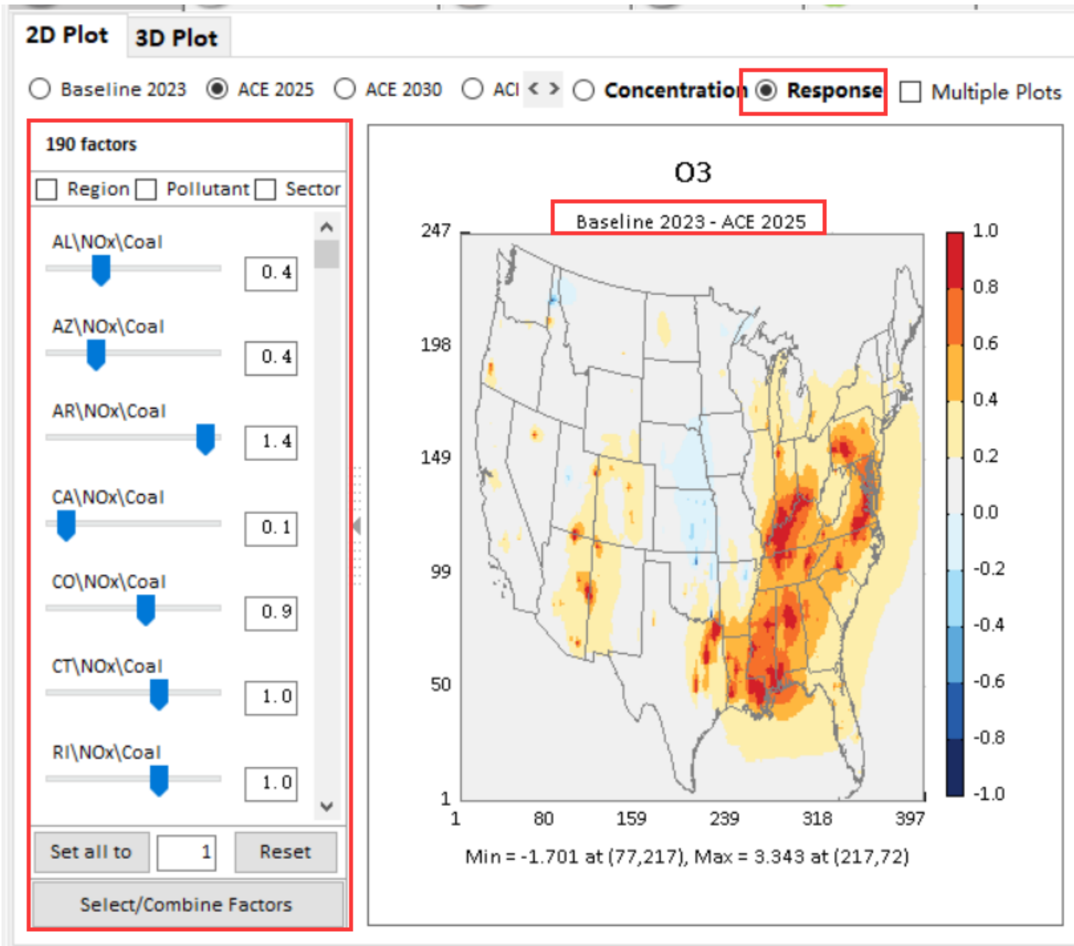


Fig. 26 Show response value of base/control cases

Users can also check the "Multiple Plots" option to display multiple results at one time.

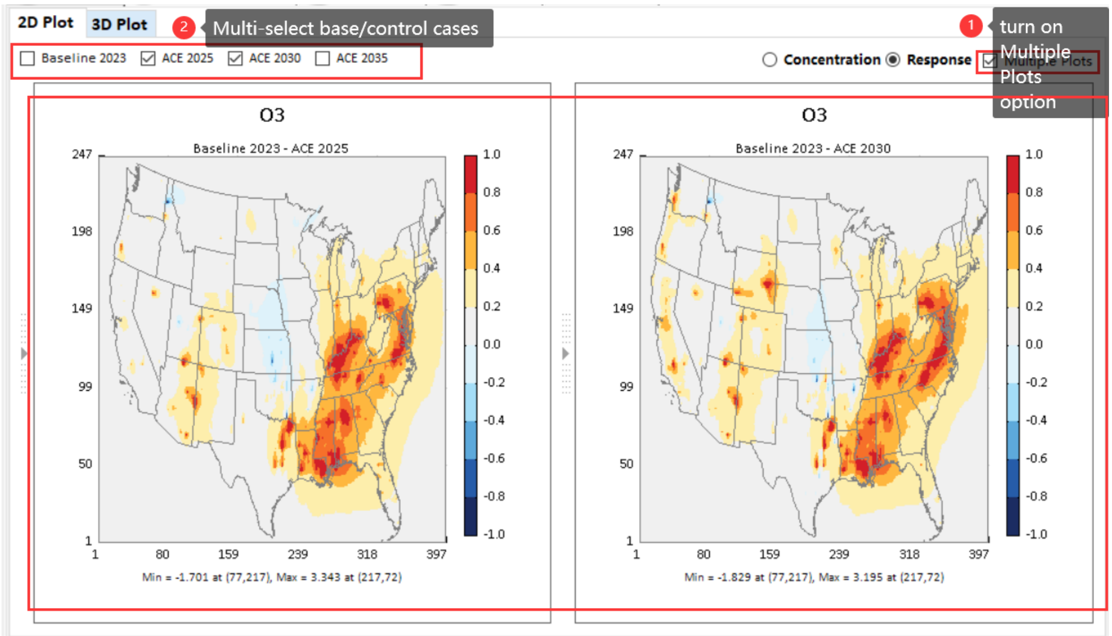


Fig. 27 Show multiple plots

6.1.4 Customize control factors

FAST-CE allows the user to flexibly change the input control factor and show the corresponding response value of concentrations in real-time. The panel on the left lists all control factors. The sliders may be adjusted to change a single factor or multiple factors at the same time.

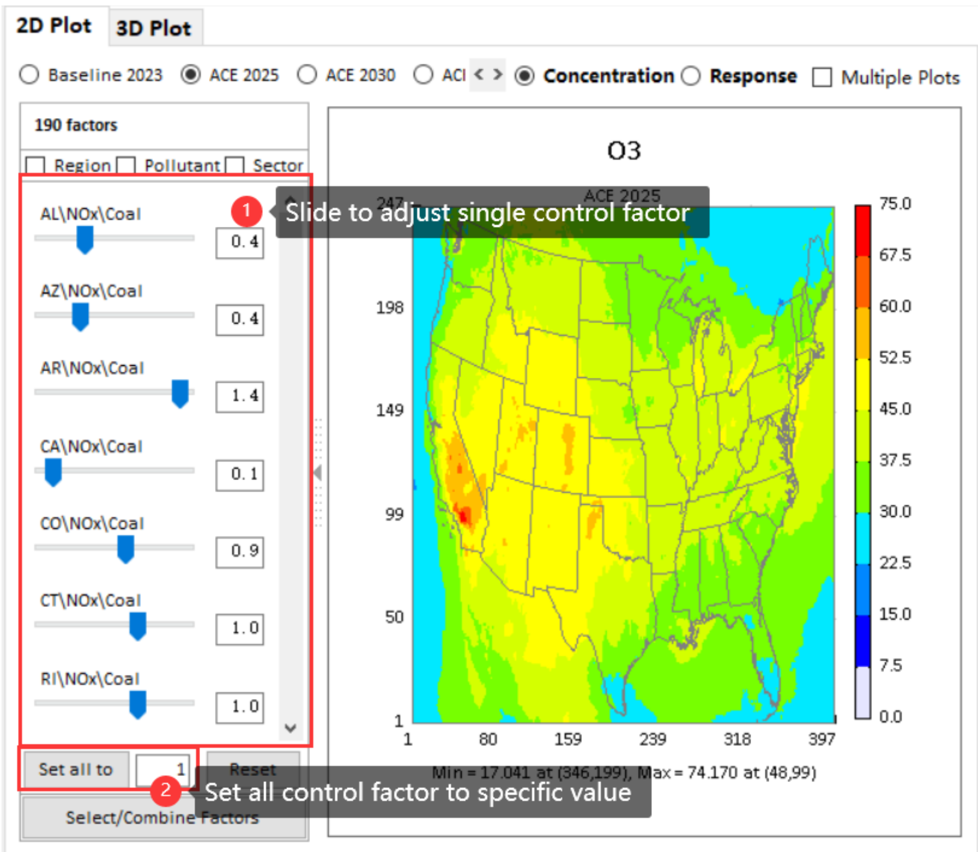


Fig. 28 Customize control factors and displaying results

Moreover, users can group/combine specific factors by region/pollutant/sector in the control factors panel to change the selected control factors to some extent.

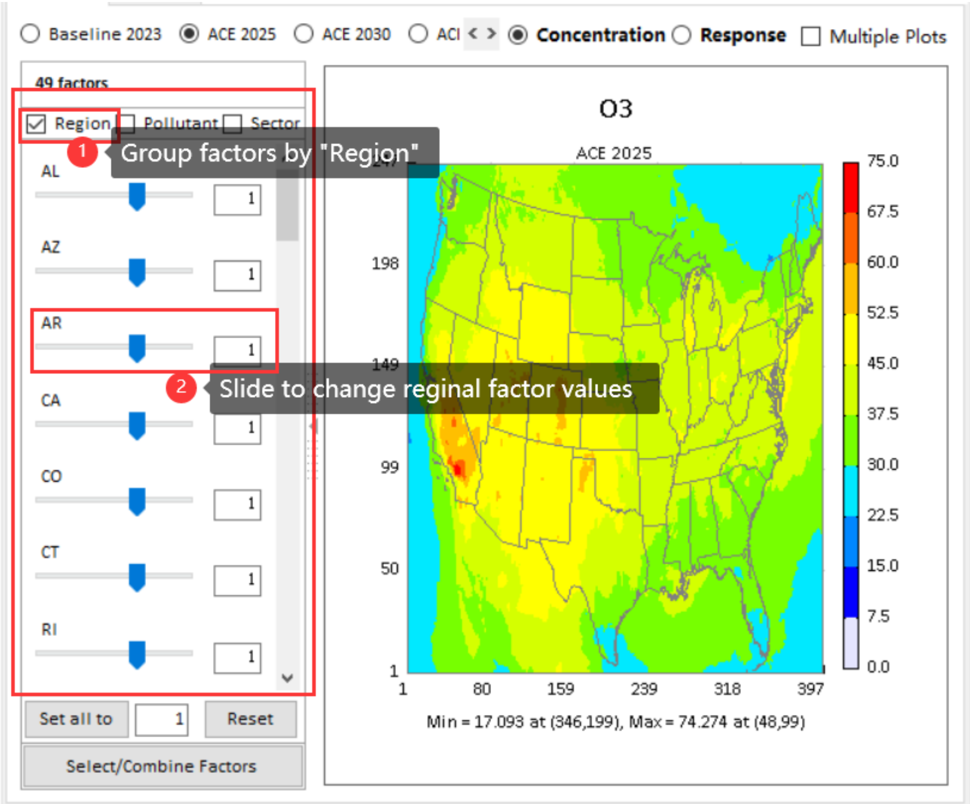


Fig. 29 Group/combine specific factors

Users can also define control factors through the following two ways according to their needs.

