METexpress

METexpress User's Guide

version 5.2.3

Smith, M., R. PierceJeff Hamilton, N. Babij, I. McGinnis, G. Padmanab

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Foreword: A note to MET users

This User's Guide is provided as an aid to users of the Model Evaluation Tools Express (METexpress). METexpress is an easy-to-use interface that displays plots of statistical verification metrics for data that a user defines interactively. It was developed by NOAA/Global Systems Laboratory the Developmental Testbed Center (DTC) as part of the METplus suite of verification tools. It is also the core component of the unified METplus verification framework. More details about METplus can be found on the METplus website.

It is important to note here that METexpress is an evolving software package. This documentation describes the 5.2.3 release dated 20240308. METexpress may be able to accept contributions from the community. If you have code you would like to contribute, we will gladly consider your contribution. Please send an email to: mats.gsl@noaa.gov. We will then determine if we will be able to include the contribution in a future version.

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Chapter 1

Overview of METexpress

1.1 The METplus suite

METexpress is an easy-to-use interface that displays plots of statistical verification metrics for the data that a user defines interactively. Prior to using METexpress, these verification metrics must generated from model output and "truth" data (usually observations or gridded model analyses) by the MET verification tools (https://met.readthedocs.io/en/latest/), and the output files produced by this MET verification must be loaded into a MET database. *METexpress is not used to create this database, only view its contents.* It allows a model developer to explore metrics about their model runs quickly and flexibly without relying on someone else producing pre-generated plots. The developer can slice and dice data in the way that best gives them insight into how their model performed.

METexpress is one component of the METplus verification tool suite, which is created and managed by the Developmental Testbed Center (DTC) and is the official verification tool for NOAA's Unified Forecast System. Figure 1.1 shows a graphic of the entire METplus package and how METexpress integrates with the other tools.

In the simplest workflow for verifying model outputs, the model output data and "truth" or observation data are input into the MET software package which outputs statistical information in an ASCII format. That statistical information is then read into and stored in the METdatadb database using the METdbload tool. METexpress allows the user to specify various parameters for the plot they want to create and then queries the database to get the relevant information and creates a plot.

1.2 METexpress Features

METviewer performs a similar functionality of querying the database and producing a plot. However, METviewer has a lot more flexibility and many options that the user must know to specify, with the result that it requires more training to fully understand it and use it effectively and accurately. METexpress provides an alternative simplified, more intuitive interface, which guides the user through selection of parameters needed in order to produce a given type of plot. The expectation is that METviewer would be used by expert users who understand its extensive capabilities and advanced features, but that METexpress would provide an interface for users to quickly generate commonly used plots without having to gain the expertise

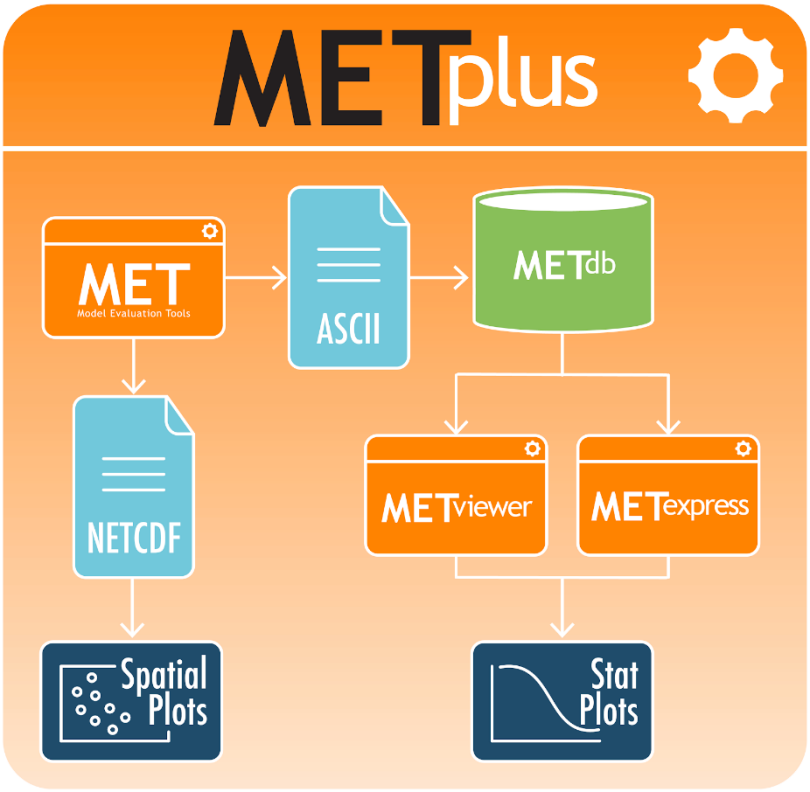


Figure 1.1: Schematic diagram of the structure of METplus, including METexpress

needed to run METviewer. METexpress guides the user to define each parameter that is needed to produce a given type of plot, with default parameter values available also.

METexpress was developed at NOAA/OAR Global Systems Laboratory (GSL) based on a verification system developed in-house at GSL named the Model Analysis Tool Suite, or MATS. METexpress uses the basic framework of MATS but it has been modified to work with the METplus database.

It is very important to understand that METexpress can only produce plots based on the data that has been loaded into the METdatadb database.

The verification measures or statistics produced by METexpress follow definitions set by the MET package with input from the mathematical expertise within the Developmental Testbed Center (DTC). To learn more about the metrics and how to interpret them, please see the MET User Guide, particularly Appendix C about Verification Measures and additional material.

One of the features of METexpress is that, generally, it only presents the user with choices for data parameters that are valid for the data sets that the user has selected. For example, if the user selects the model "GFS", the choices available for "variable" will be only the variables that have been loaded into the database for the GFS model. In this way, the user will not go through the process to select variables, heights, statistics, etc that don't exist in the database and cannot be plotted. This is achieved in the interface by creating metadata (data that describes the data) in the database that describe the available parameters for each data set. The generation of metadata will be discussed later.

Chapter 2

METexpress Release Information

2.1 METexpress Release Notes

When applicable, release notes are followed by the GitHub issue number which describes the bugfix, enhancement, or new feature (METexpress GitHub issues). Important issues are listed **in bold** for emphasis.

2.1.1 METexpress Version 5.2.2 release notes (20240126)

Repository, build, and test

- None

Documentation

- None

Bugfixes

- Improved handling of datestrings.

Enhancements

- Updated all apps to Meteor v2.14.

Miscellaneous

- None

2.2 METexpress Upgrade Instructions

2.2.1 METexpress Version 5.1.2 upgrade instructions

Download and deploy the new v5.1.2 docker containers from the dtcenter repository.

Chapter 3

General Interface Description

METexpress is a web space that includes various apps for specific purposes. The current list of apps includes:

- MET Upper Air
- MET Anomaly Correlation
- MET Surface
- MET Air Quality
- MET Ensemble
- MET Precipitation
- MET Cyclone
- MET Objects

Future development of METexpress is likely to add more apps.

Each app can have multiple plot types, such as time series and vertical profiles. The available plot types include those appropriate to each app.

Note that each app will have a similar layout for selecting parameters and interacting with plots. These general features are described in detail here using the Upper Air app as an example. Individual apps are then described only in terms of their specific information and functionality.

3.1 Home Page

The METexpress home page is shown in Figure 3.1. The home page has a button for each available app. Each app lets the user create certain types of plots for a certain type of data. The user must begin by selecting the app they want to use.

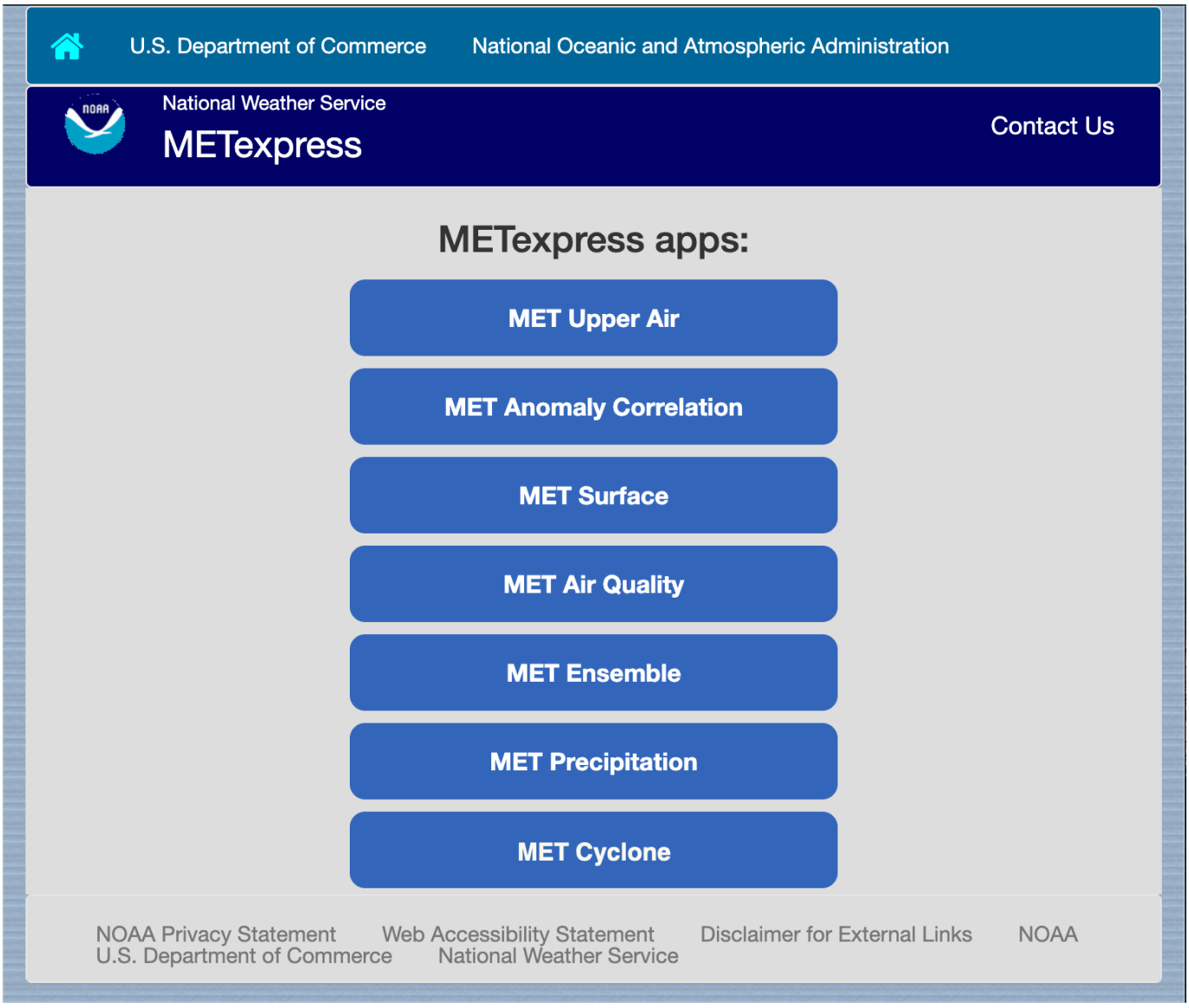


Figure 3.1: METexpress Home Page (MET Objects not yet pictured)

3.2 User Interface Layout Common to Each App

The Upper Air app is used as an example here to describe the general layout that is carried through on all apps. The Upper Air user interface before any curves have been defined is shown in Figure 3.2. There are 3 parts to this screen:

- Plot Type
- Curve Data Parameters
- Plot Parameters

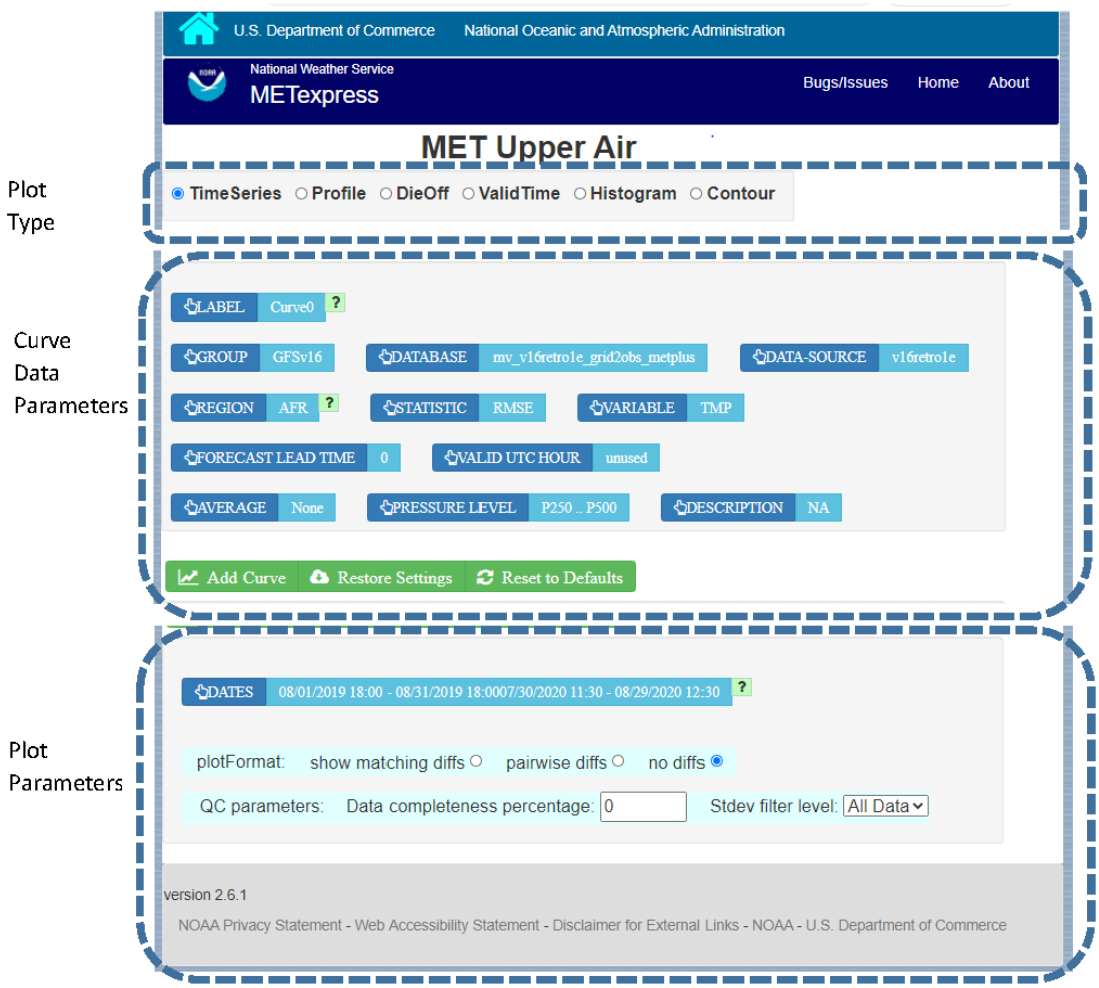


Figure 3.2: Upper Air User Interface screen before any curves have been defined

After any curves have been added, the user interface screen includes a fourth area, as shown in Figure 3.3, that shows what curves have already been defined. The section for the Curve Data Parameters then allows the user to create additional curves to be added to the plot.

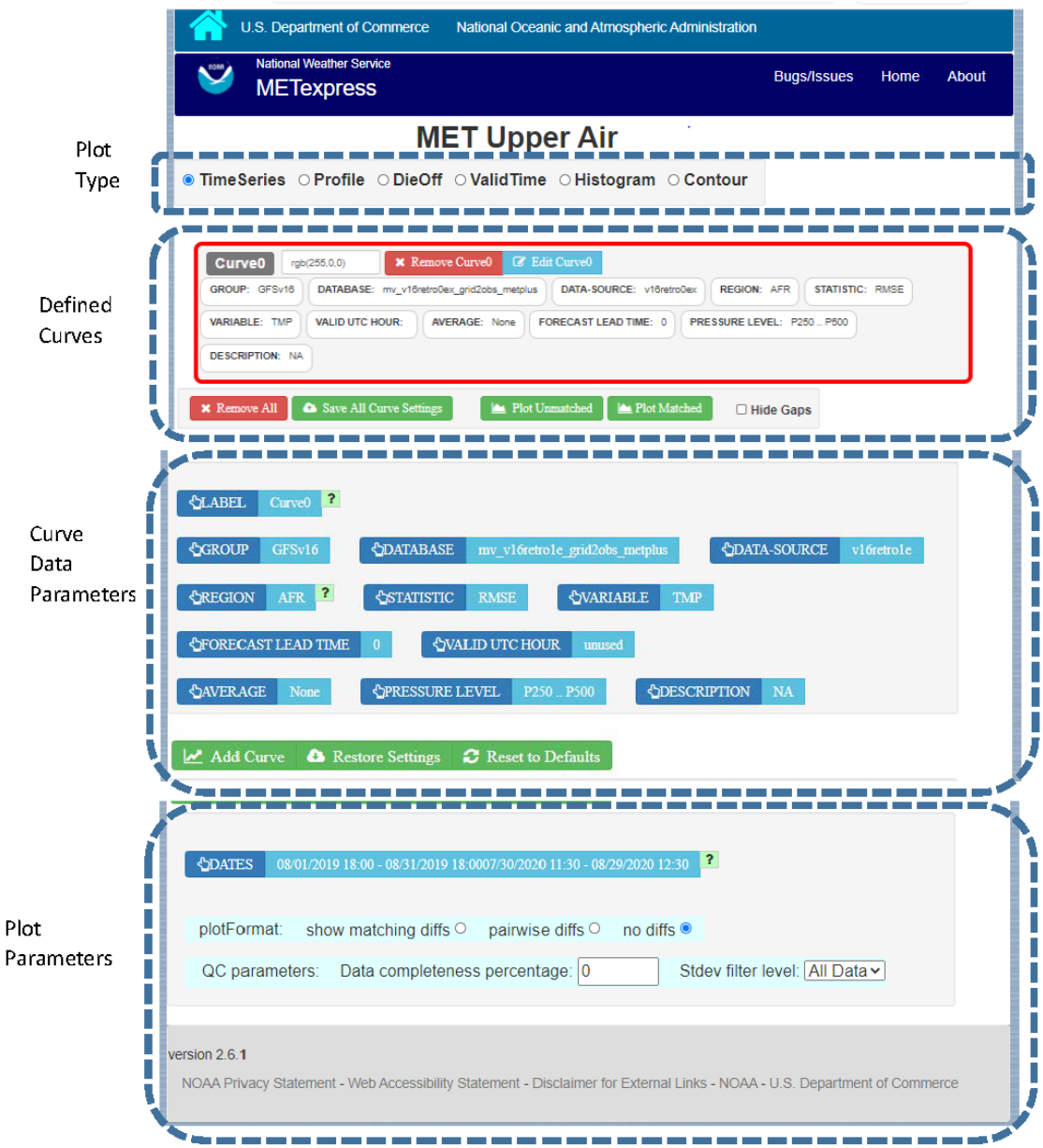


Figure 3.3: Upper Air User Interface screen after Curve0 has been added, showing the addition of the area for Defined Curves above the Curve Data Parameters

3.3 Plot Types

Immediately below the name of the app is a bar that allows selection of the plot type. Available types for Upper Air include Time Series, Profile, Dieoff, ValidTime, Histogram, and Contour. Other apps include some plot types specific to that application domain, such as Reliability plots in the Ensemble app or GridScale plots in the Precipitation app. The section for each app below will describe the available plot types for that app.

The user will first want to decide what type of plot they want to produce initially. Most apps default to Time Series, but the user should change to the type of plot they want to create. If the plot type is changed after curves have been defined, the user will be prompted whether to keep all existing defined curves or to remove all the existing curves.

3.4 Curve Data Parameters

In the central area of the screen is a box to define the data parameters associated with each curve to be plotted. Blue fields are selectors and green fields are action buttons.

A default set of selections for each parameter (in blue boxes) will be shown, which will define the data to be plotted. The user can change any of these selectors. The values available for most selectors depend on what data is stored in the database, and on the values selected for other fields. For example if the DATA-SOURCE selected is GFS, the values available for REGION will be only the regions that are stored in the database for GFS.

For these parameters there is a superior-dependent relationship. For example DATA-SOURCE (which is most typically the name of a model) is superior to VARIABLE and REGION because only certain variables and regions are available for a given DATA-SOURCE. It is recommended that a user change parameters starting at the top left and progressing across then down the page in typical reading order. This ordering generally keeps the superior-dependent relationship intact. If a dependent parameter is set and the superior parameter is subsequently changed, the program attempts to maintain the dependent parameter value if it is still available for the new superior value. If the dependent value is not available for the new superior then a default value is automatically set for the dependent. This maintains consistency and prevents invalid parameter choices.

In the example Upper Air app, the selectable values are derived from the data for these parameters:

- Group (as defined in the MET database)
- Database (name of user database)
- Data-Source (usually a model name)
- Region
- Statistic
- Variable
- Interp-Method
- Scale
- Forecast lead time

- Pressure level
- Description
- Dates – date range that applies to all curves, used for plot types like time series
- Curve-dates – range of dates used to filter data for a particular curve, such as seen in vertical profiles, where each curve may potentially be based on data from different date ranges

3.4.1 Static fields

Some fields are not dependent on data. In the Upper Air app, these are Valid UTC Hour and Average, but these will vary for each app. Average and Valid UTC Hour tend to have standardized choices available across many apps.