(1) Pre-defined control filter: all existing control factors can be classified by pre-defined filters, including "Region", "Pollutant" and "Sector". Users can select interested filter to re-organized control factors and get the corresponding air quality surfaces by changing these new defined factors, as shown in Fig. 30.

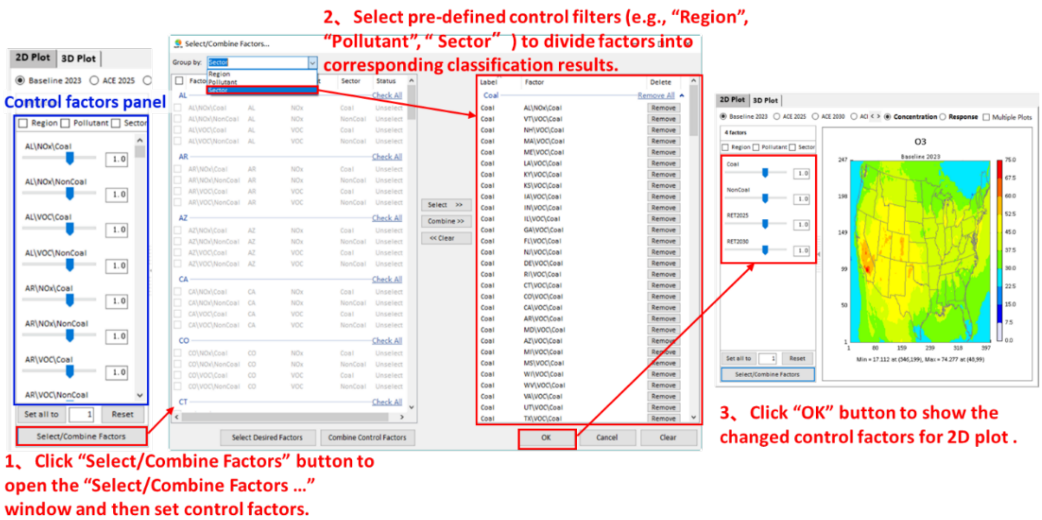
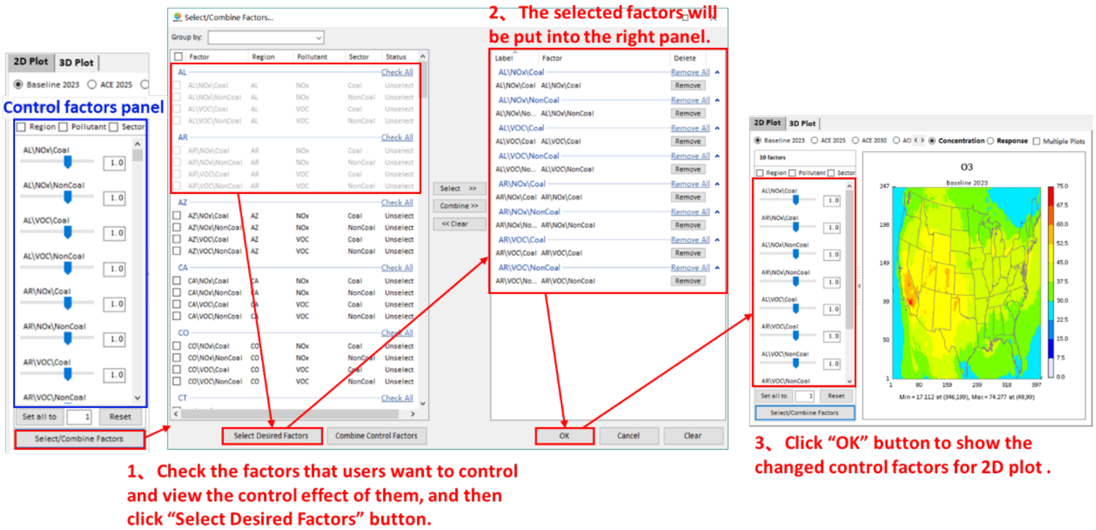
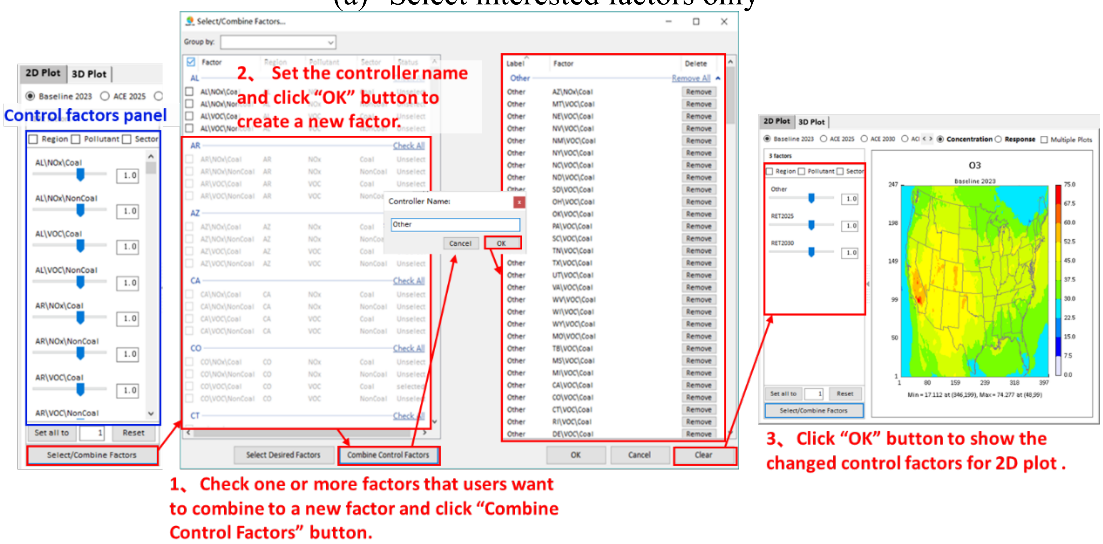


Fig. 30 Pre-defined control filter

(2) User-defined control method: it provides two kinds of ways to define control factors as needed. a) Select interested factors only. This means that those factors you want to control will be selected and listed in control factors panel while those unselected factors will be kept as baseline (equal to 1). To do this, users just need to check the interested factors from the left panel of Fig. 31(a), and then click "Select Desired Factors" to move these factors to right panel and finally click "OK" to return control factors panel. b) Select any combination of factors. This means that you can combine one or more factors to form a new factor by using "Combine Control Factors", as shown in Fig. 31(b).



(a) Select interested factors only



(b) Select any combination of factors

Fig. 31 User-defined control method

6.2 Receptor Analysis

Under the **Receptor Analysis** module, users can also view the effects of emission reduction at different scales through the chart and configure the plotting according to their preferences.

There are four types of charts in this module:

(1) Emission Control 1

(2) Emission Control 2

(3) Source Contribution 1

(4) Source Contribution 2

6.2.1 Emission Control 1

Under **the Emission Control 1** module, users can view the effects of different emission control scenarios on selected receptor regions through bar charts.

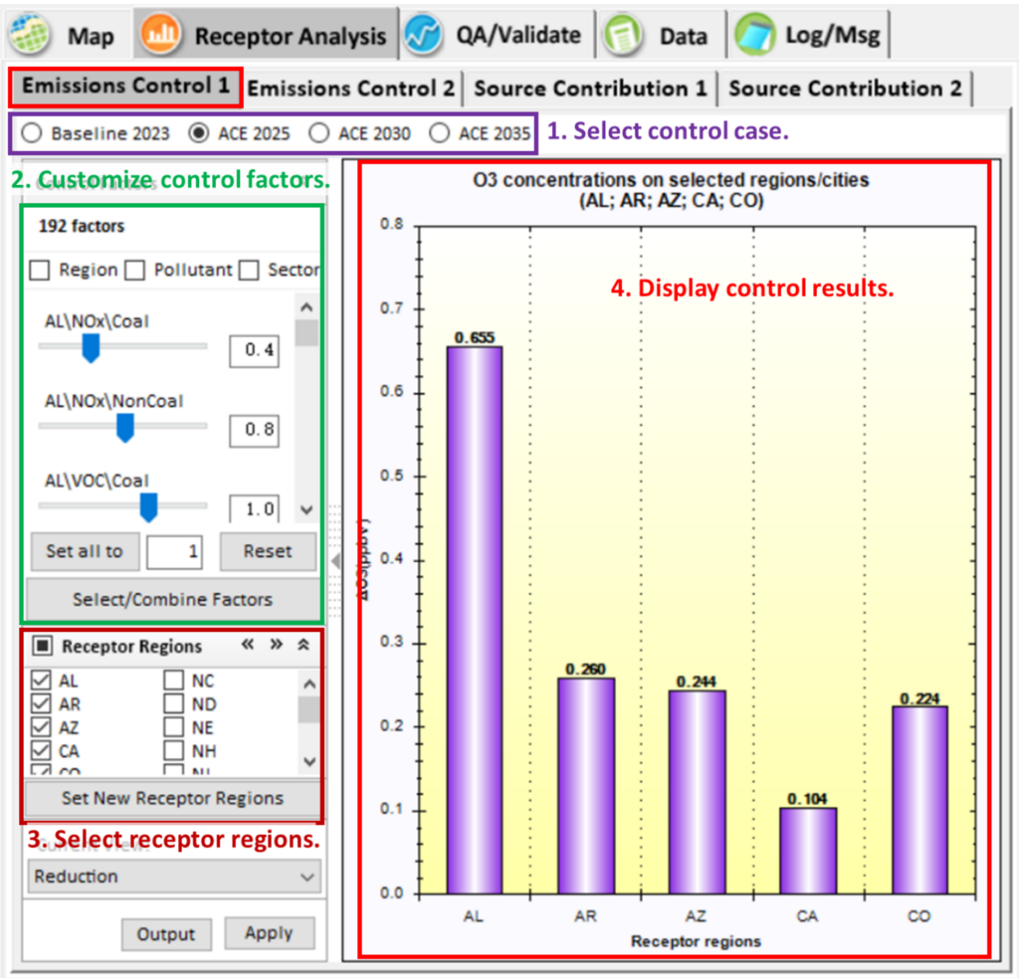


Fig. 32 Emission Control 1

6.2.2 Emission Control 2

Under **the Emission Control 2** module, users can view the effects of emission control scenarios at different levels in one bar chart.

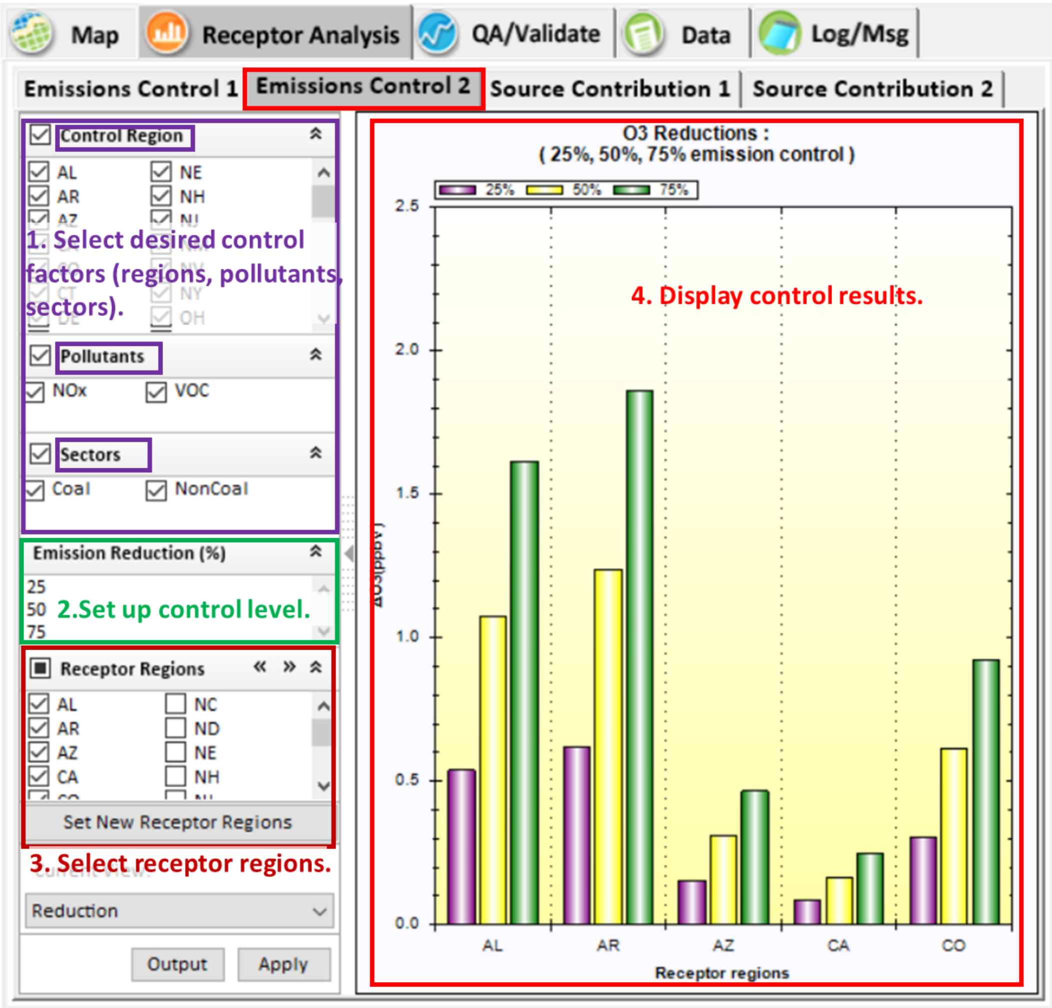


Fig. 33 Emission Control 2

6.2.3 Source Contribution 1

The **Source Contribution 1** module displays a bar chart of the total source contribution to receptors caused by all user-selected control factors.

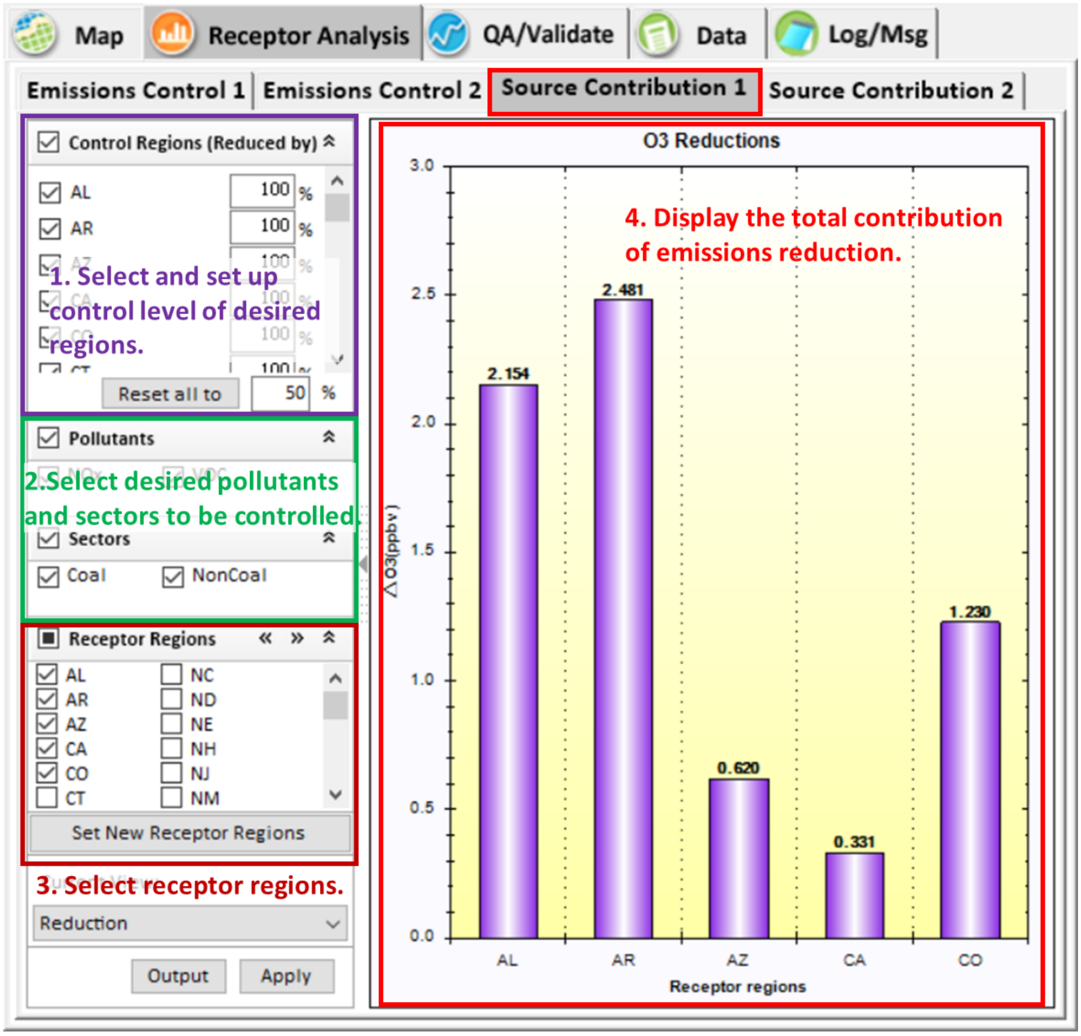


Fig. 34 Source Contribution 1

6.2.4 Source Contribution 2

The **Source Contribution 2** module displays a stacked bar chart of the source contribution to receptors caused by each user-selected control factor.