Valid UTC Hour: This can be set to any whole number 0 to 23 for all of the apps.

Average: If the value for AVERAGE is none, then all points available will be plotted. Otherwise, all points in the selected interval are averaged into a single value. Available choices are as follows for all of the apps:

- None
- 1hr
- 3hr
- 6hr
- 12hr
- 1D
- 3D
- 7D
- 30D
- 60D
- 90D
- 180D

Aggregation Method: This selector specifies the method by which sub-values returned by the database are combined into points on the graph. Options will vary by statistic, but will be some subset of the following:

- Overall statistic (combines partial sums and contingencies from sub-values, then calculates statistic)
- Mean statistic (calculates one statistic for each sub-values' partial sums and contingencies, then takes mean)
- Mean statistic weighted by N (like above but the mean is weighted by N)
- Median statistic (calculates one statistic for each sub-values' partial sums and contingencies, then takes median)

After selecting all data parameters as desired, the user would click the Add Curve action button inside the green bar, and the area outlined in red in Figure 3.4 would be added to show the parameters selected for Curve0. The color for Curve0 has been given the default value of red and will also be shown with a red line and/or symbols in the plot. The color assigned to this curve can be changed within the outlined box with the button labeled "rgb(255,0,0)".

Note that the user has the option to supply whatever label they prefer to use for each curve, but the default is to create labels "Curve0", "Curve1", etc.

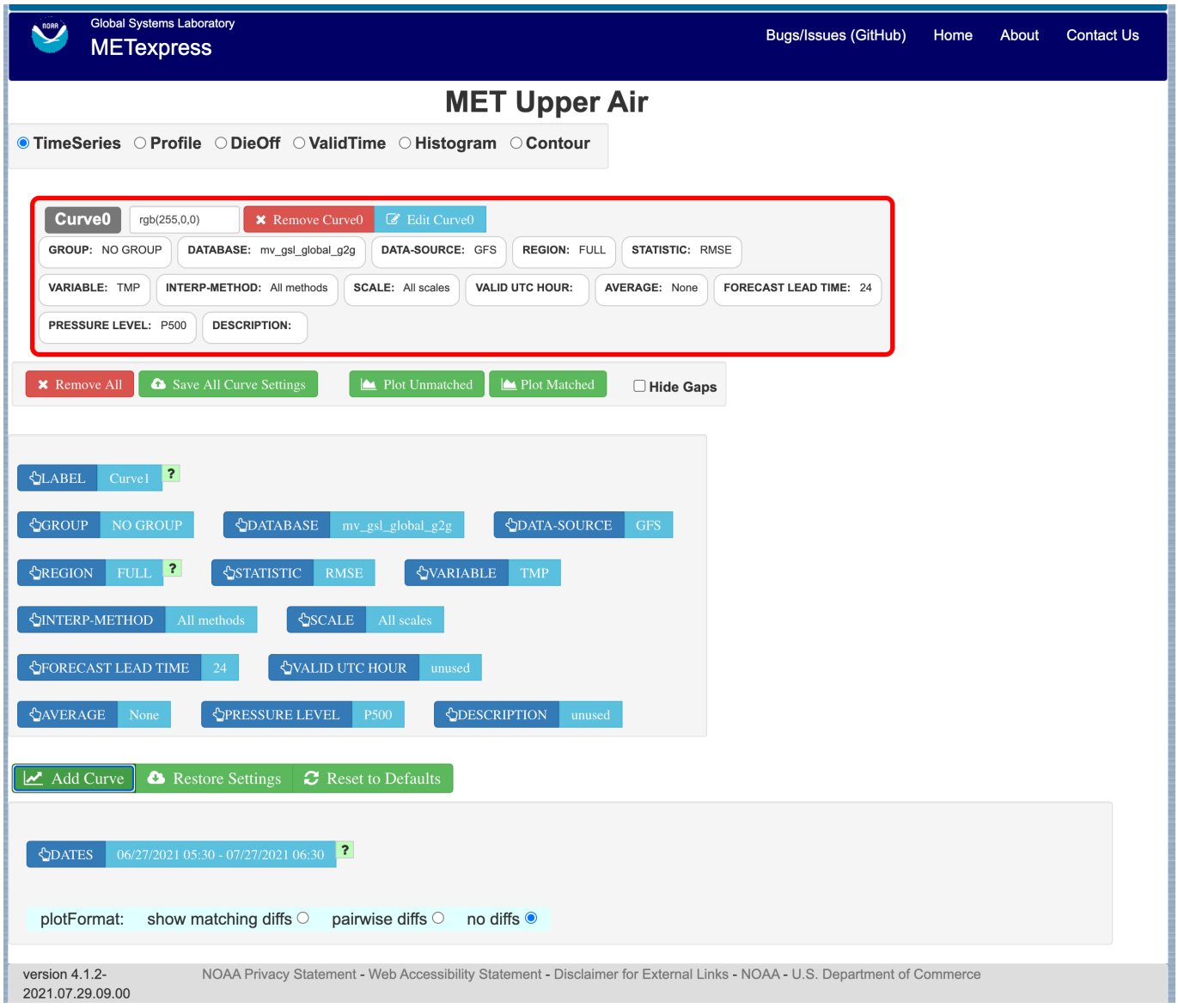


Figure 3.4: Interface screen after defining a single curve with default values, then selecting Add Curve

3.4.2 Editing a Curve

Once a curve is added, a user can go back and change any of its parameters. There are two ways to do this: by clicking directly on the selector value to be changed within the red outlined area, or by clicking "Edit Curve" inside the red outline. The user would then set any selectors to their updated values. If "Edit Curve" was used, or if the value of a multi-select (a selector that can have multiple values chosen) was altered, the user must finish the edit by clicking "Save Curve Changes".

3.4.3 Defining Multiple Curves

In Figure 3.4 "Curve0" has been defined. The user can then repeat the selection of curve data parameters followed by Add Curve for as many curves as they wish to show on the plot. Each new curve will be assigned a new color.

An example of the interface screen with 2 curves defined is shown in Figure 3.5 Curve0 data parameters are shown in the red box and Curve1 data parameters are shown in the blue box.

3.5 Plot Parameters

The Plot Parameters appear in the box below the Curve Data Parameters box and apply to all curves defined in the Curve Data Parameters. The user can select the dates to be included in the plot, plus the plotFormat. Note that MATS also has an option to define QC parameters, but these are not readily supported from the METviewer database.

The plotFormat defines whether or not to show differences between curves. It has 3 options: "show matching diffs", "pairwise diffs" or "no diffs".

Show matching diffs takes the difference of each of the curves from Curve0. For example, if a user had defined Curve0, Curve1, Curve2, and Curve3, and selected "Show matching diffs", the plot would have three difference curves: Curve1-Curve0, Curve2-Curve0, and Curve3-Curve0.

Pairwise diffs takes the difference of each pair of adjacent curves. So, if a user had defined Curve0, Curve1, Curve2, and Curve3, and selected "pairwise diffs", the plot would have two difference curves: Curve1-Curve0, and Curve3-Curve2.

All difference curves calculate differences only where the data is matching.

No diffs is the default and will not include any difference curves in the plot.

3.6 Saving and Restoring Settings

When all parameters have been set as desired – including curve data parameters, plot parameters, and plot types - the user has an option to Save All Curve Settings. If selected, the user will be prompted to provide a name for the saved settings. In future the user has the option for "Restore Settings". If selected, they will be prompted for the saved-settings name. After selecting saved-settings, all curve definitions, plot parameters, and plot type will be reset from the saved-settings definitions.

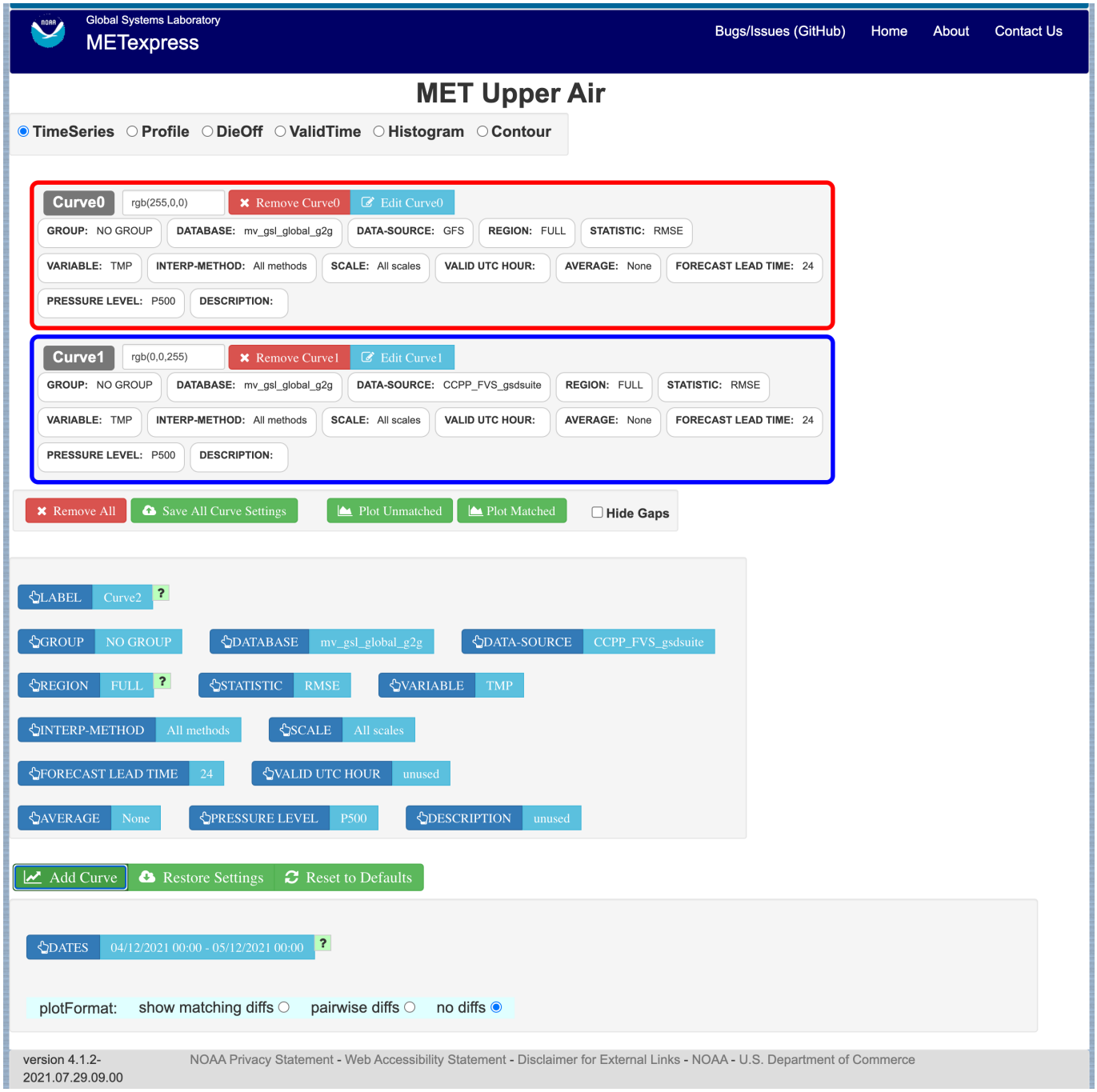


Figure 3.5: Interface screen after defining 2 curves and selecting Add Curve after each

3.7 Generating a Plot

When the user is ready to generate a plot, the user would click either the "Plot Unmatched" or the "Plot Matched" action button directly below the outlined boxes with curve definitions.

Plot Unmatched will plot points for all data available for each defined curve.

Plot Matched will only plot points at x-axis values (y-axis for vertical profiles) where data values exist for all defined curves. In addition, only database values that exist at the same time period and same vertical level for all defined curves will be considered when computing y-axis values (x-axis for vertical profiles).

Hide Gaps: Note that when data points are missing, by default a line is not shown connecting the surrounding points. The user can force METexpress to draw lines between points in all cases, by selecting Hide Gaps.

Figure 3.6 shows the plot screen after the user selects Plot Unmatched or Plot Matched with a single curve defined. The same curve data as defined in Figure 3.6 is used to generate the plot in Figure 3.7, but with Hide Gaps selected.

Figure 3.8 shows a sample plot with 2 curves: Curve0 and Curve1 in red and blue, and has also added a difference curve in yellow showing the difference between Curve0 and Curve1 and error bars on all curves.

3.8 User controls on plot screen

After the plot has been produced, the user can interact with the plot in various ways. For example, the user might want to focus on one particular area of the plot to examine more detail, or the user might want to change titles, line widths, etc to produce a plot suitable for publication. Figure 3.9 highlights the tools available to interact with a plot.

The user can choose to dynamically zoom in and out on the plot. In order to zoom in on a plot, the user can click and drag a box over the area of interest on the graph, and the zoom level will be automatically adjusted to reflect the bounds of the box. To zoom back out, the user should double click on the plot or click the blue refresh button to the far right the dark blue toolbar.

METexpress plots are produced with the graphing package Plotly, and as such inherit a suite of basic graph controls from Plotly. These tools appear in the upper right corner of the plot when a user hovers their cursor over the graph area. From left to right, the Plotly tools allow a user to:

- Icon 1) Save a low-resolution PNG of the plot (METexpress has a separate capability to save high-resolution PNGs, as described below).
- Icons 2-3) Toggle between clicking to zoom (default) and clicking to pan.
- Icons 4-5) Toggle between using a box to zoom or pan (default) and using a lasso.
- Icons 6-7) Zoom in or out while maintaining the current center point of the graph.
- Icon 8) Have Plotly guess what the appropriate zoom level is to best frame the plot contents.
- Icon 9) Reset the x- and y- axes to their original zoom and pan settings.
- Icon 10) Turn on/off lines that trace the cursor's position on the x- and y- axes.

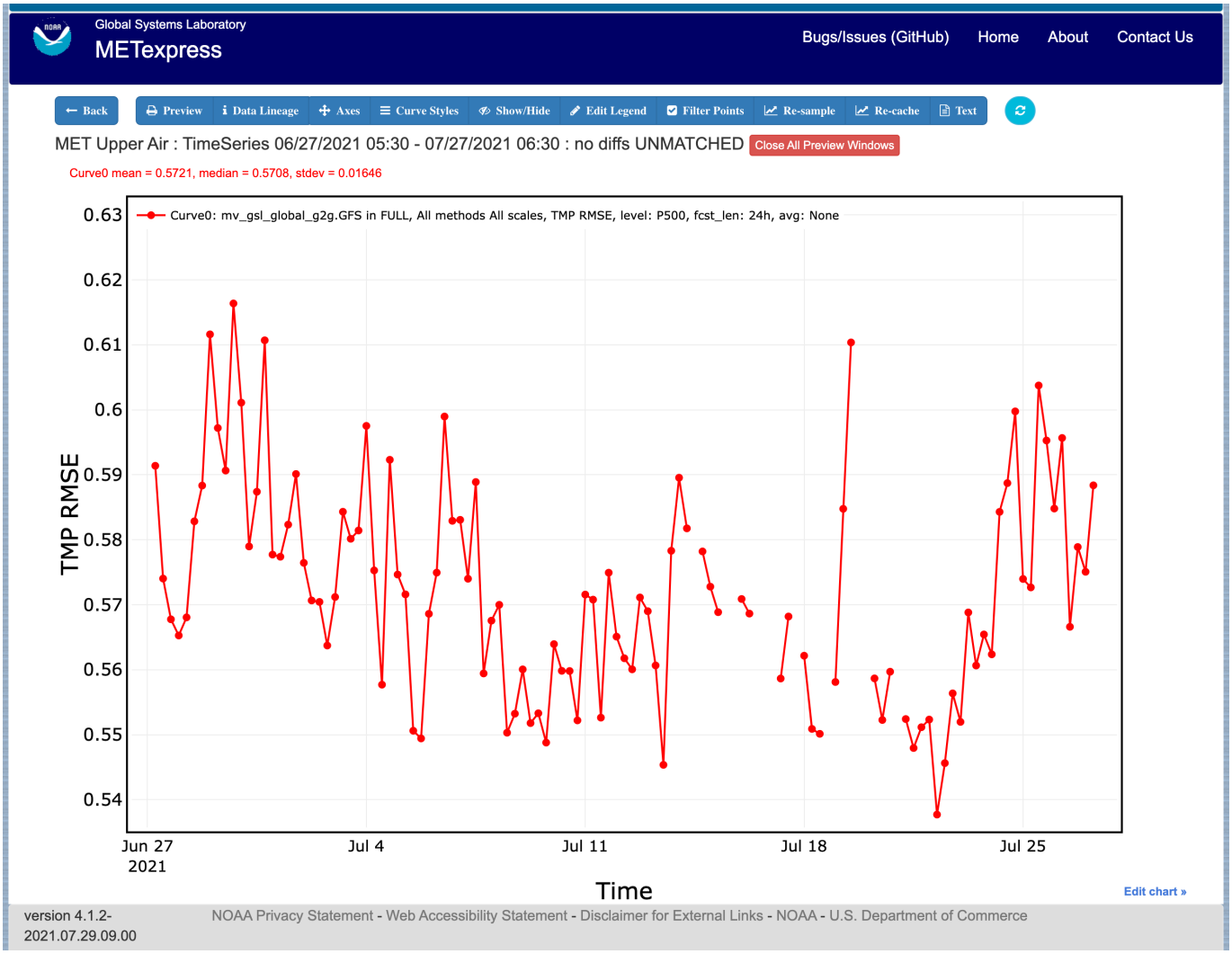


Figure 3.6: Plot of Time Series for a single curve with default values

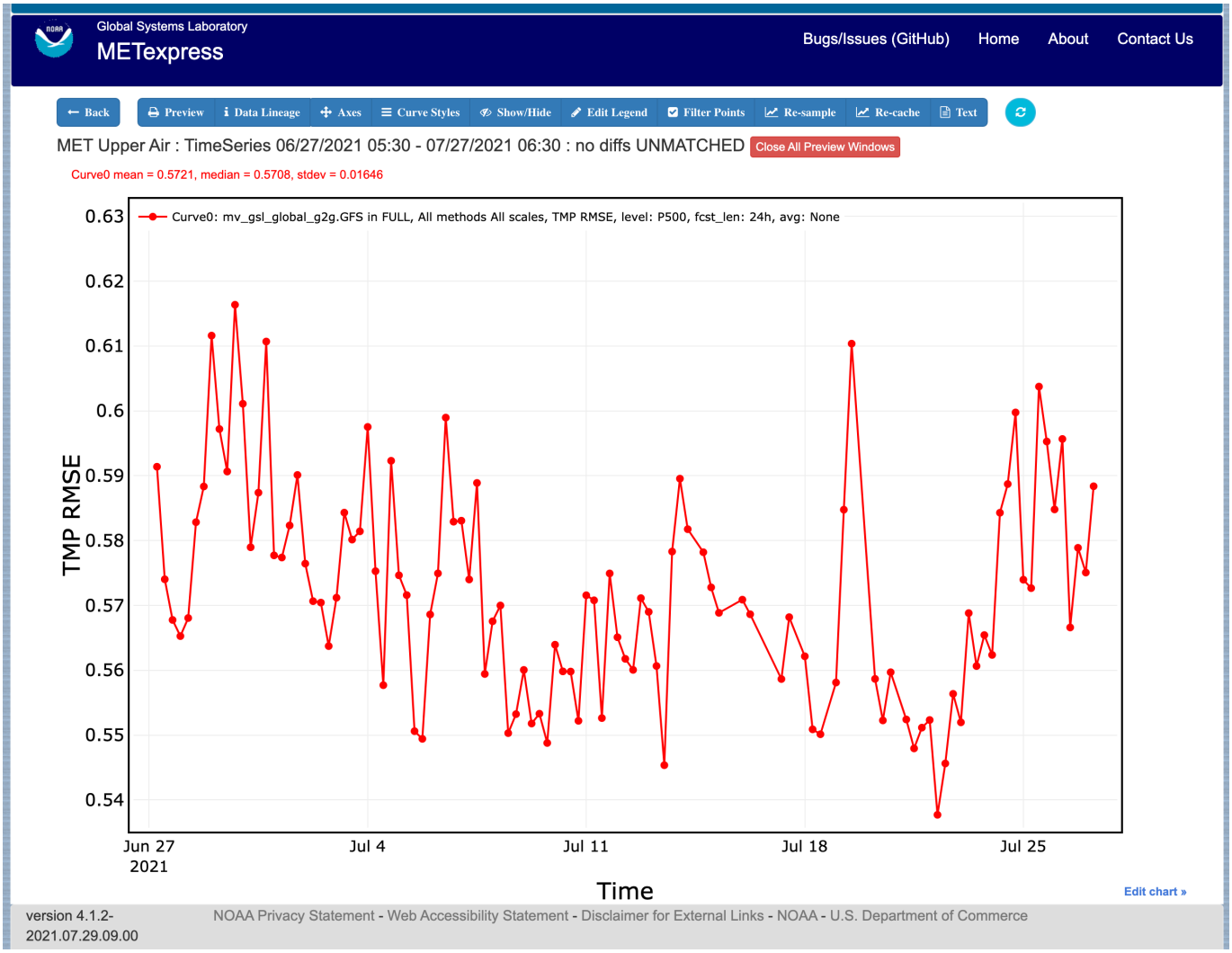


Figure 3.7: Same plot as shown in Figure 3.6, but with Hide Gaps selected.