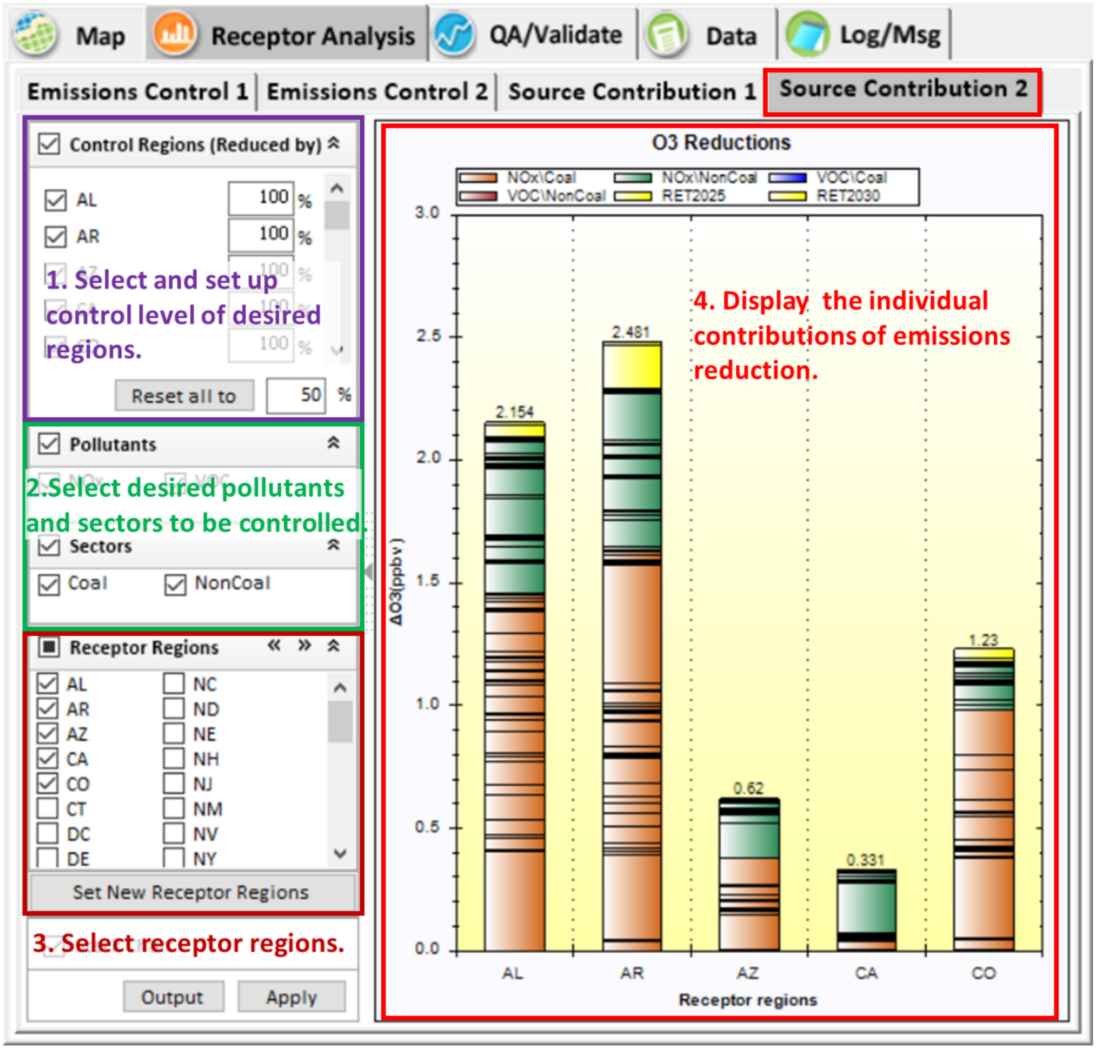


Fig. 35 Source Contribution 2

6.2.5 Customize receptor regions

FAST-CE allows the user to flexibly customize the receptor regions and show the corresponding response results of new receptor regions in real-time. For example, users can select desired states or CBSA regions by selecting the default file "US_states.csv" or "US_cbsa.csv" or checking the regions of interest on the right panel, and then click "Apply" to display the corresponding response results of new receptor regions (Fig. 36). Users can also add new receptor regions by importing receptor region files in the specified format according to their needs (Fig. 37). Besides, users can extract the desired regions for further study.

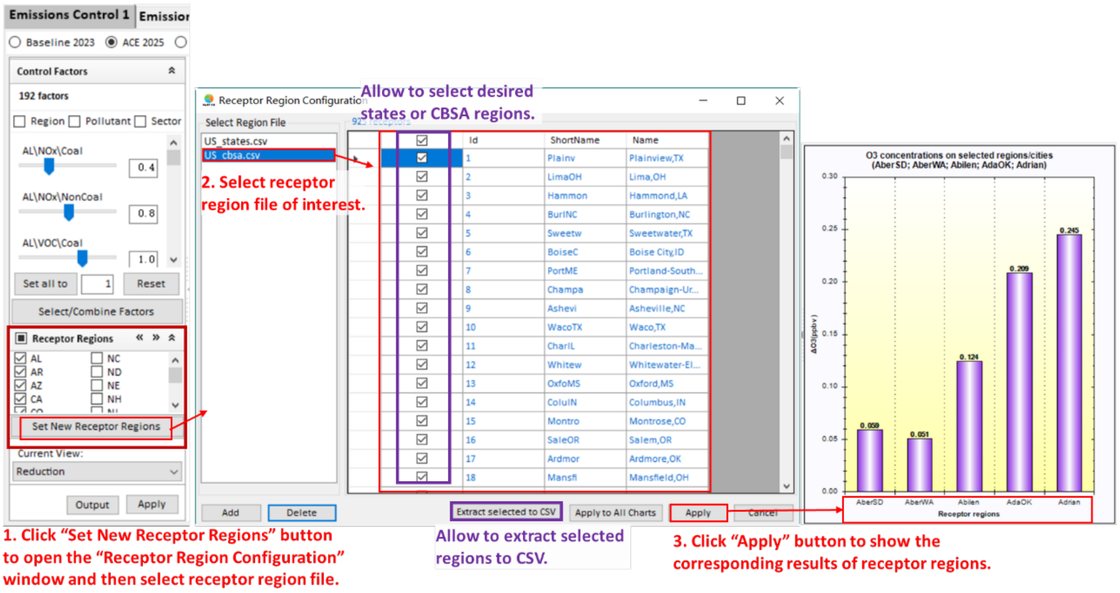


Fig. 36 Select receptor regions of interest

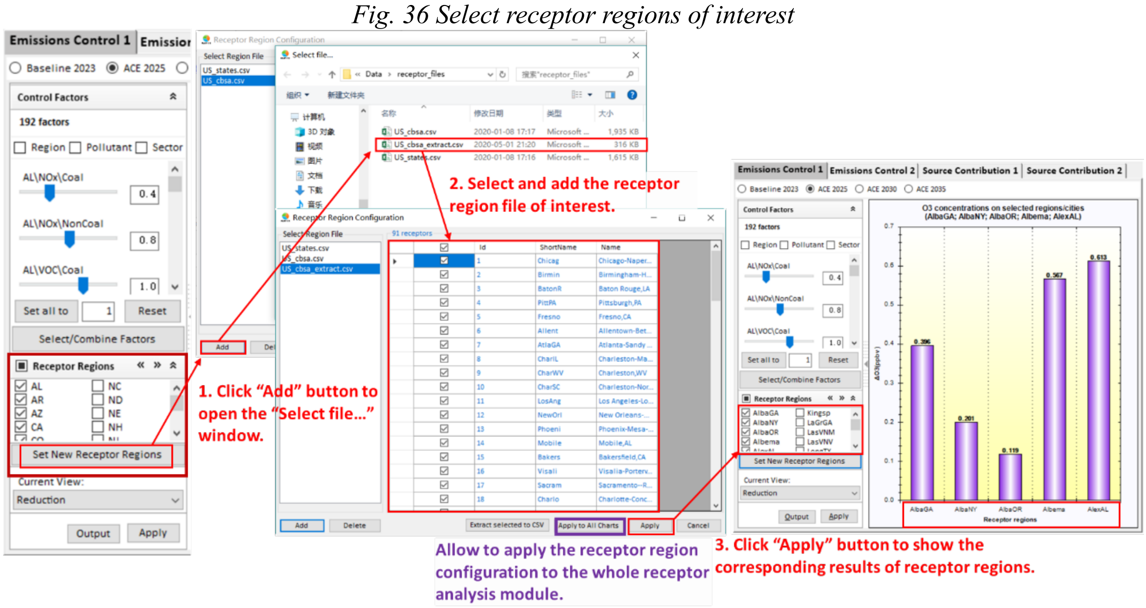


Fig. 37 Add new receptor regions

6.3 QA/Validation

The **QA/Validation** module evaluates the performance of FAST-CE. Users can specific the receptors or grids to be included in the analysis for generating the scatter plots to compare the user-generated FAST-CE results with EPA validation data, as shown in Fig. 38. This module not only supports to display the comparison results about concentration between FAST-CE predicted and EPA but their corresponding response comparison results. The default scatter plots displayed are normal scatter plots, but users can switch to the color density scatter plots by checking "Color Density Plot". Besides, users can also compare the results of multiple control scenarios simultaneously by checking the "Multiple Plots".

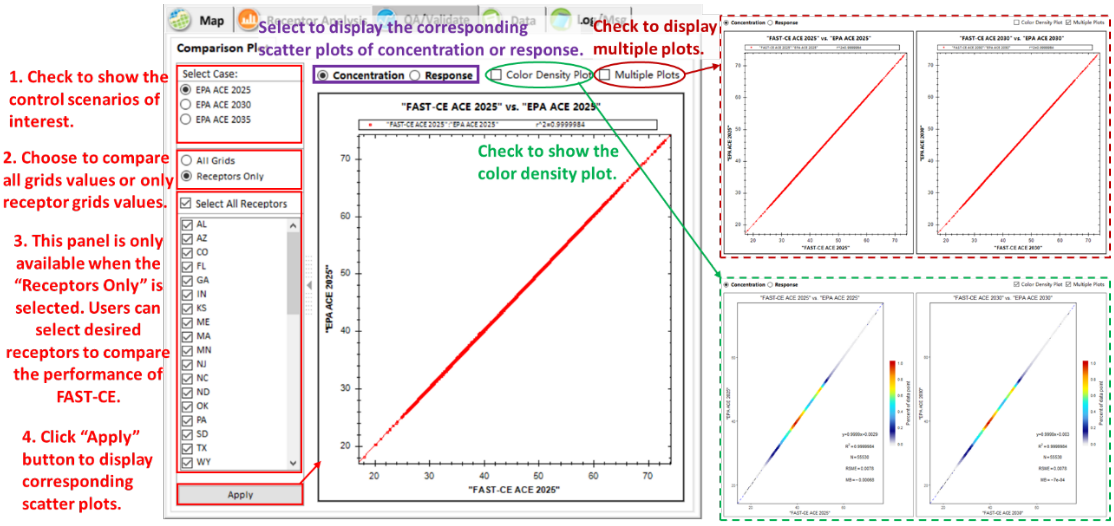
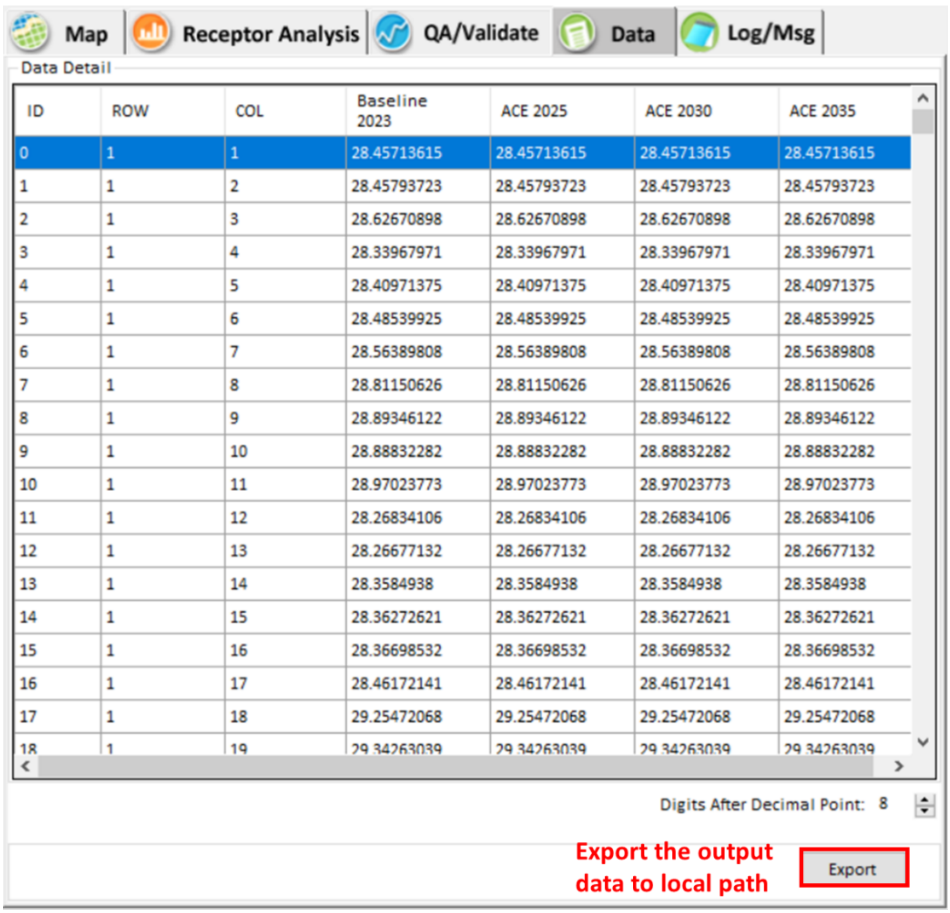