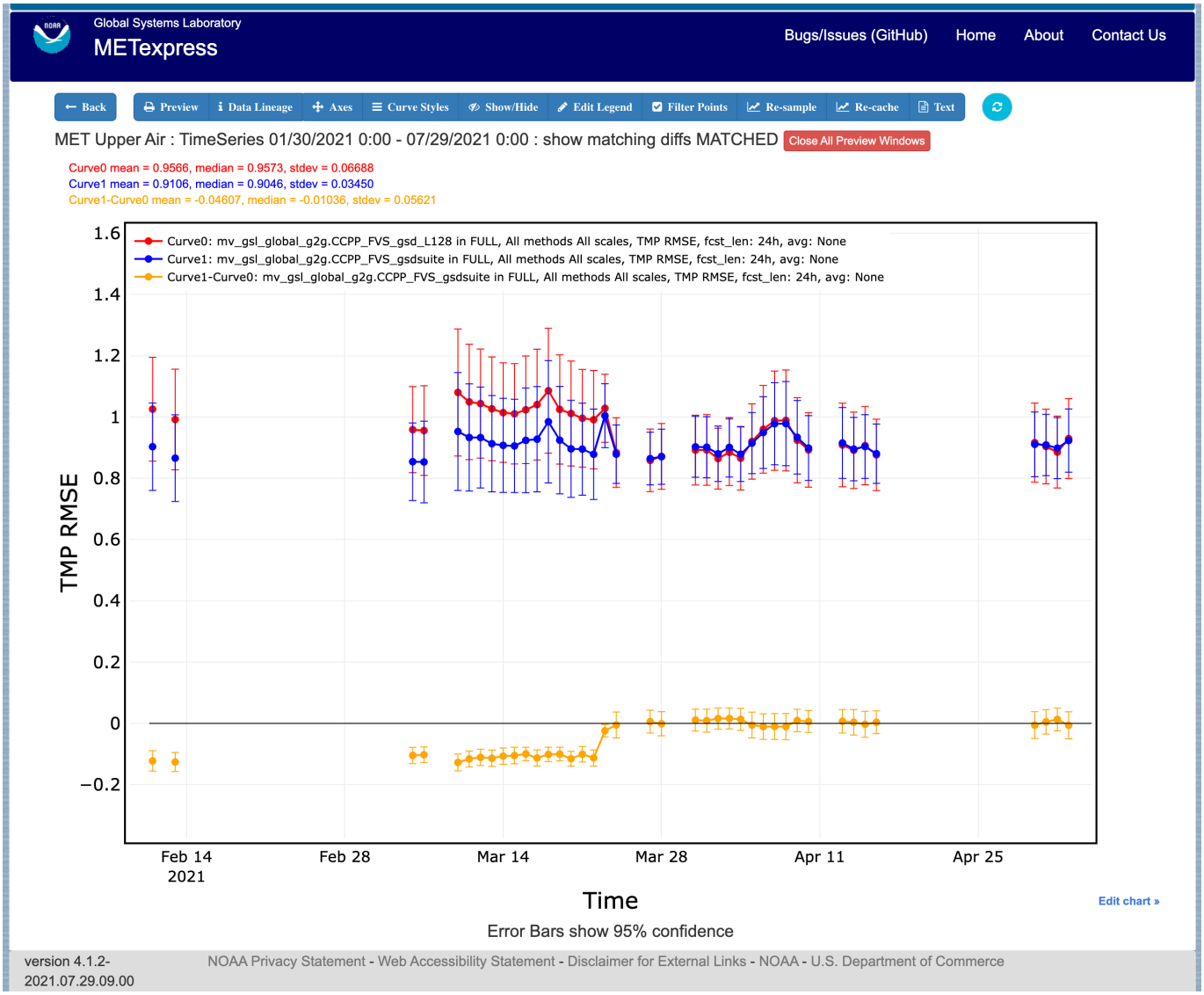


Figure 3.8: Plot with Multiple Curves for Time Series, including Error Bars and Difference Curves. The yellow curve shows the difference between the red and blue curves.

Figure 3.9: Detail of plot controls from figure above

- Icons 11-12) Toggle between only displaying the data tooltip when the cursor is over a point (default), or always displaying the nearest tooltip to the user.
- Icon 13) Visit Plotly's website.

Beyond the inherited Plotly controls, a number of buttons on the plot screen allow the user to interact with the displayed plot.

The **Back** button will return the user to the main app page, where the curve parameters were defined. This would allow the user to modify the plot definitions and re-plot.

The **Preview** button will copy the interactive plot into a separate window, to store it for comparison with future plots. The plot preview window also has the functionality to save each plot as a PDF or PNG.

The **Data Lineage** button displays all of the plot parameters, data queries, point values, and other metadata in a JSON format.

The **Axes** button allows users to customize the plot axes. This includes options to change the x- and y-axis limits, labels, label font sizes, and tick font sizes, as well as the plot legend font size and font color, and the grid line weight and color. These modifications all occur instantly, without the user having to regenerate the plot.

The **Y Linear/Log** button appears for profile plots, and allows users to toggle between having a linear vertical scale (the default), and a logarithmic one.

The **Merge Y Axes** button appears for all types of line plots that can have more than one Y axis, and allows users to condense all curves on those plots onto one Y axis. Clicking the button again will revert the graph to its default Y axes.

The **Merge X Axes** button appears for profile plots, and allows users to condense all curves on those plots onto one X axis. Clicking the button again will revert the graph to its default X axes.

The **Equi-space X** button appears for threshold plots, and allows users to toggle between having a linear x-axis scale (the default), and equally spacing all of the returned threshold values.

The **Curve Styles** button allows users to customize the appearance of the curves in the plot. Here, users can change each curve's color, line style, line weight, marker style, and marker weight.

The **Colorbar** button appears for contour plots, and allows users to customize the appearance of the contours. Here, users can change the colorbar label, colorbar range, colorbar stride, colormap being used, the direction of the chosen colormap (normal or reversed), and whether to interpolate over any null points in the graph.

The **Show/Hide** button allows users to show/hide individual curves, the markers on individual curves, the error bars on individual curves (if applicable), the bars of individual histograms (if plotting histograms), the mean/median/stdev annotation corresponding to individual curves, and the entry for each curve in the plot legend.

The **Edit Legend** button allows users to customize the legend text for each curve. By default, the legend displays the curve label, followed by each of the curve parameters contributing to that plot trace.

The **Filter Points** button allows users to hide certain points on the graph, for quality control, to increase the time interval between each point, etc. Users uncheck independent variable values that they wish to hide when the Filter Points Modal appears.

The **Re-sample** button allows users to change the zoom level of the x-axis and then re-query the database with the new x-axis limits. This has two advantages. Firstly, if the user initially asked for too narrow a time period on a time series, they can increase the x-axis limits to their new time range of interest, click the Re-sample button, and receive a new plot with the full time range, all without having to return to the main app page. Secondly, if the user initially requested a large time period, METexpress will downsample the returned data with the Largest Triangle Three Buckets algorithm, in order to prevent huge datasets from slowing down the user's web browser. The user can zoom in on a time period of interest, click Re-sample, and receive the full, un-downsampled dataset for that smaller time range.

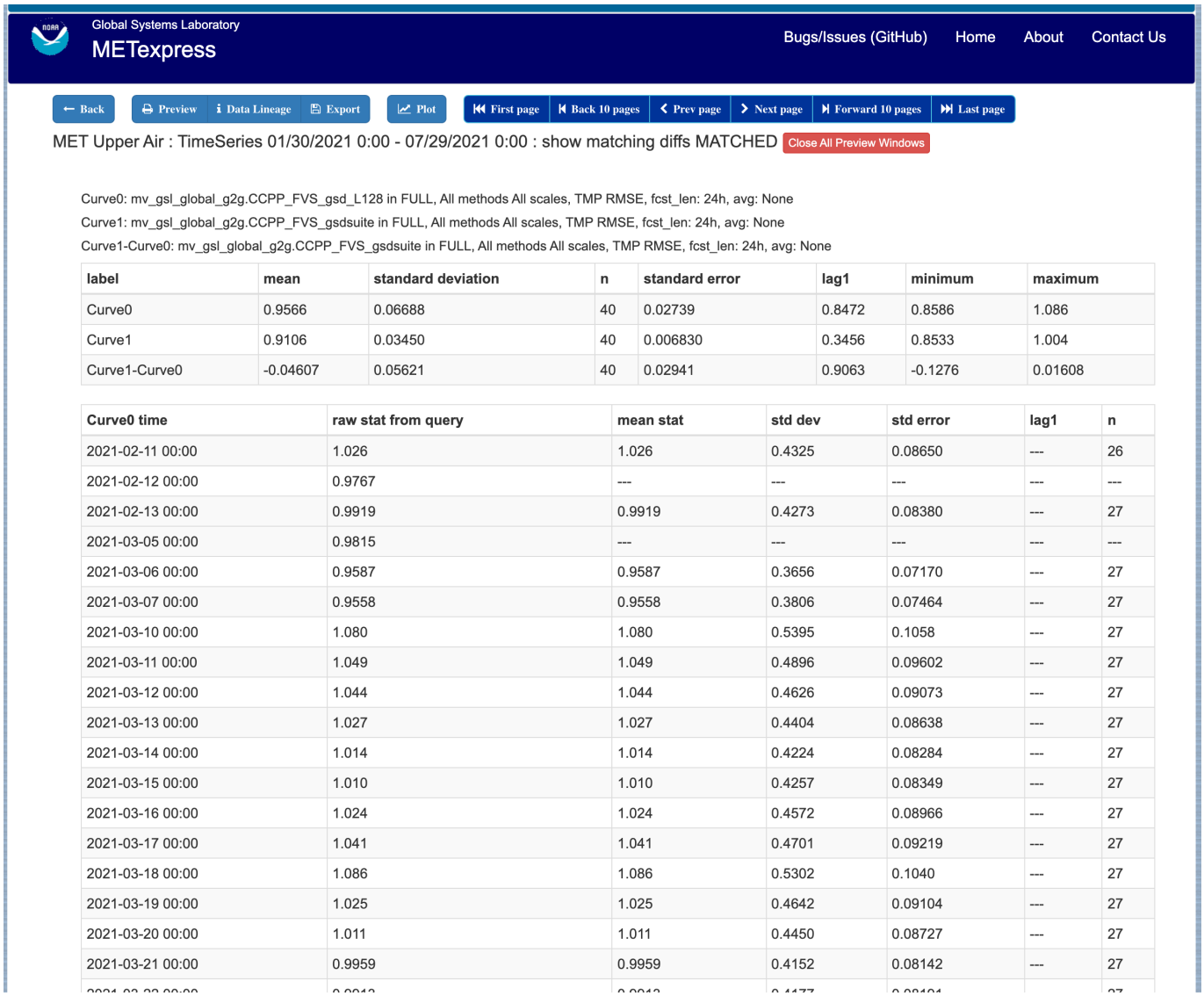
The **Re-cache** button forces METexpress to re-query the database in the event of new data being ingested. For the most part, METexpress will cache requested plots for eight hours, and if another user requests the identical curve/plot parameters within that eight hours, METexpress will return its cached plot, instead of re-generating it. Re-cache forces it to actually re-retrieve the data from the database and remake the plot.

The **Text** button changes from the plot page to a text page, which displays all of the data on the graph in tables, along with statistics relating to each point, as shown in Figure 3.10 for the plot in Figure 3.8. These data tables can be exported as CSV files by clicking the "Export" button at the top (next to the "Data Lineage" button), so that users have the option of creating their own plots from the queried data.

The **blue refresh** button to the right of the text button will reset the graph to its original pan and zoom settings, as well as reverting any customization that the user has done to the axes or curves.

Tool-tips: On the graph itself, each point on each curve has an interactive tool-tip. When a user mouses over a point, the tool-tip pops up, providing details about that point's x- and y-value and statistics.

Error bars: When the user clicks the "Plot Matched" action button instead of "Plot Unmatched", the points on the graphs will display error bars, which are useful for comparing multiple curves. It should be noted, however, that error bars will not display if each point only has one database value contributing to it, as error bars are based on standard deviation, and the standard deviation of one value is zero.



label	mean	standard deviation	n	standard error	lag1	minimum	maximum
Curve0	0.9566	0.06688	40	0.02739	0.8472	0.8586	1.086
Curve1	0.9106	0.03450	40	0.006830	0.3456	0.8533	1.004
Curve1-Curve0	-0.04607	0.05621	40	0.02941	0.9063	-0.1276	0.01608

Curve0 time	raw stat from query	mean stat	std dev	std error	lag1	n
2021-02-11 00:00	1.026	1.026	0.4325	0.08650	---	26
2021-02-12 00:00	0.9767	---	---	---	---	---
2021-02-13 00:00	0.9919	0.9919	0.4273	0.08380	---	27
2021-03-05 00:00	0.9815	---	---	---	---	---
2021-03-06 00:00	0.9587	0.9587	0.3656	0.07170	---	27
2021-03-07 00:00	0.9558	0.9558	0.3806	0.07464	---	27
2021-03-10 00:00	1.080	1.080	0.5395	0.1058	---	27
2021-03-11 00:00	1.049	1.049	0.4896	0.09602	---	27
2021-03-12 00:00	1.044	1.044	0.4626	0.09073	---	27
2021-03-13 00:00	1.027	1.027	0.4404	0.08638	---	27
2021-03-14 00:00	1.014	1.014	0.4224	0.08284	---	27
2021-03-15 00:00	1.010	1.010	0.4257	0.08349	---	27
2021-03-16 00:00	1.024	1.024	0.4572	0.08966	---	27
2021-03-17 00:00	1.041	1.041	0.4701	0.09219	---	27
2021-03-18 00:00	1.086	1.086	0.5302	0.1040	---	27
2021-03-19 00:00	1.025	1.025	0.4642	0.09104	---	27
2021-03-20 00:00	1.011	1.011	0.4450	0.08727	---	27
2021-03-21 00:00	0.9959	0.9959	0.4152	0.08142	---	27

Figure 3.10: Beginning of text screen for plot in Figure 3.8

Chapter 4

METexpress Apps

This section includes a description of the unique features of each app.

4.1 Upper Air App

The Upper Air app is designed for plotting scalar and contingency table statistics at different pressure levels in the atmosphere.

The user interface for Upper Air follows the general description from above. Choices specific to this app are shown below.

Choices for Statistic (depending on available line types):

- RMSE
- Bias-corrected RMSE
- MSE
- Bias-corrected MSE
- ME (Additive bias)
- Fractional Error
- Multiplicative bias
- Forecast mean
- Observed mean
- Forecast stdev
- Observed stdev
- Error stdev
- Pearson Correlation
- Forecast length of mean wind vector

- Observed length of mean wind vector
- Forecast length - observed length of mean wind vector
- abs(Forecast length - observed length of mean wind vector)
- Length of forecast - observed mean wind vector
- Direction of forecast - observed mean wind vector
- Forecast direction of mean wind vector
- Observed direction of mean wind vector
- Angle between mean forecast and mean observed wind vectors
- RMSE of forecast wind vector length
- RMSE of observed wind vector length
- Vector wind speed MSVE
- Vector wind speed RMSVE
- Forecast mean of wind vector length
- Observed mean of wind vector length
- Forecast stdev of wind vector length
- Observed stdev of wind vector length

The Upper Air app includes functionality for these types of plots:

- Time Series
- Profile
- Dieoff
- ValidTime
- Histogram
- Contour

The Upper Air app includes the following plot types.

Time Series: The default plot type is Time Series, which has date on the x-axis and the mean value of the selected parameter for that date on the y-axis.

Profile: The Profile plot type displays pressure level on the y–axis and the mean value of the selected parameter on the x-axis.

Die-off: Die-off plots show how skill (or the inverse, error) changes with increasing lead time. Figure 4.1 shows the user interface page after selecting the plot type of Dieoff. Note that another selector is included for DIEOFF TYPE, which has the following possible values:

1. Dieoff
2. Dieoff for a specific UTC cycle start time

3. Single cycle forecast

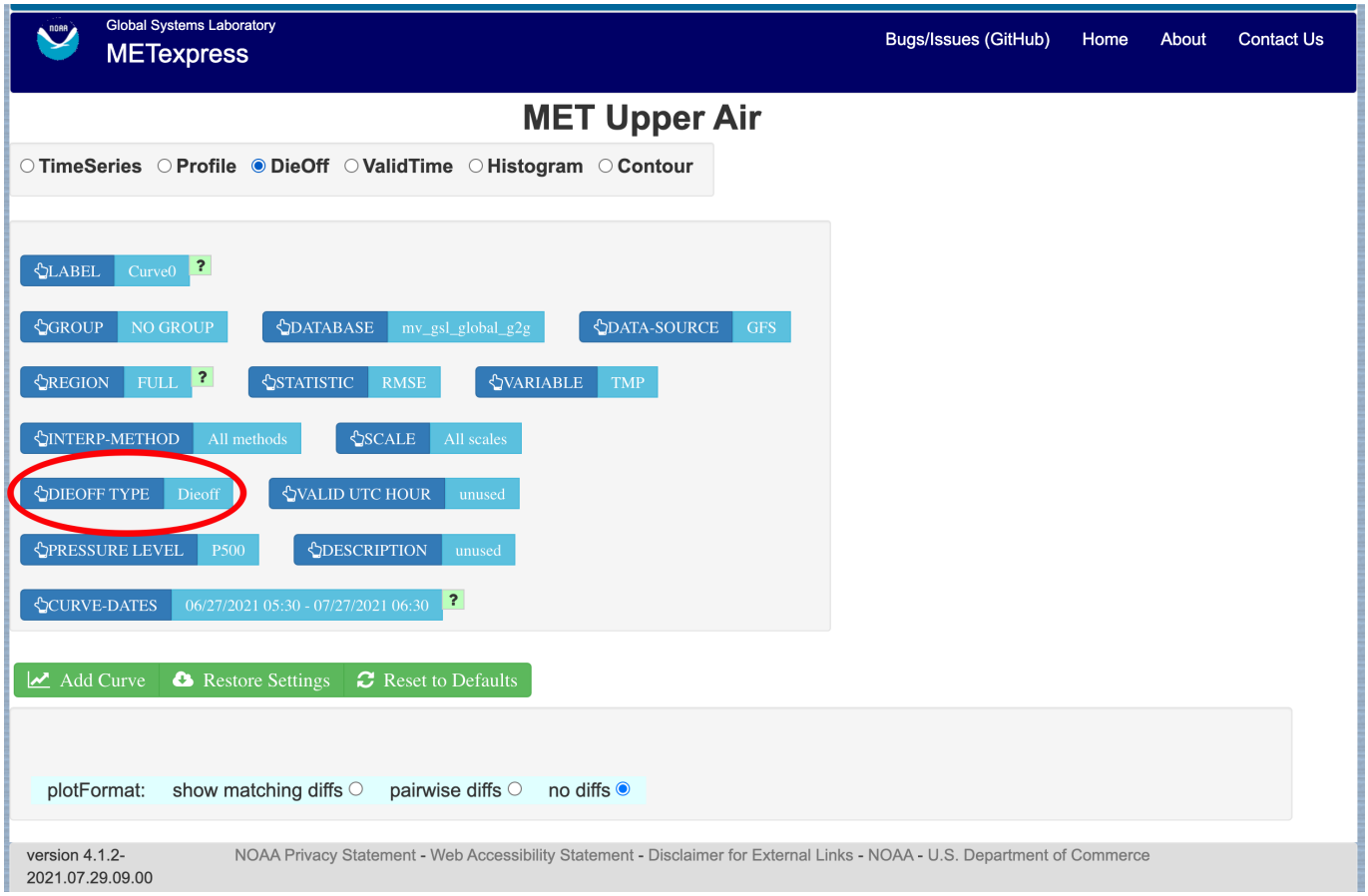


Figure 4.1: User Interface screen after selecting plot type of Dieoff.

Figure 4.2 shows a sample of a Dieoff plot in METexpress. This looks more like a familiar die-off curve when plotting skill, such as anomaly correlation as plotted in Figure 4.3 using the Anomaly Correlation app, rather than error as is plotted with the Upper Air app.

The option "dieoff" for Dieoff Type uses all data at each given forecast hour within the specified date range. The option for "Dieoff for a specific UTC cycle start time" filters data to only use those at a specified cycle initialization time, such as 0 or 12. The option "Single cycle forecast" uses only the forecasts from the first cycle in the specified date range.

ValidTime: The ValidTime plot type (also sometimes known as diurnal cycle plots) displays valid UTC hour on the x–axis and the mean value of the selected parameter on the y-axis.

Histograms: Histograms allow users to visualize the distribution of a given statistic over a specified time period. For example, if a user requested a histogram of RMSE for 144-h GFS forecasts over the global domain for a month, they would see the frequencies of specific RMSE values produced by individual GFS runs over that month. Histograms have statistical value bins on the x-axis, and number or frequency counts on the y-axis.

Histograms have a number of additional selectors that control their appearance:

- Y-axis mode: Can be set to either "Relative frequency" or "Number", depending on whether a user

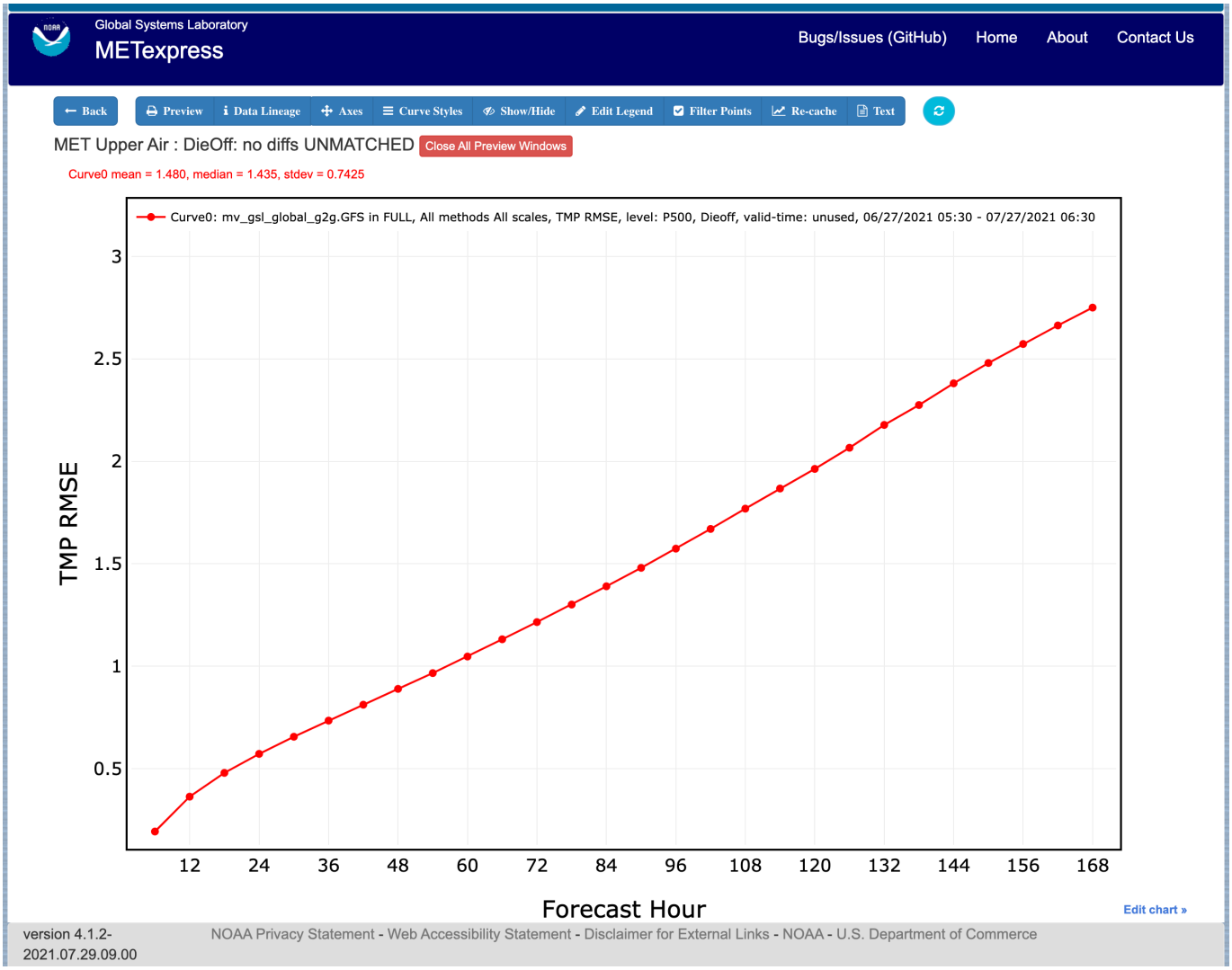


Figure 4.2: Upper Air Dieoff plot

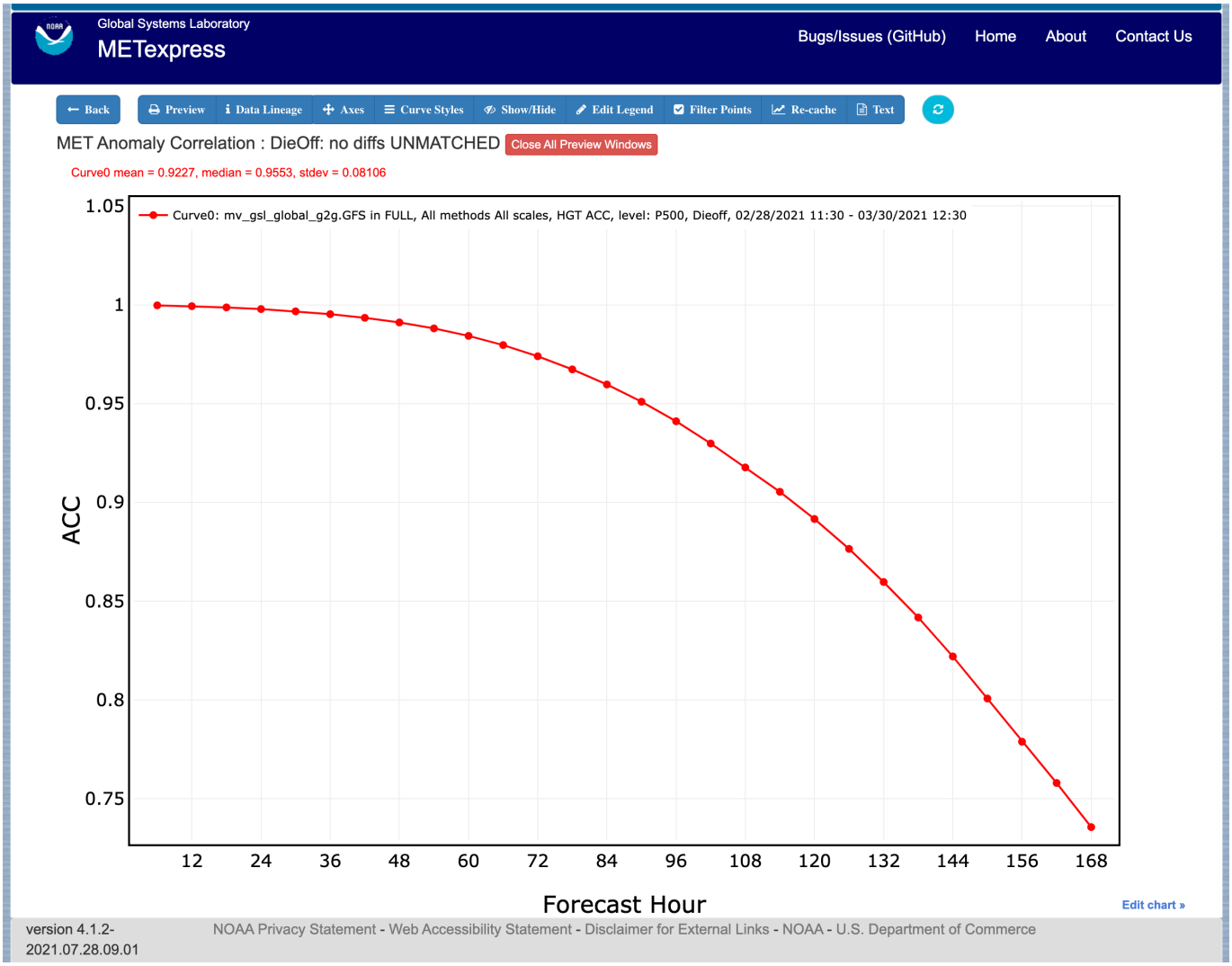


Figure 4.3: Anomaly Correlation Dieoff plot

wants the frequency of a given statistic displayed as a fraction of 100, or as a raw count.

- Customize bins: With this selector, the user can choose one of the following options to customize their x-axis bins:
  - Default bins
  - Set number of bins
    - Has sub-selector "Number of bins"
  - Make zero a bin bound
  - Choose a bin bound
    - Has sub-selector "Bin pivot value"
  - Set number of bins and make zero a bin bound
    - Has sub-selector "Number of bins"
  - Set number of bins and choose a bin bound
    - Has sub-selectors "Number of bins" and "Bin pivot value"
  - Manual bins
    - Has sub-selector "Bin bounds"
  - Manual start, number, and stride
    - Has sub-selectors "Number of bins", "Bin start", and "Bin stride"

Figure 4.4 shows the user interface for histogram plots and Figure 4.5 shows a sample plot.

Contour: Contour plots can be used in many ways. One can illustrate data with respect to height, as in plots seen at http://www.emc.ncep.noaa.gov/gmb/STATS_vsdb/, which have height on the y-axis and forecast hour (as in lead time) on the x-axis. These VSDB stat plots can be easily replicated in METexpress by using the contour plot type, except that the plot in METexpress will have only one pane, not two. In addition, METexpress users are not bound to have only pressure level / height on the y-axis or forecast lead time on the x-axis. They can reverse the two, place valid or init UTC hour on one of the axes, create Hovmoller diagrams, and many other combinations.

Contour plots have two additional selectors, x-axis-parameter and y-axis-parameter. With these, a user can decide which field to place on the x-axis (e.g. forecast lead time), and which to place on the y-axis (e.g. pressure level or valid UTC hour).

Figure 4.6 shows an example of an Upper Air profile plotted as a contour plot.

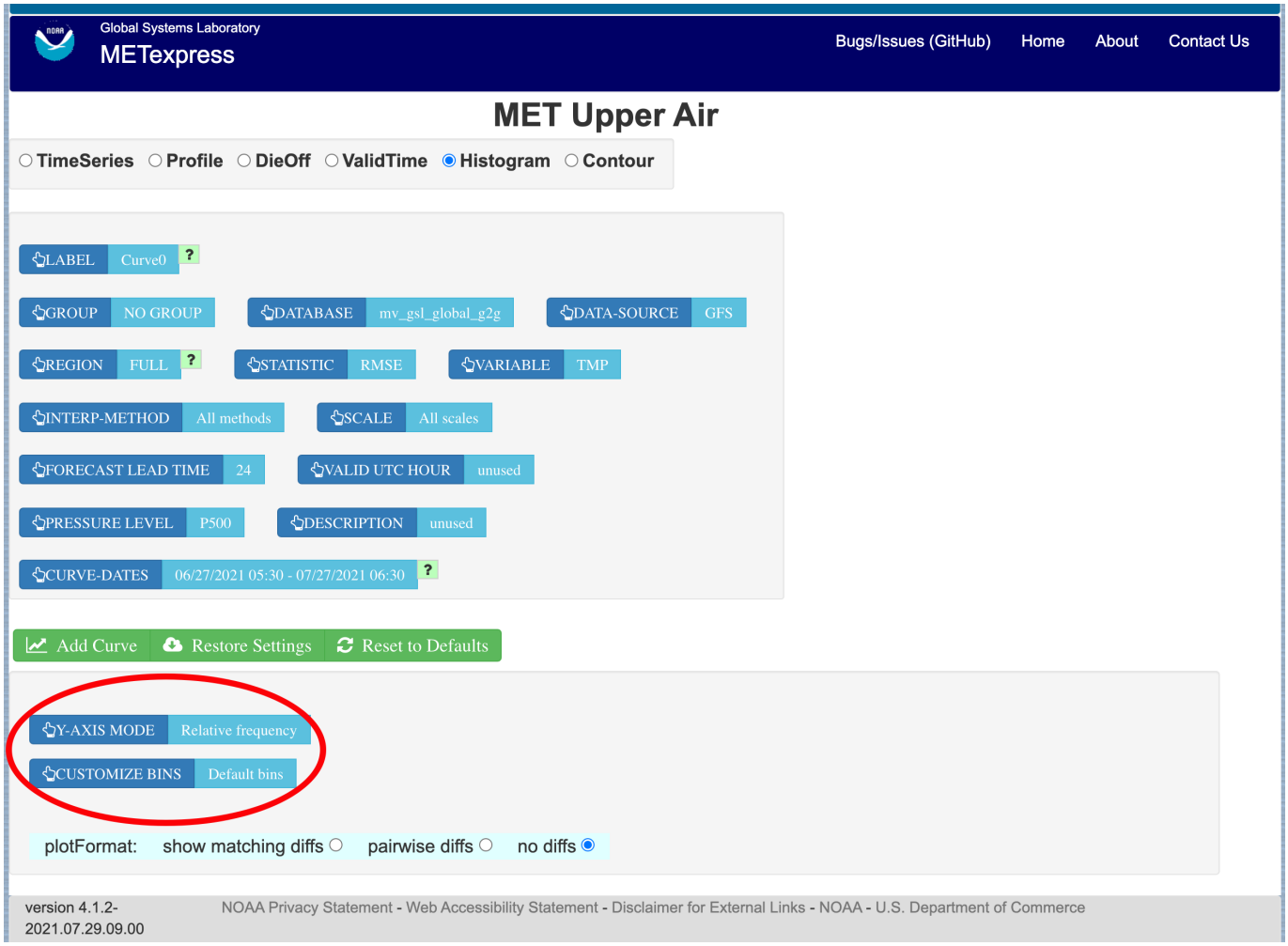


Figure 4.4: The user interface for histogram plots.

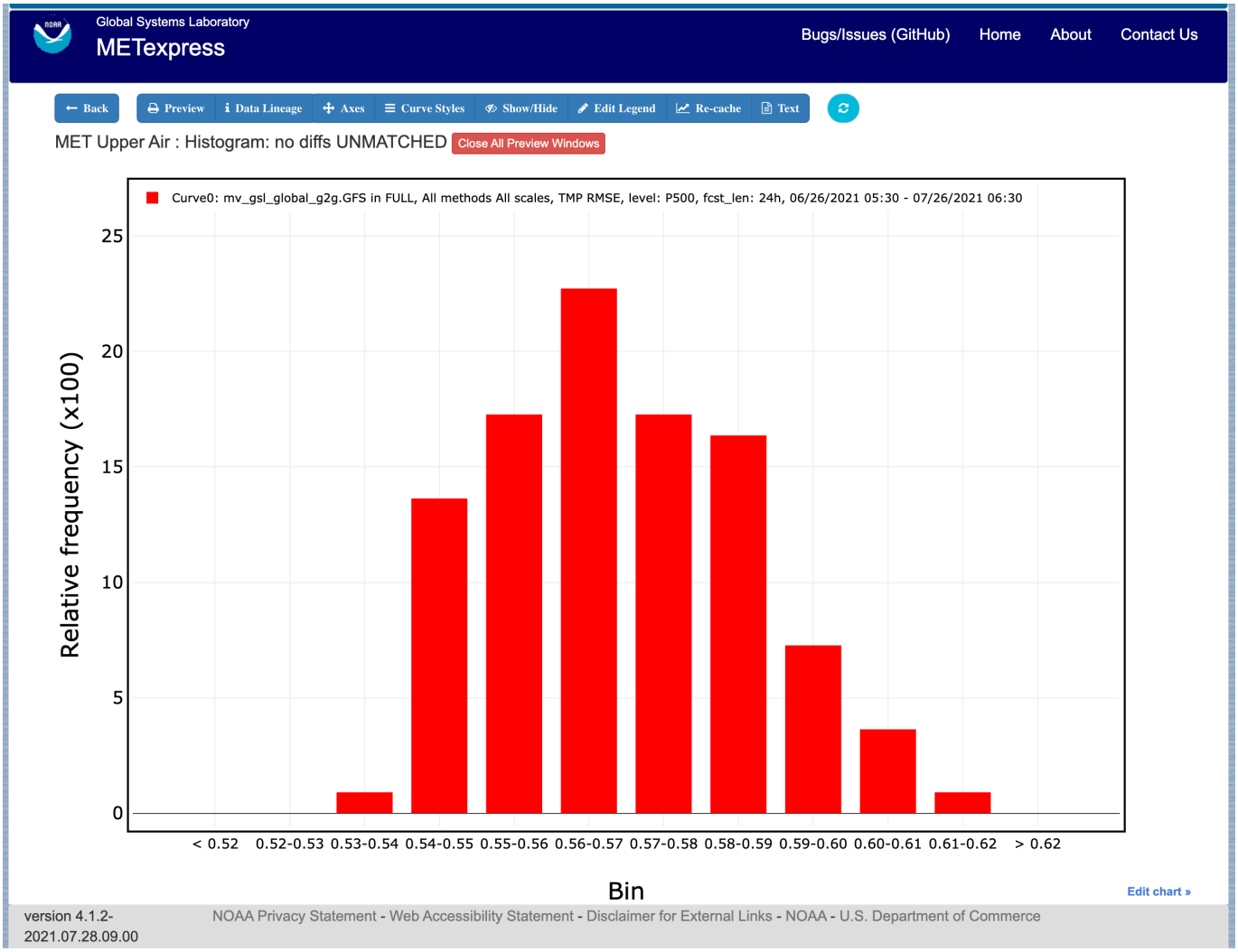


Figure 4.5: Plot generated from selections in Figure 4.4

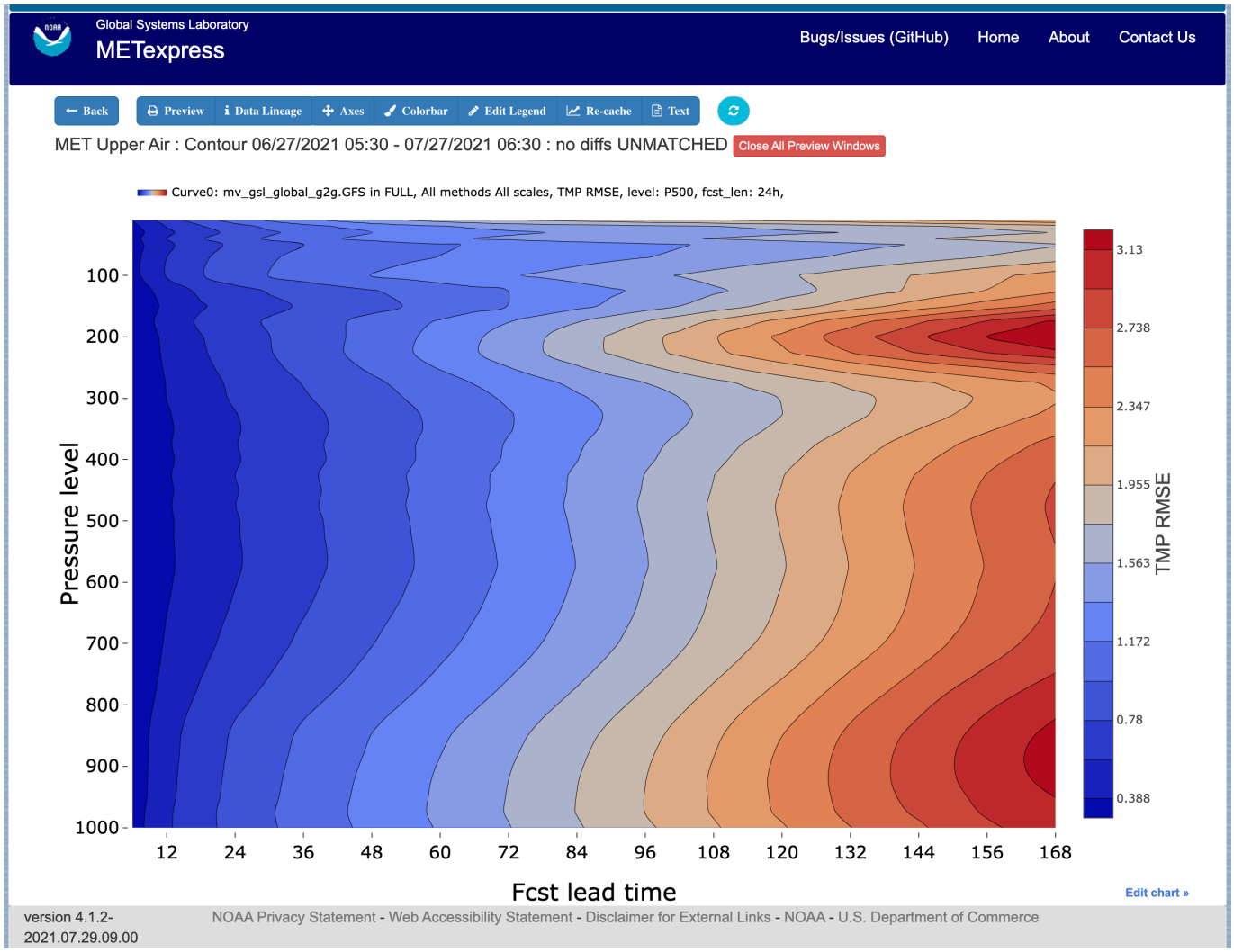


Figure 4.6: Upper Air profile, as a contour plot

4.2 Anomaly Correlation App

The Anomaly Correlation app is designed for plotting anomaly correlations at different pressure levels in the atmosphere, and at different heights above the ground.

An example of the Anomaly Correlation app user interface is shown in Figure 4.7 This interface is similar to the one for Upper Air but has fewer selectable parameters.