Fig. 38 QA/Validate module

6.4 Data

The **Data** module provides more detailed information about the concentration of the target pollutant at each grid. Users can export the data for further study, as shown in Fig. 39.



ID	ROW	COL	Baseline 2023	ACE 2025	ACE 2030	ACE 2035
0	1	1	28.45713615	28.45713615	28.45713615	28.45713615
1	1	2	28.45793723	28.45793723	28.45793723	28.45793723
2	1	3	28.62670898	28.62670898	28.62670898	28.62670898
3	1	4	28.33967971	28.33967971	28.33967971	28.33967971
4	1	5	28.40971375	28.40971375	28.40971375	28.40971375
5	1	6	28.48539925	28.48539925	28.48539925	28.48539925
6	1	7	28.56389808	28.56389808	28.56389808	28.56389808
7	1	8	28.81150626	28.81150626	28.81150626	28.81150626
8	1	9	28.89346122	28.89346122	28.89346122	28.89346122
9	1	10	28.88832282	28.88832282	28.88832282	28.88832282
10	1	11	28.97023773	28.97023773	28.97023773	28.97023773
11	1	12	28.26834106	28.26834106	28.26834106	28.26834106
12	1	13	28.26677132	28.26677132	28.26677132	28.26677132
13	1	14	28.3584938	28.3584938	28.3584938	28.3584938
14	1	15	28.36272621	28.36272621	28.36272621	28.36272621
15	1	16	28.36698532	28.36698532	28.36698532	28.36698532
16	1	17	28.46172141	28.46172141	28.46172141	28.46172141
17	1	18	29.25472068	29.25472068	29.25472068	29.25472068
18	1	19	29.34263039	29.34263039	29.34263039	29.34263039

Fig. 39 Detailed data results and configuration

7 Case Study

To illustrate how to run the FAST-CE, an example case study of the OSAT method in the U.S. is given as follows.

7.1 Ozone MDA8 Analysis – OSAT.

7.1.1 Create a new project

- Click the **File** button and choose the **New Project** option to create a new project.
- Click the **Analysis** button and choose **the Ozone** option to create a new O_3 project.

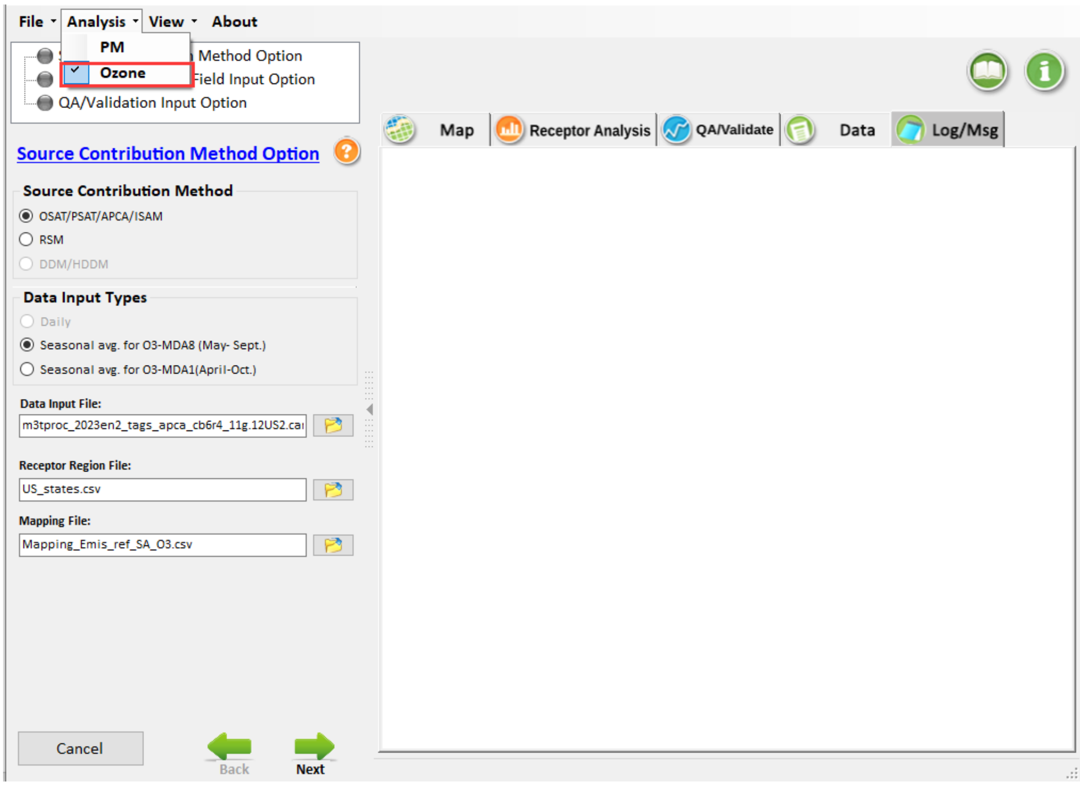


Fig. 40 Create a new O3 project

7.1.2 Set up input parameters

- Double-click the Source Contribution Method Option, then select the OSAT/PAST/APCA/ISAM method.

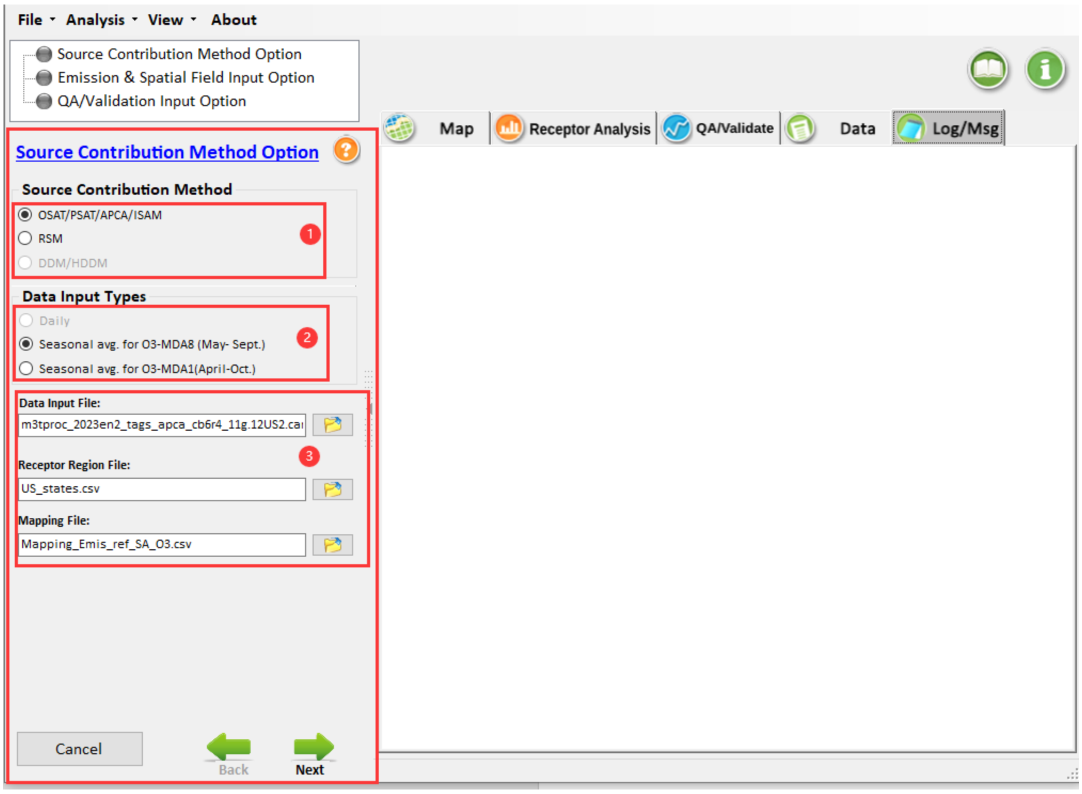


Fig. 41 Source Contribution Method Option for O_3-MDA8 analysis

- Set the **Data Input Type** to Seasonal avg for O_3-MDA8 (May-Sept), which can be explained by the nonattainment of the National Ambient Air Quality Standards (NAAQS) over many areas in the U.S caused by the high summertime ozone concentrations (Hakami, Seinfeld et al. 2006, Liao, Hou et al. 2014, Couzo, Mccann et al. 2016).
- Click button and choose 

  "m3tproc_2023en2_tags_apca_cb6r4_11g.12US2.camx.contrib8hrmax_LST.5-9.ioapi" as the **Data Input File**, "US_states.csv" as the **Receptor Region File** and "Mapping_Emis_ref_SA_O3.csv" as the **Mapping File.** The details of the Receptor Region File and Mapping File are shown in Fig. 42 and Fig. 43, respectively.

id	col	row	ratio	code	name
0	271	48	9.737915	AL	Alabama
0	272	48	12.86595	AL	Alabama
0	273	48	5.293122	AL	Alabama
0	274	48	2.088029	AL	Alabama
0	270	49	0.282446	AL	Alabama
0	271	49	6.46118	AL	Alabama
0	272	49	23.70747	AL	Alabama
0	273	49	7.831478	AL	Alabama
0	274	49	12.34819	AL	Alabama
0	275	49	29.54417	AL	Alabama
0	276	49	64.83163	AL	Alabama
0	277	49	28.82144	AL	Alabama
0	278	49	0.166814	AL	Alabama
0	270	50	34.35461	AL	Alabama
0	271	50	90.43996	AL	Alabama
0	272	50	97.86503	AL	Alabama
0	273	50	0.452968	AL	Alabama
0	274	50	19.25944	AL	Alabama
0	275	50	87.06078	AL	Alabama
0	276	50	100	AL	Alabama
0	277	50	99.88901	AL	Alabama
0	278	50	24.55923	AL	Alabama
0	270	51	50.19201	AL	Alabama
0	271	51	100	AL	Alabama
0	272	51	98.41516	AL	Alabama
0	273	51	6.253357	AL	Alabama
0	274	51	57.52388	AL	Alabama

Fig. 42 Receptor Region File

IPM_Variables	RRF_Emiss	Region	Source	Pollutant
AL_C_03N	RRF_AL_C_NOx	AL	Coal	NOx
AZ_C_03N	RRF_AZ_C_NOx	AZ	Coal	NOx
AR_C_03N	RRF_AR_C_NOx	AR	Coal	NOx
CA_C_03N	RRF_CA_C_NOx	CA	Coal	NOx
CO_C_03N	RRF_CO_C_NOx	CO	Coal	NOx
CT_RI_C_03N	RRF_CT+RI_C_NOx	CT+RI	Coal	NOx
DE_NJ_C_03N	RRF_DE+NJ_C_NOx	DE+NJ	Coal	NOx
FL_C_03N	RRF_FL_C_NOx	FL	Coal	NOx
GA_C_03N	RRF_GA_C_NOx	GA	Coal	NOx
IL_C_03N	RRF_IL_C_NOx	IL	Coal	NOx
IN_C_03N	RRF_IN_C_NOx	IN	Coal	NOx
IA_C_03N	RRF_IA_C_NOx	IA	Coal	NOx
KS_C_03N	RRF_KS_C_NOx	KS	Coal	NOx
KY_C_03N	RRF_KY_C_NOx	KY	Coal	NOx
LA_C_03N	RRF_LA_C_NOx	LA	Coal	NOx
MEMANHVT_C_03N	RRF_ME+MA+NH+VT_C_NOx	ME+MA+NH-	Coal	NOx
MD_C_03N	RRF_MD_C_NOx	MD	Coal	NOx
MI_C_03N	RRF_MI_C_NOx	MI	Coal	NOx
MN_C_03N	RRF_MN_C_NOx	MN	Coal	NOx
MS_C_03N	RRF_MS_C_NOx	MS	Coal	NOx
MO_C_03N	RRF_MO_C_NOx	MO	Coal	NOx
MT_C_03N	RRF_MT_C_NOx	MT	Coal	NOx
NE_C_03N	RRF_NE_C_NOx	NE	Coal	NOx
NV_C_03N	RRF_NV_C_NOx	NV	Coal	NOx
NM_C_03N	RRF_NM_C_NOx	NM	Coal	NOx
NY_C_03N	RRF_NY_C_NOx	NY	Coal	NOx
NC_C_03N	RRF_NC_C_NOx	NC	Coal	NOx

Fig. 43 Mapping File

➢ Click  and go to set up the Emission & Spatial Field Input Option.

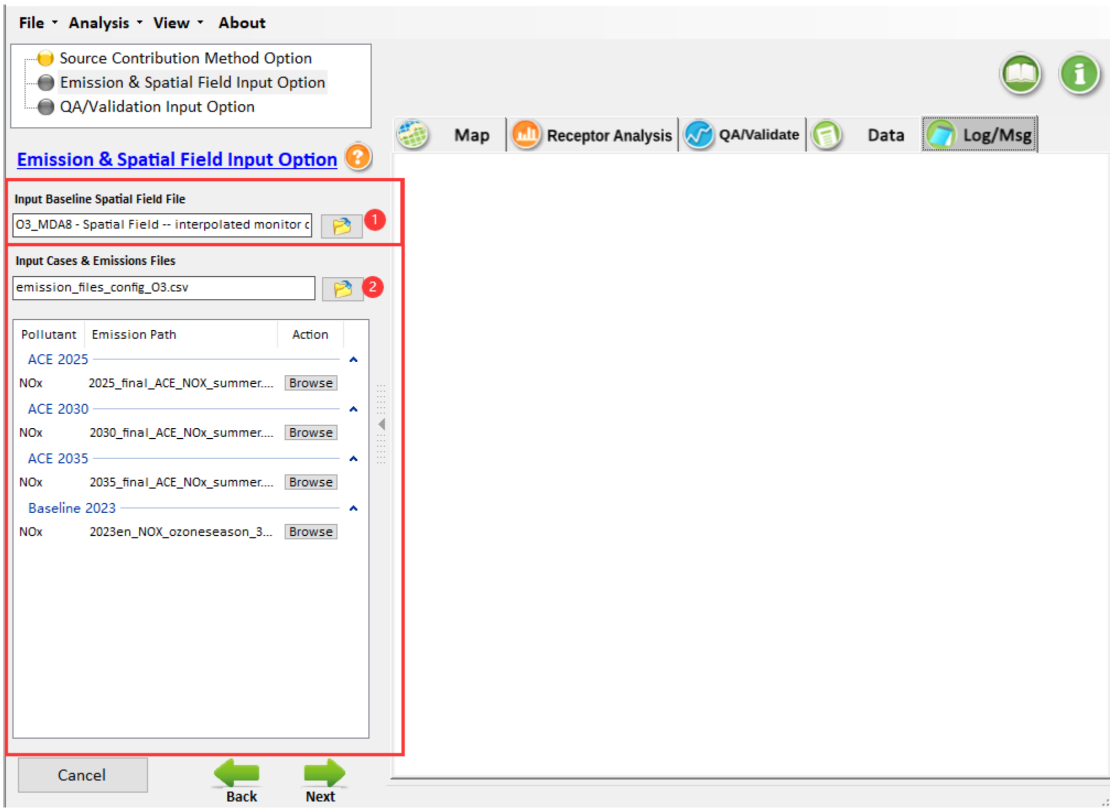


Fig. 44 Emission & Spatial Field Input Option for O_3-MDA8 analysis

➢ Click  button and select

"O3_MDA8 - Spatial Field -- interpolated monitor data, temporally adjusted; gradient-adjusted monitor data, 2023.csv" as the **Input Baseline Spatial File.** The details of the Baseline Spatial File are shown in Fig. 45.

Year_id	_type	lat	long	date	ga_conc	i_b_o3(eVNA)	i_f_o3(eVNA)	b_o3_model	f_o3_model	ppb	days	referencecell	rrf
1001		22.84721	-119.977	2012	31.21051	28.78528976	28.45713615	31.21051025	30.85471044	15	153	1001	0.9886
1002		22.94839	-120.006	2012	31.21051	28.78561974	28.45746422	31.21051025	30.85471044	15	153	1002	0.9886
1003		23.04962	-120.034	2012	31.27938	28.87817383	28.55762482	31.2793808	30.93217967	15	153	1003	0.9889
1004		23.15088	-120.063	2012	31.2672	28.8784256	28.56076241	31.26720047	30.92326126	15	153	1004	0.989
1005		23.25218	-120.091	2012	31.28422	28.65414047	28.33034897	31.28421974	30.93070806	15	153	1005	0.9887
1006		23.35351	-120.12	2012	31.29253	28.65569305	28.32042122	31.29253006	30.92640746	15	153	1006	0.9883
1007		23.45489	-120.149	2012	31.32635	28.6572113	28.29899597	31.32634926	30.93476989	14	153	1007	0.9875
1008		23.5563	-120.178	2012	31.3349	28.65869522	28.29472923	31.3348999	30.93694667	14	153	1008	0.9873
1009		23.65775	-120.206	2012	31.3412	28.6601429	28.293293	31.34119987	30.94003252	13	153	1009	0.9872
1010		23.75923	-120.235	2012	31.35295	28.75312424	28.38508415	31.35294914	30.95163139	12	153	1010	0.9872
1011		23.86075	-120.264	2012	31.36377	28.75450325	28.386446	31.36376953	30.96231328	12	153	1011	0.9872
1012		23.96231	-120.294	2012	31.3739	28.75584412	28.38489342	31.37389946	30.96917616	12	153	1012	0.9871
1013		24.0639	-120.323	2012	31.37764	28.75714302	28.3804245	31.37763977	30.96659269	11	153	1013	0.9869
1014		24.16553	-120.352	2012	31.36869	28.75840569	28.38167	31.36869049	30.95776065	11	153	1014	0.9869
1015		24.2672	-120.381	2012	31.35721	28.75962448	28.37999725	31.35721016	30.94329499	11	153	1015	0.9868
1016		24.36889	-120.411	2012	31.33914	28.66920853	28.2907753	31.33913994	30.92546329	11	153	1016	0.9868
1017		24.47063	-120.44	2012	31.29808	28.67034149	28.30049515	31.29808044	30.89433521	11	153	1017	0.9871
1018		24.57239	-120.47	2012	31.23832	28.57983208	28.22544098	31.2383194	30.85096424	11	153	1018	0.9876
1019		24.67419	-120.499	2012	31.16891	28.5808754	28.24076271	31.16890907	30.79799905	10	153	1019	0.9881
1020		24.77603	-120.529	2012	31.08628	28.49026871	28.16263008	31.08628082	30.72878859	10	153	1020	0.9885
1021		24.87789	-120.559	2012	31.0081	28.39961243	28.08153725	31.00810051	30.66080978	10	153	1021	0.9888
1022		24.97979	-120.588	2012	30.94471	28.0970192	27.77952385	30.94470978	30.59503456	10	153	1022	0.9887
1023		25.08173	-120.618	2012	30.88716	28.09727287	27.77696419	30.88715935	30.53504573	10	153	1023	0.9886
1024		25.18369	-120.648	2012	30.82867	28.00654221	27.6872673	30.8286705	30.47722366	10	153	1024	0.9886
1025		25.28569	-120.678	2012	30.76567	28.00668716	27.69301224	30.76567078	30.42109526	10	153	1025	0.9888
1026		25.38772	-120.708	2012	30.69919	27.91584587	27.60318947	30.69919014	30.35535921	11	153	1026	0.9888

Fig. 45 Baseline Spatial File

➢ Click the next button and select "emission_files_config_O3.csv" as **the Cases & Emission Files.** The details of the Cases & Emission Files are displayed in Fig. 46 and Fig. 47.