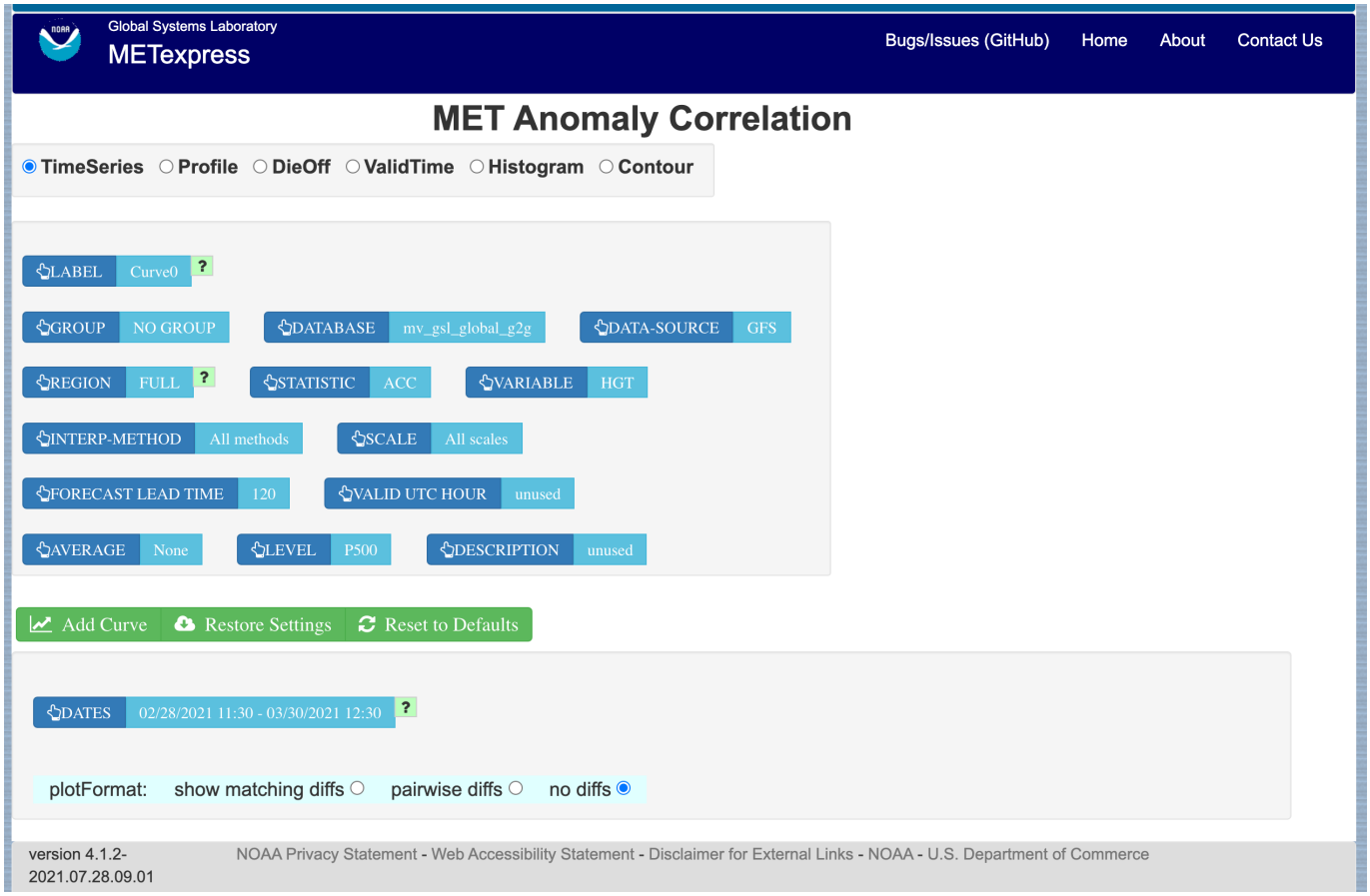


Figure 4.7: Anomaly Correlation app user interface

In this application, the selectable values are derived from the data for these parameters:

- Group
- Database
- Data-Source
- Region
- Statistic
- Variable
- Interp-Method
- Scale

- Forecast lead time
- Level
- Description
- Dates
- Curve-dates

The selector for the Statistic has these possible choices (depending on available MET line types):

- ACC
- Vector ACC

Plot types available include

- Time Series
- Profile
- Dieoff
- ValidTime
- Histogram
- Contour

All plot types function the same here as they do in MET Upper Air described above. A sample anomaly correlation plot is shown in Figure 4.8.

4.3 Surface App

The Surface app is designed for plotting scalar and contingency table statistics at different heights above the ground.

The user interface for the Surface app is shown in Figure 4.9.

For this app, the following parameters have choices derived from the data.

- Group
- Database
- Data-source
- Region
- Statistic
- Variable
- Interp-Method
- Scale
- Forecast lead time

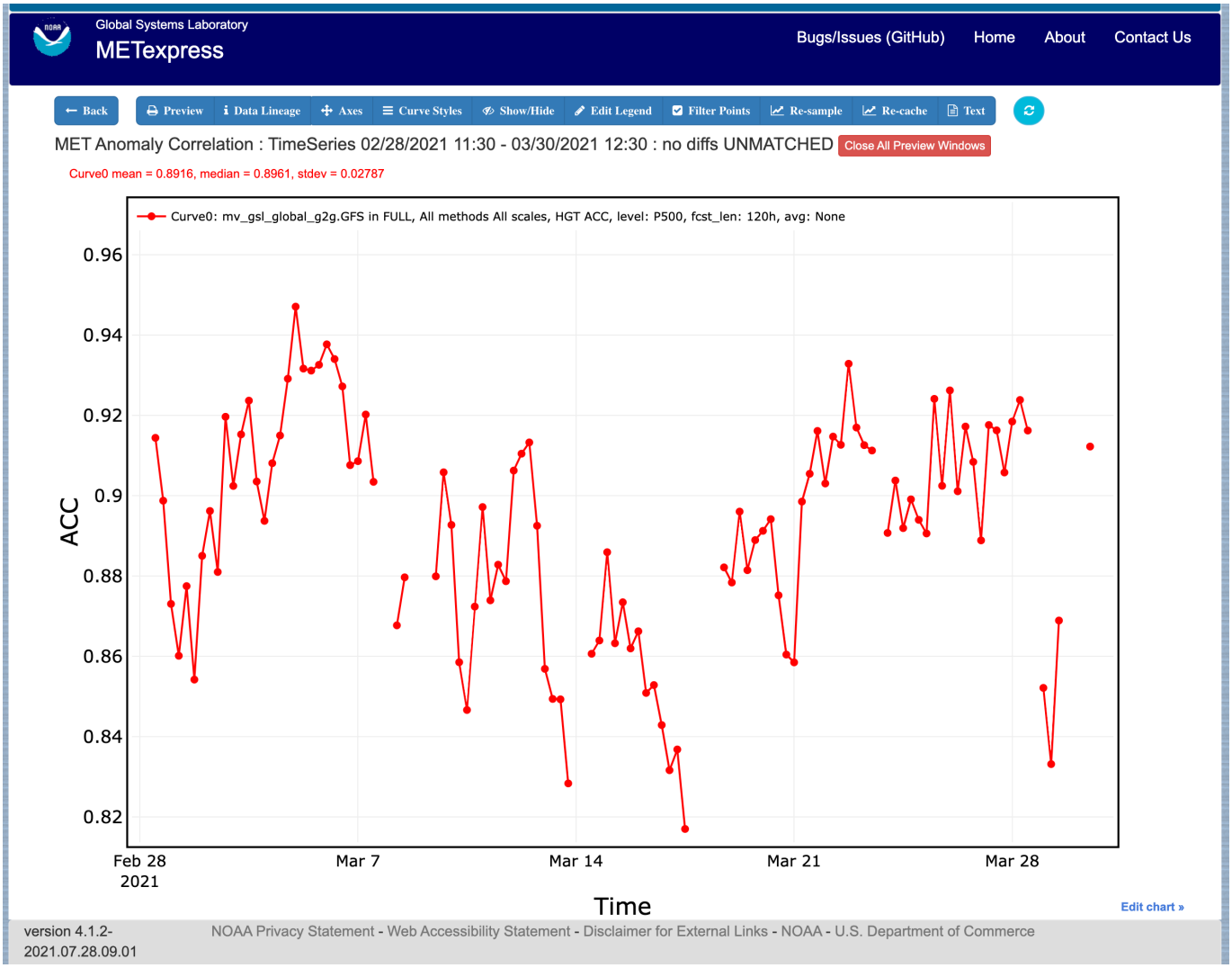


Figure 4.8: Anomaly Correlation sample plot.

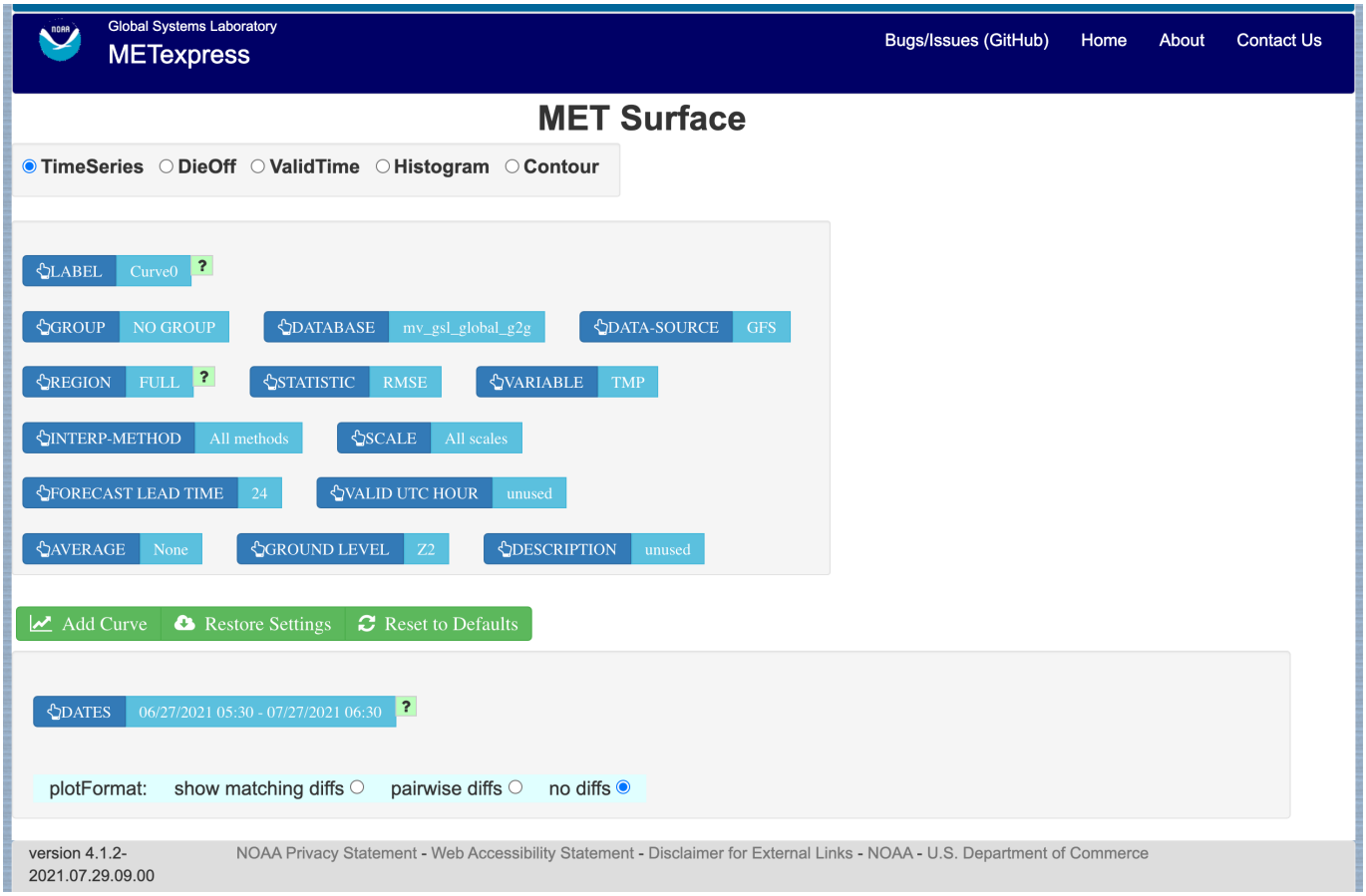


Figure 4.9: User Interface for the Surface app

- Ground level
- Description
- Dates
- Curve-dates

The selector for the Statistic has these possible choices (depending on available MET line types):

- RMSE
- Bias-corrected RMSE
- MSE
- Bias-corrected MSE
- ME (Additive bias)
- Fractional Error
- Multiplicative bias
- Forecast mean
- Observed mean
- Forecast stdev
- Observed stdev
- Error stdev
- Pearson Correlation
- Forecast length of mean wind vector
- Observed length of mean wind vector
- Forecast length - observed length of mean wind vector
- abs(Forecast length - observed length of mean wind vector)
- Length of forecast - observed mean wind vector
- Direction of forecast - observed mean wind vector
- Forecast direction of mean wind vector
- Observed direction of mean wind vector
- Angle between mean forecast and mean observed wind vectors
- RMSE of forecast wind vector length
- RMSE of observed wind vector length
- Vector wind speed MSVE
- Vector wind speed RMSVE
- Forecast mean of wind vector length

- Observed mean of wind vector length
- Forecast stdev of wind vector length
- Observed stdev of wind vector length

Plot types available include:

- Time Series
- Dieoff
- ValidTime
- Histogram
- Contour

Plots in the Surface app for Time Series, Dieoff, ValidTime, Histogram, and Contour are the same as in Upper Air. An example of a Valid Time plot is shown in Figure 4.10.

Figure 4.10: Surface app ValidTime plot

4.4 Air Quality App

Similarly to the Surface app, the Air Quality app is designed for plotting scalar and contingency table statistics at different heights above the ground, but with a focus on variables related to air quality.

For this app, the following parameters have choices derived from the data.

- Group
- Database
- Data-source
- Region
- Statistic
- Variable
- Threshold
- Interp-Method
- Scale
- Forecast lead time
- Ground level
- Description
- Dates
- Curve-dates

The selector for the Statistic has these possible choices (depending on available MET line types):

- CSI
- FAR
- FBIAS
- GSS
- HSS
- PODy
- PODn
- POFD
- RMSE
- Bias-corrected RMSE
- MSE
- Bias-corrected MSE
- ME (Additive bias)

- Fractional Error
- Multiplicative bias
- Forecast mean
- Observed mean
- Forecast stdev
- Observed stdev
- Error stdev
- Pearson Correlation

Plot types available include

- Time Series
- Dieoff
- Threshold
- ValidTime
- Histogram
- Contour

Plots in the Air Quality app for Time Series, Dieoff, ValidTime, Histogram, and Contour are the same as in Upper Air.

An additional plot type, Threshold, is available in this app. Threshold plots display threshold on the x-axis, and the mean value of the selected parameter on the y-axis.

Figure 4.11 shows an example of an Air Quality Threshold plot.

4.5 Ensemble App

The Ensemble app is designed for plotting scalar and contingency table statistics, as well as ensemble metrics, for multi-member ensemble model runs.

For this app, the following parameters have choices derived from the data.

- Group
- Database
- Data-source
- Region
- Statistic
- Variable
- Forecast lead time

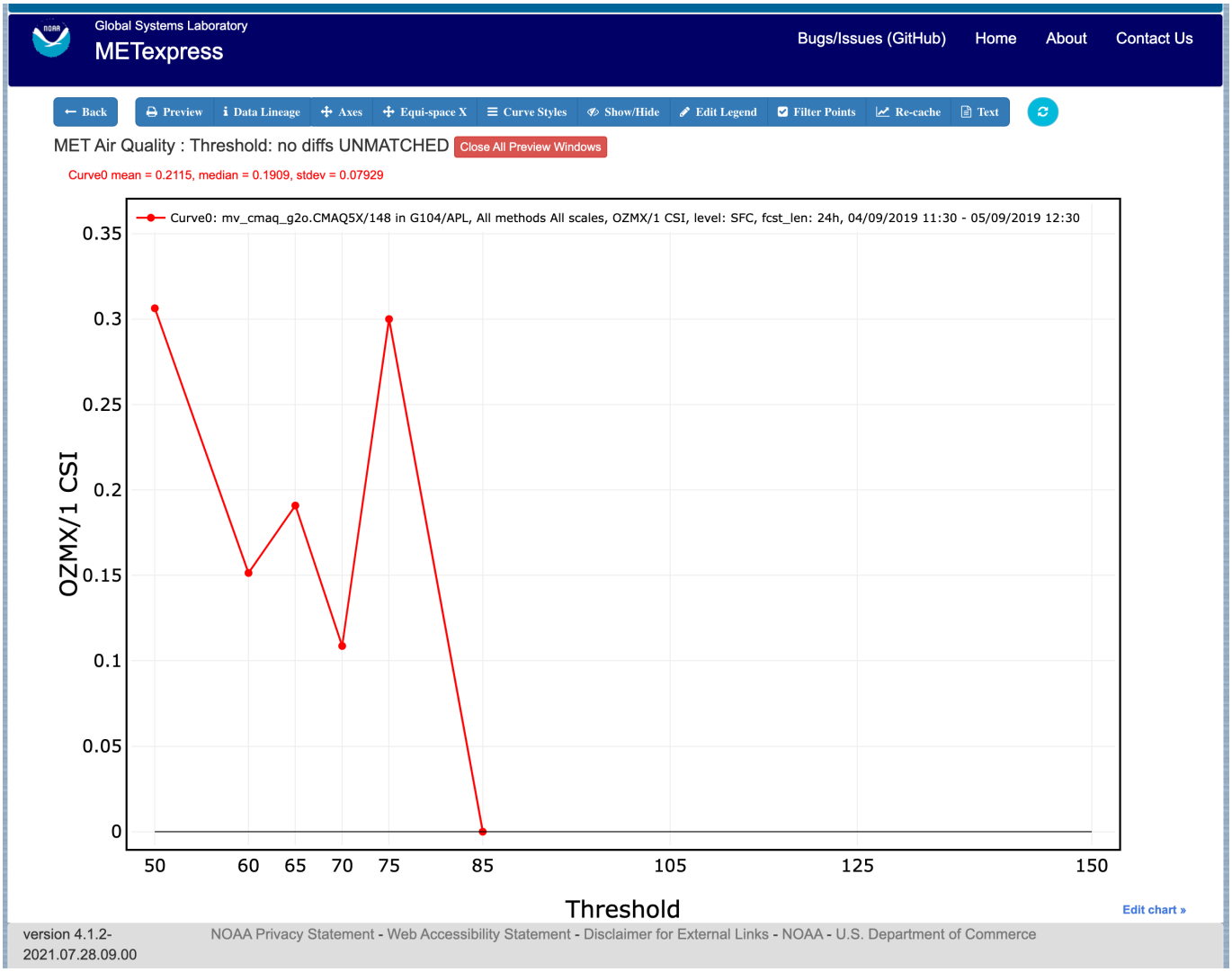


Figure 4.11: Air Quality app Threshold plot

- Level
- Description
- Dates
- Curve-dates

The selector for the Statistic has these possible choices (depending on available MET line types):

- RMSE
- RMSE with obs error
- Spread
- Spread with obs error
- ME (Additive bias)
- ME with obs error
- CRPS
- CRPSS
- MAE
- BS
- BSS
- BS reliability
- BS resolution
- BS uncertainty
- BS lower confidence limit
- BS upper confidence limit
- ROC AUC
- FSS

Plot types available include

- Time Series
- Dieoff
- ValidTime
- Histogram
- Ensemble Histogram
- Reliability
- ROC
- Performance Diagram

Plots in the Ensemble app for Time Series, Dieoff, ValidTime, and Histogram are the same as in Upper Air.

Four plot types are specific to this app: Ensemble Histogram, Reliability, ROC, and Performance Diagram.

Ensemble Histograms are controlled by the Histogram type selector that appears at the bottom of the main app page when the plot type of Ensemble Histogram is selected. This can be set to Rank Histogram, Probability Integral Transform Histogram, or Relative Position Histogram. Selecting one of these will produce the corresponding plot, with bins pre-calculated in the MET verification process. As with regular histogram plots, the user has the option of setting the Y-axis mode to either "Relative frequency" or "Number".

Reliability plots produce a single curve for the chosen parameters (probabilistic variables only), with Forecast Probability on the x-axis, and Observed Relative Frequency on the y-axis. Four additional lines will be displayed on the graph, denoting perfect skill, no skill, x climatology, and y climatology.

ROC plots can display multiple curves (probabilistic variables only), with False Alarm Rate on the x-axis, and Probability of Detection on the y-axis. An additional diagonal line will be displayed on the graph, denoting no skill.

Performance Diagrams can also display multiple curves (probabilistic variables only), with Success Ratio (1-FAR) on the x-axis, and Probability of Detection on the y-axis. Additional solid black curves are displayed on the graph to denote lines of constant bias, and additional dashed black curves are displayed on the graph to denote lines of constant CSI.

Figure 4.12 shows the user interface for defining an Ensemble Histogram and Figure 4.13 through Figure 4.15 show examples of the 3 types of Ensemble Histograms.

Figure 4.16 shows an example Reliability plot, Figure 4.17 shows an example ROC plot, and Figure 4.18 shows an example Performance Diagram, all for the same data set.

4.6 Precipitation App

The Precipitation app is designed for plotting scalar and contingency table statistics for variables relating to precipitation.

For this app, the following parameters have choices derived from the data.