CaseName	Pollutant	EmissionPath
Baseline	NOx	\My FAST-CE Files\Data\emission_files\2023en_NOX_ozoneseason_3mar2018.csv
ACE 2025	NOx	\My FAST-CE Files\Data\emission_files\finalACE\2025_final_ACE_NOX_summer.csv
ACE 2030	NOx	\My FAST-CE Files\Data\emission_files\finalACE\2030_final_ACE_NOx_summer.csv
ACE 2035	NOx	\My FAST-CE Files\Data\emission_files\finalACE\2035_final_ACE_NOx_summer.csv

Fig. 46 Cases & Emission Files

State	NonCoal	Coal
AL	1725.5	3439.7
AZ	934.1798	1837.566
AR	863.9	10365.6
CA	2849	63.8
CO	823.4	7407.2
CT	1919.3	0
DE	336	0
FL	13638.8	6095.8
GA	1228.2	6652.7
ID	83.29959	0
IL	1994.6	11089.1
IN	1168.5	16724.6
IA	543.1	10870.5
KS	2090.1	7286.9
KY	1694	7695.3
LA	7550.8	2418.9

Fig. 47 An example of "Emission File"
("2025_final_ACE_NOX_summer.csv")

➢ Click Next and go to set up the QA/Validation Input Option.

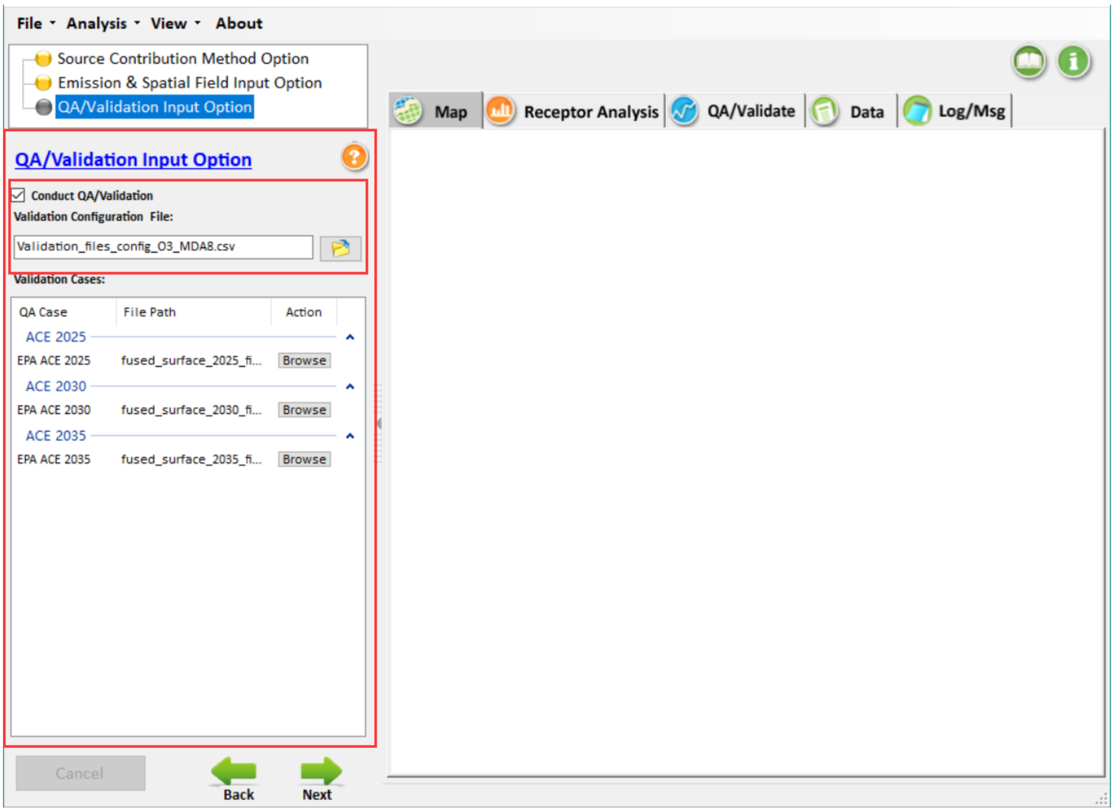


Fig. 48 QA/Validation Input Option for O_3-MDA8 analysis

- Check "Conduct QA/Validation", click button and select "Validation_files_config_O3_MDA8.csv" as the **Validation Configuration File.** The details of the Validation Configuration File and an example of "QA File" are shown in Fig. 49 and Fig. 50, respectively.

FAST-CE Case	QA Case	QA File
ACE 2025	EPA ACE :	\My FAST-CE Files\Data\QA_files\O3\fused_surface_2025_final_ACE_MDA8.BenMAP_ready.O3_Spatial_Field_Future_eVNA.csv
ACE 2030	EPA ACE :	\My FAST-CE Files\Data\QA_files\O3\fused_surface_2030_final_ACE_MDA8.BenMAP_ready.O3_Spatial_Field_Future_eVNA.csv
ACE 2035	EPA ACE :	\My FAST-CE Files\Data\QA_files\O3\fused_surface_2035_final_ACE_MDA8.BenMAP_ready.O3_Spatial_Field_Future_eVNA.csv

Fig. 49 Validation Configuration File

Column	Row	Metric	Seasonal	Statistic	Values	gridcell_lat	gridcell_long
1	1	D8HourMax		Mean	28.4485	22.847208	-119.977
1	2	D8HourMax		Mean	28.44883	22.948393	-120.006
1	3	D8HourMax		Mean	28.54896	23.049616	-120.034
1	4	D8HourMax		Mean	28.54921	23.150877	-120.063
1	5	D8HourMax		Mean	28.32175	23.252176	-120.091
1	6	D8HourMax		Mean	28.31182	23.353514	-120.12
1	7	D8HourMax		Mean	28.28753	23.454887	-120.149
1	8	D8HourMax		Mean	28.28327	23.556299	-120.178
1	9	D8HourMax		Mean	28.28469	23.657747	-120.206
1	10	D8HourMax		Mean	28.37358	23.759232	-120.235
1	11	D8HourMax		Mean	28.37494	23.860754	-120.264
1	12	D8HourMax		Mean	28.37052	23.962311	-120.294
1	13	D8HourMax		Mean	28.36892	24.063904	-120.323
1	14	D8HourMax		Mean	28.37017	24.165531	-120.352
1	15	D8HourMax		Mean	28.36849	24.267195	-120.381
1	16	D8HourMax		Mean	28.27931	24.368893	-120.411
1	17	D8HourMax		Mean	28.28903	24.470625	-120.44
1	18	D8HourMax		Mean	28.21401	24.572392	-120.47
1	19	D8HourMax		Mean	28.22933	24.674192	-120.499
1	20	D8HourMax		Mean	28.15124	24.776026	-120.529
1	21	D8HourMax		Mean	28.07018	24.877893	-120.559
1	22	D8HourMax		Mean	27.77109	24.979794	-120.588
1	23	D8HourMax		Mean	27.76573	25.081728	-120.618
1	24	D8HourMax		Mean	27.67887	25.183693	-120.648
1	25	D8HourMax		Mean	27.68181	25.28569	-120.678
1	26	D8HourMax		Mean	27.59202	25.38772	-120.708
1	27	D8HourMax		Mean	27.59206	25.489782	-120.739

Fig. 50 An example of "QA File"
("fused_surface_2025_final_ACE_MDA8.BenMAP_ready.O3_Spatial_Field_Future_eVNA.csv")

- Click 

button to run FAST-CE.

7.1.3 View results

7.1.3.1 Map results

The map results show the distribution of O_3-MDA8 concentration and the corresponding O_3-MDA8 response under selected control scenarios (i.e., ACE 2025, 2030, 2035), as displayed in Fig. 51. With the strengthening of the control scenarios, O_3-MDA8 pollution has improved significantly throughout the U.S., especially in the southeastern U.S.

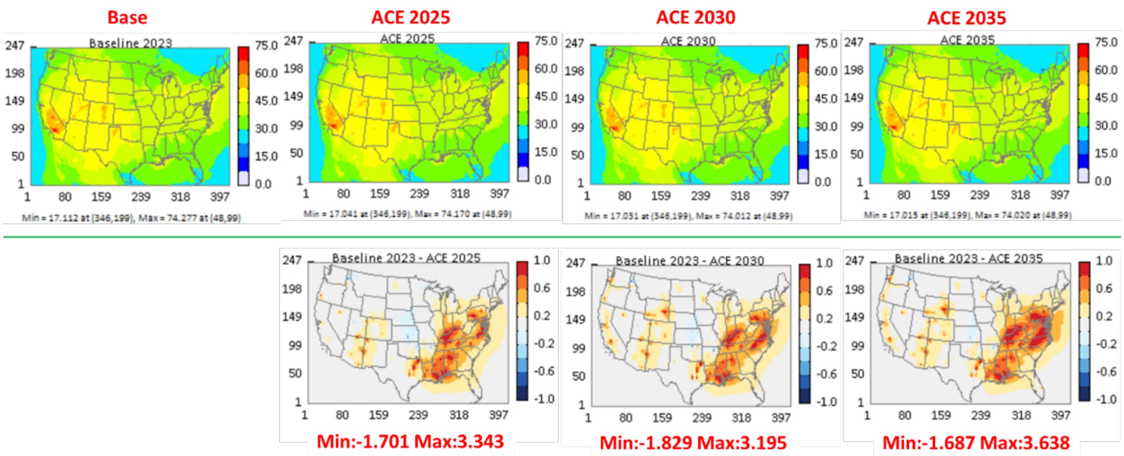


Fig. 51 Map results

7.1.3.2 The results of Receptor Analysis

The effects of emission reduction on selected receptor regions are displayed in the Receptor Analysis module, as shown in Fig. 52. For example, the top 3 contributors to the overall O_3-MDA8 reductions from control scenarios of ACE 2025 to 2035 are slightly different but all include DC, which indicates that more stringent control measures on DC can effectively alleviate the O_3-MDA8 pollution to a certain extent.

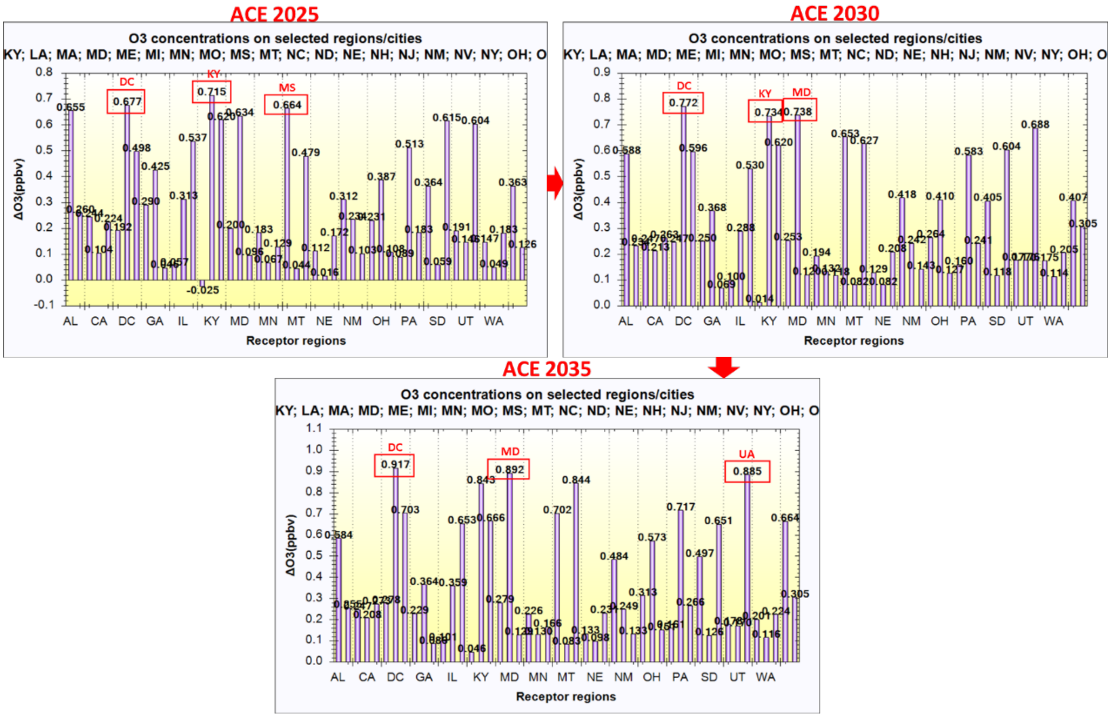


Fig. 52 Results of "Emission Control 1"

7.1.3.3 The results of QA/Validation

In the OA/Validation module, it can be seen that the FAST-CE predictions of O_3-MDA8 show good performance with the EPA's ACE results, with the R^2 of both concentration and response more than 0.99 (Fig. 53).

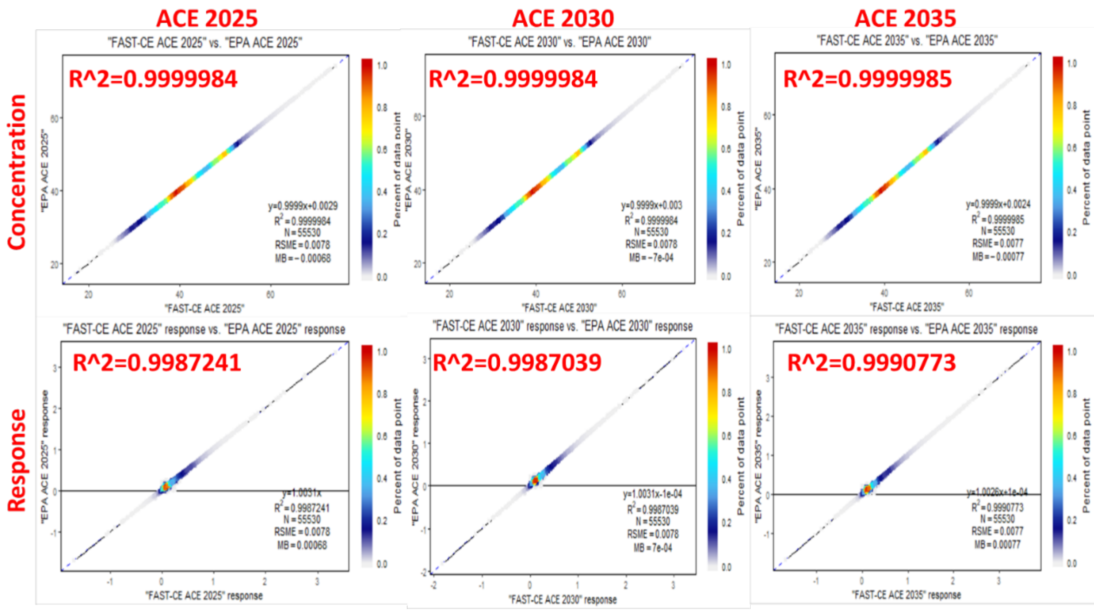
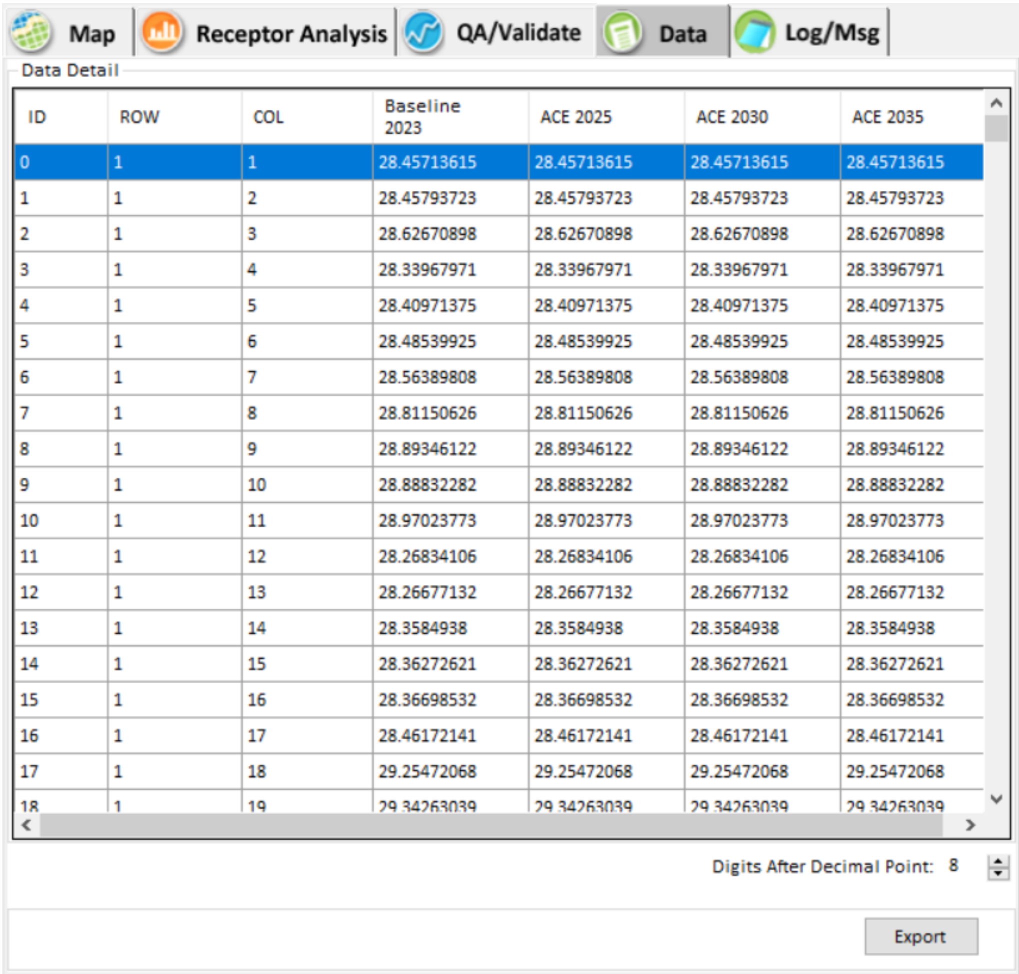


Fig. 53 Results of QA/Validation

7.1.3.4 Data results

The more detailed information about the O_3-MDA8 concentration of each grid, including the baseline concentration and the concentration that responds to the control scenarios (i.e., ACE 2025, 2030, 2035), can be seen in the Data module (Fig. 54).



ID	ROW	COL	Baseline 2023	ACE 2025	ACE 2030	ACE 2035
0	1	1	28.45713615	28.45713615	28.45713615	28.45713615
1	1	2	28.45793723	28.45793723	28.45793723	28.45793723
2	1	3	28.62670898	28.62670898	28.62670898	28.62670898
3	1	4	28.33967971	28.33967971	28.33967971	28.33967971
4	1	5	28.40971375	28.40971375	28.40971375	28.40971375
5	1	6	28.48539925	28.48539925	28.48539925	28.48539925
6	1	7	28.56389808	28.56389808	28.56389808	28.56389808
7	1	8	28.81150626	28.81150626	28.81150626	28.81150626
8	1	9	28.89346122	28.89346122	28.89346122	28.89346122
9	1	10	28.88832282	28.88832282	28.88832282	28.88832282
10	1	11	28.97023773	28.97023773	28.97023773	28.97023773
11	1	12	28.26834106	28.26834106	28.26834106	28.26834106
12	1	13	28.26677132	28.26677132	28.26677132	28.26677132
13	1	14	28.3584938	28.3584938	28.3584938	28.3584938
14	1	15	28.36272621	28.36272621	28.36272621	28.36272621
15	1	16	28.36698532	28.36698532	28.36698532	28.36698532
16	1	17	28.46172141	28.46172141	28.46172141	28.46172141
17	1	18	29.25472068	29.25472068	29.25472068	29.25472068
18	1	19	29.34263039	29.34263039	29.34263039	29.34263039

Fig. 54 Data results

8 Reference

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