- Group
- Database
- Data-source
- Region
- Statistic
- Variable
- Threshold
- Interp-Method
- Scale
- Obs type

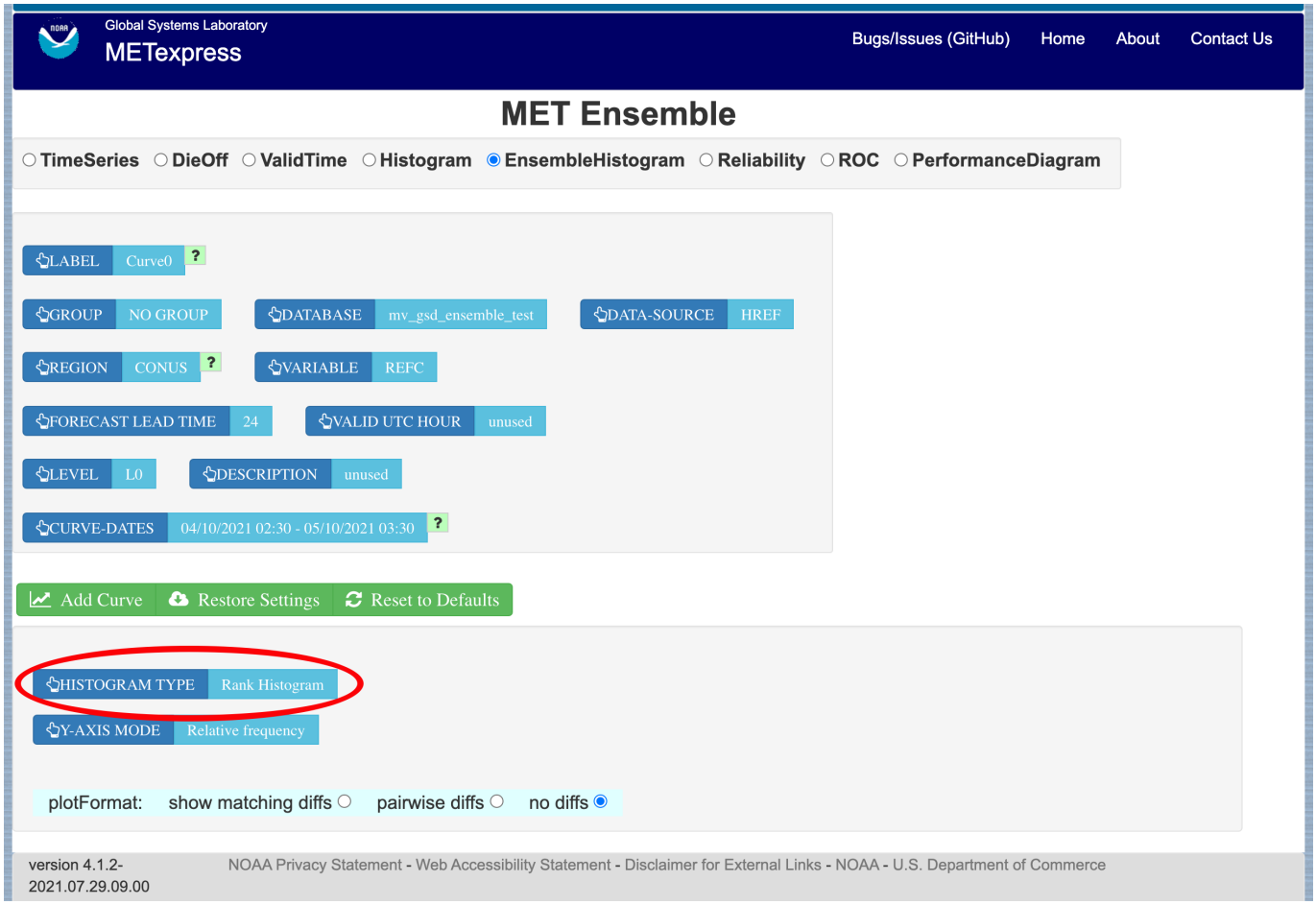


Figure 4.12: The Ensemble app user interface for Ensemble Histogram plots. Note the selector for Histogram Type which is unique to this plot type.

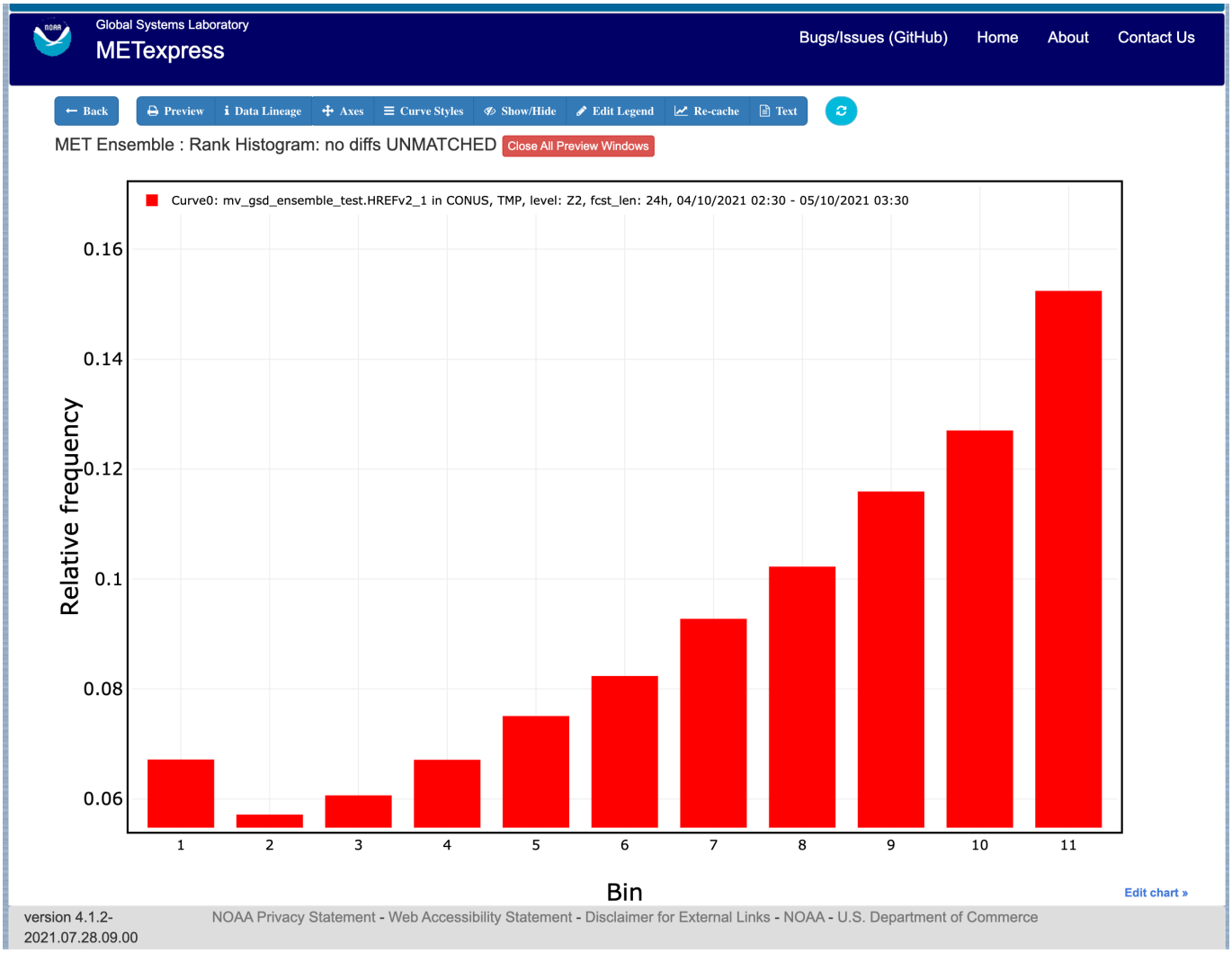


Figure 4.13: Ensemble Histogram plot type with Histogram Type of Rank Histogram.

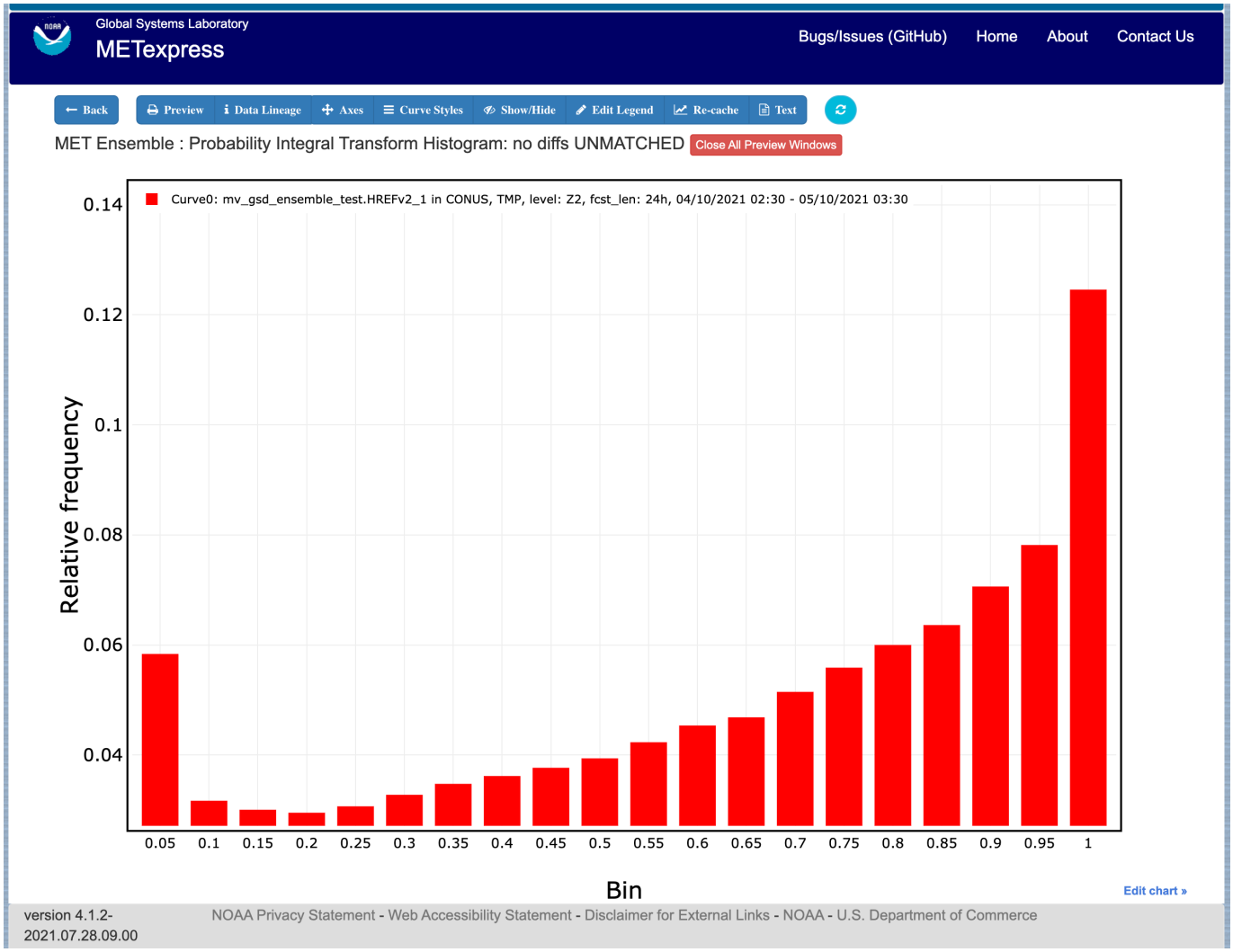


Figure 4.14: Ensemble Histogram plot type with Histogram Type of Probability Integral Transform Histogram.

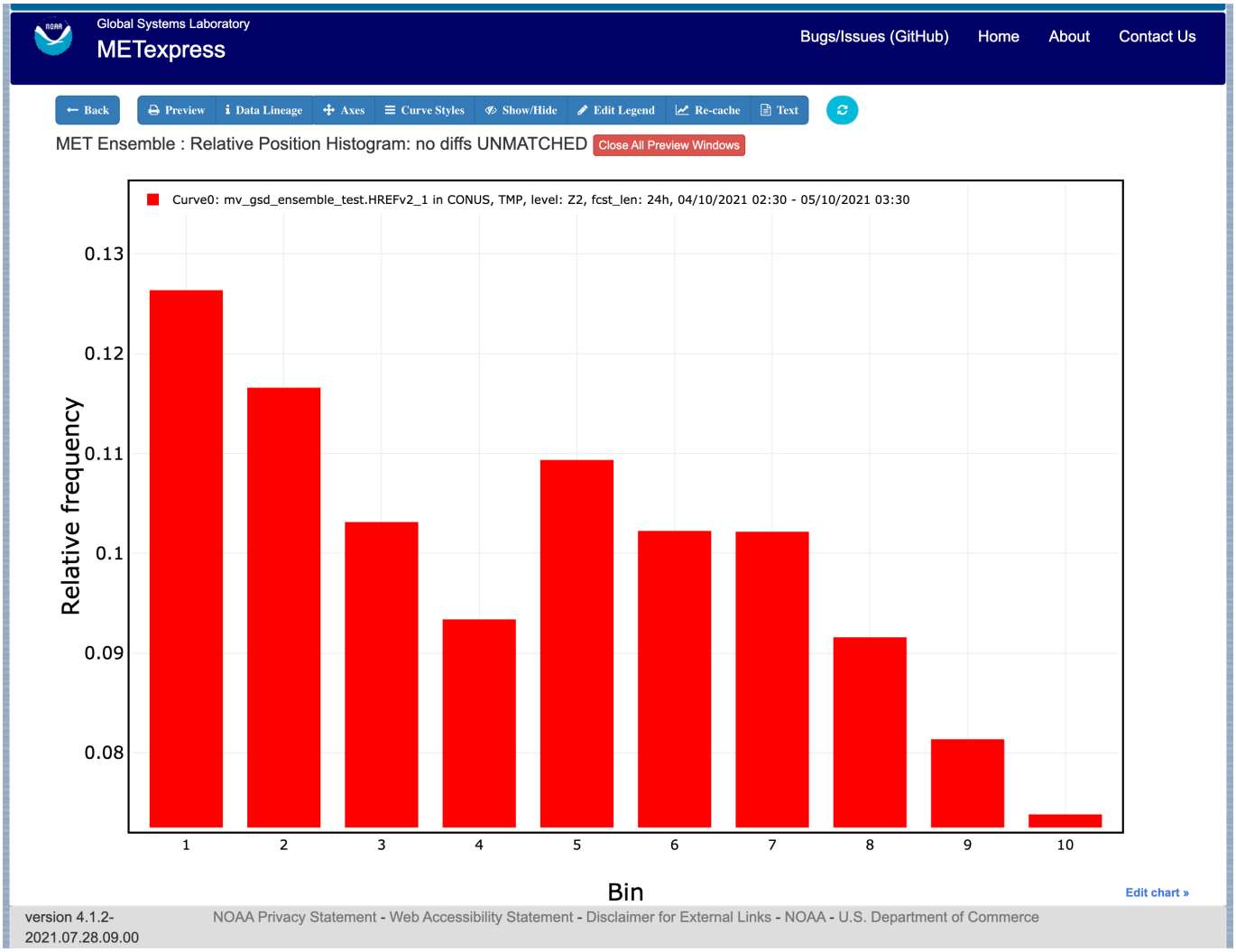


Figure 4.15: Ensemble Histogram plot type with Histogram Type of Relative Position Histogram

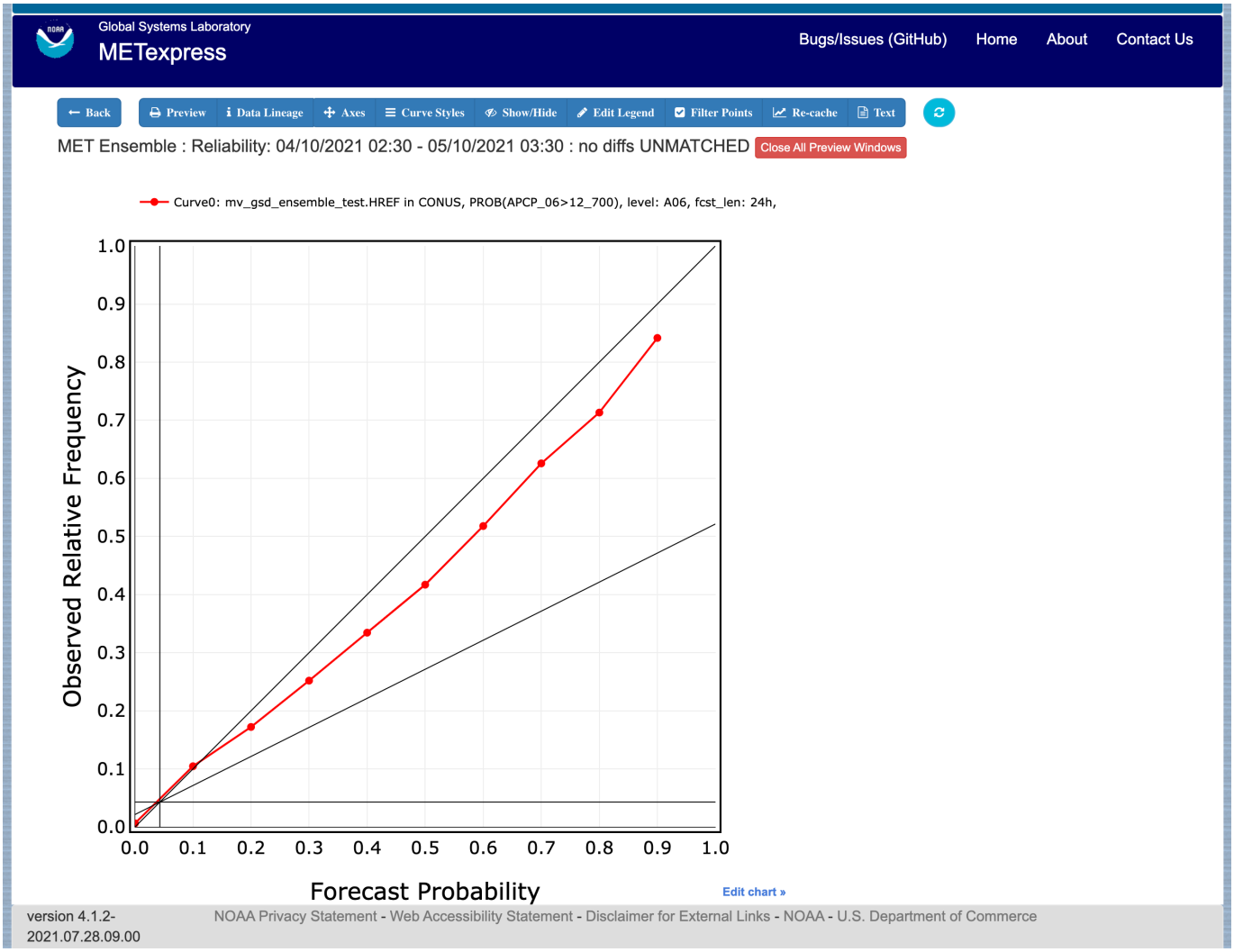


Figure 4.16: Ensemble app Reliability plot. The 1:1 diagonal gray line represents perfect skill between forecast probability and observation frequency. The diagonal line with the lower slope indicates the point above which the forecast becomes more skillful than climatology, and the vertical and horizontal lines indicate climatology.

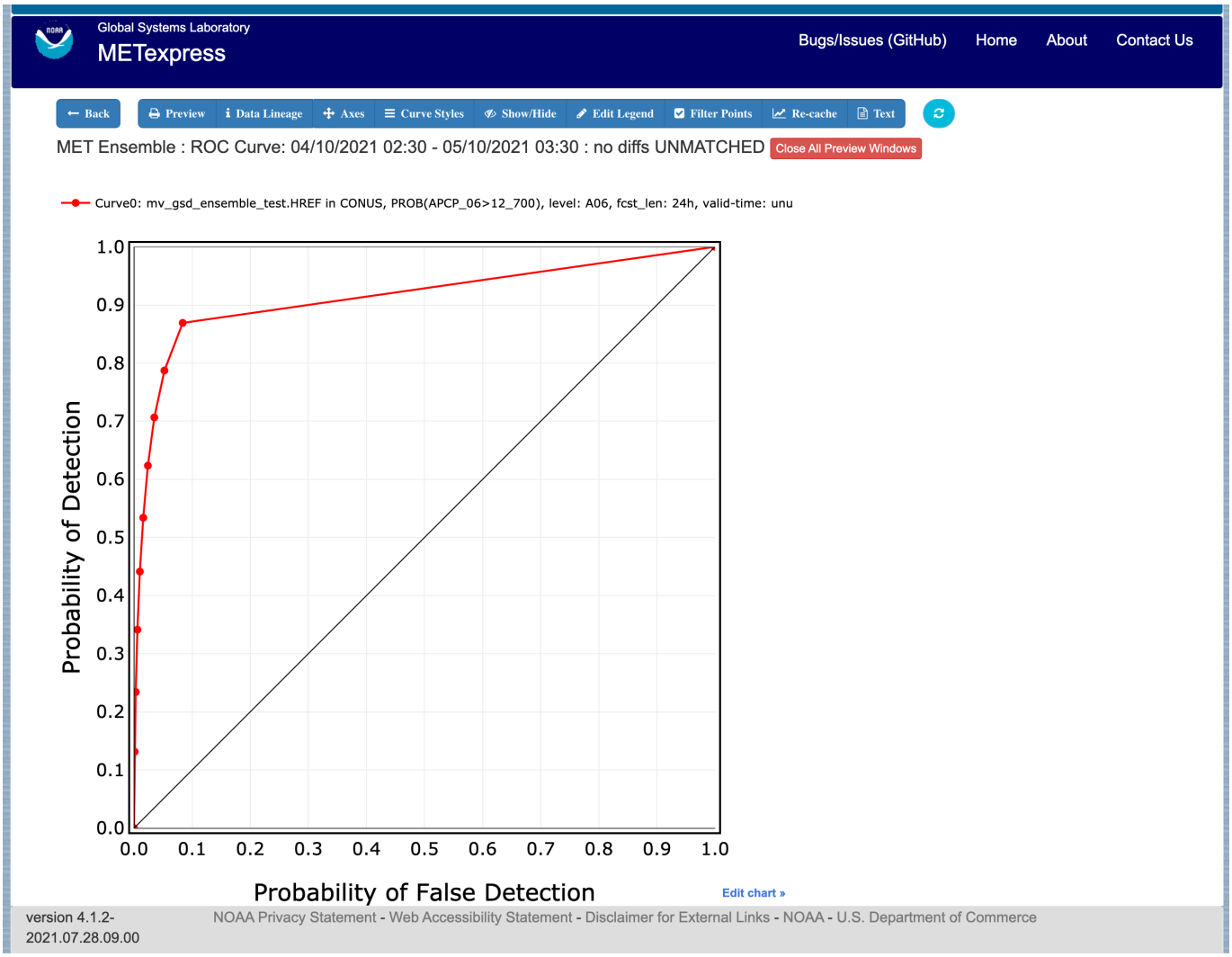


Figure 4.17: Ensemble app ROC plot for the same data set defined in Figure 4.16.

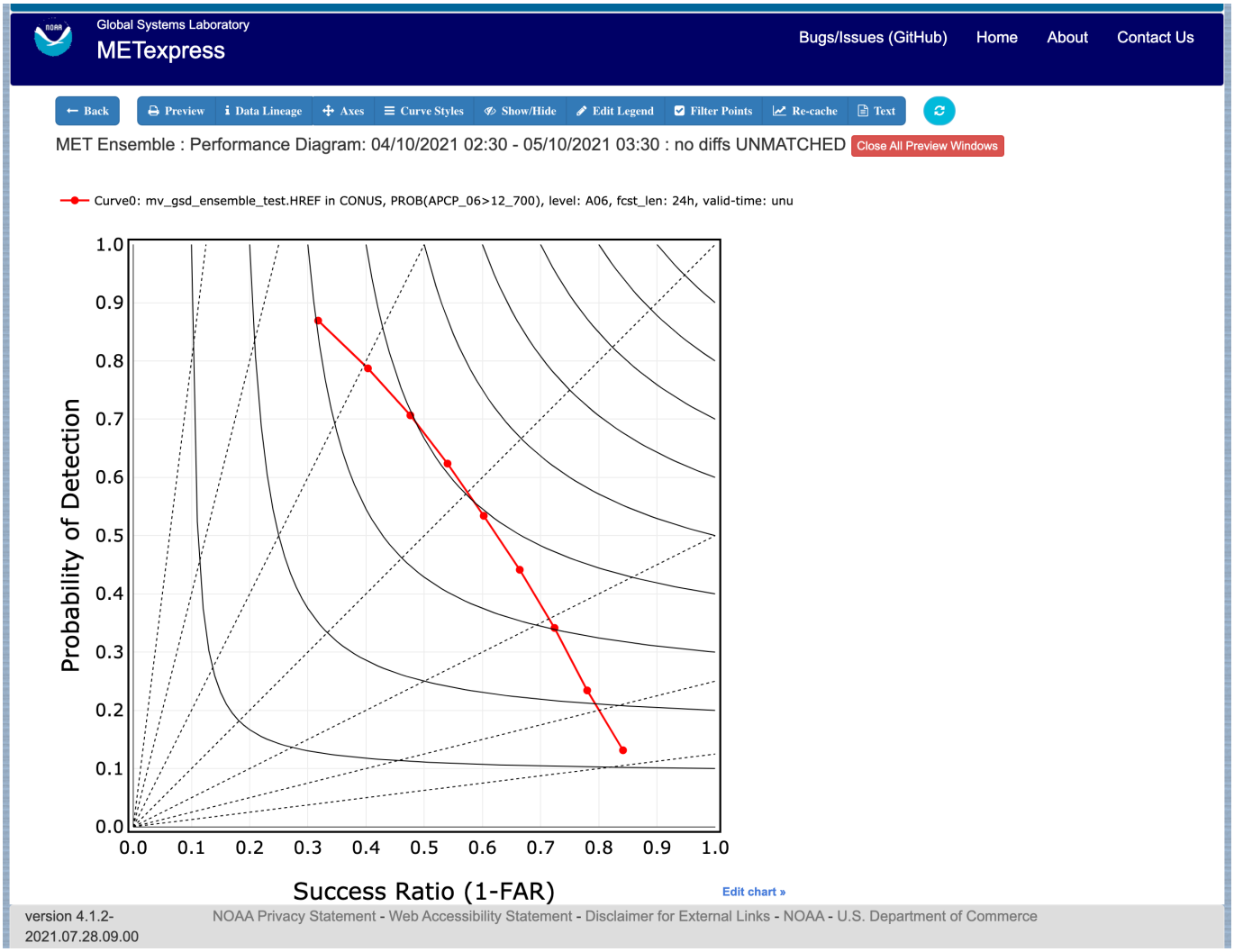


Figure 4.18: Ensemble app Performance Diagram for the same data set defined in Figure 4.16.

- Forecast lead time
- Level
- Description
- Dates
- Curve-dates

The selector for the Statistic has these possible choices (depending on available MET line types):

- CSI
- FAR
- FBIAS
- GSS
- HSS
- PODy
- PODn
- POFD
- FSS
- RMSE
- Bias-corrected RMSE
- MSE
- Bias-corrected MSE
- ME (Additive bias)
- Fractional Error
- Multiplicative bias
- Forecast mean
- Observed mean
- Forecast stdev
- Observed stdev
- Error stdev
- Pearson Correlation

Plot types available include

- Time Series
- Dieoff
- Threshold

- ValidTime
- GridScale
- Histogram
- Contour

Plots in the Precipitation app for Time Series, Dieoff, ValidTime, Histogram, and Contour are the same as in Upper Air.

A different plot type, Threshold, is present in this app. Threshold plots display threshold on the x-axis, and the mean value of the selected parameter on the y-axis.

Another unique plot type, GridScale, is included in this app. GridScale plots display grid scale on the x-axis, and the mean value of the selected parameter on the y-axis.

Figure 4.19 shows an example of the user interface for the Precipitation app, Figure 4.20 shows an example Threshold plot, and Figure 4.21 shows an example GridScale plot.

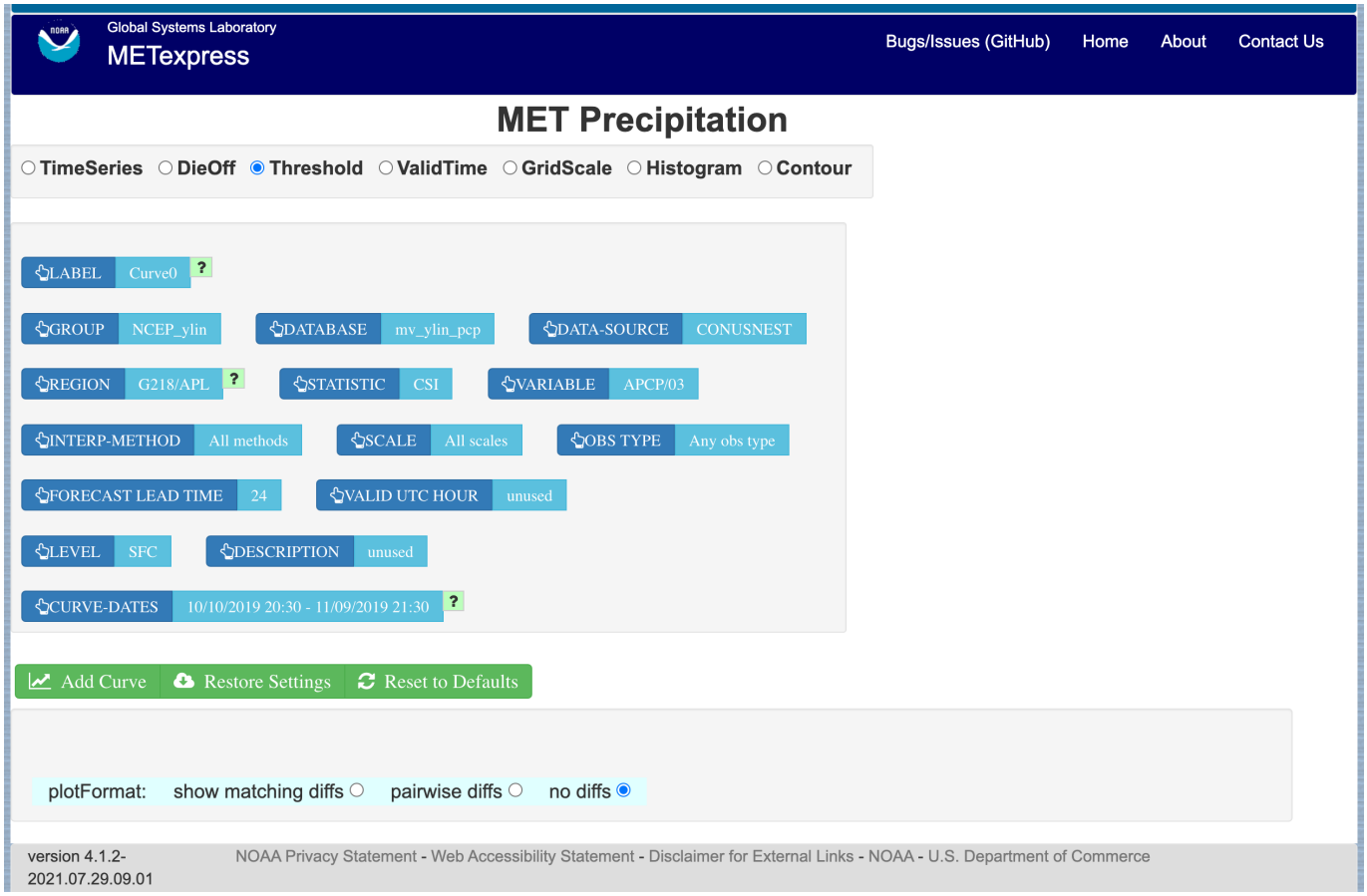


Figure 4.19: User interface screen for a Threshold plot in the Precipitation app

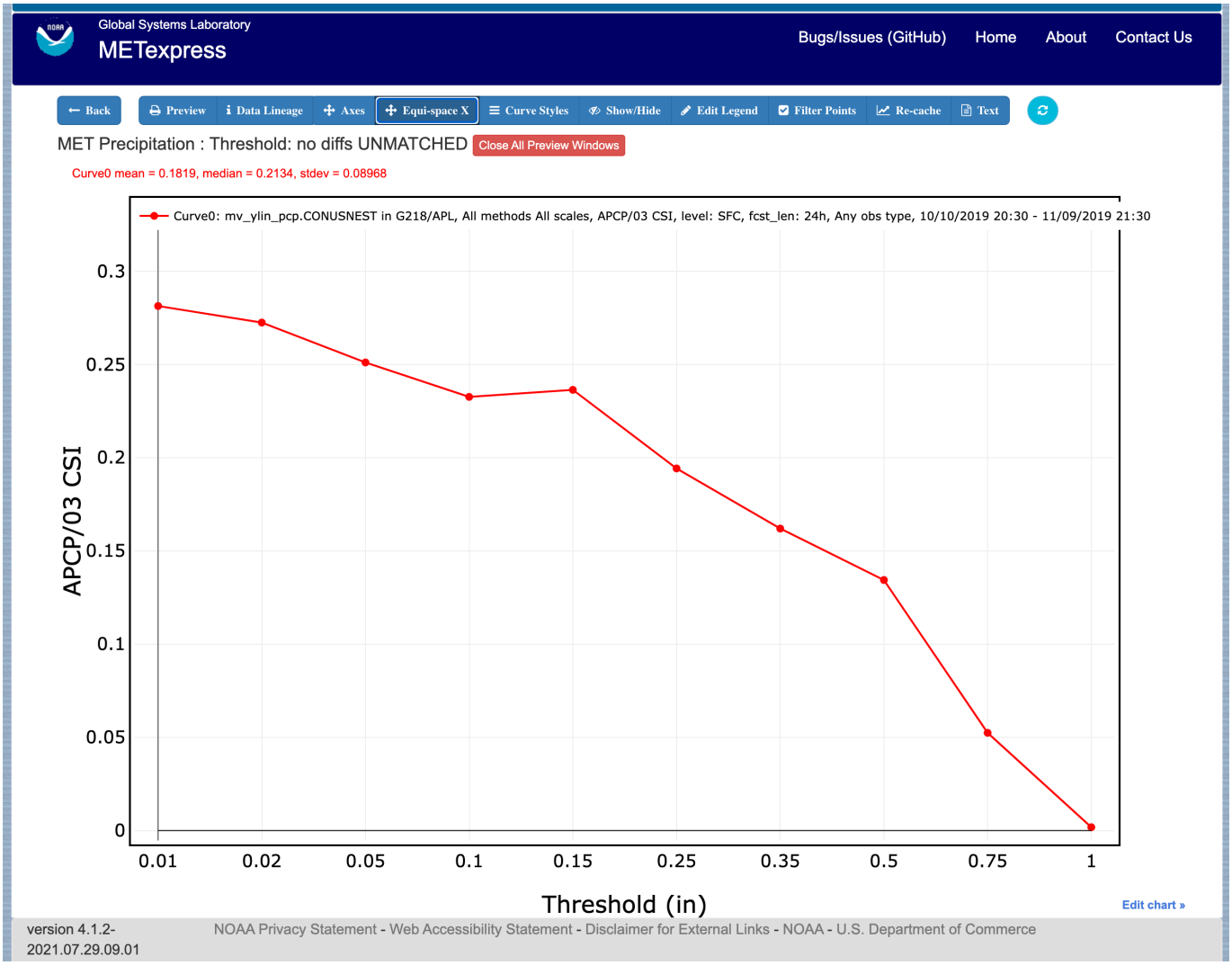


Figure 4.20: Threshold plot in the Precipitation app produced from selections in Figure 4.19

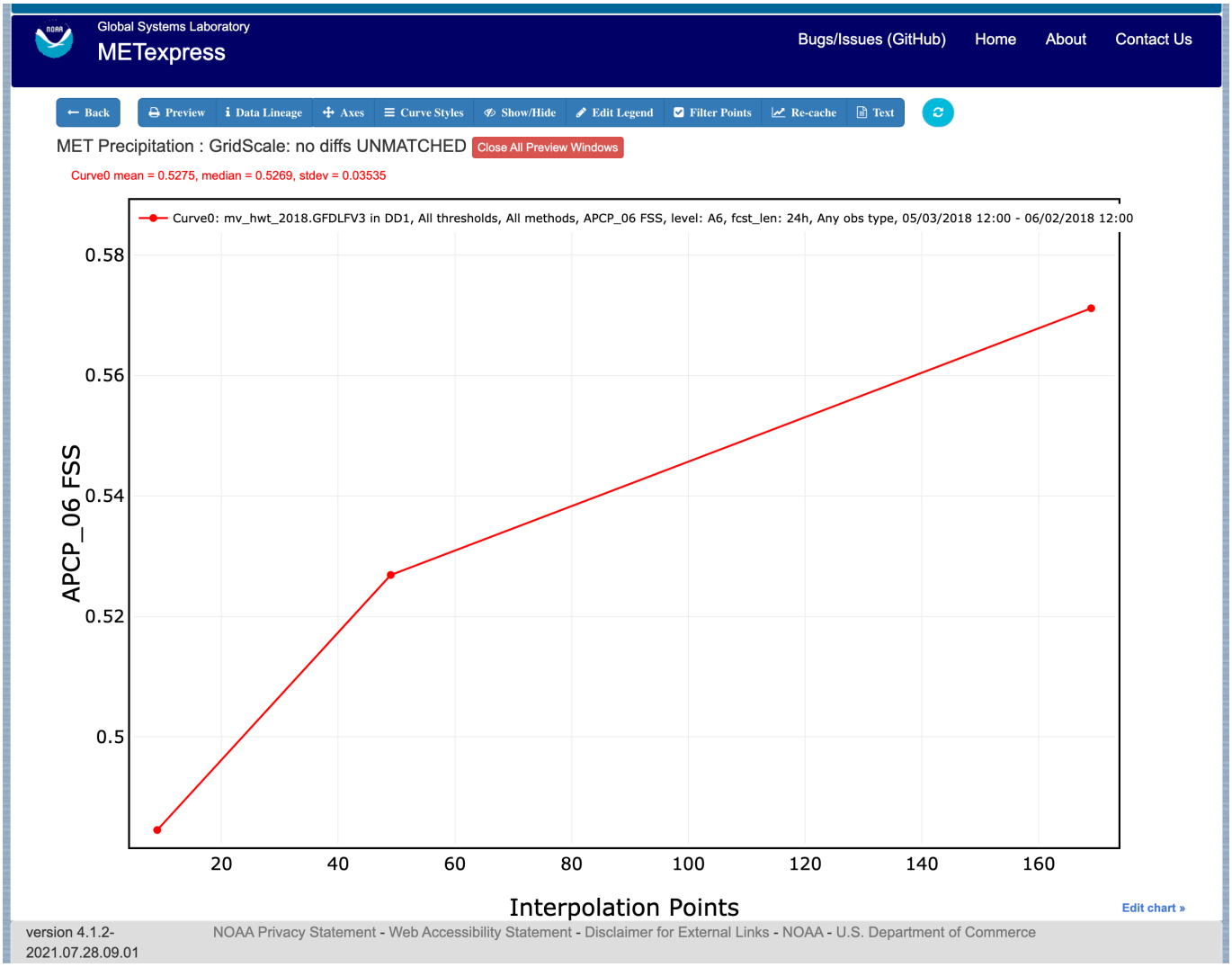


Figure 4.21: GridScale plot in the Precipitation app produced from selections in Figure 4.19

4.7 Cyclone App

The Cyclone app is designed for plotting track and intensity verification statistics for both tropical and extratropical cyclones.

For this app, the following parameters have choices derived from the data.

- Group
- Database
- Data-source
- Basin
- Statistic
- Year
- Storm
- Truth
- Forecast lead time
- Storm classification
- Description
- Dates
- Curve-dates

The selector for the Statistic has these possible choices (depending on available MET line types):

- Track error
- X error
- Y error
- Along track error
- Cross track error
- Model distance to land
- Truth distance to land
- Model-truth distance to land
- Model MSLP
- Truth MSLP
- Model-truth MSLP
- Model maximum wind speed
- Truth maximum wind speed
- Model-truth maximum wind speed

- Model radius of maximum winds
- Truth radius of maximum winds
- Model-truth radius of maximum winds
- Model eye diameter
- Truth eye diameter
- Model-truth eye diameter
- Model storm speed
- Truth storm speed
- Model-truth storm speed
- Model storm direction
- Truth storm direction
- Model-truth storm direction
- RI start hour
- RI end hour
- RI time duration
- RI end model max wind speed
- RI start truth max wind speed
- RI end truth max wind speed
- RI truth start to end change in max wind speed
- RI truth maximum change in max wind speed

Plot types available include

- Time Series
- Dieoff
- ValidTime
- YearToYear
- Histogram

Plots in the Cyclone app for Time Series, Dieoff, ValidTime, and Histogram are the same as in Upper Air.

A different plot type, YearToYear, is present in this app. YearToYear plots display individual years on the x-axis, and the mean value of the selected statistic for each year on the y-axis. This is useful for seeing how forecast quality has changed from year to year for each ocean basin.

Figure 4.22 shows an example of the user interface for the Cyclone app, and Figure 4.23 shows an example YearToYear plot.

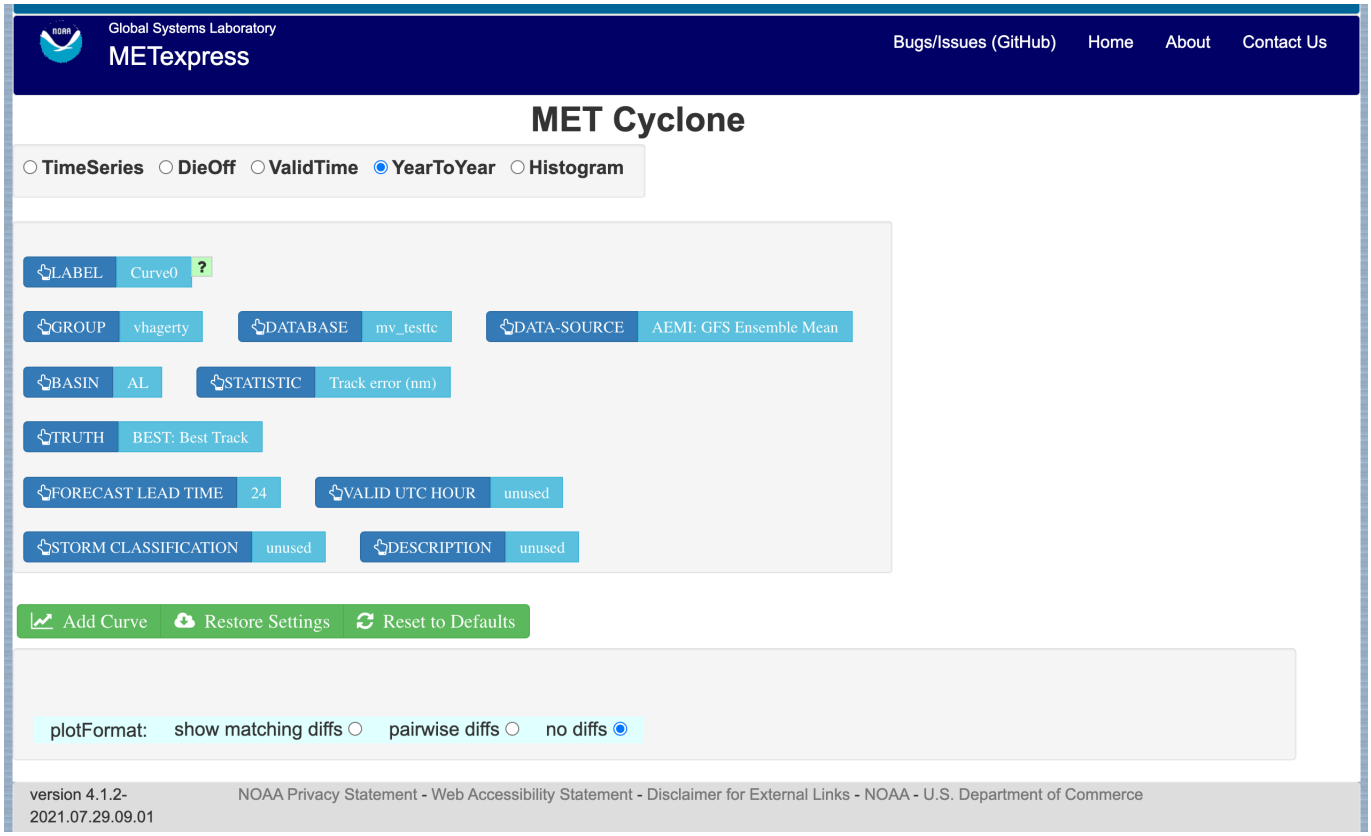


Figure 4.22: User interface screen for a YearToYear plot in the Cyclone app

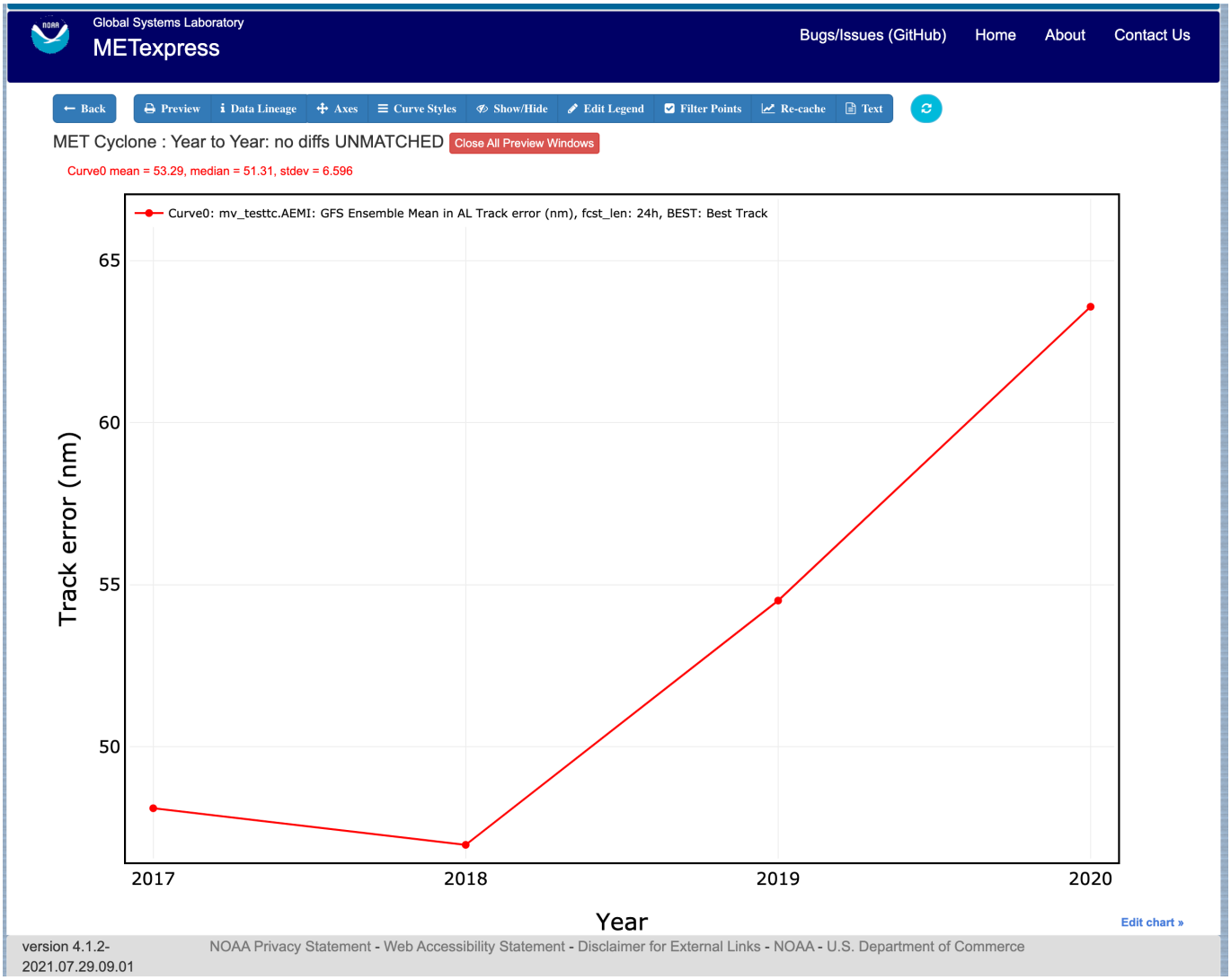


Figure 4.23: YearToYear plot in the Cyclone app produced from selections in Figure 4.22

4.8 Objects App

The Objects app is designed for plotting skill scores and model-obs pair verification statistics for convective objects.

For this app, the following parameters have choices derived from the data.

- Group
- Database
- Data-source
- Statistic
- Variable
- Threshold
- Radius
- Scale
- Forecast lead time
- Level
- Description
- Dates
- Curve-dates

The selector for the Statistic has these possible choices (depending on available MET line types):

- Model-obs centroid distance
- Model-obs centroid distance (unique pairs)
- Model-obs angle difference
- Model-obs aspect difference
- Model/obs area ratio
- Model/obs intersection area
- Model/obs union area
- Model/obs symmetric difference area
- Model/obs consumption ratio
- Model/obs curvature ratio
- Model/obs complexity ratio
- Model/obs percentile intensity ratio
- Model/obs interest
- OTS (Object Threat Score)

- MMI (Median of Maximum Interest)
- CSI (Critical Success Index)
- FAR (False Alarm Ratio)
- PODy (Probability of positive detection)
- Object frequency bias
- Ratio of simple objects that are forecast objects
- Ratio of simple objects that are observation objects
- Ratio of simple objects that are matched
- Ratio of simple objects that are unmatched
- Ratio of simple forecast objects that are matched
- Ratio of simple forecast objects that are unmatched
- Ratio of simple observed objects that are matched
- Ratio of simple observed objects that are unmatched
- Ratio of simple matched objects that are forecast objects
- Ratio of simple matched objects that are observed objects
- Ratio of simple unmatched objects that are forecast objects
- Ratio of simple unmatched objects that are observed objects
- Ratio of forecast objects that are simple
- Ratio of forecast objects that are cluster
- Ratio of observed objects that are simple
- Ratio of observed objects that are cluster
- Ratio of cluster objects that are forecast objects
- Ratio of cluster objects that are observation objects
- Ratio of simple forecasts to simple observations (frequency bias)
- Ratio of simple observations to simple forecasts (1 / frequency bias)
- Ratio of cluster objects to simple objects
- Ratio of simple objects to cluster objects
- Ratio of forecast cluster objects to forecast simple objects
- Ratio of forecast simple objects to forecast cluster objects
- Ratio of observed cluster objects to observed simple objects
- Ratio of observed simple objects to observed cluster objects
- Area-weighted ratio of simple objects that are forecast objects

- Area-weighted ratio of simple objects that are observation objects
- Area-weighted ratio of simple objects that are matched
- Area-weighted ratio of simple objects that are unmatched
- Area-weighted ratio of simple forecast objects that are matched
- Area-weighted ratio of simple forecast objects that are unmatched
- Area-weighted ratio of simple observed objects that are matched
- Area-weighted ratio of simple observed objects that are unmatched
- Area-weighted ratio of simple matched objects that are forecast objects
- Area-weighted ratio of simple matched objects that are observed objects
- Area-weighted ratio of simple unmatched objects that are forecast objects
- Area-weighted ratio of simple unmatched objects that are observed objects
- Area-weighted ratio of forecast objects that are simple
- Area-weighted ratio of forecast objects that are cluster
- Area-weighted ratio of observed objects that are simple
- Area-weighted ratio of observed objects that are cluster
- Area-weighted ratio of cluster objects that are forecast objects
- Area-weighted ratio of cluster objects that are observation objects
- Area-weighted ratio of simple forecasts to simple observations (frequency bias)
- Area-weighted ratio of simple observations to simple forecasts (1 / frequency bias)
- Area-weighted ratio of cluster objects to simple objects
- Area-weighted ratio of simple objects to cluster objects
- Area-weighted ratio of forecast cluster objects to forecast simple objects
- Area-weighted ratio of forecast simple objects to forecast cluster objects
- Area-weighted ratio of observed cluster objects to observed simple objects
- Area-weighted ratio of observed simple objects to observed cluster objects

Plot types available include

- Time Series
- Dieoff
- Threshold
- ValidTime

Plots in the Objects app for Time Series, Dieoff, and ValidTime are the same as in Precipitation.

Figure 4.24 shows an example of the user interface for the Objects app.

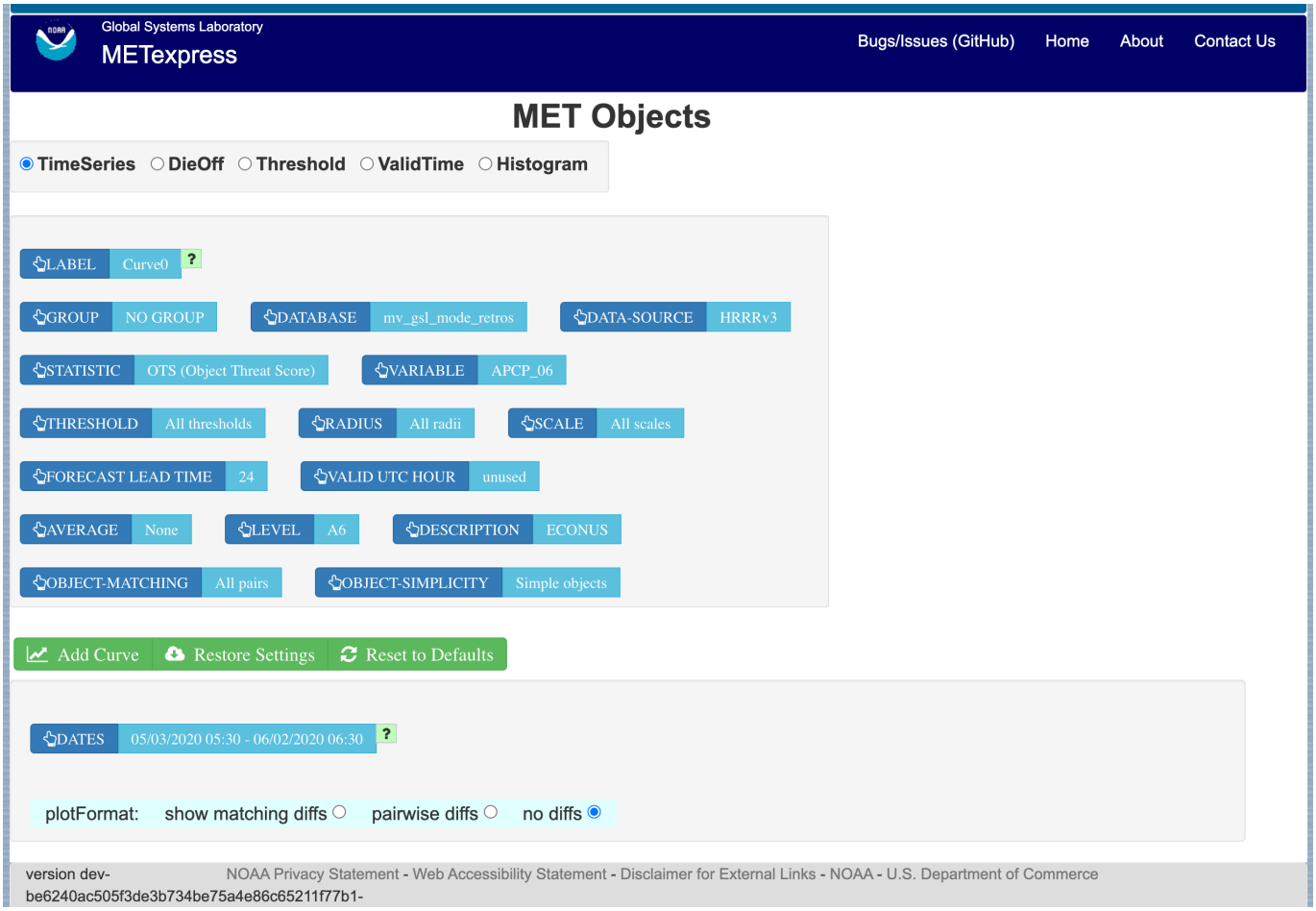


Figure 4.24: User interface screen for the Objects app

Chapter 5

METexpress System Requirements, Installation and Support

Repository: METexpress is a community software package managed by the Developmental Testbed Center (DTC) and is available through Github.

This repository includes a README file at the top-level that covers an overview and build instructions, with further links to installation instructions.

System requirements:

- Hardware: METexpress runs on Docker. It can successfully run on a system with four cores, 8 GB of memory and 10GB of free disk space. METexpress has been tested on Linux and MAC systems. It may run on Windows but this has not been tested and the configuration and management scripts are written in bash.
- Software: These packages must be installed: docker, docker-compose, httpaswd, and jq. For a robust testing environment, install the certificate located in /etc/ssl/certs (see SSL certificates below). A simple testing system can be deployed on the localhost without certificates for testing by answering yes to the question "Are you setting up a simple test environment?" in the configure program.
- Python 3: There is a dependency on Python 3 which should be accessible in /usr/bin/python3, and requires a number of Python modules to be installed, including pymysql, abc.abstractmethod, urllib.request, traceback, ssl, getopt, and json. These may need to be added to the Python environment with a package manager.

Meteor Framework: METexpress is built on the Meteor free and open-source JavaScript web framework. Meteor must be installed in order to build METexpress. Meteor is not required to deploy METexpress containers.

Database requirements: METexpress must have access to a METdatadb database and must have read/write privileges. For further information about installation of this database please see https://metviewer.readthedocs.io/en/latest/Users_Guide/installation.html and https://metviewer.readthedocs.io/en/latest/Users_Guide/database_loading.html.

Configuration: In order to install METexpress, a configuration script needs to be run which will give a prompt to provide information specific to the installation. Below is a list of information that usually needs to be provided:

- Networking information:
  - The domainName of the deployment server.
    - METexpress uses this to configure its own proxy service that fronts the apps.
  - Fully qualified proxy hostname, defaulting to the domainName
    - The deployment might be behind a redirection proxy with redirection to a different path than what is actually on the host. For example, the METexpress server might be deployed on a server with an internal URL "https://something.subnet.esrl.noaa.gov" and have a landing page location of "/", while the public URL is a proxy redirect like "https://www.esrl.noaa.gov/gsd/mats".
    - In this case the fully qualified proxy hostname is www.esrl.noaa.gov and the proxy_prefix_path needs to be set to "/gsd/mats".
  - Proxy redirection path
    - This allows a different path other than "/"
- Database credentials: Building on the architecture of MATS, METexpress has a construct for a database role. Within METexpress the only role that is used is one named "sums_data". METexpress requires that a user exist in the MET database that has database read and write permissions. Write permissions are needed to create metadata entries. During the installation, it will be necessary to provide the username and password for this user. The username and password for the sums_data role is required for each app.
- SSL certificates: An SSL certificate is required to run METexpress. This is usually an externally acquired certificate for the users domain, which users will need to place in a directory as instructed by the setup script. Alternatively, a no-cost certificate can be used provided by traefik using Let's Encrypt software from within METexpress containers. Instructions for this option are available in the overview for traefik. Be aware, however, that this option requires modifications to the server's firewall by someone with network administrative privileges.

Building METexpress: It is only necessary to build METexpress if a custom build is required. Otherwise, it is recommended that METexpress be installed directly from the provided docker images. See the overview and build README.

Installation: METexpress can only be installed from Docker images. The most recent images are maintained by METexpress developers and are available in the dockerhub repository.

For guidance on the installation see the METexpress Deployment for Containers README.

Support: For support for METexpress, please email mats.gsl@noaa.gov.

Chapter 6

METexpress Metadata

6.1 What is metadata for METexpress?

Generally, the term metadata refers to data about the data. METexpress stores metadata about each data set in the database to describe parameters such as the model (or data source), regions, variables, levels, dates, etc that are included in that data set.

This metadata is then used to populate the selectors displayed on the initial page of each METexpress app, so that only valid data combinations are presented to the user for plotting. For example, select a data-source of GFSFV3. The selections that are listed for Regions will only include regions actually produced and stored with the GFSFV3 data set.

6.2 Generating metadata for a MySQL database

The metadata scripts must be run at least once before attempting to run METexpress with a new database, or the apps will fail to start.

The scripts can be run from any host (with UNIX) that has access to the MET database, but must be run by a user with write permissions to that database. This is because after generating the metadata required by each app, the metadata scripts will create a new schema within the MySQL database called mats_metadata, and store the metadata within it. The scripts will never write to any other location.

The metadata scripts are written in Python 3, and require a number of Python modules, including pymysql, abc.abstractmethod, urllib.request, traceback, ssl, getopt, and json, which may need to be added to the Python environment with a package manager.

To run the metadata scripts for the first time:

- The scripts are located in the METexpress repo.
- After cloning this repo, link the contents of the scripts/matsMetaDataForApps/createMetaData/mysql directory to the preferred run directory (e.g., something like /home/metexpress/scripts).
- A .my.cnf file with the login credentials will be needed for the mysql database. Remember, the credentials must be for a user with write permissions.

- Change directories to the run directory. Remember, the contents of this run directory should be identical to the contents of scripts/matsMetaDataForApps/createMetaData/mysql. Please note that this is ONE LEVEL ABOVE the directory where the metadata scripts are actually located. For example:

```
cd /home/metexpress/scripts
```

- Set the PYTHONPATH to the run directory. For example:

```
export PYTHONPATH="/home/metexpress/scripts").
```

- Run the scripts from the command line. Pass in the path to the .my.cnf file and the URL where METexpress will be available as arguments. The URL <metexpress_url> is the actual access URL of the metexpress installation, e.g. **https://yourdomain/metexpress**. The URL is necessary so that the metadata scripts can inform METexpress that new metadata is available. For example:

```
/home/metexpress/scripts/metexpress/MEmetadata_update.py
    -c /home/metexpress/.my.cnf -u <metexpress_url>
```

- The scripts should generate the necessary metadata and store it in the database.
- A METexpress instance that looks at this database can now be run.

Once the apps are up, any new MET data loaded into the database will not appear in METexpress until the metadata scripts are run again. Because of this, it is recommended to run the following steps from the write access user's crontab, either once a day or at another interval of the user's choosing. The metadata scripts can also be run manually at any time.

To run the metadata scripts subsequent times (such as from the crontab):

- Set the PYTHONPATH to the run directory. For example:

```
export PYTHONPATH="/home/metexpress/scripts"
```

- Run the scripts from the command line. Pass in the path to the .my.cnf file and the URL where METexpress is available as arguments. For example:

```
/home/metexpress/scripts/metexpress/MEmetadata_update.py -c /home/metexpress/.my.cnf -u
↪<metexpress_url>
```

- The scripts should generate the necessary metadata and store it in the database.
- The scripts will then briefly connect to each app at the provided URL, triggering a metadata update and causing the selectors to display the latest information.

Having mv_load or METdbload trigger a metadata update:

In addition to running the metadata scripts from the crontab at a given interval, it is also possible to invoke the metadata script when any new data is loaded into the database. To do this, insert a metadata script invocation (using the steps given in the previous section) into the end of the METviewer mv_load.sh script. Be sure to set the PYTHONPATH in the script invocation.

Chapter 7

Appendix A - Public Deployments of METexpress

For NWS/NCEP/EMC, METexpress is currently running on the Amazon Web Services cloud and is available at metexpress.nws.noaa.gov.